Seminar series nr 140

Do landscape properties influence the migration of Ospreys?

- A study of migration patterns using GIS -

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2007
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Degree thesis in Physical Geography and Ecosystem Analysis

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Abstract

Three Ospreys were fitted with satellite transmitters including GPS receivers in autumn 2006. These transmitters provide hourly data of the birds' positions during their migration from Sweden to Africa. These data, together with land cover data, was used in this study to develop a method for investigating the influence of landscape properties on different aspects of bird migration. The Ospreys were assumed to choose a route that goes through a landscape rich in feeding habitat and in these areas the migration speed was believed to be slower. Since Ospreys feed on fish their feeding habitat consists of water. Two different methods were developed to estimate the availability of feeding habitat in the landscape:

1. The proportion of water within buffer areas around the route was calculated.
2. The distance to nearest water body from the route was calculated.

The choice of route was analysed by comparing the real route to either simulated routes or the shortest route. The comparison was made for each day. Routes were simulated by rearranging the different segments of the real route. The shortest route was drawn as a straight line from the first to the last position of the day.

The relation between migration speed and the proportion of water in the landscape was tested. The route was divided into different segments and the proportion of water and speed for each segment was calculated.

Land cover data was available in 1 km resolution globally, 250 and 100 m for Europe and 25 m for Sweden. An evaluation of land cover data showed that the calculation of distance to water was more resolution dependent than calculating the proportion of water.

No definite conclusions about the Osprey's behaviour could be drawn. The only significant result was from the comparison between distance to water and choice of route, but since this was done with 1 km resolution it is not very reliable. When the proportion of water was calculated to analyse the migration route no relationship was found. This could be because of the coarse resolution in data. On several of the days the proportion of water was 0 % when the 1 km resolution in data was used, even in areas where there was water represented in finer resolution data.

Migration speed did not seem to be dependent on the proportion of water. Only when the days were not divided into segments there is some indication that there is a relationship. The time of day probably affects the length of the segments to a greater extent than proportion of water.

Sammanfattning

Tre fiskgjusar utrustades med sändare innehållande GPS-mottagare inför hösten 2006. Sändarna gav information om fågelns position varje timme under hela flytten från Sverige till Afrika. Data från sändarna användes i den här studien tillsammans med marktäckedata för att ta fram en metod för att undersöka samband mellan landskapet och olika aspekter av flytten. Fiskgjusen förväntades välja en väg som passerar områden med stor tillgång på föda och i dessa områden flyga långsammare. Fiskgjusar äter fisk och därmed är det i sjöar och vattendrag som de hittar sin föda. Två olika metoder användes för att utvärdera tillgången på vatten i landskapet.

1. Andelen vatten beräknades inom buffertzoner runt flygvägen.
2. Avståndet till närmsta vatten från flygvägen beräknades.

Vägvalet analyserades genom att jämföra den verkliga vägen med antingen simulerade vägar, eller den kortaste vägen. Vägar simulerades genom att dela upp den verkliga vägen i olika segment och kasta om dem. Den kortaste vägen skapades genom att dra en rak linje från start till mål varje dag.

För att undersöka om fiskgjusarna flög snabbare inom områden med mycket vatten jämfördes flytthastigheten med andelen vatten. Flyttvägen delades upp i segment för vilka hastighet och andel vatten i buffertzoner runt dem beräknades.

Marktäckedata fanns tillgänglig i 1 km upplösning globalt, 250 och 100 m för Europa och 25 m för Sverige. En jämförelse av olika data visade att metoden för att beräkna avstånd till vatten var mer beroende av upplösning än metoden för beräkning av andel vatten.

Inga säkra slutsatser kunde dras om fiskgjusarnas beteende under flytten. Det enda resultat som var signifikant var när påverkan på vägval av avstånd till vatten analyserades, men eftersom resultatet baserades på 1 km upplösning i data är det tveksamt om det är tillförlitligt. Inget samband hittades mellan andelen vatten och flyttväg. Det skulle kunna bero på den grova upplösningen i marktäckedata. Under flera dagar var andelen vatten 0 % när den beräknades med 1 km upplösning, även i de områden där det i finare upplösning i data visade sig finnas vatten.

Något samband mellan flyghastighet och andel vatten kunde inte visas. Antagligen påverkas hastigheten mer av vilken tid på dagen det är. Det verkar fungera bättre att dela in vägen i längre dagslånga segment istället för att dela upp varje dag.

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1 INTRODUCTION

1.1 Background

Bird migration is a solution to the problem that the distribution of resources changes with the seasons. When it gets colder the availability of resources will be reduced and birds travel far to reach areas where there is food available (Alerstam 1990).

The studies of bird migration started with field observations, where binoculars and telescopes were the only instruments available. Ringing made it possible to find out where the birds went, but only provided one observation per bird. Modern technology has increased the opportunities to follow birds' migration routes in more detail. First radar was used to study migration intensity and the directions of migration. Later a radio transmitter could be attached to the bird, making it possible to follow the journey of individual birds. The latest development is a solar panel driven transmitter including a GPS (global positioning system) receiver, giving very detailed data of the bird's journey, including hourly information of its location in three dimensions (op. sit.). Despite these technical advances, little is known about the factors that affect the route travelled and migratory performance on a small scale.

Topography influences the speed and migration route. Soaring birds can use the upwinds caused by rising air being pressed up by a mountain ridge. Upwinds are also caused by the ground being heated, and are then called thermals. Large birds, such as raptors, use these thermals to gain altitude, spending as little energy as possible. They soar in circles, rising higher and higher to a certain altitude from where they take off, gliding in the migratory direction. While doing so, they lose altitude, having to find a new thermal to rise higher again. This is an energy efficient way of travelling, since the bird does not have to flap its wings. Thermals normally only occur over land. Therefore birds depending on thermals avoid migrating over larger water bodies and cross the sea at the shortest passage-ways. An example of such a passage-way is Falsterbo, in the south of Sweden, where many birds make the crossing to the European main land during autumn migration (op. sit.).

Another factor affecting the route and speed of migration is the weather. For example, Thorup et al. (2003) found a relationship between both perpendicular and forward movement and wind in Ospreys (*Pandion haeliatus*) and Honey Buzzards (*Pernis apivorus*). Perpendicular displacement due to wind was more pronounced in juvenile birds, i.e. adult birds instantly compensates for the wind drift.

A highly likely influence on the choice of route and speed is other landscape properties than topography. Strandberg and Alerstam (2007) studied Ospreys, when they where passing by a lake during migration. They found that Ospreys use a fly-and-forage strategy, meaning that they combine foraging with migration. Some of these birds deviated from the mean direction of migration to follow a river or fly towards the coast. There is a possibility that birds would chose to migrate through areas rich in feeding habitat, affecting their migration route. Combining migration and foraging is expected to slow down the migration speed.

GPS receivers now make it possible to investigate the link between landscape features and migration. In this case study of the Osprey a method for analysing this relationship using standard GIS (Geographical Information System) software will be presented.

1.2 Material

In a project run by the the Migration Ecology Research Group at the Department of Animal Ecology, Lund University, three Ospreys have been equipped with GPS receivers and radio transmitters (Fig. 1), which provide hourly information of their position, altitude, velocity and bearing. Fig. 2 shows the positions from the birds' migration in the autumn 2006. Some of these data will be used in this study to analyse if the choice of a migratory route is related to landscape properties such as abundance of water, and to investigate the link between landscape properties and migratory performance.

Land cover data is used to analyse the landscape around the route of the birds. Since Ospreys almost solely feed on fish, water is the most interesting land cover class.

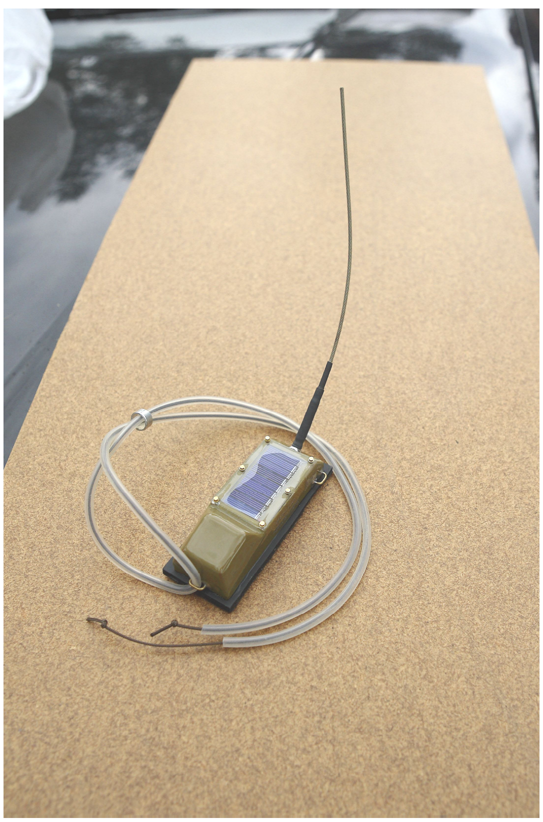


Figure 1. The radio transmitter witch was attached to the back of the birds.

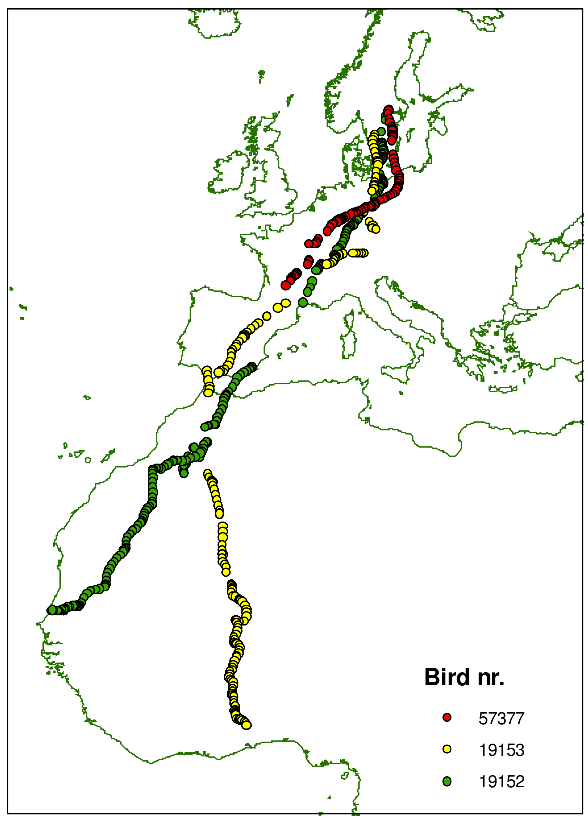


Figure 2. Positions of three Ospreys *Pandion haliaetos* during the autumn migration 2006. Bird nr. 57377 stopped transmitting after the 24th of September in the south of France.

1.3 Aims

The aim of this study is to develop a GIS based method for analysing landscape features' influence on migration, using the Osprey as an example.

There are two parts of the project. The first will be focusing on the effect water has on the choice of migratory route. Since the Osprey feeds on fish, it is dependent on water for finding food. Therefore, the availability of water in the landscape may influence the route that is chosen. If the Osprey was selecting for possible feeding grounds, it is likely that it would choose a route that passes by more water bodies than if it was going in a random or straight direction.

The second part focuses on the abundance of water to find out if this has an effect on the speed of migration. Things that influence the speed of migration are temperature, wind and other aspects of the weather. The opportunity to stop to eat might also be an influencing factor. If the bird makes more stops it would decrease the bird's migration speed. With more water in the landscape there would be more opportunities to stop. Are the Ospreys going faster when they are passing through landscapes with less water?

There will also be an evaluation of land cover data. A problem with using this kind of data is the spatial resolution. There is 1 km data available globally, but for Sweden and Europe finer resolution is available. An evaluation of the influence of resolution in data will be made.

1.4 Study species

Ospreys (*Pandon haliaetus*) are large birds, with a wingspan of more than 1.5 m. They are raptors that feed mainly on fish. They are breeding all over the northern hemisphere, but in the autumn they migrate southwards (Alerstam 1990). The Swedish Ospreys mainly winter in West Africa north of the Equator, in areas were there is water available, along the coasts, lakes and rivers (Österlöf 1977).

Ospreys do not concentrate at the shortest sea crossings as other soaring migrants, and they do not avoid deserts to the same extent. (op. sit.). They regularly use updrafts and thermals for soaring, but they are also strong fliers and do not hesitate to migrate by flapping flight (Poole 1989).

Radio transmitters with GPS receivers were attached to three adult Ospreys, one female and two males, at Grimsö National Park in Sweden (one of them is shown in Fig. 3 with a transmitter on its back). A data logger hourly stores the bird's positions in WGS (World Geodetic System) 84 Lat/Long from the GPS receiver as well as information about altitude, heading and speed. Stored data is relayed to the Argos System in France using satellites. Two of the birds made it to their wintering sites in Africa, whereas one of the males reached the south of France where transmission stopped.

One of the Ospreys (No 19152 in Fig. 2) was chosen to develop a method for analysing the migratory route. This bird is a male who migrated to a wintering area in Senegal. The detailed route through Europe is shown in Fig. 3. Missing positions are due to transmission failure.

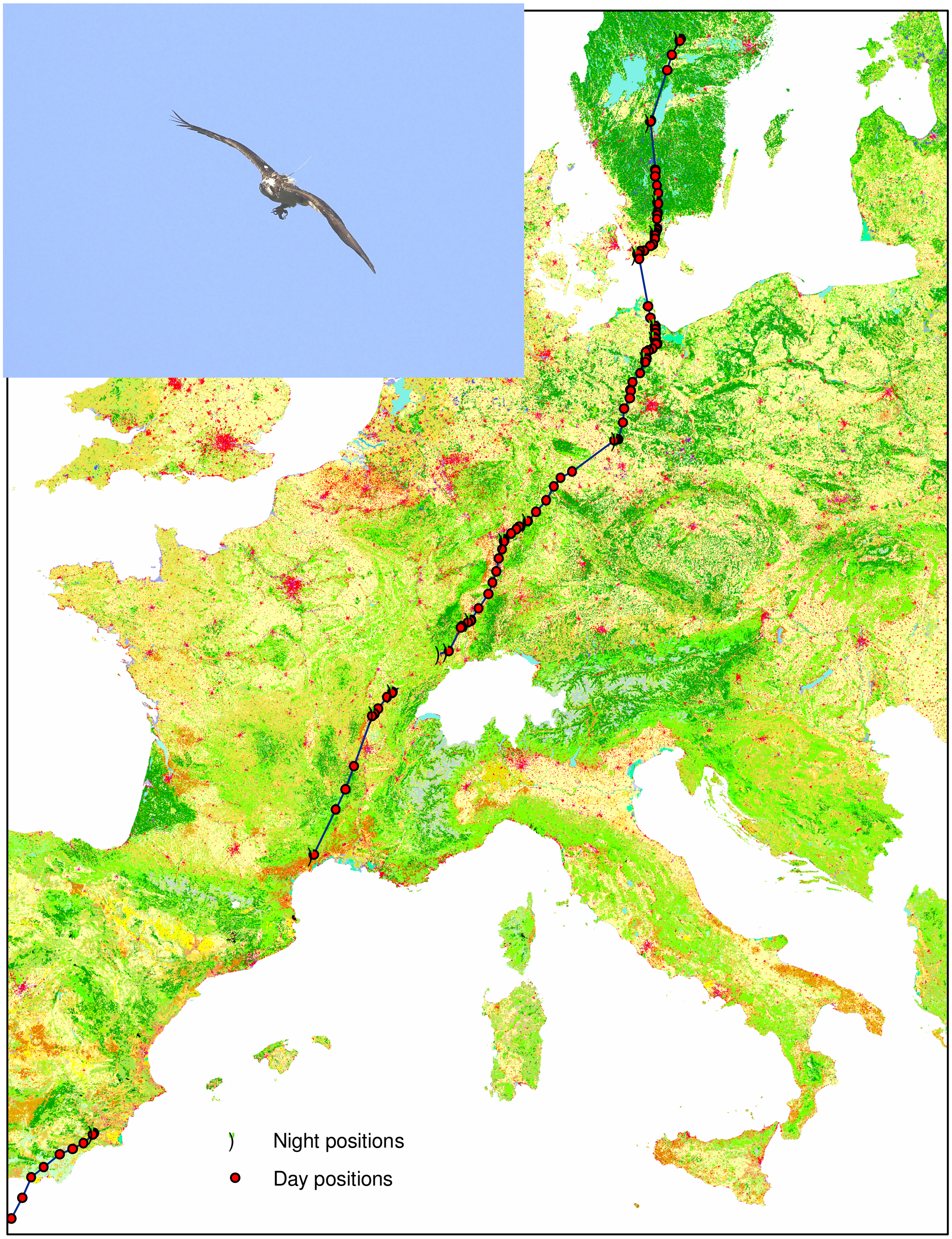


Figure 3. The picture in the top left corner shows one of the Ospreyys with a satellite transmitter on its back. The map shows positions of one Osprey male (19152) in Europe during the autumn migration 2006.

