Caluta

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Contents

Weather versus bird numbers observed on active migration at Põõsaspea neem, Estonia

ANTERO LINDHOLM

Weather and bird migration

The impact of weather on bird migration has been studied extensively and we will not attempt to produce a real summary here. See for example chapter 5 of Newton (2010) for a good introduction, and references.

The bird numbers observed on migration is a function of several factors e.g. locality, season, time of the day, species abundance as well as the observability of the species. These are more or less constant over the years, but the weather brings stochastic variability into the equation.

Weather has an impact on bird migration, some weather types are better for birds to undertake the task of moving to the next goal on their route towards the wintering grounds or breeding sites. Naturally, it is not only (or even mainly) the local weather at the observation point which is significant, but also the weather at the starting point of the migration and in the areas the birds are passing through, and these areas may be quite far away from the observation point, and experiencing different weather conditions. However, these areas vary between the species and even within the species, and are in many cases unknown, or not known with any precision. The weather at the observation point is more concrete and a definite factor. There is some analysis of Põõsaspea migration in relation to weather of White Sea, the area of origin of many species, in Ellermaa *et al* (2010).

Local weather also has an impact on the visibility of the migration. For example, in some weather conditions, the migration can take place too high to be visible from the observation point, or too far inland or too far out to the sea, especially if the watch point is coastal, as they often are. The visibility of the migration is very species dependent as well. The

migration of some species may almost always be visible, while some other species are more prone to change their routes or detectability. At the other extreme, strictly nocturnal migrants are rarely seen on active migration. This study concerns birds associated with water and which are easier to detect and count than many small landbirds.

Bird observation data

In autumn, Põõsaspea neem, Spithami küla, Noarootsi osavald, Lääne-Nigula vald, Lääne maakond, Estonia is an excellent place to watch the migration of waterbirds heading towards their wintering areas, towards the southwest. Most of the birds breed in northern Russia, many of the species in arctic areas, and spend their winter in the southern Baltic or somewhere in western Europe. Many species avoid crossing land, and when they are heading southwest, they turn in a more westerly direction, to follow the northern Estonian coastline. After Põõsaspea neem this concentration of birds thins out somewhat, although good migration totals are possible to see from Hiiumaa island, for example. Species which do not avoid crossing the mainland, like swans, are seen at Põõspaspea in smaller numbers only. We will not give any more in-depth description of the migration and the totals here, see the specific count reports cited below for that information.

Whole-season counts of migrating birds have been organized at Põõsaspea neem in the autumns of 2004, 2009, 2014 and 2019 (Ellermaa & Pettay 2006, Ellermaa *et al* 2010, Ellermaa & Lindén 2015, Ellermaa & Lindén 2020). The counting period has lasted from the beginning of July to at least early November. Counted bird totals have been recorded in half-hour periods, and the sex and age of the birds
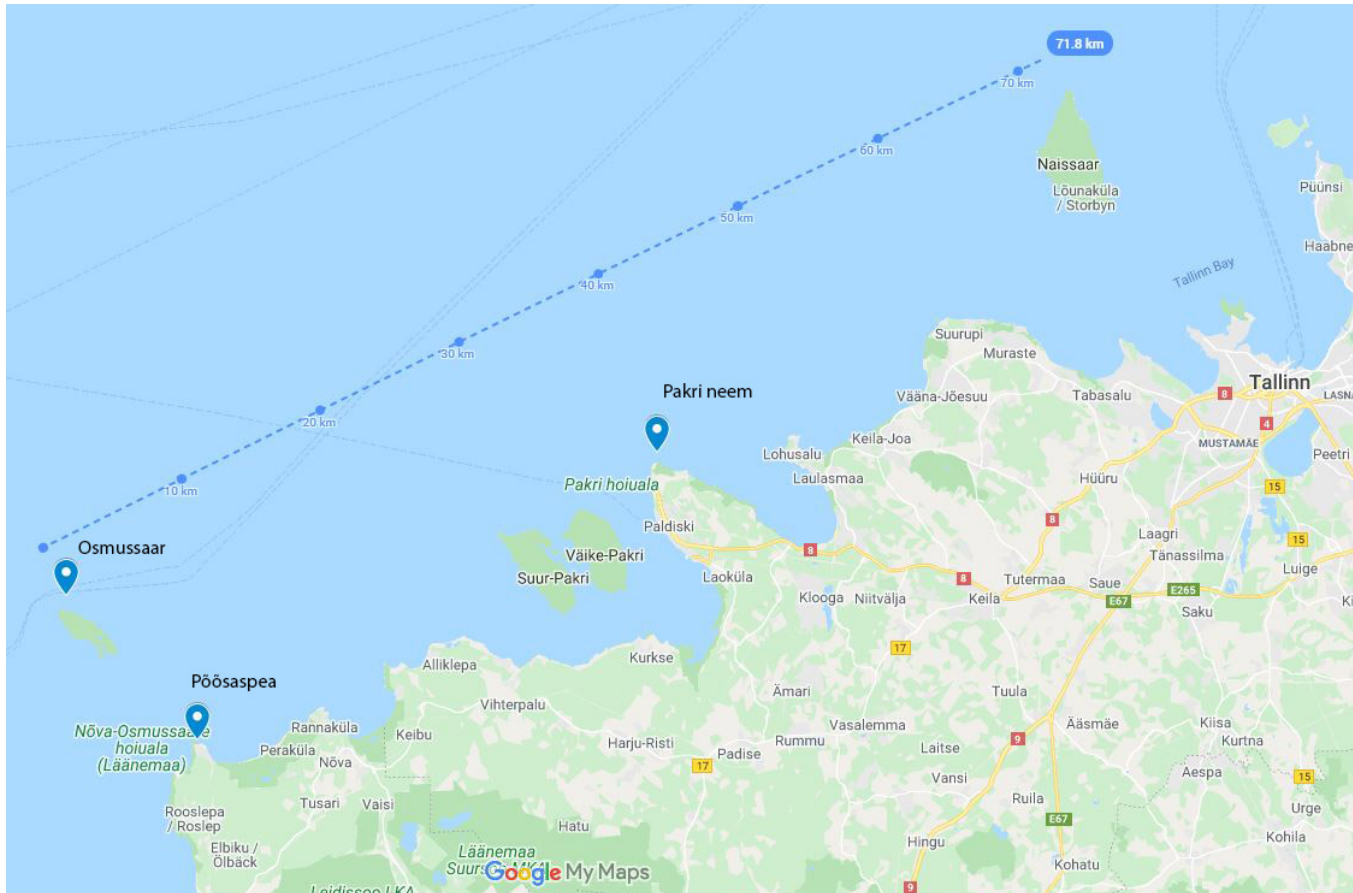
Map 1. Location of the Põõsaspea neem observation point and Pakri weather station, in NW Estonia.

have been determined whenever it has been possible. In autumn of 2020 counting was also carried out almost daily, although on most days not for as long periods as in the official counts, but the bird numbers were recorded with even more exact time stamps. In this study, we compared the totals from these five seasons to the hourly weather observation data.

We do not have data of the exact directions (only two direction classes were used), nor of the height or how far away from the observation point the birds passed. However, generally the waterbirds at Põõsaspea fly more or less in the same direction in autumn - in a westerly or southwesterly direction. Wind strength and direction has an impact on the route as well as on the direction the birds take.

The species presented here are typical and numerous on migration at Põõsaspea neem. A similar analysis would have been possible of many other species as well.

The count data has been stored in several places, but we used the data from Trektellen.org. The Excel file downloads were transferred to SQL Server Express by using a C# program with standard .net libraries and the library ClosedXML.

Weather data

The weather data is from the Estonian Weather Service EMHI.ee (2020), processed using R (R Core Team 2019) with the libraries RSelenium (Harrison 2019), XML (Temple Lang *et al* 2019) and RODBC (Ripley & Lapsley 2017), the last of which were used for updating the data in a SQL Server Express database.

There are several weather stations close to Põõsaspea neem. The closest are situated at Dirhami, located 2.3 km towards the SSW (206 degrees), and at the island of Osmussaar, which is 12km to the NW (315
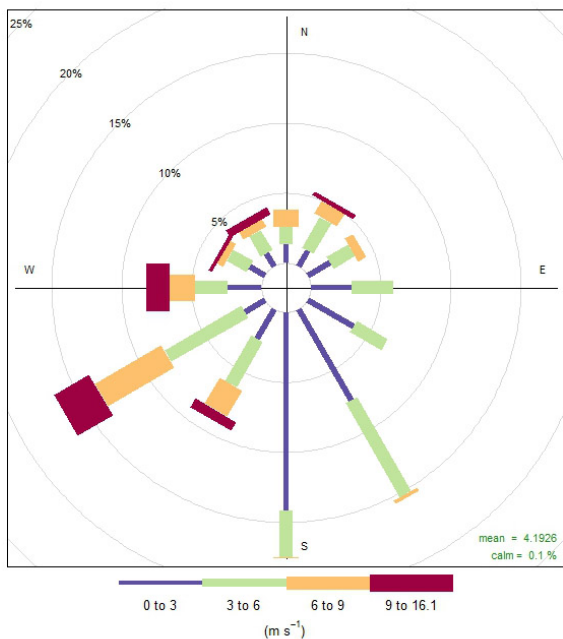
Fig 1. Frequency of different wind directions and strengths (in %) at Pakri, July to 10 November 2020.

Fig 2. Frequency of different wind directions and strengths (in %) at Dirhami, July to 10 November 2020.

degrees). Both these stations produce smaller sets of data, and the data is available from a shorter period than the ornithological observations. More complete sets can be obtained from Pakri (35.3 km to the east-northeast = 59 degrees) and we have mostly used data from that site. Pakri is actually in the direction most of the birds come towards Põõsaspea neem from during the autumn seabird migration, which makes the Pakri weather data quite useful.

Wind

There are distinct differences between the data sets from the different observatories. See fig 1 for wind information from Pakri in 2020, and compare that to fig 2 for the same time from Dirhami. The latter location records stronger winds from northwest to southwest, and winds from these directions are also more frequent. These differences are caused by the geography of the coast.

Fig 3 shows the combined wind data from Pakri for all the study years (2004, 2009, 2014, 2019 and 2020). Figs 4-7 show winds from the years when the complete autumn counts were conducted. There is
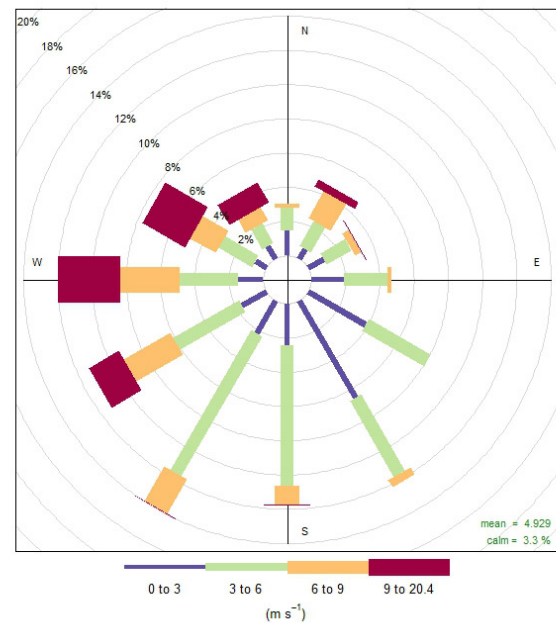
some variation between the years but the overall pattern is still rather similar. Figs 8-12 show monthly data with the years combined. In autumn, the main wind direction seems to vary between southwest and southeast, and on average, the wind strength increases towards late autumn. Southern and southeastern winds are always weaker, on average, than those from other directions.

