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Bird Collisions with an Unmarked Extra-High Voltage Transmission Line in an Average Riverine Landscape: An Appeal to Take a Closer Look

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Simple Summary: Under certain circumstances, birds can collide with man-made structures, such as overhead powerlines, potentially leading to the deaths of millions of birds each year and thus posing a high risk to the affected populations. Notably, however, previous studies on this topic have often been biased towards known collision hotspots or have focused primarily on threatened species. To enhance our knowledge of this problem and to overcome the above biases, we used advanced field and statistical methods to assess bird collisions in a typical German riverine landscape with intensive agricultural use. We demonstrated that pigeons accounted for the largest proportion of collision victims and provide important insights into bird-strike occurrences in an 'average' German riverine floodplain landscape.

Abstract: Anthropogenic structures such as overhead powerlines pose potentially high collision risks to flying animals, particularly birds, leading to millions of fatalities each year. Studies of bird collisions with powerlines to date, however, have estimated different numbers of collision per year and per kilometer in highly variable landscapes. This study aimed to clarify the risk of bird collisions with powerlines in an average landscape, to overcome the bias towards studies in collision hotspots. We conducted experiments to determine searcher efficiency, removal, and decomposition rates of collided birds as well as searching for collision victims and recording flight movements and flight reactions towards the powerlines. Annual bird-strike rates and flight phenology were analyzed using generalized additive models (GAMs). We estimated 50.1 collision victims per powerline kilometer per year and demonstrated that pigeons (especially Wood Pigeon, *Columba palumbus*) accounted for the largest proportion of collision victims (approximately 65%). Our study thus offers the opportunity to estimate the number of bird collisions (and the range of species) that can be expected in areas that are not particularly rich in bird life or sensitive, especially in view of the planned intensive expansion of energy structures in the context of the green energy transition.

Keywords: Wood Pigeon (*Columba palumbus*); removal rate; searcher efficiency rate; mortality rate; generalized additive model; carcass data; flight reactions; powerlines; Germany

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1. Introduction

Many anthropogenic structures pose collision risks to birds and bats, especially those with poorly visible or fast-moving parts. This is the case, for example, for overhead powerlines and wind turbines [1,2], the numbers of which are increasing continuously by several

percent per year worldwide, especially in the context of energy transition [3,4]. Estimates suggest that powerline collisions may cause between 20 million [5] and one billion bird fatalities in the USA [6]. Studies in other countries, e.g., reported 2.5–25.6 million collision casualties in Canada (the most realistic assessment, according to Rioux et al. [7]) and 1.5–2.8 million in Germany [8]. Studies estimating the number of victims of collisions with specific structures in a specific time window are thus of ecological importance to quantify the potential dangers, make projections and, if necessary, take measures to minimize the risks.

A general disadvantage of previous collision studies for such large-scale estimates is that most have been carried out in areas where powerlines are known to pose particularly high collision risks [1], thus hindering extrapolation to population-level impacts. The present study thus investigates the number of bird-strikes during one year along an unmarked transmission grid overhead powerline in an 'average' intensive-use, grassland-dominated agricultural landscape influenced by a watercourse (the Lippe River) in Germany. We defined the study area as an average landscape because it was typical of most riverine floodplain landscapes in Germany, comprising an averagely structured semi-open landscape with intensive grassland and arable cultivation with few near-natural elements. The quantification of bird-strike victims in this habitat could thus contribute to comprehensive studies [5,7] to estimate nationwide collision numbers, assuming that the investigated area is approximately representative of the described landscape type. Furthermore, numbers of bird-strike victims are related to recorded fly-through intensities, which then allows the calculation of collision rates.

In summary, the aim of the present study is to consider the qualitative and quantitative aspects of bird collisions on overhead powerlines in a representative landscape in Germany. This is particularly important since the planned green energy transition is accompanied by a massive expansion of additional overhead powerlines. We therefore aim to provide a basis for estimating the potential conflict in this regard, which in turn might influence planning, avoidance measures or compensatory actions.

2. Material and Methods

The investigated powerline was a 380 kV overhead line supported by fir pylons with three crossbeams and one earth cable tip, forming part of the transmission grid. For more information about powerline features, see Supplementary Material Chapter S1.2. The investigated section comprised four spans between pylons 46 and 51, with a total length of approximately 1.5 km (Figure 1).

2.1. Study Site

The study area was located in the natural area 'Kölner Bucht and Niederrheinisches Tiefland' (D35) near the border with the natural area 'Westfälische Tieflandsbucht' (D34) in the northwestern German lowlands and thus in the Atlantic-influenced region of North Rhine-Westphalia (alphanumerical codes refer to specific natural regions in Germany's system of geographical classification based on landscape and geological features).

The powerline section investigated crossed the districts of Wesel and Recklinghausen and was located south of the municipality of Schermbeck and west of the city of Dorsten in North Rhine-Westphalia. The powerline section was almost completely located in the nature reserve 'Lippeaue' (WES-001/RE-029), which also includes the special area of conservation (SAC) 'Lippeaue' (DE-4209-302) in the eastern part of the study area. While the powerline section lay entirely within the Hohe Mark-Westmünsterland Nature Park (NTP-007), the 'Lippeaue' landscape conservation area (LSG-4306-0008) was crossed exclusively between pylons 46 and 47 (Figure 1).