2 METHOD

2.1 The migratory route

One way of testing whether the Osprey select to migrate through landscapes that are rich in water is to look at the proportion of water within an area around the route. The proportion of water should be higher here compared to the surrounding area if areas with a lot of water were chosen by the bird. Another test is to look at the distance from each position to the nearest water body. The distance to water should have a lower value for the real route, if the Osprey would choose a route that was closer to water than a random or straight route.

Two alternatives were compared to the real route, simulated routes and the shortest route. The simulated routes were based on the real route so that they could be possible alternatives. They had the same length, start and stop points as the real route. The idea with the shortest route was to test what makes the bird deviate from the route that is a straight line between start and goal. It would be most energy efficient to go the shortest way if there wasn't some factor that made it worth taking a detour. These comparisons were made within days, but the same method could be used for looking at the choice of route on a larger scale.

Simulated routes were generated in order to compare water availability along the real route to water availability along other possible routes. The simulations where made by rearranging the different segments of the real routes. The different route segments were given a random number and then rearranged based on these numbers. By using the same starting points, all routes end up in the same end point (Fig. 4). The simulated routes will also have the same length as the real one. Using this method, it is possible to generate (n-1)! simulated routes per day, where n is the number of positions along the real route. 100 simulations per day were made. A minimum of 6 positions was required to make it possible to create at least 100 simulated routes. On several days, data is missing due to transmission failure. On two of these days no data was transmitted and on 5 days there were less than 6 positions. These days were not included in this analysis. An example of the real and simulated routes for one day is shown in Fig. 5.

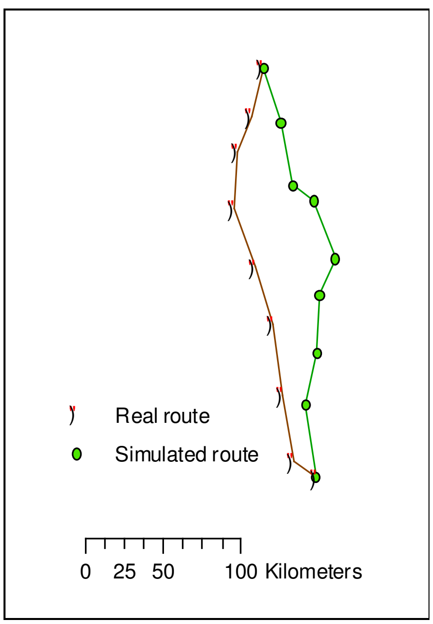


Figure 4. Simulation of routes. The line segments of the real route are rearranged in a random order to create a new route with the same length, start and stop positions.

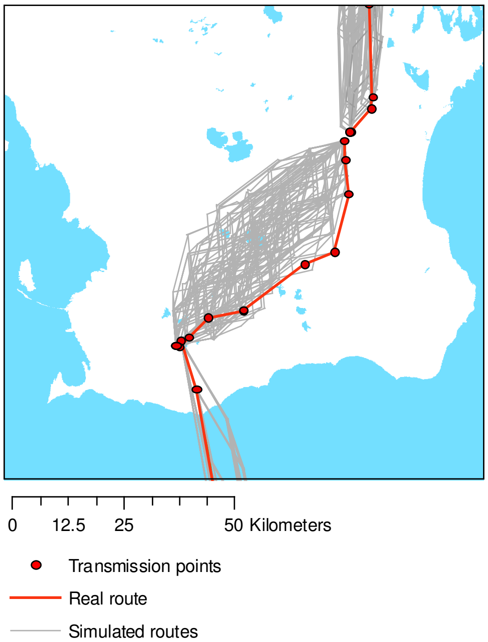


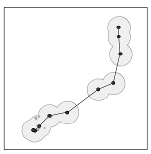
Figure 5. Real route and 100 simulated routes on the 2nd of September.

To test if water availability is a factor that makes the bird deviate from the *shortest route* between start and goal, a line was drawn from the first to the last position of the day. To do this a gnomonic projection was used. In this projection the great circles are straight lines. A line will always be the shortest route between the two end points (Ekman, 2002). This route was compared to the actual flight route.

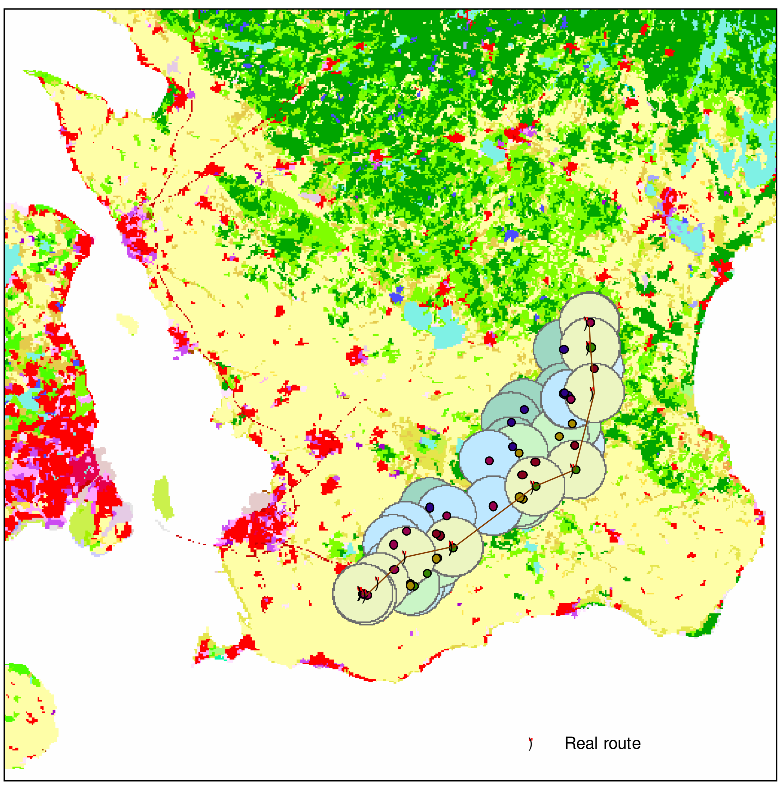
2.1.1 The migratory route in relation to the proportion of water in the landscape

To calculate the proportion of water along the different routes an area had to be created around them. To achieve this, buffer zones were used, based on either points or lines. These areas were used to extract land cover data. From the extracted surface the proportion of water along the line could be calculated

The circular buffers were chosen, because the points are known positions of the bird. Between these positions the bird might be making detours, which will not show in the data. The reason for using linear buffers for the shortest route comparison was that the route was generated as a line. Another possibility could be to create points along the line, to create the buffer areas from, but the positions of these points would be completely arbitrary.



The positions from the real and simulated routes were used as a point layer and circular buffer areas around the points were created (Fig. 6). These areas were then used to extract land cover data from which the proportion of water along each route was calculated.



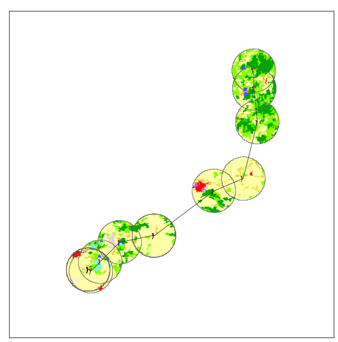
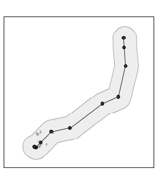
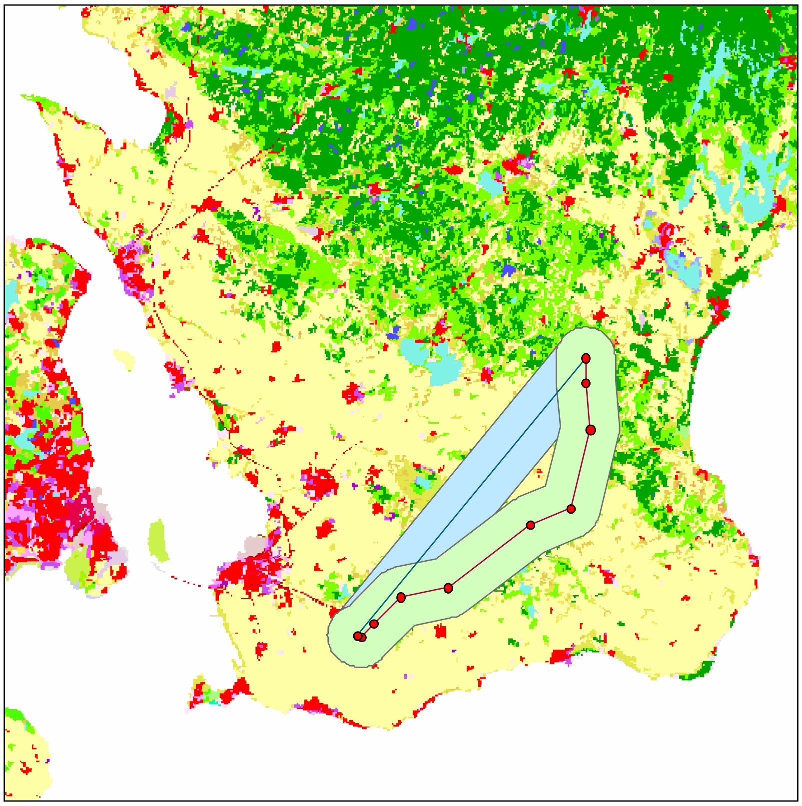


Figure 6. Real and simulated routes and buffer areas with a 5 km radius. The small figure to the right shows the area extracted from the land cover data.



Buffer areas were created around the lines (see the small figure to the left) when comparing the real and shortest route and land cover data from that area was extracted (Fig. 7). Too large buffer areas would cause overlap, whereas too small buffer areas would not include enough data.



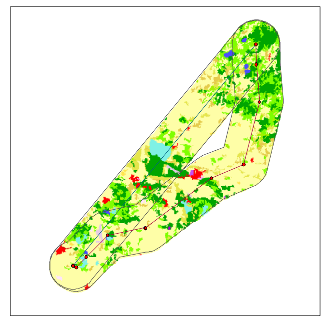


Figure 7. Comparing the real route to a straight line between the first and last position of the day. The small figure to the right shows the area extracted from the land cover data.

Table 1 shows the different tests that were made to relate the migratory route to the proportion of water in the landscape. In Test 1 and 2 the real route was compared to the simulated and shortest routes. The buffer areas for the real and simulated routes were calculated from points and for the shortest route the buffer areas were calculated from lines.

Table 1. The different tests that were made to relate the migratory route to the proportion of water in the landscape.

Test	1. Real route compared to shortest and simulated	2. Real route compared to shortest and simulated (2/9)	3. Real route compared to shortest (Different buffers)
Resolution	1 km	100 m	100 m
Buffer distance	5 km	5 km	1, 5 and 20 km
Lines or points	Lines and points	Lines and points	Lines
Number of days	30	1	17

2.1.2 *The migratory route in relation to distance to water*

To calculate the distance to the nearest water body a raster containing distances to water was created. Water bodies were extracted from the land cover data, forming a raster with only water. For the cells in a new raster the distances to the water bodies were calculated. This resulted in a raster with each cell values representing the Euclidean distance (the distance in a straight line) from that cell to the nearest water body (see Fig. 8).

By combining the distance raster with the positions from the real and simulated routes, the distance from each point to water could be extracted. This resulted in a table containing the distance to nearest water body for all positions along the real and simulated routes. When distances from the shortest route were calculated a line was used. The cell values from under the line were extracted and an average of all values was calculated.

A X^2-test was used to test whether the frequency of days when the real route was closer to water than the simulated or shortest routes was higher than the frequency of days when the real route was further away from water.

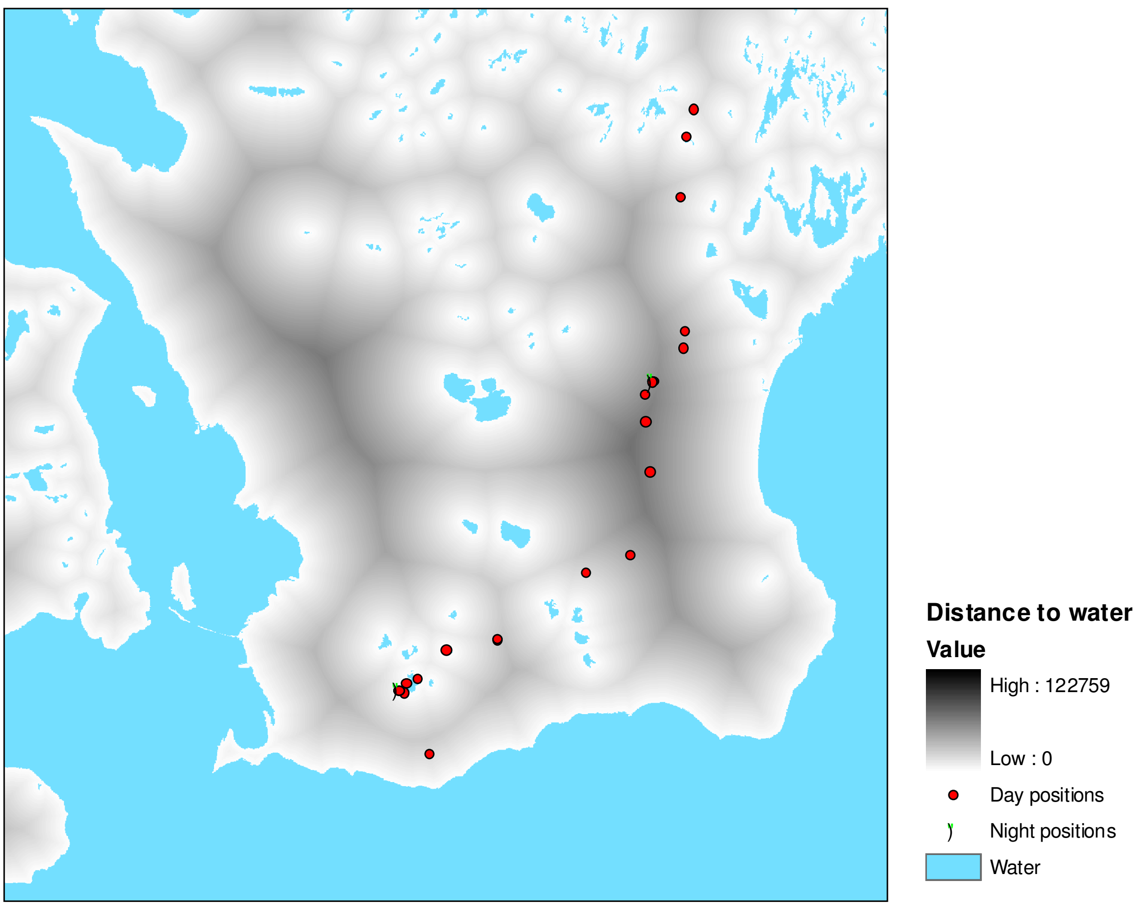


Figure 8. Distance to water raster generated from 100 m resolution Corine land cover data. Each cell value of the distance raster represents the distance to nearest water body from that cell.

