Investigation on the effectivity of bat and bird detection at a wind turbine: Final Report Bird Detection

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Report to Interwind AG, Swiss Federal Office of Energy (SFOE) and Federal Office for the Environment (FOEN)

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Pictures, Illustrations (Front page)

Above: DTBird-system at the wind turbine in Haldenstein, Mehmet Hanagasioglu; Below: Laser range finder Aero 21, www.vectronix.ch

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Summary

At the wind turbine in Haldenstein close to Chur (GR) a system to detect birds and bats was installed to mitigate possible collisions. The Interwind AG has closed a research contract with the Swiss Federal Office of Energy (SFOE) and the Federal Office for the Environment (FOEN) to launch an investigation on the effectiveness of the bat and bird detection of the system. The Swiss Ornithological Institute agreed to collaborate for the bird detection part of the study. Furthermore, the study was a chance to generate knowledge on flight behaviour of birds in the surrounding of a wind turbine.

After end of August 2014, the camera system was fully operational to record videos of flying targets approaching the wind turbine together with data on triggered mitigation measures. The mitigation modules “warning” and “dissuasion” were executed either physically or only virtually. The module “stop” was implemented only virtually during the whole time. Independently of the camera system, data on the flight behaviour of birds in the surrounding of the wind turbine was collected by direct visual observations using a high-tech laser range finder to get three dimensional localisations of birds. The direct visual observations were carried out during the breeding season (12 days for a total of 60 h between 06.05. – 16.06.2014) and during the autumn migration season (19 days for a total of 74 h between 22.08.2014 – 26.10.2014). The detection of small birds, like passerines is hardly possible with any of the visual systems. Therefore, the focus for a comparison was set on “larger” birds for which the detection probability was high with both systems. Additionally, a radar system was used to quantify the intensity of flight activity in the area in autumn (13.08. – 22.09.2014).

All unedited raw data which were recorded by the camera system between 25.08.2014 – 26.10.2014 were screened and mainly determined whether the detected target was a bird or not and whether a mitigation module was triggered or not. The single localisations of birds recorded by direct visual observations were connected to three-dimensional flight trajectories and the closest point of such a trajectory to the nacelle of the wind turbine was determined. Because the camera system was operational only after 25.8.2014 just autumn season data could be compared. For each single direct visual localisation it was figured out whether or not the target was within the detection range of one of the cameras . The general nocturnal and diurnal flight activity rates within the area of the wind turbine were calculated based on radar data.

30,5 % of the 886 targets detected by the camera system were birds (“True Positives”). Aircrafts and insects were responsible for most of the “False Positives”. A stop event was never triggered by a bird. The direct visual observations showed that birds avoided the close proximity of the wind turbine and regularly passed the wind turbine at a distance of more than 100 m to the nacelle. Within the time frame of the direct visual observations two birds were expected to be detected by the cameras according to the given assumptions. Those two flights were at the limit of the detection range of the system and were not saved as valid flights by the DTBird-system. The other way around, there were 6 bird movements detected by DTBird which were not expected to be in the detection range. In three cases, the localisations of the visual observations did not represent the closest position of the bird to the camera and three flight movements were missed by the visual observer. The average general flight traffic rate measured by radar up to 1’000 m above ground level was 110 echos/(km*h) during the day and 380 animals/(km*h) during the night. Most of the passage occurred in altitudes above the rotor of the wind turbine.

The DTBird-system does detect “larger” birds within the given detection range. But almost all the common bird species of Switzerland which are known to collide regularly at wind turbines in other countries are smaller than Red Kites (*Milvus milvus*). For Red Kites, the maximum detection range is about 150 m. Thus, the size of the rotor and the size of bird species which should be surveyed, play

an important role for the configuration of the system. The effectiveness of the mitigation module "stop" was not assessable as birds were avoiding the close proximity of the wind turbine and a stop event was never triggered by a bird. However, the emission of the acoustic mitigation signals (warning and dissuasion) seem to have a deterrent effect on larger birds approaching the nacelle of the wind turbine closer than 100 m. In areas with a dense airtraffic of other flying objects than birds, false alarms and false stop events have to be expected as the system is technically not equipped to consider distance of flying objects and to identify targets automatically. No collisions of birds were recorded/observed during diurnal observations (camera and direct visual observations).

An analysis of the behavioural reaction of local compared to migrating birds was not carried out. The general flight behaviour showed that there is good evidence that "larger" birds avoid the close proximity of the wind turbine in the topographically complex area during daytime. Nonetheless, the probability of a collision event of such birds cannot be excluded completely. A generalisation of the results with respect to bird behaviour and wind turbines has to be done very carefully due to the small sample size (one wind turbine) and the specific location. In addition, the results of this study are not suitable to assess the flight behaviour of the mass of small birds in direct relation to the wind turbine as well as the number of collisions. Compared to other locations, the estimation of the number of birds exposed to a collision risk based on the radar data results in a low average potential collision risk.

1. Introduction

1.1 Initial situation

The Interwind AG has closed a research contract (SI/500974-01) with the Swiss Federal Office of Energy (SFOE) and the Federal Office for the Environment (FOEN) to launch an investigation on the effectivity of bat and bird detection at a wind turbine. The Swiss Ornithological Institute agreed to collaborate for the bird detection part of the study. Furthermore, the study was a chance to generate knowledge on flight behaviour of birds in the surrounding of a wind turbine.

The bat and bird detection was conducted with a system of the spanish company DTBird. The system was installed at an existing wind turbine in Haldenstein at Chur in April 2014 and was fully operational after 25th August 2014. For the detection of birds the system promises to survey the rotor swept area of the wind turbine by cameras. An image analysis process allows the detection of flight movements of birds in real time and triggers mitigation measures to minimise collisions.

The present document is the final report about the bird detection part of the study. A synthesis of the whole study will be composed by Interwind AG.

1.2 Research questions

Originally, the DTBird-system was developed for the detection of Griffon vultures with wingspans of 230-265 cm to mitigate collisions at wind turbines in Spain. Recently, it is more and more taken into account to apply the system for the mitigation of collisions of birds at wind turbines in general.

The principle of the system is to send on a first level an acoustic warning signal when a bird is approaching a wind turbine to bring the bird to change his flight direction. On a second level, if the bird is still approaching the wind turbine an acoustic deterrent signal is triggered by the system. Finally, on a third level, when the acoustic signals did not lead to a reaction of the bird, the wind turbine is stopped

The optical detection probability for birds is strongly depending on the size of a bird species and visibility conditions. The most common bird species of Switzerland which are regularly colliding at wind turbines in other countries (Dürr & Langgemach 2006, Dürr 2014) have much smaller wingspans than Griffon vultures: Red Kite (*Milvus milvus*) 140-165 cm (population size in CH: 1‘200-1‘500 breeding pairs), Common Buzzard (*Buteo buteo*) 113-128 cm (population size in CH: 20‘000-25‘000 breeding pairs) and Common Kestrel (*Falco tinnunculus*) 71-80 cm (population size in CH: 3‘000-5‘000 breeding pairs).

While local birds are present in a region the whole year or at least during several months in the breeding season, migrating birds are passing an area twice per year. Therefore it is reasonable that local birds get habituatet to a system which is sending warning and dissuasion signals while no habituation is expected for migrating birds. Habituation effects concerning acoustic bird deterrent systems are already known for a long time from airports.

Until now, most studies on the flight behaviour of birds relating to wind turbines were conducted in flat open landscapes in other countries. But there is a lack of data for wind turbines placed on topographically more complex areas like mountain ridges or mountain valleys. Furthermore, bird observations including the estimation of flight altitudes which are essential for the assessment of the impact of wind turbines on birds are usually conducted only by eye (or telescopes). This estimation of flight altitudes of birds by eye is highly prone to errors, especially when no calibration of estimations are carried out.

Based on these explanations, the following research questions are derived for the present study:

- How effective is the detection of birds which are common in Switzerland by the DTBird-system?
- Where are the limits of the detection of birds which are common in Switzerland?
- Do the acoustic warning and disuassion signals trigger a behavioural reaction of the birds?
- Is there a difference in the behavioural reaction of local and migrating birds?
- How is the general flight behavior of birds in the surrounding of a wind turbine placed in a topographically complex area?

2. Methods

2.1 Principle of the investigation

After end of August 2014, the camera system DTBird was fully operational to record videos of flying targets approaching the wind turbine together with data on triggered mitigation measures. The emmission of the “warning” and “dissuasion” signals was weekly either enabled or disabled. In spite of that, the information was virtually recorded whether the “warning” and “dissuasion” modules were triggered by a flying target or not. The module “stop” was implemented only virtually during the whole time.

Independently of the camera system, data on the flight behaviour of birds in the surrounding of the wind turbine was collected by direct visual observations using a high-tech laser range finder. The direct visual observations were carried out during the breeding season and during the autumn migration season 2014. The focus was set on “larger” birds for which the detection probability was high on one hand for the direct visual observer and on the other hand for the camera system.

Additionally, a radar system was used to quantify the intensity of broad front migration in the area in autumn 2014. Those data will be also used to develop and improve the radar data analysis process with respect to the determination of bats within the framework of another project.

2.2 Camera system DTBird

2.2.1 Description of the cameras of the system

The camera system consisted of four cameras placed on four points around the tower of the wind turbine. The two cameras of the northern- and southern side of the wind turbine were installed at 31 m and the other two cameras of the eastern and western side of the wind turbine at 5 m above ground.

Each camera had a horizontal opening angle of 90° and a vertical opening angle of 68°. The center of the surveyed area was 56° above the horizon. At a horizontal distance of 250 m the lowest altitude of the detection range of the cameras was 132 m above ground for the cameras placed at 31°m and 106 m for the cameras placed at 5 m above ground (Fig. 1 to Fig. 3).

The maximal distance from which a bird is detected by a camera is strongly depending on the size of the wingspan of a bird. A single Griffon vulture with a wingspan of 230-265 m is detected from a maximal distance of about 250 m, a Red Kite from a distance of 145 m and a Common Kestrel from a distance of 70 m. Furthermore, the maximum detection distance for flocks consisting of several individuals is larger than that of single individuals. According to the specifications of DTBird, the maximal detection distance (X) is calculatable using the formula X = (1,5 * Y) / 0,017, with Y standing for the wingspan of a bird.

The flight movements of targets detected by the system are stored in form of a video. The videos are accessible on an internet-platform. In addition to the videos for each flight movement further data are recorded: e.g. date, time, duration of the detected flight movement, type of the triggered mitigation module, duration of mitigation measures, light conditions and information in reference to the wind turbine (direction of the rotor, rotor speed).

In commercial operation process, data are manually post-processed and edited by ornithologists to sort out recordings of non-birds (False positives) and to determine bird species/species group before they are available on the internet platform. For the present study and analysis, the Swiss Ornithological Institute had access to the unedited raw data. The detection of targets and triggering of mitigation measures worked independent of the operation status of the wind turbine. Mitigation measures were also triggered when the rotor of the turbine was not turning.

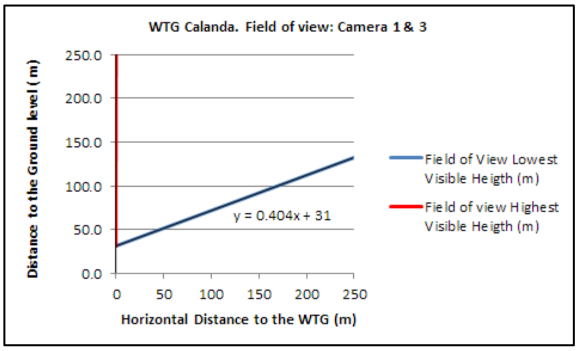

Fig. 1. Surveillance angle of the cameras placed at 31 m above ground (copy of the specifications of DTBird).

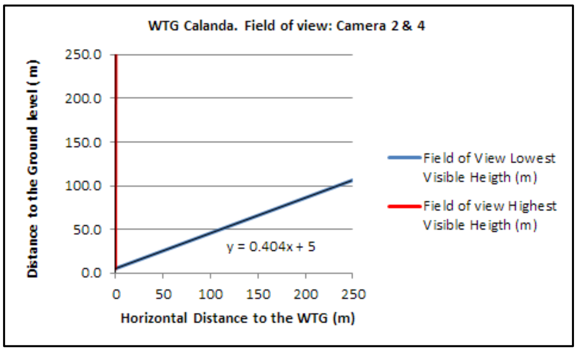

Fig. 2. Surveillance angle of the cameras placed at 5 m above ground (copy of the specifications of DTBird).