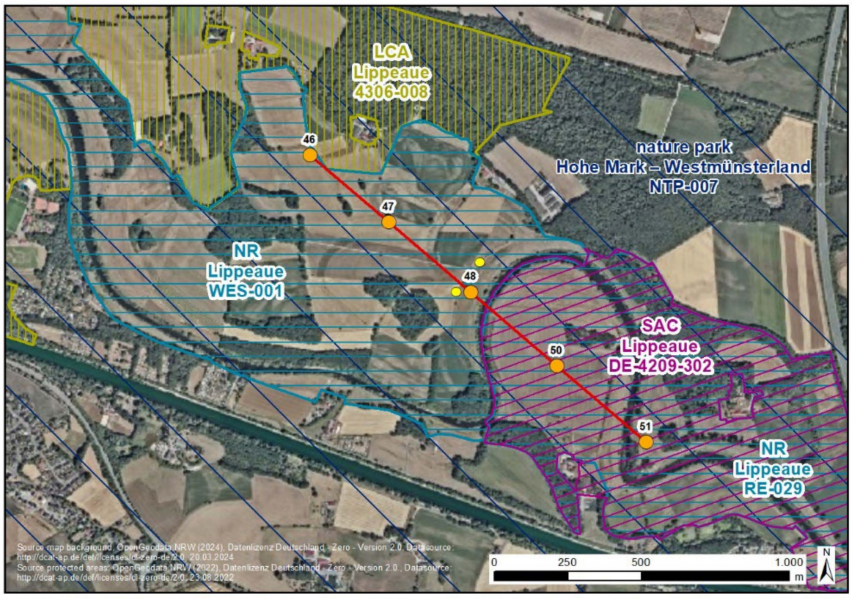


Figure 1. Location of the investigated powerline section (red line), location and numbering of the powerline pylons (orange dots) and observation points for flight movements (yellow dots). Purple shaded area: special area of conservation (SAC); dark green shaded area: nature reserve (NR); light green shaded area: landscape conservation area (LCA). Data source for background map: OpenGeodata.NRW (2024), Datenlizenz Deutschland-Zero-Version 2.0. Data source: http://dcat-ap.de/def/licenses/dl-zero-de/2.0 (accessed on 20 March 2024), Data source for protected areas: OpenGeodata.NRW (2022), Datenlizenz Deutschland-Zero-Version 2.0. Data source: http://dcat-ap.de/def/licenses/dl-zero-de/2.0 (accessed on 23 August 2022).

Despite the protected areas, the area including the investigated powerline section was under intensive agricultural use, mainly in the form of intensive grassland (50.8% of the study site), as well as two large and two small arable fields (36.2%). The arable fields were cultivated with corn, oilseed rape, ryegrass and winter cereals during the study period. The north-western section between pylon 46 and about halfway between pylons 47/48 included a large mowing pasture divided by several fences, which was grazed by a suckler cow herd, including a bull, for about half of the study period and was therefore partly inaccessible for searching for collision victims. Grazing was conducted at high intensity resulting in short grass. There was also a small ditch with reedbed vegetation (0.7%) adjacent to the mowed pasture. The remaining north-western part of the study area was characterized by two smaller arable fields and intensively used mowed grassland. This was followed by areas located south of the Lippe River (which itself accounted for 4.3% of the study site), due to a bend in the river, dominated by arable land use (ryegrass) in two large-scale plots and some intensively used mowing grassland. The south-eastern-most part of the study site was located again on the north side of the Lippe River and compromised the only extensively used grassland (3.8%). The remaining 4.2% of the study site consisted of wooded areas (shrubs, trees, riverine trees and shrubs), agricultural roads and drinking water well areas.

2.2. Methodological Overview

Bird-strikes with overhead powerlines were investigated by regular and systematic searches for carcasses under and next to powerlines, and bird-flight data were monitored in addition. The study was conducted between 16 September 2020 and 11 October 2021 (with two pauses from 8–17 February 2021 and from 16–26 September 2021 due to weather and organizational constraints). The fieldwork was carried out by four specifically trained ornithologists. Collision victim searches were conducted throughout the study at 3- or 7-d

search intervals, with shorter intervals (3 d) during periods with (presumed) higher bird numbers (1 August–31 October and 1 February–30 April) and weekly searches outside these peak migration periods. The collected bird flight and carcass data were analyzed descriptively and statistically.

2.3. Recording Flight Movements and Reactions (Overflights)

Each flight observation was conducted from a single fix observation point and during the same survey periods as the collision victim search, with an additional flight survey between two collision victim searches. A total of 172 flight observations were carried out. The observation point varied between 'north' and 'south', depending mainly on the light conditions on the survey day. Each observation lasted for 2 h and was carried out in the morning (starting between 05:15 and 08:45, depending on the season) when highest flight activity was expected.

All flight observations were logged in the field and provided essential information on species, number, direction of flight, flight altitude and behavior in relation to the overhead line. Each crossing observation was temporally assigned to the nearest full 15-min interval. Information on species and numbers of resting birds close to the transmission line were additionally recorded.

The behavior (i.e., responses) of birds flying close to the transmission lines was of particular interest and we therefore recorded corresponding relative flight altitude (under-, through- overflights, flight direction in eight cardinal directions). Regarding flight behaviors, climbing or sinking flights were differentiated (and also if there was no change in flight altitude) and each change in flight direction (leading effect, circling, inverted flight) was noted. Similarly, the strength of a response to the powerline (none, slight, strong or collision) was recorded, e.g., a strong reaction indicated a near collision, and a weak reaction indicated a slight adjustment of altitude to fly over the wire. Flight movements involving landing on or under the powerline were categorized separately. The beginning of the reaction to the powerline was classified into the distance classes 0–5 m, 5–30 m, 30–100 m, 100–200 m and >200 m (the last three categories only if they were possible, e.g., for larger birds). All observers were trained correspondingly.