Rain

During the study years, it rained 25.5 – 177 mm during 15-156 hours per month between July and October. In July-September the average number of rainy hours were 53.4-59.2, and October was the most rainy month with an average of 112.8 hours. In mm, October was again the wettest month with 86.46 mm, but July was close, with 78.68 mm. As only 7-8% (Jul-Sep) or 15% (Oct) of all hours were rainy, rain had limited effect on bird migration. Fig 13 shows the weighted average of rain from different wind directions. Southwestern winds bring rain most often, while southeastern and western winds do so the least often.
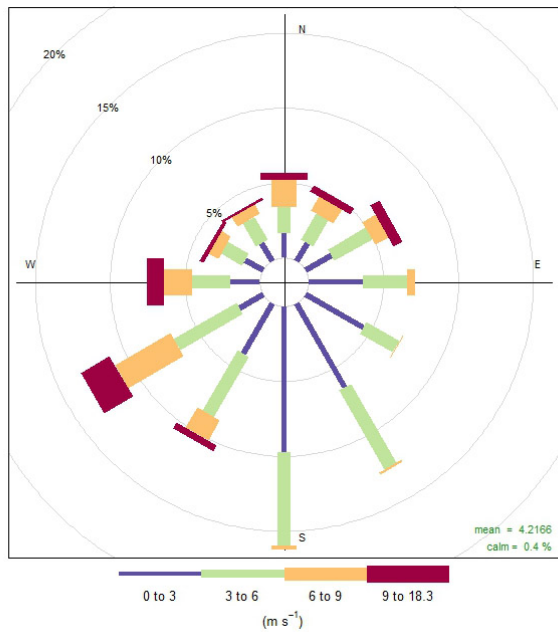
Fig 3. Winds at Pakri, July to 10 November 2004, 2009, 2014, 2019 and 2020.
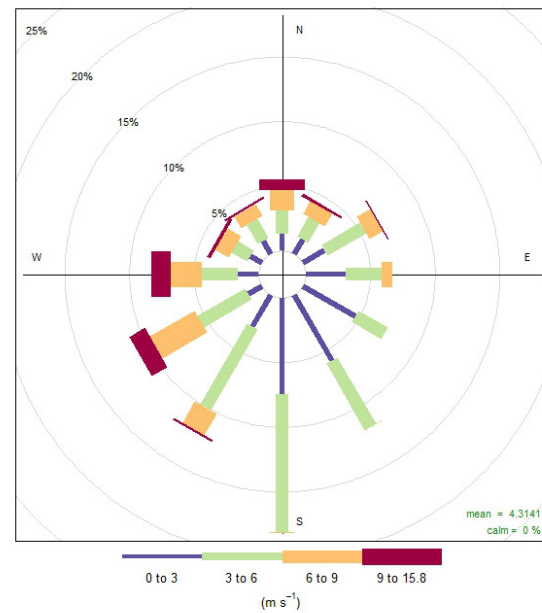

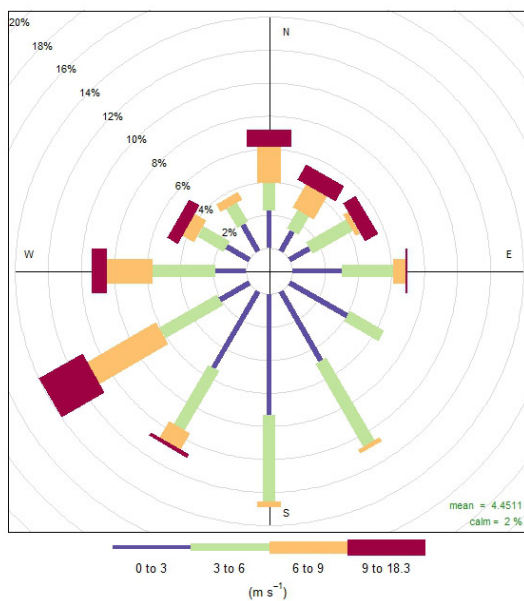Fig 4. Winds at Pakri, July to 10 November 2004.
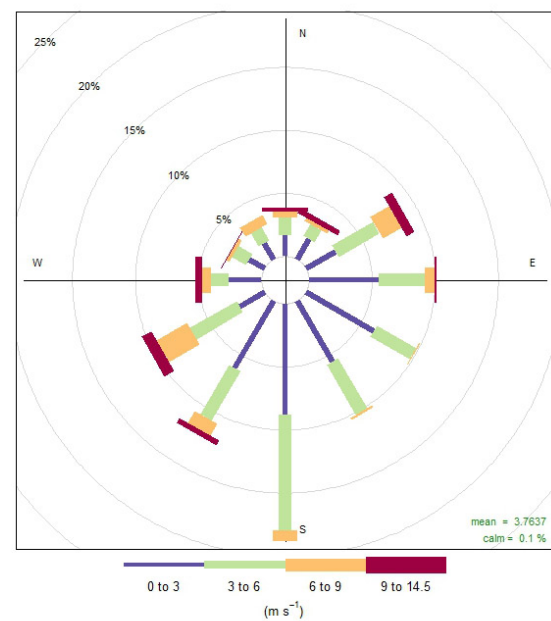

Fig 5. Winds at Pakri, July to 10 November 2009.

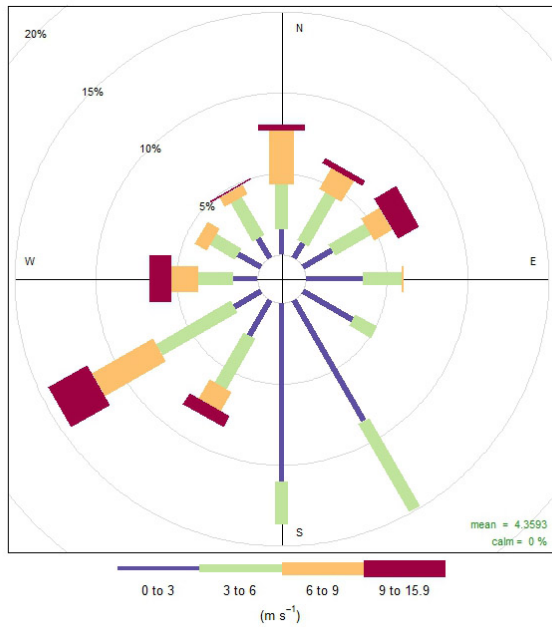Fig 6. Winds at Pakri, July to 10 November 2014.

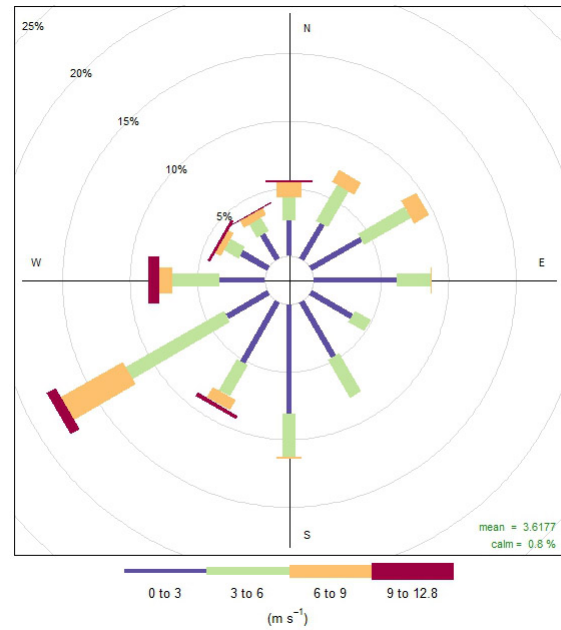Fig 7. Winds at Pakri, July to 10 November 2019.

Fig 8. Winds at Pakri, July 2004, 2009, 2014, 2019 and 2020.
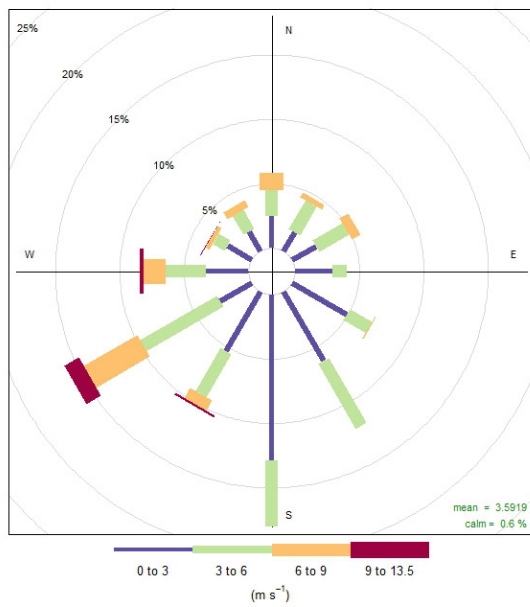

Fig 9. Winds at Pakri, August 2004, 2009, 2014, 2019 and 2020.
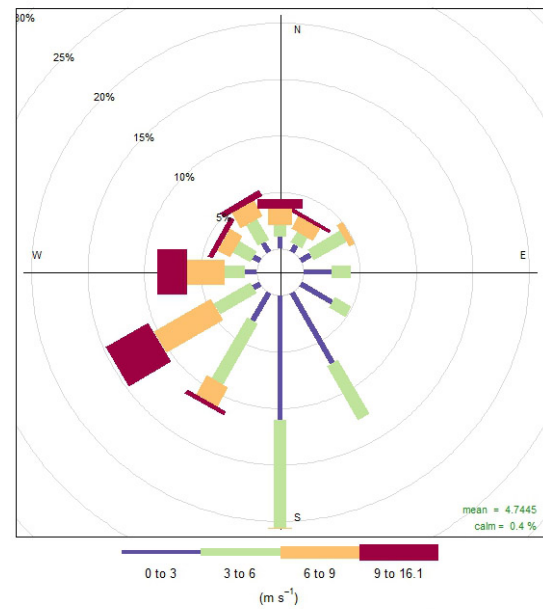

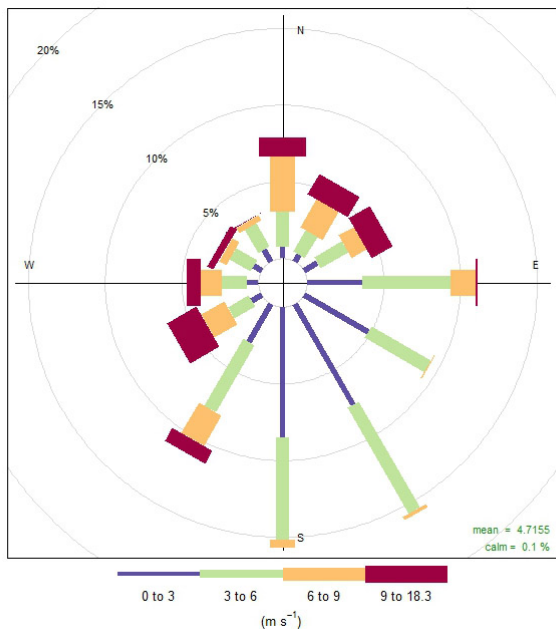Fig 10. Winds at Pakri, September 2004, 2009, 2014, 2019 and 2020.

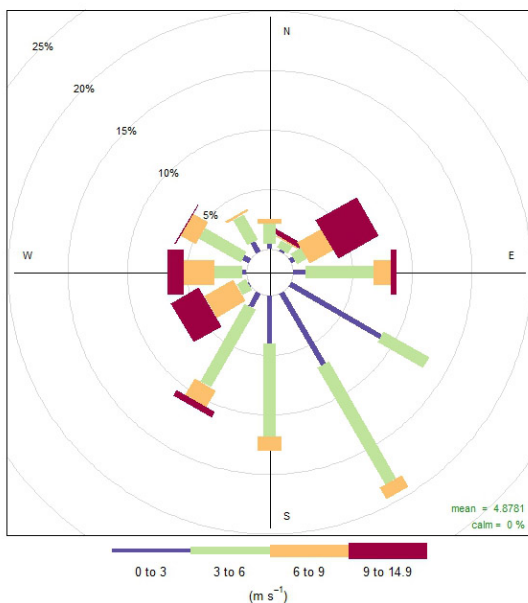Fig 11. Winds at Pakri, October 2004, 2009, 2014, 2019 and 2020.

Fig 12. Winds at Pakri, 1 to 10 November 2004, 2009, 2014, 2019 and 2020.

The analysis

The charts showing wind directions and strengths in different years and at different weather observatories, as well as the "raw" data of the bird migration, were plotted using the R package openair (Carslaw & Ropkins 2012) with the function WindRose. The input is a simple data frame with wind strength in one column and the direction in another, every row representing one observation (hourly data in case of the weather data, and hourly weather data corresponding to one bird individual in case of the bird record data).

Other charts are showing "weighted" data – bird totals in proportion to the prevailing wind directions. When preparing these, the 360 degrees of wind directions were grouped in 36 classes so that each class n includes wind directions between n*10-5 degrees and n*10 + 4 degrees, e.g. the class 36 includes the wind degrees 355-4 and class 1 the wind degrees 5-14. Wind strengths of less than 1 m/s were omitted from this analysis, because in near calm weather reported wind directions seemed to vary quite a lot between the different weather observatories, and also in consecutive observations from the same observatory. Omitting these did not have a big impact on the analysis. Wind directions from 1 July to 10 November were used, as well as all observations of the species from the same period. No effort was made to restrict this period case by case as to the main migration period of that particular species.