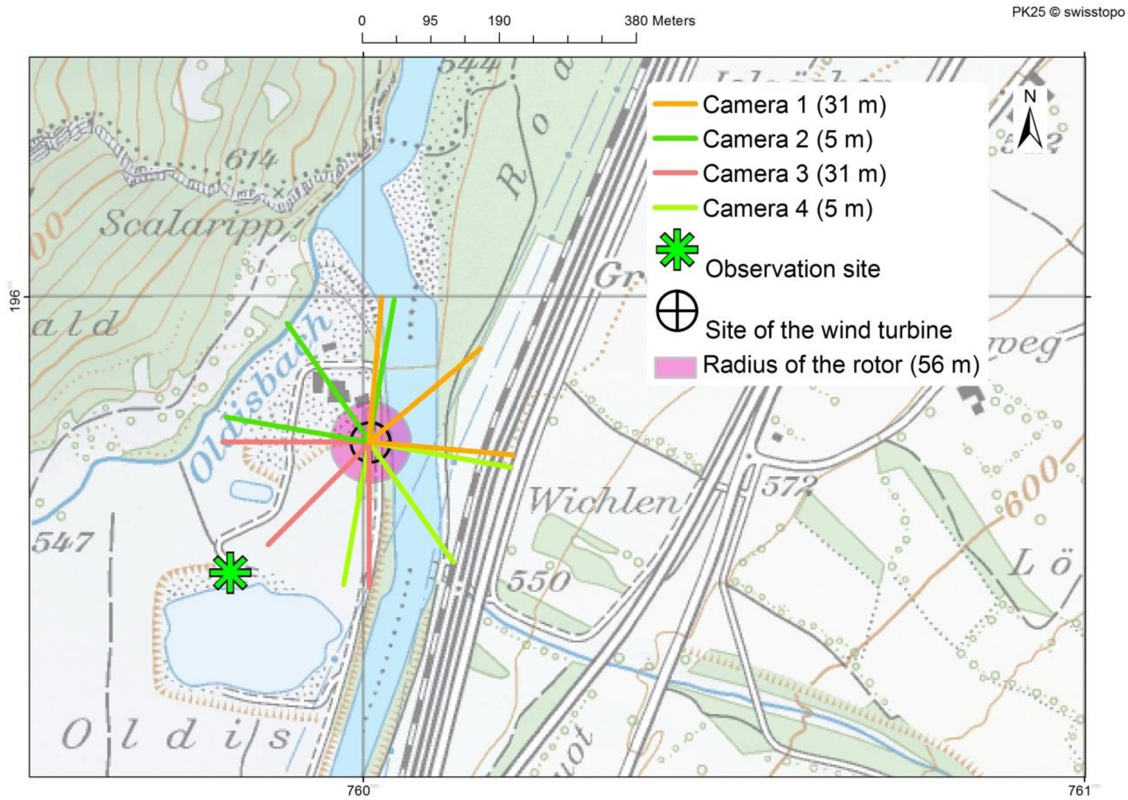

Fig. 3. Field of view of the cameras in the study area. The lines reflect the left and right limit of the range and the centre of view. The length of the lines does not reflect the maximum detection range for any bird species.

2.2.2 Mitigation modules

The principle of the DTBird-system is to send on a first level an acoustic warning signal when a bird is approaching a wind turbine (module “warning”). On a second level, if the bird is still approaching the wind turbine an acoustic deterrent signal is triggered by the system (module “dissuasion”). Finally, on a third level, when the acoustic signals did not lead to a reaction of the bird, the wind turbine is stopped (module “stop”).

The physical emission of the “warning” and “dissuasion” signals was weekly either muted or not. In spite of that, the information was virtually recorded whether the “warning” and “dissuasion” modules were triggered by a flying target or not. The module “stop” was implemented only virtually during the whole time.

2.2.3 Screening and analysis of the data recorded by the camera system

All unedited raw data which were recorded by the camera system between 25.08.2014 – 26.10.2014 were screened and downloaded from the internet-platform. For each recorded flight movement it was determined whether the detected target was a bird or not, which species/group, whether a mitigation module was triggered or not, which mitigation module was triggered and the length of the duration of a mitigation measure.

2.3 Direct visual observations

2.3.1 Observation periods and sites

The direct visual observations took place during the breeding season on 12 days for a total of 60 h between 06.05.2014 – 16.06.2014 and during autumn migration season on 19 days for a total of 74 h between 22.08.2014 – 26.10.2014.

All the observation sites were situated southwesterly to the wind turbine on the area of the gravel plant Oldis AG (Fig. 4). The distance between the observation site and the wind turbine was about 150 m in the breeding season and about 265 m in the autumn migration season. The observation sites were chosen to optimally survey the airspace with respect to the bird behaviour (focus on local birds during breeding and focus on migrating birds in autumn).

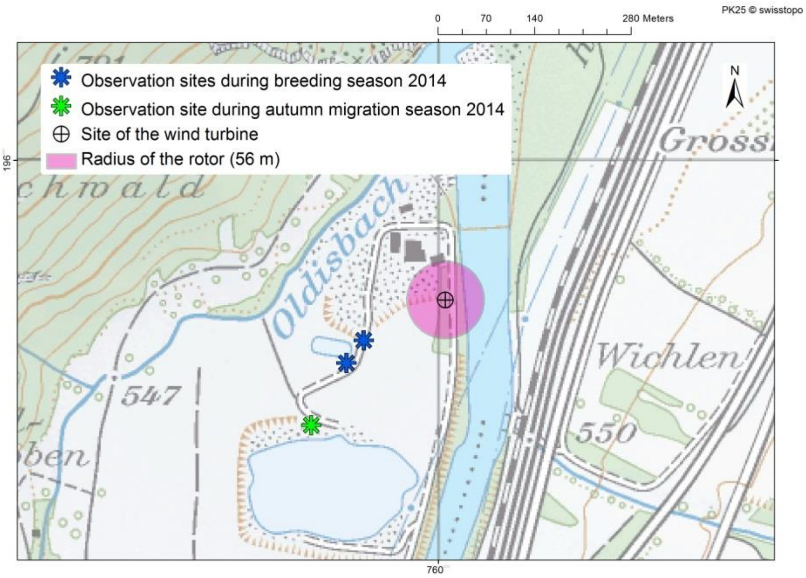

Fig. 4. Map of the study area with the location of the wind turbine and the observation sites chosen for the direct visual observations using the laser range finder.

2.3.2 Laser range finder Vector 21 Aero

The direct visual observations were carried out by ornithologists using a laser range finder model type Vector 21 Aero produced by Vectronix AG (Fig. 5). The device was developed for military use and is dedicated to store the distance, azimuth and elevation to a target in reference to the observation site at the push of a button. Based on these data, it is possible to determine the three-dimensional position of a target in the airspace (Fig. 6) and to compose three-dimensional flight trajectories by linking several localisations of a target.

To store data digitally, the laser range finder was directly connected to a notebook by a data cable. For the visualisation and editing of the data points a software was developed by the Swiss Ornithological Institute (Fig. 7).

Fig. 5. Laser range finder Vector 21 Aero (www.vectronix.ch).

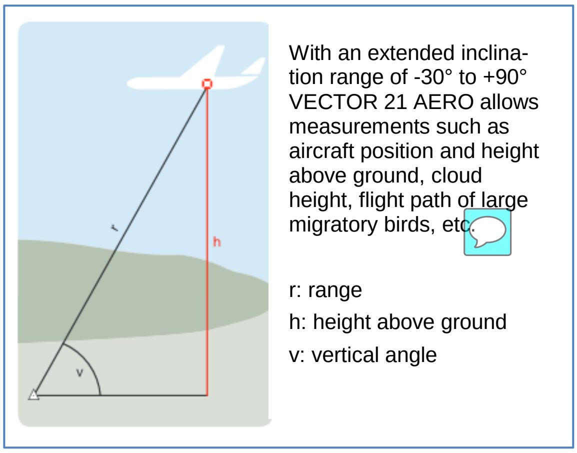

Fig. 6. Determination of flight altitude using the laser range finder Vector 21 Aero (www.vectronix.ch).

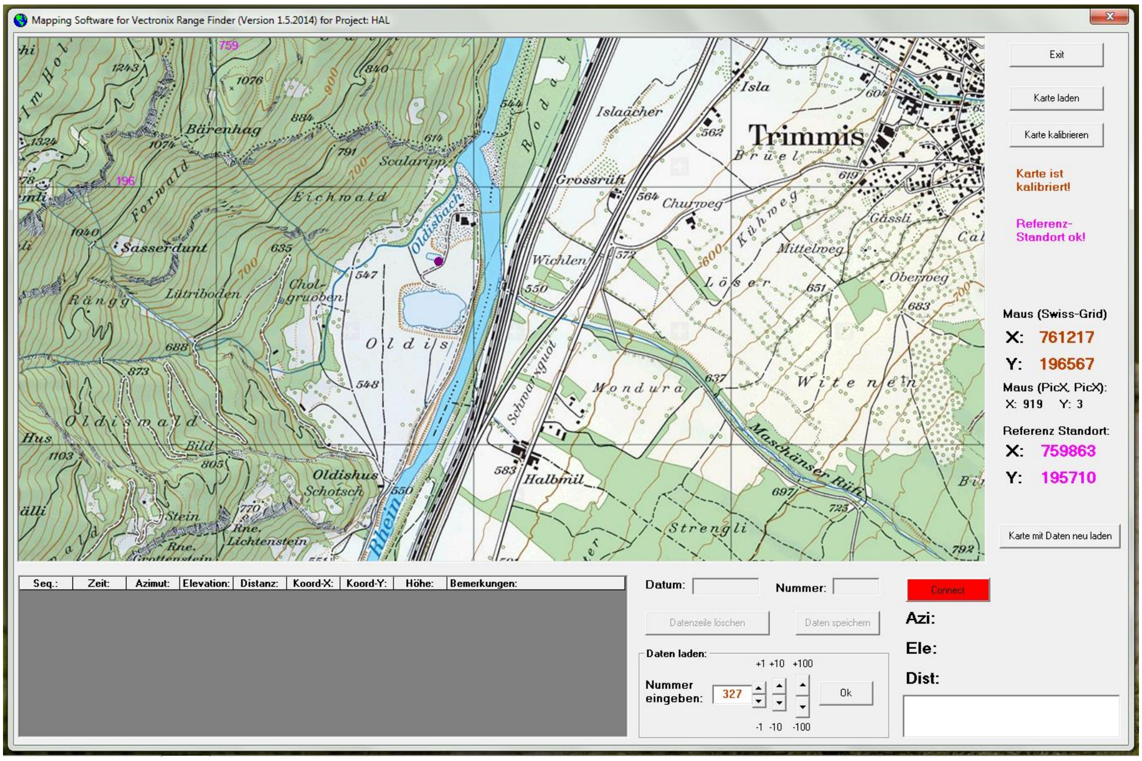

Fig. 7. User interface of the software „Vectronix Mapper“ developed by the Swiss Ornithological Institute for the visualisation and editing of data points measured using the laser range finder Vector 21 Aero.

2.3.3 General analysis of observation data

In a first step, three-dimensional flight trajectories were composed out of the single locations of a target. In a second step, for each flight trajectory, the closest point to the nacelle of the wind turbine was determined by dropping a perpenicular from the line connecting two localisations to the nacelle (Fig. 8). Thus, it was possible to calculate the closest approaching distance of a bird in respect to the wind turbine.

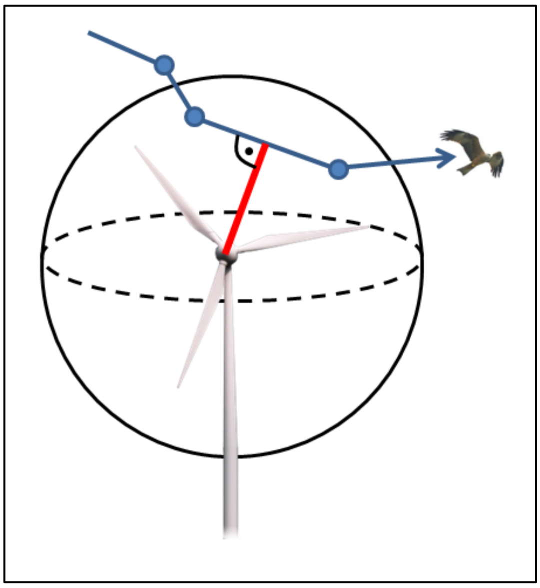

Fig. 8. Determination of the closest distance (red line) of a flight trajectory (blue line) composed of single 3D-localisations (blue spots) to the nacelle of the wind turbine.

