Analysis of red kite flight behaviour under different weather and land-use conditions with special consideration of existing wind turbines in the Vogelsberg SPA

Final report

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Contracting authority: Hessian Ministry of Economics, Energy, Transport and Housing (HMWEVW)

Contracting authority:

Hessian Ministry of Economics, Energy, Transport and Housing (HMWEVW)
Kaiser-Friedrich-Ring 75
D-65185 Wiesbaden, Germany

Contractors:

NABU Landesverband Hessen (Conservation NGO)
Friedenstraße 26
D-35578 Wetzlar, Germany
Maik.Sommerhage@NABU-Hessen.de

Bioplan Marburg GbR (Consultancy)
Deutschhausstrasse 36
D-35037 Marburg, Germany
c.heuck@bioplan-marburg.de

Büro für faunistische Fachfragen (Consultancy)
Rehweide 13
D-35440 Linden, Germany
info@bff-linden.de

Researchers:

Capture and fitting of transmitters:	Christian Gelpke, Steffen Koschkar (BFF Linden)
Data collection:	Kristin Geisler, Maik Sommerhage (NABU Landesverband Hessen)
Data analysis:	Christian Heuck, Pablo Stelbrink, Christian Höfs (Bioplan Marburg GbR)

Quality assurance: Dr. Marc Reichenbach (ARSU GmbH), Martin Sprötge (planungsgruppe grün GmbH)

External expert: Ubbo Mammen (Ökotop GbR)

Project advisory council:

Iris Otto (HMWEVW – Hessian Ministry of Economics, Energy, Transport and Housing)

Charlotte Matthias (HMWEVW)

Dr. Natalie Scheck (HMWEVW)

Klaus-Ulrich Battefeld (HMUKLV – Hessian Ministry for the Environment, Climate Protection, Agriculture and Consumer Protection)

Claudia Sattler (HMUKLV)

Gudrun Huber (UNB Vogelsbergkreis – lower nature conservation authority of the Vogelsberg district)

Gerrit Oberheidt (ONB RP Gießen – upper nature conservation authority at the Gießen Regional Council)

Oliver Tschirschnitz (ONB RP Gießen)

Martin Hormann (Vogelschutzwarte Frankfurt – ornithological centre)

Gerd Morber (HessenEnergie – energy provider)

Michael Häußer (Luftstrom Projektgesellschaft mbH & Co KG – renewable energy company)

Renate Falk (Luftstrom Projektgesellschaft mbH & Co KG)

Dr. Wolfgang Dennhöfer (BUND Hessen e.V. – ENGO in Hesse)

Hartmut Mai (NABU Hessen e.V. – conservation NGO in Hesse)

Translation: Christopher Hay, Übersetzungsbüro für Umweltwissenschaften

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1 Summary

More than half of the global red kite population breeds in Germany. The regional state of Hesse hosts between 1000 and 1300 breeding pairs, representing approximately 5% of the European and 10% of the German population respectively. The presence of this above-average proportion of the total population means that Hesse carries great responsibility for this bird species in terms of species conservation and conservation policy. As a species that is vulnerable to collision mortality, the red kite regularly finds itself at the conflict interface between wind power and species protection in Hesse and elsewhere.

The aim of the study was to improve the understanding of red kite flight behaviour in relation to a variety of influencing factors. In 2016, the Hessian Ministry of Economics, Energy, Transport and Housing commissioned a three-year telemetry study in order to gain an understanding of potential links between weather conditions, land use/land management and red kite flight behaviour (activity range, flight altitude). This contribution to the knowledge base is also designed to provide the opportunity to optimise mitigation measures. The project area chosen for this study is the Vogelsberg natural landscape unit. This choice was due to the fact that, within the state of Hesse, the red kite has its centre of distribution in this richly structured cultural landscape with its high proportion of grassland, and at the same time there are a large number of wind turbines (WTs) in the area. Following the full-coverage mapping of red kite nests and territories in the two focal areas of the study, i.e. Freiensteinau and Ulrichstein, six red kites were captured and fitted with transmitters. In the course of the study period (June 2016 - July 2018), the transmitters provided a total of 800,905 telemetry points from the red kites' breeding area. However, originally a total of 12 red kites were to be fitted with transmitters. As a result of low catch success and due to the loss of three transmitter birds during the project term to predation, traffic and poisoning respectively, the available data base is smaller than planned. In parallel to data acquisition by means of telemetry transmitters, data were collected on land-use types and land management events in the vicinity of the transmitter birds' nesting sites. In addition, weather data from several wind farms as well as data recorded at the meteorological station on the Hoherodskopf mountain peak by the German Meteorological Office (Deutscher Wetterdienst, DWD) were used in the analysis.

The project area was found to have a higher red kite population density than other parts of the state of Hesse. The species' breeding success, however, was lower than in other parts of the state during the study period and also lower than success rates found in earlier studies in the project area (see Chapter 4.1.2). During the course of the day, red kite flight activity generally increased up to midday and then declined again. While around midday during the breeding period more than 60% of all telemetry points were regularly recorded in flight, flight activity decreased significantly once the young kites had fledged. Eighty-one percent of the telemetry points recorded in flight had a flight altitude of less than 100 m above ground level, and 72% were recorded at less than 75 m above ground level.

Significant changes were recorded in flight altitudes in the course of the year. The recorded flight altitudes decreased from the courtship period to the rearing period and slightly increased again in the post-breeding period. The impact of weather variables on red kite flight behaviour was very minor overall. It is therefore not possible to deduct from weather variables any distinct behavioural patterns in terms of flight activity, flight altitude or daily activity range size. North-western, western and south-western slopes had a slight positive effect on flight activity which may be explained by orographic updraughts at these locations. Sunshine duration and unstable air stratification, two weather variables that are important preconditions for thermals, also had a slight positive impact on flight activity. While wind speeds had a slight negative impact on flight altitude, daily activity range size tended to be greater with higher temperatures and unstable air stratification. Only incidental findings for individual birds elucidate the effect of land use and land management on flight behaviour of red kites fitted with transmitters. Most of the land-use types were not utilised by the birds proportionally to their share in land cover. However, significant differences were found for almost all land-use types in the course of the breeding season as well as between individual red kites. Sites that had recently been subject to agricultural management tended to be visited more frequently than sites not currently managed. The analysis of flight behaviour in the vicinity of wind farms showed that the red kites did not fly around entire wind farms or individual wind turbines. There were no indications of obvious avoidance behaviour. Taking into account flight altitudes and rotor blade positions relative to the birds' direction of flight (e.g. parallel flight), no flights of transmitter birds were recorded in the immediate WT danger zone (traversing the rotor-swept zone).

Telemetry data analysis indicates that the technical possibilities of the transmitter type used (e.g. Geofences) combined with the locally recorded data on weather and land use offer significant potential for new insights to be gained on red kite flight behaviour. A large amount of data was collected by means of the transmitter birds (a total of 800,905 telemetry points) which, together with the continuous weather and land-use data records, allowed for robust statistical analyses with a view to answering the crucial question as to the links between weather, land use and the species' flight behaviour (flight altitude, activity range). The data situation for statistical analysis was too poor only with regard to flight behaviour in the immediate vicinity of wind farms. The present study can therefore only offer some initial observations in this regard. It would be desirable in future to also fit red kites with transmitters in landscape regions less structurally rich than the Vogelsberg SPA, with a view to allowing for general and transferable conclusions to be drawn for such regions as well.

2 Introduction

Maik Sommerhage (NABU Landesverband Hessen), Christian Heuck (Bioplan Marburg)

Red kite distribution is restricted to Europe where the species occurs in a narrow band from the Baltics and southern Sweden down to Portugal (Hagemeijer & Blair 1997, Aebischer 2009, Gedeon et al. 2014). The global population is estimated at 19,000 to 24,000 pairs. More than 50% of the global population breeds in Germany, with the regional state of Hesse hosting between 1000 and 1300 breeding pairs, representing an above-average proportion of approximately 5% of the European and 10% of the German population respectively (HGON 2000; Gelpke & Hormann 2012; Gedeon et al. 2014). Red kites are widespread in Hesse and population densities are high to very high in parts of the regional state (see Chapter 6.1.1). The latter includes the Vogelsberg, with recorded population densities of more than 20 breeding pairs per 100 km² recorded in some areas (Gelpke & Hormann 2012). The Vogelsberg SPA 5421-40 is the largest Special Protection Area under the EU Birds Directive in Hesse. Species-specific conservation objectives for red kites in this Natura 2000 site have been drawn up (PNL 2011).

Red kites breed predominantly in landscapes providing varied mosaics of forests and open countryside characterised by a high number of boundary structures such as forest edges or hedgerows as well as by a high proportion of grassland (e.g. Gelpke & Hormann 2012, Heuck et al. 2013, Gedeon et al. 2014). The birds generally seek food in flight over open country. In addition to springtime courtship flights, thermaling flight and high-altitude distance flights, foraging flights may also take place at the wind turbine rotor blade altitude (cf. Mammen et al. 2010 for older generation turbines). According to current knowledge, the species does not fly around either entire wind farms or individual turbines (Gelpke & Hormann 2012; Bellebaum et al. 2013). Indications of fatal collisions between red kites and wind turbines are quite frequent relative to the species' comparatively small population size. To date there have been 458 records of dead red kites discovered underneath wind turbines in Germany, with a total population of approximately 12,000 pairs (as of 9 January 2019; central index at the Brandenburg ornithological centre (*Staatliche Vogelschutzwarte Brandenburg*)). In absolute terms, buzzards are the most frequent victims of collisions. However, relative to the population sizes of the various birds of prey, red kites suffer the highest rates of collision mortality with wind turbines after the three eagle species, i.e. white-tailed eagle, lesser spotted eagle and osprey (Grünkorn et al. 2016; Sprötge et al. 2018; Langgemach & Dürr 2019).

In order to gain insights into red kite flight behaviour and to find out how to mitigate the risk of the birds colliding with wind turbines, the Hessian Ministry of Economics, Energy, Transport and Housing commissioned the following study: "Analysis of red kite flight behaviour under different weather and land-use conditions with special consideration of existing wind turbines in the Vogelsberg SPA". It was anticipated that as part of the three-year project (2016-2018) up to 12 red kites in the study's focal areas of Ulrichstein and Freiensteinau (see Chapter 3.1) were to be fitted with transmitters in order to collect data on red kite flight behaviour in the Vogelsberg region. These data help to address the project’s core questions as to potential links between weather conditions, land use, land management and red kite flight behaviour (activity range, flight altitude) and allow for the analysis of flight behaviour in the vicinity of wind farms. The knowledge on flight behaviour thus obtained are to contribute to the more targeted design of mitigation measures based on more precise predictions.

3 Materials and methods

3.1 Study area

Maik Sommerhage, Kristin Geisler (NABU Landesverband Hessen)

For initial orientation, the contracting authority communicated roughly delineated areas around Ulrichstein and Freiensteinau at the start of the project. As part of the full-coverage red kite surveys in 2016, the areas were further adjusted by means of prominent features in the terrain (forest margins, roads, settlements etc.) to ultimately form the two focal areas of the study in which a full mapping of nest trees and territories was carried out (Map 1.1).

Ulrichstein and Freiensteinau, the two focal areas of the study, are almost fully located within the Vogelsberg administrative district (Gießen administrative region) in the middle of Hesse, with only small areas extending into the Kassel and Darmstadt administrative regions. The study region is located at altitudes of between 340 m and 620 m a.s.l. and is characterised by a richly structured cultural landscape with a significant proportion of grassland, low forest cover, small settlements, and a relatively high number of wind turbines (WTs).

The study's focal area of Ulrichstein at the centre of the Vogelsberg mountain range comprises a total of 131 km², while the Freiensteinau focal area in the southern Vogelsberg mountain range covers a total of 84 km² (see Maps 2 and 3).

The Vogelsberg area is located in the temperate climate zone at the transition between Atlantic and continental climate influences. Climatically the mountain ranges are characterised by high precipitation, with annual precipitation between 900 mm and 1100 mm. Winds most frequently come from the south-west and annual mean temperatures are between 6°C and 7.5°C. With its high precipitation and low temperatures, the Vogelsberg climate is typical of a low mountain range (PNL 2011).

In geological terms the Vogelsberg in its entirety is the largest basalt formation in central Europe. It emerged in the Tertiary and is volcanic in origin.

Figure 1: Southern Vogelsberg at Grebenhain looking north-westward.

Figure 2: Unter-Seibertenrod. Looking towards the Ulrichstein-Platte wind farm.

3.2 Survey of nest trees and territories

Maik Sommerhage, Kristin Geisler (NABU Landesverband Hessen)

In preparation for the fitting of transmitters in the first year of the project (2016), nest trees were mapped at the start of the year in the study's two focal areas of Ulrichstein and Freiensteinau. The survey was conducted between 15 January and 24 February. A total of 86 nest sites were recorded. Previous known red kite nest sites were also checked (sites indicated from baseline data collected, sites noted in the IGK, and sites recorded as part of the "mice for kites" ("*Mäuse für den Milan*") NABU project which has been mapping nest sites since 2013). From mid-March to mid-April 2016 the recorded nest sites were observed from greater distances for signs of occupancy, in accordance with the standards set out by Südbeck et al. (2005). Using observation points with 360° views, the resident birds' flight movements were recorded up until mid-May. Initial inspections of the nest sites were only conducted from mid-May onward, i.e. just before the young birds fledged. These inspections were designed to gather information on young birds in the nest and on potential nest abandonment. These inspections were also important with regard to the planned fitting of transmitters as the optimum time for capturing adult red kites is immediately prior to their offspring's fledging. In this small time window there is great pressure on the adults to obtain food for the almost fledged juveniles and therefore they tend to react strongly to the eagle owl dummy, thus maximising the chances of successful capture.

Similarly, in preparation for the fitting of transmitters in 2017 a full-coverage mapping of nest trees was conducted in the study's two focal areas of Ulrichstein and Freiensteinau at the start of the year on 24, 28 and 29 January and on 8 February (for delineation of areas mapped refer to Maps 2 and 3). Nest sites occupied in the first year of the study (2016) were checked and a search was conducted for new nest sites. From 13 March 2017 onward the recorded nest sites were observed from greater distances for signs of occupancy, in accordance with the standards set out by Südbeck et al. (2005). From the same date, birds exhibiting territorial behaviour away from the known nest sites as well as individuals carrying nest material were also recorded, and potential new nest sites were cartographically recorded. The search for nest sites in the newly recorded territories was conducted along with additional territory mapping on 15, 23, 27 and 28 March. Subsequently, using observation points with 360° views, the resident birds' flight movements were recorded without visiting the areas around the nest sites. This conduct made it possible to largely avoid any project-related disturbance. As in the previous year, initial inspections of the nest sites were conducted from mid-May onward in order to gather information on young birds in the nest and on potential nest abandonment (on 7 dates: 15, 16, 17, 18, 29 May and 7 and 8 June). During the spring and summer 2017, a total of 124 nest sites were checked for occupancy.

No further investigations of settlement density and breeding success were conducted in 2018 as no additional fitting of transmitters was planned.

3.3 Satellite telemetry

Christian Heuck, Pablo Stelbrink, Christian Höfs (Bioplan Marburg), Maik Sommerhage (NABU Landesverband Hessen)

Fitting of transmitters

Originally a total of 12 adult red kites were to be fitted with transmitters. The fitting of birds with transmitters requires permission for conducting an animal experiment (Application No. G29/2016) which was granted in May 2016 by the animal welfare commission of the Gießen administrative region.

Five birds were fitted with transmitters in 2016. In that year a total of 19 red kite nest sites with successful hatches were recorded in the two focal areas of the study (Map 2.1). However, due to a high number of abandoned hatches, presumably due to weather conditions (see Chapter 4.1.2) at the optimum time for capture (immediately prior to the young birds' fledging) only a few occupied nests remained that were also suited for capturing. An initial attempt at capturing adults was undertaken on 9 June 2016. However, at that time the young birds may still have been too small to allow for the adults to be successfully captured. Subsequent attempts were therefore only undertaken after an additional 11 days had passed (20, 22 and 28 June 2016). Out of a total of 13 individual attempts at capturing adult birds, four were successful. According to the *Büro für faunistische Fachfragen* consultancy this represents a good rate of capture. No other attempts were undertaken as the other nest sites were not suited to capturing adults (they were not suited to installing the requisite net). On the morning of 20 June 2016, between Heisters und Steinfurt, the red kite female Ronja was captured, ringed and fitted with a transmitter. She was followed on 22 June 2016 by the pair Tristan and Isolde in the early afternoon near Salz and the male Noah Bobenhausen II just before sundown, and in the early afternoon of 28 June 2016 by the one year old male Neptun. Neptun was fitted with a transmitter when on 25 June near Bobenhausen II his plumage became soaked in a thunderstorm, briefly rendering him incapable of flight. He was taken into care for a short number of days. In consultation with the contracting authority, he was ringed and fitted with a transmitter as it was reasonable to assume that following the winter season he would return to the Vogelsberg area in 2017 as a breeding bird. As early as the night of 1 July 2016, the female Ronja was caught by an Eurasian eagle owl. The temperature measured by the transmitter, a composite of external temperature and body temperature, began to decline from 2:30 a.m. A few days later only a feather of an Eurasian eagle owl and some remains of the transmitter bird were recovered. Despite an intensive subsequent search the transmitter could not be found.

In 2017 only one additional red kite was fitted with a transmitter. As all attempts at capturing adults in 2017 within the two focal areas of the study were unsuccessful, a search for additional territories was conducted in adjacent areas (Herbstein, Schwalmtal and Schotten as well as near Alsfeld) on four dates (15, 16, 18 and 23 June) and the nest sites discovered were checked for juvenile birds. Subsequently, attempts at capturing adults were undertaken at five different sites near Dirlammen and in the Stockhausen area. One male red kite was successfully captured near Stockhausen and fitted with a transmitter on 23 June 2017. A total of 28 red kite nests with successful hatches were recorded in 2017. One of these nests was occupied by a transmitter bird fitted the previous year (Isolde). As the potential site for a net for capturing could not be viewed from afar, no attempt was made to capture her male partner. Moreover, it was important to avoid injuring the female (the transmitter can get caught in the net). For a variety of reasons an additional ten nest sites proved to be unsuitable for capturing adults (location within dense coniferous forest; game tenant denied capturing; grazing cattle prevented net installation). Of the remaining 17 nest sites for capturing adult birds, the conditions for using nets were optimal only at nine sites. Due to a lack of alternatives, almost all sites were subject to two attempts at capturing adults in 2017 (31 May and 12, 13, 16, 20, 23, 26 and 27 June). The experience of C. Gelpke and S. Koschkar over many years has shown that on average every third attempt at capture is successful where nest sites are optimal to this end. Therefore, the available number of nest sites was too small for achieving the planned goal of fitting seven additional transmitters. However, the capture and fitting with a transmitter of just one red kite resulting from attempts at 17 nest sites constitutes a below-average result. An overview of the project's transmitter birds is given in Table 3 under "Transmitters".

Figure 3: Red kite fitted with a OrniTrack-20B transmitter (Photo: M. Sommerhage).

Transmitter type

The GPS tracking device used was an "OrniTrack-20B" satellite telemetry transmitter with solar panel manufactured by the Lithuanian company Ornitela (Figure 4). The transmitter weighs approximately 20 g which is on average only about 2% of the bodyweight of even the smaller males (cf. Bauer et al. 2005). It is therefore in line with the recommendation to not exceed 3% of the bodyweight (Kenward 2001). Not only the date, time and coordinates (geographic latitude and longitude) for each telemetry point are transmitted but also additional data. These include the battery charge status, GPS-based speed and altitude as well as raw data from a barometric pressure sensor installed in the transmitter.

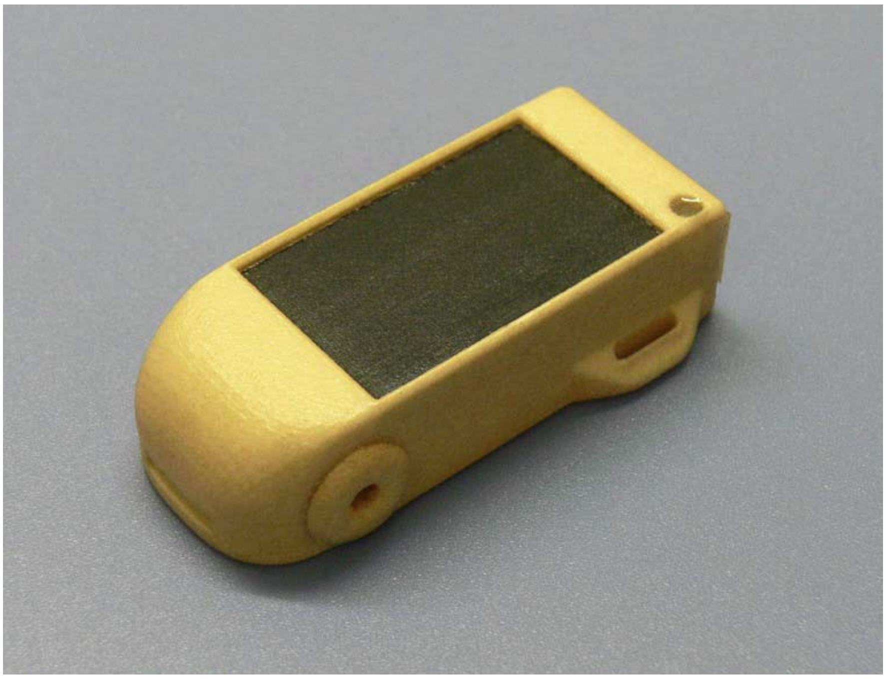

Figure 4: The "OrniTrack-20B" telemetry transmitter by Ornitela used for the study.

With the transmitter used it is possible to remotely control the transmitter's settings (positioning schedules etc.) from a computer via the mobile phone network (GPRS) and to download the data obtained in the same manner. Other transmitter types generally require radio-controlled read-outs in the field. A further advantage of the transmitter type used is the option to establish spatially delimited areas (geofences) for which separate GPS logging intervals can be set. Given limited battery capacity, the highest available data logging interval (continuous GPS logging at 1 second intervals = burst) cannot be used all the time. Geofences make it possible to supplement a lower baseline interval (e.g. one telemetry point every 15 minutes) with higher temporal resolution data for specific defined sites (Figure 5). However, geofence recording only commences when a telemetry point as part of the baseline interval is registered within the geofence. If a bird flies through the geofenced area without a telemetry point as part of the baseline interval being recorded, the bird's transit through the area is not recorded. Geofences therefore do not fully depict all flight events within a specific area. An overview of the geofences defined for the study is given in Map 1.1.

Ornitela transmitters had previously only been used for larger bird species such as black storks or lesser spotted eagles. These birds are significantly more heavy and therefore the commonly used transmitters were not an option for red kites. Only just before the project commenced, Ornitela had developed the "OrniTrack-20B" device which due to its lower weight can also be used for smaller birds of prey such as red kites.

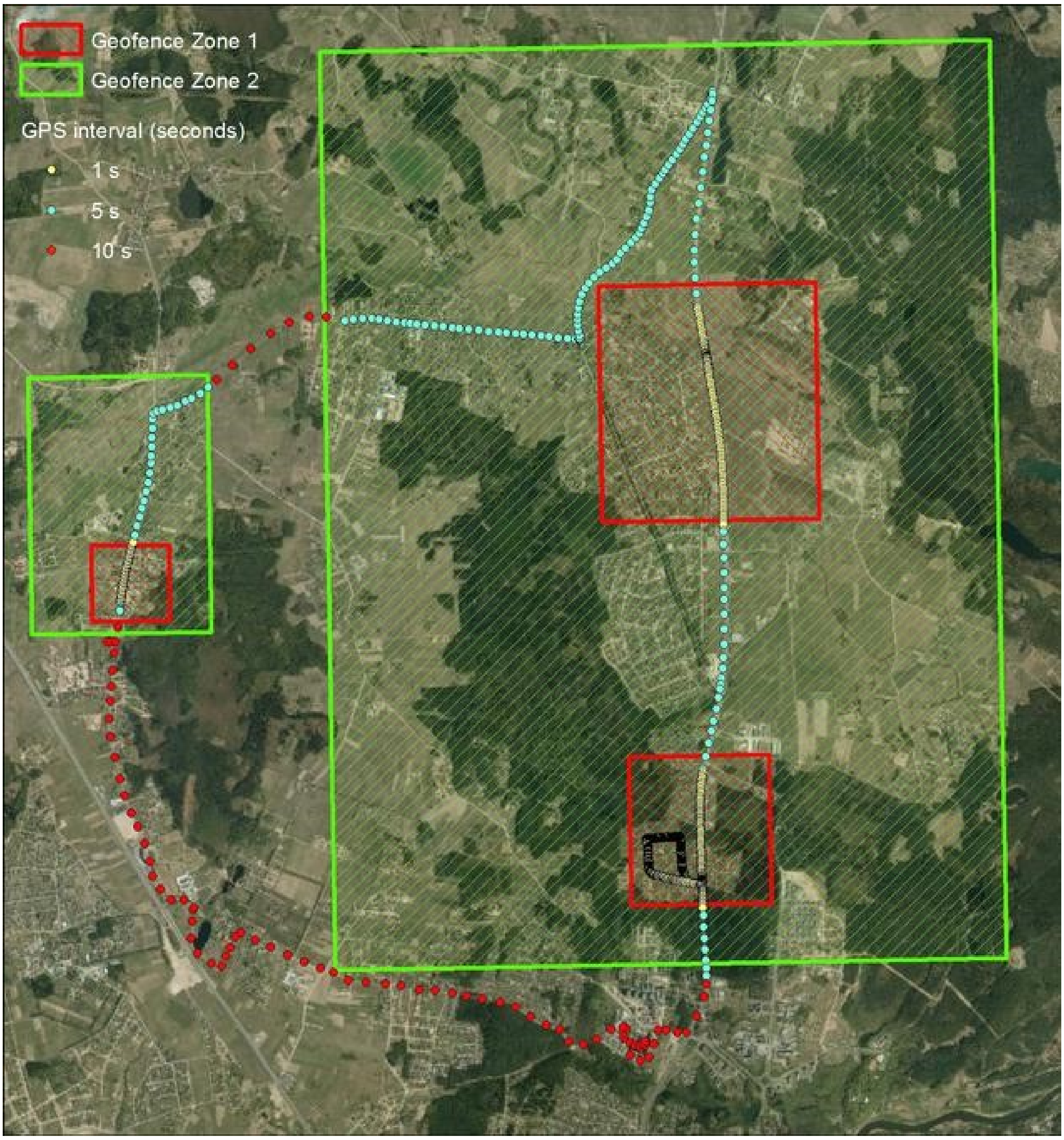

Figure 5: Example track illustrating the operation of multiple geofence zones (Source: Ornitela).

Transmitter settings

Since the transmitter type used had only been developed a short time before the project commenced, no practical experience with regard to red kites was available on the part of the manufacturer. Immediately after the first birds had been fitted with transmitters, a testing phase was conducted in close cooperation with the manufacturer with the aim of defining a baseline interval which keeps the battery charge status at a level sufficient for logging. A number of different GPS logging intervals were tested to achieve maximum information density. In some cases this resulted in problems with the charge status of the transmitters' batteries. It became apparent that there are major differences between the individual birds (or between the transmitters). Tristan and Noah, for example, reliably delivered data in fair weather in July 2016 at GPS logging intervals of five and four minutes respectively. However, similar to transmitter types from other manufacturers, these intervals could not be used on an ongoing basis. Ronja's transmitter was used to test regular bursts (GPS logging at one-second intervals); even in good weather they quickly discharged the batteries (Figure 6). The differences between Tristan and Isolde were notable, given that as a breeding pair they were exposed to the same weather conditions. The differences may be due to the fact that the males frequently search for food, resulting in a greater level of sun exposure, while the females frequently stay near their offspring in the vicinity of the nest site and therefore in the shade of the nest tree.

In order to obtain the greatest possible number of telemetry points from each of the transmitters while simultaneously keeping the need for supervision as low as possible, the GPS logging intervals were automatically regulated from 2017 onward. Since then the logging intervals have been increased and decreased in keeping with the individual transmitters' battery charge status (Table 1). The intervals set took into account the manufacturer's information that the batteries should not discharge to less than about 40% as discharging accelerates below this level. When the charge status reached 50%, GPS logging intervals was therefore already reduced to 120 minute intervals. At under 25% charge emergency intervals of 480 minutes kicked in; these allow for a transmitter to be reactivated in situations where, for example, the transmitter bird spent a long period of time within a geofenced area without the transmitter correctly turning off. The transmitters were programmed to turn off between sundown and sunrise in order to conserve battery capacity.

Table 1: Automatic adaptation of GPS logging intervals dependent on battery charge status from February 2017.

Transmitter charge [%]	Logging interval [min.]	Geofence trigger
75 – 100%	5	Yes
50 – 75%	20	Yes
25 – 50%	120	No
0 – 25%	480	No

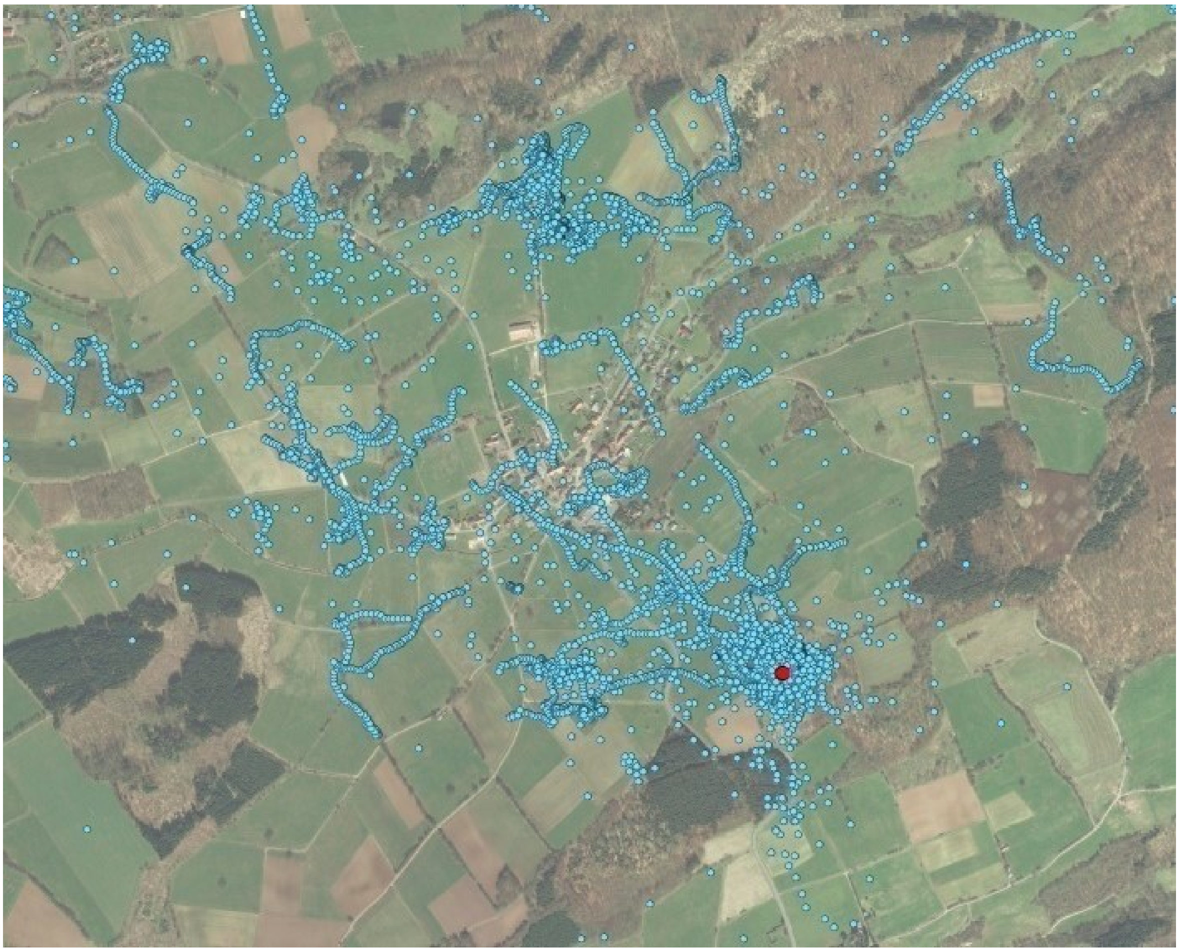

Figure 6: Ronja's nest site between Steinfurt and Heisters (red dot) and telemetry points (light blue). The burst test data sets can be seen as individual flight sequences (no colour differentiation for different flight altitudes; 20-30 June 2016). Baseline digital orthophotos (DOP40) used with permission from the Hessian Administration for Land Management and Geoinformation (HVBG), © HVBG 2016

Accuracy of location data

Transmitter tests were conducted in the spring of 2017 in order to assess the absolute accuracy of the geographic coordinates recorded by the transmitters. To this end, six transmitters were mounted directly adjacent to each other on the roof of a house in Marburg for a period of 14 days. The transmitters were set to 5-minute logging intervals and recorded a total of 11,615 telemetry points. The transmitters' exact location was calculated as the median of all the telemetry points' geographic coordinates.

Fifty percent of the GPS locations were located within 7.01 m of the transmitter location and 95% of the locations were within 26.24 m (Table 2). Some individual telemetry points deviated from the transmitter location by several hundred metres and must be regarded as outliers or faulty measurements. The accuracy of the GPS measurements as determined by this test is in keeping with expectations.

Table 2: Test run of six transmitters for 14 days, yielding 11,615 GPS locations. The figures indicate the radii containing 50% and 95% respectively of all GPS locations as well as the maximum deviation of a GPS location measured from each of the transmitter locations.

Test transmitter	Deviation 50% of locations [m]	Deviation 95% of locations [m]	Maximum deviation [m]
16059	7.32	26.79	675.19
16061	6.39	21.88	148.62
16063	6.63	22.52	623.97
16065	7.13	26.87	318.62
16067	7.20	25.05	286.66
16068	8.13	36.31	211.89
All transmitters	**7.01**	**26.24**	**675.19**

Table 3: Data points in the breeding region of red kites fitted with transmitters; data after correction for faulty localisation etc. The figures show the numbers of telemetry points recorded between the birds' arrival and departure from the project region or between 1 March and 30 September, whichever period was shorter, for the overall study period of 20 June 2016 to 31 July 2018.

Trans-mitters	Date of capture	Last localised	Data points 2016 (total / without geofence or burst)	Data points 2017 (total / without geofence or burst)	Data points 2018 (total / without geofence or burst)
Tristan (16016)	22.06.16	30.01.17	8,125 / 8,125	-	-
Isolde (16066)	22.06.16	-	3,974 / 3,974	27,414 / 12,745	2,908 / 513*
Noah (16064)	22.06.16	-	21,370 / 13,416	182,139 / 10,308	81,485 / 2,769**
Ronja (16069)	20.06.16	01.07.16	13,978 / 3,111	-	-
Neptun (16062)	28.06.16	20.10.17	6,520 / 4,244	71,748 / 4,489	-
Max (16065)	23.06.17	-	-	5,866 / 5,866	375,378 / 5,961
Totals			**53,967 / 32,870**	**287,167 / 33,408**	**459,771 / 9,243**

*Isolde's transmitter had not been working for extended periods since her over overwintering period in Spain. As a result a relatively small number of telemetry points was recorded.

**The figures in Annex 2 show that Noah's transmitter battery very rarely carried more than a 75% charge in 2018 which resulted in only brief periods with data recording at five-minute intervals. During a number of periods in 2016 and 2017, Noah's transmitter recorded almost constantly at five-minute intervals, thus yielding a significantly greater number of data points.

Transmitter data

During the study period (red kites fitted with transmitters until 31 July 2018, excluding the winter months of October to February) the six transmitter birds yielded a total of 800,905 telemetry points (excluding faulty records etc.; Table 3). A large proportion of these points are components of sequences (bursts) recording at one second intervals inside the geofences. An overview of the telemetry points recorded is given in Maps 3.1 – 3.3. Additionally, the telemetry points obtained from the individual transmitter birds are shown in individual figures contained in Annex 1.

The interrelationship between logging intervals and battery charge status can be seen in Annex 2. For Noah and Neptun, a longer presence inside a geofence in mid-September 2017 resulted in the almost complete discharge of the transmitters which shows that the automatic adaptive regulation applied from 2017 onwards did malfunction at times. In addition, the GPS altimeter of Noah's transmitter failed for roughly a month during the spring of 2017 which means that no altitude data are available for this period.

Transmitter logging intervals strongly fluctuated between individual transmitters and over time. Many analyses, however, require data recording that is as consistent as possible in space and time. In such instances a partial dataset ("5-minute dataset") was used which excluded all telemetry points that had been recorded less than five minutes after the previous point. This affected geofence data in particular.

3.4 Land-use types and management events

Maik Sommerhage, Kristin Geisler (NABU Landesverband Hessen), Christian Heuck, Pablo Stelbrink (Bioplan Marburg)

Land-use types

In each of the study years, the land-use types were recorded in a radius of approximately 1.5 km around the nests occupied by the transmitter birds (Maps 5.1, 5.2 and 5.4). The land-use types were categorised as follows:

- Settlements and buildings
- Grassland (intensive/extensive)
- Forest (deciduous, mixed, coniferous as well as sites under trees/hedgerows and meadows in equal proportions)
- Arable land (intensive/extensive), differentiated by crop type (root crops, oilseed rape, maize, summer and winter cereal crops)

Management events

In addition to the land-use mapping, management events were recorded weekly on plots totalling approximately 200 ha, involving the recording of both management events observed on the day of mapping and of the current status of the plots. This then allowed for inferences as to management events that had taken place since the previous field visit. Agricultural management was categorised as follows:

<u>Management events on survey days</u>:

Mowing, turning, removal of grass, harvesting, ploughing, sowing, fertiliser applications, pesticide applications, grazing, subsoiling, no management.

<u>Management events since the last field visit</u>:

- for grassland: mowed (grass lies as cut), turned (grass arranged in swathes), grass has been removed, fertiliser applied, grazed.
- for arable land: harvested, ploughed, subsoiled, crop sowed.
- no management (no change since previous field visit).

Given that red kites generally hunt for food only on sites the vegetation of which is less than 40 cm in height (Gelpke & Hormann 2012), vegetation height was also recorded from the 2017 study year onward and was categorised as follows: 0 – 20 cm, 20 – 40 cm, > 40 cm, uneven (primarily in grazed plots).

In the first year of the study (2016), the investigation of management events was governed by the preferred locations sought out by the individual red kites in question, i.e. only those plots were mapped which, according to the transmitter data, the birds had frequently visited in the week prior (example maps are shown in Map 5.3). The survey dates are given in Table 4. However, due to the small size of the mapped plots, this approach did not lend itself to properly depicting the frequenting of sites subject to management events (insufficient number of points on mapped plots) even where the logging intervals were as low as five minutes (Noah).

In order to improve the available evidence base, management events in 2017 were recorded in as much as possible (see below for Max and Isolde) in separate land-use geofences. To this end, two geofences were created for Noah (one in a feeding ground frequently visited in 2016 in the east of the territory [2017-1-LN], the other in the area of the "Ulrichsteiner Platte“ wind farm [2017-5]). When the bird frequented these geofenced areas, the transmitter recorded data at one-second intervals (Map 5.4). The geofence created for Neptune was based on a feeding area in the north-west of the territory which the bird regularly visited in the early spring of 2017 and which was located outside of the project area (it is therefore not depicted in Map 1.1). For Isolde a 200 ha area was delineated in the south of the territory. Given the experiences with the often very low charge status of Isolde’s transmitter in the first year of the study, this geofence was not enabled so as not to excessively drain the transmitter battery. For bird “Max” who had been fitted with a transmitter in June 2017 it proved difficult to delineate a geofenced area. Following the fitting of the transmitter, this red kite initially tended to stay close to the nest site and along the forest margin. At that time there were no indications as to a regularly utilised feeding area in the open country which would have lent itself to the creation of a geofence. In order to maximise the number of telemetry points above the mapped areas, mapping in this case was undertaken in open habitats in the vicinity of the nest site and without establishing a geofence (cf. Map 5.4).