The third type of charts show wind strengths when the species was migrating. Wind strengths were rounded up to full m/s. The wind strength 0 could mean that no wind was observed or reported – this is quite a rare situation, which hardly affects the analysis. Another column shows the bird totals in proportion to the frequency of the wind strength class. The frequency is calculated using all hours from 1 July to 10 November. In the second column, classes with very small totals of birds were omitted at both ends.

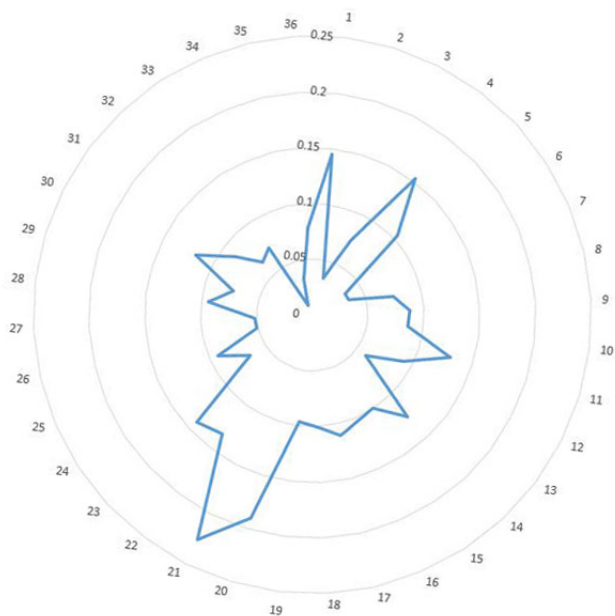These two types of charts were produced using

Fig 13. Pakri, rainfall by wind direction, in proportion to the frequency of the different wind directions.

Microsoft Excel.

The fourth type of chart shows the density of bird observations in relation to the wind factor which is parallel to the migration direction. This can be regarded as the wind assistance. Tailwinds show as positive and headwinds as negative.

Parallel wind factor = wind strength in m/s * cos(abs(Angle between wind direction and migration direction))

The problem is to define the main migration direction. It could be discussed whether it should be the local direction where the birds are seen flying or the direction in which their destination is. Wind direction affects the first and therefore it should be more objective to choose the latter. Naturally, this choice is not without problems. Because several Red-throated Diver migrations have been satellite-tracked between western Europe and northern Russia, quite a lot is known about their migration pattern (see Lindholm & Forsten 2020 and the literature cited there) so we can take that as an example. It is quite certain that the Red-throated Divers are heading southwest at Põõsaspea neem. It is possible that while many of them first fly

west along the northern coast, as they reach the NW point of the mainland at Põõsaspea neem, they encounter the open sea and change course. We have chosen to regard 226 degrees as their migration direction, as this is pointing towards the southern Baltic sea, classing winds from the degrees 136-316 as headwinds and other directions as tailwinds. Different species certainly have somewhat different destinations and some may be heading to staging areas and not straight to the wintering areas. However, observations on site show that wildfowl are mostly heading W or SW at Põõsaspea neem with no clear differences between the species. We have therefore decided to use the same main direction for all species.

We also provide a small table describing the effect of rain on recorded bird numbers. For every hour, rain is described in three categories: no rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C). The bird totals counted in these situations are presented, as well as the frequency of that rain class. Only the main migration period of the species is selected for this, and only the hours when the observed migration can be supposed to have been the strongest. The exact date and time intervals are not that important, they are chosen only to filter out most of the hours when the observed migration would have been more or less non-existent – including the hours of darkness.

Barnacle Goose *Branta leucopsis*

The migration of Barnacle Goose is comparatively easy to observe, and even predict. The migration is concentrated at Põõsaspea neem, but the movement is still on a broad front, and includes a lot of nocturnal migration, so only a smaller part of the population is actually seen.

Barnacle Goose is a typical example of a species, which starts migrating when colder northern and good tailwinds occur. Wind strength seems not to have much impact on observed numbers of Barnacle Geese. Numbers seen in any kind of headwind are small. It seems very probable that the birds start from areas

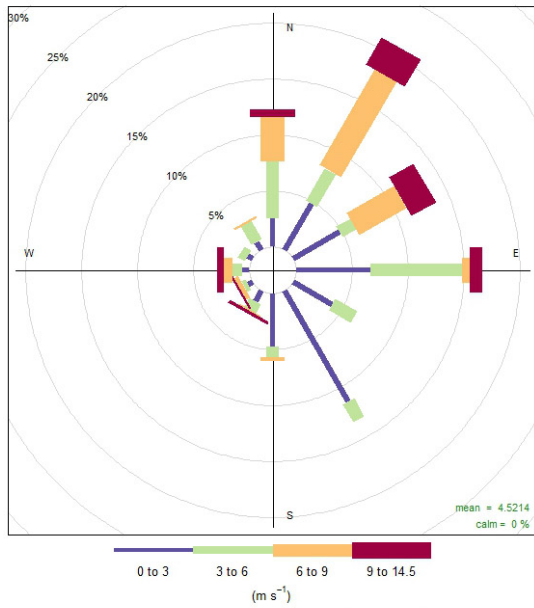**Barnacle Goose figures, commented on page 7. Figure types explained on pages 6-7.**

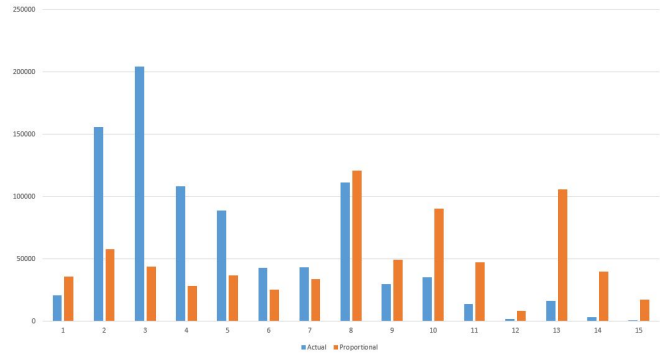Fig 14. Barnacle Goose totals by different wind directions and strengths (in %).

Fig 16. Barnacle Goose totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
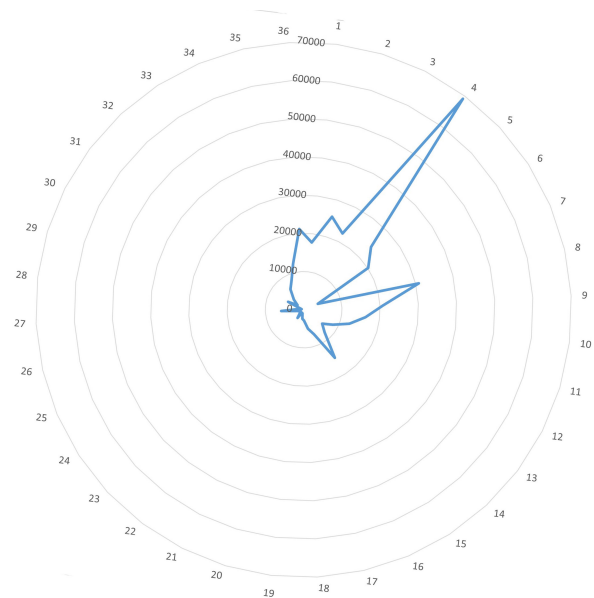

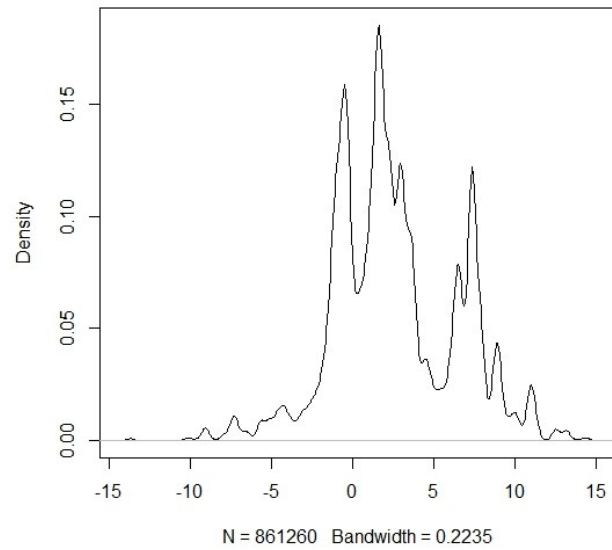Fig 15. Barnacle Goose totals by wind direction, in proportion to the frequency of the different wind directions.

Fig 17. Barnacle Goose. Density of observations in relation to the wind factor parallel to the migration direction.

Rain class	Hours	Birds	Birds/h
A	1538	658085	428
B	212	52518	248
C	84	2858	34

Table 1. Barnacle Goose. Totals by rain class. October 6 am to 5 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).

which often are comparatively close, for example in southern Finland, and fly with tailwinds towards their Western European wintering grounds. Because of that it is typical that during the peak days the weather conditions are similar in their area of origin and at Põõsaspea.

Brent Goose *Branta bernicla*

The observed numbers of Brent Goose vary a great deal, with only 28% seen in the weakest project year (2014) compared to the total of the best year (2009). This species also migrates in some numbers during the night.

The observed migration of Brent Goose is very different from that of Barnacle Goose. Wind directions 220 – 280 degrees dominate – the biggest Brent Geese numbers are seen during west to southwest winds, but some also during northerly winds. It seems that most Brent Geese tend to be observed during quite strong winds, and the species favours winds of around 8-10 m/s. This also means that most individuals of this species are observed when there is some headwind.

These results suggest that when the winds are between northeast and south, Brent Geese migration is not concentrated at the Põõsaspea tip, but probably rather further out to sea. It is less likely that they pass inland or too high to be observable. Also, these results show that even quite strong headwinds do not stop the migration movement of this species. This may be because stopping in the Gulf of Finland area is even less affordable, probably because of limited availability of food. It is also possible that strong winds help in finding areas of eelgrass in the more western parts of the gulf. In any case, they probably have started the migration with different winds than those that occur around NW Estonia.

Eurasian Wigeon *Mareca penelope* and Northern Pintail *Anas acuta*

Eurasian Wigeon and Northern Pintail are two numerous migrants, which often migrate in the same flocks, and their patterns show similarities. Neither favour winds from SW-SE and for both, western and the unusual NW winds are good. Wind strength does not seem to make a big difference to them. They may even prefer rain, or at least rainy weather, or just darker conditions.

Eurasian Teal *Anas crecca*

Eurasian Teal shows a strange pattern. There does not seem to be any classic weather for the migration of this species. Wind strength does not seem to be important, but some element of headwind is common.

Greater Scaup *Aythya marila*

Greater Scaup is a bird of E-S winds. Winds from SW through NW to NE are not good. The wind strength is not that important. The strong migration seen during the frequent southerly winds, which are slight headwinds, has a big impact on the wind factor figure.

Greater Scaup and Velvet Scoter are two duck species which are seen during winds with an eastern and southern element. Another aspect they have in common is that they are only seen in smaller numbers along the northern shore of the Gulf in Finland in both in spring and autumn. That means that their migration routes are more southerly than in other species, such as Common Scoter or dabbling ducks. Their starting areas should also be more southerly than in most species, possibly lakes to the east.

