Bird Conservation International (2011) 21:142–155. © BirdLife International, 2010
doi:10.1017/S0959270910000432

Effects of power lines on flight behaviour of the West-Pannonian Great Bustard *Otis tarda* population

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Summary

Flight directions of Great Bustards *Otis tarda* after take-off were used to analyse effects of power lines on spatial movements of this highly endangered bird species. Data on flight directions came from Great Bustard observations conducted in eastern Austria (northern and eastern parts of Lower Austria, northern part of Burgenland), western Slovakia and western Hungary. Flight directions were determined by a constructed line connecting take-off site and the bird's position after a flown distance of 100 m. Up to a distance of 800 m from the nearest power line, mean flight direction of Great Bustards after take-off deviated significantly from a random distribution. The mean flight direction angles clearly indicate that take-off flight routes point away from power lines at an angle of approximately 180°. Furthermore, flight directions of bustards still deviated from a random distribution in two 200-m distance bands much further away from power lines (> 1,200–1,400 m, > 1,400–1,600 m), possibly suggesting that even at larger distances from power lines flight directions might still be affected by such artificial linear landscape structures. With increasing distance to nearest power lines, mean vector length r values of flight paths decrease significantly, while circular standard deviations S values increase significantly. Very similar results were achieved independently if all data were pooled or analysed separately for individual study areas for which the number of flight observations was large enough to conduct reliable analyses. Our study reports a strong effect of power lines on the flight behaviour of Great Bustards, at least up to a distance of 800 m, perhaps even up to 1,600 m. Although this may significantly reduce the risk of collision with power lines it most likely has severe consequences for the spatial movements of birds within the entire landscape and between potentially suitable breeding and foraging habitats.

Introduction

Spatial movements of highly mobile vertebrates such as birds are affected by natural and artificial landscape structures or direct anthropogenic disturbance (Burger 1998, Drewitt and Langston 2008). Artificial structures – such as wind farms or power lines – can affect flight behaviour or, in severe cases, increase bird mortality due to deadly collisions (wind turbines: Osborn *et al.* 1998, PNAWPPM-III 2000; power lines: Bevanger 1995, Bevanger and Brøseth 2004, Drewitt and Langston 2008, Jenkins *et al.* in press, Rollan *et al.* in press). Wind turbines can have a particularly strong effect on migrating birds when bad weather conditions induce them to fly low, or during take-off and landing. Collision risk for migrating birds flying low just after take-off and just before landing could be reduced by not placing tall structures near locations where migratory birds concentrate before or during migration (Hanowski and Hawrot 2000). However, migratory birds conducting daily flights from overnight roosts to feeding areas appear to be at a particularly high risk (Hanowski and Hawrot 2000), a situation which should also apply to resident birds.

Although mortality caused by collision with wind turbines can be higher than that caused by any other human-made structures (Barrios and Rodríguez 2004), power lines can also have severe effects (Nelson and Curry 1995, Osborn *et al.* 1998). For example, the annual losses of Western Capercaillie *Tetrao urogallus*, Black Grouse *Tetrao tetrix* and Willow Grouse *Lagopus lagopus* due to collisions with high voltage power lines in Norway were estimated at 20,000, 26,000 and 50,000 birds, respectively, representing about 90%, 47% and 9% of the annual hunting harvest of these species (Bevanger 1995).

Concerning wind farms, bird mortalities have not been found to be associated with either structural attributes or visibility of these artificial structures (Barrios and Rodríguez 2004). The collision risk of birds with power lines has been shown to depend on their morphology and consequently their flight performance, particularly their manoeuvrability. Principally, species with high wing loading and low aspect run a high risk of colliding with power lines. They are characterised by rapid flight and a combination of heavy body and small wings, which restricts swift reactions to unexpected obstacles (Bevanger 1998). When the number of reported collision victims is considered relative to the abundance and population size of the species concerned, some Galliformes, Gruiformes, Pelecaniformes and Ciconiiformes seem to be affected in disproportionately high numbers (Bevanger 1998). A study on power line collisions in west-central Spain indicated that birds with a high body mass and relatively short wings and tails, described as ''poor fliers,'' such as Great Bustard and Little Bustard *Tetrax tetrax*, are at greatest risk of collision (Janss 2000).