For Isolde, who in 2017 occupied the same nest site near Salz as in the previous year, weekly surveys of management events were undertaken between 12 April and 4 August 2017, and for Noah, who occupied the same nest site near Bobenhausen II as in 2016, the surveys were undertaken between 11 April and 3 August 2017. It was late April before Neptun decided on a nest site near Grünberg in the Gießen administrative district and the weekly surveys of management events therefore did not commence until 5 May and were continued until 27 June 2017. Neptune and his partner abandoned their nest as early as mid-May. In early July Neptun undertook longer journeys, including flights down to Bavaria; the weekly surveys were therefore no longer of any benefit. Surveys for Max as a new transmitter bird were conducted between 5 July and 3 August (Table 4).

Table 4: Overview of survey dates for agricultural management events.

Transmitter bird	Survey dates in 2016	Survey dates in 2017	Survey dates in 2018
Tristan	06.07., 13.07., 20.07., 27.07., 03.08.	/ (died in February in Spain)	/
Isolde	06.07., 13.07., 20.07., 27.07., 03.08.	12.04., 21.04., 25.04., 02.05., 10.05., 18.05., 24.05., 03.06., 09.06., 16.06., 23.06., 29.06., 06.07., 13.07., 22.07., 29.07., 04.08.	/ (no mapping due to transmitter malfunctioning)
Noah	06.07., 13.07., 20.07., 27.07., 03.08.	11.04., 20.04., 25.04., 03.05., 09.05., 19.05., 24.05., 09.06., 14.06., 22.06., 27.06., 05.07., 11.07., 20.07., 28.07., 03.08.	20.03., 03.04., 09.04., 16.04., 24.04., 03.05., 07.05., 17.05., 22.05., 29.05., 04.06., 14.06., 21.06., 25.06., 03.07., 10.07., 17.07., 23.07.,31.07., 02.08.
Ronja	06.07. (fell prey to eagle owl a mere 10 days after having been fitted with transmitter; no further records as a result)	/	/
Neptun	06.07. (in the vicinity of the roost; bird subsequently left the project area)	05.05., 10.05., 17.05., 24.05., 29.05., 07.06., 14.06., 22.06., 27.06.	/ (traffic victim, Spain, autumn 2017)
Max	/	05.07., 12.07., 19.07., 26.07., 03.08.	21.03., 04.04., 08.04., 13.04., 23.04., 28.04., 02.05., 08.05., 16.05., 24.05., 29.05., 05.06., 13.06., 19.06., 26.06., 04.07., 13.07., 24.07., 30.07., 01.08.

Silvicultural activities in the immediate vicinity of nest sites

The vicinity of the transmitter birds' nests sites (200 m radius) were checked on a monthly basis for silvicultural activities which may constitute a disturbance for the birds (Table 5). However, no silvicultural exploitation/forestry-based disturbances were recorded.

Table 5: Overview of field visits aimed at recording disturbances in the vicinity of nests resulting from silvicultural activities.

Transmitter bird	Survey dates in 2016	Survey dates in 2017	Survey dates in 2018
Tristan	06.07.	/ (died in February in Spain)	/
Isolde	06.07.	21.04., 08.05., 16.06., 22.07.	/ (no mapping due to transmitter malfunctioning)
Noah	06.07.	20.04., 19.05., 22.06, 20.07.	20.03., 03.04., 03.05., 04.06., 03.07., 10.07., 02.08.
Ronja	(fell prey to eagle owl a mere 10 days after having been fitted with transmitter; no further records as a result)	/	/
Neptun	(not breeding in the area)	10.05., 14.06.	/ (traffic victim, Spain, autumn 2017)
Max		05.07., 26.07.	21.03., 04.04., 02.05., 05.06., 04.07., 01.08.

3.5 Additional geodata

Christian Heuck, Pablo Stelbrink, Christian Höfs (Bioplan Marburg)

The Hessian Administration for Land Management and Geoinformation (HVBG) made available a range of geodata. A digital terrain model (DGM20) and a digital landscape model (Basis-DLM) are available for the project area. As the digital landscape model (DLM) is not sufficiently up-to-date, only the land-use types surveyed in the course of the project are used for analyses. Detailed crop data from the IACS-GIS (EU system for the identification of plots under agricultural land use) are incomplete, i.e. they are available only for individual plots and could therefore not be taken into account either. Since landform is important for the formation of updrafts, slope steepness (in degrees) and aspect (compass direction that a slope faces) were calculated for each of the grid cells based on the available DGM20. For the purposes of statistical modelling, slope and aspect were categorised as follows: No slope (less than 5° angle) or slope (5° angle or more) and indication of aspect in the form of N, NE, E, SE, S, SW, W or NW.

The contracting authority provided data on existing wind turbines (WTs) in the two focal areas of the study, i.e. Freiensteinau and Ulrichstein. These data were checked for completeness and WTs newly erected during the project term were added (Map 1.1). Outside of the areas delineated in consultation with the HMWEVW, WT locations are depicted only in areas regularly visited by the transmitter birds.

The NABU’s HALM sites (Hessian programme for agri-environmental and landscape management measures, German acronym: HALM) discussed in the project advisory council meetings are largely located in the immediate vicinity of the Obermoos pond. To take them into consideration is meaningful only as part of the “normal” mapping of land-use types and management events, and only where a transmitter bird occupies a nest nearby. The red kite feeding sites established by NABU are located away from the transmitter birds’ home ranges and are therefore shown only for information purposes (cf. Map 1.1). Since the majority of occupied red kite nest sites in the study’s focal areas had protective collars fitted around the nest trees’ trunks, it was not possible to undertake a comparative analysis of breed success data in this regard. Data on plantings designed to prevent collisions are only available for a single wind turbine. Moreover, the transmitter birds do not regularly frequent the wind farm in question. In the context of the present study, this wind farm and the associated planting will therefore not be examined in any detail. The quantitative estimate of most populations in the study years is not taken into account as the absence of a methodological basis does not allow for robust data analysis.

3.6 Meteorological data

Christian Heuck, Pablo Stelbrink, Christian Höfs (Bioplan Marburg)

Meteorological data for the purposes of this study were derived from four different sources (Table 6) the locations of which in the project area are shown in Map 1.2. A total of 18 wind turbines in three wind farms provide median values derived from measurements recorded at 10 minute intervals; these allow for the calculation of wind farm-specific median values for wind speed and external temperature at nacelle height. Data on rotor revolution speeds and nacelle position were taken into account for each individual WT. In addition, the seven turbines as part of the Freiensteinau wind farm are fitted with visibility meters. Data on precipitation, sunshine duration and atmospheric pressure above sea level and at station altitude are available in the form of median values derived from measurements recorded at 10 minute intervals at the German Meteorological Office’s (Deutscher Wetterdienst, DWD) meteorological station on the Hoherodskopf mountain peak. In addition, the DWD uses a number of different weather parameters recorded at this meteorological station to calculate hourly values for air stratification (dispersion classes after Klug/Manier), a crucial parameter for the vertical dispersion of air masses (e.g. thermals). The more unstable the air stratification, the better the conditions for the formation of thermals (cf. Table 7). In project council meetings the albedo values[1] of different land-use types were also discussed as an additional factor which may influence the formation of thermals and thus the red kites’ flight altitudes. However, given that the albedo values of grassland, cropland, deciduous and coniferous forest hardly differ and overlap in part they cannot be taken into consideration (Oke 1987; Helbig et al. 1999).

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[1] Albedo is a measure of the reflectivity of reflective surfaces.

Table 6: Overview of data sources for the various meteorological parameters

Data source	Ulrichstein-Platte wind farm	Helpershain-Meiches wind farm	Freiensteinau wind farm	Hoherodskopf meteorological station
No. of datasets (WTs)	7	4	12	
Wind speed [m/sec]	x	x	x*	
Rotor rotational speed [1/min]	x	x	x*	
Nacelle position [°]	x	x	x*	
Outside temperature [°C]	x	x	x*	
Visibility [km]			x*	
Precipitation [mm]				x**
Sunshine duration [min/h]				x**
Air stratification (dispersion classes)				x**

*Data gap 18.09.17 - 21.09.17; **Data gap 23.07.17 - 31.07.17 (complete instrument failure); other DWD meteorological stations are located at significant distances to the Vogelsberg which is why this data gap could not be closed using data from other stations.

Table 7: Dispersion classes after Klug/Manier as a measure of air stratification.

KM	Meaning
1	Dispersion class I (highly stable)
2	Dispersion class II (stable)
3	Dispersion class III1 (neutral (– stable))
4	Dispersion class III2 (neutral (– unstable))
5	Dispersion class IV (unstable)
6	Dispersion class V (highly unstable)
7	Dispersion class could not be determined
9	Invalid

Determination of error values

While the DWD data are subject to intensive quality assurance, the raw data from the wind farms had to be checked for measurement errors and instrument failure. Datasets from individual WTs that state a value of "0" for all measured meteorological parameters are considered indicative of data storage errors or complete instrument failure. Such datasets were removed from the database given that there is a very low probability of four true "0" values occurring during the study period. The review of the wind farm data also revealed obvious error values or instrument failure for individual parameters or instruments (e.g. no wind at a single WT while temperature values matched those of the other WTs). Statistical methods for outlier detection were also tested (comparison between individual data point and scatter of all data points recorded at the same time) but proved to be insufficiently accurate. However, data analysis by individual wind farm showed that the error values observed only had a very minor impact on the wind farm's median values. With regard to the requisite accuracy, no further data correction was therefore deemed necessary. For the June-September 2016 data, the scatter (standard deviation) between the outside temperature values for the seven wind turbines as part of the Ulrichstein-Platte wind farm was greater than 1°C for only 2.7% of measurements. For wind speed measurements, which can be subject to small-scale variation due to vegetation and topography, for example, differences of more than 1 m/s were found for 7.3% of measurements at individual WTs (cf. Figure 7). These data are much more homogeneous for the Luftstrom/Freiensteinau and Helpershain-Meiches wind farms. Given that the variance of measured values within and between the three wind farms was found to be very low, contrary to original planning no further exclusion of anomalous values was undertaken.

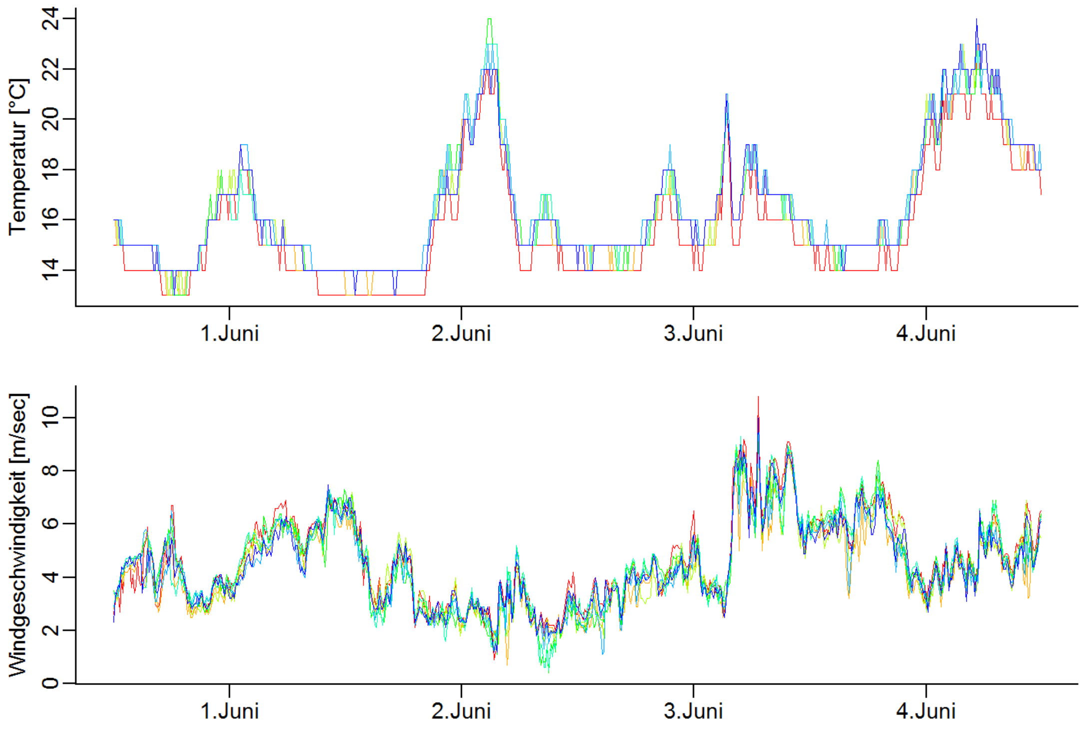

Figure 7: Temperature and wind speed measurements for seven wind turbines in the Ulrichstein-Platte wind farm. Measurements for individual WTs are shown in different colours (example for a four day period in June 2016).

Temperatur …	Temperature [°C]
Wind…	Wind speed [m/s]
1. Juni, 2. Juni etc.	1 June, 2 June …

Utilisation of meteorological data

In order to ensure that no false data are used as a result of the often significant distances between red kite telemetry points and meteorological stations, the data for precipitation, sunshine duration, outside temperature and wind speed were aggregated into 60-minute values. Data on air stratification were already available in the form of hourly values. Subsequently, each telemetry point is assigned the means recorded at the nearest data source, up to a maximum distance of 30 km, for wind speed, outside temperature, precipitation, sunshine duration and air stratification (cf. Map 1.3). This spatial limit ensures that more distant flights, such as Neptun’s excursion to Nuremberg, are not taken into account in the analysis of meteorological data. The data on rotor rotational speed and nacelle position are only used for analysis within the wind farms. As fog is a highly local event, these data can only be used with respect to the immediate vicinity of the Freiensteinau wind farm. Given that only a small number of telemetry points are available for this location, the parameter “visibility” cannot be used. The aspect of visibility constraints was recorded as part of the weekly land-use surveys. However, no visibility constraints were noted due to fog or heavy precipitation, for example.

Time standards

The various datasets were made available in different time formats (Coordinated Universal Time UTC, Central European Time, Central European Summer Time CEST). For the purposes of combining the data, they were converted to a standard format. Given that most of the study period fell into the summertime, CEST was used as the reference time standard. All the timestamps given in the text and figures are therefore given in the CEST format.

3.7 Classification of flight activity

In order to analyse flight behaviour (flight activity, flight altitude, home range) in relation to weather conditions it is necessary to distinguish as precisely as possible between telemetry points recorded in flight and those not recorded in flight. Following a review of the red kite data for speed and flight altitude and a comparison with published data, all telemetry points showing a measured GPS speed of more than 10 km/h were categorised as in-flight telemetry points (cf. Nathan et al. 2012, Duerr et al. 2012, Phipps et al. 2013).

3.8 Correction and calibration of altitude data

Christian Heuck, Pablo Stelbrink, Christian Höfs (Bioplan Marburg)

Accuracy of GPS altitude and barometer raw data

The accuracy of GPS altitude readings is generally dependent on the number of satellites from which the GPS unit receives signals. Dependent on the terrain's landforms and the transmitter bird’s location, the accuracy of the readings will be subject to regular fluctuations (e.g. in valleys or in the vicinity of forest margins; cf. Katzner et al. 2012, Miosga et al. 2015, Reid et al. 2015). In order to assess the accuracy of the altitude data recorded by the transmitters, tests were conducted with six transmitters in the spring of 2017 (see Chapter 3.3). The median of all GPS altitude readings taken by all transmitters was used as the defined reference altitude for the transmitters in the test run.

On average the various transmitters’ GPS altitudes deviated from the reference altitude by only a few metres. Fifty percent of the recorded telemetry points vertically deviated from the reference altitude by a maximum of 7 m, and 95% of the telemetry points vertically deviated by a maximum of 33 m (depicted in black in Figure 8; Table 8). As in the horizontal positioning, the GPS data contained some outliers, in this case deviating by up to 883 m from the reference altitude. Dependent on satellite reception and the location of a transmitter bird it is reasonable to assume that the readings for transmitter birds perching in the forest, for example, fluctuate even more strongly than the readings taken in stationary tests. In order to improve the accuracy of the altitude readings for red kite telemetry in the Vogelsberg SPA, transmitters were chosen that allow for both GPS altitude readings as well as altimeter readings. However, as expected the raw data provided by the transmitters’ barometers fluctuated very strongly (depicted in red in Figure 8). High accuracy is only achieved if the barometric altitude data are corrected for a number of different parameters. The corrective steps included first a correction for fluctuations in atmospheric pressure and subsequent transmitter-specific calibration[2].

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[2] In the first interim report, geoid undulation was erroneously taken into account in the processing of altitude data. An updated manual issued by the transmitters‘ manufacturer showed that this correction is already implemented in the transmitters used. This step is therefore moot.

Correction for fluctuations in atmospheric pressure

The Ornitela telemetry transmitters used for this study use the barometric formula to calculate the altitude in metres based on the standard atmospheric pressure at sea level p_0 = 1013.25 hPa and the atmospheric pressure measured by the transmitter's altimeter. However, given that atmospheric pressure fluctuates depending on weather conditions, the altitude readings are subject to inaccuracies. These inaccuracies can be corrected by means of local data for atmospheric pressure that are measured at a constant altitude (in this case: data provided by the Hoherodskopf meteorological station).

The barometric formula describes how atmospheric pressure changes with altitude, up to a maximum altitude of 11 km based on the International Standard Atmosphere (temperature of 15 °C = 288.15 K, atmospheric pressure p_0 = 1013.25 hPa, temperature lapse rate of 0.65 K per 100 m).

$$p_h = p_0 \left(1 - \frac{0{,}0065 \frac{\mathrm{K}}{\mathrm{m}} \cdot h}{288{,}15\mathrm{K}} \right)^{5{,}255877}$$

Formula 1

$$= p_0 \cdot \left(1 - \frac{h}{44330{,}77\mathrm{m}} \right)^{5{,}255877}$$

If this formula is solved for height h, a measured atmospheric pressure p_h can be converted to the corresponding height in metres (m).

$$h = \frac{288{,}15\mathrm{K}}{0{,}0065 \frac{\mathrm{K}}{\mathrm{m}}} \cdot \left(1 - \left(\frac{p_h}{p_0} \right)^{\frac{1}{5{,}255877}} \right)$$

Formula 2

$$= 44330{,}77\mathrm{m} \cdot \left(1 - \left(\frac{p_h}{p_0} \right)^{0.1902632} \right)$$

In order to correct for atmospheric pressure fluctuations in calculating altitudes, Formula 1 was used as a first step in order to calculate the atmospheric pressure p_h measured by the transmitter's altimeter. In a second step, Formula 2 is used to calculate the corrected altitude. To this end, the atmospheric pressure values measured by the data loggers are employed in the formula for p_h and the atmospheric pressure values measured at the Hoherodskopf meteorological station at the time in question and standardised to sea-level pressure are employed for p_0. An example of the result of this correction is shown in Figure 9 (red to blue).

Transmitter-specific calibration

In order to allow for the correction of the atmospheric pressure data from the transmitter test, a digital barometer (LOG 32 THP manufactured by Dostmann electronic GmbH) was used to locally measure atmospheric pressure at five-minute intervals during the test period. While the values, as corrected for atmospheric pressure fluctuations, from all six tested transmitters had low variance, on average they deviated significantly from the reference altitude, thus indicating a systematic error (blue in Figure 8, Table 8). These deviations are due to different calibrations of the transmitters' altimeters. In the course of data processing the transmitters must therefore be calibrated in accordance with the deviations detected (results are depicted in green in Figure 8).

However, it was not possible to establish this transmitter-specific systematic error by means of the stationary test for the five transmitters already fitted to red kites in 2016. Given that the GPS altitude data were on average found to be highly accurate and hardly differed between transmitters (see Figure 8), it is reasonable to assume that the median deviation between GPS altitude and corrected barometer altitude represents a good estimate of the transmitter-specific deviation for the transmitters already fitted to the birds. Therefore, separately for the individual red kite-fitted transmitters, the deviation between the two altitude measurements was determined for each telemetry point. Subsequently, the transmitter-specific median deviation was substracted from all barometer altitude values, thus calibrating for transmitter-specific deviations. The resultant values are given in Table 9. Red kite Max's transmitter 16065 demonstrates the actual comparability of the deviations determined by means of stationary tests as well as the approach described above based on telemetry data. As Max was only fitted with a transmitter in the summer of 2017, test data as well as field data are available for this transmitter. This transmitter's deviations are -22.92 m as determined by means of the stationary test (Table 8) and -22.03 m based on the field data (Table 9). This high level of agreement shows that transmitter-specific calibration with sufficient accuracy is feasible for all the transmitters used.

Accuracy of the corrected and calibrated barometer altitude

The barometrically determined altitude values, after correction for atmospheric pressure and after calibration, show considerable less scatter than the GPS altitude values and there are no outliers at all (depicted in black and green respectively in Figure 8; Table 8). Fifty percent of the test transmitter telemetry points deviated from the reference altitude by a maximum of 1.30 m, and 95% of the telemetry points deviated by a maximum of 3.88 m (Table 8). The combination of the two correction and calibration methods achieves a high level of accuracy for altitude data. GPS-based altitude measurement alone does not achieve this level of accuracy. Therefore, all further analyses draw on the corrected barometer altitude data instead of the GPS altitude data.

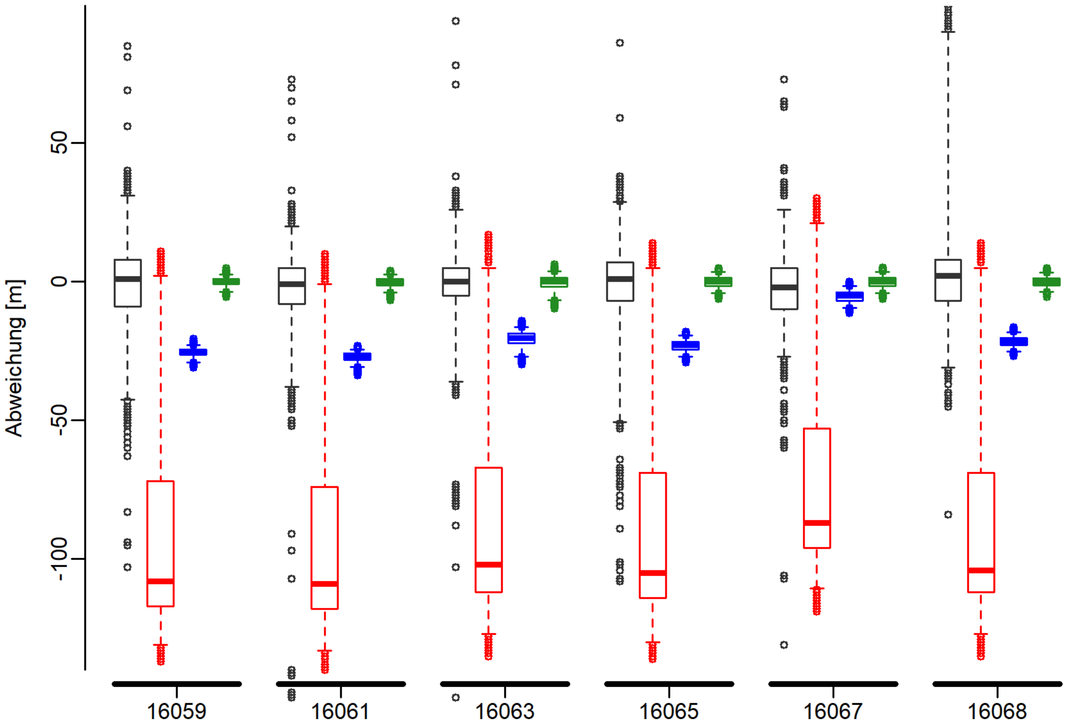

Figure 8: Deviation between altitude measurement and reference altitude for six tested transmitters. For each of the transmitters, the diagram shows GPS-based altitude (black), uncorrected barometrically determined altitude (red), barometric altitude after correction for atmospheric pressure fluctuations (blue), and barometric altitude after correction for atmospheric pressure fluctuations and after transmitter-specific calibration (green). Some outlier GPS data are not shown. The solid horizontal line marks the median; the box contains the middle 50% of values; the dashed line encloses the middle 95% of values. [Abweichung = Deviation]

Table 8: Test run of six transmitters for 14 days, yielding 11,615 GPS locations. The figures indicate the deviations between the defined reference altitude and the measured GPS-based and barometrically determined altitudes respectively. The 50% and 95% data are given as absolute values regardless of the direction of deviation.

Test trans-mitter	GPS-based altitude			Barometrically determined altitude			
	Median	50% of locations	95% of locations	Before calibr.	After calibration		
				Median	Median	50% of locations	95% of locations
16059	1	8	37	-25.39	0	0.99	3.09
16061	-1	6	23	-26.93	0	1.13	3.30
16063	0	5	31	-20.24	0	1.59	5.41
16065	1	7	34	-22.92	0	1.42	3.84
16067	-2	8	27	-5.17	0	1.50	3.93
16068	2	8	63	-21.39	0	1.26	3.53
All trans-mitters	**0**	**7**	**33**	**-22.64**	**0**	**1.30**	**3.88**

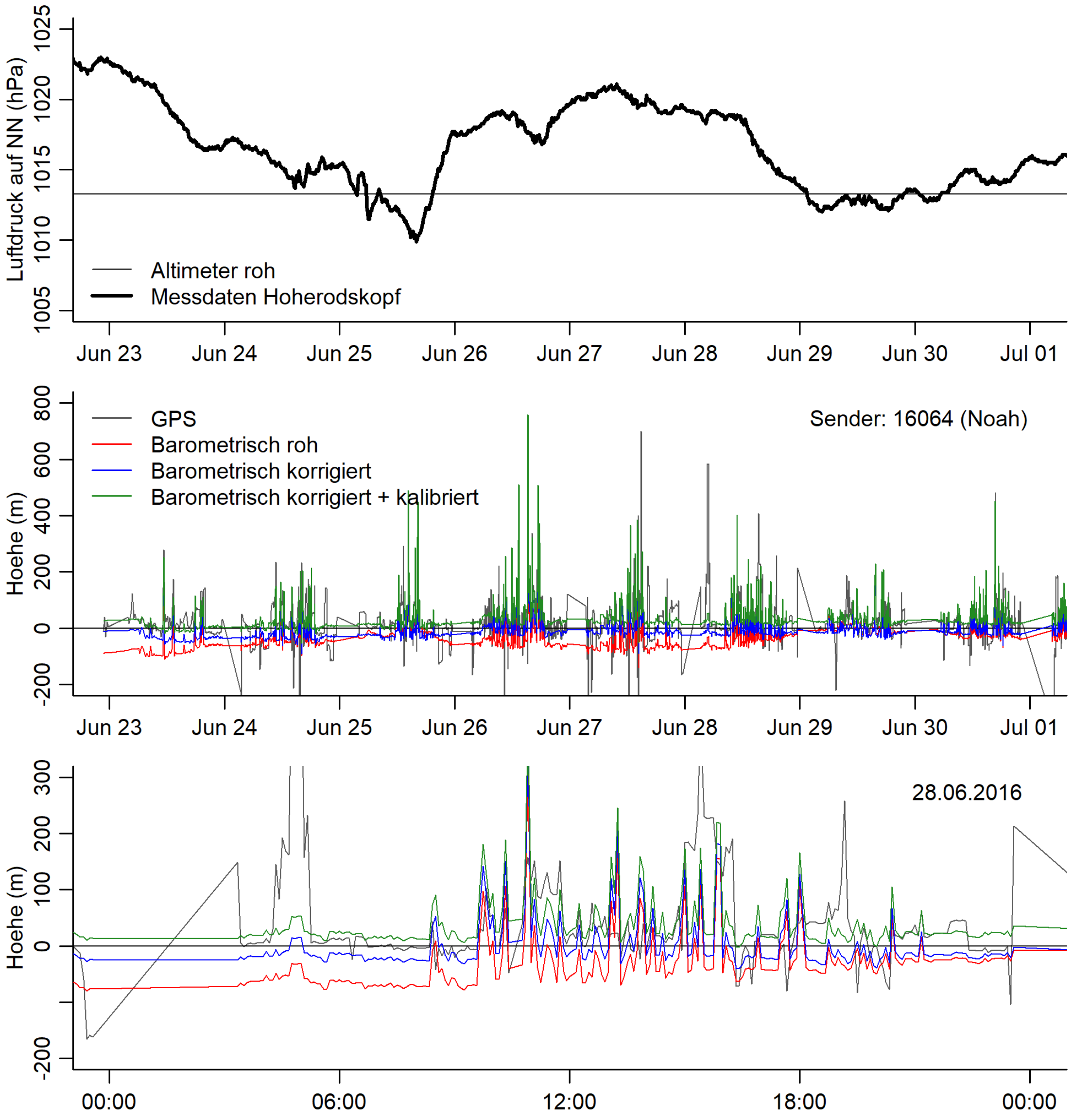

Figure 9: Example of correction of altitude data for transmitter bird Noah. Top: Atmospheric pressure fluctuations as measured at Hoherodskopf which are to be used to correct the transmitter data (time period in late June 2016). Middle: Comparison of uncorrected altitude data (Altimeter raw), altitude data corrected for atmospheric pressure at Hoherodskopf and GPS-based altitude data. Bottom: Detailed view of data for 28 June 2016.

DE	EN
Luftdruck auf …	Atmospheric pressure a.s.l (hPa)
Altimeter roh	Altimeter raw
Messdaten Hoh…	Measurements Hoherodskopf
Hoehe (m)	Altitude (m)
GPS	GPS
Barometrisch roh	Barometric raw
Barometrisch korrigiert	Barometric corrected
Barometrisch korrigiert + kal…	Barometric corrected + calibrated
Sender: 16…	Transmitter: 16064 (Noah)

Table 9: Medians of deviations between the birds' transmitters' barometrically determined altitudes and GPS-based altitudes.

Transmitter	Median deviation [m]
Tristan (16016)	- 7.43
Isolde (16066)	- 58.93
Noah (16064)	- 37.10
Ronja (16069)	- 31.57
Neptun (16062)	- 27.03
Max (16065)	- 22.03

3.9 Data analysis

Christian Heuck, Pablo Stelbrink, Christian Höfs (Bioplan Marburg)

3.9.1 Home ranges of the red kites fitted with transmitters

Home range analysis: MCP (Minimum Convex Polygon) and AKDE (Autocorrelated Kernel Density Estimation)

The home range is the area which a specific animal utilises on a periodic basis (cf. Burt 1943). A widely employed method for calculating home rage sizes is the Minimum Convex Polygon (MCP) method (Mohr 1947). It constructs the smallest possible polygon around the existing telemetry points. For the present study we calculated the 95%, 75% and 50% MCP. The percentage denotes the proportion of telemetry points enclosed in the polygon for the analysis in question. For example, a 95% MCP excludes from the polygon the 5% most distant locations. Another and a significantly more precise method for measuring home ranges is the kernel method (Kernel Density Estimation; Worton 1989). This method uses a density function to predict, based on the telemetry points, how likely the animal is to be found in a particular area. However, since the traditional Kernel Density Estimate (KDE) disregards spatial and temporal autocorrelation to which animal movement data are generally subject, the Autocorrelated Kernel Density Estimation (AKDE) method was used here to calculate home ranges (Fleming et al. 2015; Fleming und Calabrese 2017). Again we calculated the 95%, 75% and 50% kernels, using the "ctmm" R package (Calabrese et al. 2016), R software (R Core Team 2016) and the 5-minute dataset. Red kite Ronja only provided 10 days worth of data which is not sufficient for the calculation of a home range. Neptun did not breed as a one year old bird in the first year of the study, and in the second year he abandoned the nest; comparable and representative home ranges could therefore not be calculated for this bird either.

Spatial behaviour in relation to distance from nest

Given that during the breeding period the nest site is the focus of activity, an analysis was undertaken of the relative distribution of telemetry points by distance from the nest. To this end, percentage shares of telemetry points were calculated in relation to their distance from the nest site for the breeding individuals Noah, Isolde and Tristan. These calculations were performed for all telemetry points recorded over the entire breeding period as well as for the individual stages as part of the breeding phenology.

3.9.2 Flight activity and flight altitude in relation to weather conditions and landform

Three statistical models were used to analyse as to whether and in what manner the red kites’ flight behaviour was dependent on weather conditions and/or landform. Given that the individual environmental variables are not independent of each other, no individual models were to be applied to examine their impact on flight behaviour. Multiple models were chosen instead; these assess the impact exerted by all environmental variables taken together. In accordance with the dependent variable (flight behaviour) structure, linear (continuous variable structure, altitude in metres) or generalised linear models assuming binomial distribution (categorical variable structure with two levels) were calculated (cf. Korner-Nievergelt et al. 2015). In order to account for differences in the individual birds’ flight behaviour, the bird ID was included as a random effect[3] in all models which were therefore calculated as mixed models. The study year was also included as a random effect in all models so as to allow for an assessment of the differences between years. The 5-minute dataset was used in all models for reasons of temporal comparability. According to the criteria set out in Chapter 3.7, 25,336 out of the 74,767 telemetry points were recorded in flight. In order to ensure that the analysis of flight activity only takes into account weather conditions during times at which flight activity was likely, telemetry points recorded during night time (22:00 - 5:00 Uhr CEST) were excluded. In addition, only those telemetry points were included in the statistical models to which data for all meteorological variables could be assigned (a maximum of 30 km between telemetry point and source of meteorological data, cf. Map 1.3, N=65,805, of which 23,236 were recorded in flight).

Flight activity (flight/no flight)

A generalised linear mixed model (GLMM) with flight activity as the dependent variable was used in order to test whether flight activity was influenced by weather variables. the five weather variables precipitation, windspeed, sunshine duration, temperature and air stratification as well as categorised landform were chosen as the independent (explanatory) variables. The category “no slope” was chosen as the reference category[4] for landform. In order to allow for comparisons between the calculated effect sizes, all

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[3] In contrast to explanatory variables, i.e. the fixed effects, a random effect categorises the data points (in this case by bird ID). However, the strength or direction of a random effect is not known and is not estimated as part of the model.

[4] For factorial influencing variables, a factor category must normally be chosen as reference in statistical models. The impact of the other categories is then calculated in relation to the reference category, with no statistical values being available for the reference category.

continuous variables were z-standardised (transformation of the data to a distribution with mean μ=0 and standard deviation σ=1).

Flight altitude

In addition to the influence of the weather on flight activity (flight/no flight) its influence on the red kites' flight altitude was also analysed. To this end, a linear mixed model (LMM) was calculated (cf. Korner-Nievergelt et al. 2015). The corrected barometric flight altitude, i.e. continuous figures (z-standardised), was used as the dependent variable. As in the first model, the five weather variables and the categorised landform were used as explanatory variables. All telemetry points recorded in flight (N=22,758) served as baseline data.

Given that for some baseline data generalised models with categorical variables are more sensitive to potential relationships, a third procedural step was taken in which the red kites' flight altitude was analysed by means of categorised flight altitudes instead of continuous altitude data. To this end, flight altitude was categorised as high-flying red kites (≥ 80m, at and above WT rotor height) and low-flying red kites (< 80m, below the bottom edge of WT rotor blades) and used as the dependent variable in a GLMM. Again, the five z-standardised weather variables as well as landform were used as the explanatory variables, and all telemetry points recorded in flight for which barometric flight altitude information was available (N=22,758) served as baseline data.

Modelling

Modelling was undertaken using the *lme4* package for R (Bates et al. 2015). In all models, the effect size with standard error was calculated for each of the environmental variables (weather variables and landform), and the *multcomp* package (Hothorn et al. 2008) was used to calculate correlation significance. Correlations with a P value of <0.001 were considered significant. Using the *MuMIn* package (Barton 2016), the R-squared value as the coefficient of determination was calculated for each of the models. R-squared is the percentage of the response variable variation that is explained by the model, i.e. the explained variation out of the total variation in the dependent variable data (flight activity, flight altitude) ($R^2 = 1$ is equivalent to 100%). Additionally, the marginal R-squared value was calculated for each of the models; it denotes the percentage of the variation that is explained only by the environmental variables and not by differences between birds or years. Moreover, the *hier.part* package (Walsh & Nally 2013) was used to calculate the R-squared values for each individual weather variable as well as for the landform categories. These two parameters are of relevance because statistical models with large sample sizes, as is the case for the models computed here, very often reveal statistically significant correlations ($p < 0.001$). However, these correlations are not necessarily of great ecological relevance. The ecological significance of influencing factors can only be estimated when P-value, R-squared value and effect size are considered together.

In interpreting the models’ statistics, collinearity[5] between the explanatory variables must be taken into consideration. The weather variables are not independent of each other and and observed effect can not always clearly be distinguished from the impacts exerted by the other variables. According to Dormann et al. (2013), misinterpretations of the estimated parameters generally only arise with a correlation coefficient |R| > 0.7 between two variables. Based on the dataset of the binomial model on flight activity, the maximum correlation coefficient found between two variables (temperature ~sunshine duration) was 0.45. Most of the linear regression correlation coefficients were significantly smaller (Table 10). It is therefore safe to assume that the weather parameters’ collinearity is sufficiently low as to not result in misinterpretations of the models’ statistics.

Table 10 Correlation coefficients |R| of linear regressions between the environmental variables, based on the dataset of the binomial model for flight activity (N = 65,805).

Environmental variable	Precipitation	Wind speed	Temperature	Sunshine duration	Air stratification	Landform
Precipitation		0.14	0.10	0.16	0.07	0.03
Wind speed			0.32	0.26	0.32	0.11
Temperature				0.45	0.42	0.06
Sunshine duration					0.40	0.06
Air stratification						0.05
Landform						

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[5] Collinearity or multicollinearity describes dependencies between explanatory variables in statistical models. A high degree of collinearity, for example, may considerably increase the estimated standard error. However, almost all statistical models of ecological data are subject to a certain degree of collinearity. In a statistical analysis collinearity should ideally be equal to zero.

As a further test of the impact of the environmental variables' collinearity on the estimated model parameters, Variance Inflation Factors (VIF, Fox & Monette 1992) were calculated for each of the models. A VIF<10 indicates that the impact of collinearity does not warrant concern (cf. Dormann et al. 2013). All variables in the three models run had a VIF<2 (Table 11).

Table 11: Variance Inflation Factors (VIF) of the environmental variables and their categories in the three statistical models run.

Environmental variable	GLMM Flight activity	LMM Flight altitude	GLMM Flight altitude
Precipitation	1.05	1.03	1.03
Windspeed	1.28	1.40	1.37
Temperature	1.52	1.69	1.67
Sunshine duration	1.43	1.52	1.48
Air stratification	1.44	1.65	1.63
Slope N	1.25	1.21	1.20
Slope NE	1.11	1.09	1.09
Slope E	1.09	1.07	1.06
Slope SE	1.12	1.11	1.09
Slope S	1.26	1.26	1.24
Slope SW	1.17	1.22	1.20
Slope W	1.12	1.14	1.13
Slope NW	1.14	1.13	1.12

Supply-demand graphs

In order to visualise the connections between flight behaviour and weather, so-called supply-demand graphs were drawn up. The sum total of telemetry points as part of the 5-minute dataset which were recorded under certain weather conditions constitute the "supply", while the number of telemetry points recorded in flight during the same weather conditions constitute the "demand". In addition, the percentage shares of in-flight telemetry points in the sum total of all telemetry points were calculated, thus illustrating the disproportionately higher or lower flight activity during certain weather conditions. An analogous second graph juxtaposes the number of telemetry points recorded at >80m flight altitude and the sum total of telemetry points recorded in flight (categorised by weather conditions, as above). Given that the sum total of telemetry points does not constitute a meaningful "supply" with regard to the "landform" environmental variable, this variable was not taken into account in the supply-demand graphs.

3.9.3 Home range size in relation to weather parameters

In order to analyse the relationships between weather conditions and home range size, the utilised home range was calculated for every red kite and every day. Since in this instance extreme home range size values are also relevant, the daily home ranges were calculated in the form of 100% MCPs, based on the 5-minute dataset (see Chapter 3.9.1). The weather parameters used were the means for all the weather variables assigned to the red kite telemetry points on the days in question.