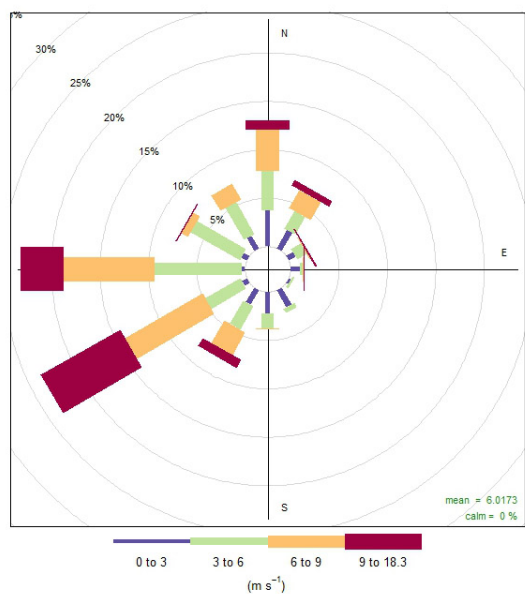**Brent Goose figures, commented on page 9. Figure types explained on pages 6-7.**

Fig 18. Brent Goose totals by different wind directions and strengths (in %).
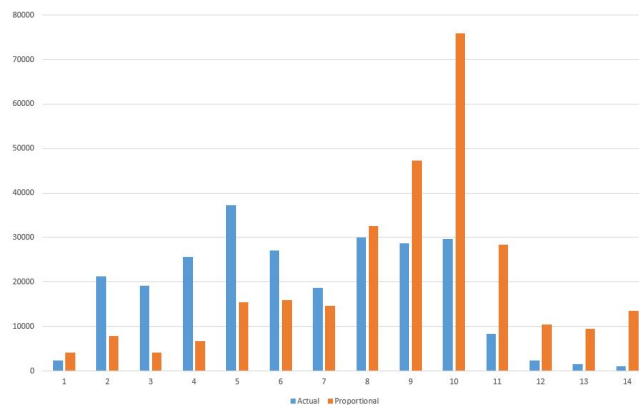

Fig 20. Brent Goose totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
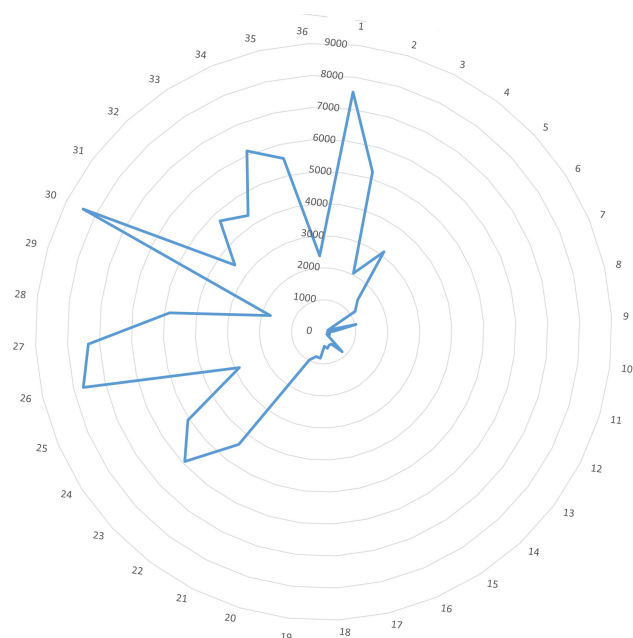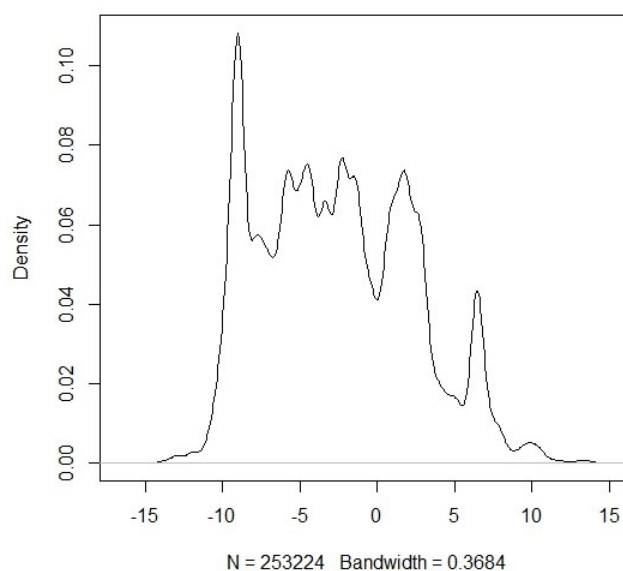

Fig 19. Brent Goose totals by wind direction, in proportion to the frequency of the different wind directions.

Fig 21. Brent Goose. Density of observations in relation to the wind factor parallel to the migration direction.

```
Rain class Hours  Birds  Birds/h
A          1568   191419 122
B          165    12947  78
C          57     3805   67
```

Table 2. Brent Goose. Totals by rain class. 15 September to 15 October 6 am to 5 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).

Eurasian Wigeon figures, commented on page 9. Figure types explained on pages 6-7.
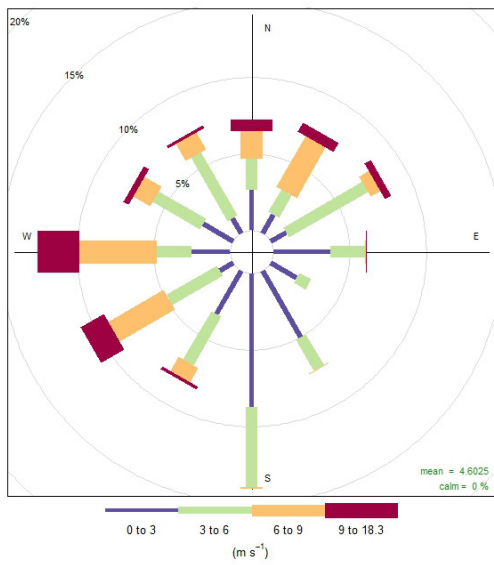

Fig 22. Eurasian Wigeon totals by different wind directions and strengths (in %).
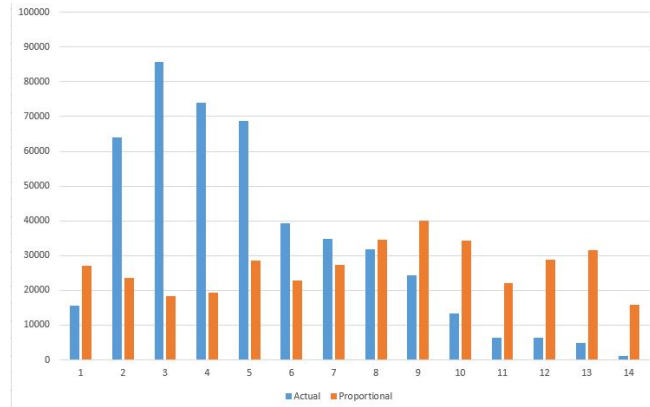

Fig 24. Eurasian Wigeon totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
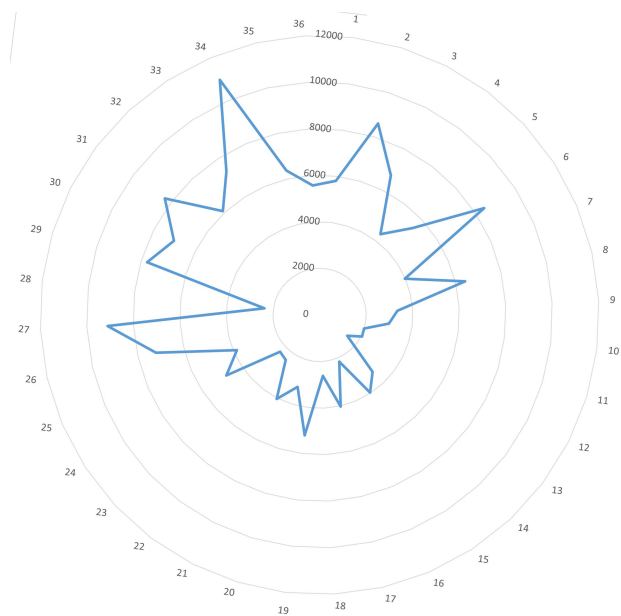

Fig 23. Eurasian Wigeon totals by wind direction, in proportion to the frequency of the different wind directions.

Fig 25. Eurasian Wigeon. Density of observations in relation to the wind factor parallel to the migration direction.

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Rain class Hours Birds  Birds/h
A          1568  257387 164
B          165   34963  212
C          57    13044  229
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Table 3. Eurasian Wigeon. Totals by rain class. 15 September to 15 October 6 am to 5 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).
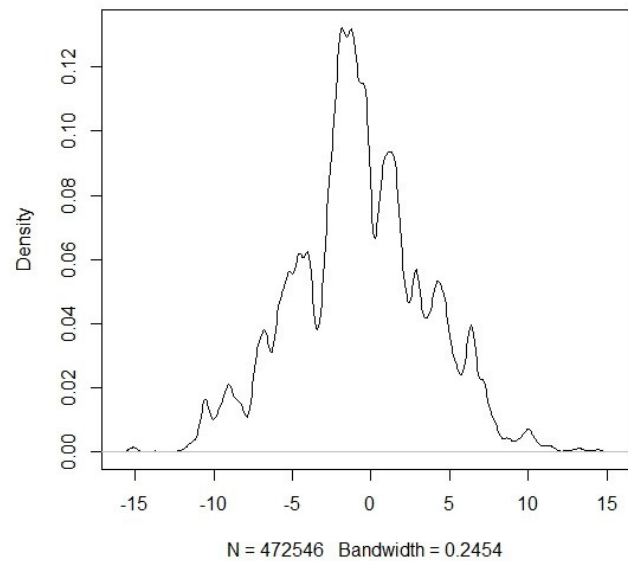
Northern Pintail figures, commented on page 9. Figure types explained on pages 6-7.
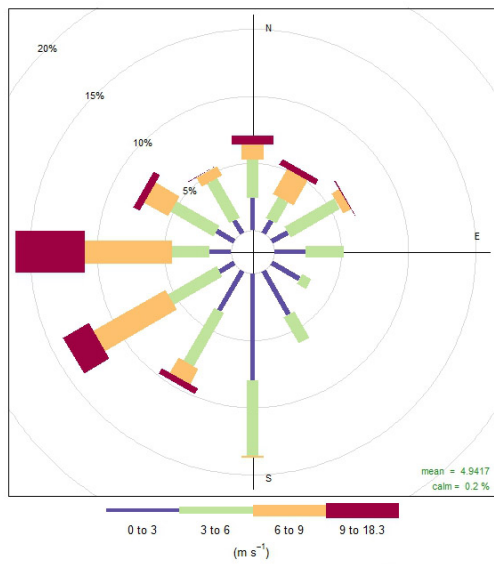

Fig 26. Northern Pintail totals by different wind directions and strengths (in %).
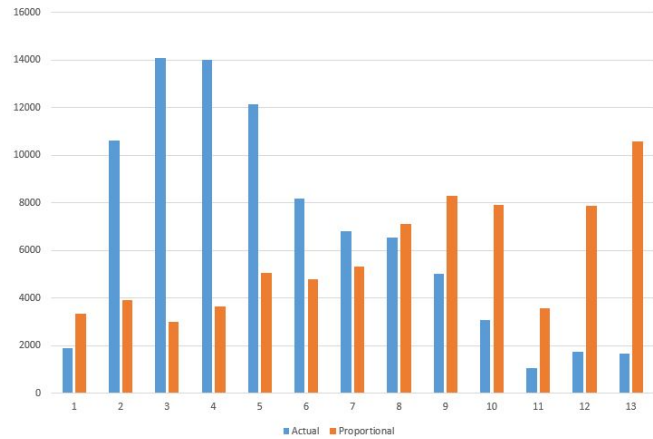

Fig 28. Northern Pintail totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
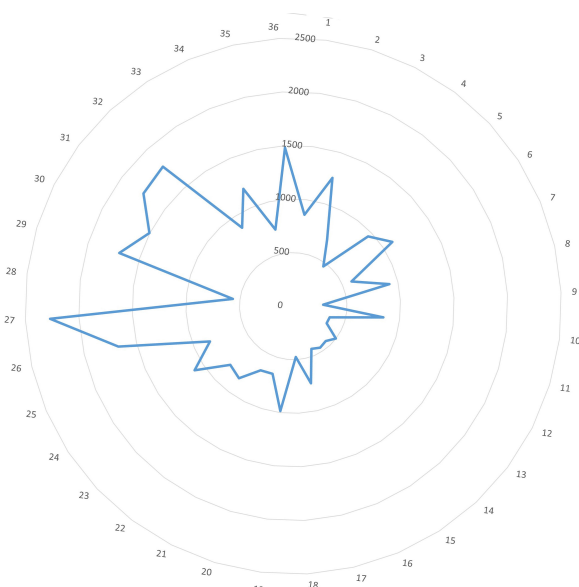

Fig 27. Northern Pintail totals by wind direction, in proportion to the frequency of the different wind directions.

Fig 29. Northern Pintail. Density of observations in relation to the wind factor parallel to the migration direction.