2.4 Comparison of data between camera system and direct visual observations

2.4.1 Compared time frame

For the comparison of data between the camera system and the direct visual observations, only those data of the camera system were used which were recorded during time frames where the direct visual observations took place, and only those data of the direct visual observations were used, where no technical inconviences were disturbing the detection capability of the DTBird-system. Based on technical inconveniences there is a lack of data for the following time frames:

- after 28.08.2014, 17:15 h until 02.09.2014, 10:07 h
- after 19.09.2014, 20:16 h until 22.09.2014, 19:19 hr
- on 13.10.2014 until 15:16 Uhr
- after 13.10.2014, 18:30 h until 16.10.2014, 18:02 h
- blackout of camera 4 after 13.10.2014, 15:16 h until 24.10.2014, 08:24 h

2.4.2 Comparison related analysis of direct visual observation data

The comparison was based on the single localisations of birds recorded by direct visual observations. If a localisation of a bird flight trajectory was within the detection angle of a camera and closer than the maximal detection distance of this camera, the flight movement of this bird was expected to be detected by the DTBird-system.

To do so, each bird localisation was allocated to one of the four cameras by considering the detection angle and the distance from the bird localisation to the camera was determined. Furthermore, the maximal detection distance was calculated depending on the bird species according to the formula given in chap. 2.2.1. When there was an uncertainity about the species determination, the wingspan of the smaller species was used. This leads to an underestimation of the detection distance of the camera system. To account for the individual variability of sizes in birds, a lower and an upper value for the wingspan size was considered in the analysis. For a Red Kite a minimal wingspan of 140 cm and a maximal wingspan of 165 cm was assumed. Thus, the maximal detection distance for a Red Kite was between 123.5 m and 145.6 m

The time stamp of such visually observed bird flights was used to double-check with the DTBird database on the internet-platform. Furthermore, it was checked whether there were bird flights detected by DTBird which were not recorded by the direct visual observations.

2.5 Radar measurements

2.5.1 Radar observation period and site

A radar system was used to quantify the intensity of broad front migration in the area and to get a sample of radar data also including activity of bats groundtruthed by the bat detectors of the bat monitoring study going on at the wind turbine.

The radar measurements were carried out during autumn migration season between 13.08.2014 and 22.09.2014. The radar station was installed southwest from the wind turbine, about 170 m away (Fig. 9).

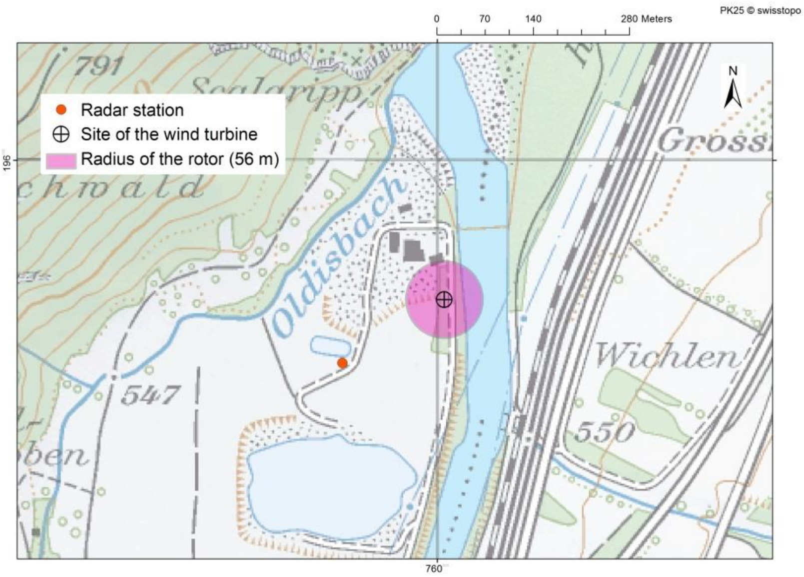

Fig. 9. Map of the study area with the location of the wind turbine and the location of the radar station.

2.5.2 Description of the radar

A fixbeam radar model Swiss BirdScanMV1 was used (Fig. 10). This radar was modified for the detection of birds and is based on a commercial shipradar of the type Sperry Marine Bridgemaster 65825H. The wave length of the radar is 3 cm (X-band radar), has a nominal peak power output of 25 kW and a pulse frequency of 1’800 Hz. The detection range for birds is about 1 km and data are stored digitally.

The radar device has a fix horn antenna which generates a radar beam having an operational beam width of about 60 °. The radar location has to to be chosen in a way that the radar measurments are as less influenced by echoes reflected by the ground or other objects in the surrounding of the radar as possible (clutter). Such clutter echoes interfere with the echoes of birds.

2.5.3 Radar data analysis

The data analysis process consists of several steps. In a first step, clutter of the ground or other disturbing echoes (z.B. rain clouds) are erased. In the next step, the remaining echoes are detected and classified using a tailor made software. In the classification process it is determined whether an echo is that of a bird or not. The classification is based on the analysis of the variability of the echo intensity which, at least in birds, reflects the wing-beat pattern.

On the basis of the number of echoes per time and the size of the surveyed volume, a so-called "migration traffic rate (MTR) is calculated. This is a standardized measure for migration intensity and denotes the number of birds crossing a hypothetical line of one kilometre perpendicular to the main flight direction within one hour (birds/(km*h)).

At night, most birds are migrating solitary or the distance between the flying birds is large enough that they are recorded by the radar as single echoes. According to this, nocturnal migration rates are reflecting the absolute values of birds. During the day, many bird species are migrating close to each other in small to large flocks. Thus, a flock of birds is often represented on the radar only by one broad echo. Therefore, in contrast to nocturnal migration, diurnal migration rates have to be considered as a relative values of migration intensities.

The present location is known to have a high bat activity. For the time being, it is not possible to distinguish between radar echoes of birds and bats. Therefore, the nocturnal migration intensity might be composed of birds and bats, and we therefore used the term "flight traffic rate" (animals/(km*h)) instead of MTR.

The "civil twilight" (sun 6° below the horizon; Komenda-Zehnder et al. 2010; Appendix) was chosen as point in time to differentiate between diurnal and nocturnal flight intensities.

Fig. 10. Radar device model BirdScanMV1 on the rack at the right side with the radome (white dome) covering the antenna. The metal box contains the computer for the data registration and radar control.

2.5.4 Height interval of the wind turbine and collision risk

Flight traffic rates were calculated for height intervals of 50 m from 50 to 1'000 m above ground. The lowest three height intervals above ground included the area surveyed by the radar containing the airspace in which birds are exposed to a collision risk. The flight traffic rate within this height interval is the number of animals which are crossing an area of 150 m height and 1'000 m length (reference area). The size of this area is 150'000 m^2.

The occurrence of collisions is influenced in an unknown way by numerous factors. Up-to-now, there is a lack of knowledge on the relationship between migration intensity and the number of collisions. The analysis of collision risk is figuring out, how many birds are exposed to a collision risk. The number of animals exposed to a collision risk is the proportion of animals which was moving within the height interval of the wind turbine and might collide in relation to a supposed size of a collision surface of the wind turbine. But it is not known how many of those birds which are exposed to a collision risk are effectively encountering the wind turbine.

There are many different ways to determine the size of the collision surface of the wind turbine which is influencing the number of birds exposed to a collision risk. For this analysis, simple conservative assumptions were made. The animals are equally distributed in the airspace and do not avoid the wind turbine. The wind turbine is directed perpendicularly towards the main flight direction of the animals and animals are **not** able to savely cross the rotor swept area between the rotor blades.

The mean flight traffic rate within the height interval of the wind turbine refers to a vertical area of 150'000 m^2 (reference area). The diameter of the rotor of the wind turbine is 112 m swepping an vertical circle with an area of 9'852 m^2. This rotor swept area covers 6,6 % of the reference area. Therefore, 6,6 % of the animals moving within the reference area are exposed to a collision risk.

3. Results

3.1 Camera system DTBird

3.1.1 Detected targets

The DTBird data set of the time frame between 25.08.2014 and 26.10.2014 contained recordings of 897 flying targets. Five recordings were duplicates and six recordings were not assessable because the videos were lacking. After subrtraction of duplicates and unassessable recordings there remained 886 recordings of targets.

270 of the 886 recordings (Fig. 11) were triggered by birds (= 30,5 %), 2 by bats (= 0,2 %) and 614 by other targets 69,3 % (False Positive). Within the „False Positives" (Fig. 12) 318 cases were recordings of aircrafts like helicopters and airplanes (= 51,8 %), in 276 cases the recordings were triggered by insects (= 45,0 %), and the other triggers in 20 cases (= 3,2 %) were movements of the rotor blades of the wind turbine, maintenance work and a leaf or peace of paper.

The bird species/group were determined by assessing the videos. The most frequently detected species group were Corvids (Fig. 13). However, one has to keep in mind that species idenfitication based on the videos is often difficult and results have to be carefully interpreted.

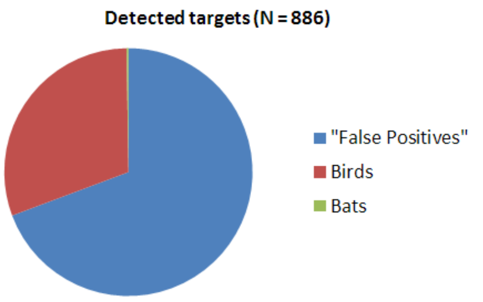

Fig. 11. Proportion of target classes which triggered the detection of flight movements (N = 886).

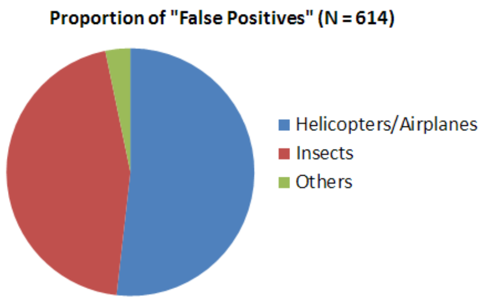

Fig. 12. Proportion of target classes whithin „False Positives" which triggered the detection of flight movements (N = 614).

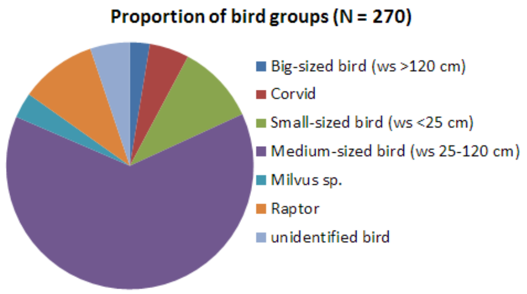

Fig. 13. Proportion of bird species/groups whithin birds which triggered the detection of flight movements (N = 270).

3.1.2 Mitigation modules

The 886 recordings of the DTBird data set were analysed in respect to whether a mitigation module was triggered or not, which mitigation module was triggered and the length of the duration of a mitigation measure. The module "stop" was only virtually implemented while the operation of the acoustic modules "warning" and "dissuasion" were applied either virtually or physically.

Out of the 270 detected flight movements of birds, an acoustic signal was triggered in 236 cases (Tab. 1)., the module "Warning" in 184 and the module "Dissuasion" in 52 cases. The module "Stop" was never triggered by a bird. On average the duration of a warning signal was 20.7 s (± 5,8 s) and of a deterrent signal 23.1 s (± 5,4 s).

Out of the 614 „False Positives" an acoustic signal was triggered 714 times (Tab. 1). Thus, one target triggered several levels of the mitigation chain. 381 warning signals with a mean duration of 15,9 s (± 9,9 s) and 333 deterrent signals with a mean duration of 25,2 s (5,9). The module "Stop" was virtually triggered by 32 flight movements of "False Positives".

Tab. 1. Index numbers about the operation of the DTBird mitigation modules „Warning", „Dissuasion" and „Stop" in respect to birds and "False positives".