Bird behavior is highly dependent on the prevailing wind and weather conditions and thus all relevant weather variables (temperature, wind strength, wind direction, cloud cover, precipitation, visibility) were, in addition, noted hourly or immediately after weather changes during each field survey. It was not permitted to selectively increase surveys on days with good weather or good migration conditions, in order to prevent systematic bias.

In summary we observed bird flight responses to the lines in terms of (1) the existence of a response, (2) response distance, (3) response strength and (4) avoidance behavior.

2.4. Collision Victim Search

Six transects, each 20 m wide, were surveyed under and next to the overhead powerlines spanning pylons 46–51 (Figure 1). A transect width of 20 m provided the best results in terms of effort versus search success ratio [9,10]. Furthermore, our own experiences and those of Jödicke et al. [10] showed that, e.g., for a 380 kV powerline with a crossbeam width of about 30 m, >90% of collision victims are found within a 120 m survey corridor. Searches within a transect followed a central line, with two 10 m-strips searched on each side of the line (Figure 2). The search speed was approximately 2 km/hr, based on the findings of Jödicke et al. [10] and our own experience. The survey covered approximately 1.5 km of the line (pylons 46–51, Figure 1), accounting in total for 9 km and 4.5 h of search effort. A total number of 88 collision victim searches were conducted.

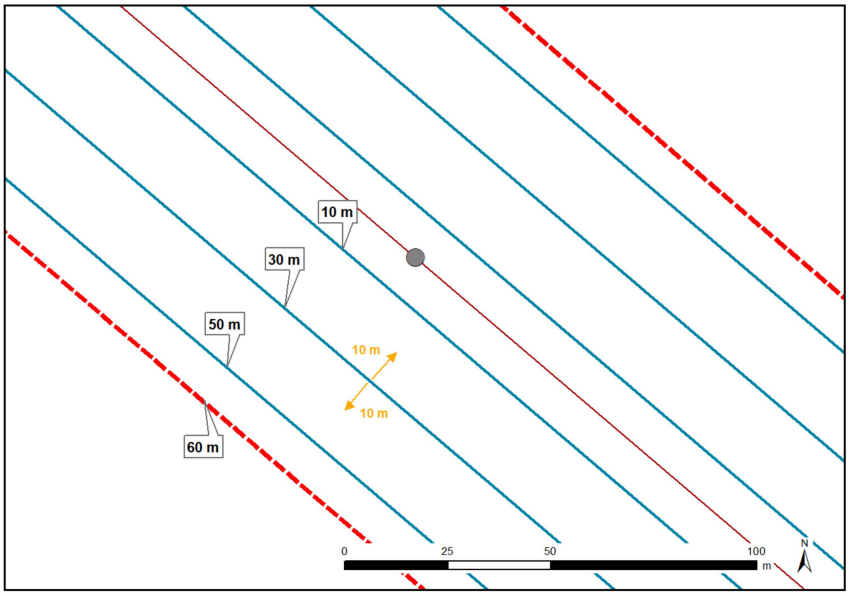


Figure 2. Schematic representation of transects (blue lines) used to record collision victims in the field. The thin red line shows the axis of the powerline, the dashed red line the outer boundary of the study area, and the grey dot an example pylon center.

Each detection of a bird carcass (or several feathers) was documented by GPS coordinate, photograph and field protocol, including information on the date, time, type and condition of the carcass and cause of death (if clearly determinable). The vegetation condition at the discovery location was also documented (vegetation species class, height, cover, and homogeneity). Birds (or their remains) that could not be clearly identified were collected and determined later. Collision victims that were identified and documented on site were removed and the site was marked to prevent double counting.

Determining the cause of death of the found birds was critical to the study but this was sometimes impossible or very difficult to determine unequivocally. Visible injuries (to carcasses or live birds) such as fractures or open wounds were considered as clear evidence of a collision event. All carcasses for which there was no direct evidence of collision-related injuries, but which were found under or close to the powerline in the transect area, were evaluated as presumed collision victims and included in the analysis. It was possible that in an unclear case (characterized by plucking or laceration), the carcass may have been carried in by scavengers from outside the study area and was not a collision victim. However, this probability was considered to be very low and carcasses under and next to the powerline were thus considered much more likely to be collision victims. Finally, molted or preened feathers were often found and were not classified as collision victims.

The present study area included three categories of areas with missing data: (1) areas that could never be surveyed; (2) areas that could not be surveyed in distinct phases, and (3) short-grassed areas that could only be viewed from the outside (with binoculars) in some phases, and were therefore not considered to be surveyed with regard to small birds (but were considered to be surveyed with regard to larger birds, namely pigeon-size and larger). Areas that could never be surveyed (1) were completely removed from the analysis but an appropriate correction factor was applied when calculating the collision rates to avoid any bias of the number of carcasses per kilometer of line. Areas that could not be surveyed in distinct phases (2) were imputed based on statistically well-developed spatial imputation methods, and short-grassed areas that could only be viewed from the outside (3) were imputed for small birds but counted as monitored for larger birds (size “medium” and “large”, cf., Supplementary Material Chapter S2.4).

2.5. Statistical Methods

All statistical methods, as described in more detail below, were based on the statistical open-source software R (version 4.3.1) [11].

2.6. Correction Factors

A certain proportion of carcasses was not found by the observers for various reasons, as detailed below, and specific correction factors were therefore applied. In particular, corrections were applied for incomplete detection (searcher efficiency), removal of carcasses by scavengers, and for the fact that a (small) fraction of collided birds died outside the search area. We conducted field experiments (see Supplementary Material Chapters S2.1–S2.3) to address the first two points (and the additional issue of decomposition, which turned out to be negligible), and quantified these influences. The bias resulting from the proportion of birds that die outside the standardized transects can be calculated mathematically (based on a truncated normal distribution) from the distances of the detected collision victims to the powerline axis (see Supplementary Material Chapter 3.1 for further details).