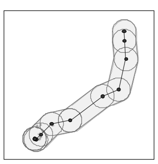
The different tests that were made to relate the migratory route to the distance to water are shown in Table 2. In Test 4 and 5 the distances from the real and simulated routes were calculated from points and for the shortest routes the distances were calculated from lines.

Table 2. The different tests that were made to relate the migratory route to the distance to nearest water body.

Test	4. Real route compared to shortest and simulated	5. Real route compared to shortest and simulated (2/9)	6. Real route compared to shortest
Resolution	1 km	100 m	100 m
Lines or points	Lines and points	Lines and points	Lines
Number of days	30	1	17

2.2 Migratory speed in relation to the proportion of water in the landscape

When the proportion of water along the route was compared to migration speed, the route was divided into different segments. One segment was the route travelled between two positions, or the line between the start and end positions in one day. The proportion of water was calculated within a buffer area around each segment. The speed of migration could be calculated from the length of the segment. The proportion of water was related to the speed of migration to test if a higher proportion of water would decrease the flight speed.



The Osprey's positions were used to create lines. To find out the proportion of water in the landscape along the flight route a buffer zone area was created. These areas were used to extract land cover data (see Fig. 9). The proportion of water within the buffer areas could then be calculated.

Table 3 shows the different tests that were made to relate migratory speed to the proportion of water in the landscape. In Test 7 and 8 the route was divided into the shortest segments possible. In Test 9 the lines were drawn from start to end each day.

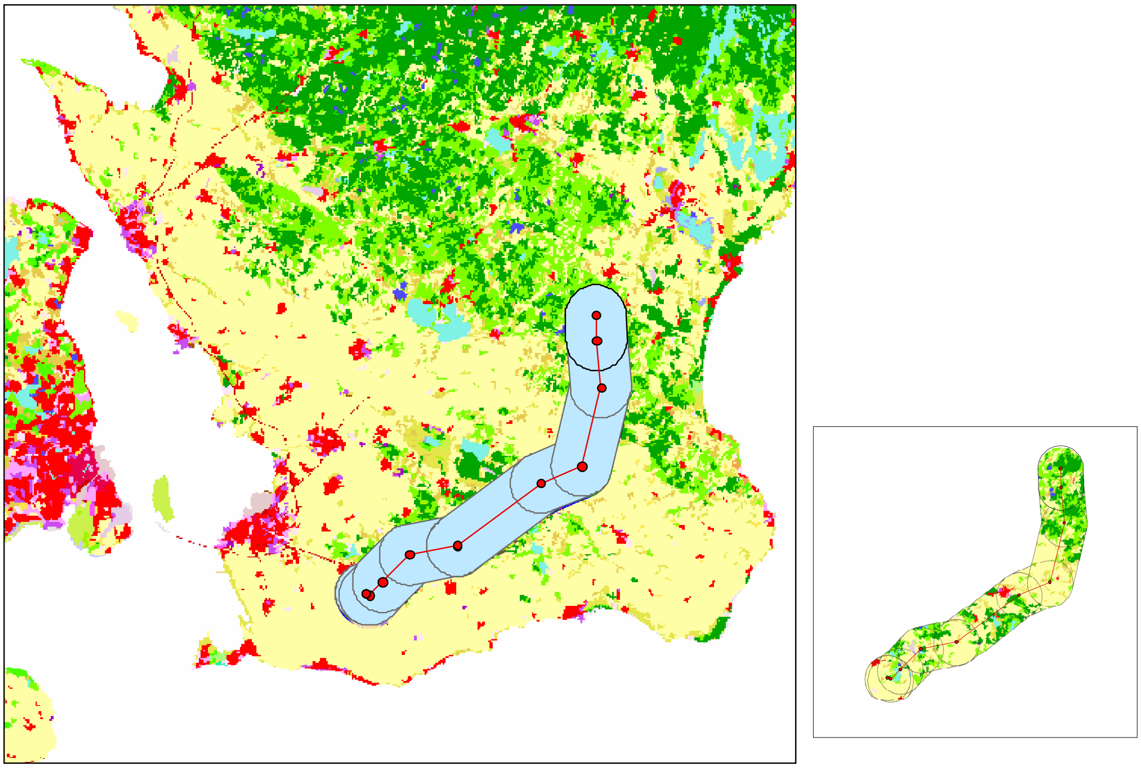


Figure 9. Lines and buffers with 5 km buffer distance. One buffer is created for each line segment and land cover data is extracted separately, for each buffer. To the right the small figure shows the extracted areas.

Table 3. The tests that were made to relate the migratory speed to the proportion of water in the landscape.

Test	7. Sweden, hourly data	8. Europe, hourly data	9. Europe, daily data
Resolution	25 m	100 m	250 m
Buffer distance	5 km	5 km	20 km
Lines or points	Lines	Lines	Lines
Number of days	4	17	17

2.3 Land cover data

Table 4. The land cover data and their spatial resolution, which was used in this study.

Sweden:	Svenska Marktäckedata, 25 m resolution
Europe:	Corine Land Cover, 100/250 m resolution
Global:	Modis Land Cover (used in the final analysis), GLCC (Global Land Cover Characteristics) and GLC2000 (Global Land Cover 2000), all in 1 km resolution

The land cover data used in this study is shown in Table 4. All land cover data is in raster format and is based on satellite data. The data from the satellites has been classified into different land cover classes. The class definitions and classification methods differ to some extent between different datasets.

Raster data was transformed into the reference system WGS 84, UTM (Universe Transverse Mercator) zone 30N (see Appendix 1), except when the shortest route was analysed, in which case a gnomonic projection was used. A line drawn in a gnomonic projection will always be the shortest way between its end points. The UTM projection was used because the birds migrate in a north south direction. Since the UTM zones are also positioned in this direction, the errors will be smaller. The Ospreys migrated through six UTM zones (28 – 33). To minimise the error one of the middle zones was chosen.

Svenska Marktäckedata with 57 classes in 25 m resolution is available for Sweden. The Corine data in 44 classes is available for EU in 100 and 250 m resolution. The classification of Svenska Marktäckedata is based on the Corine classification system. The different main classes of Corine, which are the same for Svenska marktäckedata, are shown in Appendix 2. In this study all of the classes under the main class "Water bodies" were included when the proportion of water and distance to water were calculated. The minimum mapping unit in Svenska Marktäckedata is 1 ha for seas, lakes and ponds. Watercourses have to be at least 50 m wide to be represented in data and the minimum mapping unit is 2 ha. For Corine it is 25 ha for all classes, and watercourses have to be at least 100 m wide.

Svenska Marktäckedata comes in tiles of 25×25 km, which had to be merged into a larger raster to cover the area of one day's buffers. Handling too large datasets is too time consuming, which is the reason for merging data for only one day. Corine with 100 m resolution was divided into three parts to cover Europe.

For Africa only data with 1 km resolution is available. Three different datasets derived from Modis, Advanced Very High Resolution Radiometer (AVHRR) (GLCC) and Spot-Vegetation (GLC2000) satellite data were compared (Test 11 in Table 5). The different classes included in these datasets are shown in Appendix 2. For all three "Water bodies" was the only class used in all calculations. Distance to water and proportion of water along the real route was calculated for all three datasets. The distance rasters, which were generated, were also compared by subtracting part of them from each other. This gave an idea about the differences between them. Based on this comparison, the Modis dataset was chosen to use in the analysis.

The different data was compared to see how spatial resolution would affect the results (Test 10 in Table 5). Since Svenska Marktäckedata was only available for Sweden the comparison to Corine had to be done on the 4 days that the bird was in Sweden. The comparison between 1 km data and Corine was done on the days when the bird was passing through Europe. On these days the proportions of water and distances to water were calculated and compared for the real routes.

Table 5. The different comparisons of land cover data that were made. In both tests points were used to create buffers and calculate distances.

Test	10. Different resolutions	11. Different global datasets
Resolution	25 m, 100 m and 1 km	1 km
Buffer distance	5 km	5 km
Lines or points	Points	Points
Number of days	4	17

3 IMPLEMENTATION OF METHOD

3.1 Simulation of routes

The simulation of routes was done in Matlab®. The coordinates were recalculated from latitude, longitude to UTM x,y coordinates. The distance in x and y between each position, (first to second, second to third etc.) was calculated and put in a matrix. A column of random numbers was added to the matrix, which was then sorted using the random numbers. New positions could then be calculated using the rearranged distances with the first position of the day as the starting point (see Appendix 2). The last position for all the simulated routes would then be the same as for the real route. In Fig. 10 the workflow of simulating routes is illustrated.

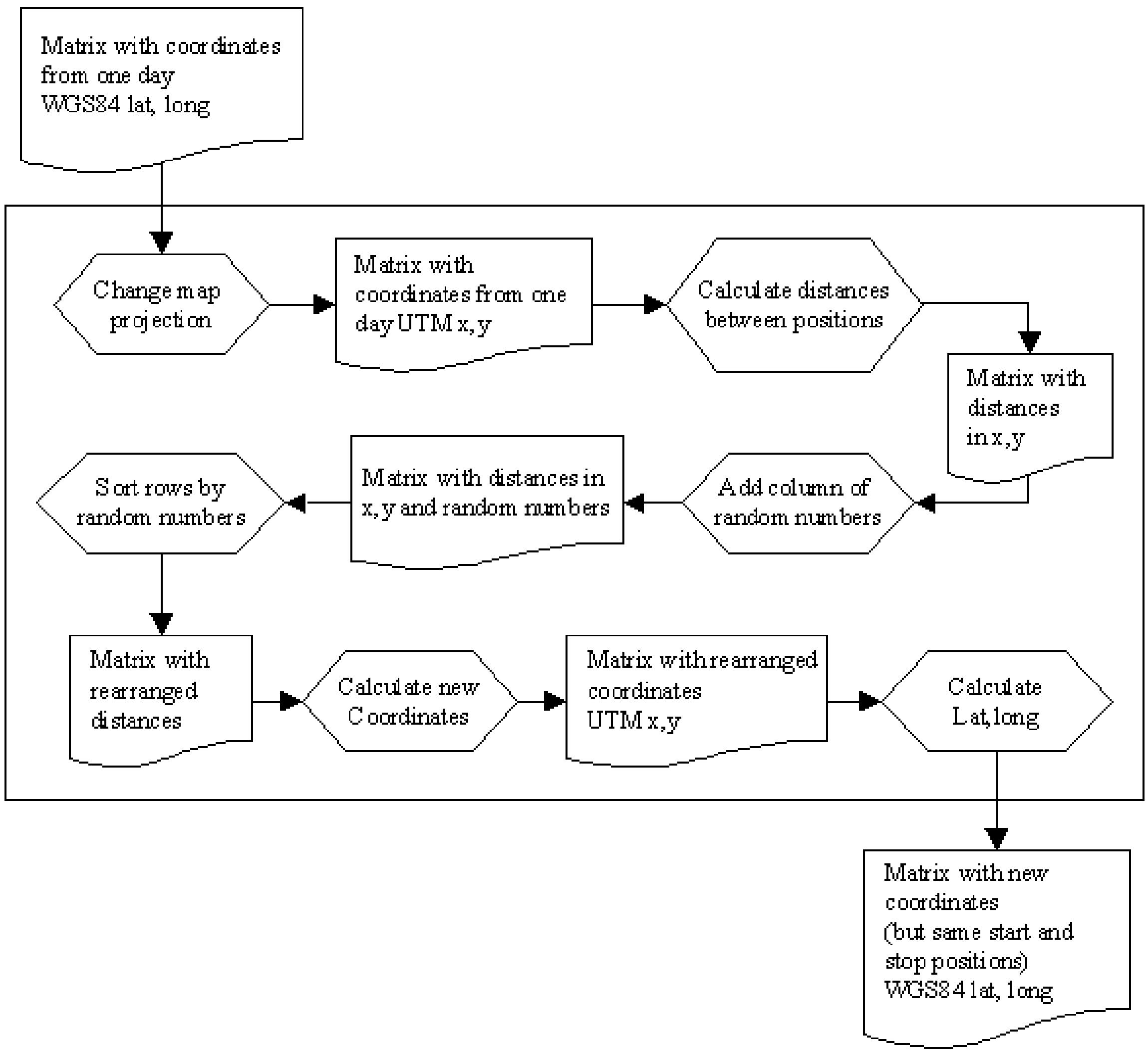


Figure 10. Flow chart showing the creation of the simulated routes.

3.2 Creating lines and points

The GIS analysis was performed in ArcGIS®. To create lines or points in ArcGIS®, the positions received from the transmitters had to go through some conversions. Matlab® was used to rearrange the data in text files that could be read by ArcGIS® (Appendix 3).

A simplified image of all the steps performed in the analysis is shown in Fig. 11. The analysis in ArcGIS® involved several steps, which all have to be repeated for every line segment or simulated route, i.e. creating lines, points and buffers. This process was partly automatized by creating short scripts in PythonWin. A script can loop over the files in a directory performing the same operation on all of them. This was very useful, since it would have been too time consuming to go through all route segments manually.

Line and point objects were created from the text files by using a script (see Appendix 4). The script lists and creates a line from each text file in a directory. The geodetic reference system was defined to WGS 84.

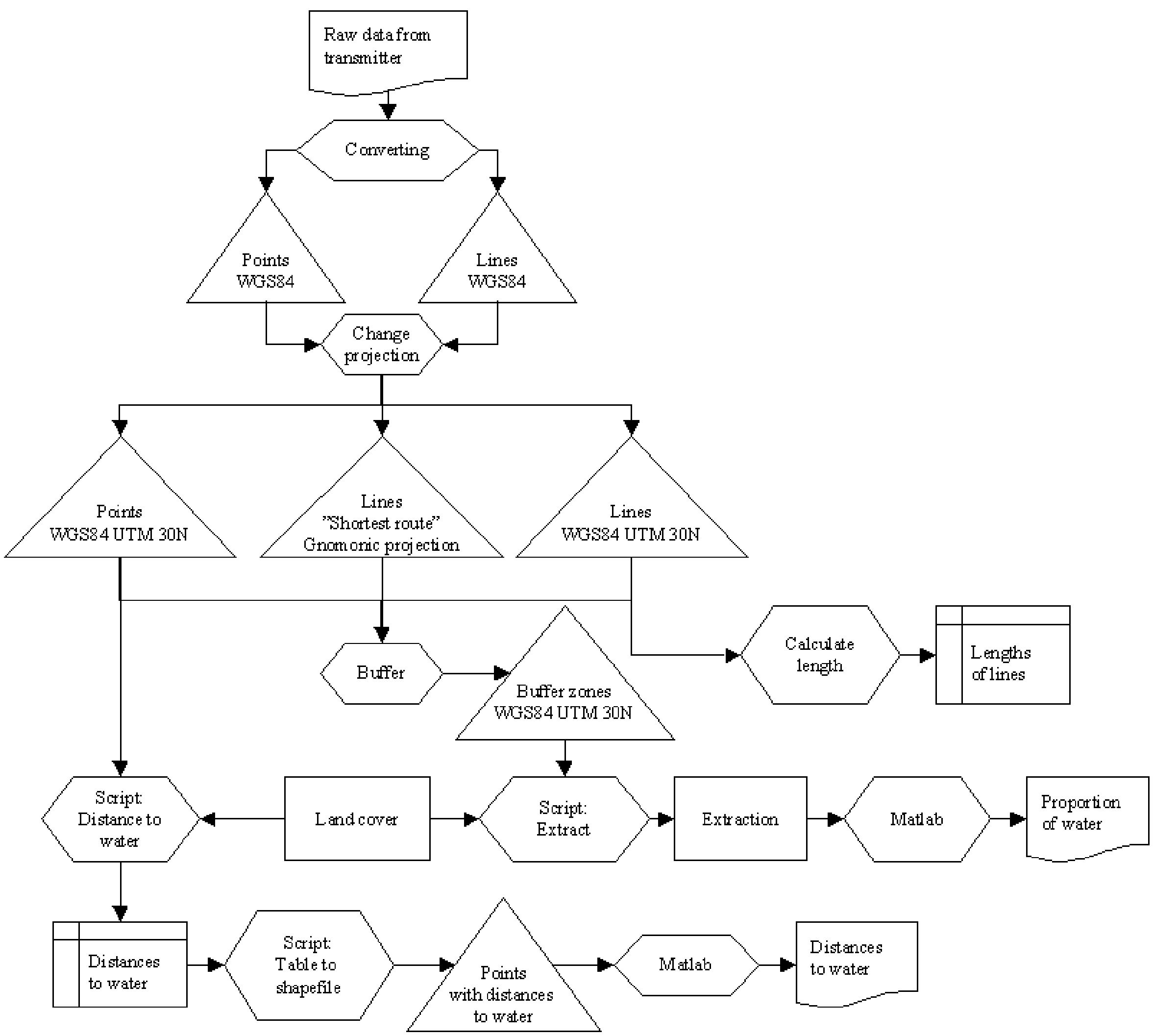


Figure 11. Flow chart showing the different steps of the analysis.