To answer the question as to whether the daily home range size is influenced by weather conditions, a linear mixed model (LMM) was calculated (cf. Korner-Nievergelt et al. 2015), with daily home range size as the dependent variable (z-standardised) and the five z-standardised weather variables as the explanatory variables. The daily home range sizes for red kites Tristan, Isolde, Noah and Max to which all weather variables could be assigned (only days that yielded a minimum of five telemetry points, N=906) were used as input data for the model. In order to take account of differences between individual birds and between study years, bird ID and the year were included into the model as random effects. The model was run analogous to the analyses of flight activity and flight altitude (see Chapter 3.9.2). Given the smaller sample size, a significance level of $p<0.05$ was used.

3.9.4 Effect of land use and land management on flight behaviour

Land-use types

The spatial intersection of telemetry data and recorded land-use types makes it possible to quantify the frequentation of the areas in question. In order to avoid a distortion of the results due to nest attachment or regular roosting in the vicinity of the nest, land-use data in a 200 m radius around the nest site as well as telemetry points recorded between 22:00 und 5:00 hrs were excluded. The 5-minute dataset was used as input data.

In addition, Jacobs' preference index[6] (Jacobs 1974) was used as a tangible measure identifying the red kites' preference or avoidance of certain land-use types. The mean of the index values for each individual red kite and year was determined for each land-use type. Given that the structure of land-use types changes in the course of a study season (March to September) and since it is likely therefore that the red kites' preference for being present above certain land-use types changes in the course of the year, the Jacobs' preference index was also calculated by month. In this assessment, the values for the individual red kites and years were averaged for each month. A mean was considered

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[6] Jacobs‘ preference index is a measure of the proportionality or otherwise of the utilisation of a resource type relative to the total available resources. The index values range from -1 (strong avoidance) to +1 (strong preference) of/for the resource type. A value of 0 indicates that resource use is proportionate to its availability.

significantly non-proportional if the 90% confidence limits of the mean did not contain 0, meaning that the birds' presence above a land-use type was clearly disproportionate in that to a certain extent they were either favouring or avoiding the land-use type in question (after Kauhala & Auttila 2010).

Management events

In order to analyse whether and how the management events impacted on the red kites' spatial behaviour, the telemetry points recorded in flight were spatially and temporally intersected with the recorded management events. In all the study years, only a very small number of telemetry points were recorded above the surveyed sites on the actual survey days, thus not offering baseline data that could be analysed. In 2017, for example, (and excluding grazed sites) management events taking place on the survey day were only recorded for seven out of 51 site checks, and only six telemetry points could be assigned to these sites. This sample size is so small as to be meaningless for analysis. From 2017 onward, additional data were collected by recording management events since the previous survey; these wider baseline data made it possible to assign not only telemetry points recorded on a certain day but also data points encompassing a number of days (appr. one week). However, the temporal uncertainty with regard to the management event increases for these data, possibly rendering potential effects less pronounced in the analysis.

The ratio of telemetry points above managed and not currently managed sites respectively as well as the size of the sites in question was calculated, differentiated by study year, bird, and survey round. The ratios between these values indicate whether the red kites disproportionately frequented either managed or not currently managed sites. Moreover, as for each of the red kites the same sites were surveyed throughout 2017 and 2018 it was possible to calculate means for the sum total of survey rounds. At a temporal resolution of approximately one week, it is not possible to break down grassland management into mowing, turning and removal as these three steps are generally undertaken in swift sequence within such a time window. In this context, the categories of mowing, turning and removal are therefore combined under the heading of grassland management.

Step-selection analysis

In order to analyse the influence of land-use types and management events on the red kites' movement behaviour, a step-selection function (SSF) analysis (Thurfjell et al. 2014) was conducted based on the data from the geofences in which management events had been recorded. In this analysis method of movement ecology, observed steps (i.e. the step from one telemetry point to the next) are compared to computer-generated random steps. Land-use type, management event and vegetation height at the step's target point are assigned to each of the real and randomly generated steps in order to test the influence of these environmental attributes on the movement choices between consecutive telemetry points.

Given the sample's limitation to a small number of birds and individual geofenced areas, the analysis did not however yield representative and meaningful results. The results are therefore not shown in this report.

3.9.5 Flight behaviour in the wind farms' vicinity

Weather conditions during flight events in wind farm geofences

In order to illustrate a potential relationship between flight events in wind farms and prevailing weather conditions, the number of telemetry points recorded during particular weather conditions was determined and contrasted with the number of telemetry points that would be expected under the actually prevailing weather conditions if flight events in the wind farm were evenly distributed. In addition to the weather, the WTs' rotor rotational speed was also taken into account. The baseline data used included all telemetry points recorded in flight inside the geofences established around wind farms, as well as the weather conditions during daytime hours (5:00-22:00 hrs) during the study period.

Flight events in the vicinity of the WT rotor blades

The flight events in the vicinity of the WT rotors are described together with the relevant data on rotor alignment and rotational speed. Vicinity in this context was defined as a cylinder around each WT with a diameter of twice the rotor radius plus a 10 m buffer to account for the mean measurement error of GPS positioning under conditions of good satellite reception. The cylinders' height was defined as the individual turbine's nacelle height plus/minus the rotor radius plus a 10 m buffer, as above. In the case of the seven ENERCON E-82 E2 WTs as part of the Ulrichstein-Platte wind farm (nacelle height 138 m, rotor diameter 82 m), the vicinity is thus defined as a cylinder with a 51 m radius at an altitude of between 87m and 189 m above ground.

Ring buffer analysis

In order to investigate the impact of WTs on the flight behaviour of red kites, the frequentation of different ring buffers around WTs was compared. Within all wind farm geofences for which telemetry points are available, buffers were drawn around the WTs at 50 m intervals. A comparison of the ring buffers (telemetry points per area) may provide indications of distancing behaviour with respect to WTs (e.g. a significantly smaller number of telemetry points per area in the 0 to 50 m ring compared to the outer rings). Figure 10 demonstrates this approach, using the example of the Alte Höhe wind farm to the south of Noah's nest site and its 250-300 m ring buffer.

In a second step, the same analysis was conducted using altitude-differentiated red kite data. Altitudes were differentiated as follows: below rotor height, at rotor height, above rotor height. In order to account for differences in turbine height, each telemetry point was referenced to the nearest WT and this WT's nacelle height and rotor diameter was used to define the altitude categories for the telemetry point in question. The baseline data used included all telemetry points recorded in flight during daytime hours (5:00-22:00 hrs) inside the geofences established around wind farms.

Step-selection analysis in wind farm geofences

With a view to determining the impact of WTs, a further step selection analysis was conducted for geofences containing WTs and management data. However, as relevant data were only available for one bird and two years, the analyses did not yield meaningful results, as above. The results are therefore not shown in this report.

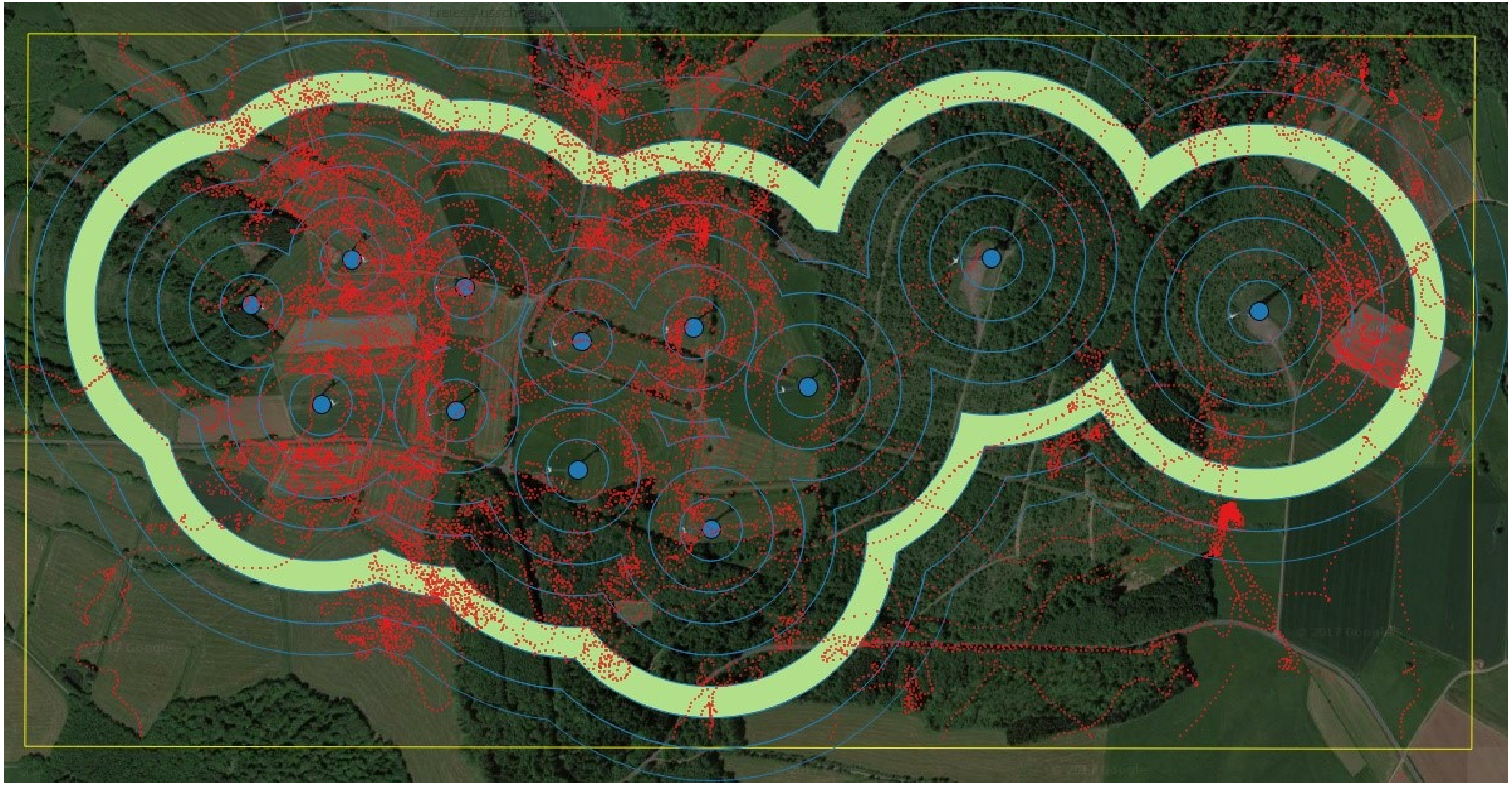

Figure 10: Example depiction of ring buffer analysis. Yellow = geofence; red = telemetry points; blue = WT locations and consecutive 50 m buffers; light green = 250-300 ring buffer. Baseline digital orthophotos (DOP40) used with permission from the Hessian Administration for Land Management and Geoinformation (HVBG), © HVBG 2016.

3.9.6 Overview of the various baseline data

The baseline data used for the various analyses are summarised in Table 12. Overall the available baseline data allow for robust analyses of flight activity and flight altitude (diurnally and annually as well as in relation to weather parameters). Similarly, the data are suited to determining the home range sizes of the various transmitter birds as well as the effect of land use and land management on their flight behaviour. However, given the relatively small number of red kites fitted with transmitters no general conclusions can be drawn from these analyses.

Table 12: Available baseline data for the various analyses conducted. The study period includes the following date ranges: 22.06.2016 - 30.09.2016, 01.03.2017 - 30.09.2017, 01.03.2018 - 31.07.2018.

Chapter / sub-Chapter	Birds	No. of tele-metry points	Geofence data/flight data/data characteristics[1]
4.2.1 Home ranges of the transmitter birds and spatial behaviour in relation to distance to nest site	2016: Tristan, Isolde, Noah 2017: Isolde, Noah, Neptun, Max 2018: Noah, Max	57,606	5-minute dataset
4.2.2 Diurnal and annual red kite flight activity	2016: Tristan, Isolde, Noah, Ronja, Neptun 2017: Isolde, Noah, Neptun, Max 2018: Isolde, Noah, Max	74,767	5-minute dataset[1]
4.2.3 Flight activity and flight altitude in relation to weather and landform ***(Flight activity)***	2016: Tristan, Isolde, Noah, Ronja, Neptun 2017: Isolde, Noah, Neptun, Max 2018: Isolde, Noah, Max	65,805	5-minute dataset[1] Only points to which all environmental data could be assigned.
4.2.3 Flight activity and flight altitude in relation to weather and landform ***(Flight altitude)***	2016: Tristan, Isolde, Noah, Ronja, Neptun 2017: Isolde, Noah, Neptun, Max 2018: Isolde, Noah, Max	22,758	5-minute dataset[1] Only in-flight telemetry points; Only points to which all environmental data could be assigned.
4.2.4 Home range size in relation to weather parameters	2016: Tristan, Isolde, Noah 2017: Isolde, Noah, Max 2018: Noah, Max	61,145	5-minute dataset[1] Only telemetry points for days with minimum of 5 recorded points per bird and day.
4.2.5 Effect of land use and land management on flight behaviour ***(Land-use types)***	2016: Noah, Tristan, Isolde 2017: Isolde, Noah, Max, Neptun 2018: Noah, Max	37,617	5-minute dataset[1] Only telemetry points within 1.5 km radius around nest site to which a land-use type could be assigned[2].

Chapter / sub-Chapter	Birds	No. of tele-metry points	Geofence data/flight data/data characteristics[1]
4.2.5 Effect of land use and land management on flight behaviour ***(Management events)***	2016: Noah, Tristan, Isolde 2017: Isolde, Noah, Neptun, Max 2018: Noah, Max	129,889	2017 + 2018: Only data for times and from within geofences in which land management was recorded; only in-flight telemetry points.
4.2.6 Flight behaviour in the vicinity of wind farms ***(Weather conditions during flight events)***	2016: Tristan, Isolde, Noah, Neptun 2017: Isolde, Noah, Neptun 2018: Isolde, Noah, Max	35,681	All wind farm geofences data[1]; Only in-flight telemetry points.
4.2.6 Flight behaviour in the vicinity of wind farms ***(Ring buffer analysis)***	2016: Tristan, Isolde, Noah, Neptun 2017: Isolde, Noah, Neptun 2018: Isolde, Noah	27,144	All telemetry points within 400 m radius around WTs within wind farm geofences[1]; Only in-flight telemetry points.

[1] Only telemetry points recorded between 5:00 and 22:00 hrs were used.

[2] Data within a radius of 200 m around the nest site were not taken into account.

4 Results

4.1 Survey of nest trees and territories, breeding success

Maik Sommerhage, Kristin Geisler (NABU Landesverband Hessen)

4.1.1 Settlement density

In 2016, the study's 131 km² focal area of Ulrichstein (as delineated by dashed lines in Maps 2.1 and 2.2) hosted 25 red kite pairs (plus one territory pair), a settlement density equivalent to approximately 20 pairs per 100 km² (Table 13). In 2017, the area hosted 18 pairs (plus 6 territory pairs), equivalent to approximately 18 pairs per 100 km² (Table 13).

The study's 84 km² focal area of Freiensteinau hosted 23 red kite pairs in 2016, a settlement density equivalent to approximately 27 breeding pairs per 100 km². In 2017, 22 pairs were breeding in this area (plus 6 territory pairs), equivalent to approximately 29 reading pairs per 100 km².

Table 13: Breeding population and breeding success in the study's focal areas (as delineated by dashed lines in Maps 2.1 and 2.2). BP = breeding pairs, TP = territory pairs

	Ulrichstein		**Freiensteinau**	
	2016	**2017**	**2016**	**2017**
Breeding population	25 BP + 1 TP	18 BP + 6 TP	23 BP	22 BP + 6 TP
Confirmed successful hatches	8	8	11	12
Total number of fledged juveniles	11	10	18	18
No. of juveniles/breeding pair	0.44	0.56	0.78	0.82
No. of juveniles/successful hatch	1.38	1.25	1.64	1.5
Breeding pairs/100km^2	19.85	18.32	27.38	28.6

4.1.2 Breeding success

Study year 2016

In 2016 a significant number of breeding attempts were unsuccessful (Map 2.1). In May 2016, in particular, a number of hatches were abandoned due to persistent rain showers including storms and thunderstorms. It is reasonable to assume that eggs got chilled or that very small hatchlings died in the drenched nests. The survey of nests and territories suggests that only those pairs were successful that had already started incubation at the start of April or did not start until late April. However, in the Vogelsberg area (large proportions of which are located above 400-500 m above sea level) the majority of the red kite population started incubation in mid-April of 2016.

Eleven pairs out of the 23 pairs in the Freiensteinau area bred successfully in 2016, and eight out of the 26 breeding pairs in the Ulrichstein area (including one suspected breeding attempt/territory pair). Therefore roughly 50% of all pairs were successful in Freiensteinau, but only approximately 30% in Ulrichstein (Table 13).

On foot of storms in the second half of May, six nests were found to have suffered storm damage: four nests had slipped and the other two had fallen to the ground. Predators also accounted for unsuccessful hatches (3 x Eurasian eagle owl, 2 x raccoon, 1 x northern goshawk), as indicated by tracks discovered in the vicinity of the nests.

Study year 2017

In 2017, the majority of the red kite pairs started incubation earlier, i.e. in the final days of March or early days of April. The second half of March was characterised by several days that were uncharacteristically warm and sunny for the season. April was cool and wintry conditions including snow showers briefly returned to the Vogelsberg region. With an incubation period of approximately 33 days and a nestling phase of just over 50 days, the first juveniles fledged as early as around June 20.

In the Freiensteinau area, 12 out of 22 breeding pairs (plus an additional six territory pairs) bred successfully and a total of 18 fledged juveniles were recorded. In the Ulrichstein area, eight out of 18 breeding pairs (plus an additional six territory pairs) bred successfully and a total of 10 fledged juveniles were recorded (see Annex 3 and Map 2.2). Therefore, as in the previous year approximately 50% of all breeding pairs in Freiensteinau were successful in 2017 while there was a slight increase in breeding success in Ulrichstein (eight successful hatches by 18 breeding pairs, 44%; Table 13).

Following storms and heavy thunderstorms four nests were found to have suffered storm damage, especially during the second half of May and in the first half of June. Two nests had slipped and hatches were abandoned in a further two nests. As in 2016, predators also accounted for unsuccessful hatches (1 x Eurasian eagle owl – confirmed by feathers found on site; 3 x unknown predator – potentially eagle owl; 1 x raccoon – confirmed by wildlife camera). Moreover, northern goshawks were found to have taken a total of six almost fledged juveniles from three nest sites.

The population suffered further losses in April and June when two red kites were killed in collisions with wind turbines in the study’s focal area of Ulrichstein. The nearby pairs’ nests were abandoned immediately afterwards and this may be due to the collisions as both of the victims had been adult red kites (1 x Alte Höhe wind farm on 30 April 2017; 1 x Goldener Steinrück wind farm on 17 June 2017). Both discoveries were notified to the central index at the Brandenburg ornithological centre.

In the study’s focal area of Freiensteinau, 32 nests were recorded in 2016 and 2017 combined. Thirteen nests where occupied in both these years (40.63%), with red kites successfully breeding at six sites in 2016 and 2017 (18.75%). At 19 of the sites the nest was only occupied in one of the two years (59.37%).

In the study's focal area of Ulrichstein, 41 nests were recorded in 2016 and 2017 combined. Ten nests were occupied in both these years (24.39%), with red kites successfully breeding at four sites in 2016 and 2017 (9.76%). At 31 of the sites the nest was only occupied in one of the two years (75.61%).

Six new nest sites recorded in the Freiensteinau area in 2017 saw four successful hatches yielding an average of 1.5 juveniles. Taking all six nests into account, the average nest site yielded one juvenile bird per breeding pair. In the Ulrichstein area, 11 newly occupied nest sites were recorded in 2017, yielding an average of 1.25 juveniles per successful breeding pair. Taking all 11 nests into account, the average nest site yielded 0.45 juveniles per breeding pair. Breeding success in 2017 at the newly occupied nest sites therefore did not significantly divert from the overall values. This partial dataset again indicated a higher level of breeding success in the Freiensteinau area compared to the Ulrichstein area.

4.2 Analysis of telemetry data

Pablo Stelbrink, Christian Höfs, Christian Heuck (Bioplan Marburg)

4.2.1 Home ranges of the red kites fitted with transmitters

Home range analysis: MCP (Minimum Convex Polygon) and AKDE (Autocorrelated Kernel Density Estimation)

Home range size is of particular relevance during periods of strong nest attachment (courtship, incubation, rearing of young). The following table summarises the results of the home range analysis, showing the individual, gender-specific and age-specific differences discovered (Table 14). The female Isolde significantly reduced her home range during the incubation phase. During the period of rearing the young (nestling period) her home range expanded again to roughly the same size as during the courtship period. Once the nestlings had fledged (post-breeding period) her home range further expanded sharply in size to multiples of the previous period. In contrast, the differences in home range sizes during the various phases of the breeding season were much less pronounced for the males Noah and Max, a finding that clearly reflects the female's stronger attachment to the nest and thus the gender-specific differences in parental care. Moreover, a comparison of the male transmitter birds' home ranges shows that there are also significant size differences between territories.

The home range size of the male Neptun, who was two years old in 2017 and therefore sexually mature, differed from that of the other red kites throughout all the phases of the breeding period. Neptun first attempted reproduction in 2017. However, breeding began very late at the end of April and the attempt was abandoned early, prior to 12 May 2017. Neptun therefore only had a brief attachment to the nest site and territory. Following the nest abandonment he left the territory, spent some time in the Siegen area of North Rhine-Westphalia and in southern Germany and then returned to the breeding area. The full results of the MCP and AKDE home range size calculations including all values for 50%, 75% and 95% confidence regions are given in Annex 4. Home range maps are given in Annex 5.

Table 14: Results of the home range analysis for individual red kites by phases of the breeding phenology in 2017 and 2018 (using the example of the AKDE 95% method; geofence data scaled down to 5-minute intervals). Courtship period 15 March – 14 April; incubation period 15 April – 19 May; rearing period 20 May – 30 June; post-breeding period 1 July – 30 September.

Breeding phenology			**AKDE 95% [ha]**			
			Isolde	**Tristan**	**Noah**	**Max**
Courtship period	2017	(N = 1,815)	315	-	1,481	-
Courtship period	2018	(N = 1,311)	-	-	786	566
Incubation period	2017	(N = 2,897)	10	-	1,009	-
Incubation period	2018	(N = 2,080)	-	-	610	569
Rearing period	2017	(N = 12,875)	275	-	987	-
Rearing period	2018	(N = 3,417)	-	-	628	607
Post-breeding period	2016	(N = 21,819)	433	524	828	-
Post-breeding period	2017	(N = 16,189)	1,691	-	883	718
Post-breeding period	2018	(N = 767)	-	-	673	310

Spatial behaviour in relation to distance to nest site

In order to analyse spatial behaviour, in particular during the period of strong nest attachment (courtship, incubation and rearing), for all breeding individuals in all study years the percentage share of telemetry points was depicted in relation to their distance to the nest site. While for 2016 data are available only for the post-breeding period (i.e. for a period with the low nest attachment), data are available for the entire breeding periods of 2017 and 2018, allowing for the depiction of differences with regard to breeding phenology (Figure 11). Comparing the different phases of the breeding period it is noticeable that the lines flatten out with progressing phenology. This means that in the course of the breeding period towards its completion a greater number of telemetry points can be found at greater distances to the nest site as the attachment to the nest site and its vicinity declines. During the 2017 courtship period, for example, 75% of all of Isolde's telemetry points were recorded within a radius of a mere 147 m around the nest site (50% within a 38 m radius; 5% of flights reached distances of more than 1,514 m). In contrast, the male Noah was located at much greater distances (75% of all telemetry points were recorded at distances of up to 1,361 m, 50% within a radius of up to 708 m, and 5% of flights reached distances of more than 3,274 m; Annex 8). During the incubation period, the female Isolde's nest attachment increased while male Noah's nest attachment remained largely unchanged. During the rearing period (nestling phase), Isolde's nest attachment declined strongly while the figures for Noah again remained largely unchanged. Finally, during the post-breeding period, the figures for Isolde approached those measured for the Noah. During this phase account must be taken of the fact that the home ranges were calculated based on flight movements that did not involve daily returns to the nest site, such as would have been the case during the incubation and rearing period; as a result of low nest attachment during this phase the birds also spend time in other parts of the territory.

Out of 68,823 telemetry points recorded in the three years of the study for all breeding red kites (excluding burst geofence data), 50,336 (73.1%) fall within a 1500 m radius and 34,817 (50.6%) fall within 1000 m around the nest site. For comparisons with other studies, the authors would at this point like to already refer to the discussion on the methodology employed (Chapter 6.2.1).

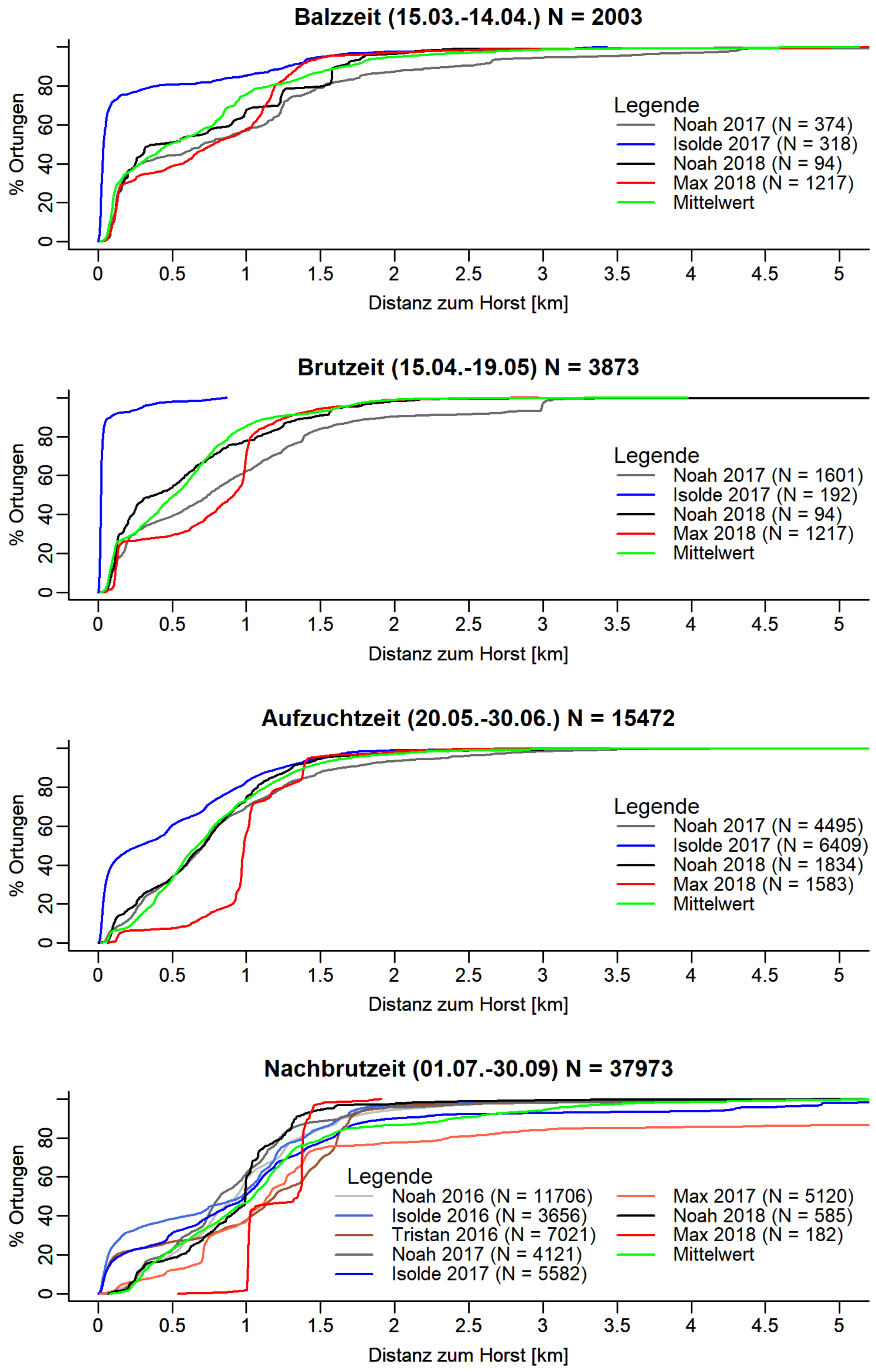

Figure 11: Percentage share of telemetry points by breeding phenology in relation to distance to nest site for the entire study period. For this illustration, the telemetry points recorded in close proximity to the nest sites were also taken into account (cf. discussion in Chapter 6.2.1).

DE **Fig. 11 & Annex 9**	EN
% Ortungen	% Telemetry points
Balzzeit	Courtship period
Brutzeit	Incubation period
Aufzuchtzeit	Rearing period
Nachbrutzeit	Post-breeding period
Distanz zum Horst [km]	Distance to nest site [km]
Legende	Key
Mittelwert	Mean

4.2.2 Diurnal and annual red kite flight activity

The share of in-flight telemetry points in the total number of telemetry points (five-minute dataset) serves as the measure of flight activity. Flight activity was recorded throughout the day (Figure 12). The telemetry points recorded between 23:00 and 4:00 hrs were almost exclusively from red kite Max and were recorded in a small number of nights. It appears that the transmitter's overnight shutdown functions as planned. Shares of more than 40% in-flight telemetry points per hour were recorded between 10:00 and 17:00 hrs CEST with a notable maximum around mid-day. While the red kites utilise the increasing daylength in the course of springtime, the curve does not become more shallow as a result (courtship, incubation and rearing). Flight activity only decreases overall after the juveniles have fledged (Figure 13). There are no discernible differences in diurnal phenology in the course of the phases of the breeding period (Figure 14).

The start and end of flight activity in relation to sunrise and sunset could not be analysed as the transmitters were calibrated to activate when the angle of the sun reaches 6° above the horizon (i.e. shortly after sunrise). As a result, the first telemetry points of the day were generally recorded when the birds' daytime activity had already commenced. However, since the overnight shutdown did not always work faultlessly, Figure 14 also shows a small number of telemetry points prior to sunrise and after sunset.

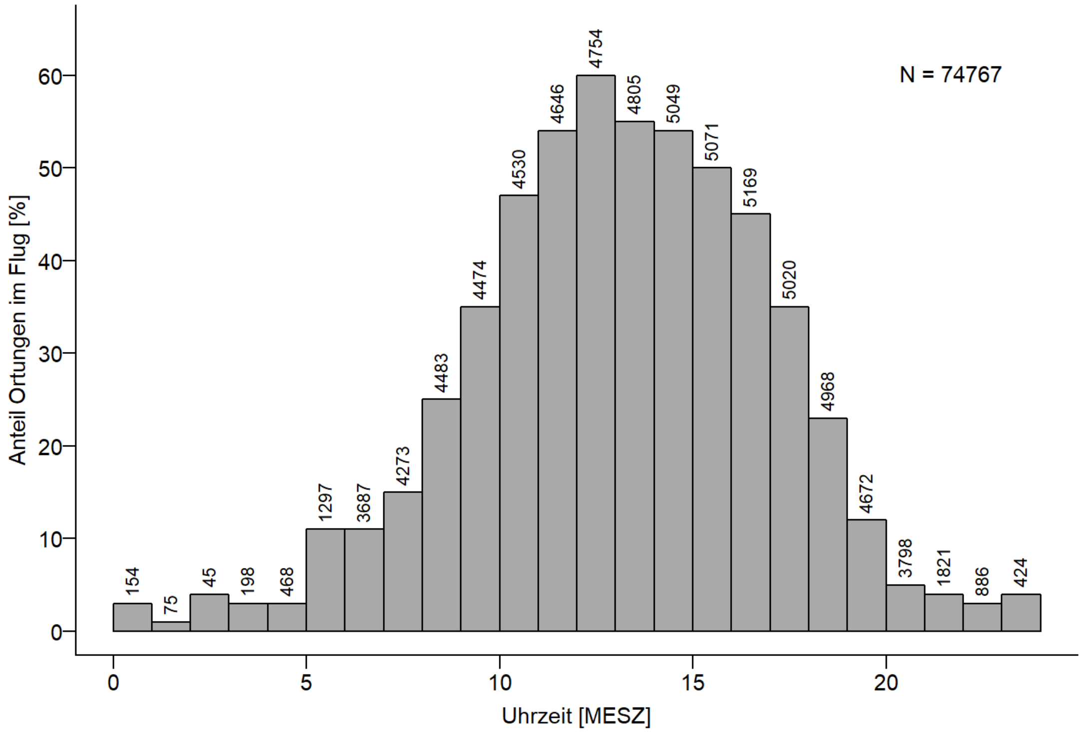

Figure 12: Flight activity in relation to time of day. The chart shows the proportion of in-flight telemetry points in the total number of telemetry points for each full hour (5-minute dataset for all available birds and for the entire study period). The figures indicate the total number of telemetry points recorded for each of the hours.

DE **Fig.12+13**	EN
Anteil Ortungen…	Proportion of in-flight telemetry points [%]
Uhrzeit…	Time of day [CEST]

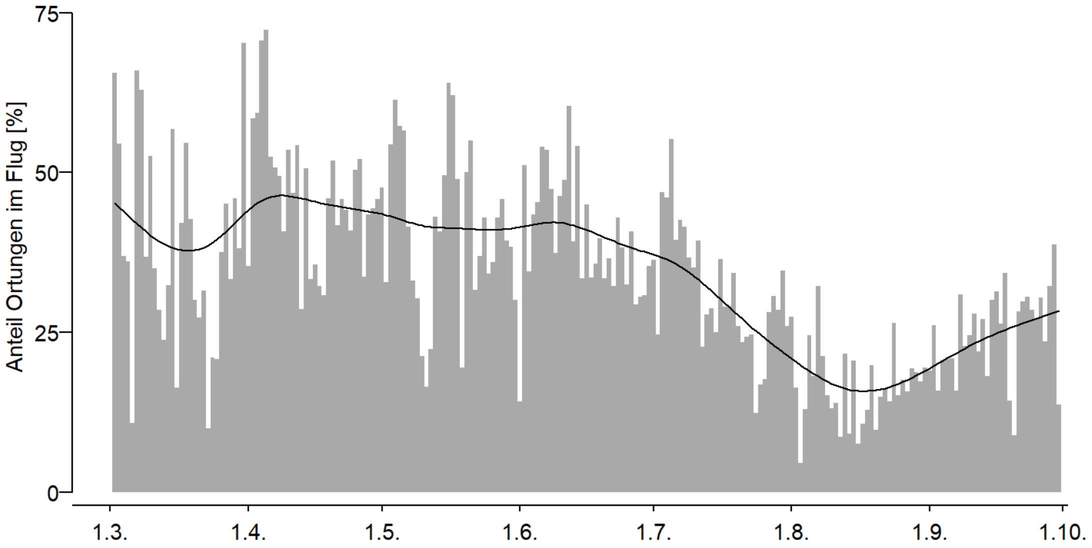

Figure 13: Flight activity in the course of the year. The chart shows the proportion of in-flight telemetry points in the total number of telemetry points recorded between 1 March and 30 September is based on the 5-minute dataset (columns) and a moving average curve (black line).

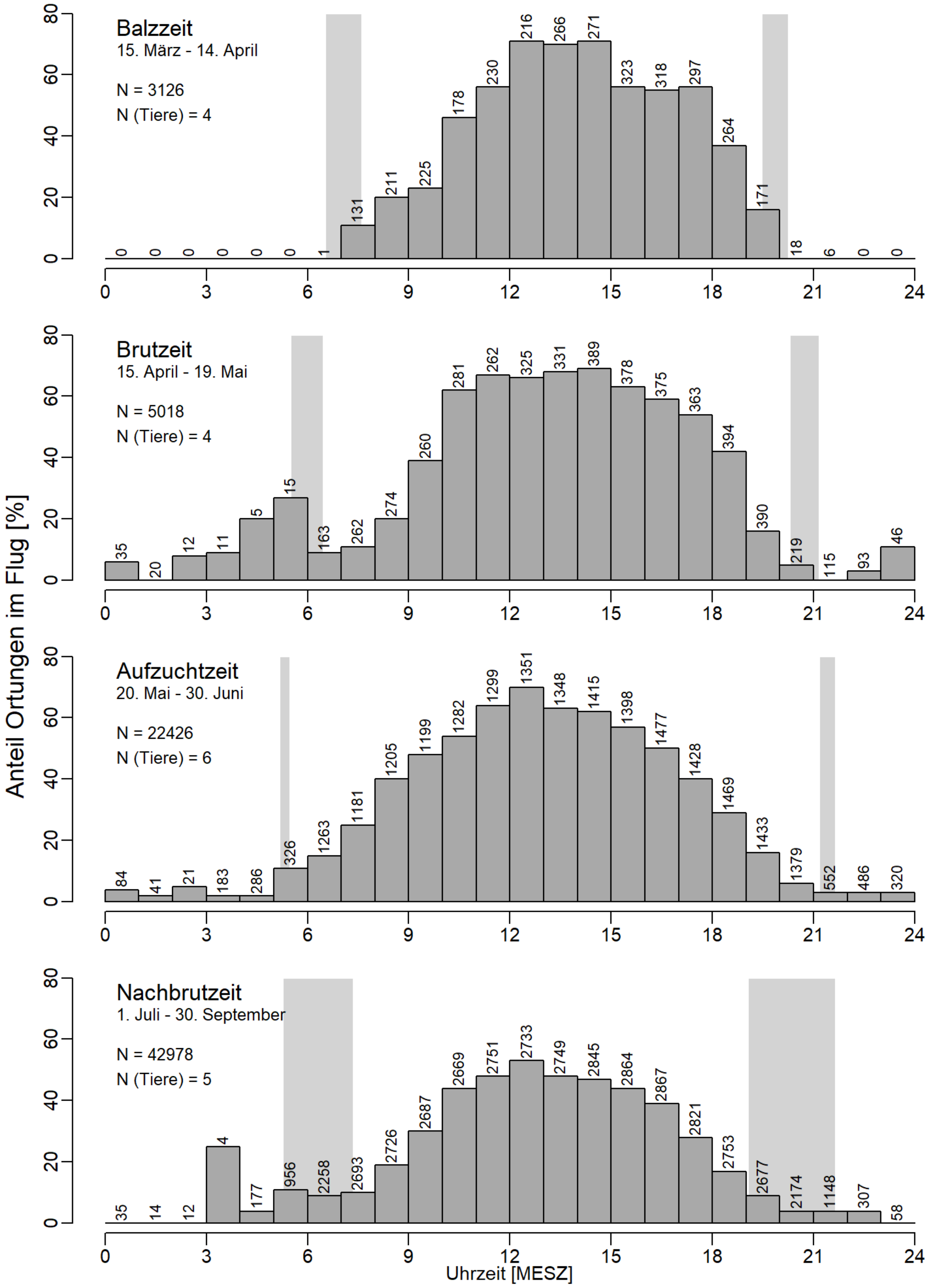

Figure 14: Flight activity in relation to time of day during the various phases of the breeding period. The chart shows the proportion of in-flight telemetry points in the total number of telemetry points recorded for each full hour (5-minute dataset for all available birds and for the entire study period). The figures indicate the total number of telemetry points recorded for each of the hours. The lighter grey bars denote the periods of sunrise and sunset within each of the phases of the breeding period.

DE (Fig. 14)	EN
Anteil Ortungen…	Proportion of in-flight telemetry points [%]
Uhrzeit…	Time of day [CEST]
N (Tiere) = …	N (birds) = …
Balzzeit…	Courtship period 15 March – 14 April
Brutzeit…	Incubation period 15 April – 19 May
Aufzuchtzeit…	Rearing period 20 May – 30 June
Nachbrutzeit…	Post-breeding period 1 July – 30 September

4.2.3 Flight activity and flight altitude in relation to weather and landform

Flight activity (flight/no flight)

The statistical model for the analysis of flight activity showed a significant ($p < 0.001$) negative effect[7] on flight activity of precipitation and temperature as well as a significant positive effect on flight activity of wind speed, sunshine duration and unstable air stratification. Compared to the "no slope" category (slope <5 degrees), slopes with N, NE, E, SE, S and NW aspects had a significant negative effect while slopes with W and SW aspects had a significant positive effect on flight activity (Table 16). However, the overall model was able to explain only 14.9% of the variance in flight activity data ($R^2 = 0.149$). Environmental variables can explain 12.3% of the variance (marginal $R^2 = 0.123$). Considering individual meteorological variables, sunshine duration ($R^2 = 0.029$) and unstable air stratification ($R^2 = 0.027$) are the most likely variables that can be assumed to have something of a positive effect on flight activity. The other three meteorological variables explain only a very minor proportion of flight activity (Table 16). With regard to landform, the positive effect on flight activity of slopes with western and south-western aspects is particularly notable. Again however, landform can only explain a small proportion of the variance in flight activity data ($R^2 = 0.025$). While the environmental variables studied can therefore be said to have an effect on flight activity (high statistical significance), this effect is very weak (small effect sizes and low ratio of explained variance).