We then combined the corrections for all these influences and applied them to the actual number of carcasses found, while explicitly integrating information on the durations between subsequent searches and the probability of finding carcasses during later searches. This mathematical approach was based on the method of sampling weights [12] in the context of sightability models [13–15]. Variance calculation was based on an appropriate re-sampling scheme. More details of the calculations are given by Mercker [16] (demonstrating the high robustness of the approach) and in the Supplementary Material (Chapter S3).

2.7. Annual Phenology

An analysis of the annual bird-strike and flight phenology was performed using generalized additive models (GAMs) [17,18] that allowed the representation of nonlinear relationships. The analysis was performed with the R package *mgcv* [18], using a negative binomial probability distribution [19] and considering temporal autocorrelation in the data [20,21]. The inhomogeneous survey effort was accounted for by using the logarithm of the time span between subsequent searches as an offset-term [21].

2.8. Collision Rates

Collision rates (the number of collided birds per 1000 crossing birds) were determined from the corrected collision victim counts related to the estimated total number of crossing birds. Flight observations were not made on a daily basis and thus a suitable (temporally autocorrelated) GAM was fitted to the bird flight data to qualify and quantify total bird flight intensity (with restrictions regarding time of day; see below), which considered both jday (Julian day—a continuous count of days starting from January 1) and time of day (relative to sunrise) in a possibly nonlinear form. The numbers of crossing birds were then predicted separately for each day and hour (up to 6 h after sunrise) and summed and the resulting total was then blended with the carcass total.

In addition to the average collision rate (i.e., total number of predicted crossing birds divided by total number of corrected carcasses), the above procedure was repeated for 1000 resamples, to represent the associated uncertainties, with carcass data resamples and bird flight resamples, the latter generated based on the uncertainties (standard errors) of the above GAM approach using negative-binomial Monte Carlo simulations. In particular, resamples of carcass data were generated as described in [16] and each of these resamples was subsequently offset against a resample of the above-mentioned bird flight-GAM-prediction, in particular by resampling the negative binomial outcome (the overall number

of crossing birds) based on corresponding underlying regression coefficients and associated standard errors, and realized via an R-script.

3. Results

3.1. Analysis of Collision Victims

A total of 67 carcasses were found during the field surveys. Carcasses detected during the first search survey (two individuals) were not considered for methodological reasons, because they collided at unknown times, before the beginning of the recording period [22]. A further five carcasses were disregarded because these birds were considered to have died from causes other than collision. In addition, three carcasses found outside the study area and two detected in an area evaluated as 'not searchable' (poplar forest in the south-east corner of the study area) were also excluded from the analysis for methodological reasons (both 'chance finds' in the absence of a systematic search). A total of 55 collision victims were therefore finally included and considered in all subsequently presented analyses.

(A) Absolute and relative total number of corrected carcasses

As described above, 'corrected collision victims' refers to the number of collision victims found and corrected for the processes of overlooking, removal, death outside the search area and gap-filling (in the case of subplots that were not surveyed during all the time), thus providing an estimate of the true number of victims, according to the methods of Mercker [16]. Results for the correction factors are available in the Supplementary Material (Chapter S4.1). The total number of corrected carcasses was 69.2 individuals (95% confidence interval: (58.4–85.1)). Thus, the corrected number of bird-strike victims per powerline kilometer per year was 50.1 individuals (95% confidence interval: (42.3–61.7)).

(B) Annual phenology and species range

The GAM-based results (Figure 3) show that from Julian day (jday) 100–200 (approximately April to July inclusive), bird-strike mortality tended to zero. In contrast, numbers increase in the cooler seasons, with peaks early in the year (late January) and in late autumn (around mid-November). The relatively large confidence intervals, however, mean that the exact timing and height of the peaks was subject to a relatively large degree of uncertainty, and the possibility that carcass numbers were roughly consistent from November to February cannot be ruled out.

An analysis of the species spectrum of the (corrected) carcasses is shown in Figure 4. Most victims were Wood Pigeons (*Columba palumbus*, 58%), while the addition of Street Pigeons (*Columba livia domestica*) increased the proportion of pigeons to approximately 65%. The second most common species were thrushes (Eurasian Blackbird (*Turdus merula*), Redwing (*Turdus iliacus*) and Song Thrush (*Turdus philomelos*)), accounting for 9.5% of the total.

3.2. Analysis of Flight Movements

(A) Annual phenology and species range

More than 70,000 crossing individuals of >135 different species were recorded, with mean flock size of just less than nine individuals. The GAM-based results showed a clear bimodal pattern, with a peak in early spring (around mid-February) and a much more pronounced peak in autumn (around late October; Figure 3).

(B) Reactions to the lines

We tested for significant differences between observers, but none were detected. The overall proportion of individual birds that responded to the unmarked lines was 3.1%. This proportion, if the analysis was applied at the level of flocks rather than individuals,

was higher (8.6%), suggesting a relationship between flock size and response probability. However, appropriate generalized mixed models (GLMs) [23,24] showed no significant relationship between flock size and response probability ($p > 0.05$). More detailed analyses suggested that a few individual large flocks strongly influenced the data, if analyzed on the level of individuals. Most responses occurred at close range (0–10 m), were moderate in strength and were predominantly 1–10 m upward (Supplementary Figure S13).