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Rain class Hours Birds Birds/h
A          1568  38353 24
B          165   5470  33
C          57    2686  47
```

Table 4. Northern Pintail. Totals by rain class. 15 September to 15 October 6 am to 5 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).
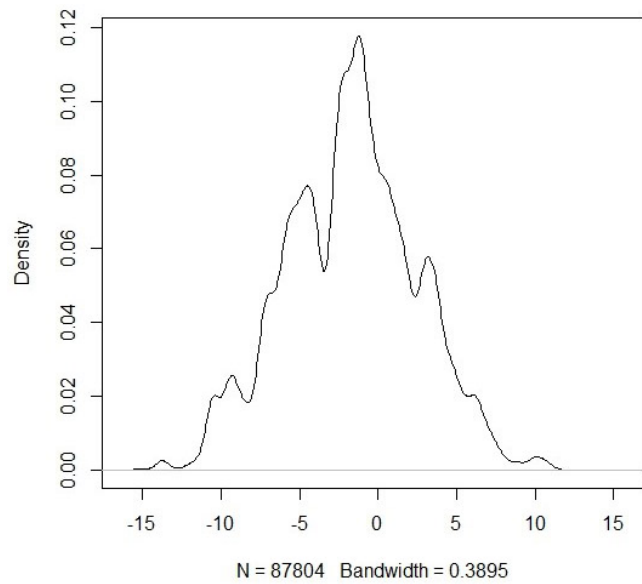
Eurasian Teal figures, commented on page 9. Figure types explained on pages 6-7.
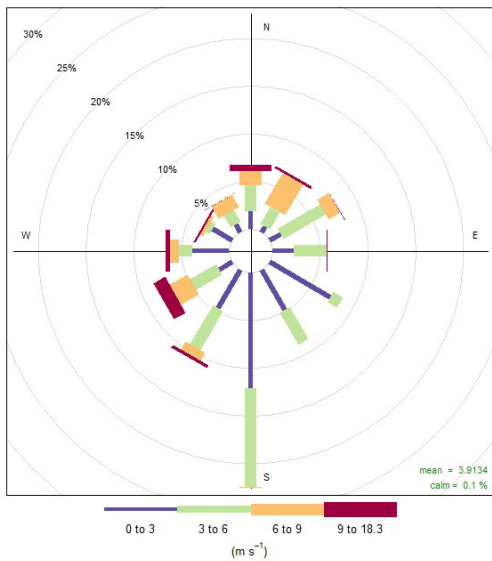

Fig 30. Eurasian Teal totals by different wind directions and strengths (in %).
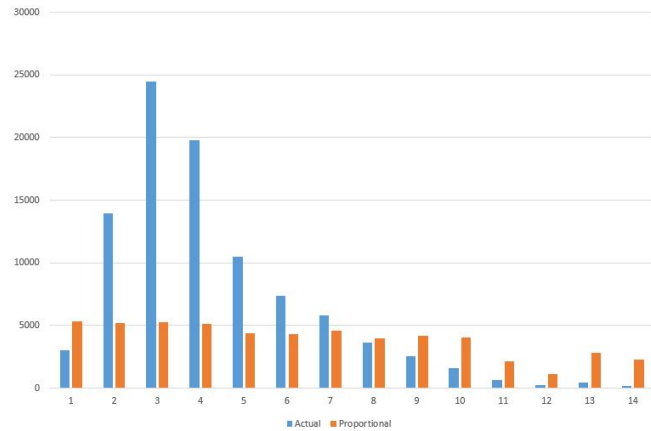

Fig 32. Eurasian Teal totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
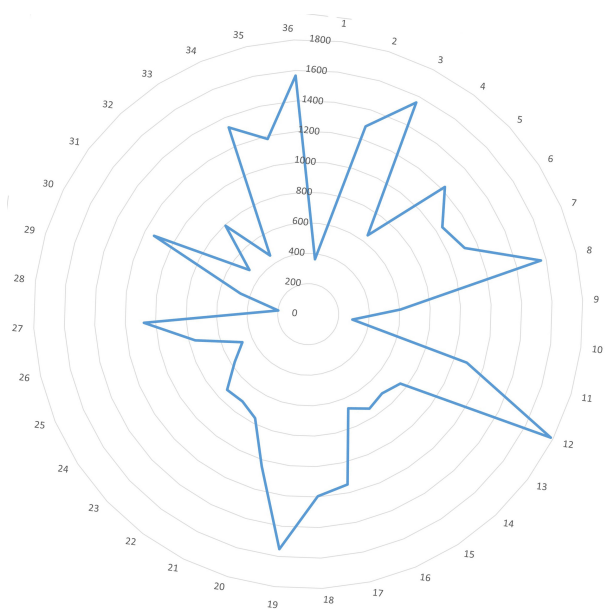

Fig 31. Eurasian Teal totals by wind direction, in proportion to the frequency of the different wind directions.
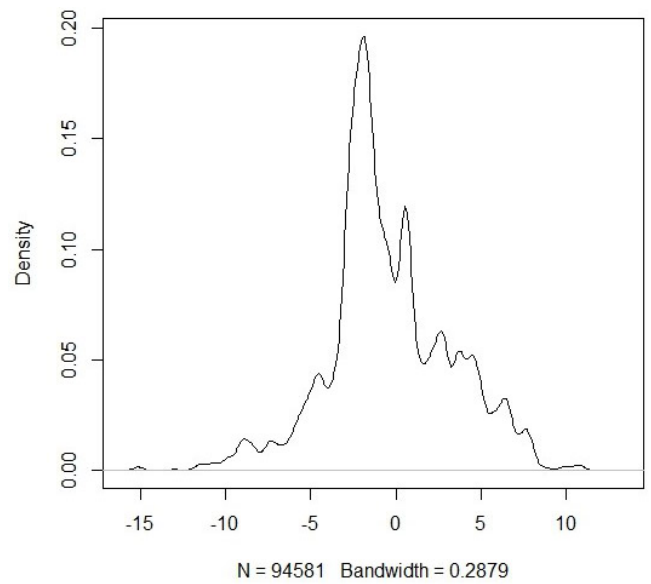

Fig 33. Eurasian Teal. Density of observations in relation to the wind factor parallel to the migration direction.

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Rain class  Hours  Birds  Birds/h
A           2682   57628  21
B           197    6161   31
C           94     2174   23
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Table 5. Eurasian Teal. Totals by rain class. 15 August to 30 September 5 am to 5 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).

Greated Scaup figures, commented on page 9. Figure types explained on pages 6-7.
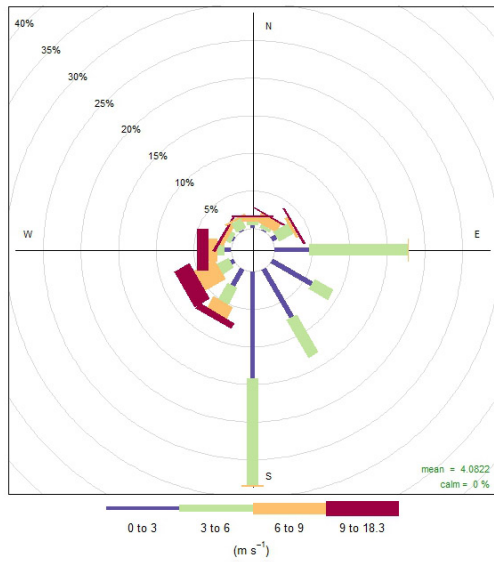

Fig 34. Greater Scaup totals by different wind directions and strengths (in %).
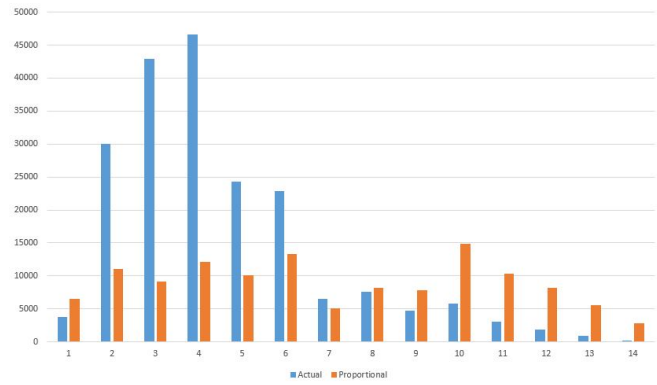

Fig 36. Greater Scaup totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.

Fig 35. Greater Scaup totals by wind direction, in proportion to the frequency of the different wind directions.

Fig 37. Greater Scaup. Density of observations in relation to the wind factor parallel to the migration direction.

Rain class	Hours	Birds	Birds/h
A	1568	144294	92
B	165	11995	73
C	57	2135	37

Table 6. Greater Scaup. Totals by rain class. 15 September to 15 October 6 am to 5 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).

Long-tailed Duck figures, commented on page 19. Figure types explained on pages 6-7.

Fig 38. Long-tailed Duck totals by different wind directions and strengths (in %).

Fig 40. Long-tailed Duck totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
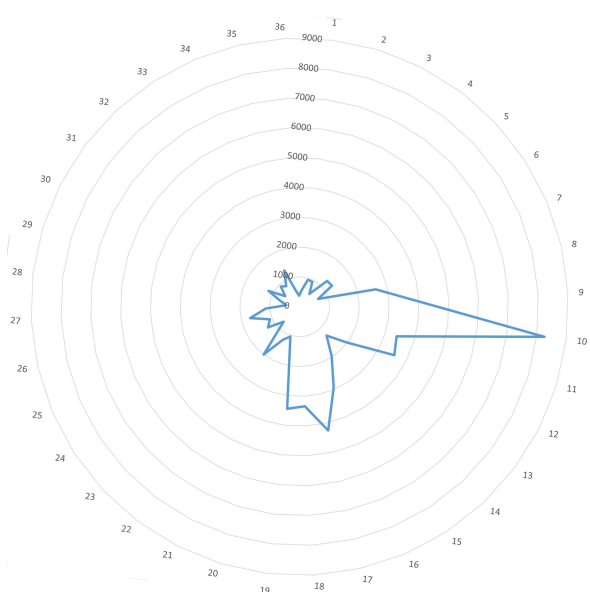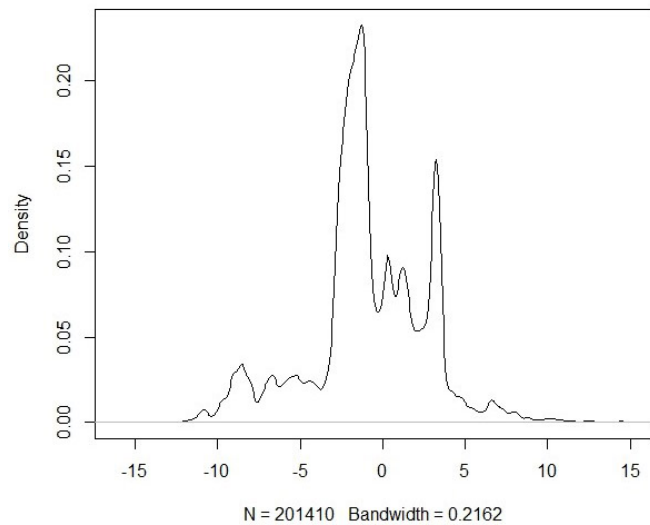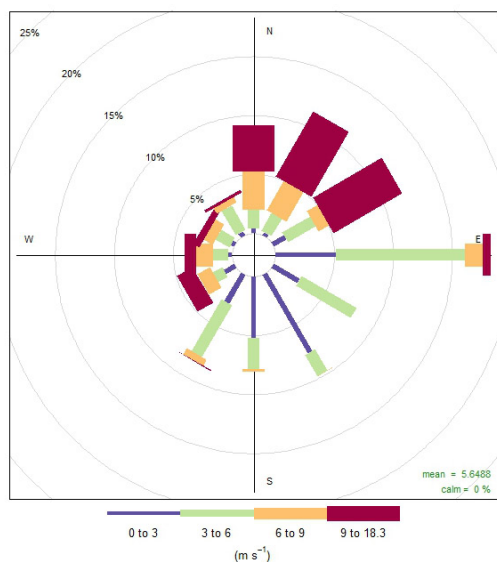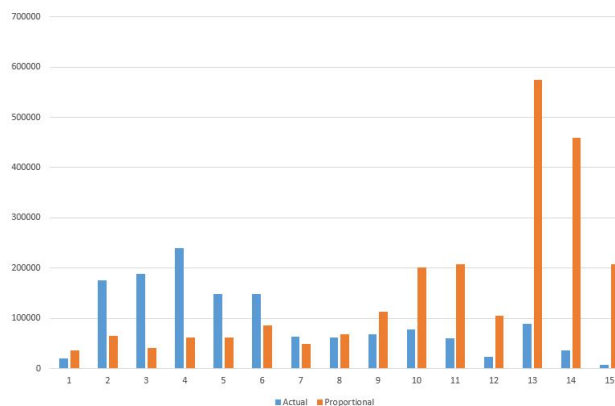

Fig 39. Long-tailed Duck totals by wind direction, in proportion to the frequency of the different wind directions.

Fig 41. Long-tailed Duck. Density of observations in relation to the wind factor parallel to the migration direction.

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Rain class  Hours Birds  Birds/h
A           1019  886829 870
B           141   149204 1058
C           58    42622  735
```

Table 7. Long-tailed Duck. Totals by rain class. October 7 am to 2 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).