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[7] A negative effect means that flight activity decreases with increasing values of meteorological parameters. A positive effect means that flight activity increases with increasing values of meteorological parameters.

Figure 15 also shows the positive effect of air stratification on flight activity (increasing height of blue bars with increasing instability as expressed by dispersion classes). The positive effects of wind speed and sunshine duration however are not very clearly visible in the charts. In Figure 15, extreme values for flight activity are evident for temperatures above 33°C. However, these are based on only a very small number of telemetry points for individual red kites and should not be interpreted as a general pattern.

In Annex 6 the results of the models for the analysis of flight activity are given for the different phases of the breeding period. These data demonstrate the constancy of the effects of precipitation, wind speed, sunshine duration and air stratification across all four phases of the breeding period. In contrast, the effects of temperature and landform vary between the phases of the breeding period. Also notable are the variations between the phases of the breeding period in the differences between R^2 and marginal-R^2 values (largest difference in the incubation phase, smallest difference in the post-breeding phase. This suggests that the individual birds' flight behaviour differs more greatly during the incubation period than during the post-breeding period. It is likely due to the differences in flight behaviour between the females, who mainly incubate the eggs, and the males who only relieve the females for short periods.

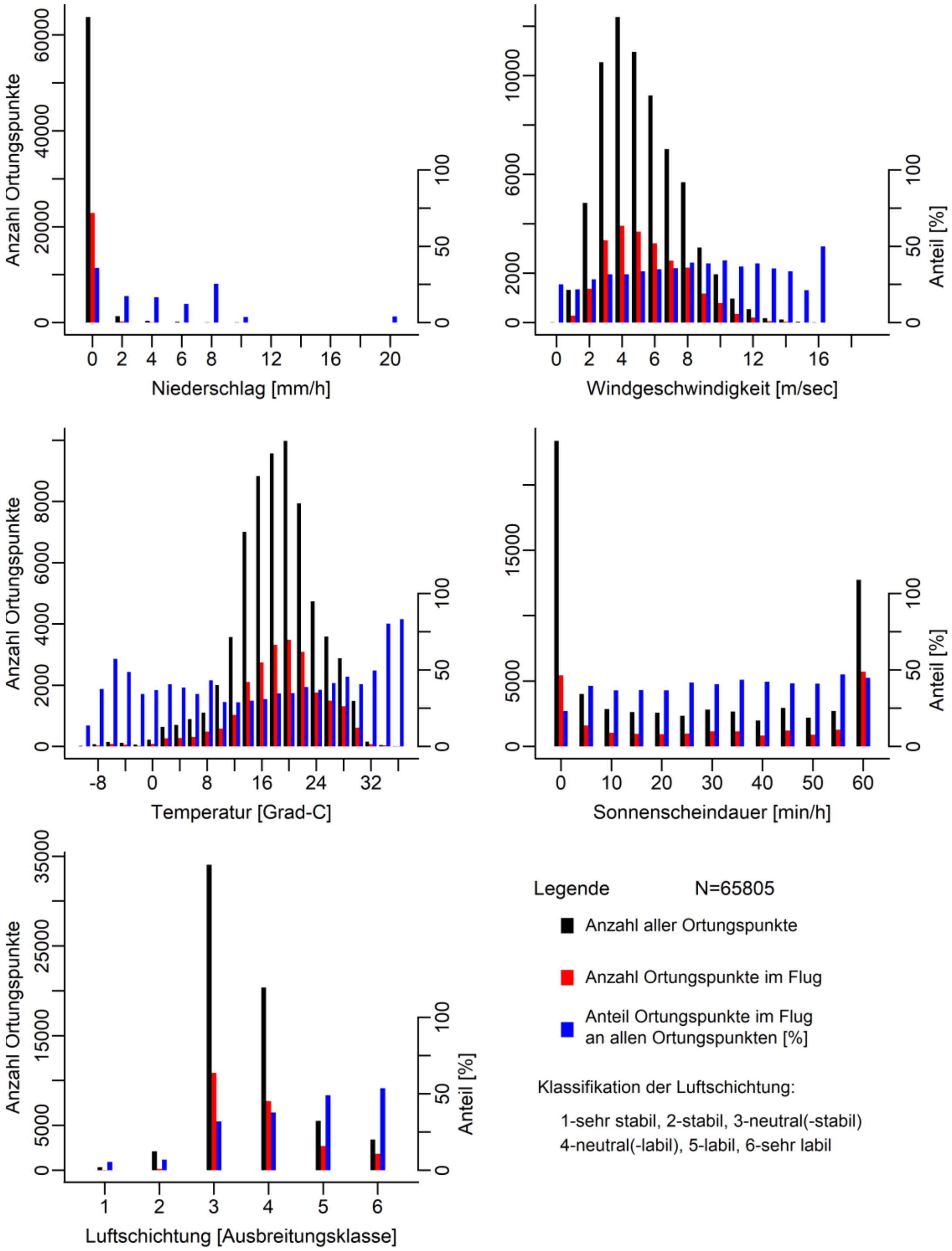

Figure 15: Distribution of flight activitity (number of in-flight telemetry points, red) by frequency of instances of five meteorological parameters (number of all telemetry points, black), and percentage share of in-flight telemetry points in all telemetry points by individual classification unit (blue). Each of the blue bars thus represents the percentage share of the red bar in the black bar. In some cases the number of telemetry points is so small that, for example, only the blue bar is visible. Based on the 5-minute dataset of telemetry points to which all environmental variables could be assigned.

DE Fig. 15	EN
Anzahl Ortungspunkte	No. of telemetry points
Anteil…	Proportion [%]
Niederschlag …	Precipitation [mm/h]
Windgeschw…	Wind speed [m/sec]
Temperatur…	Temperature [degree Celsius]
Sonnenschein…	Sunshine duration [min/h]
Luftschichtung…	Air stratification [dispersion class]
Legende	Key
Anzahl…	**No. of all telemetry points** No. of in-flight telemetry points Share of in-flight telemetry points in all telemetry points [%]
Klassifikation…	Classification of air stratification 1-highly stable, 2-stable, 3-neutral(-stable), 4-neutral(-unstable), 5-unstable, 6-highly unstable

Flight altitude

Out of the telemetry points recorded in flight, 81% were recorded at altitudes of less than 100 m and 72% at less than 75 m (cf. Figure 16). Flight altitudes varied between the different phases of the breeding period (proportion of in-flight telemetry points below 100 m: courtship period: 61%, incubation period: 72%, rearing period: 85%, post-breeding period: 81%, cf. Figure 17). Between 29% (courtship period) and 18.3% (rearing period) of in-flight telemetry points were recorded at the rotor height of modern wind turbines (80 – 250m) (Table 15).

An examination of diurnal patterns of flight altitudes shows that the dispersion of values increases from mid-morning to afternoon while the median remains almost constant between 9:00 and 19:00 hrs (Figure 18). There are no discernible deviations from this pattern even when the data are plotted by months (Figure 19).

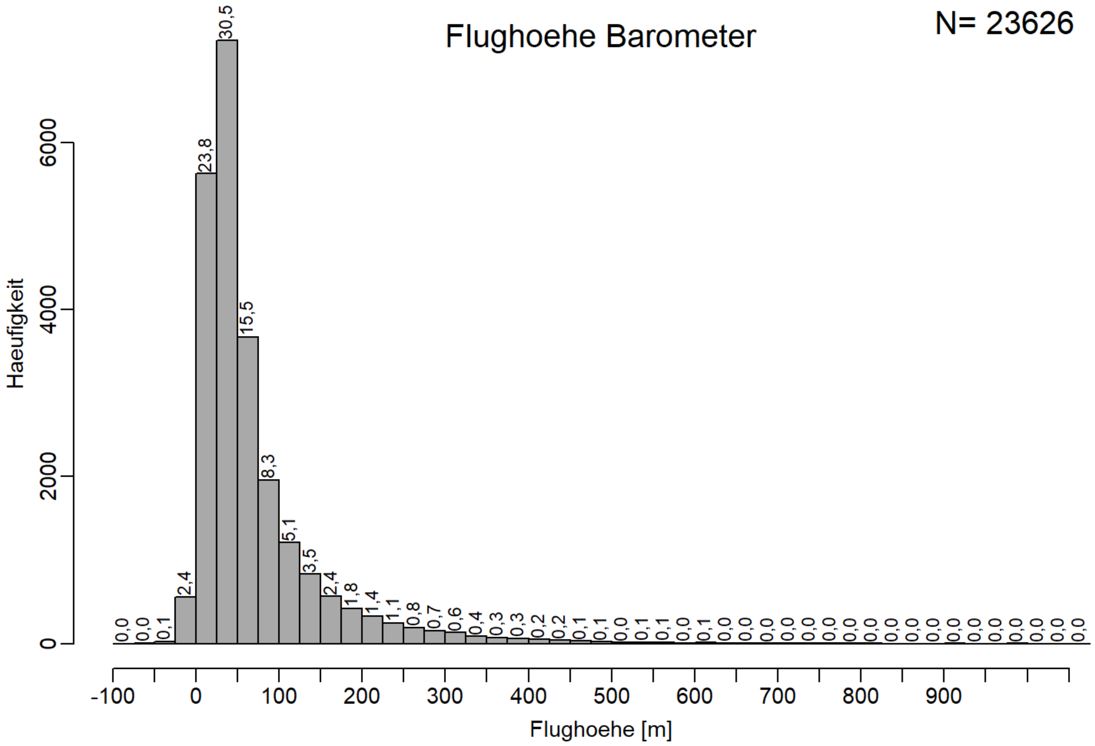

Figure 16: Histogram of flight altitudes by 25 m classes and percentage frequency distribution (covering period from fitting of transmitters to 31 July 2018, 5-minute dataset, only telemetry points recorded in flight).

DE **Fig. 16+17**	EN
Flughöhe Barometer	Barometric altitude
Häufigkeit	Frequency
Flughöhe	Flight altitude [m]
Balzzeit	Courtship period
Brutzeit	Incubation period
Aufzuchtzeit	Rearing period
Nachbrutzeit	Post-breeding period

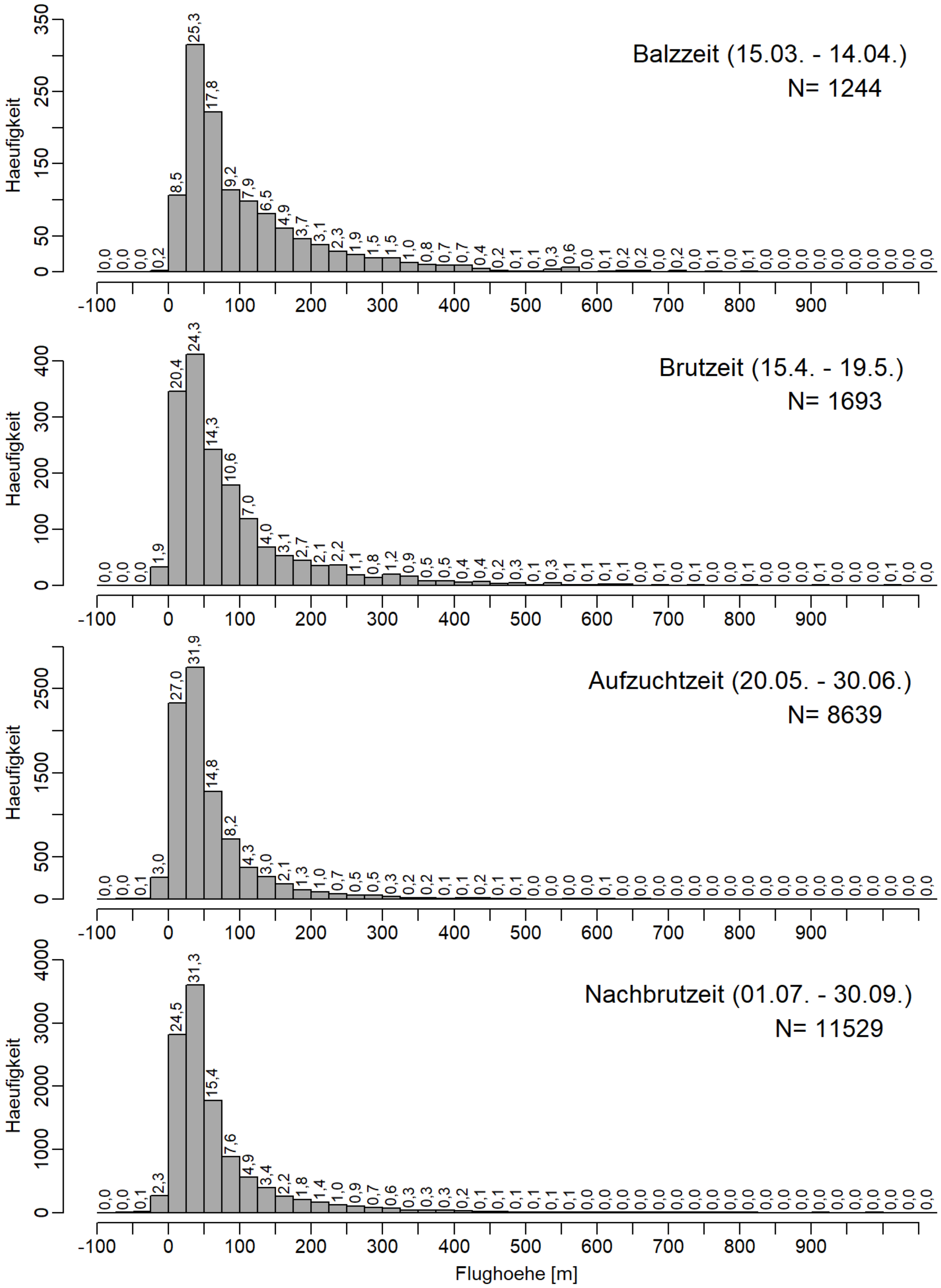

Figure 17: Histogram of flight altitudes by 25 m classes and phases of breeding period. Figures denote percentage frequencies (covering period from fitting of transmitters to 31 July 2018, 5-minute dataset, only telemetry points recorded in flight).

Table 15: Percentage share of in-flight telemetry points recorded at wind turbine rotor height (80 – 250m) in all in-flight telemetry points (5-minute dataset), differentiated by phases of the breeding period.

Phase of breeding period	Proportion recorded at rotor height [%]
Total	19.9
Courtship period	29.0
Incubation period	22.8
Rearing period	18.3
Post-breeding period	18.7

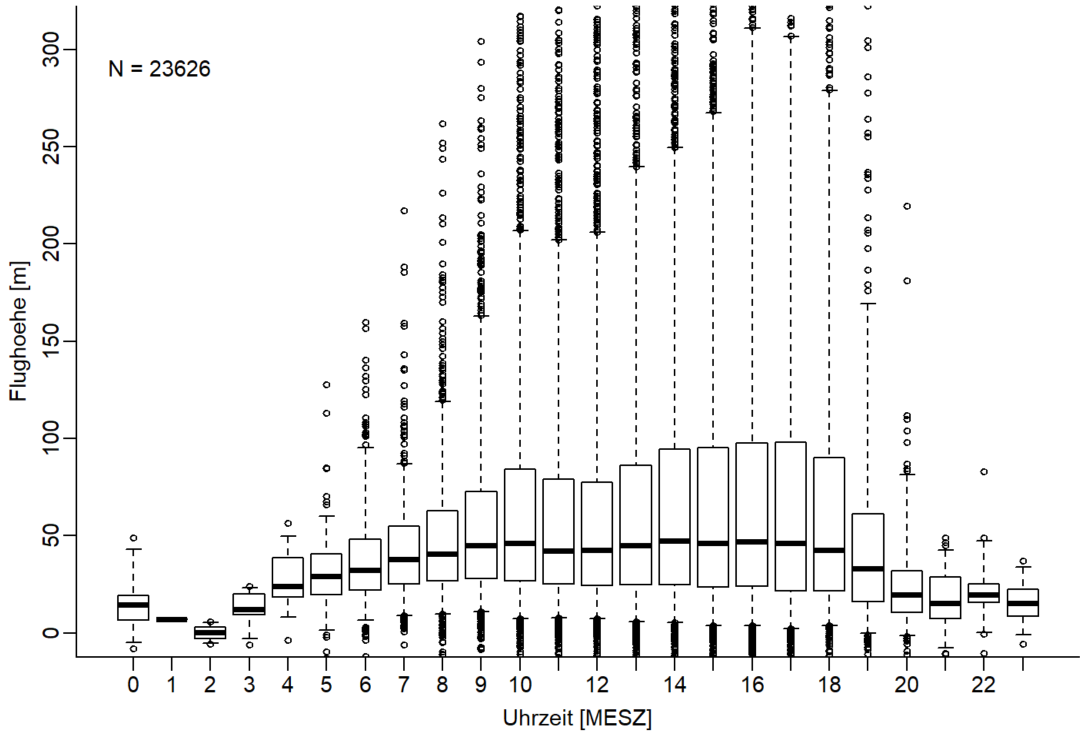

Figure 18: Boxplots of diurnal variation in flight altitudes (covering period from fitting of transmitters to 31 July 2018, 5-minute dataset, only telemetry points recorded in flight). The solid horizontal line marks the median; the box contains the middle 50% of values; the dashed line denotes the middle 90% of values.

DE **Fig. 18+19**	EN
Flughöhe…	Flight altitude [m]
Uhrzeit …	Time [CEST]
Balzzeit…	Courtship period 15 March – 14 April

Brutzeit…	Incubation period 15 April – 19 May
Aufzuchtzeit…	Rearing period 20 May – 30 June
Nachbrutzeit…	Post-breeding period 1 July – 30 September
N (Tiere) = …	N (birds) =…

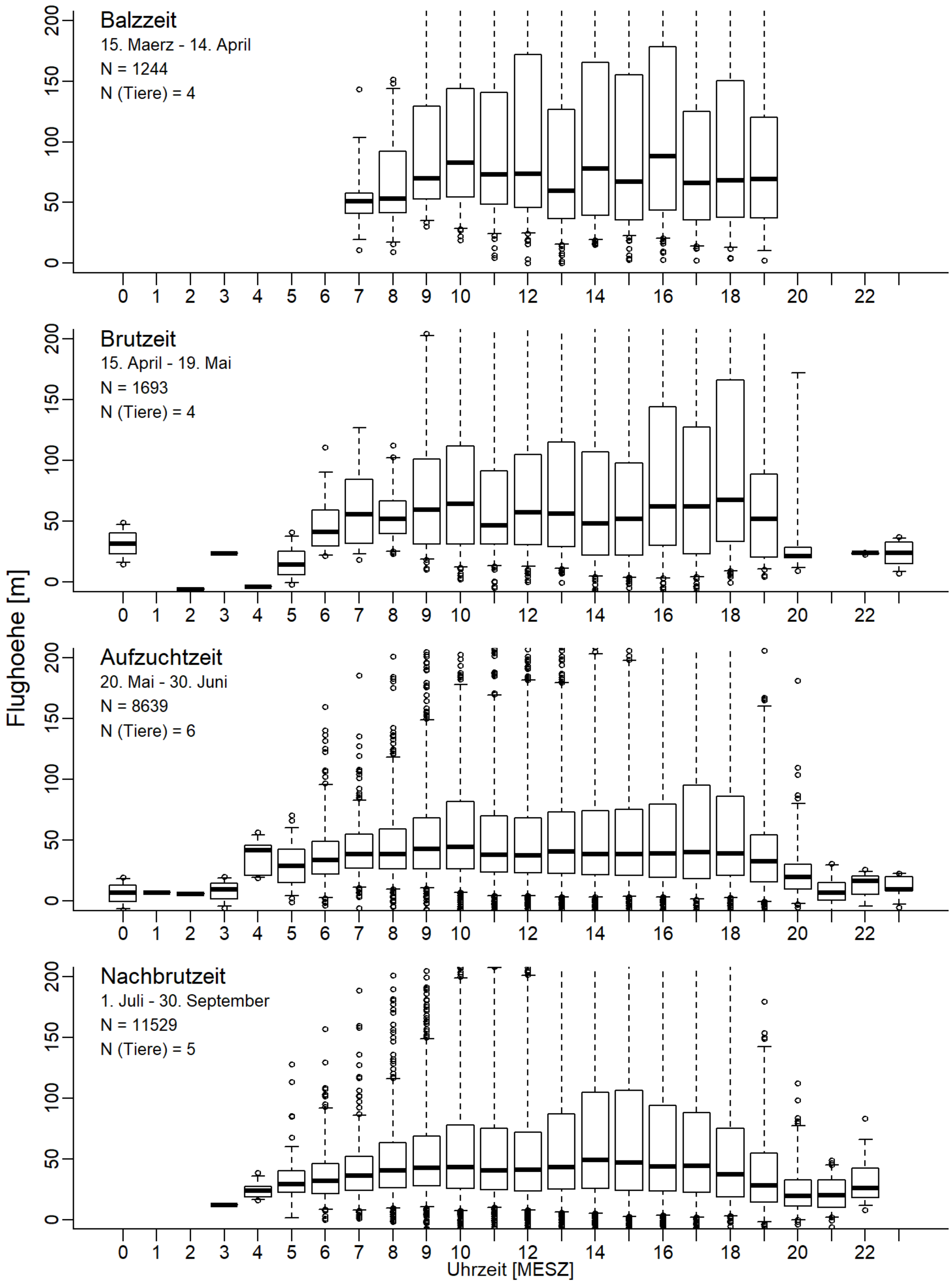

Figure 19: Boxplots of diurnal variation in flight altitudes by phases of breeding period (covering period from fitting of transmitters to 31 July 2018, 5-minute dataset, only telemetry points recorded in flight). The solid horizontal line marks the median; the box contains the middle 50% of values; the dashed line denotes the middle 90% of values.

The statistical model for the analysis of continuous flight altitude (see Chapter 3.9.2) showed a significant ($p < 0.001$) negative effect[8] on flight altitude of wind speed and temperature, a significant positive effect of sunshine duration and unstable air stratification, and no significant effect of precipitation (Table 16). With regard to landform, the model showed a significant negative effect on flight altitude of slopes with N, E, SW and NW aspects. In contrast to this model, the statistical model for the analysis of categorised flight altitude (above/below 80 m) showed a significant negative effect with respect to landform only for northern and eastern slopes ($p < 0.001$; Table 16).

However, the models for continuous and categorised flight altitude only explain 11.5% and 12.0% respectively of the variance in flight altitude data. The environmental variables only explain 2.1% and 3.3% respectively of flight altitude data (marginal R^2). Therefore the differences between individual birds and study years account for the largest proportion of the explained variance. In both of the models the individual environmental variables explained only a very small proportion of variance in flight altitude data (R^2 values max. 1.4% and 1.3% respectively for wind speed, Table 16). Visual examination of the data also does not reveal any obvious trends in terms of high-altitude flight events in relation to the five meteorological variables. Only the supply-demand graph (Figure 20) reveals a slight positive effect of air stratification on flight altitude. Similarly, no clearly discernible trends are evident from the depiction of continuous flight altitude data (Figure 21) and a differentiated analysis of the data by phases of the breeding period also does not reveal any consistent effects of the environmental variables (Annex 7). Significant effects ($p < 0.001$) were found primarily in the rearing and post-breeding periods; this is likely due to the higher sample size (N). However, even during these phases of the breeding period the R^2 values are very low.

Overall, the analyses conducted show that out of the meteorological variables taken into consideration wind speed is the variable most likely to have an effect on flight altitude, albeit a weak one.

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[8] A negative effect means that flight altitude decreases with increasing values of meteorological parameters. A positive effect means that flight altitude increases with increasing values of meteorological parameters.

Table 16: Model statistics of a generalised linear mixed model (GLMM) for categorised flight activity (flight/no flight), a linear mixed model (LMM) for continuous flight altitude, and a GLMM for categorised flight altitude (above/below 80m). Five weather variables (z-standardised) and categorised landform served as explanatory variables. Bird ID and study year were included as random effects. The effect sizes of the eight slope aspects distinguish from the “no slope” category; therefore no statistical values are available for the “no slope” category. The 5-minute dataset was used as input data for the model.

Weather variable		**GLMM Flight activity N = 65,805; R^2 = 0.149; marg. R^2 = 0.123**				**LMM Flight altitude N = 22,758; R^2 = 0.115; marg. R^2 = 0.021**				**GLMM Flight altitude N = 22,758; R^2 = 0.120; marg. R^2 = 0.033**		
		Effect size ± Standard error	**p-value**	**R^2**		**Effect size ± Standard error**	**p-value**	**R^2**		**Effect size ± Standard error**	**p-value**	**R^2**
Precipitation		- 0,23 ± 0,02	**< 0,001**	0,004		-0,01 ± 0,01	0,026	0,001		-0,06 ± 0,02	0,009	0,001
Wind speed		0.34 ± 0.01	**< 0.001**	0.005		-0.11 ± 0.01	**< 0.001**	0.014		-0.25 ± 0.02	**< 0.001**	0.013
Temperature		- 0.09 ± 0.01	**< 0.001**	0.003		-0.07 ± 0.01	**< 0.001**	0.000		-0.16 ± 0.02	**< 0.001**	0.000
Sunshine duration		0.32 ± 0.01	**< 0.001**	0.029		0.05 ± 0.01	**< 0.001**	0.006		0.14 ± 0.02	**< 0.001**	0.006
Air stratification		0.37 ± 0.01	**< 0.001**	0.027		0.05 ± 0.01	**< 0.001**	0.007		0.11 ± 0.02	**< 0.001**	0.007
Slope N		-0.25 ± 0.03	**< 0.001**	0.025		-0.10 ± 0.02	**< 0.001**	0.003		-0.22 ± 0.06	**< 0.001**	0.003
Slope NE		-0.15 ± 0.05	**< 0.001**			-0.09 ± 0.03	0.014			-0.11 ± 0.08	0.176	
Slope E		-0.51 ± 0.04	**< 0.001**			-0.12 ± 0.03	**< 0.001**			-0.36 ± 0.09	**< 0.001**	
Slope SE		-0.64 ± 0.03	**< 0.001**			-0.06 ± 0.03	0.021			-0.22 ± 0.07	0.001	
Slope S		-0.15 ± 0.03	**< 0.001**			-0.05 ± 0.02	0.021			-0.02 ± 0.05	0.687	
Slope SW		0.67 ± 0.04	**< 0.001**			-0.08 ± 0.02	**< 0.001**			-0.12 ± 0.06	0.039	
Slope W		0.35 ± 0.03	**< 0.001**			-0.03 ± 0.02	0.308			-0.09 ± 0.06	0.163	
Slope NW		-0.15 ± 0.04	**< 0.001**			-0.11 ± 0.03	**< 0.001**			-0.16 ± 0.07	0.016	

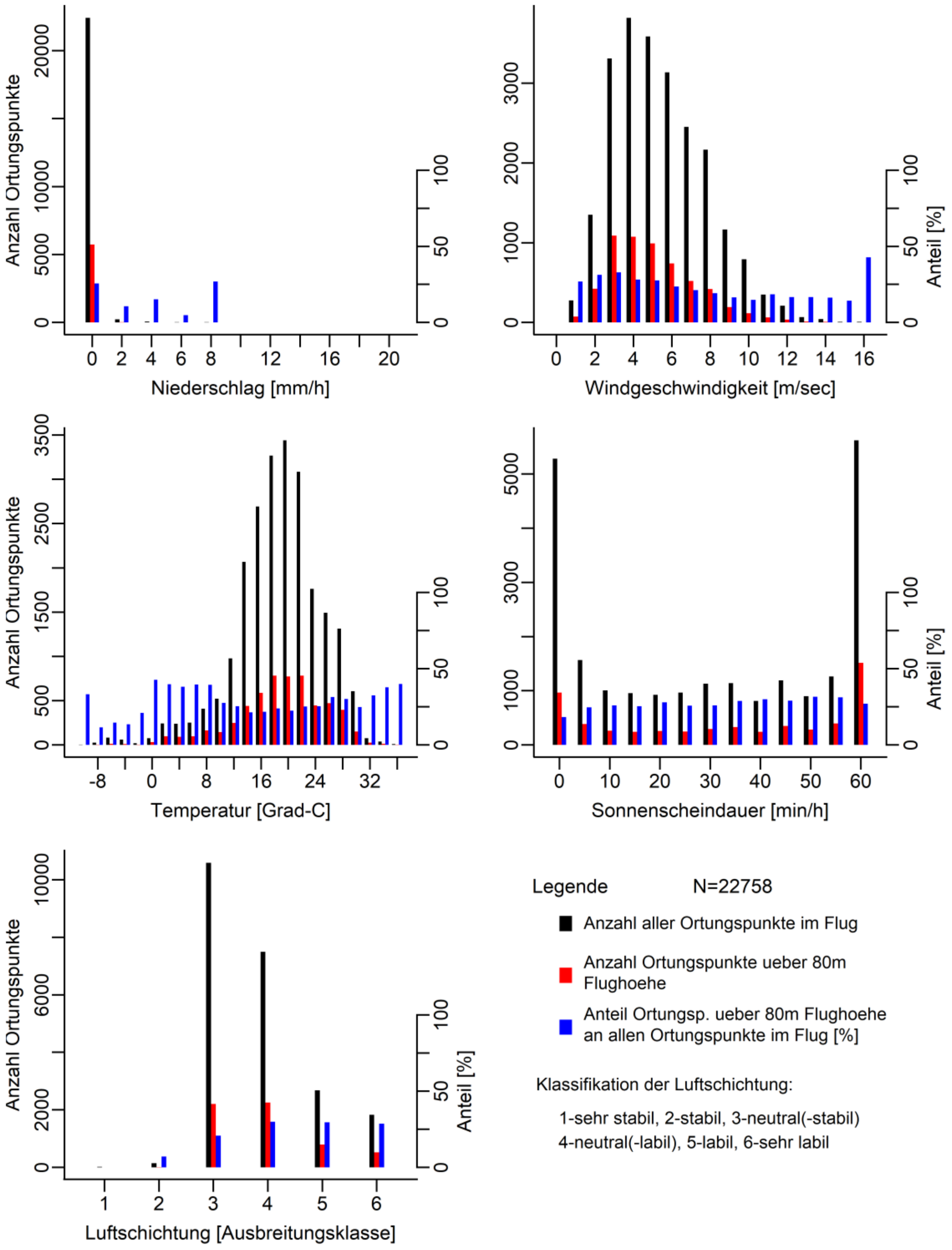

Figure 20: Distribution of flight events and high-altitude flight events (above 80 m) as well as percentage share of high-altitude flight events in all flight events by frequency of instances of five meteorological parameters (time period from fitting of transmitters on 22 June up until 30 September 2018). Each of the blue bars thus represents the percentage share of the red bar in the black bar. In some cases the number of telemetry points is so small that, for example, only the blue bar is visible. Based on the 5-minute dataset of telemetry points to which all environmental variables could be assigned. For translation of captions see Figure 15.

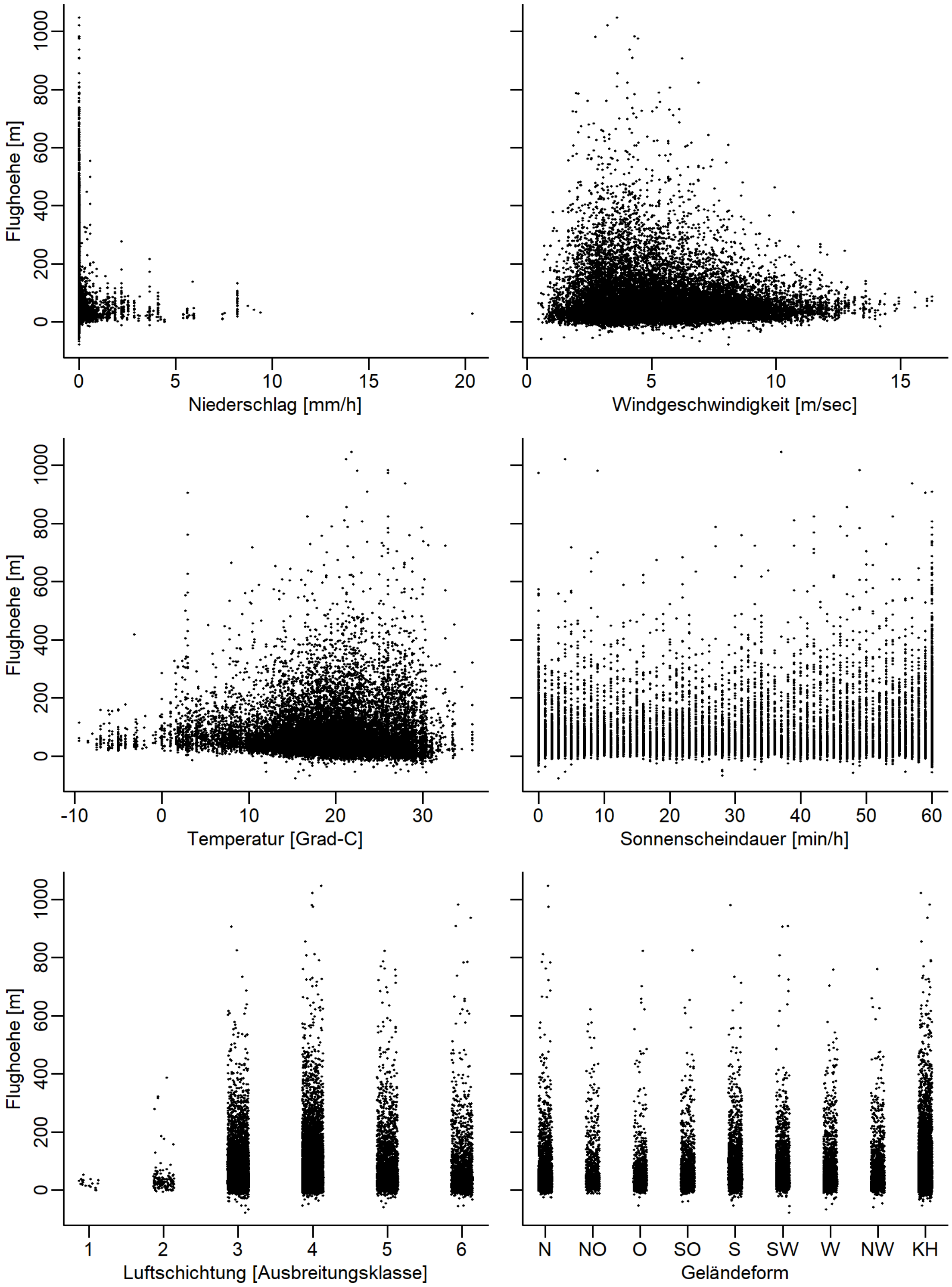

Figure 21: Flight altitude data points in relation to five weather variables and landform categories. Showing in-flight telemetry points to which all environmental variables could be assigned (5-minute dataset, N = 22.758). Landform categories: slope (min. 5 degrees) with N, NE, E, SE, S, SW, W or NW aspect and “no slope” (less than 5 degree slope, n.sl.).

DE **Fig. 21**	EN
Flughöhe [m]	Flight altitude [m]
Niederschlag …	Precipitation [mm/h]
Windgeschw…	Wind speed [m/sec]
Temperatur…	Temperature [degree Celsius]
Sonnenschein…	Sunshine duration [min/h]
Luftschichtung…	Air stratification [dispersion class]
Geländeform	Landform
N NO …	N NE E SE S SW W NW n.sl.

4.2.4 Home range size in relation to meteorological parameters

The statistical model for the analysis of diurnal home range size in relation to weather conditions shows a significant positive effect on home range size of temperature and unstable air stratification (Table 17). The model only explains 19.9% of the variance in home range size data. The environmental variables, however, only explain 4.2% of data (marginal R^2). Again the differences between individual birds and study years account for the largest proportion of the explained variance. The individual environmental variables explain only a small proportion of variance (R^2 values for temperature: 3.0%, air stratification: 1.9%). The positive effect of temperature on diurnal home range size is also visible in the scatter plot (Figure 22).

Table 17: Model statistic of a linear mixed model with diurnal home range size as the dependent variable, five weather variables (z-standardised) as explanatory variables, and bird ID and study year as random effects. N = 906; $R^2 = 0.199$ (full model); marginal $R^2 = 0.042$ (environmental variables).

Weather variable	Effect size ± standard error	p-value	R^2
Precipitation	- 0.04 ± 0.03	0.289	0.003
Wind speed	0.02 ± 0.04	0.682	0.005
Temperature	0.14 ± 0.04	**< 0.001**	0.030
Sunshine duration	- 0.01 ± 0.04	0.781	0.011
Air stratification	0.10 ± 0.04	**< 0.05**	0.019

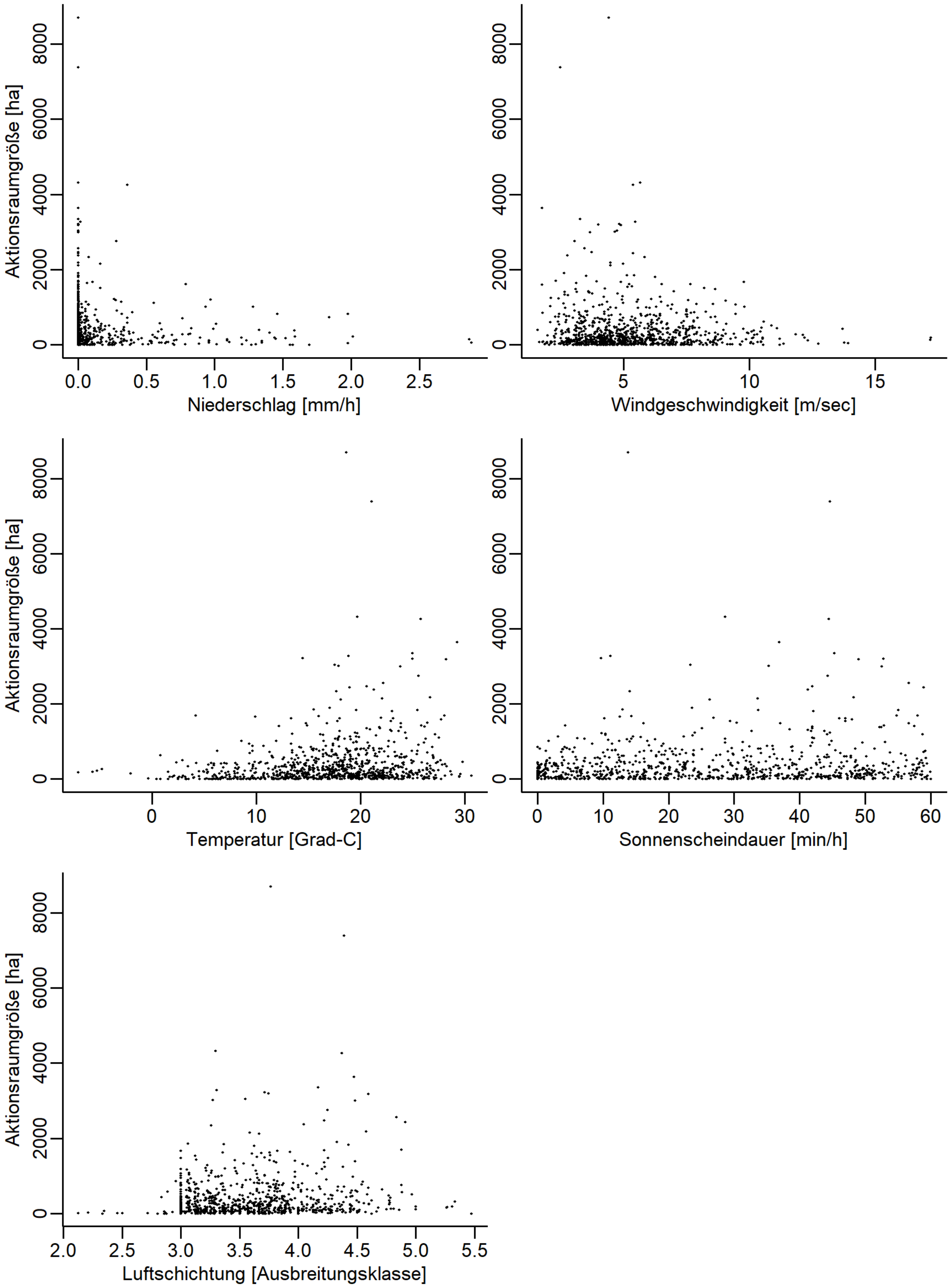

Figure 22: Diurnal home range size (100% MCP) data points in relation to five weather variables. Weather variables' values are daily averages; therefore the air stratification values are continuous averages of classes 1 through to 6. Four red kites, i.e. Tristan, Isolde, Noah and Max, yielded the data; N=906).