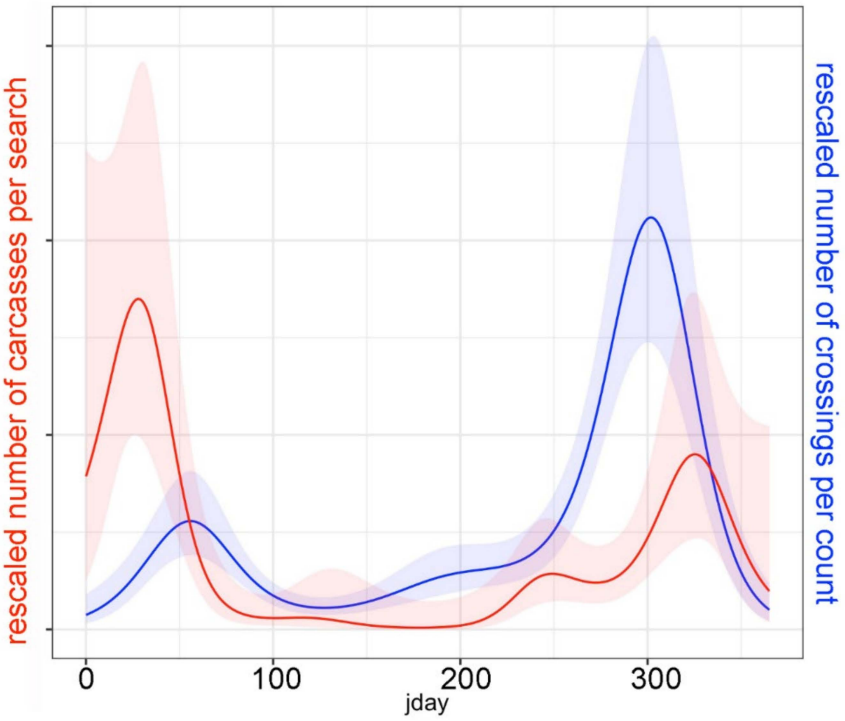


Figure 3. Annual phenology of relative number of corrected carcasses (red line) vs. crossing birds (blue line). Both measures were scaled to the same height for better visualization (i.e., divided by respective mean value and are thus unitless), and the *y*-axis therefore cannot be interpreted in absolute values and only relative changes along the *x*-axis are important. Curves based on GAM regressions; colored shaded areas indicate 95% confidence intervals. *X*-axis: Julian day (continuous count of days starting from 1 January).

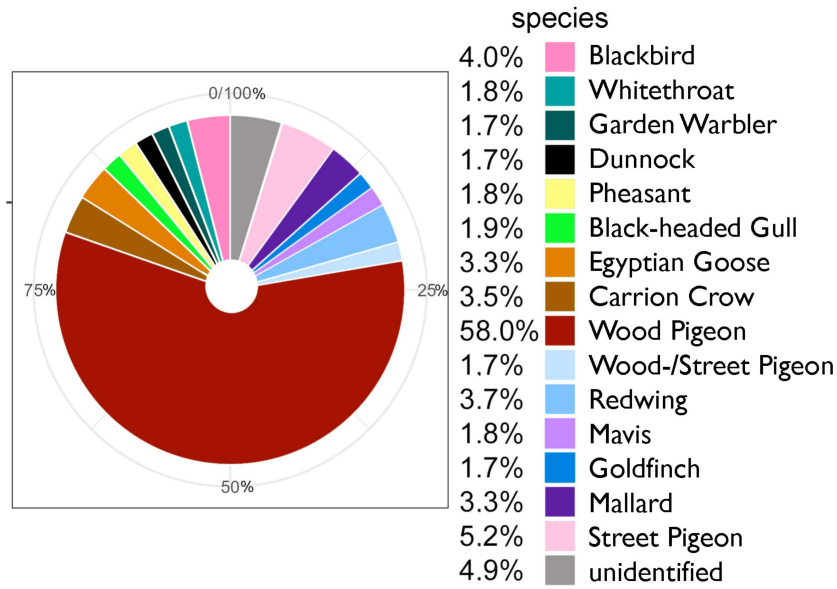


Figure 4. Proportions of different species among (corrected) collision victims. Wood/Street Pigeon indicates that the carcasses could not be distinguished between the two species.

3.3. Correlations Between Collision Victims and Flight Movements

(A) Annual phenology and species spectrum

Superimposing the yearly phenomenological relative flight and carcass numbers (based on GAM estimates; Figure 3), showed similar seasonalizes of both processes, with peaks in early spring, very low values at jday 100–200, and then a slight increase leading to another peak in late autumn. Notably however, clear differences between flight and carcass intensity were also found, with a bird-strike maximum shifted towards winter compared with the maximum in bird flights, and birds apparently at higher risk of bird-strikes in spring compared with autumn. A possible explanation for the latter finding may be a higher preferred flight altitude above overhead powerlines in autumn compared with spring. Indeed, a corresponding analysis (Supplementary Figure S14) showed that birds tended to migrate at higher altitudes in the second half of the year; however, the proportion of birds flying through the lines remained similar (or even increased slightly), suggesting that the flight altitude could not explain the different collision rates.

Another possible explanation for qualitative differences in collision vs. bird-strike intensities may be a phenological change in the species spectrum, with more birds with a higher risk of collision crossing the lines in spring. A graphical analysis of the absolute and relative differences in species complexes (Supplementary Figure S15) did not support this, however, showing only slight shifts in the species spectrum from spring to autumn (e.g., more songbirds (excluding thrushes) and fewer non-songbirds (excluding pigeons) in autumn), but these shifts were also reflected in the carcass data.