Collisions with power lines have been frequently reported for Great Bustards (Cramp and Simmons 1980, Cardoso 1985, Janss and Ferrer 1998, 2000, Alonso *et al.* 2005, Martín *et al.* 2007). The species is considered globally threatened (Birdlife International 2008) and classified as ''Vulnerable'' in the IUCN Red List (IUCN 2009). Land privatisation and subsequent land-use change in Eastern Europe, Russia and Central Asia might lead to a rapid population reduction over the next three generations (Birdlife International 2009), although a recent estimate of the global status of the species indicates that total numbers have not decreased during the last decade, in contrast to the declining trend currently assumed (Palacín and Alonso 2008). Bevanger (1998) emphasised that an alarmingly large number of species with endangered and vulnerable status are among the victims of reported bird-strikes on power lines, but there are insufficient data at present for judging the significance of this mortality at the population level.

Apart from illegal hunting, collisions with overhead power lines are currently the most significant mortality factor for Great Bustards in several countries (e.g. Martín *et al.* 2007). In Portugal, a mean annual collision rate of almost 7% (92 individuals) of the national Great Bustard population has been reported (Infante *et al.* 2005). A study on radio-tagged Great Bustards in Spain documented mortality caused by collision with power lines of 54.5% for birds during the second year of life (Martín *et al.* 2007).

The present study investigated effects of power lines on the flight behaviour of Great Bustards in eastern Austria, western Hungary and western Slovakia – home to more than 95% of the total West-Pannonian population (Raab 2009, Raab *et al.* in prep.). Although the West-Pannonian population of the Great Bustard recovered after a serious decline in the last century from about 130 individuals in 1995 to more than 370 birds in 2009 (Raab *et al.* 2010), power lines still represent a serious threat as demonstrated by 33 deadly incidents due to collisions in the period June 2001-May 2009 (Raab 2009, Raab *et al.* 2010). In particular, we investigated whether the presence of power lines affects the flight direction at take-off and up to what distance power lines have an impact on flight paths.

Methods

Study areas

The study was conducted in one Important Bird Area (''Rauchenwarther Platte'') and four Special Protection Areas (SPA ''Westliches Weinviertel'', SPA ''Sandboden und Praterterrasse'', SPA ''Waasen–Hanság'' and SPA ''Parndorfer Platte–Heideboden'' around the Austrian-Hungarian-Slovakian border) in eastern Austria; one area across the Slovakian and Hungarian border (SPA ''Sysl'ovské polia'' and the northern part of the SPA ''Mosoni-sík''), and one in the Hungarian Moson Plain (the southern part of the SPA ''Mosoni-sík'') (Figure 1), covering a total area of c.45,000 ha. The study areas are mainly flat or gently undulating agricultural areas dominated by cereal fields and comprising a varying extent of fallow fields, and are largely free of vertical structures like trees or hedges; a landscape structure preferred by Great Bustards (Collar 1996, Osborne *et al.* 2001). All study areas are crossed by power lines.