DE Fig. 22	EN
Aktions… [ha]	Home range size [m]

Niederschlag …	Precipitation [mm/h]
Windgeschw…	Wind speed [m/sec]
Temperatur…	Temperature [degree Celsius]
Sonnenschein…	Sunshine duration [min/h]
Luftschichtung…	Air stratification [dispersion class]

4.2.5 Effect of land use and land management on flight behaviour

Land-use types

There were clear differences between the individual birds in their frequentation of different land-use types within a 1.5 km radius around their respective nest sites (data not shown). The Jacobs' preference index values, a relative measure of the birds' disproportionately lower or higher presence above specific land-use types, are summarised in Table 18. Across the entire study season, the red kites' presence above intensively managed maize fields and above coniferous forest was disproportionately low. A time-differentiated analysis of the data shows a significant disproportionately low presence by the birds above a range of different of land-use types in individual months: Intensive arable land (root crops, maize and oilseed rape), extensive grassland, deciduous forest, coniferous forest, and the "settlements and buildings" land-use type. The red kites' presence above the "meadow, tree row, copse, hedgerow in equal proportion" land-use type was significant disproportionately high in March (Table 18). A trend towards giving preference to certain land-use types during more than a month was discernible for the following land-use types: Intensive arable land (cereals), intensive and extensive grassland, deciduous and mixed forests as well as the type "meadow, tree row, copse, hedgerow in equal proportion".

It should be noted in this context that the Jacobs' preference index is significantly more sensitive to avoidance than to preference being given to specific sites[9]. When the individual birds are considered, generally more negative than positive values are therefore obtained for the different land-use classes. If these individual values are averaged out over the various birds and years, more often than not the result is a negative average (siehe Table 18). Significant positive values are thus rather rare. Moreover, for several of the land-use classes, only a very small number of values are available and in some cases only for individual birds. These values therefore have no statistical significance and should not be debated in ecological terms. Overall it is difficult to identify any general patterns from the available data.

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[9] The home ranges' spatial extent changes in the course of the year. Therefore the "offering" of available land-use types always includes sites that the birds do not frequent at all.

Table 18: Jacobs' preference index for the different land-use types across the entire study period and time-differentiated by months. The index values given are averages for the various red kites and the years. Negative values indicate disproportionately low utilisation of a land-use type, positive values indicate a disproportionately high level of utilisation. Significant positive or negative values (90% confidence interval for the mean does not contain zero) are shown in bold print, with positive values depicted in green and negative values in red.

Months	Intensive arable (cereals)	Intensive arable (root crops)	Intensive arable (maize)	Intensive arable (oilseed rape)	Extensive arable (cereals)	Extensive arable (root crops)	Intensive grassland	Extensive grassland	Deciduous forest	Mixed forest	Coniferous forest	Meadow, tree row, copse, hedgerow	Settlements and buildings
entire season	0.1	-0.1	**-0.3**	-0.2	-1.0	-0.2	0.0	0.1	0.3	-0.0	**-0.8**	0.0	-0.1
March	-0.3	-0.6	**-0.8**	-0.6	-1.0	-1.0	0.0	**-0.6**	**-1.0**	0.1	-1.0	0.2	**-0.5**
April	-0.1	-0.6	-0.1	-0.2	-1.0	-1.0	-0.1	**-0.8**	-0.2	0.0	-1.0	**0.3**	-0.2
May	-0.2	-0.1	-0.1	-0.0	-1.0	-1.0	0.1	**-0.6**	-0.1	-0.1	-1.0	0.0	**-0.4**
June	-0.2	**-0.5**	**-0.4**	-0.3	-1.0	-0.2	-0.0	-0.1	-0.0	-0.1	**-1.0**	-0.0	-0.2
July	0.1	0.1	**-0.4**	-0.3	-1.0	-0.1	-0.0	0.0	0.9	-0.1	**-0.8**	-0.0	-0.3
Aug.	0.2	**-0.8**	**-0.5**	-0.1	-	-0.4	0.0	0.2	1.0	-0.1	-0.6	-0.2	-0.3
Sept.	0.1	**-0.6**	**-0.6**	**-0.7**	-	0.2	-0.2	-0.1	1.0	-0.4	**-0.9**	-0.2	-0.2

Management events

The raw data and ratios of telemetry points to available areas for managed and not currently managed sites respectively, differentiated by individual bird, are given in Annex 10 and Annex 11. In 2016, the first year of the study, the results for the two breeding territories which had been studied several times were not conclusive. There was no evidence in the 2016 data of a disproportionately high utilisation of sites subject to management events.

Similarly, the weekly data for 2017 and 2018 show significant variation in parts between the various mapping cycles. However, overall the results indicate disproportionately high frequentation by the birds, i.e. flights above sites subject to management events (mean value across all mapping cycles for the six red kite years was greater than 1; see Annex 10 and Annex 11). In other words, when management events took place within the mapped areas (Maps 5.4 and 5.5) the birds tended to fly more frequently above the sites in question. It would thus appear that for the purposes of foraging red kites give preference to sites which recently were subject to agricultural management, even though the landscape of the Vogelsberg is dominated by grassland.

4.2.6 Flight behaviour in the vicinity of wind farms

In the course of the entire study period (22.06.-30.09.2016, 01.03.-30.09.2017, 01.03.-31.07.2018), telemetry points were recorded in the various wind farm geofences (cf. Map 1.1) on 155 out of a total of 468 days. The transmitters provided a total of 98,110 telemetry points, 35,682 of which were classified as in-flight telemetry points.

Example depictions of geofence data collection are given for the regularly frequented Ulrichstein-Platte (2016-2, 2017-5) and Alte Höhe (2017-7) wind farms in Maps 4.1 – 4.3 and Maps 4.6 and 4.7. As the telemetry points were recorded at one-second intervals, the distances between points allow for conclusions to be drawn as to the speed at which the individual bird was travelling; changes in altitude in the course of a flight movement are indicated by the points' colours. The functioning of the geofences must be taken into account in order to avoid possible misinterpretations. Geofence recording at one-second intervals only commences when a telemetry point as part of the baseline interval is registered within the geofence. Telemetry points recorded within the geofences therefore do not fully depict all flight events within the geofence.

When the geofence telemetry points are scaled-down to 5-minute intervals in order to allow for comparisons with the data recorded outside of the geofences, it is evident that the red kites only rarely ventured into the wind farms' vicinity. Only 1.5% of all in-flight telemetry points were recorded inside the boundaries of the wind farm geofences, as the geofences were primarily located at the margins of the home ranges of the transmitter birds (272 out of 18,284 telemetry points at 5-minute intervals; only breeding birds: Isolde, Max, Noah and Tristan, see Maps 3.1 – 3.3). There was very strong variation with regard to the proportional amount of time spent in wind farms by month or daytime hour. No general patterns are discernible.

Weather conditions during flight events in wind farm geofences

Figure 23 shows the weather conditions during the flight events recorded in wind farms in relation to the weather conditions during the entire study period. It is notable that under favourable conditions for the development of thermals as indicated by high temperatures, high sunshine duration and unstable air stratification, a disproportionately high number of telemetry points was recorded inside the wind farm geofences while no clear effect of these parameters on general flight activity could be shown (see results in Chapter 4.2.3).

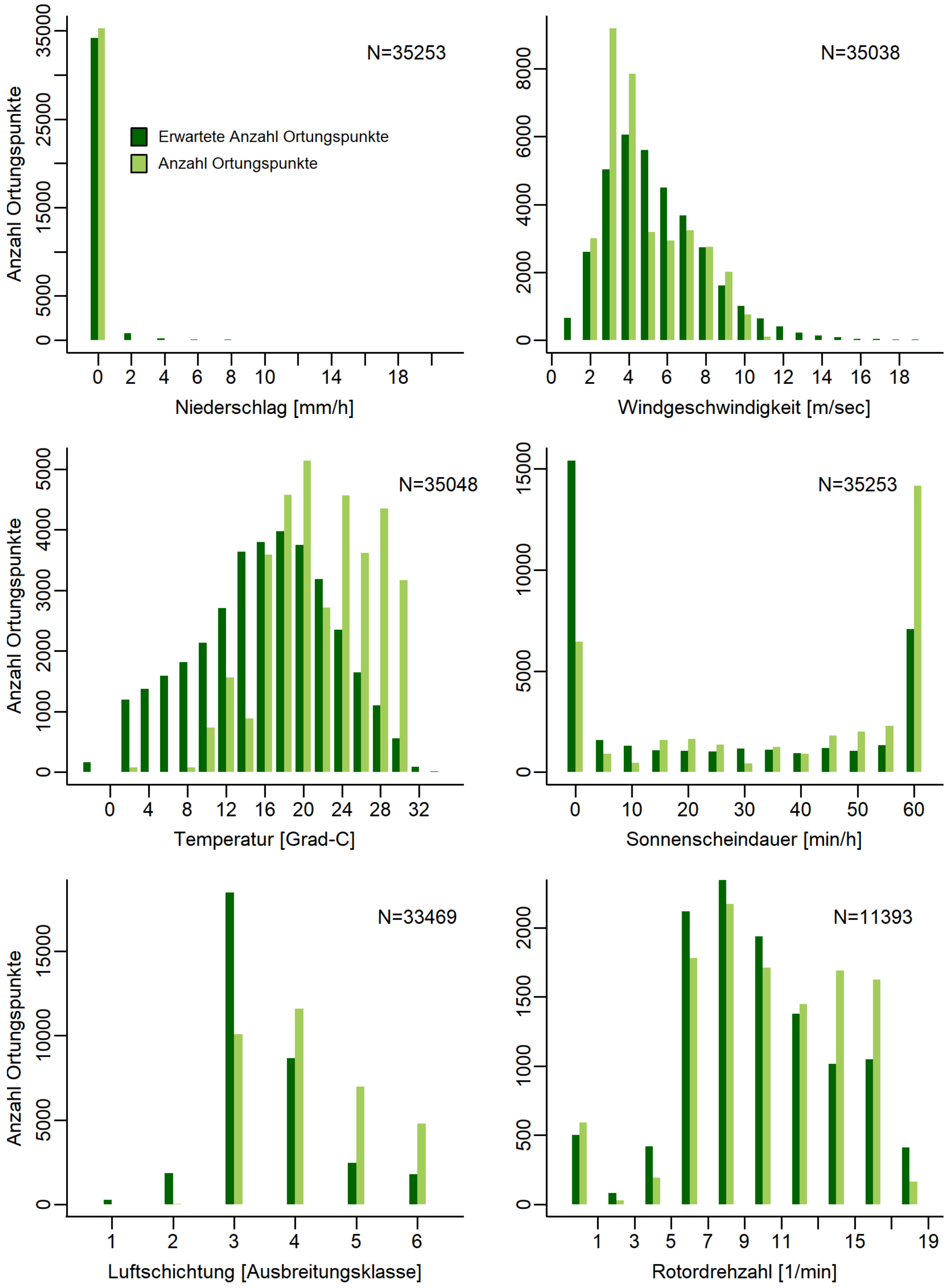

Figure 23: Weather conditions and rotor rotational speeds during flight events in all wind farm geofences, depicted as the number of telemetry points (light green) and the number of telemetry points (dark green) one would expect to record given the weather conditions prevailing in the study period (5:00 –22:00 hrs).

DE Fig. 23	EN
Anzahl Ortungspunkte	No. of telemetry points

Erwartete Anzahl…	Expected no. of telemetry points
Niederschlag …	Precipitation [mm/h]
Windgeschw…	Wind speed [m/sec]
Temperatur…	Temperature [degree Celsius]
Sonnenschein…	Sunshine duration [min/h]
Luftschichtung…	Air stratification [dispersion class]
Rotordrehzahl	Rotor rotational speed [1/min]

Flight events in the vicinity of the WT rotor blades

Noah was the only red kite to be recorded in the vicinity of the WT rotor blades, with a total of 212 telemetry points recorded in the course of 28 flight events (Ulrichstein-Platte and Alte Höhe wind farms; both located more than 2 km away from the nest site). These flight events in the vicinity of the WT rotor blades are given in Table 19 together with information on flight path and partially available data on rotor rotational speed and alignment. The Alte Höhe wind farm consists of two different types of installations; the older WTs 1-10 do not record information on rotor rotational speed and alignment. For the flight events in the vicinity of the WT rotor blades only partial data are therefore available on on rotor rotational speed and alignment. Several instances were documented of flights to within a few metres of the WT shaft axis. The available data are not indicative of any flythroughs through moving rotors, i.e. flights in the critical area for collisions.

Table 19: Flight events in the critical area for collisions (CA; rotor flythroughs) and in the vicinity (VI) of WT rotors. The table lists Noah's 28 flight events in the Ulrichstein-Platte (UP) and Alte Höhe (AH) wind farms in conjunction with data on flight paths and flight altitudes. The AH wind farm consists of two different types of installations; the older WTs 1-10 do not record information on rotor rotational speed and alignment. WTs 1-7 as part of the UP wind farm: nacelle height: 138 m, rotor diameter: 82 m, bottom edge of rotor at 97 m. WTs 1-10 as part of the AH wind farm: nacelle height: 70 m, rotor diameter: 60 m, bottom edge of rotor at 40 m.

Date	Time	Wind farm	WT	Telemetry points in VI	Rotor rotational speed [1/min]	Rotor tip speed [km/h]	Nacelle position [degrees]	Rotor alignment	Flight route in VI	Min. horizontal distance to shaft axis [m]	Flight altitude [m]
Flights in the critical area for collisions (CA) of WT rotors											
- (No flythroughs through moving rotors took place.)											
Flights in the vicinity (VI) of WT rotors											
15.07.16	13:19	UP	1	9	10.14	157	302	NNE - SSW	SW -> N; parallel to rotor	18	136
25.07.16	10:54	UP	2	4	4.0	62	276	N - S	N -> E at an angle to rotor	44	89
17.05.17	09:23	AH	4	2	-	-	-	-	In the NW, downward out of VI	33	35
03.06.17	11:48	AH	8	3	-	-	-	-	SE boundary	38	68
05.06.17	14:46	AH	7	12	-	-	-	-	Circling in SW, later at WNW boundary	27	54
14.06.17	08:56	AH	10	7	-	-	-	-	S -> W	19	89
14.06.17	08:56	AH	7	29	-	-	-	-	Circling in NW/W	11	100
14.06.17	11:40	AH	2	36	-	-	-	-	SSW -> NNE narrowly passing the shaft -> circling in NW, and again-> SSW	5	32
21.06.17	11:29	AH	5	3	-	-	-	-	ENE boundary	36	42

21.06.17	11:42	AH	5	11	-	-	-	-	NE -> passing around wind farm in the W -> S	10	33
21.06.17	11:44	AH	9	2	-	-	-	-	SE boundary	37	79
21.06.17	11:44	AH	9	6	-	-	-	-	Circling in the NE, flying upward out of VI	18	105
21.06.17	13:35	AH	6	6	-	-	-	-	NE -> NW	21	30-40
21.06.17	14:26	AH	3	6	-	-	-	-	SE -> WSW	27	32
21.06.17	14:45	AH	6	34	-	-	-	-	Circling W->SW, passing around wind farm and flying upward out of VI	5	63-109
21.06.17	15:36	AH	6	4	-	-	-	-	NE -> E boundary	32	49
21.06.17	15:37	AH	1	1	-	-	-	-	ESE boundary	39	67
21.06.17	15:41	AH	7	4	-	-	-	-	Bottom boundary in the S of the VI	35	31
25.06.17	19:32	UP	4	1	14.75	228	264	N - S	SE boundary	50	137
26.06.17	16:14	UP	1	5	8.93	138	281	N - S	W - > S, at an angle to rotor	31	97
07.07.17	14:37	AH	5	5	-	-	-	-	W -> N	23	84
09.07.17	16:28	AH	6	2	-	-	-	-	SSE boundary	37	64
27.06.18	08:04	AH	8	7	-	-	-	-	W -> S, bottom boundary of VI	23	37
27.06.18	08:07	AH	10	9	-	-	-	-	NE -> SE	30	66
27.06.18	08:07	AH	3	18	-	-	-	-	Circling in the W of the VI	19	40
27.06.18	08:09	AH	3	11	-	-	-	-	S -> E -> N, boundary of the VI	27	64-44
27.06.18	08:10	AH	2	11	-	-	-	-	E -> SE -> S	26	63
27.06.18	08:11	AH	6	10	-	-	-	-	W -> N	30	39

Ring buffer analysis

The ring buffer analysis without altitude-differentiation does not show a gradient in flight frequentation from the outside to the inside of the wind farm (Figure 24). There are therefore no indications of the red kites discernibly flying around the wind farms or individual turbines. Similarly, for the relevant area at rotor height a differentiation of the data into flight altitude categories (below, at, and above rotor height respectively) did not yield indications of a potential avoidance behaviour with regard to the rotor area.

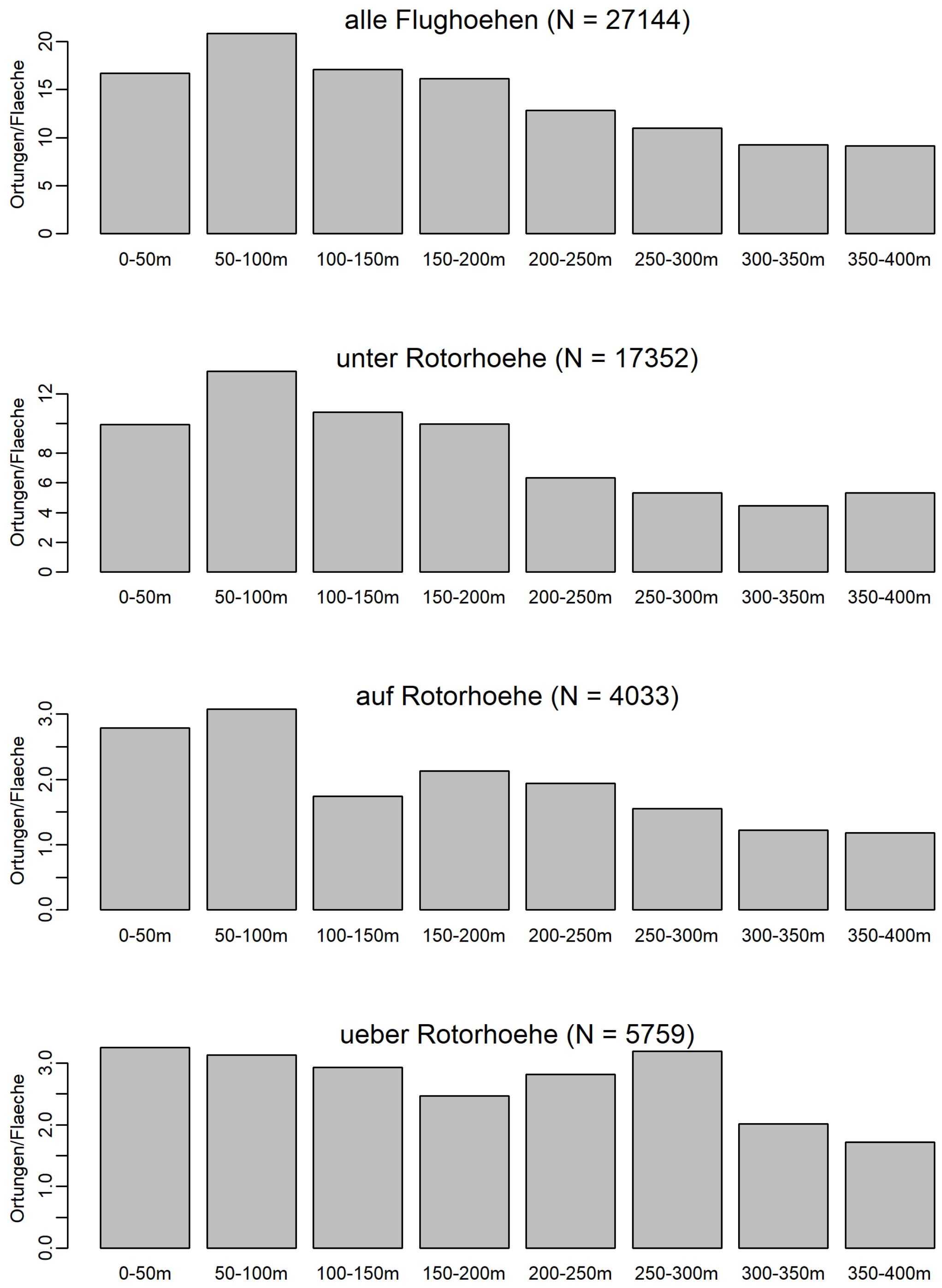

Figure 24: Results of the ring buffer analysis (telemetry points/ha in each of the ring buffers) for all flight altitudes and differentiated by flight altitude categories.

DE **Fig. 24**	EN
Ortungen/Fläche	Telemetry points/area

alle Flughöhen	all flight altitudes
unter Rotor…	below rotor height
auf Rotor …	at rotor height
über Rotor …	above rotor height

5 Winter seasons of 2016/17 and 2017/18

Maik Sommerhage (NABU Landesverband Hessen)

Pursuant to an agreement between the federal state of Hesse and NABU Landesverband Hessen e.V., outside of the breeding season (August to February) the conservation organisation may report on the transmitter birds' journey to their overwintering areas and their life in those areas, for example by means of the "On tour mit Milan" NABU blog ("On tour with the red kite"; www.Rotmilan-Blog.de). While we take the opportunity here to present this study component, it is not a component of the project reported here.

The key issues on which NABU hopes to obtain information are:

- Roosting congregations during migration (potential findings regarding important congregation areas and landmarks used as guides during migration). It is of interest, for example, for how long autumnal roosting sites exist and whether these might be traditional roosting sites.
- Migration altitudes and speeds.
- With regard to the winter roosting sites it is of interest, for example, to see how far the red kites fly each day from their roosts, whether there are any gender-specific differences, and what the birds primarily feed on (following the abandonment of many baiting sites and rubbish dumps, in Spain for example). Close cooperation with local ornithologists is envisaged to this end.
- Risk analysis during migration and in the overwintering area.
- Identification of necessary protection measures.

Important components of this project include awareness-raising with regard to European conservation directives (e.g. Natura 2000), PR work, enhancement of the species' image, networking between red kite experts in Germany and Spain, and educational work in the overwintering area.

2016/17

From October onward all four birds (Noah, Neptune, Tristan and Isolde) stayed on the Iberian Peninsula. Noah and Neptune left the Vogelsberg area on 4 October, Tristan left on 11 October and Isolde left on 13 October. While Neptune spent the winter in southern

Portugal, the other three birds overwintered in Spain (Noah in the Extremadura region near Badajoz, Tristan at a rubbish dump near Madrid, and Isolde in northern Spain near Léon). On 30 January 2017 contact with Tristan was lost. Currently available information suggests that the bird fell victim to poisoning in the vicinity of a rubbish dump.

On 14 February 2017, Noah was the first to start his homeward journey, followed by Isolde on 21 February who reached her previous year's breeding territory on 1 March, and Noah who arrived in his territory on 2 March. Neptune was the last to arrive on 3 March; from 29 March onward he once again stayed in central Hesse on the western edge of the Vogelsberg region.

During the 2016/17 winter season the transmitters' logging intervals ranged from 30 minutes to 4 hours depending on light intensity.

2017/18

From the end of October onward all four birds (Noah, Neptune, Isolde, and Max who had been fitted with a transmitter in 2017) stayed on the Iberian Peninsula. Max left the Vogelsberg area on 17 September, Noah left on 20 September, Neptune left on 30 September and Isolde left on 14 October. Isolde once again overwintered in the Léon area of northern Spain, Max stayed in the area of Salamanca, and Noah spent his second winter in sequence in the Extremadura region. Isolde and Noah chose the same overwintering areas as in the year prior. Sadly, in late October Neptune was killed by traffic at the E 80 motorway in northern Spain.

On 20 February 2018 Noah was the first to start his homeward journey and reached his previous year's breeding territory near Bobenhausen II on 13 March. Max started his return journey on 23 February and on 7 March reoccupied his previous year's nest site near Stockhausen on the eastern edge of the Vogelsberg area. No detailed information is available for Isolde's departure from northern Spain and her arrival in her previous year's breeding territory as only irregular signals have been received from her transmitter since 2017.

During the 2017/18 winter season the transmitters' logging intervals were automated, in keeping with the batteries' charge status. Normally the logging interval was 30 minutes.

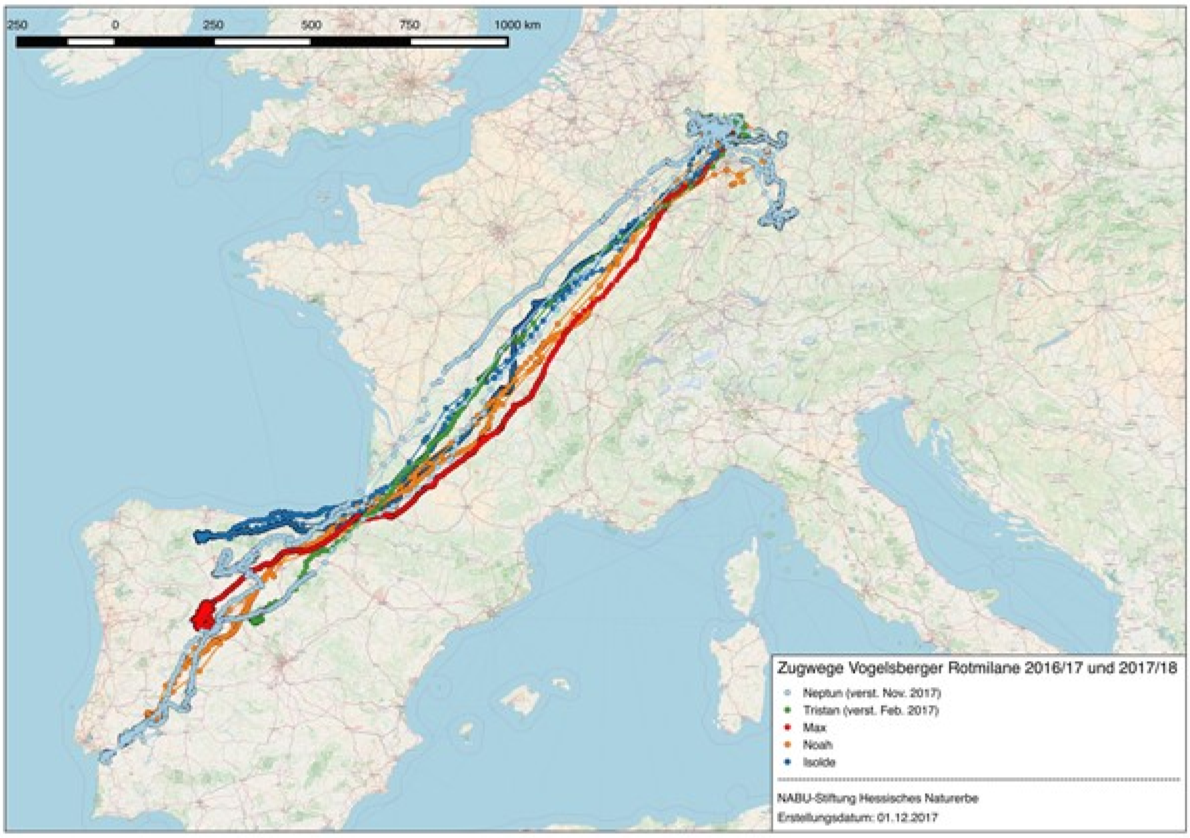

Figure 25: Migration routes from Germany to the Iberian Peninsula of the red kites fitted with transmitters as part of this study.

DE Fig. 25	EN
Zugwege…	Migration routes of the Vogelsberg red kites in 2016/17 and 2017/18
	• Neptun (died Nov. 2017) • Tristan (died Feb. 2017) • …
	NABU-Stiftung Hessisches Naturerbe Map generated 01.12.2017

6 Discussion

6.1 Population density and breeding success

Maik Sommerhage, Kristin Geisler (NABU Landesverband Hessen)

6.1.1 Population density

According to the red kite species action plan for Hesse (*Artenhilfskonzept Rotmilan Hessen*) by Gelpke & Hormann (2012), the species' average population density in the state of Hesse stands at 5.5 breeding pairs per 100 km², with a focus on the low mountain ranges such as the Vogelsberg region, the Rhön Mountains, the Westerwald region and the Rothaar Mountains. The Vogelsberg region has traditionally hosted population densities above the statewide average (PNL 2011). However, methodologically consistent, large-scale and long-term red kite surveys are lacking. The values for population densities determined as part of this study confirm this assessment.

In the study's focal area of Ulrichstein the population density was found to be 18–20 pairs per 100 km² while the Freiensteinau area hosted 27–29 pairs. Therefore the currently determined population densities for both 2016 and 2017 are considerably higher than the estimated statewide average for Hesse and also exceed the values determined by, among others, the baseline data survey (PNL 2011) on sample areas in the Vogelsberg region (75 pairs on 63,000 ha which is equivalent to close to 12 pairs per 100 km²). However, in this context it is important to take into consideration that this survey did not include extensive forest areas such as the Oberwald in which red kites breed at comparatively lower densities than in areas characterised by smaller woodland areas.

The population densities of approximately 20-30 breeding pairs per 100 km² determined as part of the current study compare well to the current figures for the population centres in the state of Saxony-Anhalt (Nagel et al. 2019). In the state of Baden-Württemberg an area is considered a red kite population centre if it hosts upwards of 11.7 breeding pairs per 100 km² (LUBW 2015; Nagel et al. 2019).

6.1.2 Breeding success

In the study's focal area of Ulrichstein, each breeding pair raised 0.5 juveniles and each successful breeding pair raised 1.3 juveniles per year on average over the two years of the study. Breeding success was slightly higher in the study's focal area of Freiensteinau with 0.8 juveniles per breeding pair and 1.6 juveniles per successful breeding pair. Overall, the species' breeding success as recorded in the study's two focal areas is considerably lower than the figures indicated by the baseline data survey (PNL 2011), i.e. 1.4 juveniles per breeding pair and 1.8 juveniles per successful breeding pair. An up-to-date review of the red kites' breeding success in Hesse shows that the figures determined as part of the baseline data survey are equivalent to the statewide averages which are based on a number of different study areas and years (Hoffmann et al. 2017).

The red kite's breeding success in the study's focal areas of Ulrichstein and Freiensteinau in 2016 and 2017 must therefore be regarded as having been below average. The year 2016, if not both years, was a bad year for mice and also saw multiple heavy rainfall and storm events during the breeding period (Hoffmann et al. 2017) which may explain this result. Density-dependent population regulation may be another explanation for low breeding success under conditions of a high population density, a mechanism that has been shown to be at work in a white-tailed eagle population (Heuck et al. 2017). Statewide, systematically recorded comparative data on breeding success in the years in question could shed light on this issue but are not available. Moreover, given that predation may occur in the course of the nestling phase, the point in time at which breeding success is determined impacts on the result. There are therefore certain differences with regard to the definition and usage of the term "breeding success". For the present study, breeding success was determined at the end of the nestling phase just prior to the juveniles fledging, as the primary goal was to identify suitable birds for capture. If breeding success is determined, for example, at the time of ringing the nestlings, the values would tend to be somewhat higher as later losses of nestlings (due to predation, for example) would not be taken into account.

6.1.3 Comparison with data contained in the integrative masterplan (*Integratives Gesamtkonzept*, IGK) for the Vogelsberg SPA

The integrative masterplan (*Integratives Gesamtkonzept*, IGK) for the Vogelsberg SPA (Regierungspräsidium Gießen 2015) was developed with a view to the drafting of the sub-regional plan for renewable energy in central Hesse (*Teilregionalplan Erneuerbare Energien Mittelhessen*) which was adopted in November 2016. One of the relevant baseline technical inputs to the IGK – especially with regard to bird populations that are sensitive to wind power installations and the habitats of significance to these bird populations – is the regional-level impact assessment, as required by the European Habitats Directive, of the planning and establishment of priority areas for wind energy development in the Vogelsberg SPA (TNL 2015). The data inventory on bird fauna and thus also for the red kites was updated as part of this impact assessment. According to the IGK, the red kite is considered to already be under particular pressure from wind power utilisation in the Vogelsberg area even though its population is currently at a favourable conservation status. Red kites need a sufficient amount of open habitats (including grassland) with good visibility for hunting prey. Pursuant to the statutory instrument establishing the Vogelsberg SPA/Natura 2000 site and the species-specific protection objectives set out therein, management measures are required for the species as part of the overall site management. Information on the nest site locations and territorial centres are of major importance for the functional implementation of the management measures in a manner that benefits as many birds as possible and also with a view to targeting measures, for example at areas in which the territories of multiple pairs overlap.

Map 2.3 in the Annex contrasts the survey data from 2016 and 2017 with the data compiled as part of the integrative masterplan (IPG). A comparison of the survey data obtained as part of this project in 2016 and 2017 with the IGK data indicates that there is an underlying dynamic to the red kite nest locations involving regular small-scale locational shifts. The reasons for these moves are not known but may be related to failed hatches (these are regularly followed by moves cf. Gelpke & Hormann 2012) or the loss of nest trees (i.a. as a result of fallen nests following adverse weather events). Only long-term surveys over many years might allow for definitive and, in particular, valid conclusions to be drawn in this regard.

It should be noted, however, that the red kite survey as part of this project covered relatively large areas (131 km² Ulrichstein, 84 km² Freiensteinau). In contrast, the compilation of data for the IGK was based on comparatively smaller mapping units as well as different survey years; data sources included, among others, the baseline data collection for the SPA (PNL 2011), the Hessian breeding bird atlas (HGON 2010), planning documents for several wind power developments and information provided by conservation organisations. Given that these sources steadily added new findings to the IGK – albeit only with reference to specific sub-areas – while the older data remained as components of the IGK and were denoted as secondary nest sites, Map 2.3 depicts numerous secondary nest sites. TNL (2015) note that "where several records could be assigned to a territory, the latest record was marked as the 'territory'; all additional records were marked as 'secondary nest sites' insofar as they could reasonably be concluded to fulfil this function given the existing habitat characteristics." The IGK thus presents summary findings from the past 10 years. A comparison between this summary presentation and the current survey results is of only limited value.

However, more densely populated areas are visible both in the IGK data and in the survey data for 2016 and 2017 as part of this project and these focal areas have remained largely unchanged. They are likely due to the areas' habitat features, in both wooded and open sections of the countryside.

6.2 Analysis of telemetry data

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6.2.1 Home ranges of the red kites fitted with transmitters

Home range size varied between individuals and genders as well as in the course of the breeding season. As expected, due to their stronger nest attachment especially during the incubation phase the females' home ranges were smaller than those of the males studied. It should be borne in mind however that home range sizes were calculated based on different baseline data during the phases of the breeding period (number of telemetry points) and that the birds occupied different territories characterised by differences in resource availability. The birds' home ranges tended to expand in the post-breeding period: once the young birds had fledged the red kites visited the nest sites considerably less frequently and also spent time in other areas of their respective territories. This is also expressed in the cumulative curves for the post-breeding period, depicting the percentage share of telemetry points in relation to distance to the nest site, which are significantly flatter than the cumulative curves for the other phases of the breeding period (siehe Figure 11).

These gender-specific and seasonal differences identified in the Vogelsberg area as well as the fluctuations between the study years are largely congruent with the results of other red kite telemetry studies (Mammen et al. 2013; Gschweng et al. 2014; Pfeiffer & Meyburg 2015). Pfeiffer and Meyburg (2015), for example, found a median home range size of 29.4 km² for 29 males fitted with transmitters, and 23.7 km² for 14 such females (MCP95 method). The authors also found very strong fluctuations between years. Mammen et al. (2013) differentiated between breeding period and post-breeding period and showed that some red kites which had had a rather small home range went on to utilise larger areas in the post-breeding period while others which at first utilised large home ranges confined their activity to smaller areas in the post-breeding period. The authors thus were not able to detect any significant differences in home range sizes between the breeding and post-breeding periods respectively, for males or for females. It is difficult to draw any direct comparisons between the different studies, given that a number of different statistical methods were used to calculate home range size values (e.g. MCP, KUD, AKDE[10]). Moreover, the seasonal differentiation between the phases of the breeding period differed between studies. In general, however, it is reasonable to assume that home range size is significantly impacted by habitat quality and food availability and is therefore also a function of population density. The transferability of results from the home range sizes as calculated for the Vogelsberg area to less diversely structured landscapes is therefore considered to be very limited.

The post-breeding period as defined for the present study (1 July – 30 Sept.) also includes, if breeding was successful, the post-nestling dependence period. There is still a certain level of nest attachment during that period and red kite activity in the vicinity of the nest site can be particularly high due to the now greater number of individuals. However, it is difficult to precisely delimit the period of post-nestling dependence as it is a relatively short phase which varies strongly between individuals depending on the time at which breeding

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[10] MCP = minimum convex polygon, KUD = kernel utilisation density, AKDE = autocorrelated kernel density estimation.

commenced. It is for these reasons that the post-nestling dependence period was not considered separately in the analysis.

A comparison between the cumulative curves given here and other already published cumulative curves on red kite spatial behaviour (Mammen et al. 2013; Gschweng et al. 2014; Pfeiffer & Meyburg 2015) must take into account that baseline data were, at least in part, treated differently. For example, in their chart Pfeiffer & Meyburg (2015) exclusively show telemetry points for males that had bred successfully and limit the analysis to the nestling phase. Moreover, the chart excludes all telemetry points recorded within a 100 m radius of the nest site. As a result of this conservative approach, the curve presented by Pfeiffer & Meyburg (2015) only starts at the distance of 100 m from the nest site and from there rises much less steeply than the cumulative curves given in the present study. Mammen et al. (2013) exclude all telemetry points within a 50 m radius of the nest site and include data recorded by both males and females. Through the exclusion of data recorded in close proximity to the nest sites, any particular percentage share of telemetry points is only reached at a greater distance to the nest site. For comparison, Annex 9 includes the cumulative curves for the Vogelsberg red kites using the methodology employed by Pfeiffer & Meyburg (2015). This shows that the inclusion of the females' telemetry points recorded in close proximity to the nest site significantly affects the curve progression while the inclusion of the males' records makes little difference. A comparison of the data from the rearing period (Annex 9) with the results presented by Pfeiffer & Meyburg (2015) also shows that the transmitter birds in the Vogelsberg region appear to have utilised smaller areas than the Thuringian red kites. During the rearing period in Thuringia, for example, 45% of all telemetry points were recorded within a 1 km radius of the nest site while in the Vogelsberg area during the same phase of the breeding period almost 70% of all telemetry points fell into that radius. These findings indicate major differences in habitat quality.