A third possible explanation is that bird abundance was not primarily related to bimodal bird migration events in the spring and autumn, but rather to birds wintering in the study area. As noted above, although there was a notable detected bimodal pattern in bird flight, the bimodal pattern in carcasses was subject to large uncertainties, not excluding a possible general increase over winter (confidence intervals are shown in Figure 3), while peak bird-strikes were shifted towards winter, compared with bird flight.

We further investigated this issue by fitting a GAM to the carcass data, but reduced the number of degrees of freedom of the regression splines (determining the amount of smoothing) from 9 to 5 knots, which effectively mapped the nonlinear relationship between carcass number and jday more 'coarsely' (i.e., in a less nonlinear/'wiggly' way). A pattern emerged in which most of the bird-strikes occurred over the entire winter, during approximately jday 220–80 (Figure 5). Using cross-validation, we verified that this nonlinear pattern represented the temporal occurrence of bird-strikes better than a bimodal pattern.

Finally, we compared the species spectrum of crossings in winter vs. summer (Supplementary Figure S16). There was good agreement between carcass totals and flight intensities (with significantly more individuals in winter) and the shifts in species spectrum coincided with the species at risk of collision, with a clear relative shift in favor of pigeons compared with other non-songbirds (Supplementary Figure S16). Comparing the overall ratios for species complexes of flight vs. carcass data (Supplementary Figure S17) showed that pigeons (which accounted for most bird-strike victims) were indeed particularly vulnerable to collision. The proportion of birds flying through the lines remained similar for the two seasons ($p > 0.05$).

(B) Collision rates

The partial effect (i.e., relative changes) in hourly bird crossings as a function of time after sunrise is shown in Supplementary Figure S18. Here, the model showed a strong dependency with maximal bird flight intensity around sunrise, dropping to nearly 0 after 6 h. The detected seasonal dependency was strongly related to Figure 3 (and modelled

with a closely related GAM that differed only by the absence of the diurnal effect) and is therefore not shown.

The correlation of flight intensities with bird-strike numbers gave a mean bird-strike rate of 0.47 individuals (95% confidence interval: 0.40–0.58) per 1000 crossings.

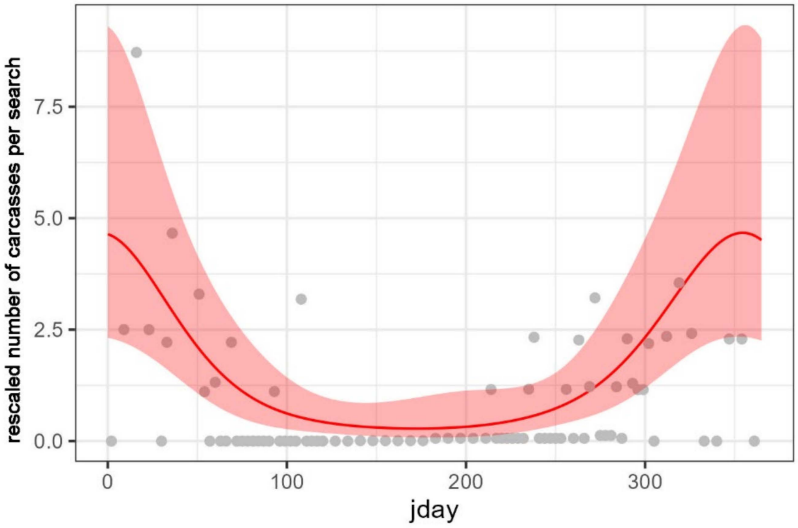


Figure 5. Number of carcasses per search run, depending on time of year. Grey dots: (corrected) carcass numbers per survey; red line: generalized additive model-based estimation of average carcass numbers per search (regression spline with 5 nodes); red shaded areas: 95% confidence intervals; *x*-axis: Julian day (continuous count of days starting from 1 January).

4. Discussion

The (adjusted) total of 69.2 carcasses (95% confidence interval: (58.4–85.1)) was approximately 1.26 times the number of carcasses that were directly observed, which is of a similar magnitude but lower than the value of 1.92 found by Jödicke et al. [10] (a recent, comprehensive German study conducted on a transmission line that bisects a marshland area; see the third paragraph below for a more detailed description). This lower correction factor in the present study may be due to several factors, including a lower mean vegetation height (on average only about 7 cm in the surroundings of detected carcasses) or density, the specific time intervals between searches, or the significantly lower removal rate (about 10% instead of about 50% [10] removal after 5 d). A lower removal rate disproportionately increases the probability of detection because carcasses can still be found after several searches. If this aspect was not adequately considered in the calculations, the estimated number of carcasses was distinctly overestimated (n = 89.4). The different numbers and sizes of unsearched areas between the two studies and the fact that pigeons (which are much easier to find than e.g., songbirds) were the main birds found in the present study may also have influenced the corrected number of carcasses. If bird size and local vegetation parameters were ignored, the corrected number of carcasses was also significantly higher, at 79.5.

Concerning flight reactions and compared with the findings of Jödicke et al. [10], a distinctly lower proportion of flocks responded to the unmarked lines (8.6% compared with about 18%). This may be due to site-specific habitat constellations (e.g., water bodies/spans), line-specific parameters, species-specific behaviors, or activity-specific reasons (e.g., different behaviors of resting vs. breeding vs. migratory birds) [22,25].