30 July 2004 51654 birds. The previous day was rainy, with winds mostly from NW. The rain stopped, and the wind dropped and turned northerly.

26 July 2009 53139 birds. No big changes in the weather, but during the evening of 26th the wind changed to NNE and dropped somewhat.

30 July 2009 73536 birds. The previous day was quite good also. The wind turned to NW (via north) for the evening of 30th.

3 August 2009 78118 birds. The previous day was quite good as well. During the afternoon of the 3rd, the wind turned from west to around north.

11 September 2009 43127 birds. During the previous day the wind turned northerly in the morning and dropped, resulting in a good day for land bird migration, but not so for scoters. On the 11th, the mass scoter migration occurred in the morning, when the wind was from the north, and the difference in the weather compared to the previous day was not that significant. In the afternoon the wind turned from north to west and strengthened, resulting in poor migration in the evening.

28 August 2014 43951 birds. The Common Scoter migration started at 9 am and continued throughout the day, with the peak being in the evening. The wind was from N-NE, but that was no big change compared to the previous day.

25 July 2019 72452 birds. Migration started at 7 am, being strong until 11 am, and again after 5.30 pm. The wind turned at 8 am from W to N and towards the evening to E.

28 July 2019 59665 birds. The previous day the wind was from NE-E with 17 000 Common Scoters. On the 28th, until 5.30 am, there was some migration but then almost none until 9.30 am, after which there was some migration into the afternoon. The really strong migration only started after 7pm. During the morning the wind turned from east via south to west. At 8 pm it was still from NW, but soon turned to NE and E for the remaining daylight hours.

Table 8. Cases of migratory peaks of Common Scoter

Rain class	Hours	Birds	Birds/h
A	699	912057	1305
B	38	28658	754
C	19	21724	1143

Table 9. Common Scoter. Totals by rain class in July from 6 pm to 10 pm. Common Scoter migration continues into late autumn and the species also migrates from early morning to midday, but the major migratory events in July often occur in the evening.

Common Scoter figures, commented on page 19. Figure types explained on pages 6-7.

Fig 42. Common Scoter totals by different wind directions and strengths (in %).

Fig 44. Common Scoter totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
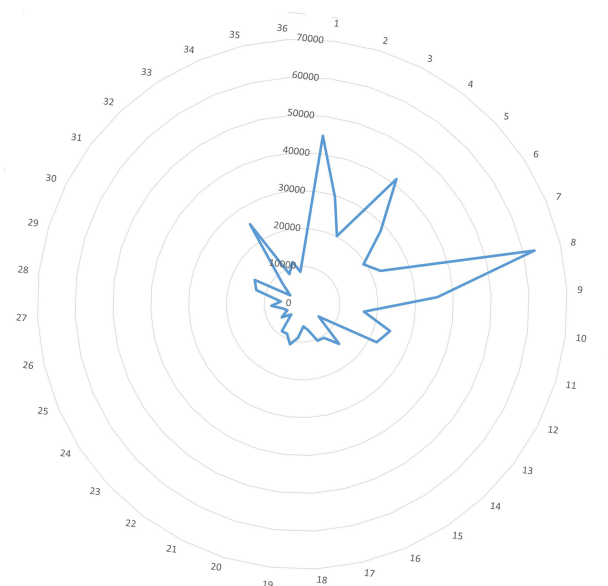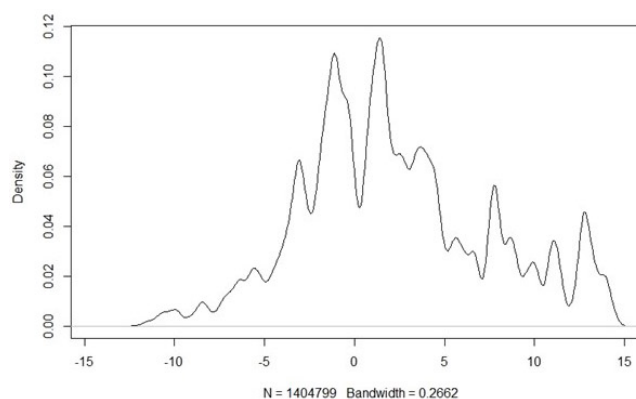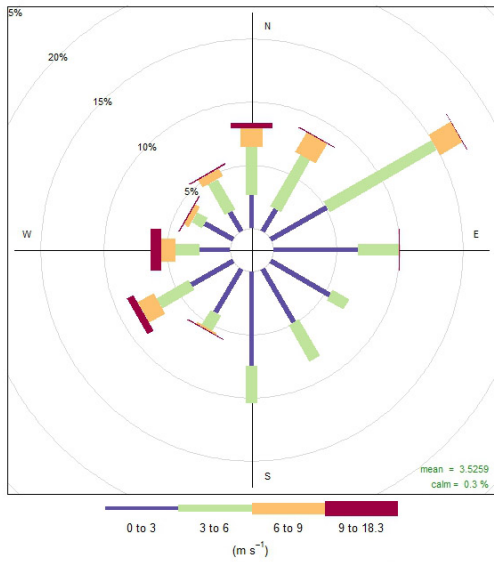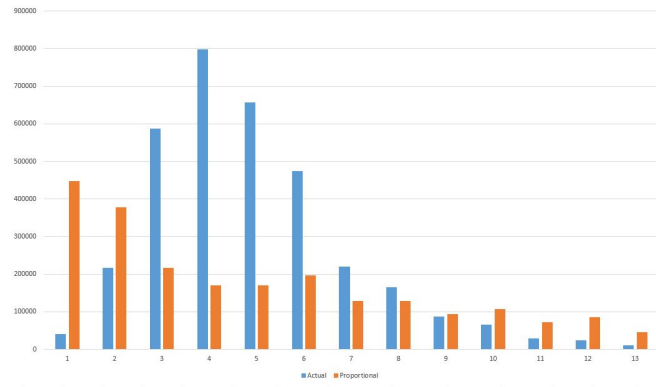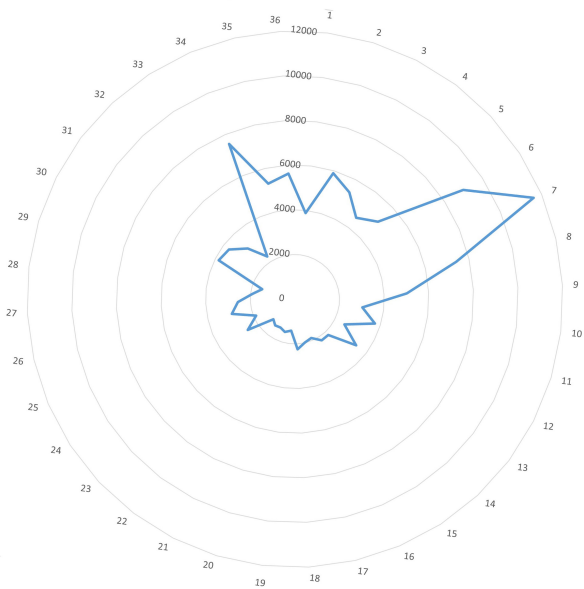

Fig 43. Common Scoter totals by wind direction, in proportion to the frequency of the different wind directions.
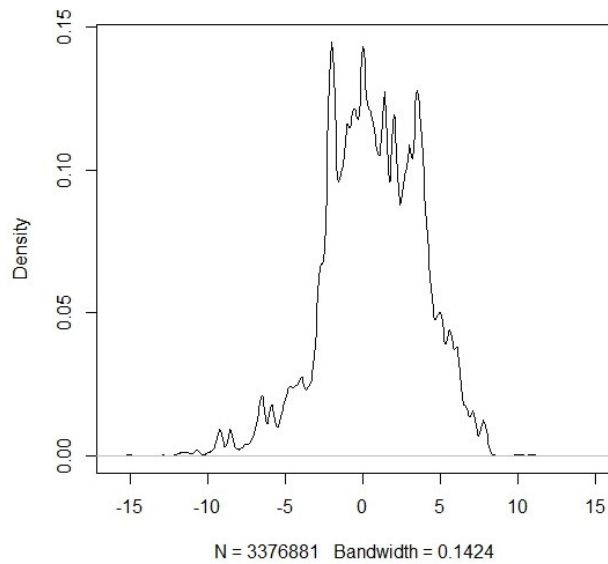

Fig 45. Common Scoter. Density of observations in relation to the wind factor parallel to the migration direction.

Velvet Scoter figures, commented on page 25. Figure types explained on pages 6-7.
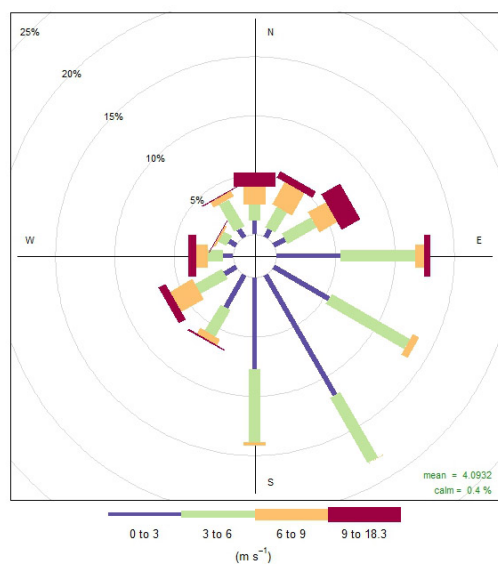

Fig 46. Velvet Scoter totals by different wind directions and strengths (in %).
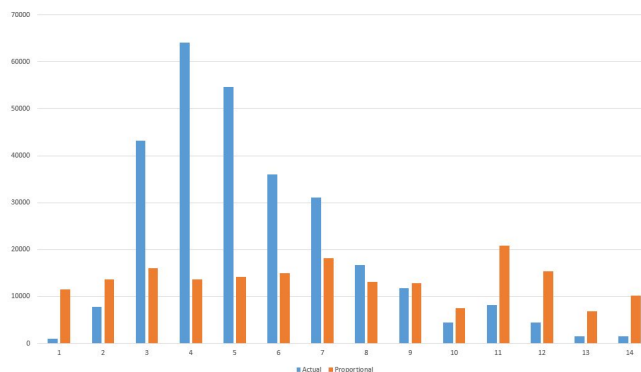

Fig 48. Velvet Scoter totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.

Fig 47. Velvet Scoter totals by wind direction, in proportion to the frequency of the different wind directions.
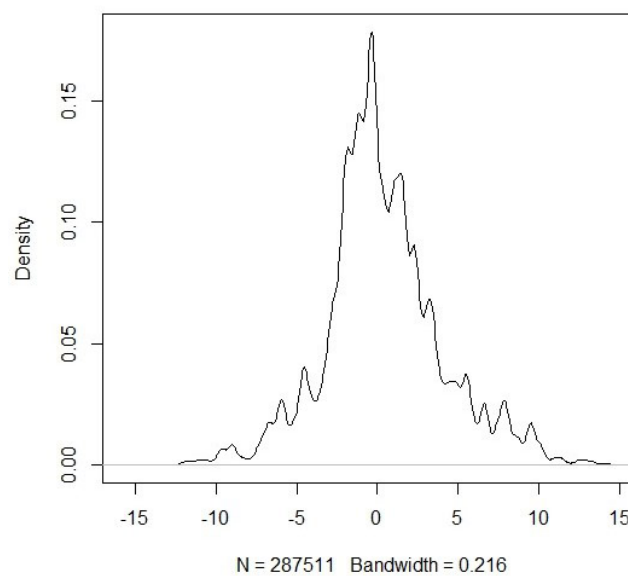
Fig 49. Velvet Scoter. Density of observations in relation to the wind factor parallel to the

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Rain class  Hours  Birds   Birds/h
A           1279   126463  99
B           179    8117    45
C           73     2223    30
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Table 10. Velvet Scoter. Totals by rain class. October. 8 am to 5 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).