DTBird-module	*Index number*	*„False Positive"*	*Birds*
Warning	Number	381	184
	Total duration (s)	6'045	3'801
	Mean duration (s) per case	15.9	20.7
	Standard deviation (±)	9.9	5.8
Dissuasion	Number	333	52
	Total duration (s)	8'394	1'199
	Mean duration (s) per case	25.2	23.1
	Standard deviation (±)	5.9	5.4
Stop	Number	32	0.0
	Total duration (s)	2'880	0.0
	Mean duration (s) per case	90.0	0.0
	Standard deviation (±)	0	0.0

3.2 Direct visual observations

3.2.1 Spatial distribution in two dimensions

During breeding season, about 980 single localisations of birds and during autumn migration season about 1'700 single localisations of birds were recorded using the laser range finder. This resulted in about 180 three-dimensional flight trajectories for the breeding season (Fig. 14) and in about 270 for the autumn migration season (Fig. 15).

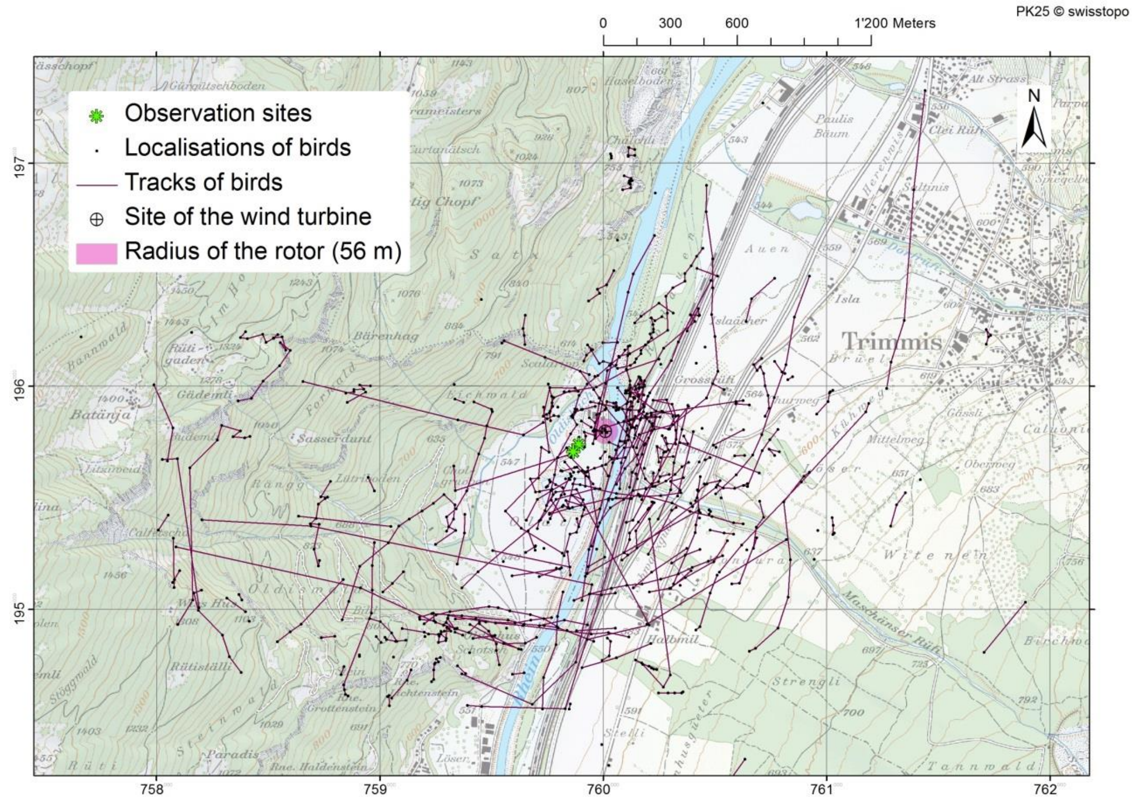

Fig. 14. Map of the study area with the tracks of birds in two dimensions observed between 06.05.-16.06.2014 during the breeding season.

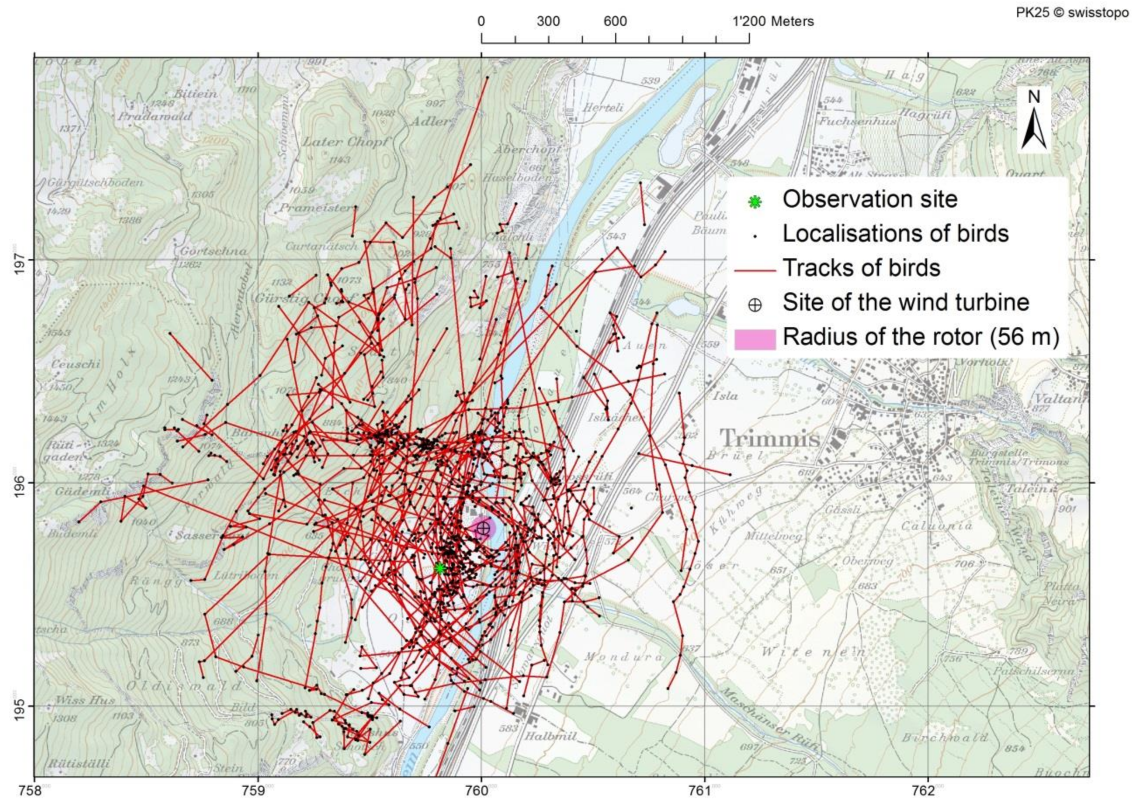

Fig. 15. Map of the study area with the tracks of birds in two dimensions observed between 22.08.-26.10.2014 during the autumn migration season.

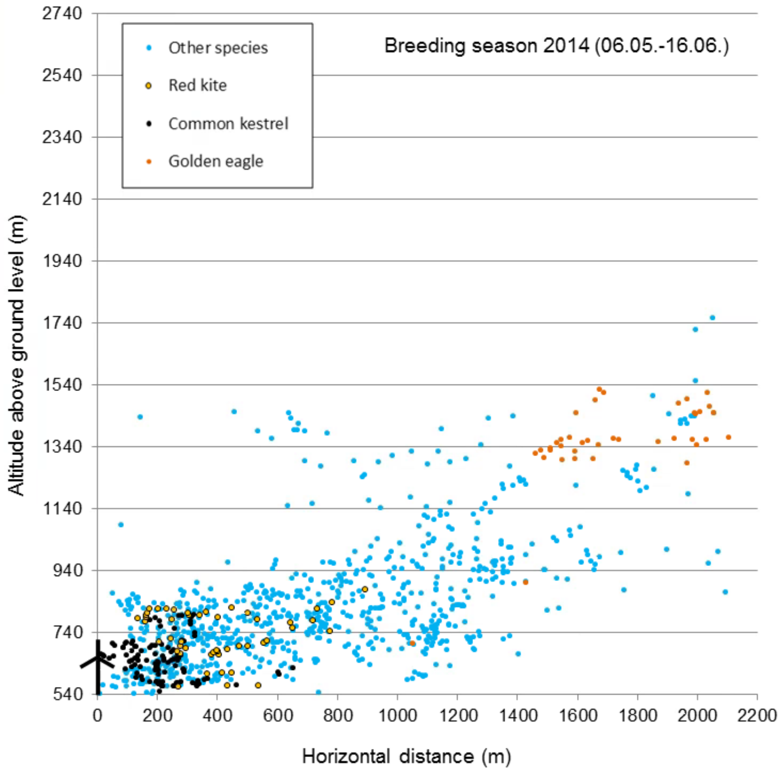

Fig. 16. Altitudinal distribution of single localisations in relation to the horizontal distance from the wind turbine independent of the geographic direction observed between 06.05.-16.06.2014 during the breeding season. Several localisations of Common kestrel were very close to the rotor of the wind turbine while the rotor was not turning.

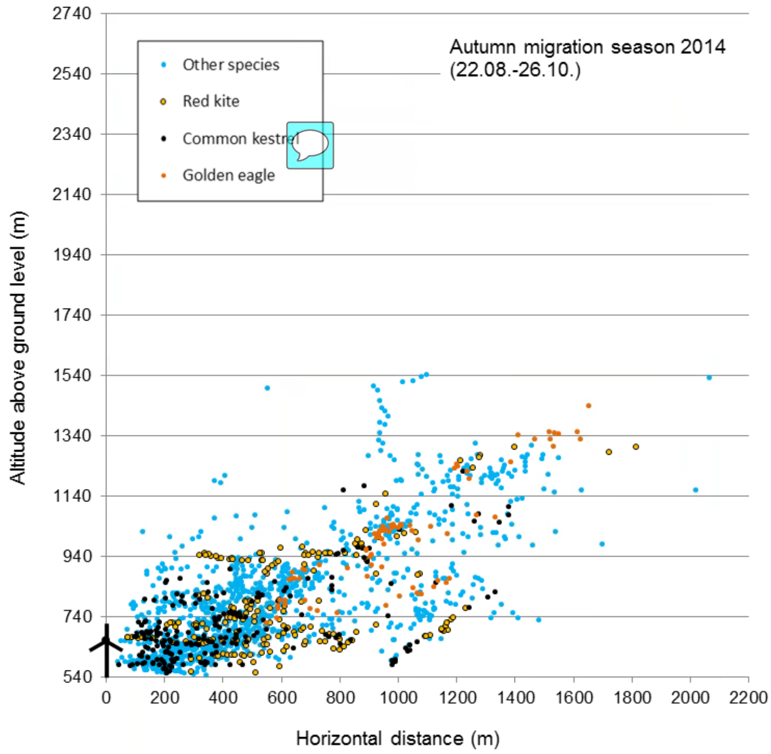

Fig. 17. Altitudinal distribution of single localisations in relation to the horizontal distance from the wind turbine independent of the geographic direction observed between 22.08.-26.10.2014 during the autumn migration season.

3.2.2 Approaching distances of birds to the nacelle of the wind turbine

For each three-dimensional flight trajectory, the closest distance of the bird in relation to the nacelle of the wind turbine was determined independently of the fact whether the rotor was turning or not. In both observation seasons, the most frequent closest distance was between 100-200 m (Fig. 18). During breeding season the proportion of cases within this distance class was 21 % and during autumn migration season 31 %. Distances closer than 100 m occurred in 12 % of the cases during breeding and in 13 % of the cases during autumn migration season.

The influence of the emission of the acoustic deterrent signals on the approaching distance was only possible to be analysed for the autumn migration season due to the operation of the DTBird system. The distance class "closer than 100 m" was more frequent when the emission of the acoustic signals of the DTBird-system (warning and dissuasion) was muted (17,5 %) compared to when it was not muted (7,5 %).

The decrease of distances further away reflects that the focus of the observations was on birds in proximity of the wind turbine and that the detection probability decreases with increasing distance to the observer.