6.2.2 Diurnal and annual flight activity and flight altitude

Flight activity

The red kites' diurnal flight activity showed a pattern of increasing activity until around noon, followed by a decrease in activity. These results, which were obtained based on up-to-date research methodology, are clearly at odds with the indications given by Südbeck et al. (2005) who describe a diurnal pattern involving peak flight activity between 10:00 and 12:00 hrs and from 16:00 to sunset. The transmitter birds in the Vogelsberg area regularly displayed their highest activity during the period from 12:00 to 16:00 hrs described by Südbeck et al. (2005) as a midday period of rest. The telemetry data obtained for a red kite study in Saxony-Anhalt show a similar pattern of activity to that displayed by the transmitter birds in the Vogelsberg area (Mammen, pers. comm.). It is possible that the information given by Südbeck et al. (2005) is a reference to the optimum time for surveys of nest sites and thus of flights undertaken more closely to the nest sites rather than a general description of a diurnal pattern for the species.

Flight altitude

More than 50% of the telemetry points recorded in flight were located at altitudes of below 50 m. Only approximately 19% of all points were recorded at altitudes of above 100 m. These findings are largely congruent with figures given in earlier studies (Strasser 2006; Mammen et al. 2013). There were significant changes in flight altitudes in the course of the year. The recorded flight altitudes decreased from the courtship period to the rearing period, followed by a slight increase during the post-breeding period. As a general trend, red kites therefore fly at greater altitudes for their courtship and territorial flights (courtship period) than during the later rearing period which is dominated by lower altitude foraging flights needed to feed the young. This pattern was particularly pronounced in the young male Neptune – a possible indication of major differences between young birds/non-breeders and breeding adults.

At first glance the trend toward higher-altitude flights during springtime fits well with the seasonal phenology of the number of cases of collision mortality recorded in Dürr's list (Sprötge et al. 2018). However, the recorded seasonal distribution of dead-bird finds may also be due to other causes. The seasonal pattern of dead-bird finds during the period in which red kites are present in the breeding area may well reflect the actual probability of finding dead red kites which changes in tandem with the height of the vegetation (e.g. better ground visibility in April due to lower plant height). Moreover, Dürr's record of collision victims includes a high number of incidental finds and is not based on a unified methodology or comparable study (Dürr 2019).

Independent of seasonality, diurnal changes in the median of recorded flight altitudes are minor. Flight events at the rotor height of modern WTs (>80 m) were recorded between 6:00 and 20:00 hrs, with few exceptions.

6.2.3 Flight activity, flight altitude and home range size in relation to weather and landform

Meteorological factors such as sunshine duration, temperature and unstable air stratification are important for good thermals and can thus have a positive effect on red kite flight activity. In poor weather conditions, however, such as strong winds or heavy precipitation, flight activity is likely to be lower as such conditions significantly increase the energetic cost of flight. An Italian black kite study was able to show, for example, that foraging performance declined with rainfall while the energetic cost of hunting increased (higher proportion of flapping flight per overall flight time; Sergio 2003). For the transmitter birds in the Vogelsberg area, sunshine duration and unstable air stratification – two important preconditions for thermals – had only a slight positive impact on flight activity. This indicates that individual weather parameters only have a minor impact on red kite flight activity. The analysis of landform indicated weak positive effects on flight activity of slopes with western and south-western aspects (W, SW) which may be due to orographic updrafts generated by the prevailing westerly and south-westerly winds in the Vogelsberg area. However, the small proportion of explained variance in the models shows that these relationships are very weak. The models do not suggest any pronounced behavioural patterns in terms of flight activity.

In contrast to the analysis of flight activity, it is not the environmental variables but the differences between individual birds and study years that account for the the majority of the (low) explained variance in flight altitude. Individual environmental variables explained only a very small proportion of the variance. Wind speed is the variable to most likely have an effect on flight altitude, albeit a weak one.

The analysis of home range size in relation to individual weather parameters similarly showed that environmental parameters explained only minor proportions of the variance. Temperature and unstable air stratification as important preconditions for thermals again had a slight positive effect on the transmitter birds' home range size. A comprehensive Swiss study based on 44 red kites fitted with transmitters was also able to show connections between weather parameters and daily home range sizes. In this study, wind speed and the amount of precipitation were shown to have a negative effect on the daily home range size of the males while they did not impact on the females' home range size (Baucks 2018). Temperature as a parameter was not found to have any significant effect in this analysis. However, in contrast to the Vogelsberg study the Swiss study does not cite R^2 values and therefore the question remains as to whether the weather variables in Switzerland did indeed have any relevant impact on flight behaviour.

Overall, the very low impact of weather parameters on flight activity and flight altitude of the red kites in the Vogelsberg area are surprising. The subjective experiences made by numerous field ornithologists would appear to point to a significantly stronger impact. It is possible that meteorological impacts on red kite flight behaviour are highly complex and cannot be described by means of linear relationships. However, an examination of the raw data does not indicate the presence of, for example, quadratic or similar correlations (see Figure 21). On the other hand, red kite feeding ecology could be well suited to explaining the findings. While red kites can regularly be observed on the ground in search of insects or earthworms, they predominantly search for food in flight. It is therefore not unreasonable to suggest that the flight activity of red kites which predominantly hunt in flight is not as strongly impacted by weather conditions than the flight activity of perch-hunting species such as the common buzzard or the European honey buzzard.

6.2.4 Effect of land use on flight behaviour

The degree to which the different land-use types in a 1.5 km radius around the nest sites were frequented was, as expected, in part reflective of the red kites' feeding ecology. As a bird of prey which hunts in the open countryside the species tends to avoid forests. This is particularly obvious for the "coniferous forest" category. The results are less unambiguous for the "deciduous forest" and "mixed forest" categories. This would appear to be due to the attachment to the nest sites which for the red kites studied here are located in deciduous or mixed forests respectively. This effect is evident despite the exclusion of all telemetry points within a 200 m radius around the nest sites. With regard to open land-use types used for foraging there is an evident trend, in certain months, of a preference for intensive and extensive grassland. Moreover, the analysis suggests that intensively used arable land tends to be frequented less often. Differences in preferences for certain land-use types in the course of the year are in part quite pronounced; these may be due to differences in vegetation height and resultant food availability.

6.2.5 Flight behaviour in the vicinity of wind farms

Weather conditions during flight events in wind farm geofences

Particularly high numbers of telemetry points were recorded in the wind farm geofences when weather conditions were favourable for the development of thermals. In other words, the red kites predominantly visited the geofence areas when weather conditions were favourable overall. Moreover, given that the wind farm geofences are all located at sizeable distances to the nest site, these findings are a further indication of the impact of weather parameters on the red kites' daily home sizes (see Chapter 4.2.4). It appears that overall the red kites do not only fly more frequently but also cover greater distances during clement weather.

Flight events in the vicinity of wind turbines

The ring buffer analysis conducted as part of this study did not indicate any potential avoidance behaviour by the red kites vis-à-vis the wind turbines' rotor areas. This finding confirms the generally held view that red kites do not deliberately fly around the rotor area (see the literature review in Langgemach & Dürr 2019). A more detailed supplementary analysis of flight behaviour in the wind farm area found that several flights out of the 28 recorded flight events in the vicinity of the WT rotors (rotor radius + 10 m buffer) came to within a few metres of the WT shaft axis. In most of the 28 recorded flight events, the direction of flight was parallel to the rotor alignment and therefore outside of the rotor-swept zone. No flythroughs through moving rotors were recorded.

7 Conclusions

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In the three years of the study, a large number of telemetry points was recorded in the red kites' breeding region (800,905 telemetry points by the end of July 2018). The technical capabilities of the transmitter type used (geofences, altimeters) in combination with the locally obtained data on weather conditions and land use offer great potential for the exploration of new aspects of red kite flight behaviour.

Originally it was anticipated that up to 12 red kites would be fitted with transmitters in 2016, the first year of the study. As a result of low catch success, i.e. a total of only six birds in 2016 and 2017, and due to the loss of three transmitter birds (to predation, traffic and poisoning respectively), the available data base is considerably smaller than planned. The resultant limitations exclusively relate to selected issues with regard to flight behaviour in the vicinity of wind farms – specifically the combination of the parameters "land use", "land management" and wind farm operation – and are already taken into consideration in the following summary of the study's main findings with regard to the various focal issues.

Population density and breeding success

- Compared to the state-wide average of 5.5 breeding pairs per 100 km² (Gelpke & Hormann 2012), the study found disproportionately high population densities in both years and in both of the study's focal areas. The population densities in Ulrichstein stood at 19.85 (2016) and 18.32 (2017) breeding pairs per 100 km² respectively. The population densities recorded at Freiensteinau were higher still at 27.38 (2016) and 28.6 (2017) breeding pairs per 100 km². This is due to the relatively low proportion of large contiguous areas of forest in the study areas which are of minor significance for red kites as breeding or foraging habitats.
- The recorded breeding success in 2016 and 2017 was lower than in other parts of the state of Hesse and also lower than success rates recorded in earlier studies conducted in the study area. The figure indicated by the baseline data survey for the Vogelsberg SPA (PNL 2011), i.e. 1.4 juveniles per breeding pair, is congruent with the state-wide average (Hoffmann et al. 2017). In contrast, the present study found lower success rates of 0.44 (2016) and 0.56 (2017) juveniles per breeding pair in Ulrichstein and 0.78 (2016) and 0.82 (2017) juveniles per breeding pair in Freiensteinau.
- In Freiensteinau only 13 out of a total of 32 nest sites were occupied in both years of the study (40.63 %). Nest affinity was significantly lower in Ulrichstein, with 10 out of a total of 41 nest sites occupied in both years of the study (24.39%).
- The integrative masterplan (*Integratives Gesamtkonzept*, IGK) for the Vogelsberg SPA provides a summary of the results of 10 years of red kite surveys. A comparison between this summary presentation and the current survey results is of only limited

value. The surveys conducted in 2016 and 2017 confirmed the presence of the red kite population foci discernible in the IGK data.

Home ranges of the red kites fitted with transmitters

The calculation of home range sizes provided a basis for the analysis of the individual birds' spatial behaviour.

- Home range size varied between individuals and genders as well as in the course of the breeding season. As expected, the females' home ranges were smaller than those of the males studied. Home range sizes continuously expanded during the post-breeding period.
- In one of the breeding seasons two birds provided the opportunity to compare gender-specific levels of attachment to the vicinity of the nest site. Periods of strong nest attachment (courtship, incubation, and rearing period) are of particular interest in this regard. Compared to the courtship period, nest attachment increased during the incubation period and then strongly decreased again during the period of rearing the young (nestling period). During the post-breeding phase as a period of low nest attachment, the distances covered by the female Isolde finally approached those covered by the male Noah, whose home range size showed only minor variation across the various phases of the breeding period.

Diurnal and annual red kite flight activity and flight altitude

- The red kites' diurnal flight activity showed a pattern of increasing activity until around noon, followed by a decrease in activity.
- Between mid-April and June, regularly more than 60% of all telemetry points recorded during the hours around noon (approximately 11:00 -15:00 hrs) were recorded in flight.
- The dispersion of flight altitude values increased from mid-morning to afternoon while the median remained almost constant between 9:00 and 19:00 hrs.
- Apart from a small number of outliers, flight events at the rotor height of modern WTs (>80 m) were recorded between 6:00 and 20:00 hrs.
- Out of the telemetry points recorded in flight, 81% were recorded at altitudes of less than 100 m and 72% were recorded at less than 75 m above ground level.

Flight activity, flight altitude and home range size in relation to weather and landform

The available baseline data proved to be well-suited to the analysis of the effect of the environmental variables (weather, landform etc.) on the transmitter birds' flight activity, thus meeting one of the key project objectives.

- Western and south-western slopes had a weak positive effect on flight activity which may be explained by orographic updrafts at these locations.
- Sunshine duration and unstable air stratification, two weather variables that are important preconditions for thermals, had a slight positive effect on flight activity.
- Wind speed had a slight negative effect on flight altitude.
- Under conditions of higher temperatures and unstable air stratification, the transmitter birds tended to have larger daily home ranges.
- The overall influence of weather variables on the red kites' flight behaviour was very minor. It was not possible to deduct from weather variables any distinct behavioural patterns in terms of flight activity, flight altitude or daily home range size.

Effect of land use and land management on flight behaviour

It was possible to determine the degree to which individual red kites frequented different land-use types and agriculture management events. The available data did not however allow for differentiation between different management events.

- Most of the land-use types were not utilised by the birds proportionally to their share in land cover. However, significant differences were found for almost all land-use types in the course of the breeding season as well as between individual red kites.
- Sites that had recently been subject to agricultural management tended to be visited more frequently than sites not currently managed.

Flight behaviour in the vicinity of wind farms

The analysis of flight behaviour in the vicinity of wind farms is based on a solid sample size (nine geofences, four birds). However, only data recorded by the red kite Noah in the Ulrichstein-Platte wind farm geofence were available for a combined consideration of land use, land management and wind farm operation. This small sample size did not yield robust results.

- The red kites did not evidently fly around entire wind farms or individual wind turbines.
- 28 flight events were recorded in the vicinity of the WT rotors (rotor radius + 10 m buffer). Several flights were recorded that came to within a few metres of the WT

shaft axis. In most of the flight events, the direction of flight was parallel to the rotor alignment and therefore outside of the rotor-swept zone. No flythroughs through moving rotors were recorded.

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C. Heu

(M.Sc.-Biol. Christian Heuck)

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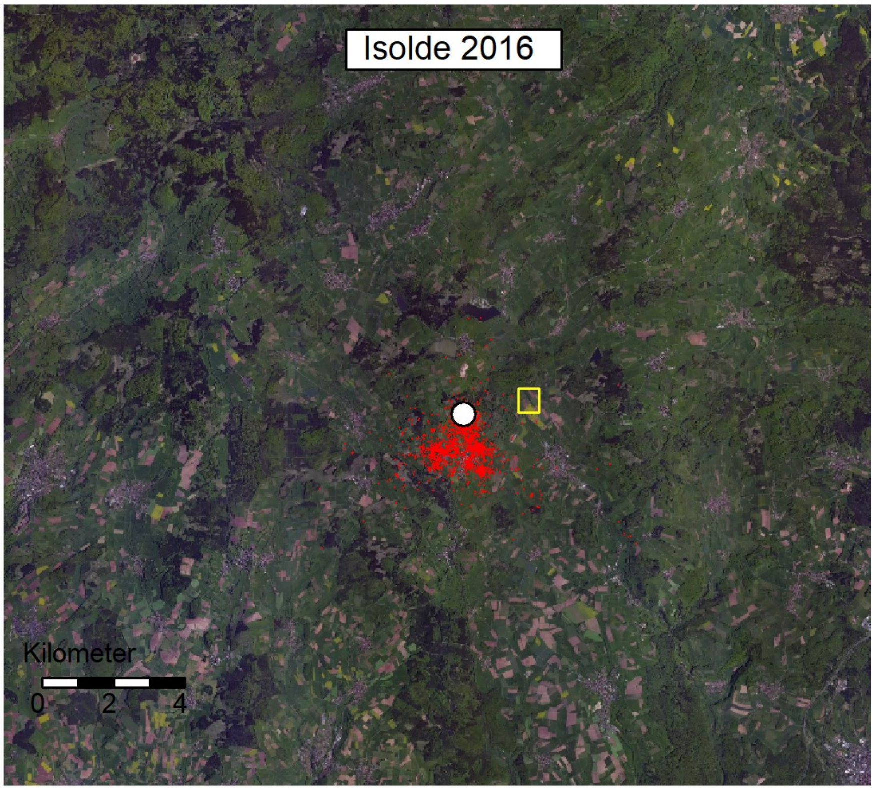
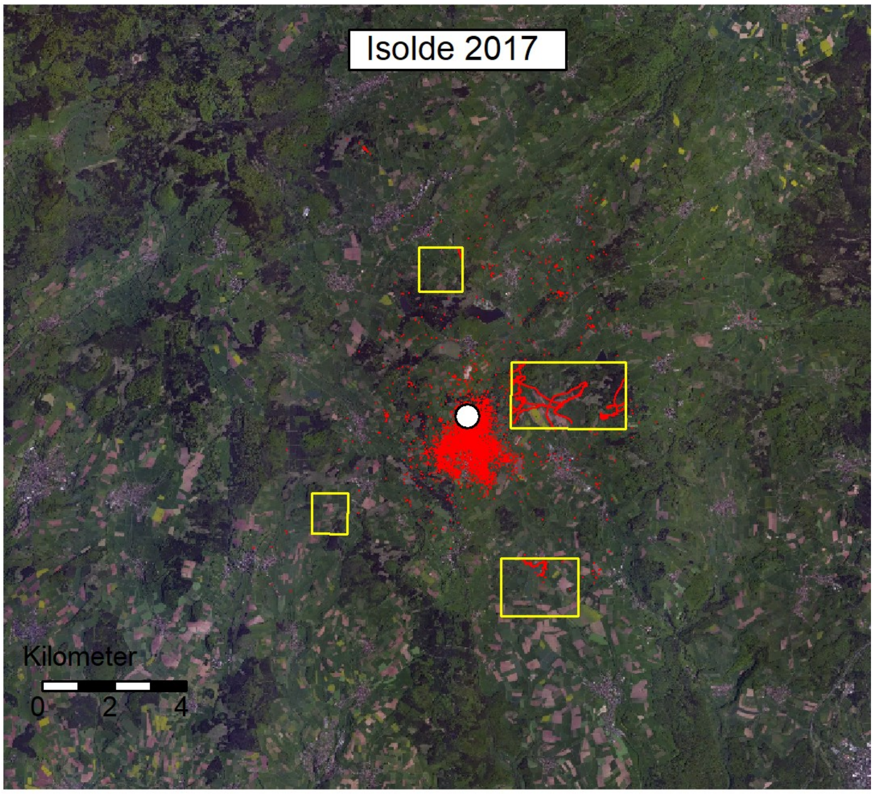
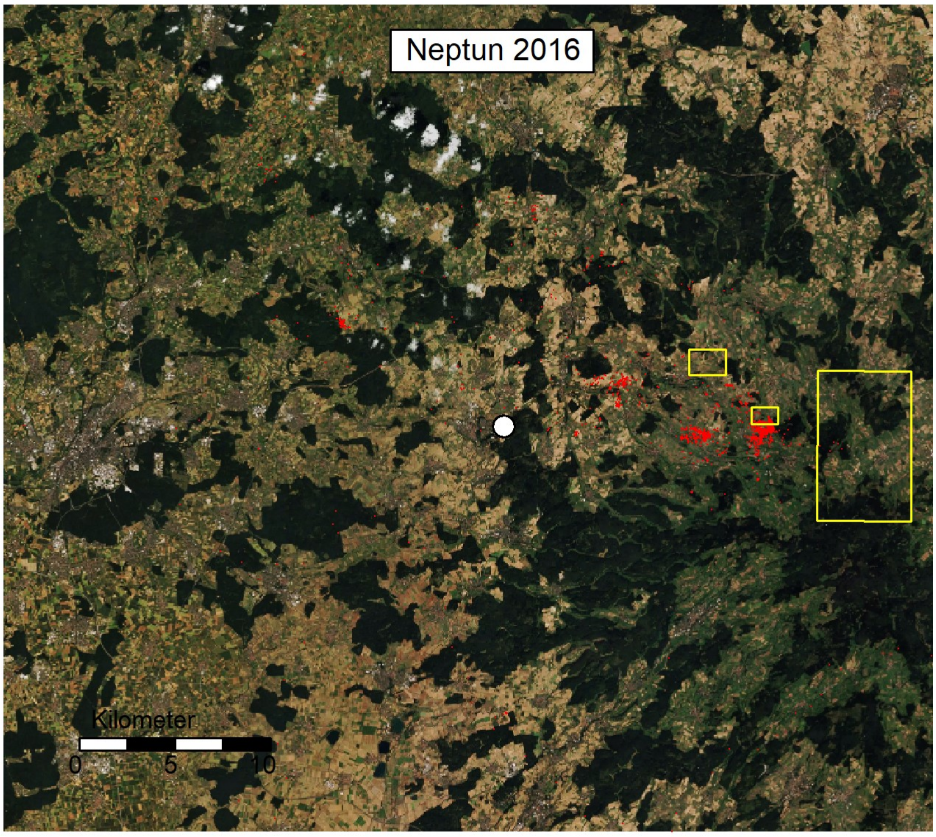
9 Annex

Annex 1: Overview of data points recorded for all transmitter birds in the breeding area. The white dots denote the individual bird's nest site; yellow rectangles denote geofences. Baseline map: Google.



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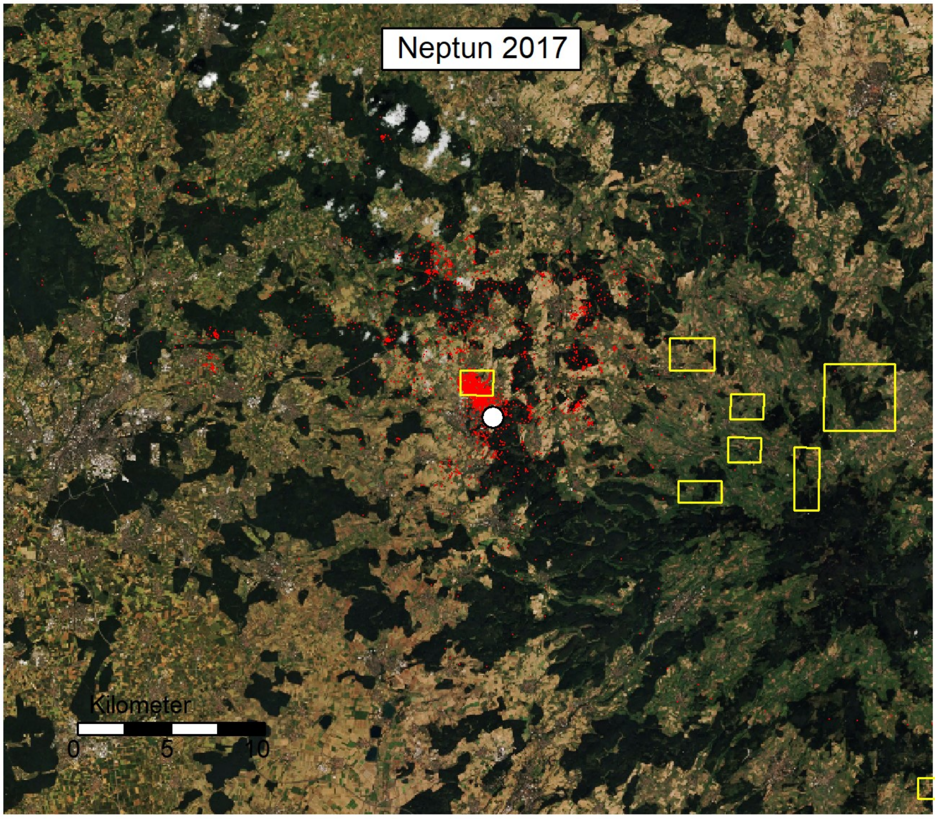
Kilometer
0
5
10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Kilometer
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5
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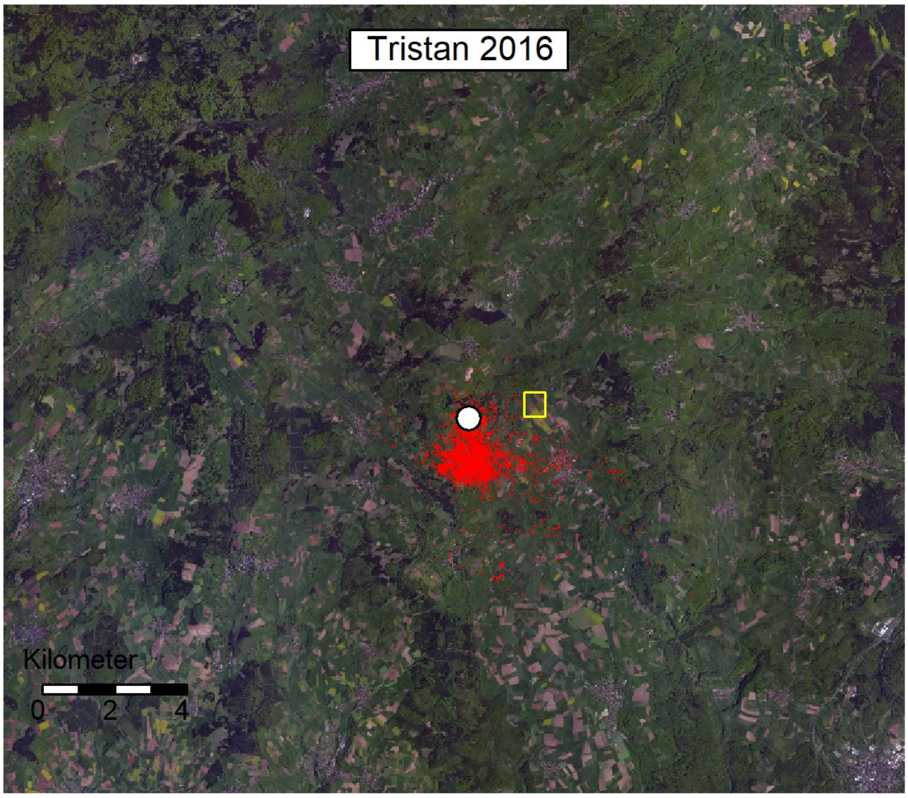
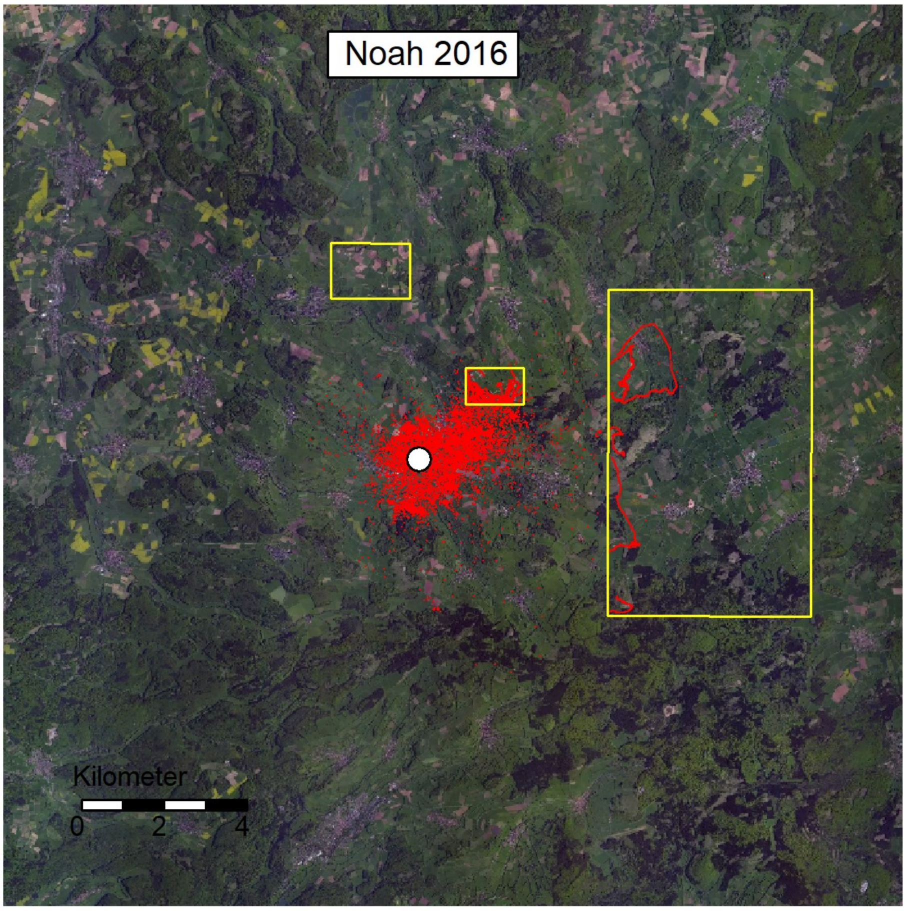
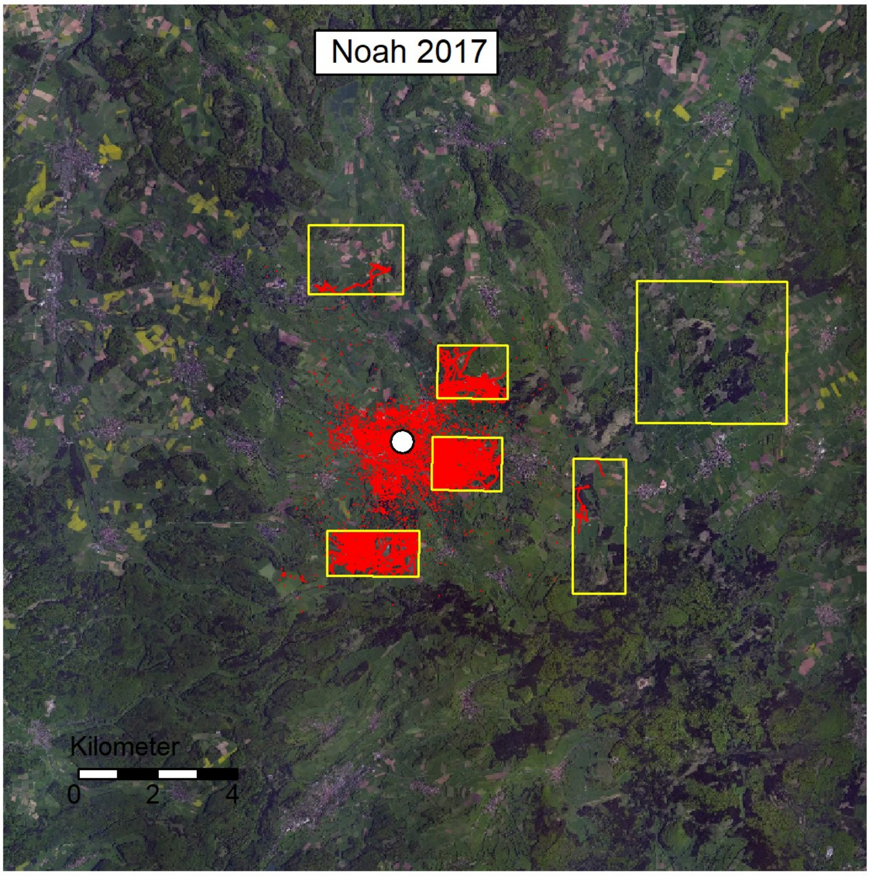

Tristan 2016
Kilometer
0
2
4


Noah 2016
Kilometer
0
2
4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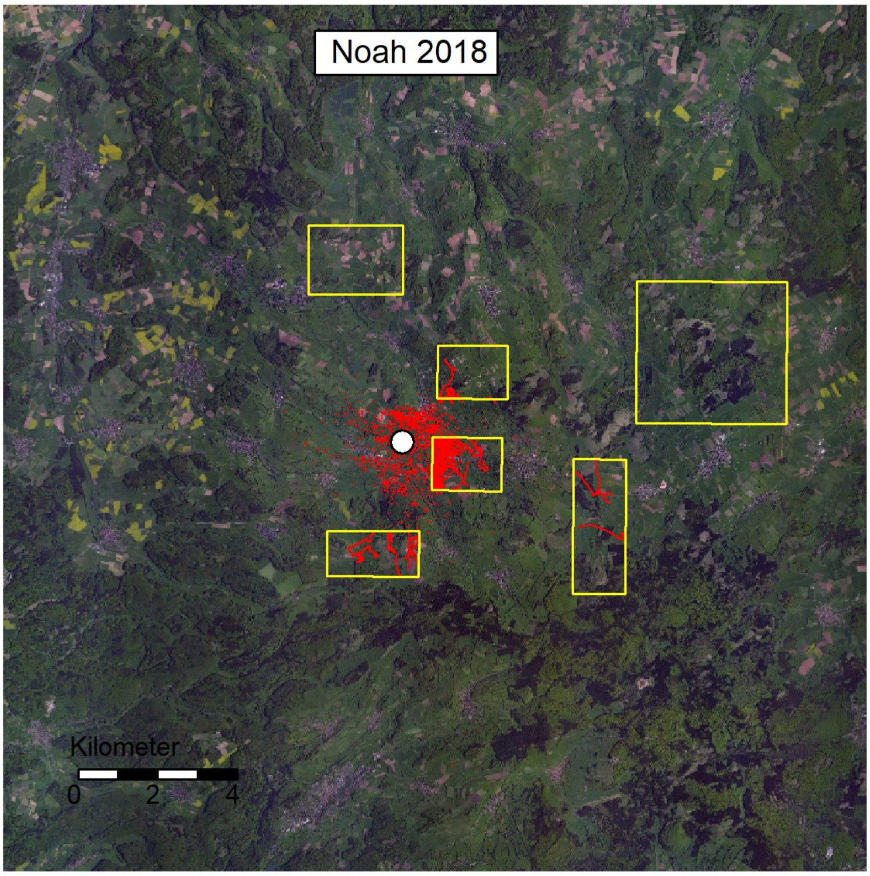
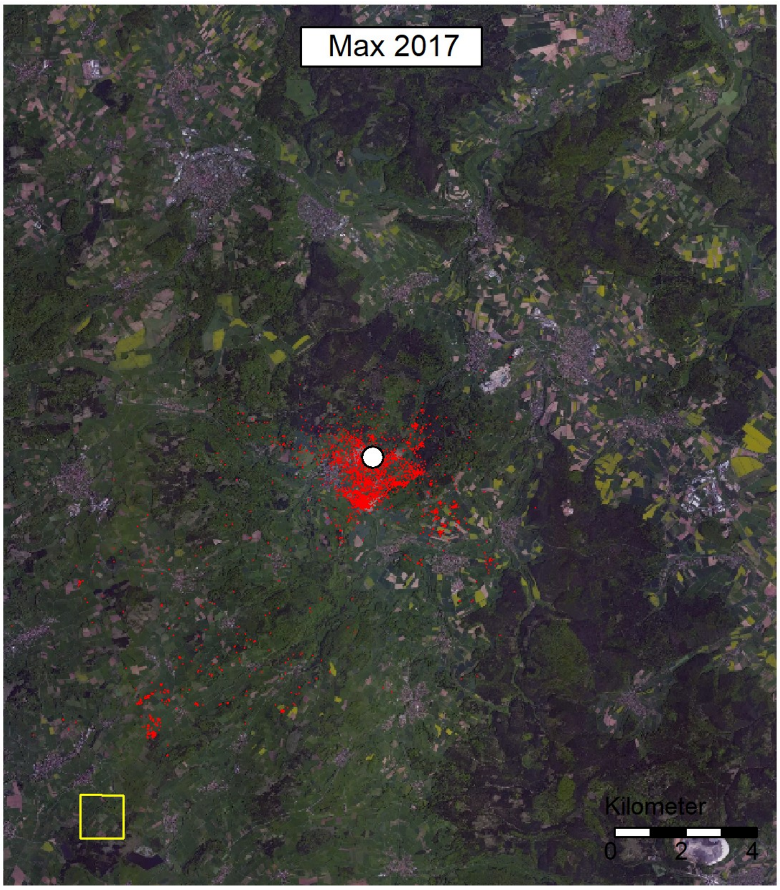
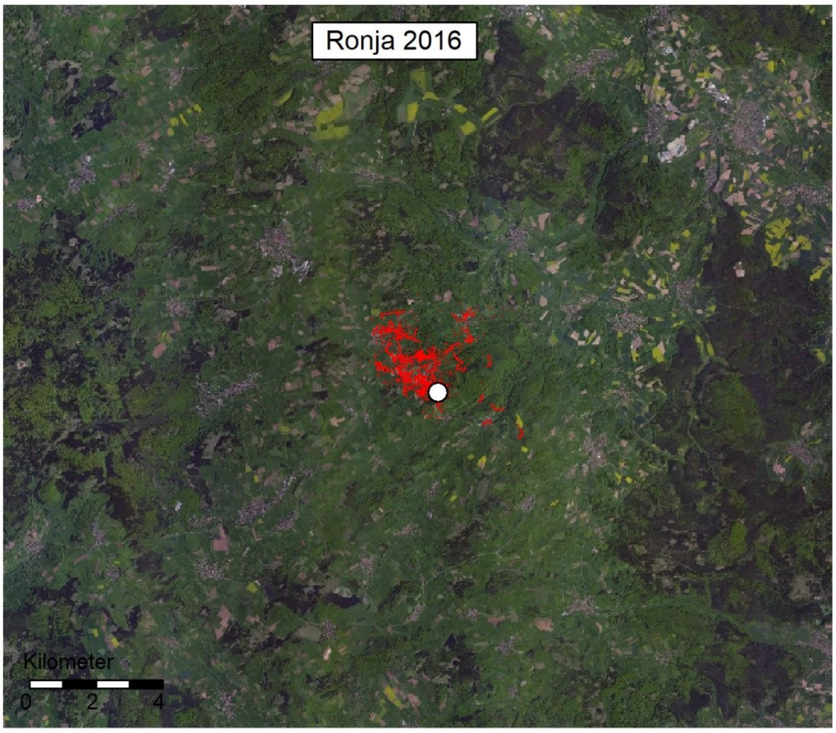
Kilometer
0
2
4


Noah 2018
Kilometer
0
2
4

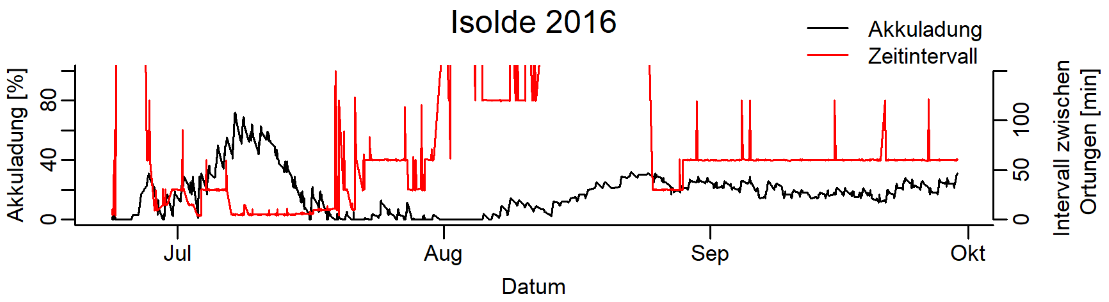

Max 2017
Kilometer
0
2
4

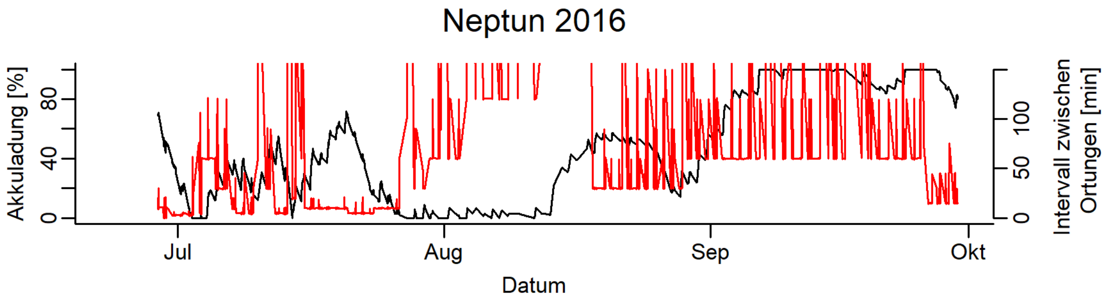

Max 2018
Kilometer
0
2
4

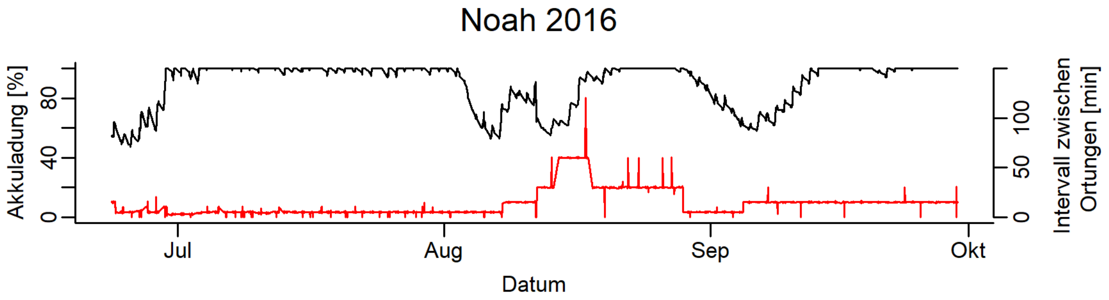

Ronja 2016
Kilometer
0
2
4

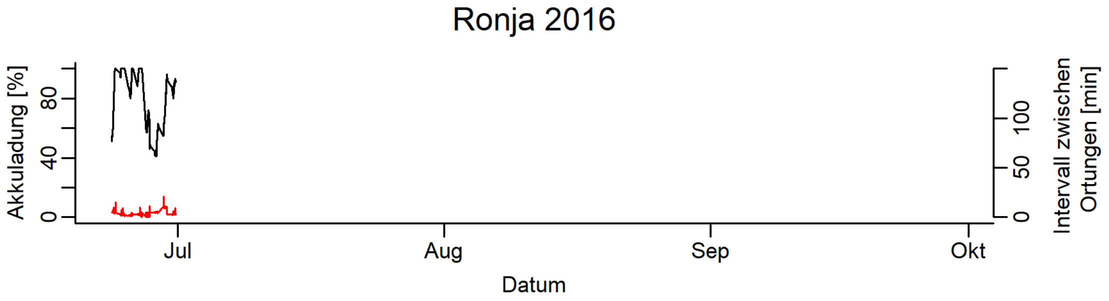
Annex 2: Battery charge status (%) and logging intervals for the red kites fitted with transmitters in the study period (March to the end of September 2016-2018). For improved visualisation of the short intervals, logging intervals >150 min. are not shown.