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Year       2004   2009   2014   2019
Birds      42254  49158  58543  57605
SE winds   467    331    540    466
```

Table 11. Velvet Scoter. 25 August - 2 November, bird totals and SE wind hours between 10 am and 5 pm.

4 October 2004 4669 birds.Generally, both this and the previous day were good and diverse migration days, and in the previous days there were as many as 1500 Velvet Scoter migrating. SE winds on both this and the previous day, with not much difference in the weather.

25 October 2009 5503 birds.The previous day was meagre for scoters, but otherwise both days showed migration of similar magnitude. The previous day saw mostly NE winds, turning to SE for 25th.

4 October 2014 5431 birds.The previous day was poor for scoters, but the peak day for Red-throated Diver. On 4th, Velvet Scoters started already at 9 am and the migration was steady for the rest of the day. Long-tailed Duck numbers were good too. Weak winds, on the previous day mostly from the south, on 4th between south and east with some fog in the morning. No big difference between the days.

22 October 2014 8031 birds. Both this and the previous days were meagre migration days. 22nd was good only for Velvet Scoters. The wind turned towards east, but never reached SE.

3 October 2019 5171 birds. A big day for many species with over 100 000 birds counted. During the afternoon of the previous day, the wind turned to E and SE (via N).

28 October 2019 7342 birds. On the previous day it rained all day, with poor migration. On the 28th the migration was good and diverse.

Table 12. Cases of migratory peaks for Velvet Scoter.

Long-tailed Duck *Clangula hyemalis*

Large flocks of Long-tailed Ducks spend time in the area during the migration as well as in winter. However, it is comparatively easy to separate local birds from those which are moving longer distances. This species is seen in higher numbers during tailwinds, and if anything, the species favours strong winds.

Common Scoter *Melanitta nigra*

Common Scoter is the most numerous migrant bird species at Põõsaspea neem, with season totals between 600 000 and 923 000 counted in the four organized counts (Ellermaa & Lindén 2020). The general view is that a large majority of the migration always passes between Põõsaspea neem and Osmussaar, where it is both observable and countable, and not too many birds pass the area far out to sea. They also never fly overland during daylight. Most of the migration is counted when tailwinds occur, which should be the optimum winds for migration - so in conditions when theoretically most of the migration should occur. That points to the theory that the majority of the migration is visible, in most years. However, the proportion of nocturnal migration in this species could be significant.

Most Common Scoters are seen during tailwinds, but good numbers have been seen during most wind directions, if the winds have not been too strong. If frequencies are taken into account, it seems that southerly winds are less favourable for the species. It is possible that some of them then fly too far out to sea to be countable. Common Scoters seem to prefer light winds, even lighter than typically available in the area at the time of migration.

Red-throated Diver figures, commented on page 25. Figure types explained on pages 6-7.

Fig 50. Red-throated Diver totals by different wind directions and strengths (in %).

Fig 52. Red-throated Diver totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
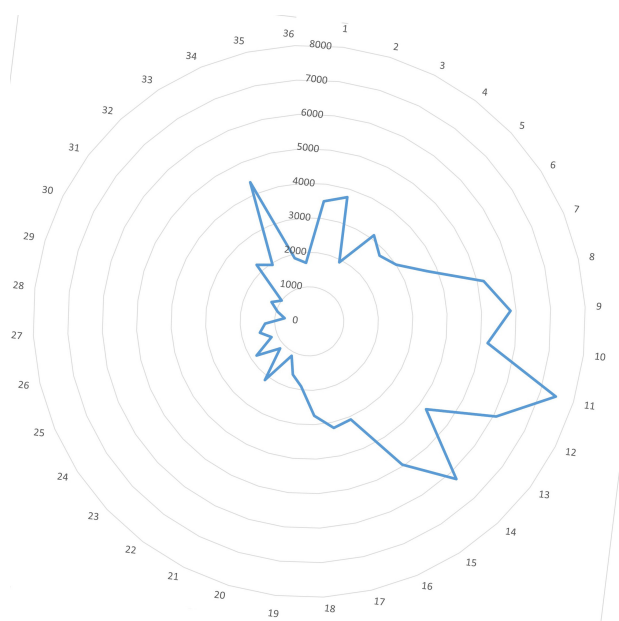

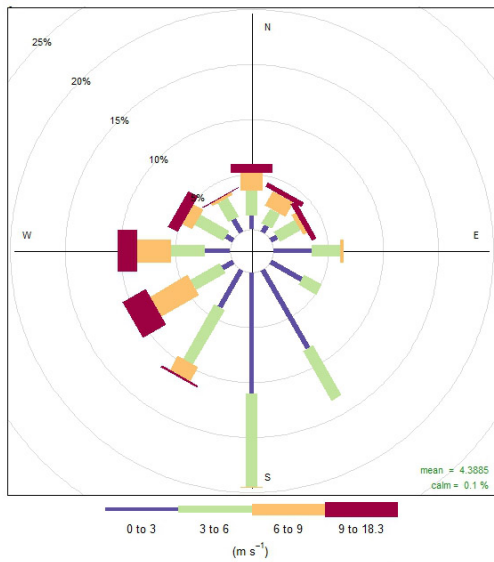Fig 51. Red-throated Diver totals by wind direction, in proportion to the frequency of the different wind directions.

Fig 53. Red-throated Diver. Density of observations in relation to the wind factor parallel to the migration direction.

Rain class	Hours	Birds	Birds/h
A	1303	49528	38
B	139	5020	36
C	49	1517	31

Table 13. Red-throated Diver. Totals by rain class. 16 September to 15 October. 6am to 3 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).

Black-throated Diver figures, commented on page 25. Figure types explained on pages 6-7.

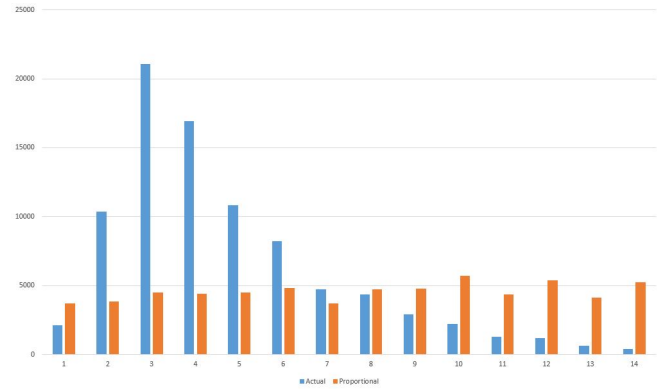Fig 54. Black-throated Diver totals by different wind directions and strengths (in %).

Fig 56. Black-throated Diver totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
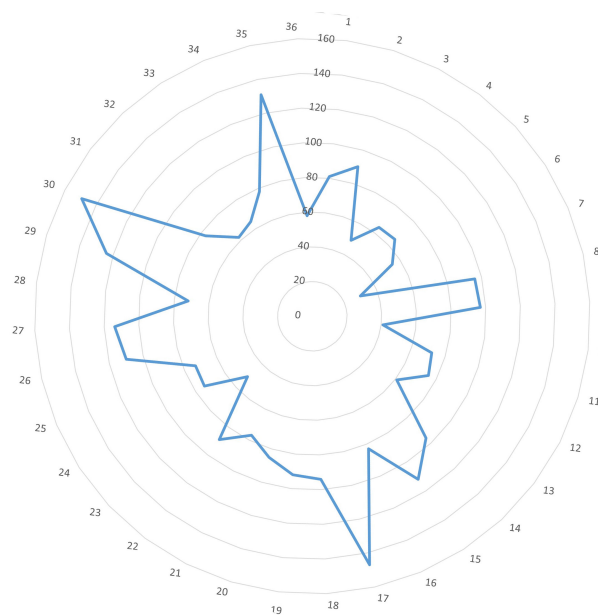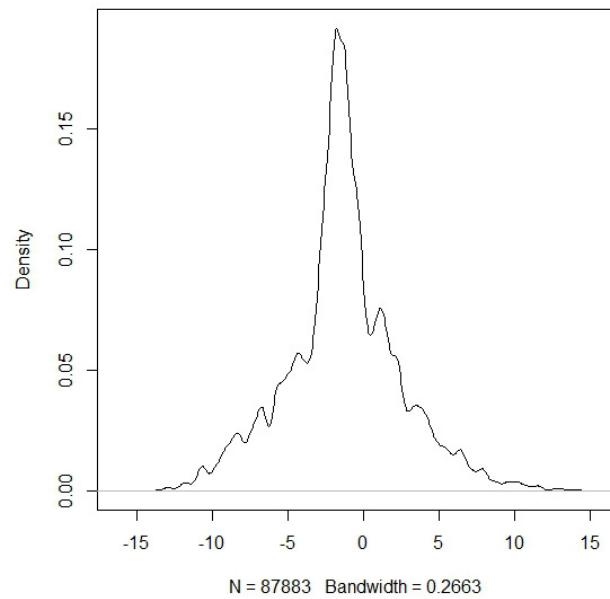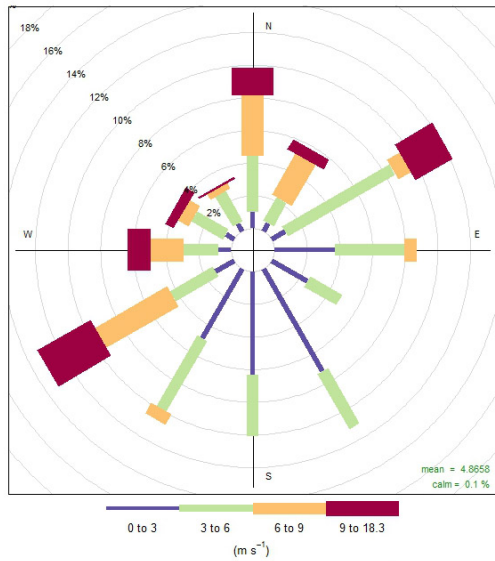

Fig 55. Black-throated Diver totals by wind direction, in proportion to the frequency of the different wind directions.

Fig 57. Black-throated Diver. Density of observations in relation to the wind factor parallel to the migration direction.

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Rain class  Hours  Birds  Birds/h
A           1280   12093    9
B           170    1109     7
C           75     637      8
```

Table 14. Black-throated Diver. Totals by rain class. October. 6am to 3 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).

16 September 2004 43 birds. Some rain during the morning, and also during the afternoon, air moisture less than 83% all day, temperature normal, wind strengthening from 4 to 9 m/s, turning from southwest to northwest. The count ended exceptionally early, at 11am.

7 October 2009 15 birds. Rain between 9 am and 4 pm, visibility good, wind SE -> S, 5-9 m/s

8 October 2014 41 birds. Slight rain from 11am until late afternoon, visibility good until late afternoon after which foggy, wind SE/S.

1 October 2019 45 birds. Rain until 7am and after 2pm, visibility good for most of the day, strong winds 11-14 m/s from SW.

Table 15. The poorest days for Red-throated Diver during the main migration period. The prevailing weather types during these example days have never been favourable for migration, but for slightly different reasons.

Fig 58. Unidentified divers totals by different wind directions and strengths (in %).

Dunlin figures, commented on page 26. Figure types explained on pages 6-7.

Fig 59. Dunlin totals by different wind directions and strengths (in %).