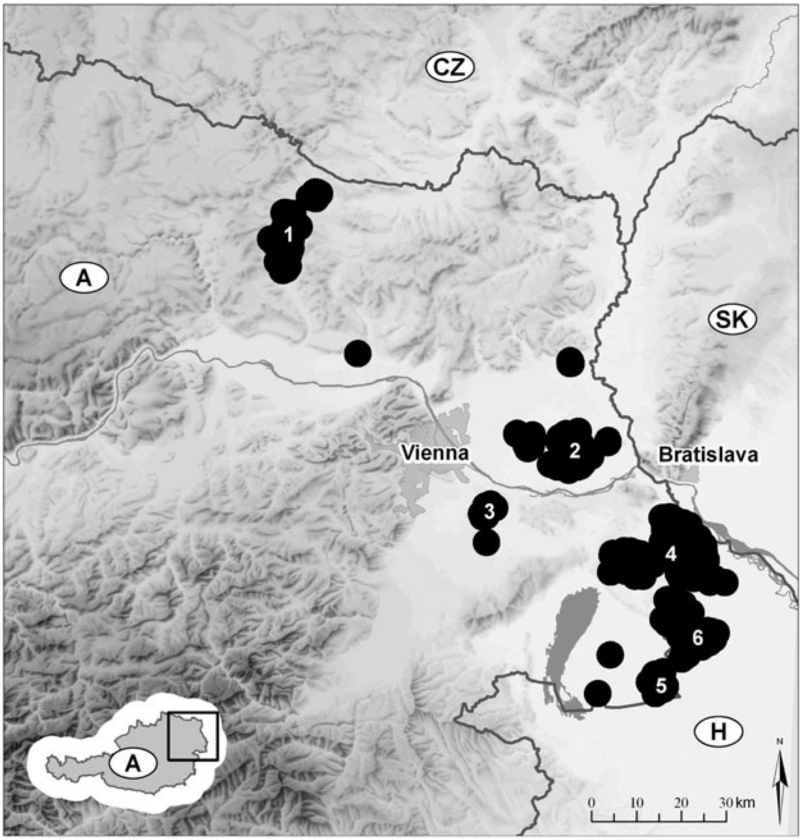

Figure 1. Locations of the West-Pannonian population of Great Bustard in the period from 2002 to 2008 with observed flight movements; locations in and around SPA ''Westliches Weinviertel'' (1), SPA ''Sandboden und Praterterrasse'' (2), ''Rauchenwarther Platte'' (3), SPA ''Parndorfer Platte–Heideboden'' (in Austria), SPA ''Sysl'ovské polia'' (in Slovakia) and the northern part of the SPA ''Mosoni-sík'' (in Hungary) (4), SPA ''Waasen–Hanság'' (5) the southern part of the SPA ''Mosoni-sík'' (in Hungary) (6) and additional locations with observations (black circles = 3 km buffer zones around Great Bustard individuals observed during take-off).

Flight directions of Great Bustards after take-off

Observations on the flight behaviour of Great Bustards were made during surveys conducted in the years 2002–2008. Flight movements of Great Bustards after take-off were recorded in the field by drawing on detailed maps (scale 1:12,500). Later, all aerial movements were digitised in a Geographical Information System (software package ArcMap 9.1, ESRI). Flight directions of Great Bustards were taken as the bearing of a straight line drawn from the birdś take-off sites to their position after the first 100 m flown. When more than one individual synchronously took off, the mean flight direction of the flock was considered, which in the vast majority of cases was identical for all birds within the flock, 100 m after take-off. In total, 2,832 such observations were available for analysis (2,604 observations by R. Raab, P. Spakovszky and E. Julius, plus 228 others). The majority of observations are from areas 4 (1,741 observations) and 1 (614). Smaller numbers of observations are available from the other study areas (area 2: 256; area 6: 195; area 5: 16; area 3: 9, between area 1 and 3: 1). The number of observations from individual years increased from 199 in 2002 to 752 in 2008. Observations cover all months of the year ranging from a monthly total of 153 in December to 390 in April. Observed flight movements of Great Bustards and exact locations of all power lines were available as shape files for further data processing with ArcView 3.3.

The following key variables were quantified for all observations: (1) shortest distance between a Great Bustard's take-off site and nearest power line; (2) the angle between flight direction and the perpendicular on the nearest power line, ranging from 0° (bird flies directly towards nearest power line) to 180° (bird flies away from nearest power line).

Landscape elements such as roads and tracks frequently used by cars, agricultural vehicles or walkers may be another source of disturbance causing avoidance by Great Bustards and therefore affecting the birdś flight direction after take-off. Therefore, we additionally digitised roads and tracks with ArcMap 9.1.