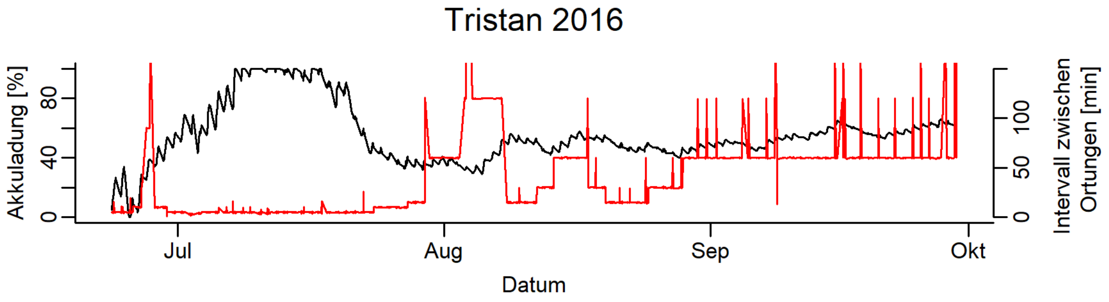
Annex 2– DE	– EN
Akkuladung [%]	Battery charge [%]
Zeitintervall	Time interval
Intervall zwischen Ortungen [min]	Logging interval [min]
Datum	Date
Jul / Aug / Sep / Okt	Jul / Aug / Sep / Oct
Mrz / Mai / Jul / Sep	Mar / May / Jul / Sep
Mrz / Apr / Mai / Jun / Jul / Aug	Mar / Apr / May / Jun / Jul / Aug

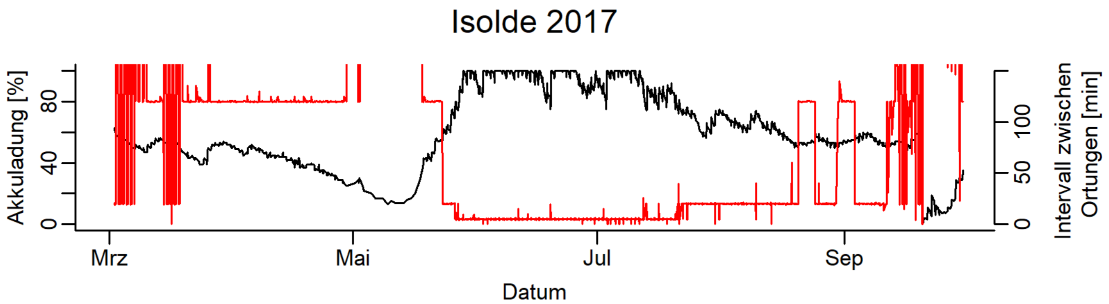

Isolde 2016
Akkuladung
Zeitintervall
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
Jul
Aug
Sep
Okt
Datum

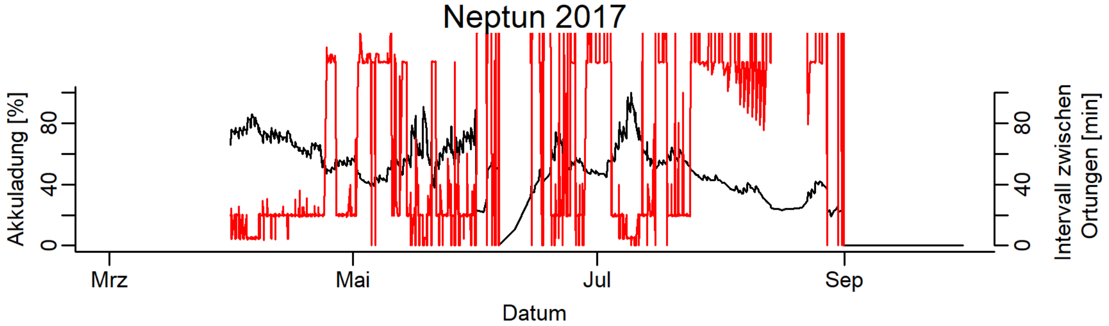

Neptun 2016
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
Jul
Aug
Sep
Okt
Datum

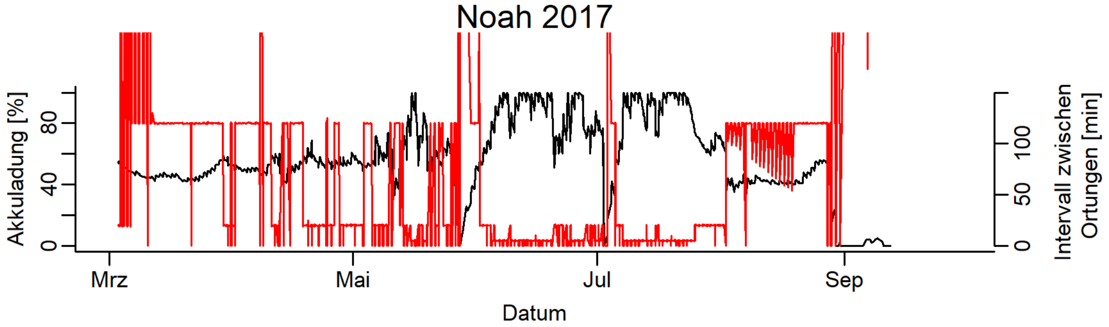

Noah 2016
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
Jul
Aug
Sep
Okt
Datum

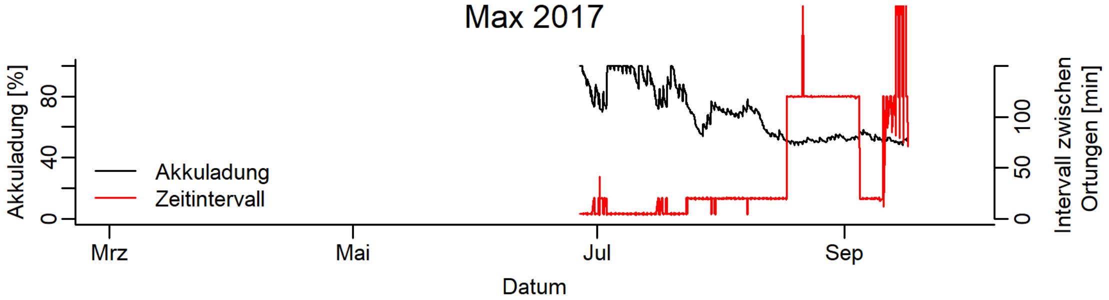

Ronja 2016
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
Jul
Aug
Sep
Okt
Datum

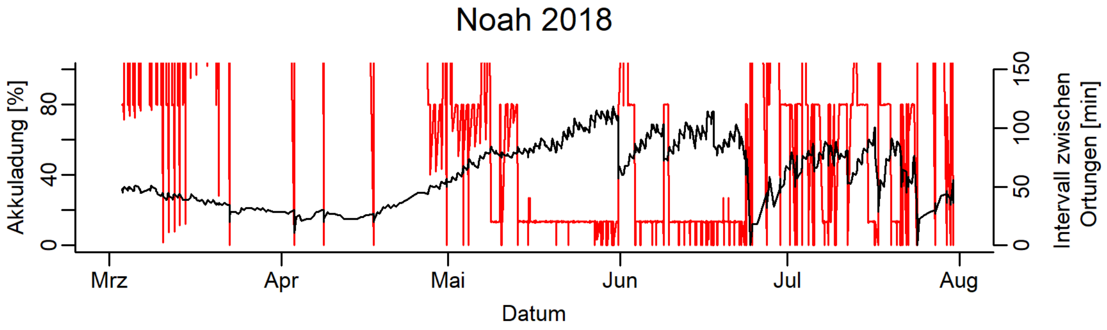

Tristan 2016
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
Jul
Aug
Sep
Okt
Datum

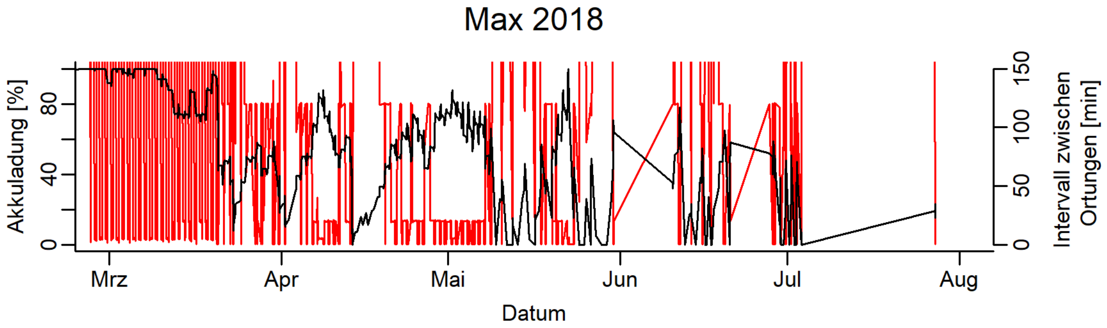

Isolde 2017
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
Mrz
Mai
Jul
Sep
Datum


Neptun 2017
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
40
80
Mrz
Mai
Jul
Sep
Datum


Noah 2017
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
Mrz
Mai
Jul
Sep
Datum


Max 2017
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
Akkuladung
Zeitintervall
Mrz
Mai
Jul
Sep
Datum


Noah 2018
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
150
Mrz
Apr
Mai
Jun
Jul
Aug
Datum


Max 2018
Akkuladung [%]
0
40
80
Intervall zwischen Ortungen [min]
0
50
100
150
Mrz
Apr
Mai
Jun
Jul
Aug
Datum

Annex 3: Overview of recorded red kite hatches in study years 2016 and 2017. The ID number in the first column is equivalent to the numbers in Maps 2 and 3. NA = Not Available (nest site not occupied or not yet known).

ID	Area	Nest site / territory	2016 Breeding success	2016 No. of young	2017 Breeding success	2017 No. of young
1	Freiensteinau	Nest site	successful	2	successful	1
2	Freiensteinau	Nest site	successful	1	successful	1
3	Freiensteinau	Nest site	successful	2	failure	none
4	Freiensteinau	Nest site	successful	2	successful	1
5	Freiensteinau	Nest site	successful	1	failure	none
6	Freiensteinau	Nest site	successful	2	successful	2
7	Freiensteinau	Nest site	successful	2	successful	2
8	Freiensteinau	Nest site	successful	1	failure	none
9	Freiensteinau	Nest site	successful	1	failure	none
10	Freiensteinau	Nest site	successful	2	failure	none
11	Freiensteinau	Nest site	successful	2	successful	2
12	Freiensteinau	Nest site	failure	none	successful	1
13	Freiensteinau	Nest site	failure	none	not known	not known
14	Freiensteinau	Nest site	failure	none	successful	2
15	Freiensteinau	Nest site	failure	none	NA	NA
16	Freiensteinau	Nest site	failure	none	NA	NA
17	Freiensteinau	Nest site/territory	failure	none	not known	not known
18	Freiensteinau	Nest site	failure	none	failure	none
19	Freiensteinau	Nest site	failure	none	failure	none
20	Freiensteinau	Nest site	failure	none	failure	none
21	Freiensteinau	Nest site	failure	none	common buzzard	??
22	Freiensteinau	Nest site	failure	none	NA	NA
23	Freiensteinau	Nest site/territory	failure	none	not known	not known
24	Ulrichstein	Nest site	successful	2	successful	1
25	Ulrichstein	Nest site	successful	2	NA	NA
26	Ulrichstein	Nest site	successful	1	not known	not known
27	Ulrichstein	Nest site	successful	1	failure	none
28	Ulrichstein	Nest site	successful	1	successful	1
29	Ulrichstein	Nest site	successful	1	failure	none
30	Ulrichstein	Nest site	successful	2	successful	2
31	Ulrichstein	Nest site	successful	1	successful	1
32	Ulrichstein	Nest site	failure	none	NA	NA
33	Ulrichstein	Territory	not known	not known	not known	not known
34	Ulrichstein	Nest site	failure	none	NA	NA
35	Ulrichstein	Nest site	failure	none	NA	NA

ID	Area	Nest site / territory	2016 Breeding success	2016 No. of young	2017 Breeding success	2017 No. of young
36	Ulrichstein	Nest site	failure	none	failure	none
37	Ulrichstein	Nest site	failure	none	NA	NA
38	Ulrichstein	Nest site	failure	none	NA	NA
39	Ulrichstein	Nest site	failure	none	NA	NA
40	Ulrichstein	Nest site	failure	none	NA	NA
41	Ulrichstein	Nest site	failure	none	NA	NA
42	Ulrichstein	Nest site	failure	none	common buzzard	common buzzard
43	Ulrichstein	Nest site	failure	none	NA	NA
44	Ulrichstein	Nest site	failure	none	NA	NA
45	Ulrichstein	Nest site	failure	none	NA	NA
46	Ulrichstein	Nest site	failure	none	NA	NA
47	Ulrichstein	Nest site	failure	none	common buzzard	common buzzard
48	Ulrichstein	Nest site	failure	none	NA	NA
49	Ulrichstein	Nest site	failure	none	NA	NA
50	Freiensteinau	Nest site	NA	NA	successful	2
51	(Freiensteinau)	Nest site	NA	NA	successful	2
52	Freiensteinau	Nest site	NA	NA	failure	none
53	Freiensteinau	Nest site	NA	NA	successful	1
54	Freiensteinau	Nest site	NA	NA	not known	not known
55	Freiensteinau	Territory	NA	NA	not known	not known
56	Freiensteinau	Nest site	NA	NA	failure	none
57	Freiensteinau	Nest site	NA	NA	successful	2
58	(Freiensteinau)	Nest site	NA	NA	successful	2
59	(Freiensteinau)	Nest site	NA	NA	successful	2
60	(Freiensteinau)	Nest site	NA	NA	successful	1
61	Freiensteinau	Territory	NA	NA	not known	not known
62	(Freiensteinau)	Nest site	NA	NA	successful	1
63	Freiensteinau	Nest site	NA	NA	successful	1
65	Ulrichstein	Nest site	NA	NA	failure	none
66	Ulrichstein	Nest site	NA	NA	successful	1
67	Ulrichstein	Nest site	NA	NA	successful	2
68	Ulrichstein	Nest site	NA	NA	failure	none
69	Ulrichstein	Territory	NA	NA	not known	not known
70	Ulrichstein	Nest site	NA	NA	failure	none
71	Ulrichstein	Nest site	NA	NA	failure	none
72	Ulrichstein	Nest site	NA	NA	successful	1
73	Ulrichstein	Nest site	NA	NA	failure	none
74	Ulrichstein	Nest site	NA	NA	failure	none
75	Ulrichstein	Nest site	NA	NA	failure	none

ID	Area	Nest site / territory	2016 Breeding success	2016 No. of young	2017 Breeding success	2017 No. of young
76	Ulrichstein	Territory	NA	NA	not known	not known
77	Ulrichstein	Territory	NA	NA	not known	not known
78	Ulrichstein	Territory	NA	NA	not known	not known
79	Ulrichstein	Nest site	NA	NA	successful	1
80	(Ulrichstein)	Nest site	successful	??	successful	3

Annex 4: Results of the home range analyses for individual red kites based on the MCP (Minimum Convex Polygon) und AKDE (Autocorrelated Kernel Density Estimation) methods and using breeding phenology data for 2016, 2017 and 2018 (5-minute dataset).

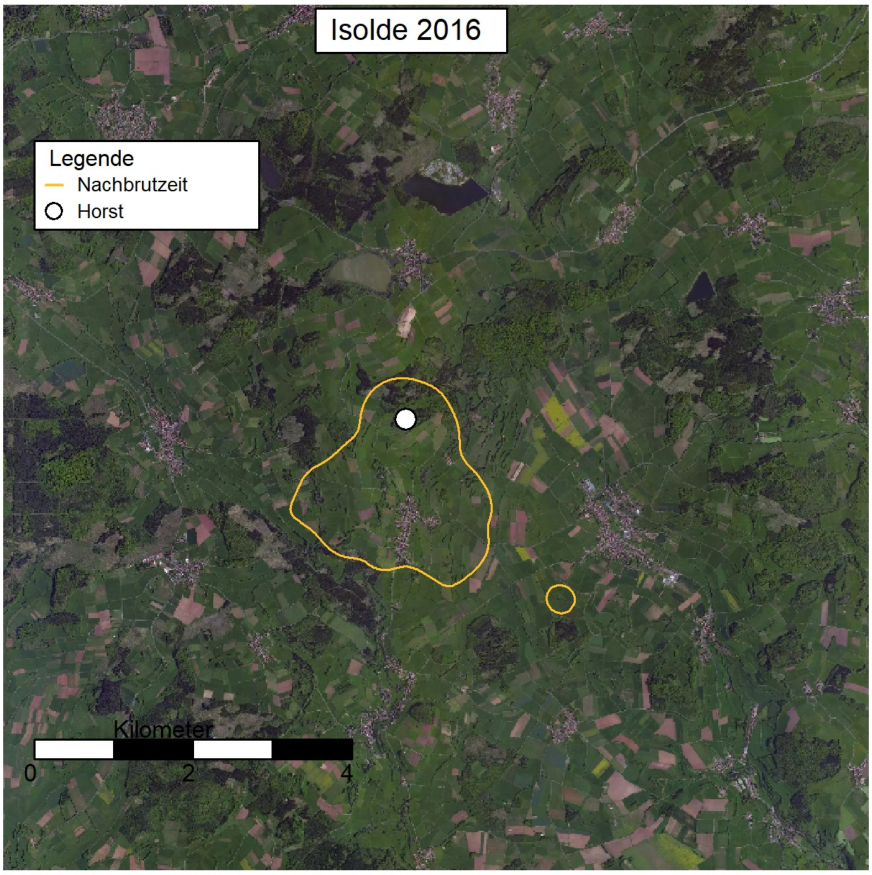
Red kite	MCP 95% [ha]	MCP 75% [ha]	MCP 50% [ha]	AKDE 95% [ha]	AKDE 75% [ha]	AKDE 50% [ha]
Home range 2016 post-breeding period (1 July – 30 September) N = 21,819						
Isolde (N = 3,611)	423	395	203	433	167	72
Noah (N = 11,401)	917	171	132	828	341	166
Tristan (N = 6,807)	545	270	161	524	168	78

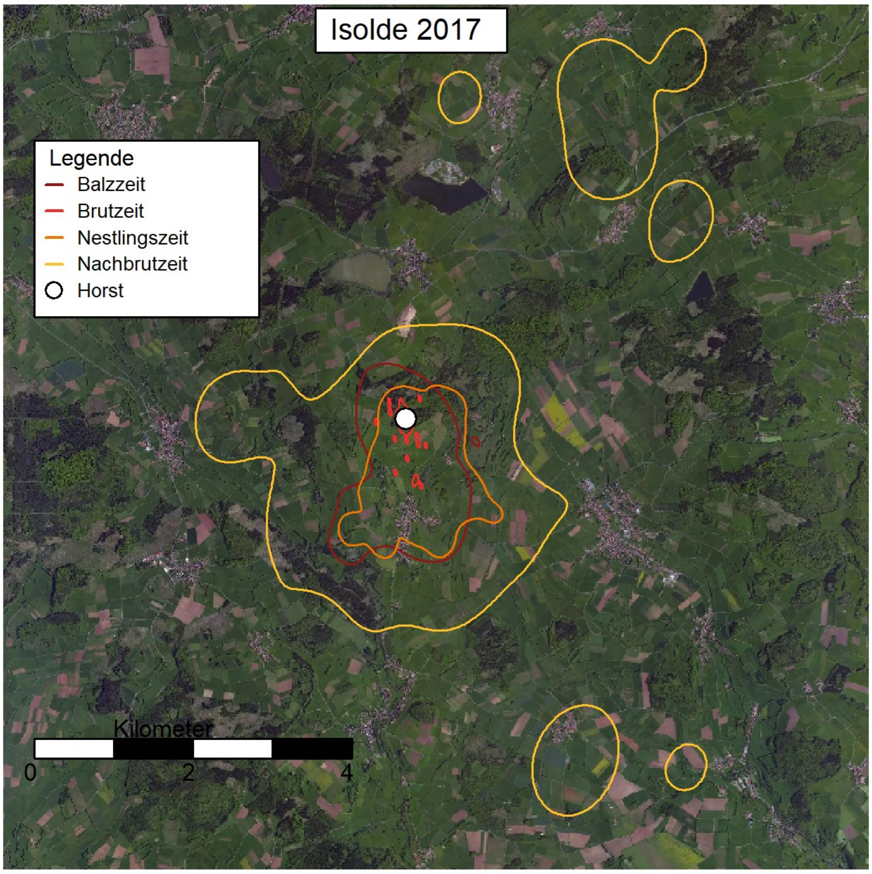
Red kite	MCP 95% [ha]	MCP 75% [ha]	MCP 50% [ha]	AKDE 95% [ha]	AKDE 75% [ha]	AKDE 50% [ha]
Home range courtship period 2017 (15 March – 14 April) N = 692						
Isolde (N = 318)	277	7	4	315	55	20
Noah (N = 374)	1,141	369	60	1.481	466	178
Home range incubation period 2017 (15 April – 19 May) N = 1,793						
Isolde (N = 192)	10	0.2	0.1	10	1	0.6
Noah (N = 1,601)	809	330	97	1,009	381	147
Home range rearing period (nestling period) 2017 (20 May – 30 June) N = 10,904						
Isolde (N = 6,409)	404	89	42	275	83	25
Noah (N = 4,495)	870	281	151	987	341	142
Home range 2017 post-breeding period (1 July – 30 September) N = 14,823						
Isolde (N = 5,582)	4,672	326	149	1,691	334	161
Noah (N = 4,121)	717	286	186	883	359	179
Max (N = 5,120)	10,172	1,239	537	718	190	76

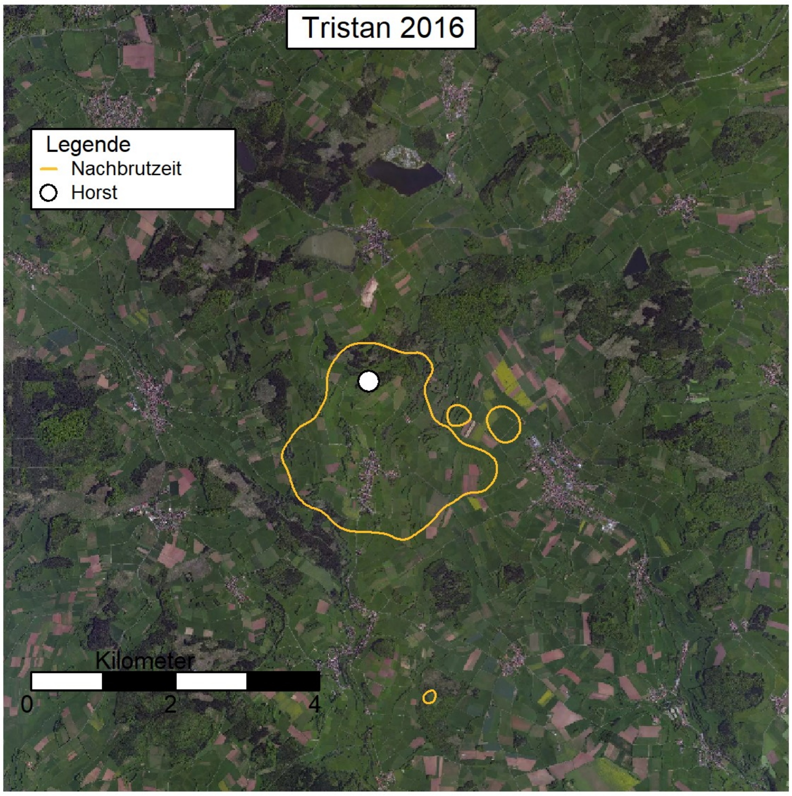
Red kite	MCP 95% [ha]	MCP 75% [ha]	MCP 50% [ha]	AKDE 95% [ha]	AKDE 75% [ha]	AKDE 50% [ha]
Home range courtship period 2018 (15 March – 14 April) N = 1,311						
Noah (N = 94)	295	213	14	786	311	130
Max (N = 1,217)	555	207	114	566	171	73
Home range incubation period 2018 (15 April – 19 May) N = 2,080						
Noah (N = 508)	511	214	32	610	222	64
Max (N = 1,572)	612	162	83	569	172	67
Home range rearing period (nestling period) 2018 (20 May – 30 June) N = 3,417						
Noah (N = 1,834)	579	241	127	628	254	105
Max (N = 1,583)	442	191	37	607	236	105
Home range post-breeding period 2018 (1 July – 30 September) N = 767						
Noah (N = 585)	630	233	92	673	282	134
Max (N = 182)	46	40	31	310	149	79

Annex 5: Result of the home range analysis (95% AKDE). Base map: Google.

Annex 5 – DE	– EN
Legende	Key
Balzzeit	Courtship period
Brutzeit	Incubation period
Nestlingszeit	Nestling period
Nachbrutzeit	Post-breeding period
Horst	Nest site


Isolde 2016
Legende
Nachbrutzeit
Horst
Kilometer
0
2
4


Isolde 2017
Legende
Balzzeit
Brutzeit
Nestlingszeit
Nachbrutzeit
Horst
Kilometer
0
2
4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Legende
Nachbrutzeit
Horst
Kilometer
0
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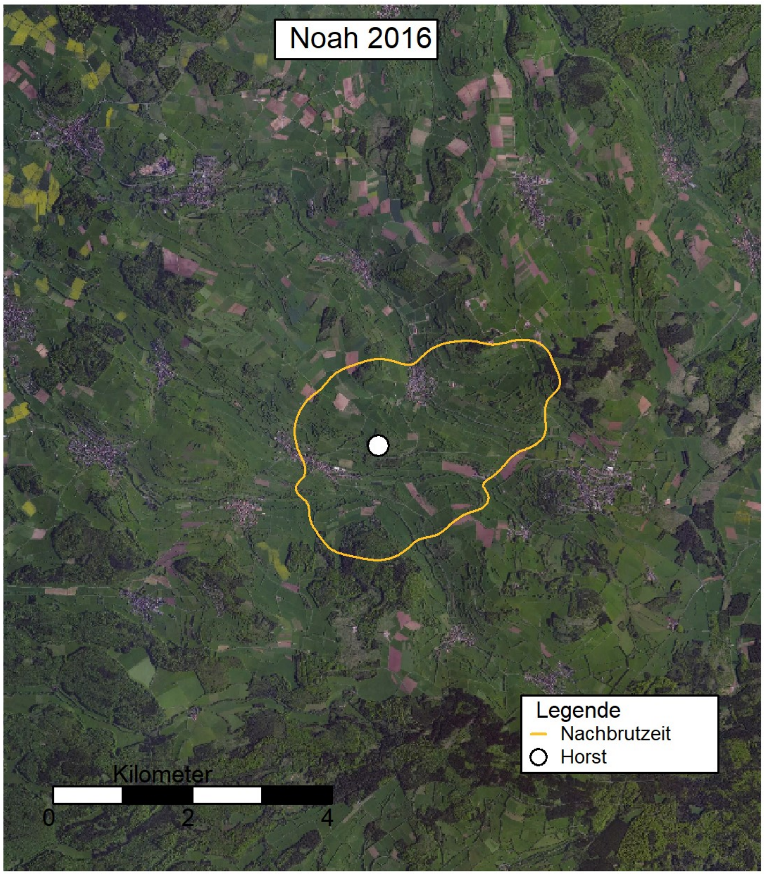
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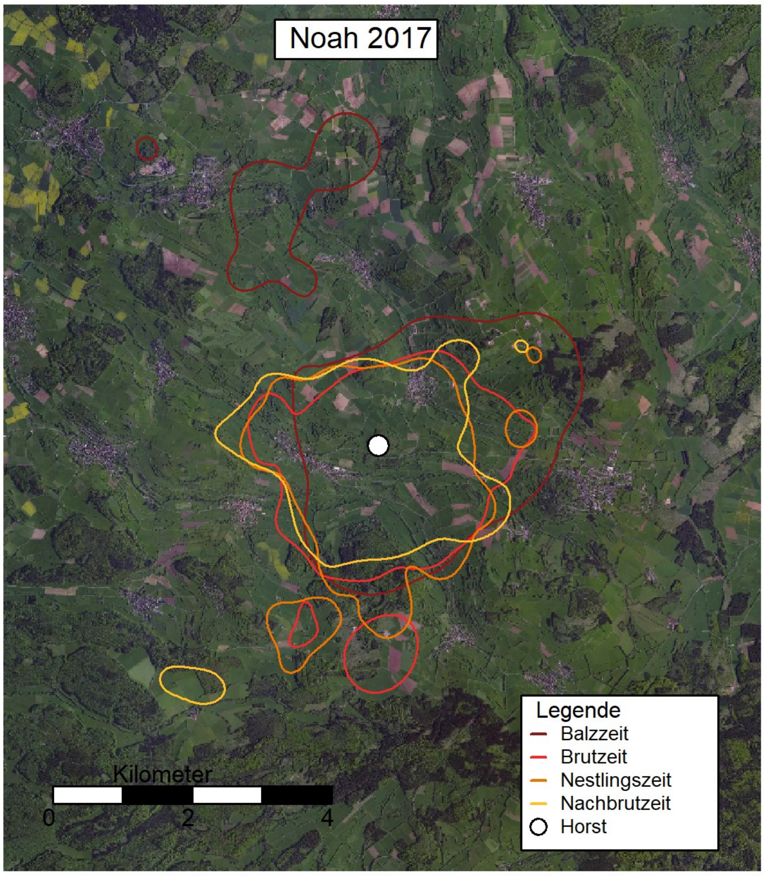
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Legende
Balzzeit
Brutzeit
Nestlingszeit
Nachbrutzeit
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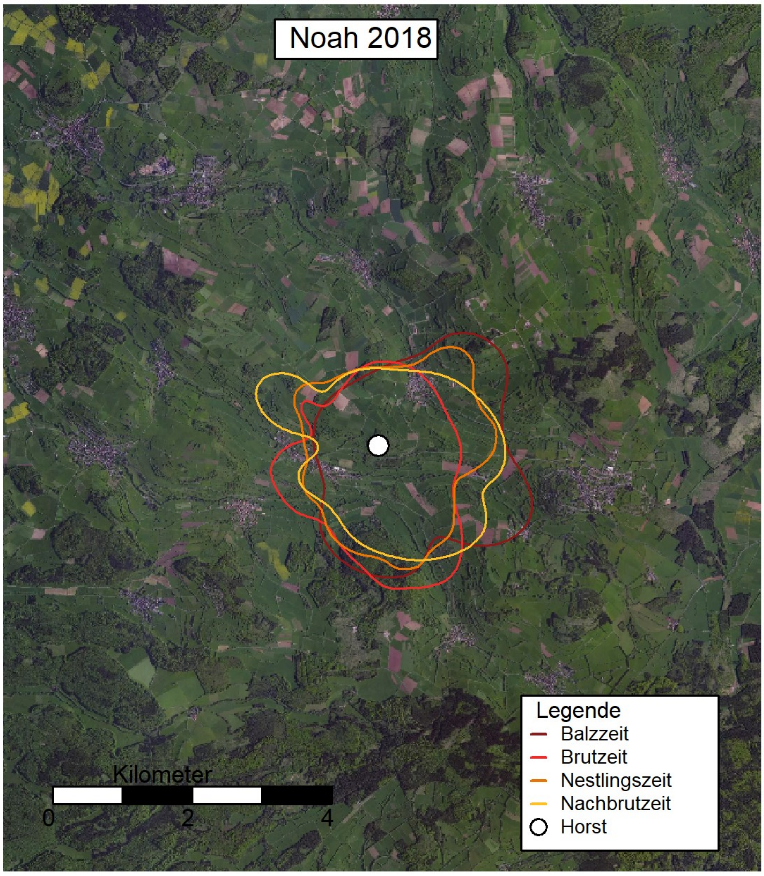
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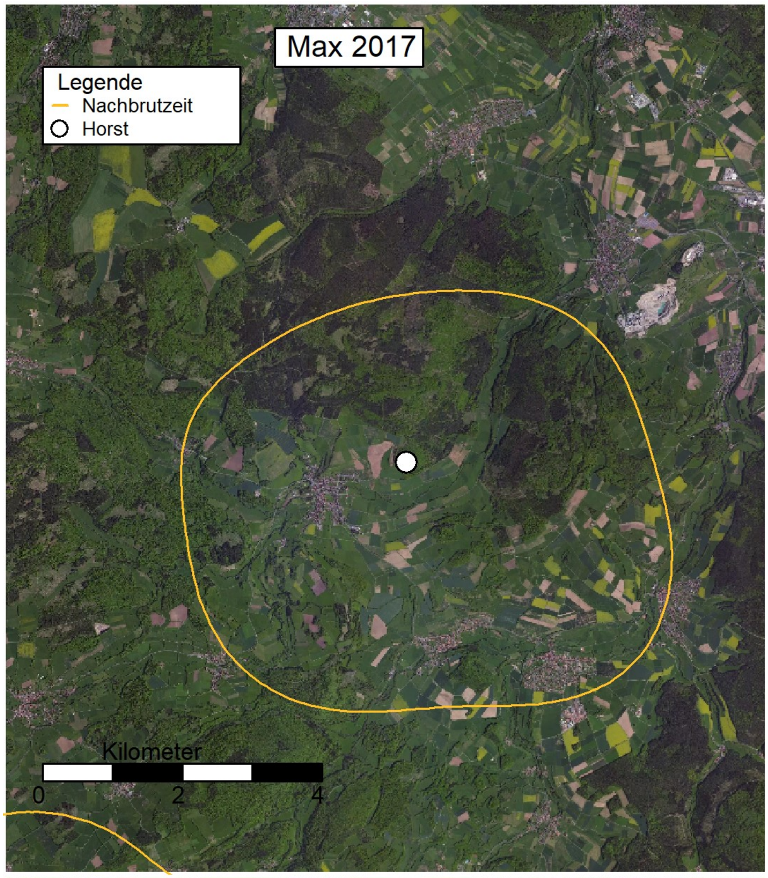
Max 2017
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Nachbrutzeit
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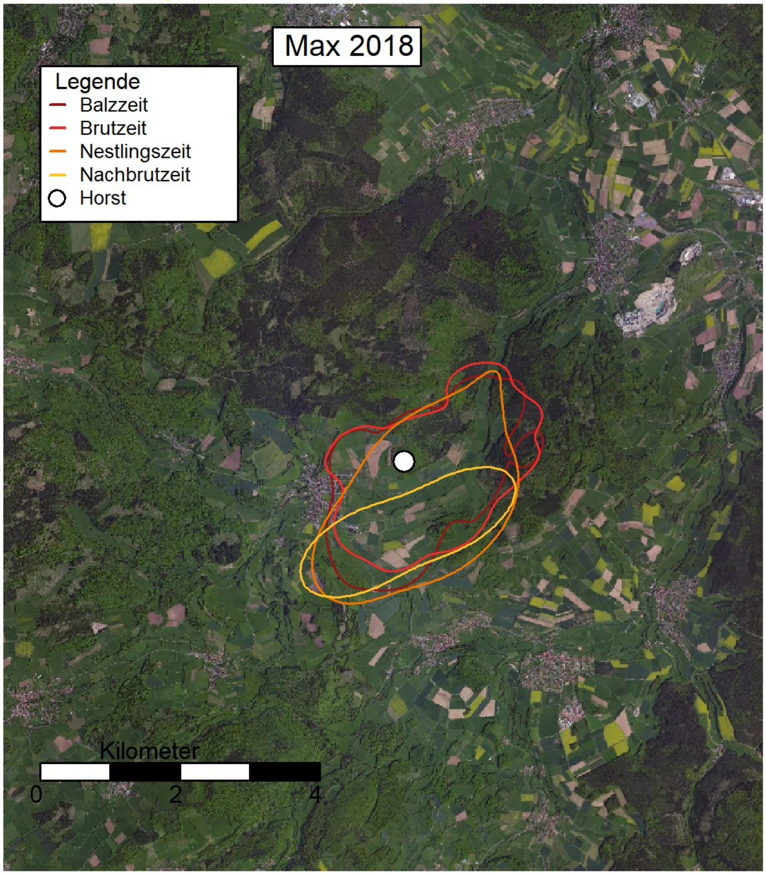
Max 2018
Legende
Balzzeit
Brutzeit
Nestlingszeit
Nachbrutzeit
Horst
Kilometer
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4

Annex 6: Model statistics of four (GLMM) for categorised flight activity (flight/no flight) during four phases of the breeding period. Five weather variables (z-standardised) and categorised landform served as explanatory variables. Bird ID and study year were included as random effects. The effect sizes of the eight slope aspects distinguish from the "no slope" category; therefore no statistical values are available for the "no slope" category.

Metereological variable	**Courtship period** **N = 2,768; N (birds) = 4** **R^2 = 0.385; marg. R^2 = 0.152**			**Incubation period** **N = 4,671; N (birds) = 4** **R^2 = 0.475; marg. R^2 = 0.248**			**Rearing period** **N = 20,293; N (birds) = 6** **R^2 = 0.255; marg. R^2 = 0.112**			**Post-breeding period** **N = 36,884; N (birds) = 5** **R^2 = 0.169; marg. R^2 = 0.144**		
	Effect size ± Standard error	**p-value**	**R^2**	**Effect size ± Standard error**	**p-value**	**R^2**	**Effect size ± Standard error**	**p-value**	**R^2**	**Effect size ± Standard error**	**p-value**	**R^2**
Precipitation	- 0.21 ± 0.06	**< 0.001**	0.013	- 0.53 ± 0.09	**< 0.001**	0.025	- 0.34 ± 0.05	**< 0.001**	0.004	- 0.14 ± 0.02	**< 0.001**	0.003
Windspeed	0.39 ± 0.05	**< 0.001**	0.003	0.31 ± 0.04	**< 0.001**	0.003	0.31 ± 0.02	**< 0.001**	0.006	0.38 ± 0.01	**< 0.001**	0.003
Temperature	0.25 ± 0.05	**< 0.001**	0.014	0.15 ± 0.04	**< 0.001**	0.031	- 0.05 ± 0.02	0.018	0.005	0.00 ± 0.01	0.915	0.016
Sunshine duration	0.25 ± 0.05	**< 0.001**	0.033	0.28 ± 0.04	**< 0.001**	0.047	0.21 ± 0.02	**< 0.001**	0.020	0.36 ± 0.02	**< 0.001**	0.034
Air stratification	0.35 ± 0.05	**< 0.001**	0.023	0.34 ± 0.04	**< 0.001**	0.045	0.36 ± 0.02	**< 0.001**	0.020	0.37 ± 0.01	**< 0.001**	0.034
Slope N	0.11 ± 0.15	0.435	0.093	- 0.34 ± 0.11	0.003	0.116	0.01 ± 0.06	0.883	0.027	- 0.37 ± 0.04	**< 0.001**	0.036
Slope NE	0.63 ± 0.30	0.036		0.90 ± 0.23	**< 0.001**		0.09 ± 0.08	0.304		- 0.36 ± 0.06	**< 0.001**	
Slope E	- 0.85 ± 0.19	**< 0.001**		- 1.46 ± 0.17	**< 0.001**		0.29 ± 0.08	**< 0.001**		- 0.63 ± 0.06	**< 0.001**	
Slope SE	- 1.00 ± 0.16	**< 0.001**		- 1.58 ± 0.16	**< 0.001**		- 0.60 ± 0.05	**< 0.001**		- 0.59 ± 0.05	**< 0.001**	
Slope S	- 1.12 ± 0.16	**< 0.001**		- 1.82 ± 0.11	**< 0.001**		- 0.32 ± 0.05	**< 0.001**		0.32 ± 0.04	**< 0.001**	
Slope SW	0.82 ± 0.23	**< 0.001**		0.13 ± 0.16	0.415		0.91 ± 0.07	**< 0.001**		0.70 ± 0.05	**< 0.001**	
Slope W	0.15 ± 0.21	0.492		- 0.11 ± 0.14	0.403		0.52 ± 0.07	**< 0.001**		0.46 ± 0.05	**< 0.001**	
Slope NW	- 0.60 ± 0.16	**< 0.001**		0.02 ± 0.14	0.864		0.06 ± 0.06	0.338		- 0.14 ± 0.06	0.009	

Annex 7: Model statistics of four (LMM) for continuous flight altitude during four phases of the breeding period. Five weather variables (z-standardised) and categorised landform served as explanatory variables. Bird ID and study year were included as random effects. The effect sizes of the eight slope aspects distinguish from the "no slope" category; therefore no statistical values are available for the "no slope" category.