3.3 Creating buffers and extracting land cover

A script changed the coordinate system from WGS 84 Lat/Long to UTM zone 30 for the points and lines and created buffer areas around them (Fig. 12). Another script extracted part of the land cover raster using the buffer areas. The extractions formed one landuse layer for each day and route.

Calculations were made in Matlab®, where the proportion of the area covered by each class was calculated. Extractions were read by Matlab® into matrices and then the different values were counted resulting in a table with frequencies of different land cover classes. Then the area covered by each class was calculated and that was used to calculate the proportion of water in each extracted area.

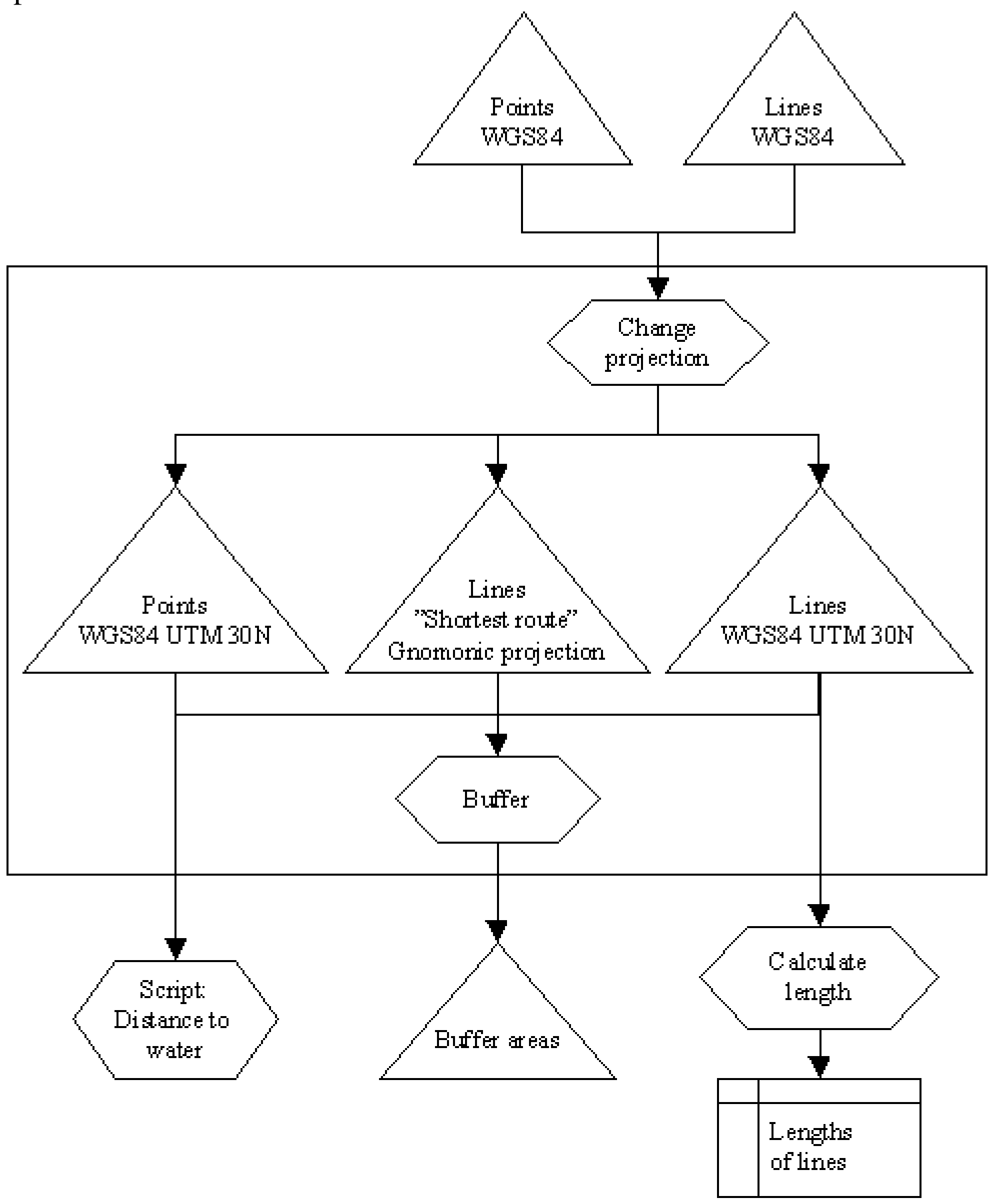


Figure 12. The project and buffer script. The points and lines are used for creating buffers or calculating distance to water. Lines are created in two different projections, UTM and gnomonic.

3.4 Calculating distance to water

The distance to water was calculated by extracting only water from the land cover data. Then a distance raster was created by calculating the Euclidean distance to the nearest water body for each raster cell. The distances were then extracted at each point along the route. All of this was done by a script. In Fig. 13 the workflow is illustrated. The script resulted in a table containing distances to water and coordinates. These values were imported to Matlab® for further calculations. In Matlab® an average value for each day and route was calculated.

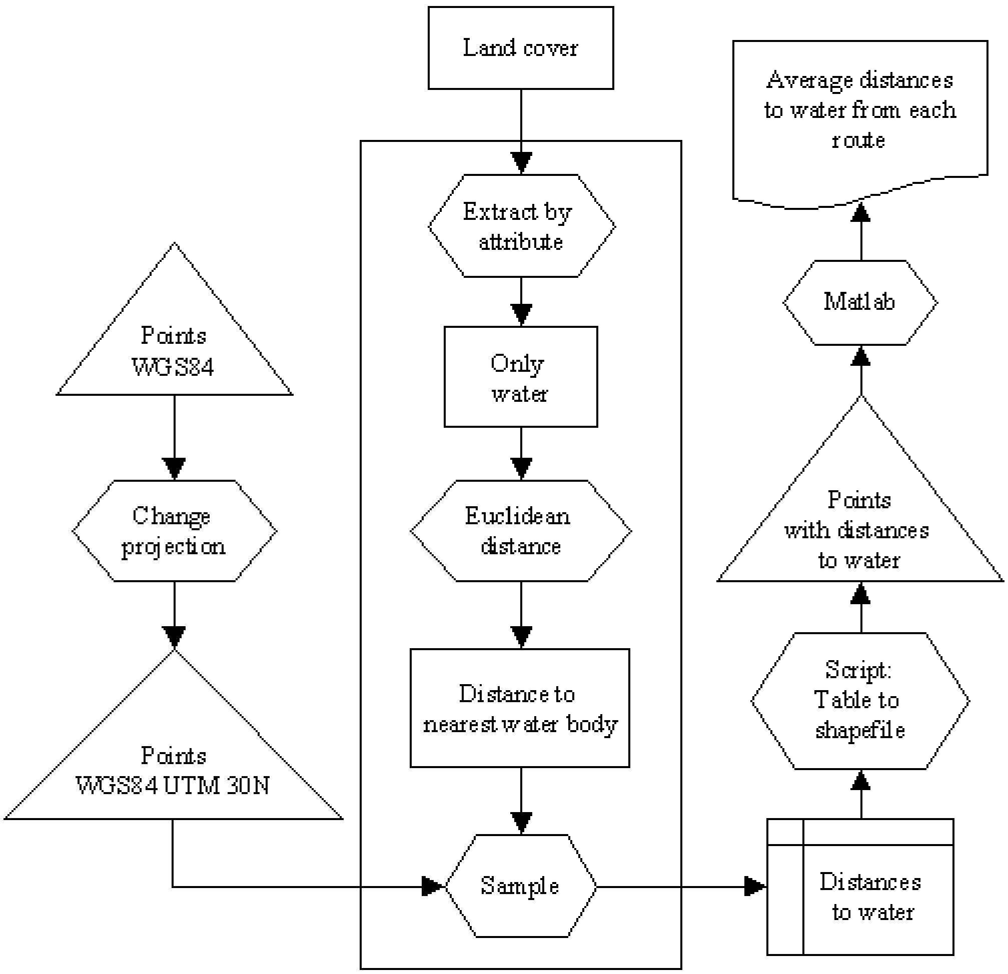


Figure 13. The workflow for the distance to water script. The input is points and land cover data.

4 RESULTS

4.1 The migratory route

Below the migration route is shown together with the simulated routes (Fig. 14). On the first four days of migration the Osprey was passing through Sweden. The first day the route is following along the shore of the lake Vättern (see the left hand map in Fig. 14). On the 4th of September the Baltic Sea was crossed. Then the bird continued south, with some stopover days about halfway trough Europe. In northern Spain there is some data missing, due to transmission failure. On the 7th of October the Mediterranean Sea was crossed, not at Gibraltar, which would be the shortest way over water, but further east (see the right hand map in Fig. 14). After first heading south it turns back, and after a few days continues in a more westerly direction. When the Osprey had crossed Sahara it arrived to its wintering site on the 29th of October after a total of about two months journey.

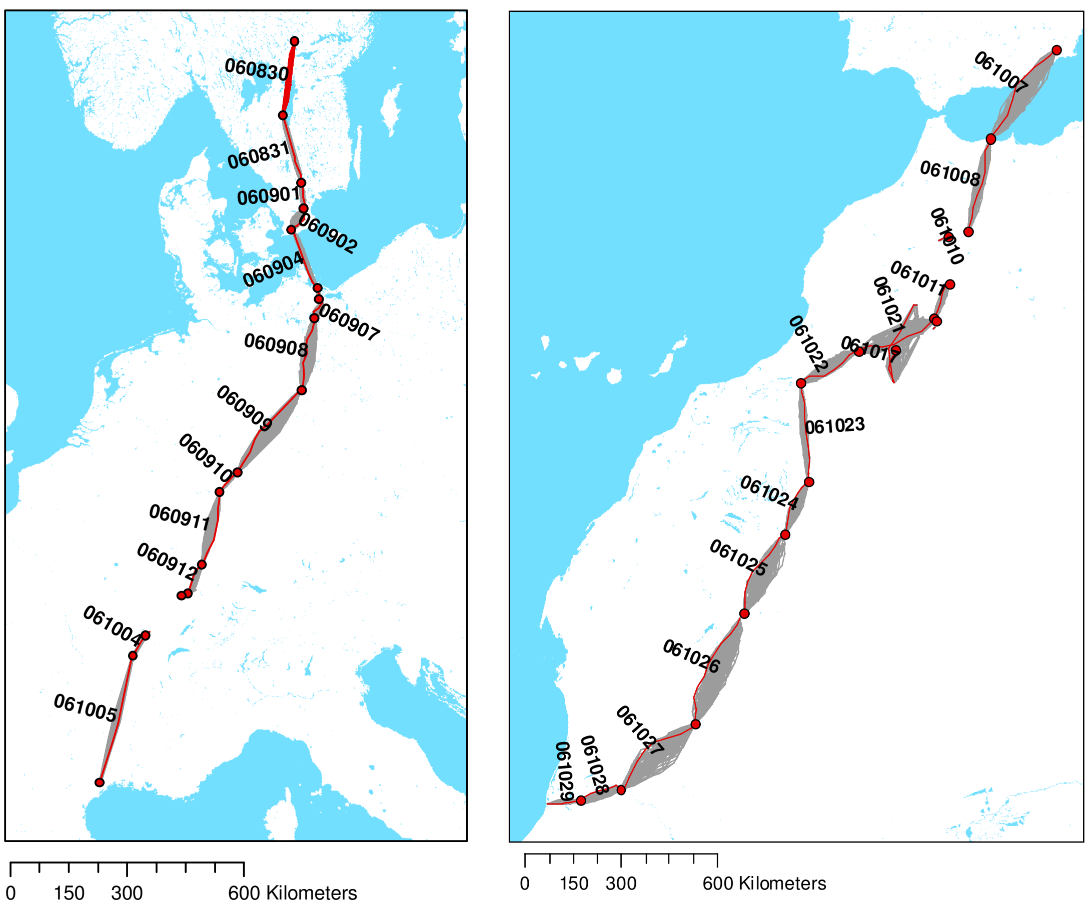


Figure 14. The complete journey of the Osprey from Sweden to Africa. The simulated routes are shown in grey.

Fig. 15 shows four examples of the width of possible migration routes (migratory corridors) as determined by the simulated routes that are based on the real routes (for maps of all days see Appendix 5). On the 2nd of September the distribution of routes is relatively wide and even, but on the 30th of August the real route is rather straight, making the corridor rather narrow. Another reason why the corridor is narrow is, as on the 7th of September, a few positions close to each other in the beginning and the end of the day. This also results in less variation between simulated routes, which will lead to overlap, when buffer areas are created.

From the 24th to the 27th of October, which are the dates when the bird is passing through Sahara, the real route is curved to the west. It always takes the most westerly way compared to all the simulated routes (see Fig. 14 and the right picture at the bottom in Fig. 15).

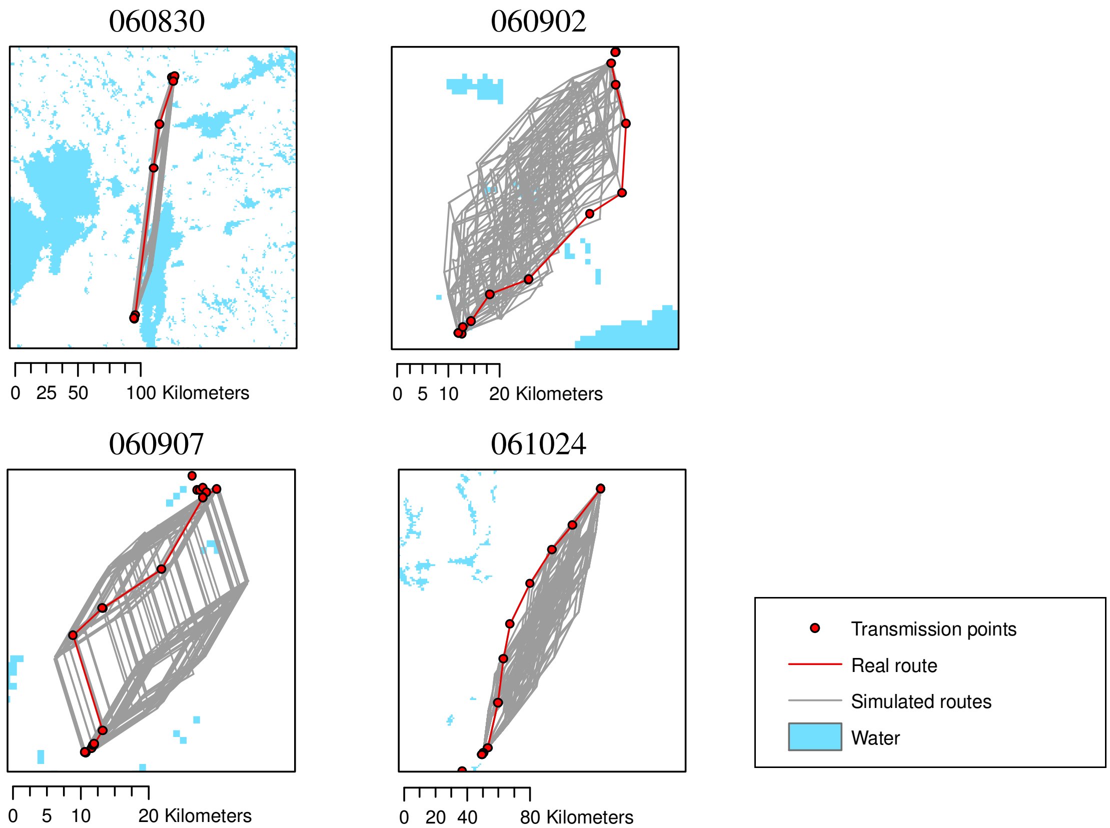
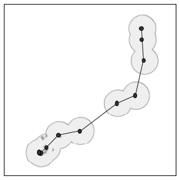


Figure 15. The real route with simulated routes for four days. The distribution of the simulated routes can look very different on different days.