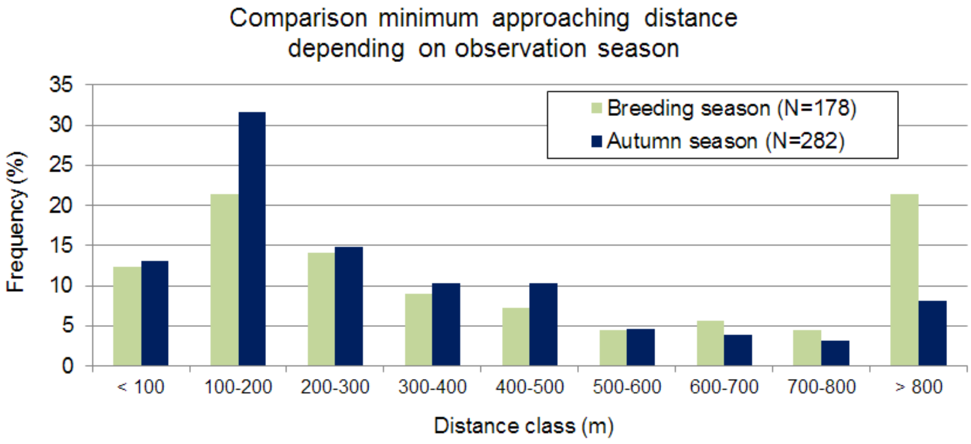

Fig. 18. Comparison of the frequency of the minimum approaching distance in relation to the nacelle of the wind turbine per distance class depending on the observation season (breeding season 06.05.-16.06.2014, autumn migration season 22.08.-26.10.2014).

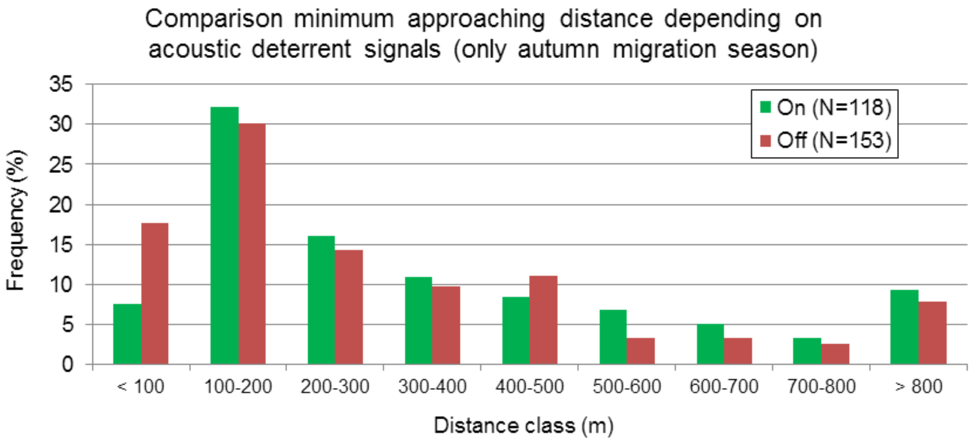

Fig. 19. Comparison of the frequency of the minimum approaching distance in relation to the nacelle of the wind turbine per distance class depending on the emission of acoustic deterrent signals of the DTBird-system in the autumn migration season (25.08.-26.10.2014).

3.2.3 Species composition

In both observation seasons, about 50 % of the direct visual observations (Fig. 20) were flight movements of raptors (Red Kite *Milvus milvus,* Black Kite *Milvus migrans*, Common Buzzard *Buteo buteo*, European Honey Buzzard *Pernis apivorus*, Common Kestrel *Falco tinnunculus*, Eurasian Hobby *Falco subbuteo*, Peregrine Falcon *Falco peregrinus*, Sparrow Hawk *Accipiter nisus*, Golden eagle *Aquila chrysaetos*.

The second frequent observed species group were Corvids (Northern Raven *Corvus corax* and Carrion Crow *Corvus corone*). The group "small sized bird" mainly includes Common swift (*Apus apus*) and Alpine swift (*Apus melba*) while the group "Others" includes Grey Heron (*Ardea cinerea*), White Stork (*Ciconia ciconia*), Great Cormorant (*Phalacrocorax carbo*), Gulls and Doves.

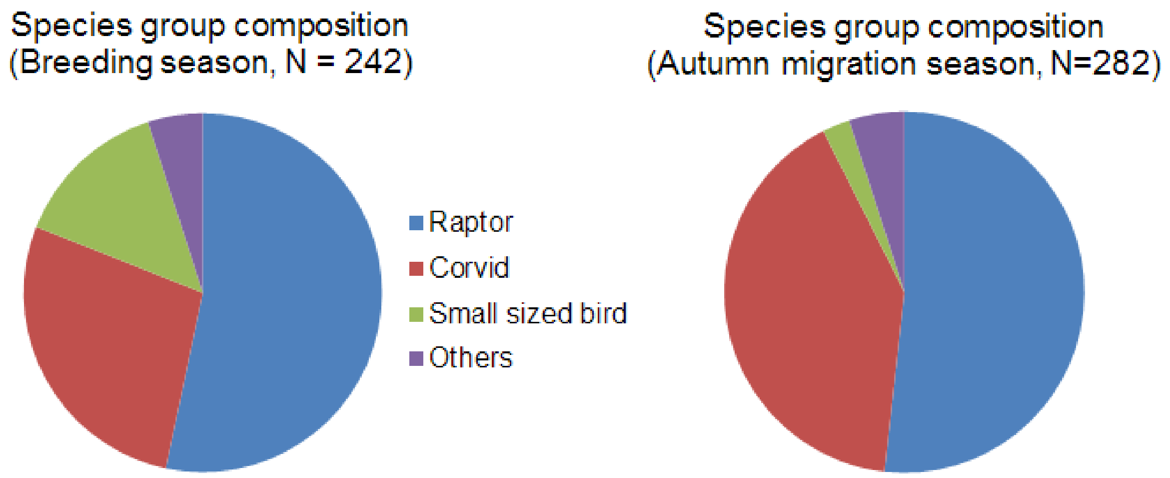

Fig. 20. Species group composition of direct visual observations during breeding season (left, 06.05.-16.06.2014) and during autumn migration season (right, 22.08.-26.10.2014).

Tab. 2. Proportion of raptor species/groups within the raptors per observation season.

	Proportion (%)	
Species	*Breeding season*	*Autumn migration season*
Black Kite	21.7	1.4
Buzzard	46.5	47.3
Golden Eagle	5.4	7.5
Falcon	3.1	2.7
Common Kestrel	16.3	21.2
Red Kite	5.4	16.4
Sparrow Hawk	0.8	3.4
Raptor unidentified	0.8	0.0

3.3 Comparison camera system and direct visual observations

For each single localisation it was determined, whether or not it was within the detection range of a DTBird camera. It turned out that localisations of two flight trajectories were within the given calculated detection range of the DTBird cameras. The time stamp of the recordings were used to double-check the flights on the DTBird data base.

There was no data set available on the DTBird platform for the two flight trajectories which were expected to be detected according to the calculations (flight ID 770 and 804). But there were six flights recorded by DTBird which were **not** expected to be detected (DTBird flight ID 52, 53, 540, 541, 571, 1160, Tab. 3).

Tab. 3. List of flight movements detected by the direct visual observervations and/or by the DTBird-system depending on the expectation of detection and the triggered mitigation level (u = upper limit of the wing span size, Cam = Camera number, which detected the flight).

Date	*Time*	*DTBird flight ID*	*Observation flight ID*	*Species/group*	*Expected to be detected?*	*Detected by DTBird?*	*Mitigation (muted all the time)*
25.08.	15:00	52	-	Corvid	No	Yes (Cam 4)	No
25.08.	15:23	53	409	Corvid	No	Yes (Cam 4)	No
13.09.	12:05	540	531	Corvid	No	Yes (Cam 2)	Yes (warning)
13.09.	12:22	541	535	Mid-sized bird	No	Yes (Cam 2)	Yes (warning)
14.09.	15:57	571	-	Big sized bird	No	Yes (Cam 4)	Yes (warning)
12.10.	16:25	-	770	Common Kestrel	Yes (u)	(No)	-
19.10.	13:52	-	804	Red Kite	Yes (u)	(No)	-
19.10.	13:58	1160	-	Corvid	No	Yes (Cam 1)	Yes (dissuasion)

3.3.1 Flight movements expected to be detected

DTBird flight ID ---/Observation flight ID 770 (Common Kestrel): There is only one localisation very close to the wind turbine on a low altitude (~40 m above ground level, 3D-distance to camera 4: 38 m). Furthermore, the localisation gets into the detection range of the camera only if the upper limit of the wingspan size is used (80 cm). Thus, the bird was moving at the limit of the detection range of the camera system.

A check of the system data by collaborators of DTBird showed that there were detection data in the system but the bird was too short in the detection process and was therefore suppressed by the system.

DTBird flight ID ---/Observation flight ID 804 (Red Kite): There are several localisations in proximity of the wind turbine on altitudes of about 130 m above ground level. The localisations only get into the detection range of the camera 3 (3D-distance to camera: 125 m), if the upper limit of the wingspan size is used (165 cm). Thus, the bird was moving at the limit of the detection range of the camera system.

A check of the system data by collaborators of DTBird showed that there were detection data in the system but the bird was too short in the detection process and was therefore discarded by the system.

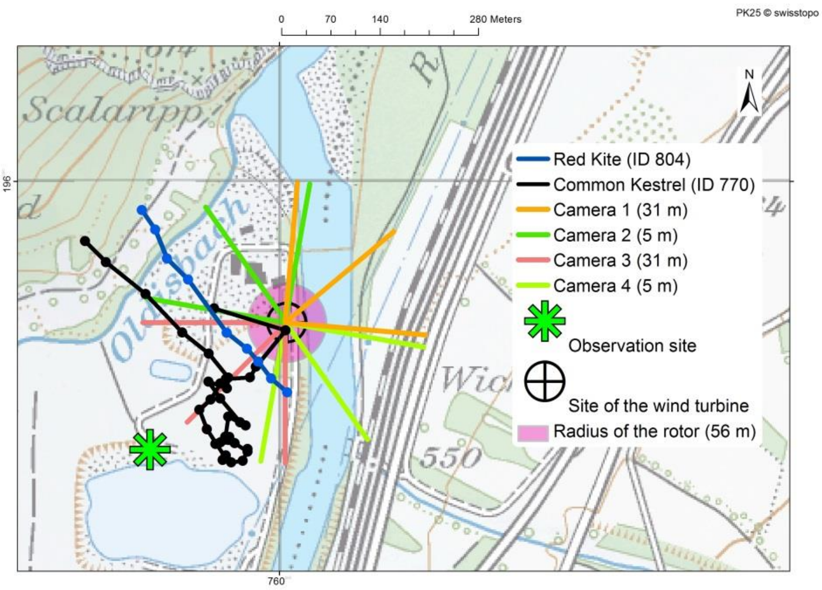

Fig. 21. Map of the study area with the tracks of birds expected to be detected together with the view angle of the cameras (the length of the lines does not reflect the maximal detection range).

3.3.2 Flight movements not expected to be detected

DTBird flight ID 52/Observation flight ID --- (Corvid): The flight was missed by the direct visual observer due to another Corvid which was tracked by the visual observer at an higher altitude during the same time (observation flight ID 406). It was common that several individuals of Corvids were moving together through the study area.

DTBird flight ID 53/Observation flight ID 409 (Corvid): The flight consists of only two localisations at an altitude of about 60 m above ground level (3D-distance to camera 2: 106 m). So it is probable that the visual observer did not get a data point of the closest position of the bird in relation to the camera.

Furthermore, the expected detection distance was calculated based on the the wingspan of a *Corvus corone* (wingspan size: 84-100 cm), whereas in reality it might had been a *Corvus corax* (a much larger bird, wingspan size 115-130 cm). So it is reasonable that the calculated detection distance of this observation was under estimated.

DTBird flight ID 540/Observation flight ID 531 (Corvid): The flight consists of three localisations at an altitude of about 55 m above ground level moving towards north (3D-distance to camera 3: 66 m). This part of the flight was too low and was not within the detection range of camera 3 (position: 31 m above ground level). After stopping the visual observation it is probable that the bird came into the detection range of camera 2 installed on 5 m above ground level.

DTBird flight ID 541/Observation flight ID 535 (Medium-sized bird): The flight consists of several localisations in proximity of the wind turbine on low altitudes of about 50 m above ground level below the range of camera 4 (3D-distance: 94 m) and 3 (3D-distance: 68 m). It might be that the bird was changing his flight direction to circle the wind turbine after stopping the visual observation and came into the detection range of camera 2.

DTBird flight ID 571/Observation flight ID --- (Big-sized bird): The flight was missed by the direct visual observer.