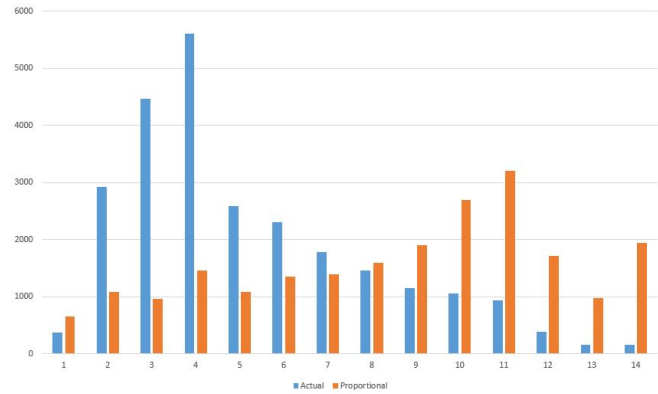Fig 61. Dunlin totals by wind strength. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.
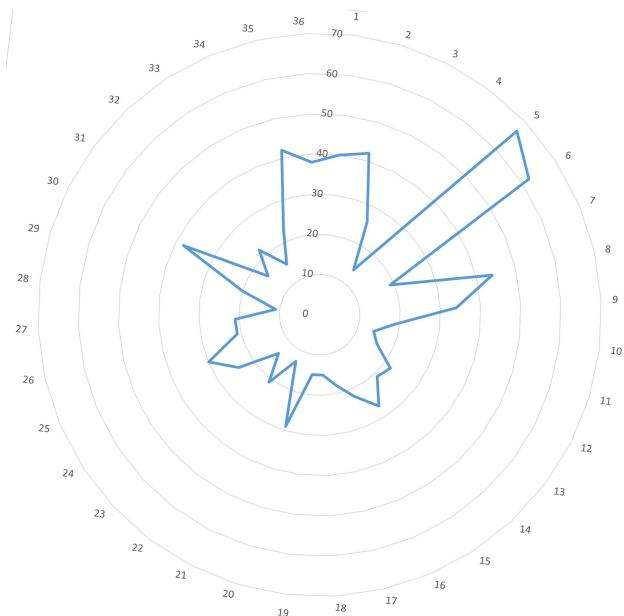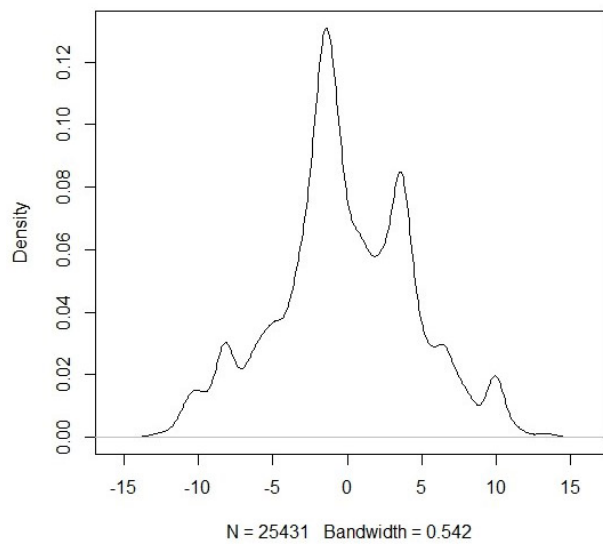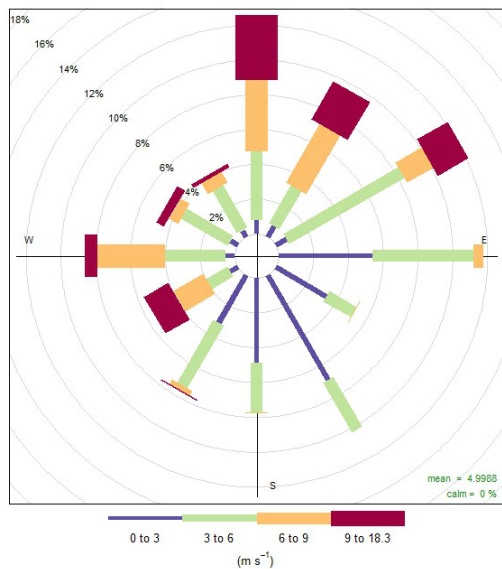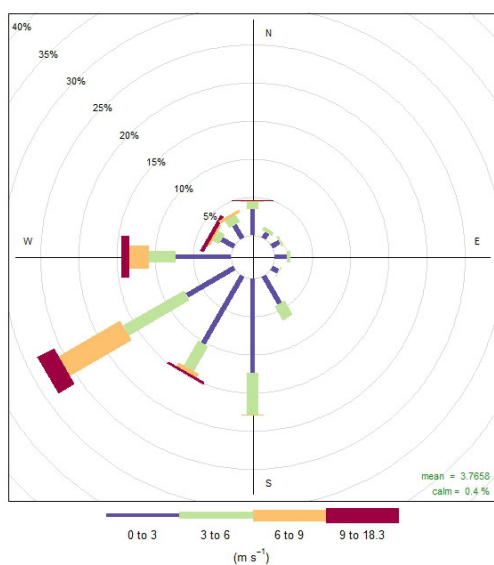

Fig 60. Dunlin totals by wind direction, in proportion to the frequency of the different wind directions.

Fig 62. Dunlin totals by wind strength, July-August. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.

Rain class	Hours	Birds	Birds/h
A	3837	52141	14
B	247	3394	14
C	121	1106	9

Table 16. Dunlin totals by rain class. 15 July to 30 September. 6am to 4 pm. No rain (A), less than 1mm of rain (B), and 1 mm or more of rain (C).
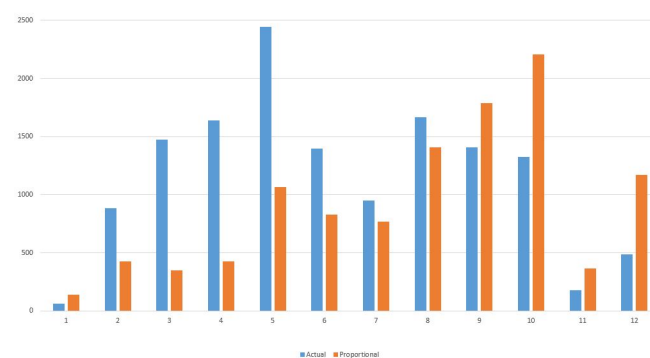
Fig 63. Dunlin totals by wind strength, 01 September - 15 October. Both actual and in proportion to the frequency of the different wind strengths. X-axis: m/s, Y-axis: number of birds.

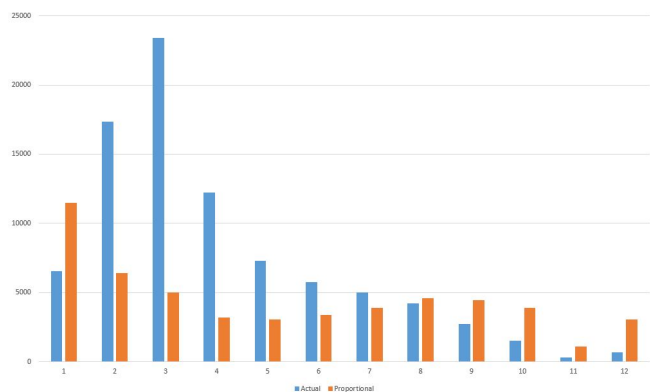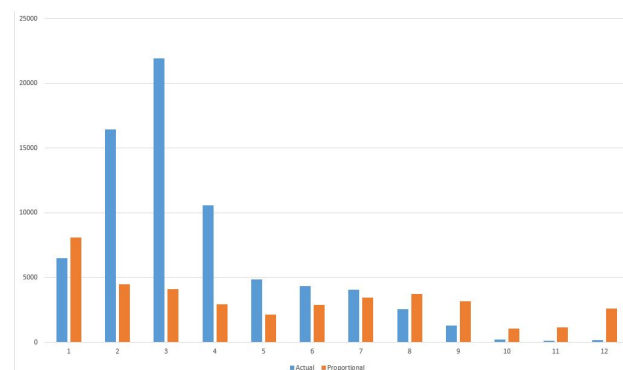|	Favoured wind direction	Wind strength preference	Avoids rain	Variation in numbers
Barnacle Goose	NE	No	Yes	45.19
Brent Goose	SW-W	Strong winds	Yes	57.67
Eurasian Wigeon	W-NW	No	No	32.03
Eurasian Teal	other than SW	No	No	14.74
Northern Pintail	W-NW	No	No	30.14
Greater Scaup	E-S	No	Yes	26.68
Long-tailed Duck	NE	Strong winds	No	18.80
Common Scoter	NE	Light winds	No	17.76
Velvet Scoter	SE	No	Yes	14.66
Red-throated Diver	Any	No	No	18.70
Black-throated Diver	NE	No	No	26.21
Dunlin	SW	Light winds	No	74.76

Table 17. An interpretation of the data.

N = 88813   Bandwidth = 0.2156

Fig 64. Dunlin. Density of observations in relation to the wind factor parallel to the migration direction.

There have been eight days when the counted total was more than 40 000 individuals higher than in the previous day. These are detailed in Table 8.

Velvet Scoter *Melanitta fusca*

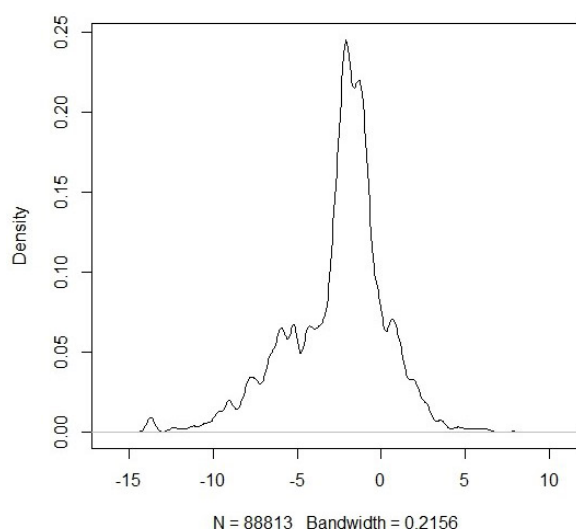The season total for Velvet Scoter has varied between 52500 and 74200 (Ellermaa & Lindén 2020). Unlike Common Scoters, they clearly prefer southeast winds. Their flight path is different too, as they fly closer to the shore and often fly over the cape. There has been some speculation that the main flyway could be further to SE, over the continent, but that SE winds cause wind drift and bring birds close to Põõsaspea neem. If that was the case, season totals should be higher when there has been a lot of SE winds during the main migration period of the species.

There is some Velvet Scoter migration around Põõsaspea neem almost all year round. But during the project period, only 13% of the Velvet Scoters had passed by 24 August but by 2 November 96% had already migrated. We have defined 25 August - 2 November as the main migration period. Table 12 shows the totals of Velvet Scoters from that period in the project years and from the same period the number of hours with southeasterly winds (between 100 and 170 degrees). The best year for Velvets was 2014, with prevailing southeasterly winds, and in 2009, with the least southeasterly winds, the total of Velvets was lower than in 2014 and 2019. The year 2004 does not fit the pattern – south-easterly winds were as prevailing as in 2019, but the number of Velvet Scoters was the lowest of all. In any case, there seems to be some relation between the Velvet migration and SE winds.

However, the variation of Velvet totals across the four project years is not large. The lowest yearly total, in 2004, is 71% of the highest count, which was in 2014 (total numbers, from Ellermaa & Linden 2020). See also Table 17 where it can be seen that this species has the smallest variation coefficient of all the studied species. This rather speaks against the

theory that Velvet Scoter numbers are very much dependent on weather or other stochastic circumstances.

Most of the Velvet Scoters have been seen when the average wind has been between 3 and 6 m/s, but in proportion to actual wind strengths, they really do not seem to show any preferences.

On six days the total had increased more than 3000 individuals compared to the previous day. They are detailed in Table 12.

Divers

Red-throated Diver *Gavia stellata* shows a pattern with a strong southerly component. In fact, it seems not to be much different from the distribution of wind direction in general. It seems that this species is about as likely to be seen on migration in any wind direction. In addition, it shows no preference for any wind strength. There is also almost no correlation between observed numbers of Red-throated Divers and amount of rain in any hour between 16 September and 15 October (Spearman's rank correlation less than 0.02).

Black-throated Diver *Gavia arctica* shows a somewhat different pattern, with a much stronger NE component. This should have something to do with the fact that this species is really a southbound migrant with many wintering in the Black Sea. Põõsaspea neem certainly concentrates the SW migration towards the southern Baltic, and it may be that NE winds may make southbound migrants change their route temporarily towards SW. Also, this could be because a larger ratio of this species start migration from inland lakes compared to Red-throated Diver, which may be in the Baltic already in larger numbers. This species seems not to avoid strong winds, but the preference for them is slight.

The pattern of unidentified divers seems to be a mixture between both species, as expected.

Because the migration of Red-throated Divers is not

that dependent on wind strength or direction, some numbers are seen daily during the main migration season. If 16 September to 15 October is defined as the main migration period, during the complete counts the days with less than 50 individuals observed and identified are listed in Table 15. It has to be remembered that a considerable proportion of the divers will always be left unidentified.

Dunlin *Calidris alpina*

Dunlin numbers are seen on southwesterly winds, while very few of them were seen during stronger tail winds. Most likely a headwind is not their preferred migration wind, but the migration is at its most visible under these circumstances. The season total of Dunlin varies a great deal, with 41600 in 2009, but in other years only between 10100 and 15200. This species has the highest variation coefficient of the studied species, see Table 17. Based on this study, Dunlin seems to prefer weaker winds and no rain. However, this is mostly true for the early season July-August only. It is quite possible to see them, in good numbers, flying straight into even quite a strong gale, close to the surface, and in rain, especially during the latter part of the migration period, compare figs 62 and 63.

Summary

Table 17 shows the presented species and conclusions based on the data. Variation in numbers refers to the variation coefficient of the season total between the four project years. Brent Goose and Dunlin are weather – dependent species, and their numbers vary a great deal between the years, because in some weather types, the main migration is not visible at Põõsaspea neem. We suspect that in other than the best conditions, Brent Geese are migrating far out to sea, and Dunlins too high to be visible.

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