4.1.1 The migratory route in relation to the proportion of water in the landscape

Test 1: *Comparison between real, simulated and shortest route*



In Table 6 the calculated proportions of water along the simulated and the real routes, all the way from Sweden to the wintering site in Senegal, are presented. The proportion of water was calculated within 5 km buffer areas around the positions as shown in the figure to the left. The resolution of the land cover data was 1 km. Average values for the simulated routes are calculated from 100 simulations per day. Values for the shortest routes were calculated using linear buffers, in the other cases circular buffers are used.

On the first day, the 30th of August, the maximum and average values of the simulated routes are very high, compared to the value of the real route. The reason for the high value is that the bird was flying along the lake Vättern and the simulated route ended up in the middle of the lake. On the following day the value of the real route is actually higher than the maximum value of all the simulated routes. This is because a few positions in the beginning of the day were close to the lake. On the 4th of September the Baltic Sea was crossed and on the 7th of October the Mediterranean was crossed. This also results in much higher values compared to other days. On several days, especially in Africa and southern Europe, the proportion of water along the real route and the average of the simulated routes is 0 %.

There are more days with higher values for the average of the simulated routes than the real route, even if the days when the oceans are crossed are removed. This is not in accordance with the hypothesis that the real route would have a higher proportion of water than the simulated routes. A comparison to the shortest route gives the same result.

Table 6. The proportion of water within 5 km buffer distance of real and simulated positions and the shortest route. Land cover data form Modis with 1 km resolution. $Average_1$ is including all days. $Average_2$ is not including sea crossings or the first day. $*_1$ shows if the difference between the average of simulated routes and the real route is positive or negative. A plus sign means that the proportion of water is higher around the real route than the simulated routes. $*_2$ shows if the difference between the shortest routes and the real route is positive or negative.

Date	Real	Simulated average	$*_1$	Simulated max	Simulated min	Shortest route	$*_2$	Location
060830	0.76%	15.95%	-	50.37%	0.00%	13.33%	-	Sweden
060831	20.44%	10.16%	+	20.08%	0.00%	12.02%	+	
060901	0.00%	0.78%	-	2.05%	0.00%	0.92%	-	
060902	0.69%	1.72%	-	3.26%	0.52%	2.16%	-	
060904	28.21%	42.11%	-	61.86%	16.92%	65.27%	-	The Baltic Sea
060905	1.39%	1.31%	+	2.79%	0.27%	1.35%	+	Europe
060906	1.41%	1.07%	+	1.49%	0.93%	1.41%		
060907	0.69%	0.52%	+	1.14%	0.00%	1.16%	-	
060908	1.49%	1.30%	+	3.19%	0.00%	1.73%	-	
060909	0.00%	0.06%	-	0.34%	0.00%	0.00%		
060910	0.00%	0.00%		0.00%	0.00%	0.00%		
060911	0.00%	0.01%	-	0.15%	0.00%	0.30%	-	
060912	0.00%	0.00%		0.00%	0.00%	0.00%		
060913	0.00%	0.00%		0.00%	0.00%	0.00%		
061004	0.00%	0.00%		0.00%	0.00%	0.00%		
061005	0.00%	0.12%	-	1.53%	0.00%	0.00%		
061007	32.67%	56.81%	-	83.41%	30.08%	60.45%	-	The Mediterranean
061008	7.70%	4.07%	+	7.53%	3.42%	1.07%	+	Africa
061011	0.00%	0.00%		0.00%	0.00%	0.00%		
061016	0.00%	0.00%		0.00%	0.00%	0.00%		
061017	0.00%	0.52%	-	4.19%	0.00%	0.74%	-	
061021	0.00%	0.21%	-	11.11%	0.00%	0.77%	-	
061022	0.00%	0.00%		0.00%	0.00%	0.00%		
061023	0.00%	0.00%		0.00%	0.00%	0.00%		
061024	0.00%	0.00%		0.00%	0.00%	0.00%		
061025	0.00%	0.06%	-	0.48%	0.00%	0.69%	-	
061026	0.00%	0.16%	-	1.27%	0.00%	0.00%		
061027	0.00%	0.10%	-	0.77%	0.00%	0.04%	-	
061028	1.28%	0.05%	+	0.71%	0.00%	0.00%	+	
061029	5.23%	4.58%	+	9.91%	1.37%	4.46%	+	
$Average_1$	3.40%	4.72%		8.92%	1.78%	5.60%		
$Average_2$	1.49%	0.99%		2.67%	0.24%	1.07%		

Test 2: *Comparison between real, simulated and shortest route using small scale land cover data*

Because of the calculations of the simulated routes was so time demanding only one day was picked out to do the same analysis with Corine data with 100 m resolution, the 2nd of September.

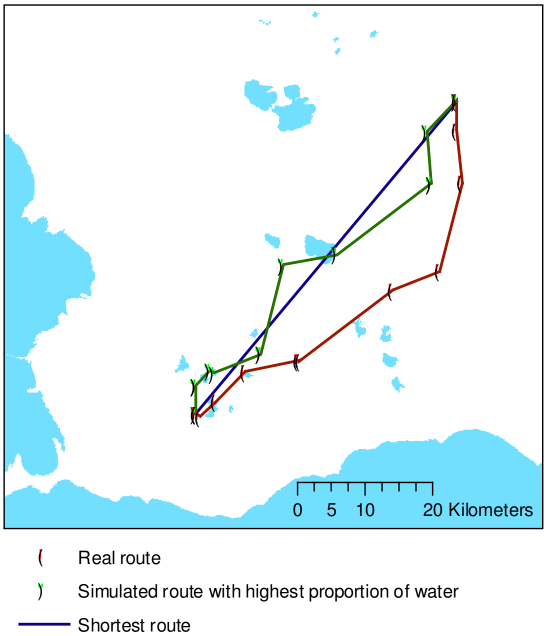
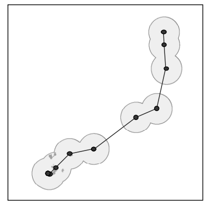


Figure 16. The 2nd of September. The simulated route with the highest proportion of water out of 100 routes. The buffer distance used was 5 km and land cover was Corine with 100 m resolution.



Circular buffers were created around the real and simulated positions. The simulated route with the highest proportion of water is shown in Fig. 16. The proportion of water along that route was 4.25 % (Table 7), which is higher than for the real route, where the proportion of water is 1.11 %. The average of all simulated routes was 2.33 %, i.e. the bird did not choose the route with most water.

The buffer area around the shortest route was drawn around the line shown in Fig. 16. The proportion of water within the area was 2.96 % (Table 7). This was also higher than the proportion of water along the real route.

Table 7. 2nd of September. Proportion of water within 5 km buffer distance

Real route	Shortest route (buffer around line)	Simulated routes				
		Average	St. dev	Max	Min	Median
1.11%	2.96%	2.33%	0.90%	4.25%	0.74%	2.26%

Test 3: *Comparison between real route and shortest using different buffer distances*

To test the different buffer distances 1, 5 and 20 km, the proportion of water along the real and shortest routes were calculated using Corine, with spatial resolution of 100 m. Since this data is only available for Europe, there are only results from 17 days. The results are shown in Table 8 below. For the real route a linear buffer was used, instead of circular buffers as above, to make the results more comparable to the shortest route. Note the difference between the buffers for the real route on the 2nd of September (Tables 7 and 8). Missing days are due to either transmission failure or the bird making a stopover.

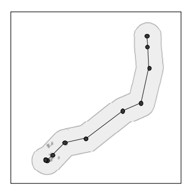
Only when the 1 km buffer was used, the average proportion of water for all days was higher along the real route than along the shortest route (see Table 9). With this buffer distance there are 7 days with lower values for the real route than for the shortest route and 9 days with higher values for the real route, including the sea crossing. On one day there is no difference. The use of the 5 km buffer resulted in 8 days with the higher values for the real route than the shortest and 9 days with lower values. For the 20 km buffer it was 7 and 10 days.

Table 8. Proportion of water within different buffer distances for the real compared to the shortest route. The land cover used was Corine with 100 m resolution.

	Real route			Shortest route		
Date	**1 km**	**5 km**	**20 km**	**1 km**	**5 km**	**20 km**
060830	4.44%	11.34%	23.30%	5.67%	13.86%	24.03%
060831	12.64%	11.25%	10.98%	7.68%	11.18%	10.97%
060901	0.34%	0.59%	5.66%	0.22%	0.84%	4.09%
060902	3.09%	1.51%	7.48%	5.70%	2.96%	5.56%
060904	70.99%	68.21%	62.83%	70.54%	68.28%	66.35%
060905	0.50%	3.16%	21.80%	0.16%	2.49%	21.15%
060906	0.27%	0.81%	6.13%	0.27%	0.73%	6.36%
060907	0.98%	1.37%	4.26%	1.07%	1.82%	4.41%
060908	2.05%	2.65%	3.02%	2.19%	2.45%	3.15%
060909	0.56%	0.30%	0.34%	0.49%	0.46%	0.35%
060910	0.93%	0.59%	0.38%	1.31%	0.58%	0.39%
060911	3.57%	3.17%	1.76%	2.89%	2.92%	1.74%
060912	0.37%	0.94%	1.02%	2.28%	1.99%	1.26%
060913	0.05%	2.04%	0.75%	0.00%	1.17%	0.47%
060929	2.91%	0.75%	0.72%	2.06%	0.83%	0.73%
061004	0.85%	0.39%	0.75%	1.02%	0.40%	0.72%
061005	0.13%	0.34%	0.87%	0.09%	0.28%	0.91%

Table 9. Averages for all dates calculated from Table 8.

Buffer distance	1 km	5 km	20 km
Real route	6.16%	6.44%	8.94%
Shortest route	6.10%	6.66%	8.98%



4.1.2 The migratory route in relation to distance to water

Test 4: *Comparison between real, simulated and shortest route*

The distances to water for the real and simulated routes, calculated with 1 km resolution data, are shown in Table 10 below. The values are averages calculated from all positions in one day. Values for the shortest routes are calculated using a line. They are also averages from one day, calculated from all cells under the line.

To perform a X^2-test the frequency of days with higher or lower values for the real route compared to simulated or shortest were calculated. On 11 days the real route had a lower value than the average of the simulated routes, and on 19 days it was higher. Comparing the real route to the shortest the result was 13 and 17 days respectively.

A X^2-test not including the two days when seas are crossed or the first day, when Vättern is passed shows that the frequency of days with the real route closer to water than the average of the simulated routes is higher than that of days when it is further away (X^2-value = 4.481, $p = 0.0343$). Though if the first day is included the result will not be significant (X^2-value = 3.571, $p = 0.0588$). When comparing the real route to the shortest there are more days with lower values for the real route, than higher, but the result of an X^2-test is not significant (X^2-value = 1.814, not including first day or sea crossings).

Table 10. Distances (m) to water from real and simulated positions and the shortest route. Based on 1 km resolution land cover data. $Average_1$ is including all days. $Average_2$ is not including sea crossings or the first day. $*_1$ shows if the difference between the average of simulated routes and the real route is positive or negative. A plus sign means that the distance to water is lower for the real route than the simulated routes. $*_2$ shows if the difference between the shortest routes and the real route is positive or negative.

Date	Real	Simulated average	$*_1$	Simulated max	Simulated min	Shortest route	$*_2$	Location
060830	6089	5034	-	9132	1070	4719	-	Sweden
060831	4025	4840	+	7527	2807	3950	-	
060901	11476	9475	-	13741	6107	8389	-	
060902	6925	8887	+	12220	5610	8514	+	
060904	3011	1367	-	3009	342	1094	-	The Baltic Sea
060905	8254	6825	-	9187	4999	7250	-	Europe
060906	7013	6973	-	9461	4014	6761	-	
060907	6663	7244	+	10060	5135	8620	+	
060908	10663	11203	+	17248	6900	10711	+	
060909	27557	28644	+	43978	15270	27345	-	
060910	30559	33379	+	38280	30271	34335	+	
060911	27603	33743	+	45383	25199	35416	+	
060912	20516	21139	+	27617	15325	27802	+	
060913	21799	23677	+	27234	16627	29012	+	
061004	16416	21513	+	32250	15220	25511	+	
061005	16677	24916	+	38395	13301	29894	+	
061007	14798	6852	-	15250	1990	6125	-	The Mediterranean
061008	41460	58959	+	76007	45527	61590	+	Africa
061011	61480	71837	+	94007	47981	75171	+	
061016	76305	75259	-	100909	54472	73786	-	
061017	72699	63060	-	88085	42252	49837	-	
061021	44666	35981	-	52780	22662	28723	-	
061022	86351	95016	+	109628	81938	100416	+	
061023	50603	54904	+	63712	48689	55662	+	
061024	39408	40444	+	51164	29205	39844	+	
061025	20545	24859	+	34468	16833	26676	+	
061026	54123	72195	+	90599	54194	72984	+	
061027	65359	58975	-	76547	39383	57127	-	
061028	16096	27359	+	37828	17343	27712	+	
061029	13838	11019	-	17726	6542	9735	-	
$Average_1$	29432	31519		41781	22573	31824		
$Average_2$	31818	34530		45409	24956	34917		

Test 5: *Comparison between real, simulated and shortest route using small scale land cover data*

The distances to water from real and simulated positions on the 2^{nd} of September were compared, using Corine land cover data (100 m resolution). In Table 11 the real route shows a lower value than the average of the simulated routes. This is in accordance with the hypothesis unlike when the proportion of water was tested on this day.

Table 11. 2nd of September. Distance to water (m).

Real route	Shortest route (buffer around line)	Simulated routes				
		Average	St. dev	Max	Min	Median
5870	6332	7010	1678	11388	3753	6859

Test 6: *Comparison between real route and shortest using different buffer distances*

Table 12 shows distances to water from the real and shortest route for the whole of Europe, calculated from the Corine land cover data with 100 m resolution. The highest average for the real routes is just above 12 km. The average of all days is 5.7 km. In Fig. 18 the flight speed is shown to be up to 55 km/h, making this only a few minutes flight.

Table 12. Distances to water for real route and shortest route in Europe, based on Corine land cover data, 100m resolution. $Average_1$ is including all days. $Average_2$ is not including sea crossings or the first day. * shows if the difference between the shortest routes and the real route is positive or negative. A plus sign means that the distance to water is lower for the real route than the simulated routes.

Date	**Real route**	**Shortest route**	*
060830	2251	2538	+
060831	1820	2108	+
060901	6639	6749	+
060902	7953	6332	-
060904	790	707	-
060905	5681	5878	+
060906	5344	4900	-
060907	3710	2174	-
060908	7957	4808	-
060909	12123	9620	-
060910	6940	7258	+
060911	3738	5045	+
060912	9554	6120	-
060913	2696	2196	-
060929	4832	5207	+
061004	5045	5261	+
061005	11361	11038	-
$Average_1$	5790	5173	
$Average_2$	6360	5646	

4.2 Migratory speed in relation to the proportion of water in the landscape

Test 7 – 9: *Relating migratory speed to the proportion of water in the landscape*

In Figs. 17 – 20 the proportion of water along the flight route is related to the migration speed. The calculations were made with different spatial resolution of land cover data. In Fig. 17, Svenska Marktäckedata was used to calculate the proportion of water along the route on the four days that the Osprey was flying through Sweden (Test 1).