Data analysis

To test for effects of the distance between take-off site and nearest power line on flight direction preferences of Great Bustards, we applied circular statistics calculated with the program Oriana version 3.01 (Kovach Computing Services). Observations were grouped according to the distance from the next power line in 200 m belts. For flight movements of each group of birds, we calculated the mean vector, which has two properties: its direction (the mean angle, μ) and its length r. The length r ranges from 0 to 1; larger r values indicate that observations are clustered more closely around the mean. The circular standard deviations were calculated as $S = (-2\ \ln(r))^{½}$ and subsequently were converted to degrees by multiplying by $180/\pi$.

Rayleigh's Uniformity Test (Fisher 1993) was used to calculate the probability that flight directions were distributed in a uniform manner. Rayleigh Z values quantify the likelihood of flight directions being uniformly distributed with larger Z values indicating greater concentration of flight directions around the mean. A probability less than a chosen significance level (in this study 0.01) indicates that the flight directions of Great Bustards are not distributed uniformly, and that there is evidence for a preferred direction.

To rule out the possibility that road and tracks as a potential source of disturbance may bias our results, a Spearman rank correlation was applied to test if they are randomly distributed or associated with power lines. Therefore, we related the total length of roads and tracks to the total length of power lines measured for 500 m × 500 m grids using ArcMap 9.1, only considering grids from which Bustard observations were available for analysis. Unfortunately, such data on the length of roads and tracks were only available for four of the larger study areas: ''Sandboden und Praterterrasse'' (2), ''Waasen–Hanság'' (5), ''Westliches Weinviertel'' (1) and ''Parndorfer Platte–Heideboden'' (including areas in SK and HU)'' (4) Figure 1.

Results

Considering all observations of flight directions after take-off, the mean flight direction of Great Bustards deviated significantly from a random distribution in all 200-m distance belts up to 800 m from the nearest power line (Figures 2–3). The mean flight direction angles (between 170° and 198°) clearly indicate that flight routes after take-off point away from power lines. At larger distances there is increasingly less evidence for a preferred flight direction (Figure 2). However, flight directions of bustards still deviated from a random distribution in two 200 m distance bands much further away from power lines (> 1,200–1,400 m, > 1,400–1,600 m), indicating that even at larger distances flight directions might still be affected by such artificial landscape elements (Figure 2).

The decreasing influence of power lines on flight directions of Great Bustards with increasing distance of take-off site from nearest power line is also indicated by mean vector lengths (*r*) of flight paths and circular standard deviations (*S*) calculated for all defined 200-m distance belts: With increasing distance to nearest power lines, *r* values decrease significantly (Figure 4a), while circular standard deviations increase significantly (Figure 4b).

No relationship between total length of roads and tracks and power line length of 500 m × 500 m grids was found at "Sandboden und Praterterrasse" (Spearman rank correlation; $r_s = -0.06$, $n = 240$ grids, $P = 0.321$) and "Waasen–Hanság" ($r_s = 0.12$, $n = 70$, $P = 0.312$), a weak negative relationship was indicated for "Westliches Weinviertel" ($r_s = -0.17$, $n = 196$, $P = 0.018$) and a strong positive relationship exists in study area "Parndorfer Platte–Heideboden" ($r_s = 0.22$, $n = 514$, $P < 0.001$). Due to these differences in the association of power lines with another