The estimated value of the mean bird-strike rate of 0.47 individuals (95% confidence interval: 0.40–0.58) per 1000 crossings in our study is within the range of values determined by Jödicke et al. [10] (the latter with low values < 0.01, medium values 0.1–1.0, and high values > 1.0). Moreover, our estimated rate (mainly based on pigeons) was approximately

in the middle of the confidence interval for Wood Pigeons (0.05–1.2) but higher than the actual value of 0.26, as estimated by Jödicke et al. [10]. This difference may be explained by several factors, such as stochasticity, the fact that Wood Pigeons were not exclusively considered in the present study, or area-specific characteristics. In addition, it should be noted that our value of 0.47 represents a maximum estimate, given that only birds that flew in the first 6 h after sunrise were considered (in contrast to the methods of Jödicke et al. [10] where the entire daytime was considered). Hence, the more flight activity that occurs in the afternoon/evening, at night, or before sunrise, the more overestimated our value will be.

Our study estimated 50.1 bird fatalities per kilometer of powerline annually (95% confidence interval: 42.3–61.7). Notably, we consider the study area as an average landscape because, despite its designated protection status, it is typical for a German riverine floodplain and, in addition, subject to intensive agricultural use. As expected, the collision numbers found in this study were significantly lower than those determined in the recent, comprehensive German study by Jödicke et al. [10] (about 105–307 bird-strike victims per year per line kilometer), the latter considering an area with hotspots for several bird species. Indeed, Jödicke et al.'s [10] study area crossed a large former foreland complex of the marshlands of the Elbe River (Haseldorfer Marsch), which, together with the banks of the Elbe, has very high avifaunistic importance as a breeding and resting area, especially for waterfowl, waders, and reedbed birds, as well as migratory species, with notable resting and wintering populations of various swans, geese, and ducks, as well as waders and terns.

The variability of collision estimates in previous studies is high, ranging from a few or even no individuals to several hundred individuals per kilometer per year (ind./km/year). A comprehensive compilation, including some less well known studies published in German, can be found in the study by TNL [8], with further summaries by Drewitt & Langston [26], Gesellschaft für Freilandökologie und Naturschutzplanung [27], Hoerschelmann [28] and Prinsen et al. [29]. However, many publications lack the information needed to understand why the results differ so much among these publications [29]. More recent works (after 2017) still present heterogeneous orders of magnitudes, such as values of approximately 230 [30], 105–307 [10], approximately 2.4 [31] and approximately 1 individual/km/year [32]. Particularly high values were reported by Heijnis [33], Scott et al. [34], and Grosse et al. [35], estimating approximately 700 individuals/km/year; as well as Hoerschelmann et al. [36], Marti [37], and Jödicke et al. [10] with approximately 390, 328/292, and a maximum of 307 individuals/km/year. All of these studies were, however, conducted near water bodies/wetlands and/or in resting and wintering areas considered to be of a significant avifaunistic value, with a corresponding inventory of species that were in part highly vulnerable to collisions and in part also highly abundant ('hotspots').

In contrast, studies carried out in 'normal landscapes' (e.g., more or less cleared agricultural landscapes, low mountain ranges, forests, etc.), usually found distinctly lower values (e.g., Alonso et al. [38] (approximately 5 individuals/km/year), Bevanger & Brøseth [39] (4 individuals/km/year), Fernandez-García [40] (approximately 2 individuals/km/year) Gutsmiedl & Troschke [41] (approximately 4 individuals/km/year); Hoerschelmann [42] (maximum 10 individuals/km/year), Janss & Ferrer [43] (approximately 1 individual/km/year), and Ferrer et al. [31] (approximately 2.4 individuals/km/year)). Finally, Bernshausen et al. [44], Hoerschelmann & Lieber [45] and Rubolini et al. [46] found no collision victims at all; however, all of these three studies had relatively short overall durations compared with other studies in which carcasses were searched.

Notably, some previous studies have reported higher values, even in so-called 'normal landscapes', such as the study by TNL [30], which was conducted along a 110 kV powerline between Hungen and Lich in Hesse, Germany. This line crossed a largely typical cultural landscape characterized by intensive-use arable land and grassland (Hungen), but also by

hedges, small wetland areas and a smaller watercourse (Lich). Thus, although the recorded species spectrum was average, the collision rate of approximately 230 individuals/km/year was comparatively high, with songbirds affected to a higher extent. This high value may have been caused by nearby important resting areas [30].

Finally, there is a study which is spatially related to the present study within the 'Lippeaue' sub-area in Bernshausen et al. [47], also located in the Lippe floodplain, near the city of Hamm (in the area of the Hamm-Uentrop power plant), and approximately a 50 km linear distance to the east of the current survey area. Bernshausen et al.'s study area [47] was, however, dominated by intensively used grassland. Here, the reported collision rate (before marking the powerline) was about 30 individuals/km/year, which was in a similar order of magnitude to the present study with about 50 individuals/km/year, especially considering that Bernshausen et al. [47] did not determine any correction factors, and the true value may therefore have been even higher. Notably, pigeons (especially Wood Pigeon) compromised the largest proportion of collision victims (approximately two-thirds) in both studies in the Lippe floodplain. Pigeons are known to be at high risk of collision [10], mainly due to their poor three-dimensional vision and fast, straight flight, in connection with their flocking behavior [48]. In addition, they can reach high abundances in the considered areas as both, breeding and resting birds, together explaining their high contribution to collision victims in both studies. In our present study, the high proportion of pigeons among the collision victims can be further explained by the importance of the area between pylons 46 and 47 for roosting and wintering Wood Pigeons (for roosting aggregation, see "Characterization of Avifauna" in Supplementary Material, Chapter S1.1). Accordingly, our data showed that most bird-strike victims were wintering individuals. Notably, the present study was only carried over one year, and whether the roosting aggregation was specific to the study year or is an annual occurrence thus remains unknown. However, this information would be essential if, for example, the area was to be evaluated as part of an impact assessment. This demonstrates the importance of obtaining long-term basic avifaunal data for a given project, either as part of an impact assessment or as general scientific research.