In Fig. 18 Corine land cover data in 100 m resolution was used and in Figs.19 and 20 250 m resolution was used. The other difference between Fig. 18 and Figs. 19 -20 is that the temporal resolution is different. In Fig. 18 all positions were used to calculate the proportion of water along each line segment of the day. In Figs. 19 and 20 a line between the first and last position of the day was used, to compare the different days. In the first case the buffer distance was 5 km. For the day lines the buffer distance was 20 km.

The difference between Fig. 19 and 20 is that in Fig. 20 the first day and the day when the Osprey is crossing the Baltic Sea has been removed.

The results from the tests where the proportion of water in the landscape was related to the flight speed are not significant.

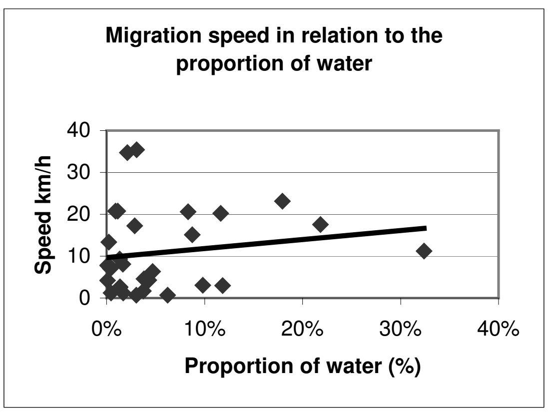


Figure 17. Lines on hourly basis with 5 km buffer distance. The speed has been calculated and is compared to the share of water within the buffer area. Data from four days (0600830-060902) in Sweden. Svenska Marktäckedata 25 m resolution.

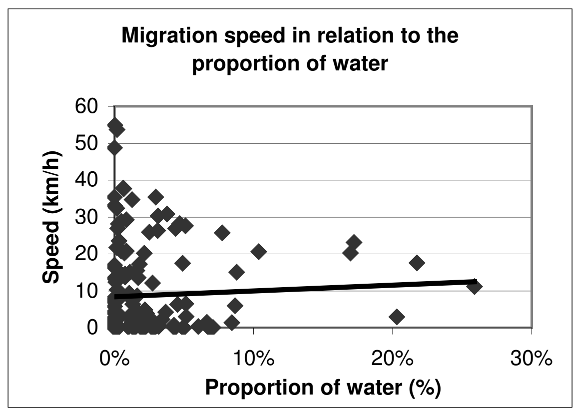
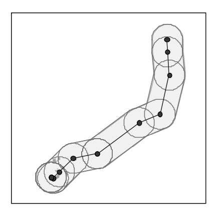


Figure 18. Lines on hourly basis, with 5 km buffer distance. Data from 17 days in Europe. The land cover data is Corine with 100 m resolution.



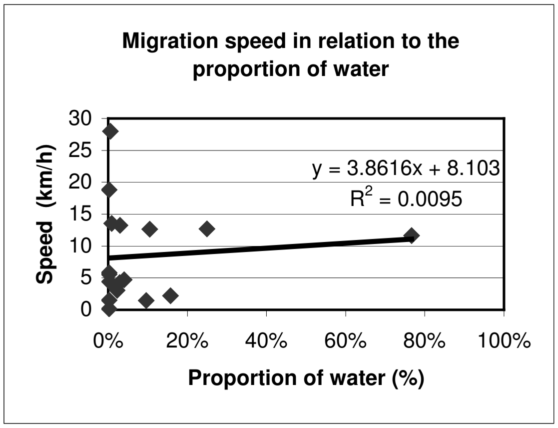


Figure 19. Lines on daily basis, with 20 km buffer distance. Data from 17 days in Europe. Corine 250 m resolution.

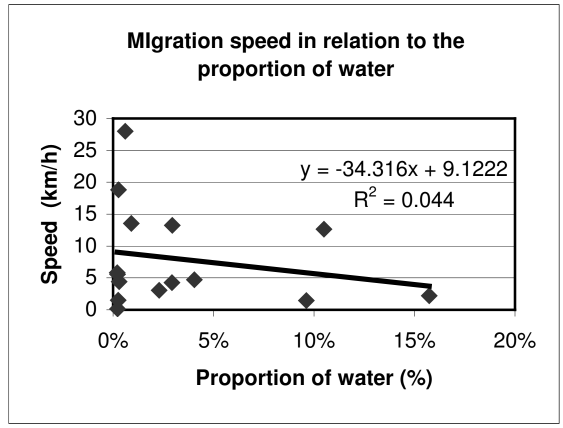


Figure 20. Same as Fig. 19, but not including first day or the crossing of the Baltic Sea

4.3 Comparison of land cover data

Test 10: *Comparison of different resolution land cover data*

Land cover data was available in 25 m resolution for Sweden, 100/250 m for Europe and 1 km globally. There were three different global datasets. These were compared to evaluate which one would suit this type of analysis best.

25 m, 100 m and 1 km resolutions were compared to test how dependent the analysis is on resolution. The average distance to nearest water and proportion of water in circular buffers (5 km buffer distance) were calculated for the real routes during the days when all resolutions are available. Results are shown in Figs. 21-22 and in Tables 12 and 14. The differences between different datasets are bigger when looking at distance to water than proportion of water within the buffers.

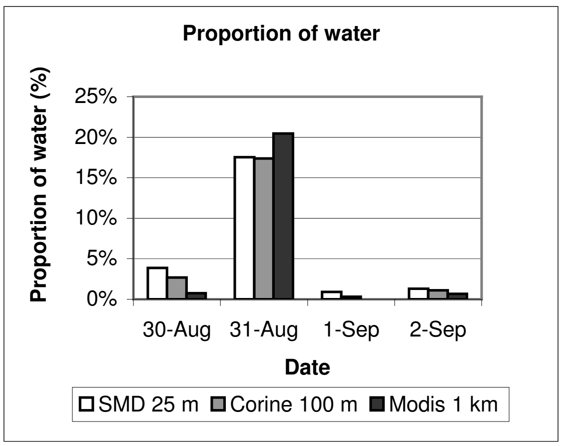


Figure 21. The proportion of water within 5 km buffer distance of the positions on four days calculated from different land cover data.

Table 13. The proportion of water within 5 km buffer distance of the positions on four days calculated from different land cover data.

	SMD 25 m	Corine 100 m	Modis 1 km
30-Aug	3.85%	2.70%	0.76%
31-Aug	17.52%	17.37%	20.44%
1-Sep	0.92%	0.32%	0.00%
2-Sep	1.32%	1.11%	0.69%
Average	5.90%	5.38%	5.47%

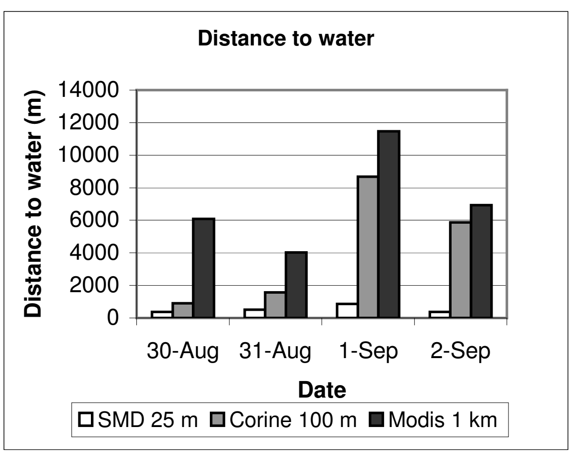


Figure 22. The distances to nearest water from positions on four days calculated from different land cover data.

Table 14. The distances to nearest water from positions on four days calculated from different land cover data.

	SMD 25 m	Corine 100 m	Modis 1 km
30-Aug	368	902	6089
31-Aug	508	1573	4025
1-Sep	855	8671	11476
2-Sep	373	5870	6925
Average	526	4254	7129

Test 11: *Comparison of different global (1 km) land cover data*

To compare the different 1 km data, the proportion of water and distance to water was calculated for the 17 days when the Osprey was passing through Europe. In Figs. 23 and 24 the results are shown together with the results for land cover from Corine in 100 m resolution. The same tendency, that differences are bigger when calculating the distance to water than the proportion of water along the route, is found here, as when comparing different resolutions.

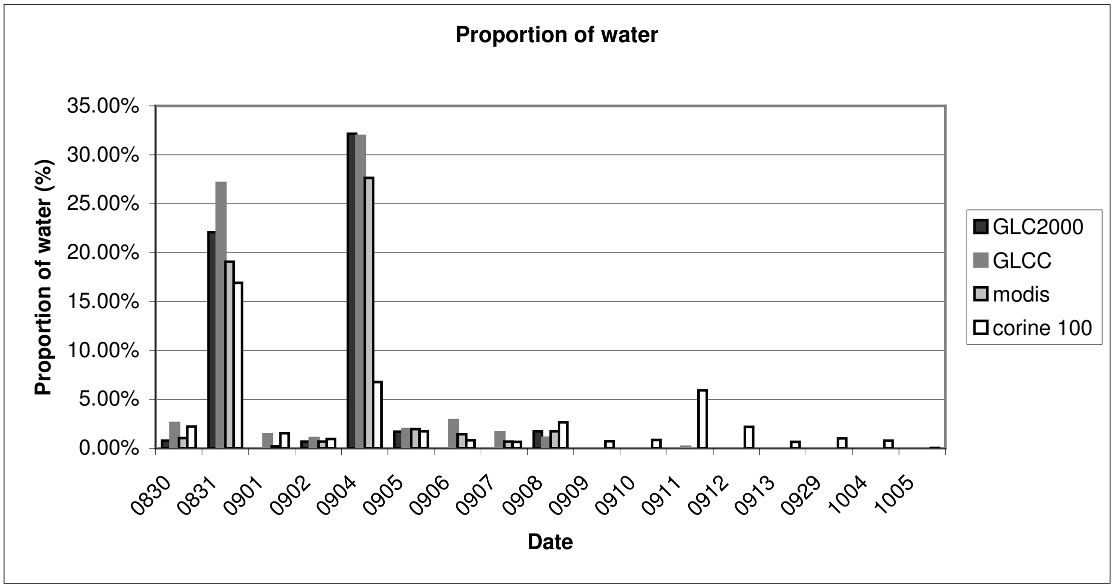


Figure 23. The proportion of water in circles around positions. Three different 1 km resolution data are compared as well as Corine with 100 m resolution.

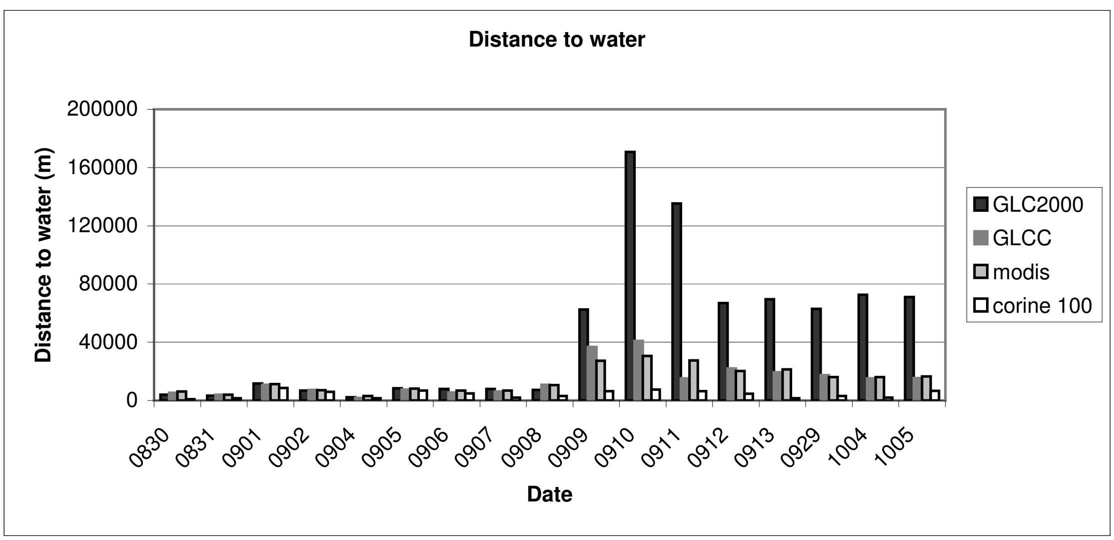
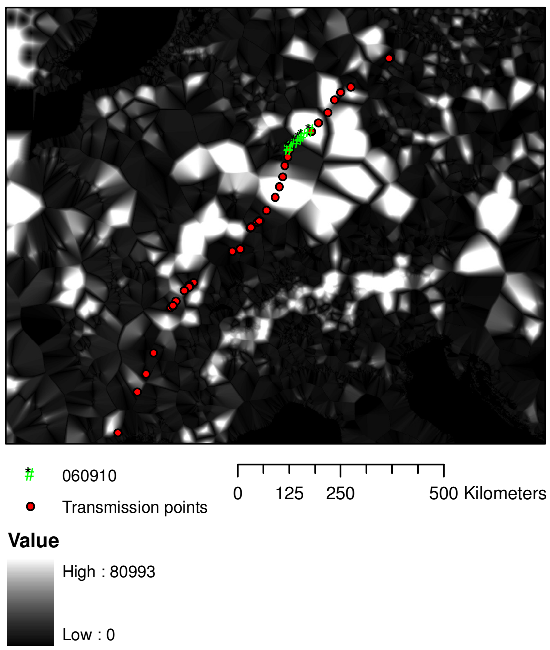


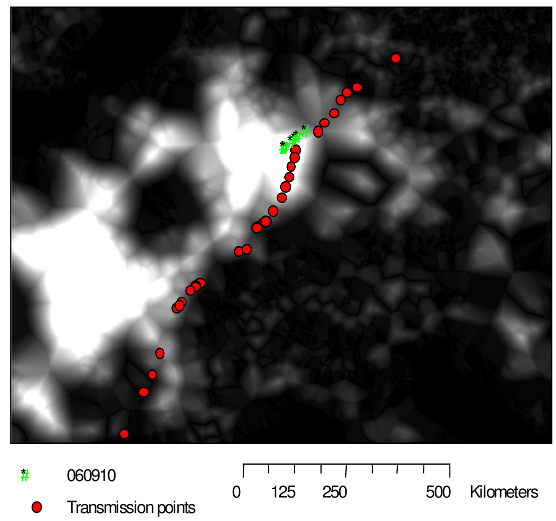
Figure 24. The distance to nearest water body. The values are averages for all positions on the same day. Comparison of different 1 km data and 100 m data.

There was a big difference in GLC2000 data compared to the two other datasets when distances to water were calculated. From the 9th of September and onwards the distances derived from GLC2000 data are much higher than any of the others. When the different datasets were compared in this area, there was less water showed in GLC2000 than the other two. The distance rasters were subtracted from each other in this area and the differences were smaller between Modis and GLCC than between these two and GLC2000 (Fig. 25).

GLC2000 – Modis



GLCC - Modis



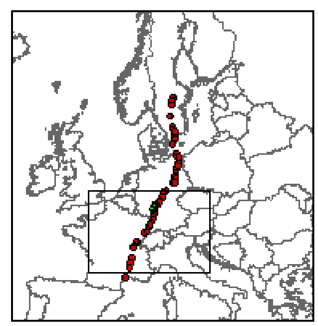


Figure 25. Distance rasters subtracted from each other. The differences as absolute values (m). The 10th of September, shown in green triangles, was the day when differences were the biggest.

5 DISCUSSION

5.1 The migratory route

The use of simulated routes gives the opportunity to find a route, with segments of the same length and direction as the real route, which is optimal in the way that it contains a lot of water. A disadvantage of this method is that it is rather time consuming.