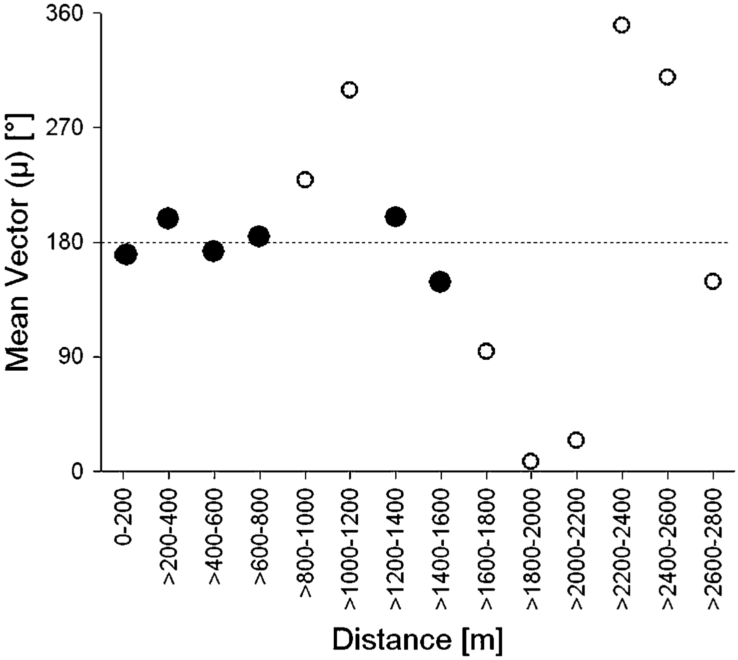

Figure 2. Mean flight directions of Great Bustards after take-off at different distances to power lines. Flight directions described by an angle of 180° point directly away from power lines. Significant deviations from a random distribution of flight directions are indicated by filled circles (at a level of $P < 0.01$; Rayleigh's Uniformity Test).