DTBird flight ID 1160/Observation flight ID --- (Corvid): The flight was missed by the direct visual observer.

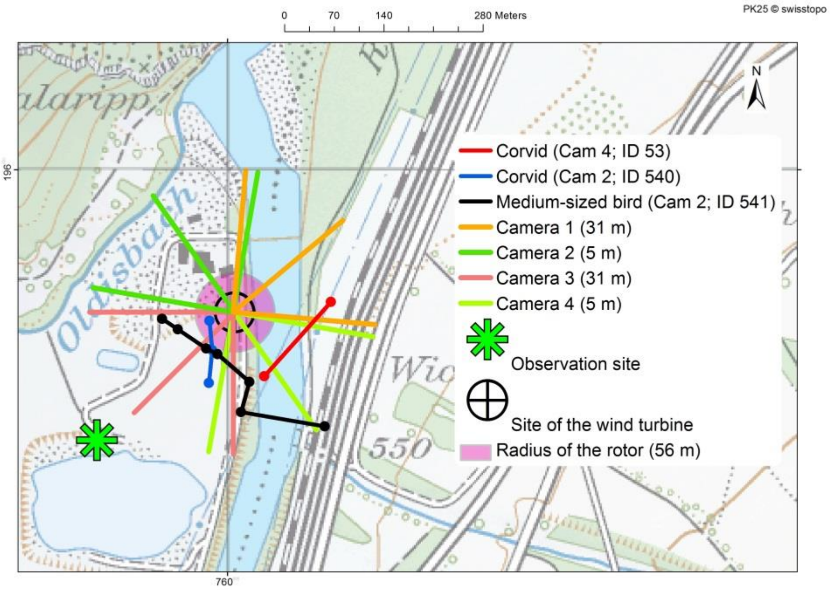

Fig. 22. Map of the study area with the tracks of birds <u>*not*</u> *expected to be detected together with the view angle of the cameras (the length of the lines does not reflect the maximal detection range).*

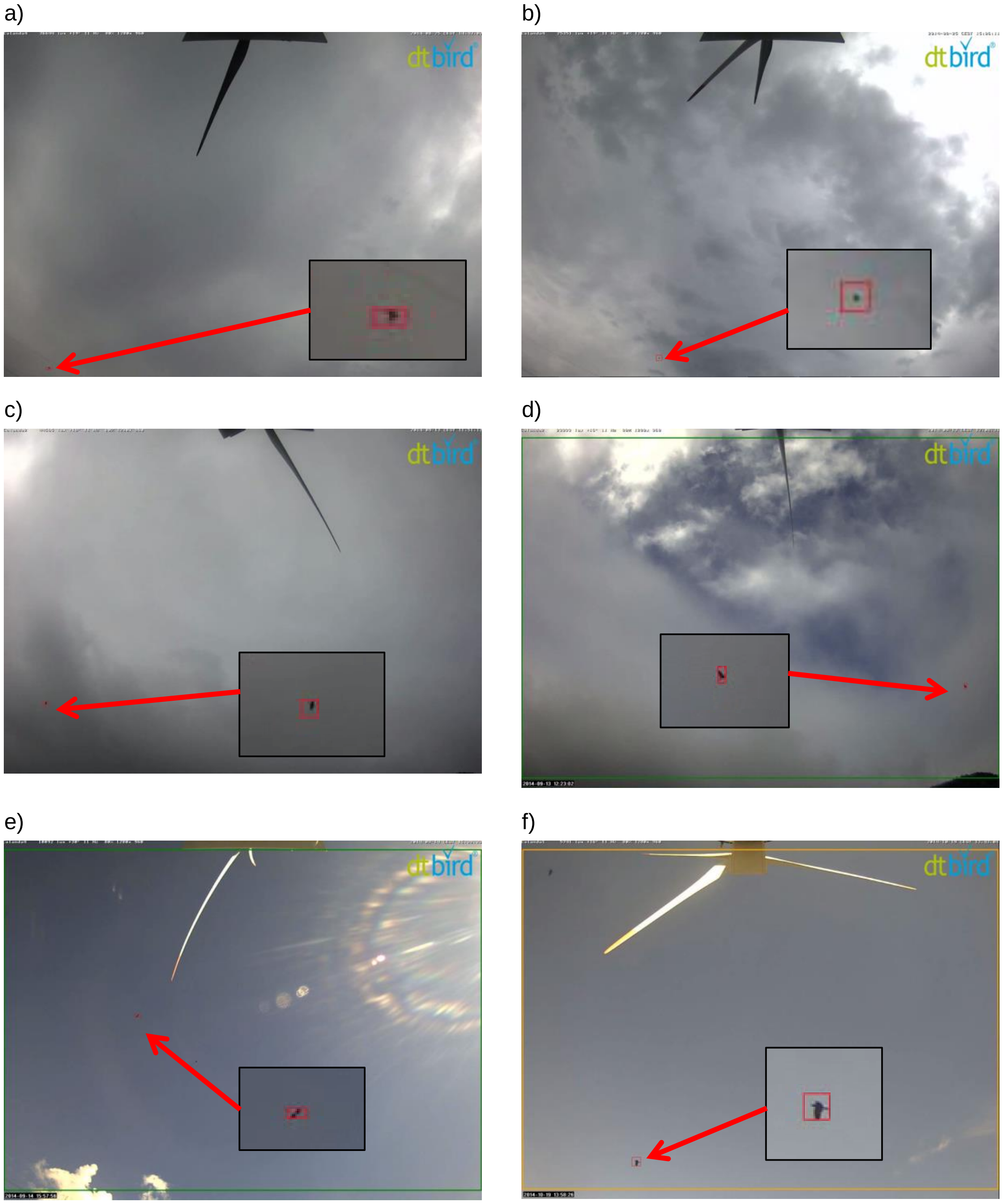

Fig. 23. Screen shots of the DTBird videos and increased detail of the bird. a) Corvid (ID 52), b) Corvid (ID 53), c) Corvid (ID 540), d) Medium sized bird (ID 541) e) Big-sized bird (ID 571) f) Corvid (ID 1160).

3.4 Radar measurements

3.4.1 Seasonal distribution

The average flight traffic rate up to 1'000 m above ground level for the time period was 110 (±75) echos/(km*h) during day and 380 (±270) animals/(km*h) during night.

The mean flight traffic rate per date for up to 1'000 m above ground was fluctuating between 20–340 echos/(km*h) during day and between 55–1'100 animals/(km*h) during night (Fig. 24). In the height interval up to 200 m above ground level which is relevant in terms of the wind turbine, the mean diurnal flight traffic rates were between 0–45 echos/(km*h) (Fig. 25) and the mean nocturnal flight traffic rates between 3–180 animals/(km*h).

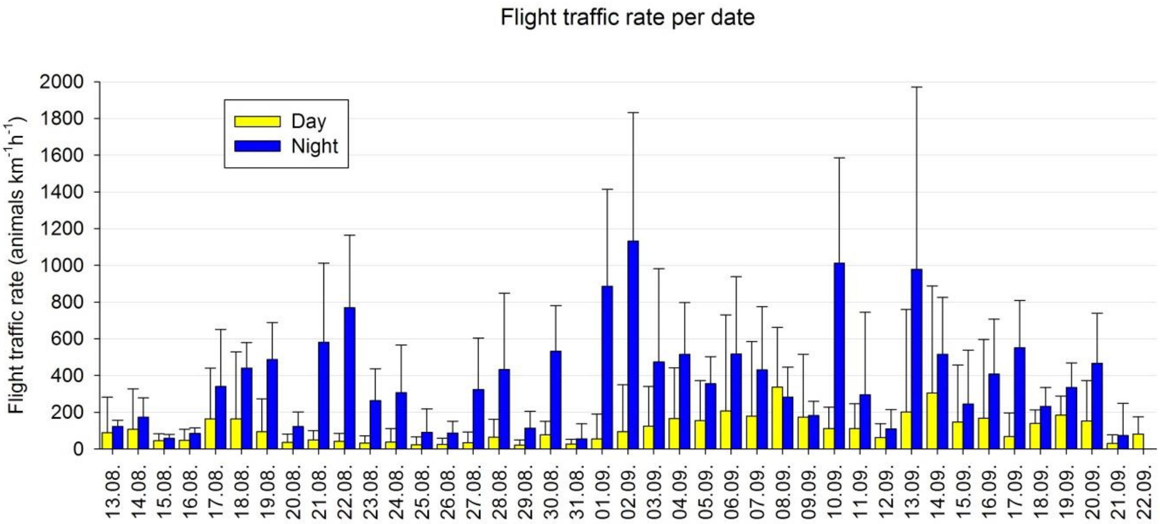

Fig. 24. Mean flight traffic rate per date (with standard deviation) splitted for day and night.

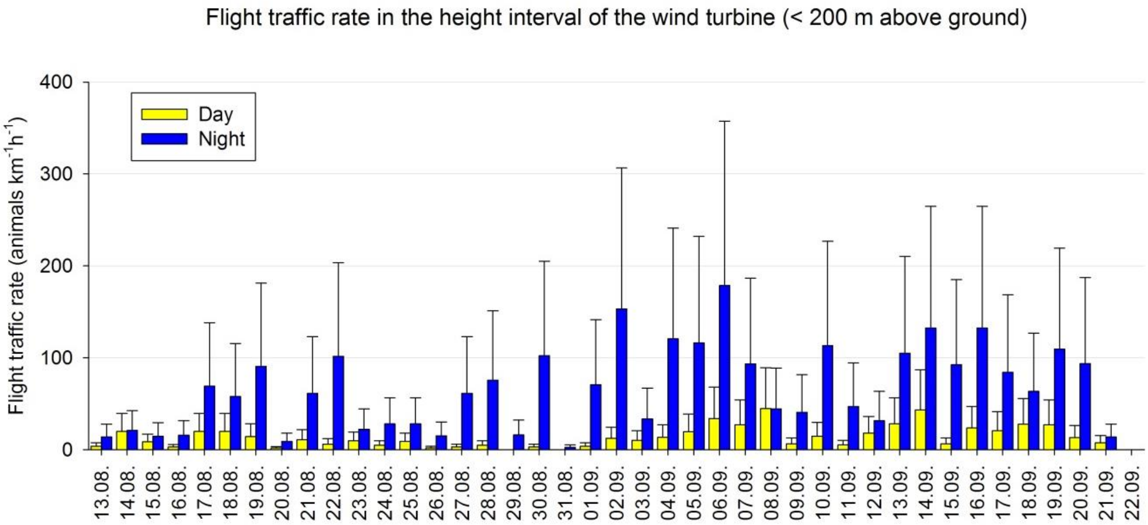

Fig. 25. Mean flight traffic rate per date (with standard deviation) in the height interval of the wind turbine (< 200 m above ground level) splitted for day and night.

3.4.2 Altitudinal distribution

For the analysis of the altitudinal distribution, the flight traffic rates were averaged for the radar observation period for each 150 m height interval (Fig. 26). The flight traffic rates per height interval were between 6-35 echos/(km*h) for the day and between 35-85 animals/(km*h) for the night. The highest values of the flight traffic rates occurred in the height interval between 890-1040 m asl (= 350-500 m above ground).

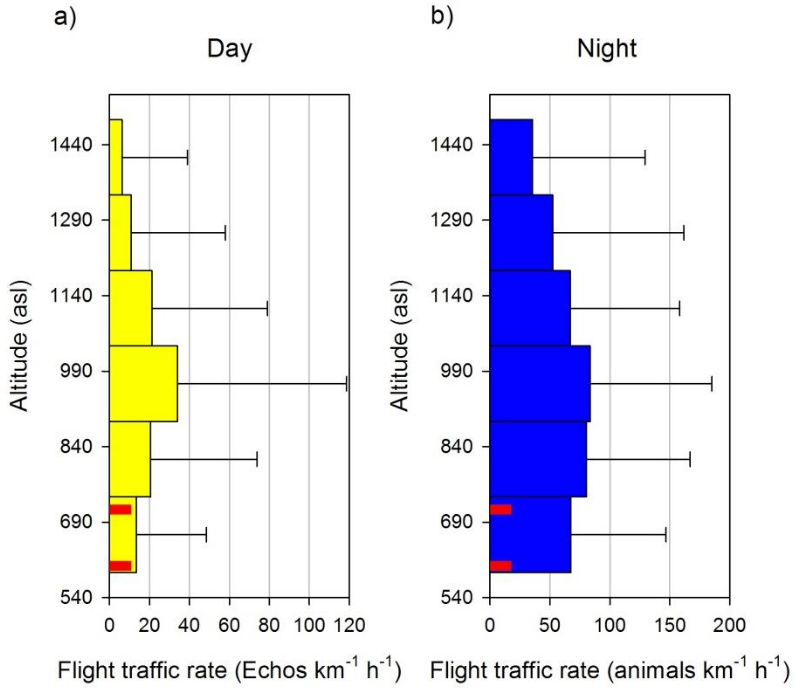

Fig. 26. Altitudinal distribution of the diurnal (a) and nocturnal (b) mean flight traffic rate (with standard deviation). Red bars display the upper and the lower limit of the wind turbine rotor diameter.