There are some days when the real route is rather straight. On these days the method of simulating routes used here is not suitable. The simulated routes will end up too close to each other, which will cause a lot of overlap of buffer areas. Another reason for overlap is when days with many points close to each other results in the simulated routes being very similar to each other. One way to overcome this problem is to not use positions within a certain distance from each other. The result will be almost the same as if there are not so many positions on that day. This would also be relevant since it is the choice of route that is being analysed and thus only points from the period when the bird is really migrating are interesting.

Advantages with comparing the real route to the shortest are that it’s simple and not very time consuming. The idea is to look at if something makes the bird deviate from the most energy efficient way. However, it does not take into consideration that the shortest route might not always be the least energy consuming. Other landscape features, such as large water bodies or high mountains might be more energy consuming to cross than to go around them and this would affect the choice of route on a large scale. On a smaller scale, wind could have an influence.

Calculating the proportion of water, as compared to distance to water, seems to be less dependent on resolution of land cover data. However, when the 1 km resolution was used on many of the days this resulted in 0 % water for all alternative routes. This is a disadvantage of the coarse resolution, since no comparison can be made on these days. If it is the case that there is actually no water in the area, then it is possible that water would not have any effect on the choice of route in a small scale and that there are other factors that determine which route the bird takes. There is also a possibility that there is water in the area, but that it is not represented in the land cover data. This is probably the case, in Europe. When the 100 m resolution was used, all days had values greater than 0 %, but on some of these days the proportion of water was 0 % calculated with 1 km data. In Africa, on the other hand, there is a higher probability that there is actually no water within the buffer areas.

When the proportion of water was calculated from the 1 km resolution land cover data, a 5 km buffer distance was used. It might be better to use a smaller distance when the high resolution land cover data is used, but for the 1 km data this buffer would be too narrow. Not enough data would be included in the buffers. This would also increase the possibility that no water will be represented within the buffer area. Too large buffers would cause overlap, and the result for the different routes would be too similar, which is the case when 1 km resolution is used.

The method where the distance to water is calculated always provides a value, since the calculation is not limited to a certain distance from a route. When this value gets very high the same reasoning can be used as when the proportion of water is 0 %. If the nearest water were out of reasonable reach for the bird it would not have an influence on the choice of route.

As is the case on the first day of migration, a big lake can influence the result significantly. This has the largest effect on the result when the proportion of water is calculated. When the bird is passing a big lake like Vättern, it will probably avoid open water and, as in this case, fly along the shore of the lake. This will result in high values for simulated routes that will end up over the lake. The effect on the result will not be as big when the distance to water is calculated, since a point ending up in a water body will be 0 m from water. At the shore of the lake the distance is also 0 m.

A larger lake will increase the proportion of water, but it is not more likely that the bird will stop at a large lake than a small one. When distance to water is calculated, the size of the water body will not affect the result. Since the smallest lakes shown in the land cover data depends on the resolution, the distance to water raster will look very differently depending on the resolution of the land cover data used. This is confirmed by the tests of different resolution in data. The distance to water is much more affected by resolution than the proportion of water.

5.2 Migratory speed in relation to the proportion of water in the landscape

The results from the comparison between migration speed and the proportion of water in the landscape did not show any relationship. In this part of the analysis, the migration through Africa was not included, since it was only made with 100 and 25 m resolution data. Perhaps including Africa would have given different results, but the 1 km resolution would probably be too coarse. When the proportion of water was calculated to analyse the choice of route, it was 0 % on several days when the 1 km resolution was used, but with 100 m resolution it was higher than 0 on all days. In Africa the proportion of water was also 0 % on several days, when the 1 km resolution was used. If these routes were divided into segments the proportion of water for them would be 0 or close to 0 %. It might be better to look at whole days instead of dividing days into segments. A coarser resolution in time might work better with the coarse resolution in land cover data.

The time of day might have some influence on the results. In the beginning and end of the day there are often several positions close to each other. This is perhaps more due to the daily routines than that the bird is in an area rich in feeding habitat. One possibility could be to compare segments of the route from the same time of day or narrow data down to just the part of the day when the bird is moving.

Klaassen et al. found, using the same satellite telemetry data as in this study, that the Ospreys spend more of their time flying in Sahara than in Europe. This should lead to higher speed in this area, when different days are compared.

5.3 Comparison of land cover data

The differences between the results calculated from different spatial resolutions in data are largest when the distance to water is calculated. This is probably because the small lakes that are not represented in coarse resolution data will have much more influence on the result when calculating distances to water than when calculating the proportion of water along the route.

The comparison between different global data with 1 km resolution resulted in the Modis data being chosen to perform the analysis on Africa, since the difference from Corine is smallest in this dataset. The AVHRR sensor is older than the Modis sensor, which could make Modis more similar to Corine. The GLCC data from AVHRR is from 1992-1993, whereas the Modis data is continuously updated.

Especially distance to water values calculated from GLC2000 are a lot higher than values from the other data sources. GLC2000 also differs most from the Corine data. This is in the area with least water, and since the dataset will be used for analysis in Africa, where water is much more rare, it seems better to use a dataset that is able to identify water in dry areas.

The data from AVHRR and Modis have the same classes, while the classes for the GLC2000 data diverse. This could be a reason for the GLC2000 data looking differently. Compared to Corine all three datasets differ in classes.

5.4 The migratory behaviour of the Osprey

No definite conclusions can be drawn from the analysis about the migratory behaviour of the Osprey. The only method that showed any results in accordance with the hypothesis was the comparison between distance to water and the migratory route. Here the results show that the Osprey is choosing a route closer to water than a random route on a daily basis. The comparison to the shortest route gives the same indication, but no significant results.

There is no indication that there is a difference in proportion of water between real and simulated/shortest routes. Based on the results from the calculations of proportion of water, the hypothesis that that the daily route of an Osprey is affected by the availability of water should be rejected.

On the days when the Osprey is passing through Sahara the routes for each day look very similar. There is probably some other factor influencing the choice of route, such as wind direction, that is more important on these days. The proportion of water calculated from the 1 km data is 0 %, and the distance to water is very high. The nearest water is probably to far away to make it worth taking a detour.

The flight speed does not seem to be affected by the proportion of water along the route. Other factors probably have greater influence on flight speed. In Europe water is so frequent that the bird will never be too far away from it. Highest value for real and simulated routes is just above 12 km. The Osprey can fly with a speed of 55 km/h, so 12 km would not take long to travel. It is also likely that the Osprey should be able to see this far, especially when flying at a high altitude. This means that it would always be within a short flight from a water body and always being able to see water. So there is no need to take the opportunity to stop at every water body. The bird could just wait until it's hungry or migration conditions deteriorate, and then look for water. It is likely that there is some threshold value were the proportion of water no longer has any influence on the migration speed and that in Europe the proportion of water is higher than this value. A schematic figure illustrating this is shown in Fig. 26. The same reasoning can be used for the choice of flight route. When water is abundant, there would be no need to take any detours to pass by a lake or watercourse.

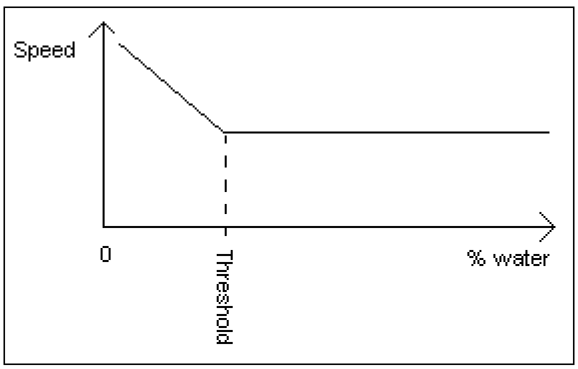


Figure 26. A schematic image. When the proportion of water is higher than the threshold value it will no longer have an influence on the migration speed.

6 CONCLUSIONS

A significant relationship was found when the flight route was related to distance to water. However, this method is very dependent on spatial resolution of land cover data, and the values are very high for Africa. The 100 m resolution did not give any results that indicate that there is a relationship. Perhaps even this resolution is too coarse. Since it would be rather time consuming to calculate distances using the simulated routes, it might be possible to use the shortest route as a comparison. The results from the two different comparisons are very similar, when looking at positive or negative differences from the real route.

The results from the comparison between proportion of water and the choice of route did not indicate any relationship. This might be because of the resolution of data is too coarse, but it might also be because this is not a good measurement for the availability of feeding habitat. Calculating the proportion of water does not give any information about how the water is distributed in the landscape. One large lake will result in a high proportion of water as well as many small lakes. There is also the possibility that the choice of route is not affected by the proportion of water in the landscape. There might be other factors that are more important. Perhaps water is so abundant that the bird does not have to take any detours to pass by it.

No clear relationship between the proportion of water in the landscape and the flight speed could be found. If we want to look at the most fine scale patterns in time, it looks as though the 1 km spatial resolution data is too coarse. It might be possible to look at data day by day, or an even larger scale, instead of dividing the days into segments. When looking at the finer scale, 100 m resolution could be enough, and then proportion of water could be interesting to calculate using 1 km buffers.

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Software:

ArcGIS® 9.1, ESRI

PythonWin, Python Software Foundation.

Matlab®, The Mathworks

Data:

Svenska Marktäckedata, LMV

Corine land cover, European Environment Agency (EEA)

MODIS/Terra Land Cover Type Yearly L3 Global 1km SIN Grid, U.S. Geological Survey (USGS), Center for Earth Resources Observation and Science (EROS), http://modis-land.gsfc.nasa.gov/landcover.htm

GLCC (Global Land Cover Characteristics), U.S. Geological Survey (USGS), Center for Earth Resources Observation and Science (EROS), http://edcsns17.cr.usgs.gov/glcc/

Global Land Cover 2000 database. European Commission, Joint Research Centre, 2003. http://www-gem.jrc.it/glc2000.

8 GLOSSARY

buffer area – Areas created around points, lines or areas.

raster – A grid with cells containing values that represent e.g. different land cover classes or heights.

euclidean distance – The distance measured in a straight line between two positions.

projection – A way of transferring coordinates on the earth to a flat surface. The projections used in this study are UTM (Universe Transverse Mercator) and a gnomonic projection.

geodetic reference system – A reference system that relates coordinates to their positions on earth, e.g. WGS 84.

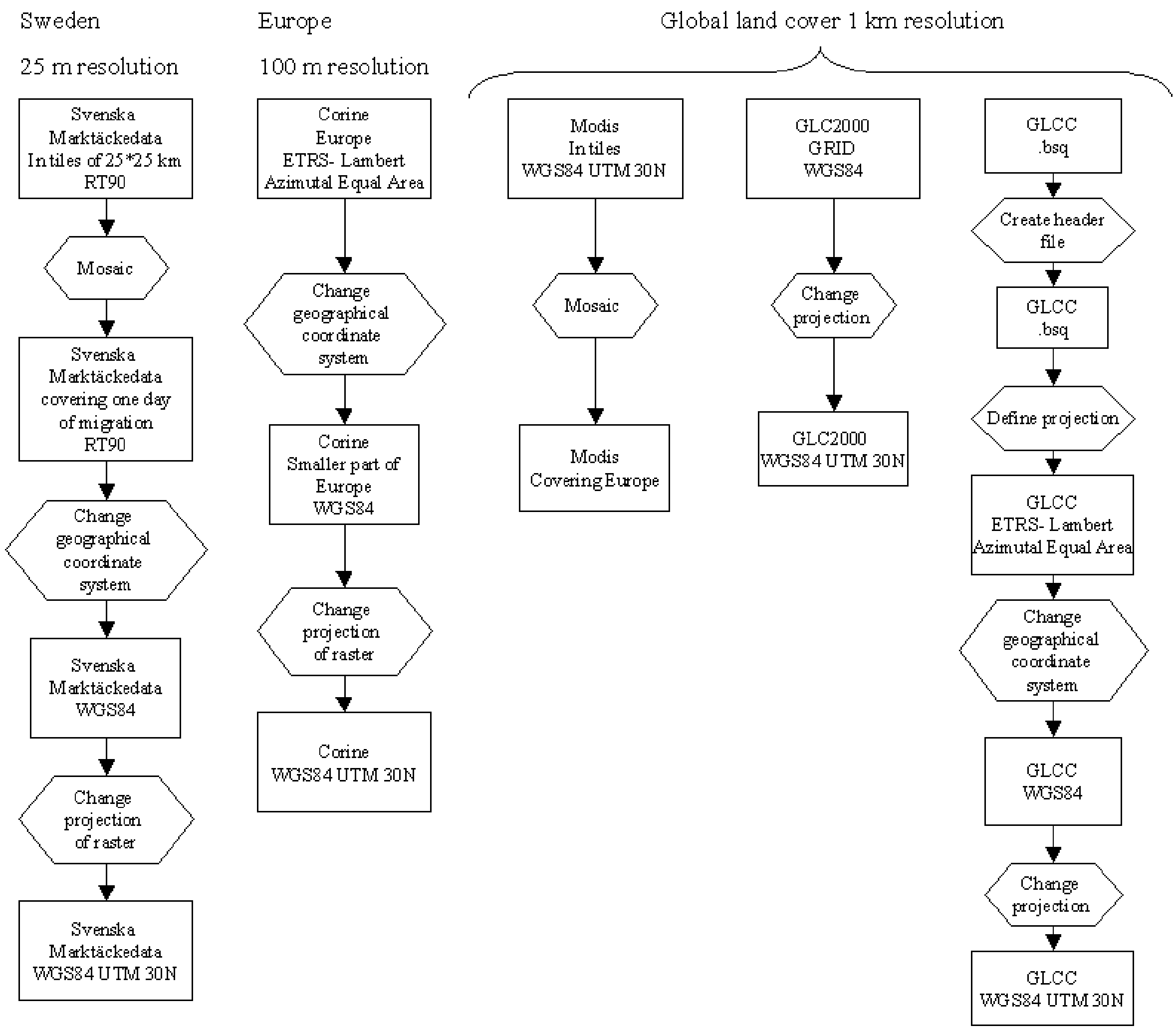
global positioning system (GPS) – A system of satellites making it possible to find out the coordinates at any position on the earth using a GPS receiver.

minimum mapping unit – The size of the smallest object shown in data.

source: Elklund (2003)

Appendix 1

Conversions of land cover data:



Appendix 2

CORINE land cover and Svenska marktäckedata main classes:

1. Artificial surfaces
    1.1. Urban fabric
    1.2. Industrial, commercial and transport units
    1.3. Mine, dump and construction sites
    1.4. Artificial non-agricultural vegetated areas

2. Agricultural areas
    2.1.Arable land
    2.2. Permanent crops
    2.3. Pastures
    2.4. Heterogeneous agricultural areas

3. Forests and semi-natural areas
    3.1. Forests
    3.2. Shrub and/or herbaceous vegetation association
    3.3. Open spaces with little or no vegetation

4. Wetlands
    4.1. Inland wetlands
    4.2. Coastal wetlands

5. Water bodies
    5.1 Inland waters
    5.2 Marine waters

Modis Land Cover and GLCC classes:

Evergreen Needleleaf Forest
Evergreen Broadleaf Forest
Deciduous Needleleaf Forest
Deciduous Broadleaf Forest
Mixed Forest
Closed Shrublands
Open Shrublands
Woody Savannas
Savannas
Grasslands
Permanent Wetlands
Croplands
Urban and Built-Up
Cropland/Natural Vegetation Mosaic
Snow and Ice
Barren or Sparsely Vegetated
Water Bodies

GLC 2000 classes:

Tree Cover, broadleaved, evergreen
Tree Cover, broadleaved, deciduous, closed
Tree Cover, broadleaved, deciduous, open
Tree Cover, needle-leaved, evergreen
Tree Cover, needle-leaved, deciduous
Tree Cover, mixed leaf type
Tree Cover, regularly flooded, fresh water (& brackish)
Tree Cover, regularly flooded, saline water, (daily variation of water level)
Mosaic: Tree cover / Other natural vegetation
Tree Cover, burnt
Shrub Cover, closed-open, evergreen
Shrub Cover, closed-open, deciduous
Herbaceous Cover, closed-open
Sparse Herbaceous or sparse Shrub Cover
Regularly flooded Shrub and/or Herbaceous Cover
Cultivated and managed areas
Mosaic: Cropland / Tree Cover / Other natural vegetation
Mosaic: Cropland / Shrub or Grass Cover
Bare Areas
Water Bodies (natural & artificial)
Snow and Ice (natural & artificial)
Artificial surfaces and associated areas