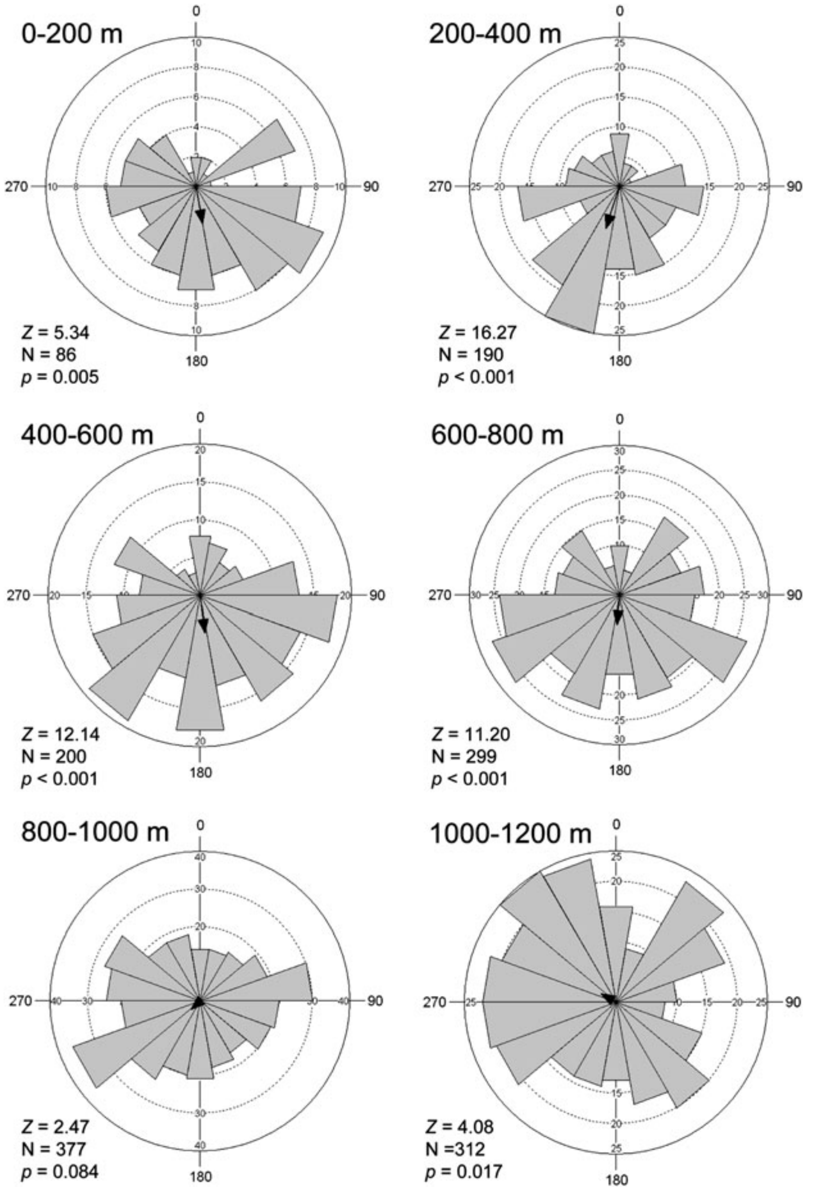

Figure 3. Flight directions of Great Bustards after takeoff in different 200 m distance belts to power lines. Mean flight directions are indicated by arrows. Additionally, results of Rayleigh's Uniformity Tests are provided. n = number of observed bustards and flocks of bustards, respectively for which flight directions.

potential source of disturbance (roads and tracks) between study areas, all analyses testing for effects of power lines on flight direction were also calculated separately for three of these study areas, for which enough observations on flight directions after take-off were available: ''Parndorfer Platte–Heideboden'' (n = 1,741 observations), ''Westliches Weinviertel'' (n = 614) and ''Sandboden und Praterterrasse'' (n = 256). While for the first study area data on flight directions

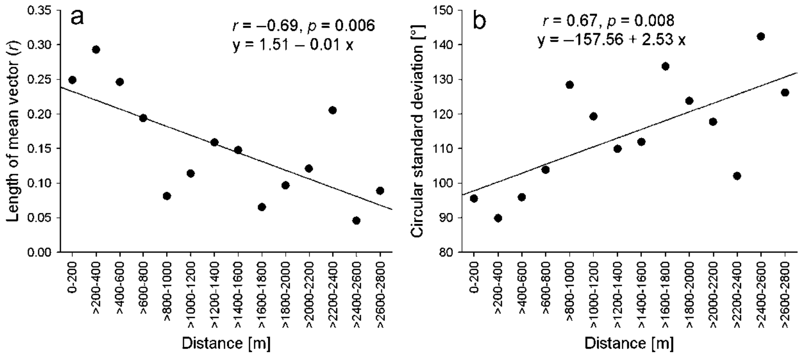

Figure 4. Effects of distance to power lines on length *r* of mean vectors (a) and circular standard deviations (b) of flight directions of Bustards after takeoff. In addition, results of linear regressions and regression functions are provided.

after take-off were again pooled for 200 m belts, for the other two, data had to be pooled for 400 m belts to achieve sample sizes large enough for conducting reliable analyses.

The separate analyses of bustard flight directions for these three study areas indicate very similar results independent if a positive association between power lines and roads (study area ''Parndorfer Platte–Heideboden''), a weak negative relationship (''Westliches Weinviertel'') or no association (''Sandboden und Praterterrasse'') existed. Mean direction angles of flight routes after take-off point away from power lines at distances up to 800 m, in some cases up to 1200–1600 m (Fig. 5). Furthermore, mean vector lengths (*r*) of flight paths decrease with increasing distance to nearest power lines (Fig. 6); circular standard deviations increase at all three study areas (Fig. 7). However, not all regression analysis achieved a significant level although the respective trends are obvious for all three study areas (compare Figs. 6–7).

Discussion

Despite the limitations of most studies on bird collisions with artificial structures such as power lines, it is apparent that bird strikes are a significant cause of mortality in larger bird species (Brown and Drewien 1992, Drewitt and Langston 2008), besides electrocution (Rubolini *et al.* 2001). Both may potentially have severe effects on bird populations (e.g. Crivelli *et al.* 1988, Rubolini *et al.* 2001). Several measures such as marking of power lines have been suggested that can successfully reduce the collision and/or electrocution risk of large birds (Brown and Drewien 1995, Bevanger and Brøseth 2001, IEEE Task Force on Reducing Bird Related Power Outages 2004). However, a study on the collision risk of Great Bustards in Spain did not find a decrease in casualties related to the marking of power lines (Janss and Ferrer 1998).