3.4.3 Hourly distribution

For the analysis of the hourly distribution, the flight traffic rate of all the height intervals up to 1’000 m above ground were averaged per hour. The mean flight traffic rates show the typical hourly pattern of migration. The flight traffic rate are highest at night-time, are decreasing in the morning hours, stay on a lower level and increase again in the evening hours (Fig. 27).

The mean migration traffic rates per hour were up to 1’000 m above ground level 40-780 animals/(km*hour) and up to 200 m above ground level 3-130 animals/(km*hour). The hourly distribution within the height interval of the wind turbine up to 200 m above ground level is more or less corresponding to the hourly distribution including all the height intervals up to 1’000 m above ground level.

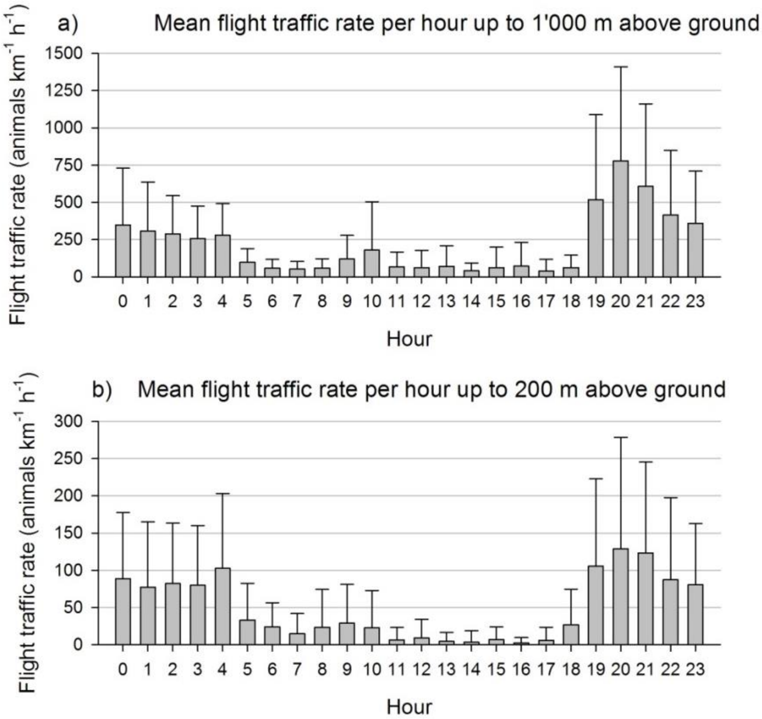

Fig. 27. Hourly distribution of the flight traffic rates (with standar deviation) for all height intervals up to 1’000 m above ground level (a) and within the height interval of the wind turbine up to 200 m above ground level (b).

3.4.4 Collision risk

According to our assumptions, 6,6 % of the animals moving within the height interval of the wind turbine are **exposed to a collision risk** (cf. chap. 2.5.4).

The mean numbers of animals exposed to a collision risk were between 0-3 animals/(km*h) during the day and 0,2-12 animals/(km*h) during the night. This means, extrapolated depending on the length of the day and the night, 13 (sd ±10) animals per day and 42 (sd ±30) animals per night resulting in a total of about 2’300 animals which were exposed to a collision risk.

Given the assumption that the period contained 50 % of the animals of the migration season, the numbers are doubled to get a value for the whole autumn migration season. Thus, about 4’600 animals were exposed to a collision risk during autumn migration season which means an average of 25 animals per day (24 h) in relation to six months (184 days) in the second half of the year.

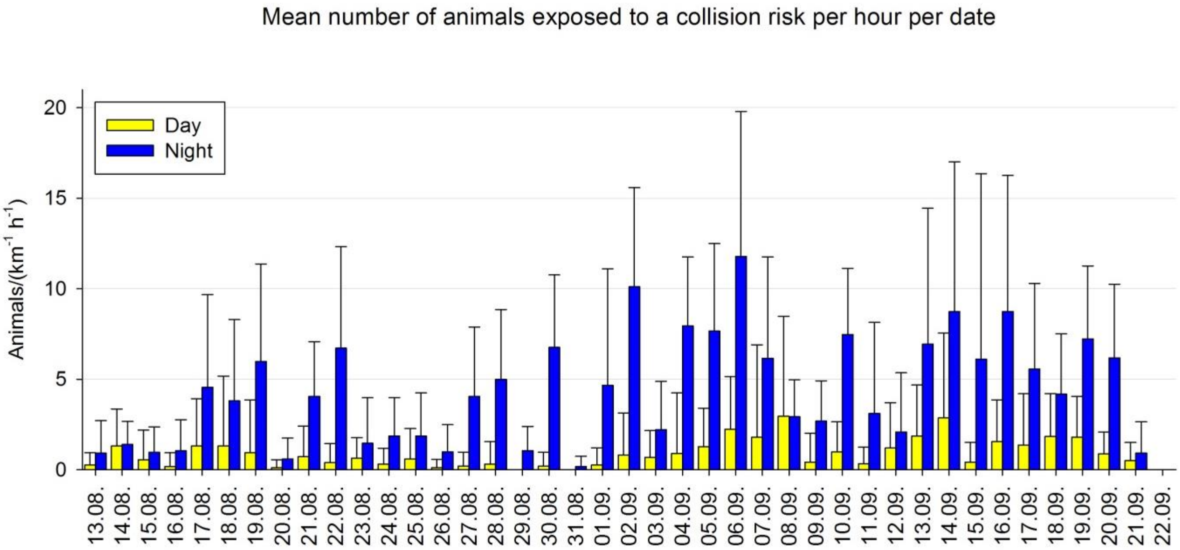

Fig. 28. Mean number of animals exposed to a collision risk per date during day and night.

3.4.5 Flight activity and wind conditions

Wind data recorded by the control system of the wind turbine were used to analyse flight traffic rate in relation to the wind conditions (22.08.2014-22.09.2014). The hourly values of flight traffic rates were allocated to hourly values of the wind conditions represented by wind direction (N, NE, O, SO, S, SW, W and NW) and speed (weak: < 5 m/s, medium: 5-10 m/s, strong: > 10 m/s).

The most frequent wind conditions were weak wind (< 5 m/s) from southwest at night and medium strong wind (5-10 m/s) from northeast during the day which reflects a channel effect along the orientation of the valley (Fig. 29). Flight traffic rate was high especially during weak wind conditions independent of the wind direction, or during medium strong wind conditions with wind either coming from south, southwest or southeast (Fig. 30). From an animals point of view migrating towards southwest, northeasterly winds mean tailwind while south- and soutwesterly winds mean head wind conditions.

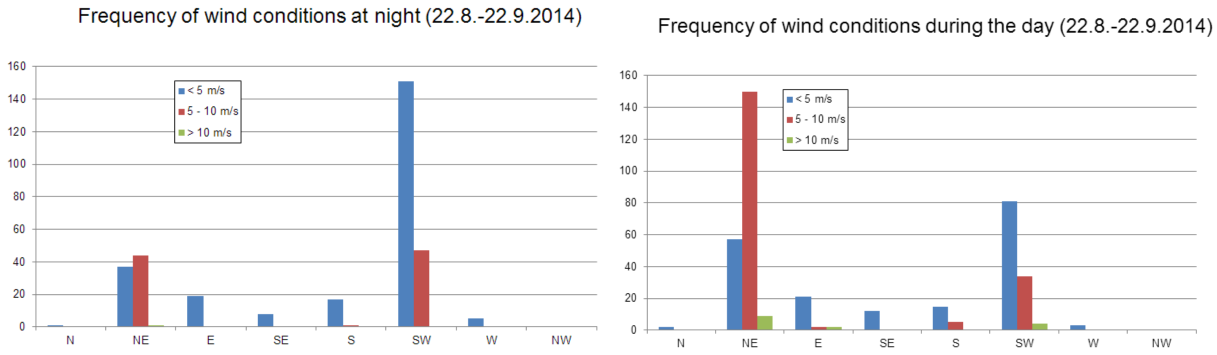

Fig. 29. Frequency of wind conditions at night (left) or during the day (right).

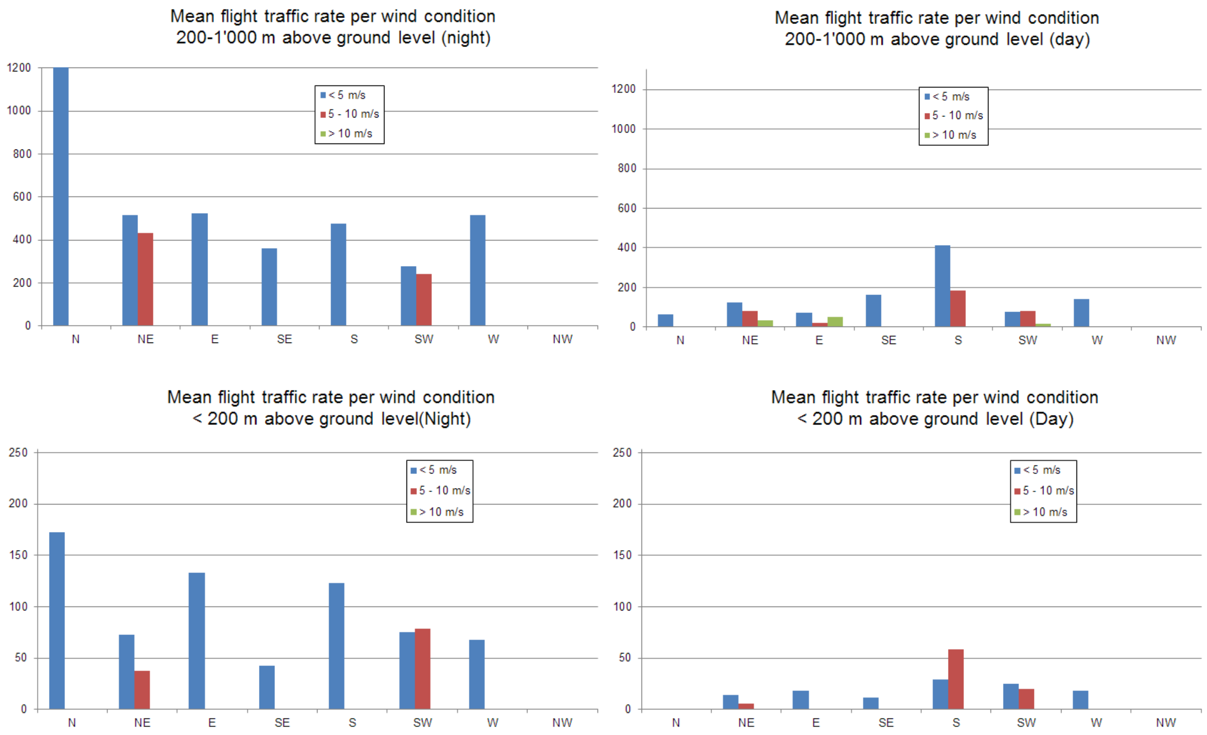

Fig. 30. Mean flight traffic rate per wind condition of all height intervals from 50 m up to 1'000 m above ground level (upper graphs) and of the height level lower than 200 m (50-200 m) above ground level (lower graphs) either for the night (left graphs) or for the day (right graphs).

4. Discussion

4.1 Effectivness of bird detection by the DTBird-system

As a matter of fact, mitigation measures for the protection of single birds have to work immediately in real-time when a bird is approaching a wind turbine. However, the DTBird-system does not have a technical possibility to measure the distance of targets which are detected by the system and to identify them automatically in real-time before a mitigation measure is triggered. Thus, every close small target (e.g. insects) or distant large target (e.g. helicopters) has the same pixel-size like a bird and is triggering the mitigation modules. This circumstance is shown by the high proportion of “False Positives”.