Appendix 3

Matlab program to simulate routes:

```
%%Random takes a matrix of coordinates and generates a matrix with new
%%coordinates but with the same starting and stopping points.
function A = Random(list)
lat = list(:,2);
lon = list(:,1);

%Set projection to UTM.
utmstruct = defaultm('utm');
utmstruct.zone = utmzone(lat,lon); %Choose UTM-zone for these
coordinates
format long g
utmstruct.geoid = almanac('earth','ellipsoid','meters','wgs84');
utmstruct.falsenorthing = 0;
utmstruct = defaultm(utmstruct);

%Recalculate to UTM coordinates
[x,y] = mfwdtran(utmstruct,lat,lon);

%The distance between each position is calculated, from first to
%second, second to third etc.
dx = [];
dy = [];
for i = 1:length(list)-1
    dx = [dx; x(i+1,1)-x(i,1)];
    dy = [dy; y(i+1)-y(i)];
end

%Creating a new matrix with distances and one row containing random
%numbers.
S = [rand(size(dx)) dx dy];
S = sortrows(S); %Matrix is sorted by the random numbers.

%New coordinates are calculated using the rearranged distances.
x = x(1,1);
y = y(1,1);
for j = 1:size(S,1)
    x = [x; x(j)+S(j,2)];
    y = [y; y(j)+S(j,3)];
end

%Back to lat,long.
[lat,lon] = minvtran(utmstruct,x,y);

A =[lon lat];
```

Appendix 4

Matlab program to write points:

```
%%punkt writes one text file with the actual route and six files with
%%simulated routes for each day.
load osprey.txt;
list = RemoveStop(osprey);

%Writing a matrix with all the positions from one day.
A = [];
while length(list)> 1;
    while list(1,1) == list(2,1);
        A = [A; list(1,[3,2])];
        list(1,:) = [];
        if size(list,1) == 1;
            break
        end
    end

%Print real and five simulated routes to text files.
    A = [A; list(1,[3,2])];
    date = num2str(list(1,1));
    list(1,:) = [];
    WritePoints(A,date,'real');
    if size(A,1)>2
        for i = 1:5
           WritePoints(Random(A),date,['rand' num2str(i)]);
        end
    end
```

Matlab program to write lines on daily basis:

```
%%linje_dag writes lines to a text file. Each line segment consists of
the
%%line between the first and last position of the day.
load osprey.txt;
osprey = RemoveStop(osprey);

%Remove days with only one value
j = 2;
while j < length(osprey);
    if osprey(j,1) ~= osprey(j+1,1) & osprey(j,1) ~= osprey(j-1,1);
        osprey(j,:) = [];
    else
        j = j+1;
    end
end

%Get first and last value for each day.
A = [];

A(1,[2,1]) = osprey(1,2:3);
```

```
k = 2;
for i = 2:length(osprey)-1;
    if osprey(i,1) ~= osprey(i-1,1) | osprey(i,1) ~= osprey(i+1,1);
        A(k,[2,1])=osprey(i,2:3);
        k = k+1;
    end
end
A(length(A)+1,[2,1]) = osprey(length(osprey),2:3);

%Print values to a text file.
fp = fopen('linje_dag.txt','wt');
fprintf(fp,'%s\n','polyline');
x = 0;
i = 1;
while i <= length(A)-1;
    fprintf(fp,'%u %u\n',x,0);
    fprintf(fp,'%u ',0);
    fprintf(fp,'%f %f',A(i,:));
    fprintf(fp,'%s\n',' 1.#QNAN 1.#QNAN');
    fprintf(fp,'%u ',1);
    fprintf(fp,'%f %f',A(i+1,:));
    fprintf(fp,'%s\n',' 1.#QNAN 1.#QNAN');
    x = x+1;
    i = i+2;
end
fprintf(fp,'%s','END');

fclose(fp)
```

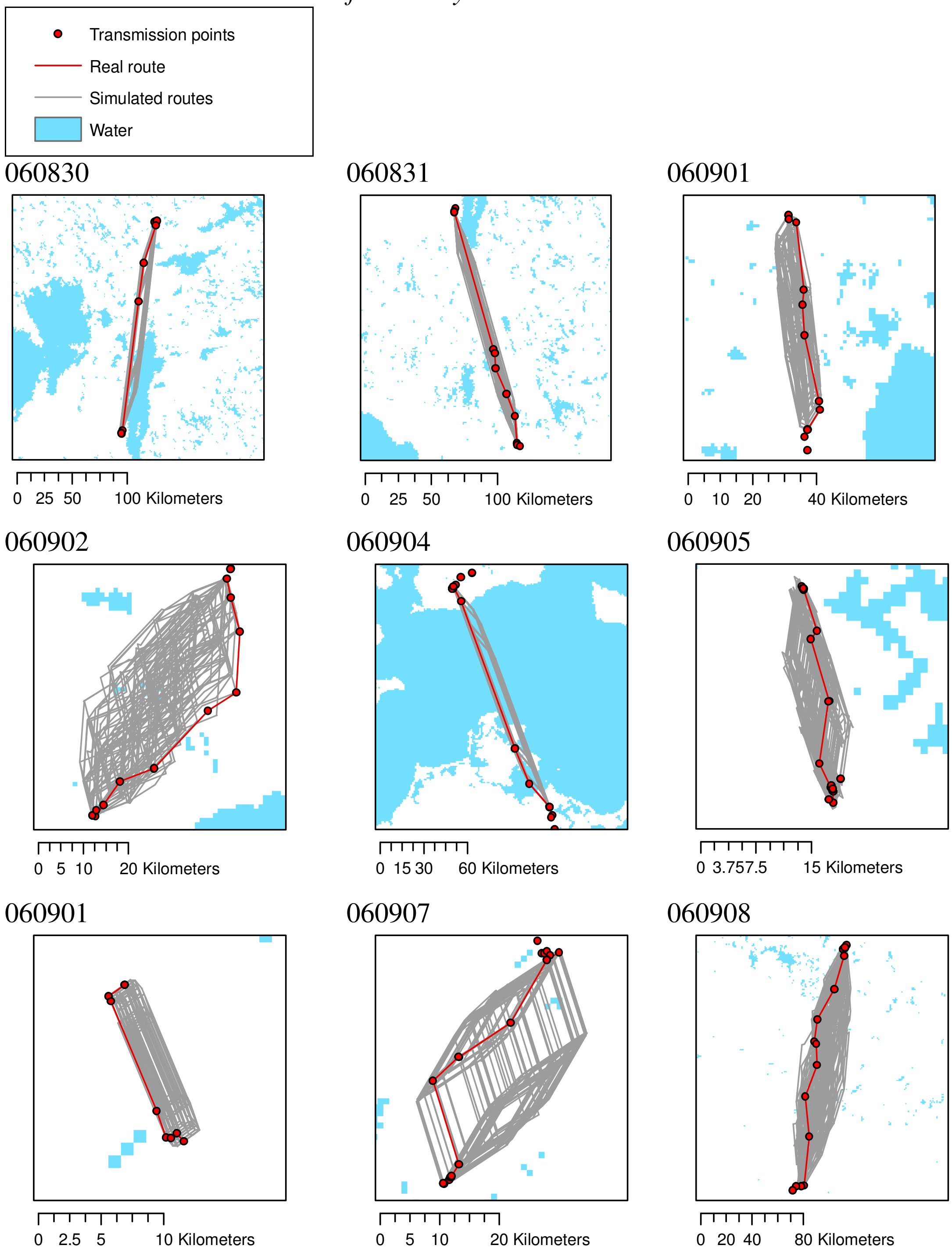
Appendix 5

Python script for creating lines and points:

```
# ---------------------------------------------------------------------------
# CreateFeatures.py
# Created on: Wed Mar 07 2007 11:47:12 AM
#   (generated by ArcGIS/ModelBuilder)
# Usage: CreateFeatures <Input_Text_File>
# ---------------------------------------------------------------------------

# Import system modules
import sys, string, os, win32com.client, glob

# Create the Geoprocessor object
gp = win32com.client.Dispatch("esriGeoprocessing.GpDispatch.1")

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Samples.tbx")

#Create a system argument variable the input workspace.
path = sys.argv[1]

#Make a list of all the textfiles in the specified directory.
tbs = glob.glob(path + "*.txt")

#Loop through the list of text files

for tb in tbs:

    # Set the outputname for each output to be the same as the input.
    outputFeature = "C:\\TempData\\Osprey\\Analysis\\Features\\" + tb[-11:-4] + ".shp"

    # Process: Create Features From Text File...
    gp.CreateFeaturesFromTextFile_samples(tb, ".", outputFeature,
"GEOGCS['GCS_WGS_1984',DATUM['D_WGS_1984',SPHEROID['WGS_1984',6378
137.0,298.257223563]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433
]];-10000 -10000 100000;0 100000;0 100000")
```

Appendix 6

The real and simulated routes for all days:



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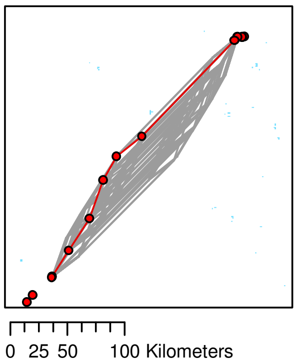

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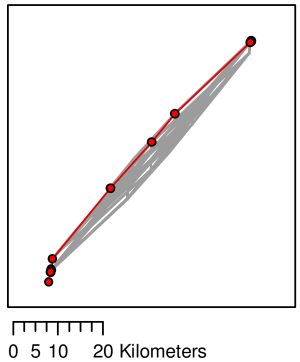

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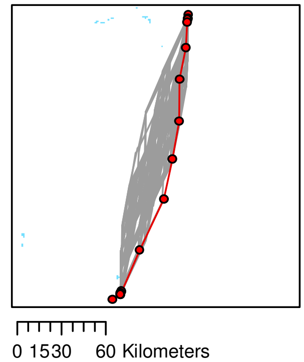

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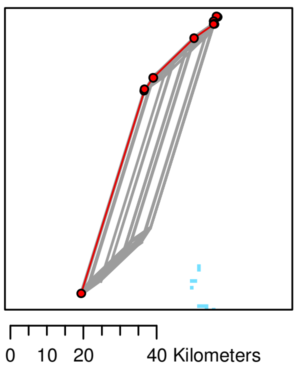

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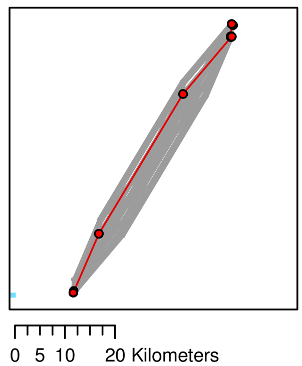
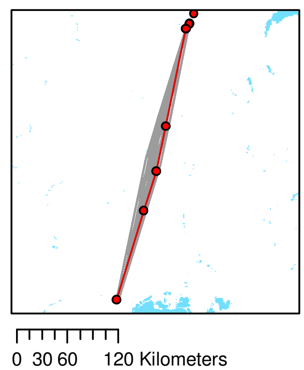
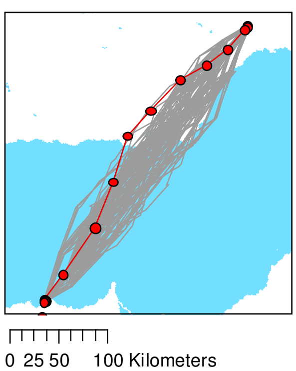


061005



061007



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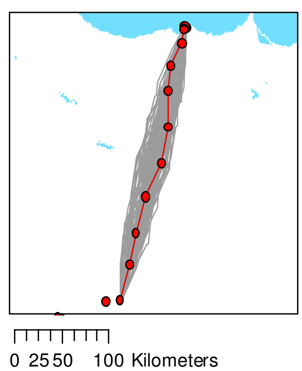

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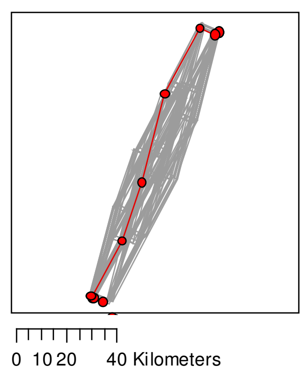

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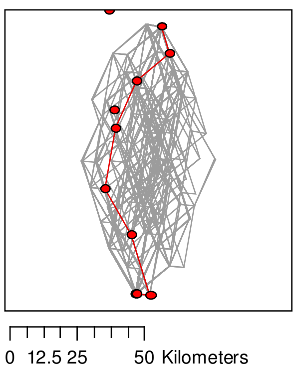

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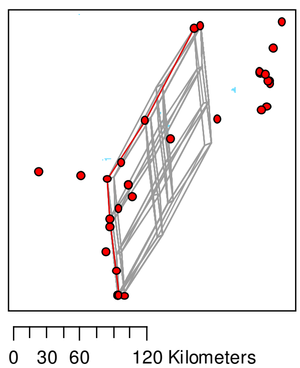

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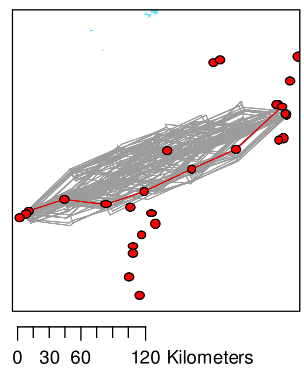

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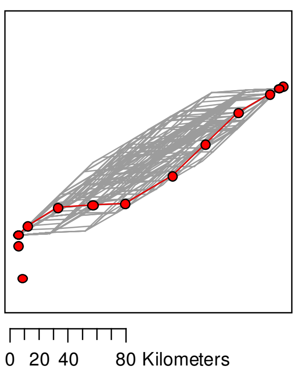

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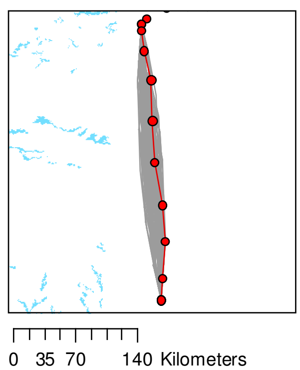

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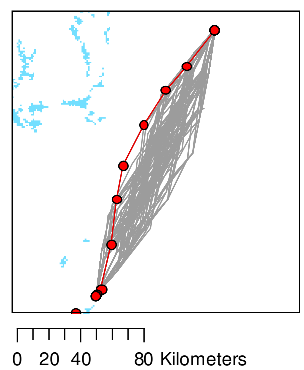

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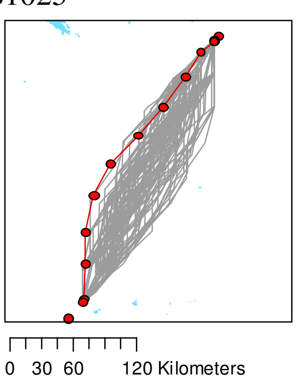

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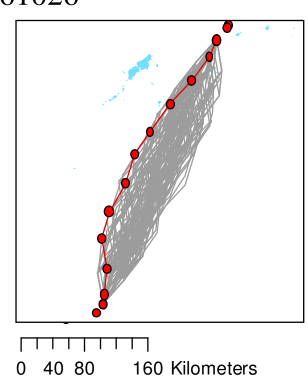

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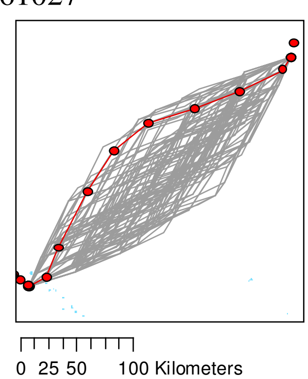

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