5. Conclusions

The present study provides important insights into bird-strike occurrences in an 'average' German riverine floodplain landscape including large open areas, intensive agricultural use and an impaired water regime. Although the current study covered a relatively short length of powerline (1.5 km) for a limited time (approximately 1 year), compared to other recent studies [31,32], we carried out frequent carcass searches (in total 88 searches) and minimized biased results by applying modern statistical methods for carcass number correction, data visualization and interpretation. The relatively high estimated value of bird-strike victims of approximately 50 individuals/km/year compared with other studies in 'normal landscapes' was not surprising, and can most probably be explained by roosting aggregations of Wood Pigeons, the comparatively mild winter climate and good feeding conditions (at least in the year under investigation), leading to a relatively high risk of bird collisions. Notably, however, no species of high conservation status relevant to environmental impact assessment of powerline projects (see [49] for species of high or very high vulnerability of collision within impact assessment in Germany) were detected as collision victims in this study. In this sense, our results also reflect the 'normal' landscape.

Our study demonstrates that a detailed examination and understanding of the local avifaunal circumstances is necessary to draw conclusions, and extrapolations to larger scales (such as nationwide numbers) must be performed with care, given the complexity of local factors influencing the collision numbers and rates. The presented results estimate

the number of bird collisions and the range of affected species in an area that is neither particularly rich in birdlife nor ecologically sensitive. This is especially relevant considering the planned intensive expansion of energy infrastructure as part of the green energy transition, mainly concerning the 'normal' landscape.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/birds6010013/s1: Figure S1: Photo of a 380 kV pylon in the study area. Figure S2: Validation plots to check the (asymptotic) normality of the residuals, linearity, and homogeneity of variances with respect to the detection regression model. Figure S3: Mean searcher efficiency rate as a function of vegetation height (cm). Figure S4: Mean searcher efficiency rate as a function of bird size (small, medium, and large). Figure S5: Removal of a Wood Pigeon (*Columba palumbus*) by a Fox (*Vulpes vulpes* 25 June 2021, 07:45) (left) and removal of a Jackdaw (*Corvus monedula*) by a Fox (29 June 2021, 00:14) (right). Figure S6: Removal of two Kestrels (*Falco tinnunculus*) by a dog on 3 December 2020, 16:03 (left) and 4 December 2020, 15:40 (right). Figure S7: A Kestrel (*Falco tinnunculus*) was dispersed by Buzzards (*Buteo buteo*) (2:29 p.m. 16 December 2020) but not removed (left), and a Buzzard was dispersed by Carrion Crows (*Corvus corone*) (12:16 p.m., 1 May 2021) but not removed (right). Figure S8: Badger (*Meles meles*) at of Buzzard (*Buteo buteo*) carcass (16 April 2021, 12:03 a.m. and 5 August 2021, 4:02 a.m.), Wild Boar (*Sus scrofa*) at Carrion Crow carcass (*Corvus corone*) (15 August 2021, 12:40 a.m.), Coypu (*Myocastor coypus*) near Kestrel carcass (*Falco tinnunculus*) (14 December 2020, 21:22 p.m.). Figure S9: Partial effect plot of regression model for removal by scavengers. Figure S10: Removal rate after end of the experiment as a function of bird size (small, medium, and large). Figure S11: Removal rate after end of the experiment as a function of month. Figure S12: Histogram of carcass counts as a function of distance (m) from the overhead line (blue bars) and fitted truncated normal distribution (red line). Figure S13: Proportion of individuals and flocks reacting to the lines (top left), more detailed analyses of the reaction distance (top right), reaction strength (bottom left) and evasion height (bottom right) in relation to the reacting birds or flocks. Figure S14: Relative proportion of different crossing heights. Figure S15: Proportion of different species complexes in bird-flight data (left) vs. (corrected) bird-strike victims (right). Figure S16: Proportion of different species complexes in bird-flight data. Figure S17: Relative proportion of the different species complexes in bird-flight data vs. carcass data averaged over whole year. Figure S18: Partial effect (i.e., relative changes) in hourly recorded bird crossings as a function of time after sunrise based on a generalized additive model analysis. Table S1: Powerline features. Table S2: Fixed predictors of the four best logistic regression models for searcher efficiency rate. Table S3: Predictors of four best survival regression models for removal. Table S4: Logistic regression results—best model for searcher efficiency rate. Table S5: Logistic regression results; best model for removal rate.

Author Contributions: A.R., F.B. and M.M. developed the study conception and design. Data collection was performed by A.R. and M.S. Data analysis, figure and table preparation as well as elaboration of the Sections 2 and 3 were performed by M.M. Non-statistical figures (Figures 1 and 2) were created by K.H. The remaining parts of the manuscripts were written by A.R. and M.S. All authors commented and provided changes on previous versions of the manuscript. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Wild bird carcasses for the field experiments were obtained from The Clinic for Birds, Reptiles, Amphibians, and Fish at Justus Liebig University, Giessen, Germany, which accepts injured wild birds in need of care with the goal of rehabilitating them and releasing them back into the wild; however individuals that die or need to be euthanized during treatment are usually disposed of and the clinic agreed to collect carcasses from as wide a range of species as possible and make them available to TNL for an expense allowance. The necessary permit for both the clinic and TNL was submitted to the responsible regional authority (Regierungspräsidium Giessen) and approved (reference: RPGI-53.2-25a020078-2019/2 of 3 September 2020).

Data Availability Statement: Data can be made available upon request and in consultation with the data owners.

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