Within the large amount of detected targets the birds are included which are regularly detected within the technically possible detection range of the cameras.

4.2 Limits of detection of the DTBird-system

The detection range of any detection system (eye, optical systems like cameras, radar devices) is naturally limited depending on the performance of a system and on the size of the targets which should be detected. Large targets are detectable in larger distances than small targets.

The size of common birds in Switzerland has a wide spectrum and reaches from the Goldcrest (*Regulus regulus*, wingspan: 13-15 cm, weight: 5-7 g) to the Bearded vulture (*Gypaetus barbatus*, wingspan: 250-280 cm, weight: 5’000-7’000 g). The DTBird-system was originally developed for the detection of Griffon vultures with wingspans of 230-265 cm. The most common bird species of Switzerland which are regularly colliding at wind turbines in other countries (Dürr & Langgemach 2006, Dürr 2014) have much smaller wingspans than Griffon vultures.

The technical maximal detection range of the DTBird cameras is about 150 m for Red Kites and 70 m for Common Kestrels while the diameter of the wind turbine rotor is 112 m. To protect single birds and trigger mitigation measures, the whole rotor swept area should be surveyed by the cameras. However, with the given configuration of the system with cameras at 5 m and 30 m above ground, the surveillance of the whole rotor swept area is only given for bird species having a wingspan size larger than 126 cm (Fig. 31). An additional set of cameras on higher positions of the tower would increase the size of the surveyed area for birds smaller than Red Kites.

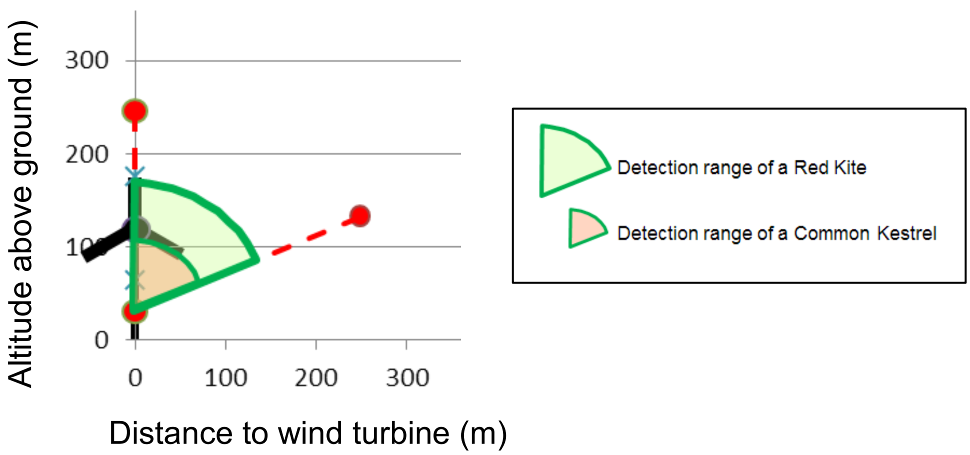

Fig. 31. Size of the detection range for Red Kites and Common Kestrels in relation to the camera position at the wind turbine.

4.3 Mitigation modules of the DTBird-system

The aim of the present study was to analyse the direct visual observation data to investigate the effect of the mitigation modules on birds. Due to the fact that birds were avoiding the close proximity of the wind turbine, it was a rare event that birds were triggering a mitigation module (virtually as well as physically).

The effectivness of the mitigation module “stop” was not assessable based on this data as a stop event was never triggered by a bird independent of whether the physical emission of an acoustic mitigation signal was muted or not. There was a higher proportion of flight movements within the class “approaching distance closer than 100 m” when the physical emission of the acoustic mitigation signal was muted. Thus, the acoustic mitigation signals (warning and dissuasion) seem to have a deterrent effect on larger birds approaching the nacelle of the wind turbine closer than 100 m.

4.4 Flight behaviour of birds around the wind turbine in general

The data set of both seasons of direct visual observations comprises a mixture of observations of local as well as of migrating birds. In most cases of the raptor observations it was not clearly assessable whether the birds were migrating individuals or not. Due to that, the analysis in the present study does not distinguish between local and migrating birds. Anyway, the observed birds seem to avoid the close proximity of the wind turbine during daylight and a closer statistical analysis is part of a current master study (deadline end of 2015).

Furthermore, the radar measurements showed that diurnal as well as nocturnal flight traffic occurred regularly in altitudes above the wind turbine. The location of the wind turbine is on the bottom of a valley which is edged by mountains exceeding 1’500 m. Thus, the location might be crossed mainly by low flying birds following the orientation of the valley and not by birds directly crossing the alps towards southwest on the top level of the mountains. Therefore, the range of the radar was suitable to record this valley specific flight traffic. An evidence for this is that flight activity was high especially under head wind conditions. It is known that birds are migrating at lower altitudes and are concentrating in the valleys during head wind conditions (Liechti 2006, Bruderer & Liechti 1998, Bruderer 1996). The concentration at lower levels is even stronger when the wind speed is medium strong. This is represented by increased diurnal and nocturnal flight traffic rates in the height interval lower than 200 m above ground level during medium strong winds coming from south or southwest (cp. Fig. 30). However, there is also a concentration of flight traffic during tailwind conditions (north-easterly winds). An explanation might be that a lot of birds are migrating within the whole airspace using all altitudes or that the tailwind conditions were concentrated to the valley with other wind conditions on higher altitudes (e.g. inversion).

4.5 Method of the direct visual observations

The direct visual observations were carried out using the military laser range finder Vector 21 Aero. The device was suitable to localise three-dimensional positions of birds in the airspace and to compose flight trajectories. However, the accuracy of a flight trajectory is depending on how many localisations that are recordable within a short time. Thus, it is possible that the visual observer did not get the exact closest positions of birds in relation to the wind turbine or in relation to the cameras. As a result the recorded localisations of birds can be outside of the calculated detection range of the cameras although the bird might have get into the detection range of the cameras between two single localisations or previous to the first or after the latest localisation of a flight trajectory. Furthermore, birds can be missed by the observer when there are several birds in the area while the observer is busy with tracking one individual.

4.6 Collision risk

No collision events of larger birds were recorded/observed during diurnal observations (camera and direct visual observations). Even when the acoustic mitigation modules of the DTBird-system were muted, birds avoided the close proximity of the wind turbine.

The detection of collisions of small birds was not possible and was not the aim of the study. But the mass of flight traffic in general occurred in altitudes above the rotor swept area of the wind turbine during the day as well as during the night. A conservativ analysis and extrapolation of the number of birds which were exposed to a collision risk in the second haft of the year (six months) estimated a number of about 2’200 birds (= 12 birds per 24 h). However, as long as avoidance behaviour of birds and bats are unknown reliable collision rates cannot be calculated. Compared to other locations, the estimation of the number of birds exposed to a collision risk based on the radar data results in a low average potential collision risk.

Taking into account all the results of this study the collision risk for birds at the wind turbine at this location seems to be relatively low. However, due to the limited study period we cannot rule out that with environmental conditions other than during this study higher collision risks might occur.

5. Implications for practice

5.1 DTBird-System

- In areas with a dense airtraffic of other flying objects than birds, false alarms and false stop events have to be expected as the system is technically not equipped to consider distance of flying objects and to identify targets automatically before mitigation measures are triggered. Frequent acoustic false alarms might lead to disturbances in quiet areas or habituation effects for birds. In addition, a species specific bird protection is not possible. The protection of a specific species would be only possible if a wind turbine was stopped for any kind of bird.
- The DTBird-system does detect "larger" birds within the given detection range. But almost all the common bird species of Switzerland which are known to collide regularly at wind turbines in other countries are smaller than Red Kites (*Milvus milvus*). For Red Kites, the maximum detection range is about 150 m. Thus, the size of the rotor and the size of bird species which should be surveyed play an important role for the configuration of the system. Especially for an effective mitigation of collisions of single birds, at least the whole rotor swept area of a wind turbine has to be surveyed by the system. Depending on the target species it might be necessary to add a further set of cameras on higher positions of the wind turbine tower.
- The effectivness of the mitigation module "stop" was not assessable based on this data as birds were avoiding the close proximity of the wind turbine and a stop event was never triggered by a bird independent of the emission of an acoustic mitigation signal. However, the emission of the acoustic mitigation signals (warning and dissuasion) seem to have a deterrent effect on larger birds approaching the nacelle of the wind turbine closer than 100 m.

5.2 Flight behaviour of birds and collision risk

- It is difficult to say whether a generalisation of the results of one wind turbine to other locations is reliable or not. The prominent landscape with the slopes, a cliff, the bottom of the valley and the river does have a strong influence on the flight trajectories of the different species. However, there is good evidence that diurnally active "larger" birds are aware of the turbine and seem to avoid the close proximity of the rotor swept area within this topographically complex area. Nonetheless, the probability of a collision event of such birds cannot be excluded completely.
- The results of this study are not suitable to assess the flight behaviour of the mass of small birds in direct relation to the wind turbine as well as the number of collisions. Compared to other locations, the estimation of the number of birds exposed to a collision risk based on the radar data results in a low average potential collision risk. However, together with the funnelling effect by the topography and some specific weather conditions, we expect that for rare occasions very high concentration of migration can occur at this site. Such events are only quantifiable with long-term studies over several years.

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7. Appendix

Length of day and night during the radar observation period (UTC +1). At dawn and dusk the sun elevation is 6° below the horizon ("civil twilight"). This time was used to distinguish between day and night.

Date	*Dawn*	*Dusk*	*Day Length*	*Night Length*	*Date*	*Dawn*	*Dusk*	*Day Length*	*Night Length*
13.08.2014	04:34	20:13	15:39	08:21	06.09.2014	05:09	19:26	14:17	09:43
14.08.2014	04:36	20:11	15:35	08:25	07.09.2014	05:10	19:24	14:14	09:46
15.08.2014	04:37	20:10	15:33	08:27	08.09.2014	05:12	19:22	14:10	09:50
16.08.2014	04:39	20:08	15:29	08:31	09.09.2014	05:13	19:20	14:07	09:53
17.08.2014	04:40	20:06	15:26	08:34	10.09.2014	05:15	19:18	14:03	09:57
18.08.2014	04:42	20:04	15:22	08:38	11.09.2014	05:16	19:16	14:00	10:00
19.08.2014	04:43	20:02	15:19	08:41	12.09.2014	05:17	19:14	13:57	10:03
20.08.2014	04:45	20:00	15:15	08:45	13.09.2014	05:19	19:12	13:53	10:07
21.08.2014	04:46	19:58	15:12	08:48	14.09.2014	05:20	19:10	13:50	10:10
22.08.2014	04:48	19:57	15:09	08:51	15.09.2014	05:22	19:08	13:46	10:14
23.08.2014	04:49	19:55	15:06	08:54	16.09.2014	05:23	19:06	13:43	10:17
24.08.2014	04:50	19:53	15:03	08:57	17.09.2014	05:24	19:03	13:39	10:21
25.08.2014	04:52	19:51	14:59	09:01	18.09.2014	05:26	19:01	13:35	10:25
26.08.2014	04:53	19:49	14:56	09:04	19.09.2014	05:27	18:59	13:32	10:28
27.08.2014	04:55	19:47	14:52	09:08	20.09.2014	05:28	18:57	13:29	10:31
28.08.2014	04:56	19:45	14:49	09:11	21.09.2014	05:30	18:55	13:25	10:35
29.08.2014	04:58	19:43	14:45	09:15	22.09.2014	05:31	18:53	13:22	10:38
30.08.2014	04:59	19:41	14:42	09:18	23.09.2014	05:32	18:51	13:19	10:41
31.08.2014	05:01	19:39	14:38	09:22	24.09.2014	05:34	18:49	13:15	10:45
01.09.2014	05:02	19:37	14:35	09:25	25.09.2014	05:35	18:47	13:12	10:48
02.09.2014	05:03	19:35	14:32	09:28	26.09.2014	05:36	18:45	13:09	10:51
03.09.2014	05:05	19:33	14:28	09:32	27.09.2014	05:38	18:43	13:05	10:55
04.09.2014	05:06	19:31	14:25	09:35	28.09.2014	05:39	18:41	13:02	10:58
05.09.2014	05:08	19:28	14:20	09:40	29.09.2014	05:40	18:39	12:59	11:01
					30.09.2014	05:42	18:37	12:55	11:05