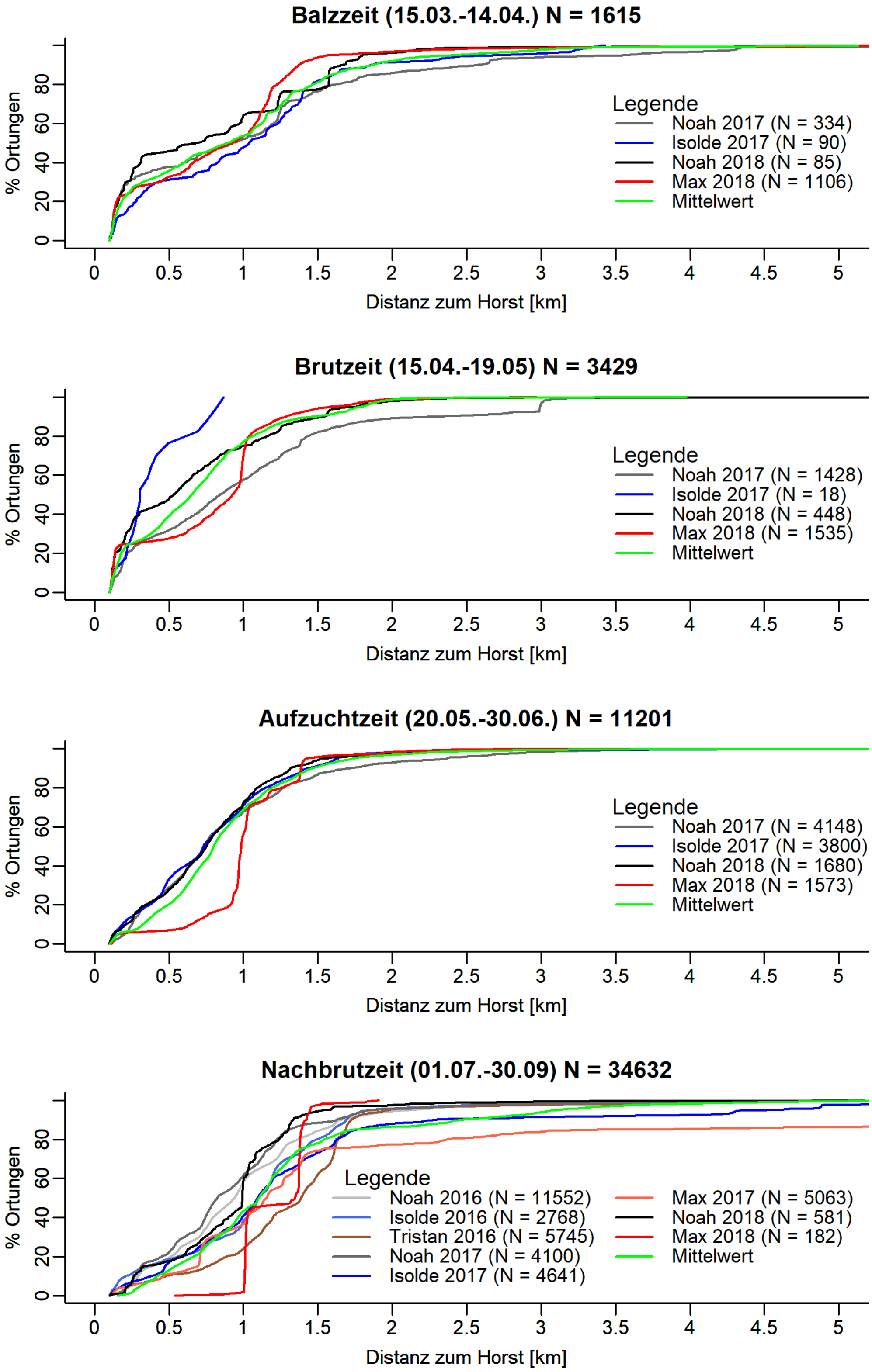
Weather variable	**Courtship period** **N = 1,216; N (birds) = 4** **R^2 = 0.133; marg. R^2 = 0.056**			**Incubation period** **N = 1,662; N (birds) = 4** **R^2 = 0.095; marg. R^2 = 0.019**			**Rearing period** **N = 8,252; N (birds) = 6** **R^2 = 0.062; marg. R^2 = 0.013**			**Post-breeding period** **N = 11,107; N (birds) = 5** **R^2 = 0.112; marg. R^2 = 0.032**		
	Effect size ± Standard error	**p-value**	**R^2**	**Effect size ± Standard error**	**p-value**	**R^2**	**Effect size ± Standard error**	**p-value**	**R^2**	**Effect size ± Standard error**	**p-value**	**R^2**
Precipitation	- 0.01 ± 0.03	0.741	0.005	-0.03 ± 0.02	0.244	0.001	-0.01 ± 0.01	0.204	0.001	-0.01 ± 0.01	0.498	0,001
Windspeed	- 0.11 ± 0.03	0.002	0.079	-0.09 ± 0.03	0.001	0.015	-0.09 ± 0.01	**< 0.001**	0.005	-0.08 ± 0.01	**< 0.001**	0,019
Temperature	0.06 ± 0.03	0.074	0.081	0.03 ± 0.03	0.392	0.000	-0.07 ± 0.02	**< 0.001**	0.001	0.02 ± 0.01	0.072	0,015
Sunshine duration	0.03 ± 0.03	0.360	0.004	0.02 ± 0.03	0.363	0.000	0.02 ± 0.01	0.111	0.001	0.05 ± 0.01	**< 0.001**	0,018
Air stratification	0.09 ± 0.03	0.004	0.035	-0.06 ± 0.03	0.024	0.001	0.06 ± 0.01	**< 0.001**	0.004	0.06 ± 0.01	**< 0.001**	0,022
Slope N	- 0.01 ± 0.08	0.859	0.042	-0.01 ± 0.07	0.933	0.018	0.08 ± 0.04	0.061	0.009	-0.20 ± 0.03	**< 0.001**	0,003
Slope NE	0.06 ± 0.14	0.677		0.07 ± 0.12	0.571		-0.17 ± 0.06	0.003		-0.09 ± 0.05	0.084	
Slope E	0.12 ± 0.12	0.311		0.06 ± 0.14	0.679		-0.16 ± 0.06	0.003		-0.15 ± 0.05	**< 0.001**	
Slope SE	- 0.00 ± 0.11	0.967		0.09 ± 0.12	0.461		-0.03 ± 0.04	0.376		-0.06 ± 0.04	0.171	
Slope S	- 0.15 ± 0.11	0.168		0.23 ± 0.09	0.009		-0.01 ± 0.04	0.851		-0.11 ± 0.03	**< 0.001**	
Slope SW	0.02 ± 0.11	0.853		0.09 ± 0.11	0.379		-0.04 ± 0.04	0.328		-0.11 ± 0.03	**< 0.001**	
Slope W	- 0.10 ± 0.11	0.363		-0.02 ± 0.09	0.847		0.02 ± 0.05	0.637		-0.06 ± 0.03	0.079	
Slope NW	- 0.18 ± 0.10	0.056		-0.11 ± 0.09	0.190		-0.01 ± 0.05	0.746		-0.13 ± 0.04	0.001	

Annex 8: Distance to nest site within which 50%, 75% and 90% respectively of all telemetry points were recorded during the various phases of the breeding period in 2017 and 2018.

Red kite	**95% [km]**	**75% [km]**	**50% [km]**
Courtship period 2017 (15 March – 14 April) N = 692			
Isolde (N = 318)	1.514	0.147	0.038
Noah (N = 374)	3.274	1.361	0.708
Incubation period 2017 (15 April – 29 May) N = 1,793			
Isolde (N = 192)	0.297	0.031	0.022
Noah (N = 1,601)	2.991	1.281	0.741
Rearing period (nestling phase) 2017 (20 May – 30 June) N = 12,055			
Isolde (N = 6,409)	1.510	0.825	0.281
Noah (N = 4,495)	2.323	1.312	0.709
Max (N = 1,151)	1.494	1.156	0.872
Post-breeding period 2017 (1 July – 30 September) N = 14,823			
Isolde (N = 5,582)	4.292	1.411	0.990
Noah (N = 4,121)	1.852	1.167	0.821
Max (N = 5,120)	9.554	1.524	1.147

Rotmilan	**95 % [km]**	**75 % [km]**	**50 % [km]**
Courtship period 2018 (15 March – 14 April) N = 1,311			
Noah (N = 94)	1.788	1.237	0.406
Max (N = 1,217)	1.539	1.169	0.780
Incubation period 2018 (15 April – 29 May) N = 2,080			
Noah (N = 508)	1.649	0.876	0.384
Max (N = 1,572)	1.572	1.012	0.916
Rearing period (nestling phase) 2018 (20 May – 30 June) N = 3,417			
Noah (N = 1,834)	1.508	1.001	0.710
Max (N = 1,583)	1.415	1.161	0.986
Post-breeding period 2018 (1 July – 31 July) N = 767			
Noah (N = 585)	1.534	1.119	0.994
Max (N = 182)	1.446	1.378	1.353

Annex 9: Percentage share of telemetry points by breeding phonology in relation to distance to nest site for the entire study period. Telemetry points within 100 m around the nest site are not included in this figure.



Annex 10: Number of telemetry points and available area by recorded management events per calendar week in 2016.

Surveyed site/area	**Tristan and Isolde**	**Tristan and Isolde**	**Tristan and Isolde**	**Tristan and Isolde**	**Tristan and Isolde**	**Noah**	**Noah**	**Noah**	**Noah**	**Noah**
Survey date	06.07.	13.07.	20.07.	27.07.	03.08.	06.07.	13.07.	20.07.	27.07.	03.08.
Calendar week	27	28	29	30	31	27	28	29	30	31
Number of telemetry points per site										
Mowing	8	4				39	2			
Mowing, turning	12		28					2	11	
Turning										
Turning, removal		1	8				1	3		
Removal	8	1		11			3	2	1	
Harvesting		7	12	13				1	1	
Grazing			1	7				23	13	
Ploughing										
no agricultural management	91	230	80	6		34	72	39	46	99
Total telemetry points/week	119	243	129	37	0	73	78	70	72	99
Site availability										
Mowing	23.81	3.59		2.57		17.27	60.72	2.11		
Mowing, turning	5.52	1.82	7.40	0.44		5.29	9.97	6.34	11.74	5.88
Turning		2.11								
Turning, removal	4.35	21.69	3.59		3.08		17.27	60.72		
Removal	37.08	5.52	3.93	7.40			5.29	9.97	6.34	11.74
Harvesting		0.76	12.39	7.59			1.52	3.14	3.34	
Grazing	4.13	2.24	2.24	3.02	2.24	1.95	2.02	8.86	11.12	5.28
Ploughing										4.33
no agricultural management	64.88	101.62	117.11	127.65	134.98	177.77	91.29	136.86	191.85	166.03
Total surveyed area/week	139.78	139.36	146.66	148.67	140.31	202.29	188.08	228.00	224.39	193.26
Points w. management / area w. management	0.37	0.34	1.66	1.47	0	1.59	0.06	0.34	0.80	0
Points no management / area no management	1.40	2.26	0.68	0.05	0	0.19	0.79	0.28	0.24	0.60

Annex 11: Number of in-flight telemetry points and available area by recorded management events per survey round (telemetry points since last survey and up to current survey day) in 2017 and 2018. *M* = mean.

Red kite	**Noah**															
Survey round (2017)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	*M*
Telemetry points per management																
Grazing	143	3	237	32	690	68	112	45	263	620	231	201	781	431		
Grassland management					692	262	928	2	40		782	492	98			
Sowing (arable land)																
Ploughing (arable land)																
Harvesting (arable land)													6			
Subsoiling (arable land)																
no agricultural management	1073	117	805	1314	1310	565	2588	518	857	4967	1544	891	2246	838	301	
Total telemetry points / round	1216	120	1042	1346	2692	895	3628	565	1160	5587	2557	1584	3131	1269	301	
Site availability																
Grazing	11.6	11.9	12.9	11.9	40.2	40.8	43.3	28.1	51.6	36.6	25.9	26.1	87.4	68.0	29.0	
Grassland management					32.6	177.8	101.7	44.7	44.0	15.3	96.6	104.5	29.9	9.8	1.1	
Sowing (arable land)																
Ploughing (arable land)																
Harvesting (arable land)													1.2			
Subsoiling (arable land)																
no agricultural management	359.4	358.5	358.1	359.1	301.2	151.7	226.0	297.5	274.8	319.0	248.4	240.4	252.6	293.2	340.9	
Total recorded area / round	371.0	370.4	371.0	371.0	374.0	370.4	371.0	370.4	370.4	371.0	371.0	371.0	371.0	371.0	371.0	
Points w. management / area w. management	12.3	0.3	18.4	2.7	19.0	1.5	7.2	0.6	3.2	11.9	8.3	5.3	7.5	5.5	0.0	
Points no management / area no management	3.0	0.3	2.2	3.7	4.3	3.7	11.5	1.7	3.1	15.6	6.2	3.7	8.9	2.9	0.9	
Ratio (>1 = Preference for managed sites)	4.1	0.8	8.2	0.7	4.4	0.4	0.6	0.4	1.0	0.8	1.3	1.4	0.8	1.9	0.0	***1.8***

Red kite	**Isolde**																
Survey round (2017)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	*M*
Telemetry points per management																	
Grazing																	
Grassland management							14	8	14	34	16	14	13	28			
Sowing (arable land)																	
Ploughing (arable land)																	
Harvesting (arable land)														20	2	1	
Subsoiling (arable land)																	
no agricultural management	2		1	2	1	6	169	100	108	61	85	106	60	78	11	7	
Total telemetry points / round	2	0	1	2	1	6	183	108	122	95	101	120	73	126	13	8	
Site availability																	
Grazing	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.9	5.9	5.9	8.1	8.1	8.1	8.4	
Grassland management					6.1	7.1	18.2	18.6	22.6	26.0	14.2	16.8	24.1	16.6	1.8		
Sowing (arable land)				1.7													
Ploughing (arable land)																	
Harvesting (arable land)														8.1	24.0	4.0	
Subsoiling (arable land)																	
no agricultural management	168.8	168.8	168.8	167.1	162.7	161.6	150.6	150.2	146.2	142.0	153.8	151.2	141.7	141.1	140.1	161.5	
Total recorded area / round	173.9	173.9	173.9	173.9	173.9	173.9	173.9	173.9	173.9	173.9	173.9	173.9	173.9	173.9	173.9	173.9	
Points w. management / area w. management	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.3	0.5	1.1	0.8	0.6	0.4	1.5	0.1	0.1	
Points no management / area no management	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.7	0.7	0.4	0.6	0.7	0.4	0.6	0.1	0.0	
Ratio (>1 = Preference for managed sites)	0.0	-	0.0	0.0	0.0	0.0	0.5	0.5	0.7	2.5	1.4	0.9	1.0	2.7	0.8	1.9	***0.8***

Red kite	**Max**					**Neptun**								
Survey round (2017)	2	3	4	5	*M*	2	3	4	5	6	7	8	9	*M*
Telemetry points per management														
Grazing														
Grassland management	13	7	1	1		7	38	245	592	198			130	
Sowing (arable land)														
Ploughing (arable land)			1											
Harvesting (arable land)		6	16											
Subsoiling (arable land)														
no agricultural management	178	81	44	17		723	848	3186	3925	2374		666	82	
Total telemetry points / round	191	94	62	18		730	886	3431	4517	2572	0	666	212	
Site availability														
Grazing	5.6	5.6	5.6	5.6		11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	
Grassland management	5.5	5.5	3.0	2.8				27.9	46.4	24.2	1.5		4.5	
Sowing (arable land)														
Ploughing (arable land)			2.8											
Harvesting (arable land)		2.8	27.8	8.3										
Subsoiling (arable land)														
no agricultural management	165.4	163.6	138.4	159.8		151.8	151.8	123.9	104.7	127.6	150.3	151.8	147.3	
Total recorded area / round	176.5	177.5	177.5	176.5		163.4	163.4	163.4	162.8	163.4	163.4	163.4	163.4	
Points w. management / area w. management	1.2	0.9	0.5	0.1		0.6	3.3	6.2	10.2	5.5	0.0	0.0	8.1	
Points no management / area no management	1.1	0.5	0.3	0.1		4.8	5.6	25.7	37.5	18.6	0.0	4.4	0.6	
Ratio (>1 = Preference for managed sites)	1.1	1.9	1.4	0.6	***1.2***	0.1	0.6	0.2	0.3	0.3	-	0.0	14.5	***2.3***

Red kite	**Max**																			
Survey round (2018)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	*M*
Telemetry points per management																				
Grazing																				
Grassland management				38	234	196	1312	437	1085	2	70	575	89	8	1769					
Sowing (arable land)				12																
Ploughing (arable land)			32								42									
Harvesting (arable land)														32	2562					
Subsoiling (arable land)															13					
no agricultural management	5637	1446	4434	4966	10994	4839	17414	1827	8398	69	793	2348	512	1444	5746					
Total telemetry points / round	5637	1446	4466	5016	11228	5035	18726	2264	9483	71	905	2923	601	1484	10090	0	0	0	0	
Site availability																				
Grazing				1.5	5.6	5.6	5.6	12.9	11.4	11.4	11.4	4.0	4.0	4.0	4.0	4.0				
Grassland management						2.0	16.6	18.3	21.6	35.7	34.9	21.9	12.5	11.2	24.9	17.6	17.6	2.5	2.3	
Sowing (arable land)				1.3																
Ploughing (arable land)			0.9	1.9							6.6							14.1		
Harvesting (arable land)										6.6				2.7	14.5	7.1	20.2			
Subsoiling (arable land)															2.7	6.4	13.2	11.0		
no agricultural management	214.3	214.3	213.4	209.5	208.7	206.7	192.1	183.1	181.3	160.5	161.4	188.3	197.7	196.3	168.1	179.1	163.4	186.8	212.0	
Total recorded area / round	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	214.3	
Points w. management / area w. management	-	-	36.5	10.5	42.1	26.0	59.3	14.0	32.9	0.0	2.1	22.1	5.4	2.2	94.0	0.0	0.0	0.0	0.0	
Points no management / area no management	26.3	6.7	20.8	23.7	52.7	23.4	90.6	10.0	46.3	0.4	4.9	12.5	2.6	7.4	34.2	0.0	0.0	0.0	0.0	
Ratio (>1 = Preference for managed sites)	-	-	1.8	0.4	0.8	1.1	0.7	1.4	0.7	0.1	0.4	1.8	2.1	0.3	2.7	-	-	-	-	***1.1***

Red kite	**Noah**																			
Survey round (2018)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	*M*
Telemetry points per management																				
Grazing																				
Grassland management						35			10	20	76	169	10	59	8					
Sowing (arable land)																				
Ploughing (arable land)																				
Harvesting (arable land)															21					
Subsoiling (arable land)																				
no agricultural management	72	160		126	15	143	134	32	255	795	1010	1691	504	809	908	92	705	270	32	
Total telemetry points / round	72	160		126	15	178	134	32	265	815	1086	1860	514	868	937	92	705	270	32	
Site availability																				
Grazing			0.7	0.7	0.7	0.7	4.9	7.8	7.8	4.0	4.0	2.9								
Grassland management					16.0	51.4	79.5	77.6	88.0	90.7	40.5	40.5	31.4	18.5	15.1	20.8	15.7	2.5	0.9	
Sowing (arable land)																				
Ploughing (arable land)										1.2	0.5									
Harvesting (arable land)									0.5	0.5				5.7	7.4	3.9				
Subsoiling (arable land)																12.5	3.9	1.8		
no agricultural management	687.2	687.2	686.5	686.5	670.5	635.2	602.9	601.8	590.8	590.9	642.2	643.9	655.9	663.1	664.7	650.1	667.7	682.9	686.4	
Total recorded area / round	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	687.2	
Points w. management / area w. management	-	-	0	0	0	0.67	0	0	0.1	0.21	1.69	3.89	0.32	2.44	1.28	0	0	0	0	
Points no management / area no management	0.1	0.2	0.0	0.2	0.0	0.2	0.2	0.1	0.4	1.3	1.6	2.6	0.8	1.2	1.4	0.1	1.1	0.4	0.0	
Ratio (>1 = Preference for managed sites)	-	-	-	0	0	3.0	0.0	0.0	0.2	0.2	1.1	1.5	0.4	2.0	0.9	0	0	0	0	***0.6***

Map legends

Maps are at: https://landesplanung.hessen.de/informationen/grundlagen-und-informationen/gutachten-vogelarten/Rotmilan

Map legends in general: Basic elements at bottom right & Copyright

DE	EN
Kilometer	kilometres
Meter	metres
Auftraggeber	Contracting authority
Hessisches Ministerium für Wirtschaft,…	Hessian Ministry of Economics, Energy, Transport and Regional Development Kaiser-Friedrich-Ring 75 65185 Wiesbaden Germany
Rotmilanprojekt Vogelsberg	Red Kite Project Vogelsberg
Untersuchung zum Flugverhalten…	Analysis of red kite flight behaviour at Vogelsberg SPA
Karte x.x	Map x.x
Maßsstab in A3	Scale (A3)
Datum	Date
Name	Name
bearbeitet	designed
gezeichnet	approved
geprüft	checked
Bearbeitung	Contractor
© Hessische Verwaltung …	© Hessian Administration for Land Management and Geoinformation (HVBG)

Karte01.1_Übersicht_Projektgebiet_190313.pdf (PDF / 1.41 MB)

DE	EN
Übersicht Projektgebiet	**Overview of project area**
Abgrenzung Untersuchungsgebiet 1 HMWEVL	Delimitation of study area 1 HMWEVL
flächige Reviererfassung Ulrichstein (131 km²)	Full-coverage survey of territories Ulrichstein (131 km²)
Abgrenzung Untersuchungsgebiet 2 HMWEVL	Delimitation of study area 2 HMWEVL
flächige Reviererfassung Freiensteinau (84 km²)	Full-coverage survey of territories Freiensteinau (84 km²)
Vogelschutzgebiet	SPA Special Protection Area for birds
Geofences 2016 Geofences 2017 zusätzlicher Geofence 2018	Geofences 2016 Geofences 2017 additional Geofence 2018
HALM-Flächen NABU	HALM sites NABU
RM-Futterstelle NABU	NABU red kite feeding site
Grünabfallsammelstelle	Green waste collection site
Windenergieanlage (nur Projektbereich)	Wind turbine (project area only)
Windenergieanlage 2018 (nur Projektbereich)	Wind turbine 2018 (project area only)
Horste der Sendervögel	Transmitter birds’ nest sites
Erfolgreicher Fang inkl. Beringung und Besenderung	Successful capture incl. ringing and fitting of transmitter
Ulrichstein	Ulrichstein
Freiensteinau	Freiensteinau
Wetterstation H…	Hoherodskopf meteorological station
Kollisionsschutzpfl….	Planting designed to prevent collisions

Karte01.2_Wetterdaten_190612.pdf (PDF / 2.22 MB)
Karte01.3_VerwendungWetterdaten_190612.pdf (PDF / 3.2 MB)

DE	EN
Übersicht Wetterdaten	**Overview of meteorological data**
Untersuchungsgebiet 1	Study area 1
Untersuchungsgebiet 2	Study area 2
Windenergieanlage; Windparks für die Witterungsdaten …	Wind turbine; wind farms for which meteorological data are available are marked in turquoise
Verwendung der Wetterdaten	**Utilisation of meteorological data**
neue Windenergieanlage 2018	new wind turbines 2018
Schnittmenge des 30 km Radius der drei Windparks und des 30 km Radius um die Wetterstation des DWD. Zur Analyse der Witterungsdaten wurden nur Ortungspunkte verwendet, die innerhalb von diesem Polygon aufgenommen wurden.	Overlap of 30 km radius around the three wind farms and 30 km radius around German Meteorological Office’s meteorological station. Only telemetry points recorded inside this polygon were used in the analysis of weather data.
Windpark Ulrich…	Ulrichstein-Platte wind farm
Windpark Helpers…	Helpershain-Meiches wind farm
Windpark Hallo	Hallo wind farm
Ulrichstein	Ulrichstein
Freiensteinau	Freiensteinau
Wetterstation H…	Hoherodskopf meteorological station

Karte02.1_Bruterfolg2016_190429.pdf (PDF / 2.31 MB)

DE	EN
Bruterfolg 2016	Breeding success 2016
Legende	Map key
Abgrenzung Untersuchungsgebiet 1 HMWEVL	Delimitation of study area 1 HMWEVL
Abgrenzung Untersuchungsgebiet 2 HMWEVL	Delimitation of study area 2 HMWEVL
flächige Reviererfassung Ulrichstein (131 km²)	Full-coverage survey of territories Ulrichstein (131 km²)
flächige Reviererfassung Freiensteinau (84 km²)	Full-coverage survey of territories Freiensteinau (84 km²)
in 2016 nicht besetzt oder noch nicht bekannt	Not occupied in 2016 or not yet known
Rotmilanhorst, erfolgreiche Brut 2016	Red kite nest, successful hatch 2016
Rotmilanhorst, erfolglose Brut 2016	Red kite nest, failed hatch 2016
Rotmilanrevier	Red kite territory
Erfolgreicher Fang inkl. Beringung und Besenderung	Successful capture incl. ringing and fitting of transmitter

Karte02.2_Bruterfolg2017_190429.pdf (PDF / 2.31 MB)

DE	EN
Bruterfolg 2017	Breeding success 2017
Legende	Map key
Abgrenzung Untersuchungsgebiet 1 HMWEVL	Delimitation of study area 1 HMWEVL
Abgrenzung Untersuchungsgebiet 2 HMWEVL	Delimitation of study area 2 HMWEVL
flächige Reviererfassung Ulrichstein (131 km²)	Full-coverage survey of territories Ulrichstein (131 km²)
flächige Reviererfassung Freiensteinau (84 km²)	Full-coverage survey of territories Freiensteinau (84 km²)
in 2017 nicht vom Rotmilan besetzt	Not occupied by red kite in 2017
Rotmilanhorst, erfolglose Brut 2017	Red kite nest, failed hatch 2017
Rotmilanhorst, erfolgreiche Brut 2017	Red kite nest, successful hatch 2017
Rotmilanrevier	Red kite territory
Erfolgreicher Fang inkl. Beringung und Besenderung	Successful capture incl. ringing and fitting of transmitter

Karte02.3_Vergleich IGK_190429.pdf (PDF / 2.31 MB)

DE	EN
Ergebnisvergleich IGK	**Comparison of results with IGK**
Legende	Map key
Abgrenzung Untersuchungsgebiet 1 HMWEVL	Delimitation of study area 1 HMWEVL
Abgrenzung Untersuchungsgebiet 2 HMWEVL	Delimitation of study area 2 HMWEVL
flächige Reviererfassung Ulrichstein (131 km²)	Full-coverage survey of territories Ulrichstein (131 km²)
flächige Reviererfassung Freiensteinau (84 km²)	Full-coverage survey of territories Freiensteinau (84 km²)
Integratives Gesamtkonzept (Ausschnitt)	Integrative masterplan IGK (extract)
Revierzentrum	Centre of territory
Wechselhorst	Secondary nest site
Rotmilanbrutplätze 2016/2017	Red kite breeding sites 2016/2017
Horst	Nest site
Revier	Territory
Erfolgreicher Fang inkl. Beringung und Besenderung	Successful capture incl. ringing and fitting of transmitter

Karte03.1_ÜbersichtRotmilandaten2016_170828.pdf (PDF / 2.4 MB)

DE	EN
Übersicht Rotmilandaten 2016	**Overview of red kite data 2016**
Untersuchungsgebiet 1	Study area 1
Untersuchungsgebiet 2	Study area 2
Ulrichstein	Ulrichstein
Freiensteinau	Freiensteinau

Karte03.2_ÜbersichtRotmilandaten2017_171108.pdf (PDF / 8.7 MB)

DE	EN
Übersicht Rotmilandaten 2017	**Overview of red kite data 2017**
Legende	Map key
Untersuchungsgebiet 1…	Study area 1 HMWEVL
Untersuchungsgebiet 2…	Study area 2 HMWEVL
Ortungs…	Telemetry points 2017

Karte03.3_ÜbersichtRotmilandaten2018_181210.pdf (PDF / 7.38 MB)

DE	EN
Übersicht Rotmilandaten 2018	**Overview of red kite data 2016**
Untersuchungsgebiet 1…	Study area 1 HMWEVL
Untersuchungsgebiet 2…	Study area 2 HMWEVL
Ortungs…	Telemetry points 2018
Ulrichstein	Ulrichstein
Freiensteinau	Freiensteinau

Karte04.1_GF_Ulrichstein2016_190612.pdf (PDF / 2.27 MB)

DE	EN
Geofence Windpark Ulrichstein-Platte 2016	**Geofence Ulrichstein-Platte wind farm 2016**
Geofence 2016-2	Geofence 2016-2
Windenergieanlage (Nabenhöhe 138 m, Rotorlänge 41 m)	Wind turbine (nacelle height 138 m, rotor length 41 m)
Nahbereich (51 m)	Rotor blade vicinity (51 m)

Karte04.2_GF_Ulrichstein2017_190612.pdf (PDF / 2.33 MB)

DE	EN
Geofence Windpark Ulrichstein-Platte 2017	**Geofence Ulrichstein-Platte wind farm 2017**
Geofence 2017-5	Geofence 2017-5
Windenergieanlage (Nabenhöhe 138 m, Rotorlänge 41 m)	Wind turbine (nacelle height 138 m, rotor length 41 m)
Nahbereich (51 m)	Rotor blade vicinity (51 m)

Karte04.3_GF_AlteHöhe_2017_190612.pdf (PDF / 2.35 MB)

DE	EN
Geofence Windpark Alte Höhe 2017	**Geofence Alte Höhe wind farm 2017**
Geofence 2017-7	Geofence 2017-7
Windenergieanlage (Nabenhöhe 70 m, Rotorlänge 30 m)	Wind turbine (nacelle height 70 m, rotor length 30 m)
Windenergieanlage (Nabenhöhe 138 m, Rotorlänge 41 m)	Wind turbine (nacelle height 138 m, rotor length 41 m)
Nahbereich (40 m bzw. 51 m)	Rotor blade vicinity (40 m / 51 m)

Karte04.4_GF_Bew_Noah_2017_190612.pdf (PDF / 2.63 MB)

DE	EN
Geofence Bewirtschaftungsereignisse Noah 2017	Geofence Agricultural management events Noah 2017
Geofence 2017-1-LN	Geofence 2017-1-LN

Karte04.5_GF_Bew_Neptun_2017_190619.pdf (PDF / 2.15 MB)

DE	EN
Geofence Bewirtschaftungsereignisse Neptun 2017	Geofence Agricultural management events Neptun 2017
Geofence 2017 (nicht in Übersichtskarte dargestellt)	Geofence 2017 (not depicted in overview map)

Karte04.6_GF_Ulrichstein2018_190619.pdf (PDF / 2.2 MB)

DE	EN
Geofence Windpark Ulrichstein-Platte 2018	**Geofence Ulrichstein-Platte wind farm 2018**
Geofence 2017-5	Geofence 2017-5
Windenergieanlage (Nabenhöhe 138 m, Rotorlänge 41 m)	Wind turbine (nacelle height 138 m, rotor length 41 m)
Nahbereich (51 m)	Rotor blade vicinity (51 m)

Karte04.7_GF_AlteHöhe_2018_190619.pdf (PDF / 2 MB)

DE	EN
Geofence Windpark Alte Höhe 2018	**Geofence Alte Höhe wind farm 2018**
Geofence 2017-7	Geofence 2017-7
Windenergieanlage (Nabenhöhe 70 m, Rotorlänge 30 m)	Wind turbine (nacelle height 70 m, rotor length 30 m)
Windenergieanlage (Nabenhöhe 138 m, Rotorlänge 41 m)	Wind turbine (nacelle height 138 m, rotor length 41 m)
Nahbereich (40 m bzw. 51 m)	Rotor blade vicinity (40 m / 51 m)

Karte05.1_LandnutzungstypenNoah2016_190826.pdf (PDF / 1.65 MB)

DE	EN
Landnutzungstypen Noah 2016	**Land-use types Noah 2016**
Legende	Map key
Landnutzungstypen	Land-use types
Extensiv Acker	Extensive arable
Intensiv	Intensive
Intensiv Acker	Intensive arable
Extensiv Grünland	Extensive grassland
Intensiv Grünland	Intensive grassland
Wiese/Baumreihe,Feldholzinsel,Hecke zu gleichen Anteilen	Meadow/tree row, copse, hedgerow at equal proportions
Mischwald	Mixed forest
Siedlungen und Gebäude	Settlements and buildings
Brutplatz Noah	Nest site Noah

Karte05.2_LandnutzungstypenTristanIsolde2016_190826.pdf (PDF / 1.53 MB)

DE	EN
Landnutzungstypen Tristan und Isolde 2016	**Land-use types Tristan and Isolde 2016**
Legende	Map key
Landnutzungstypen	Land-use types
Extensiv Acker (Hackfrüchte)	Extensive arable (root crops)
Intensiv Acker	Intensive arable
Intensiv Acker (Hackfrüchte)	Intensive arable (root crops)
Intensiv Acker (Mais)	Intensive arable (maize)
Intensiv Acker (Raps)	Intensive arable (oilseed rape)
Extensiv Grünland	Extensive grassland
Intensiv Grünland	Intensive grassland
Wiese/Baumreihe,Feldholzinsel,Hecke zu gleichen Anteilen	Meadow/tree row, copse, hedgerow at equal proportions
Mischwald	Mixed forest
Nadelwald	Coniferous forest
Siedlungen und Gebäude	Settlements and buildings
Brutplatz Tristan und Isolde	Nest site Tristan and Isolde

Karte05.3_Bewirtschaftungsereignisse2016_Beispiel_190826.pdf (PDF / 2.19 MB)

DE	EN
Bewirtschaftungsereignisse Woche 2 und 3 (2016)	**Agricultural management events Weeks 2 and 3 (2016)**
Legende	Map key
Bewirtschaftungsereignisse	Agricultural management events
Maßnahme	Management measure
Mahd	Mowing
Mahd, Wenden	Mowing, turning
Wenden	Turning
Wenden, Entnahme	Turning, removal of grass
Entnahme	Removal of grass
Ernte	Harvesting
Beweidung	Grazing
Pflügen	Ploughing
Keine Nutzung	No agricultural management
nicht erfasst	not surveyed
Brutplätze der Sendervögel	Transmitter birds’ nest sites
Ortungspunkte	Telemetry points
Datengrundlage (DTK25): mit Genehmigung der Hessischen Verwaltung für Bodenmanagement und Geoinformation, © HVBG 2016	Baseline digital topographic map (DTK25) used with permission from the Hessian Administration for Land Management and Geoinformation, © HVBG 2016
 und Woche	*In map inserts:* and Week

Karte05.4_LandnutzungstypenBewirtschaftung2017_190826.pdf (PDF / 2.37 MB)

DE	EN
Landnutzungstypen 2017	**Land-use types 2017**
Brutplätze der Sendervögel	Transmitter birds’ nest sites
zusätzliche Aufnahme von Bewirtschaftungsereignissen	additional surveys of agricultural management events
Landnutzungstypen 2017	Land-use types 2017
Extensiv Acker	Extensive arable
Intensiv Acker	Intensive arable
Intensiv Acker (Mais)	Intensive arable (maize)
Intensiv Acker (Raps)	Intensive arable (oilseed rape)
Extensiv Gruenland	Extensive grassland
Intensiv Gruenland	Intensive grassland
Hecke	Hedgerow
Laubwald	Deciduous forest
Mischwald	Mixed forest
Nadelwald	Coniferous forest
Siedlungen und Gebäude	Settlements and buildings
Datengrundlage …	Baseline digital topographic map (DTK25) used with permission from the Hessian Administration for Land Management and Geoinformation, © HVBG 2016

Karte05.5_LandnutzungstypenBewirtschaftung2018_190826.pdf (PDF / 1.75 MB)

DE	EN
Landnutzungstypen 2018	**Land-use types 2018**
Brutplätze der Sendervögel	Transmitter birds' nest sites
zusätzliche Aufnahme von Bewirtschaftungsereignissen	additional surveys of agricultural management events
Landnutzungstypen 2017	Land-use types 2017
Extensiv Acker (Wintergetreide)	Extensive arable (autumn-sown cereals)
Extensiv Acker (Hackfruechte)	Extensive arable (root crops)
Intensiv Acker (Hackfruechte)	Intensive arable (root crops)
Intensiv Acker (Mais)	Intensive arable (maize)
Intensiv Acker (Raps)	Intensive arable (oilseed rape)
Intensiv Acker (Sommergetreide)	Intensive arable (spring-sown cereals)
Intensiv Acker (Wintergetreide)	Intensive arable (autumn-sown cereals)
Extensiv Gruenland	Extensive grassland
Intensiv Gruenland	Intensive grassland
Hecke	Hedgerow
Laubwald	Deciduous forest
Mischwald	Mixed forest
Nadelwald	Coniferous forest
Siedlungen und Gebäude	Settlements and buildings
Datengrundlage …	Baseline digital topographic map (DTK25) used with permission from the Hessian Administration for Land Management and Geoinformation, © HVBG 2016

Karte06.1.1_OrtungspunkteRasterTristan2016_180129.pdf (PDF / 1.12 MB)
Karte06.2.1_OrtungspunkteRasterIsolde2016_180129.pdf (PDF / 1.11 MB)
Karte06.2.2_OrtungspunkteRasterIsolde2017_180129.pdf (PDF / 1.12 MB)
Karte06.3.1_OrtungspunkteRasterNoah2016_180129.pdf (PDF / 1.36 MB)
Karte06.3.2_OrtungspunkteRasterNoah2017_180129.pdf (PDF / 1.35 MB)
Karte06.3.3_OrtungspunkteRasterNoah2018_181217.pdf (PDF / 2.37 MB)
Karte06.4.1_OrtungspunkteRasterNeptun2017_180129.pdf (PDF / 1.2 MB)
Karte06.5.1_OrtungspunkteRasterMax2017_180129.pdf (PDF / 1.38 MB)
Karte06.5.2_OrtungspunkteRasterMax2018_181211.pdf (PDF / 2.48 MB)

DE	EN
Raumnutzung… [Name, Jahr]	Spatial behaviour… [name, year]
1.000 m-Radius	1,000 m radius
1.500 m-Radius	1,500 m radius
Horst Sendervogel	Nest site transmitter bird
… Ortungen	… telemetry points