Birds can reduce the collision risk by adapting their flight behaviour as demonstrated by our study that shows a strong effect of power lines on flight behaviour of Great Bustards. At least up to a distance of 800 m, mean flight directions after take-off pointed away from power lines. However, our results indicate that these artificial structures affect bustards' flight behaviour even at larger spatial scales up to a distance of 1,600 m. Changes in flight behaviour of larger bird species in response to man-made structures have been documented before (e.g. Shimada 2001). Large interspecific variations in sensitivity to power lines have been observed with Great Bustards preferring to avoid crossing power lines more frequently than other birds (such as cranes) (Janss and Ferrer 2000). It has been shown as well that soaring birds during migration can detect the presence of wind turbines and change their flight direction when flying in close proximity, which most likely explained the low number of dead birds found in the studied wind farm area (de Lucas

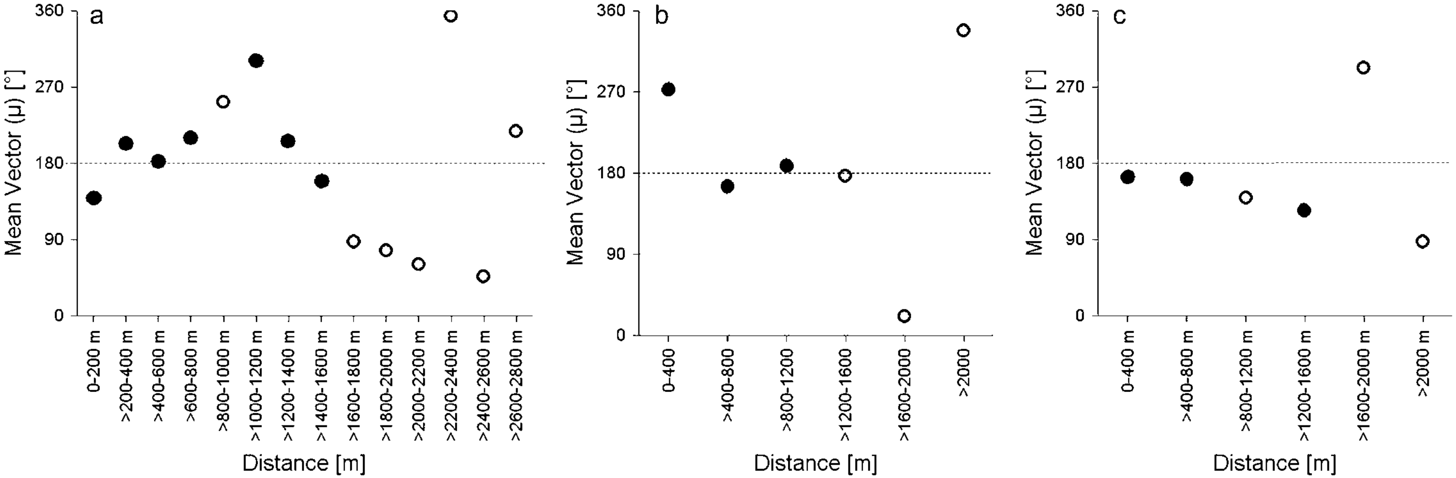

Figure 5. Mean flight directions of Great Bustards after takeoff at different distances to power lines at three different study areas: ''Parndorfer Platte–Heideboden'' (a), ''Westliches Weinviertel'' (b) and ''Sandboden und Praterterrasse'' (c). Flight directions described by an angle of 180° point directly away from power lines. Significant deviations from a random distribution of flight directions are indicated by filled circles (at a level of $P < 0.01$; Rayleigh's Uniformity Test).

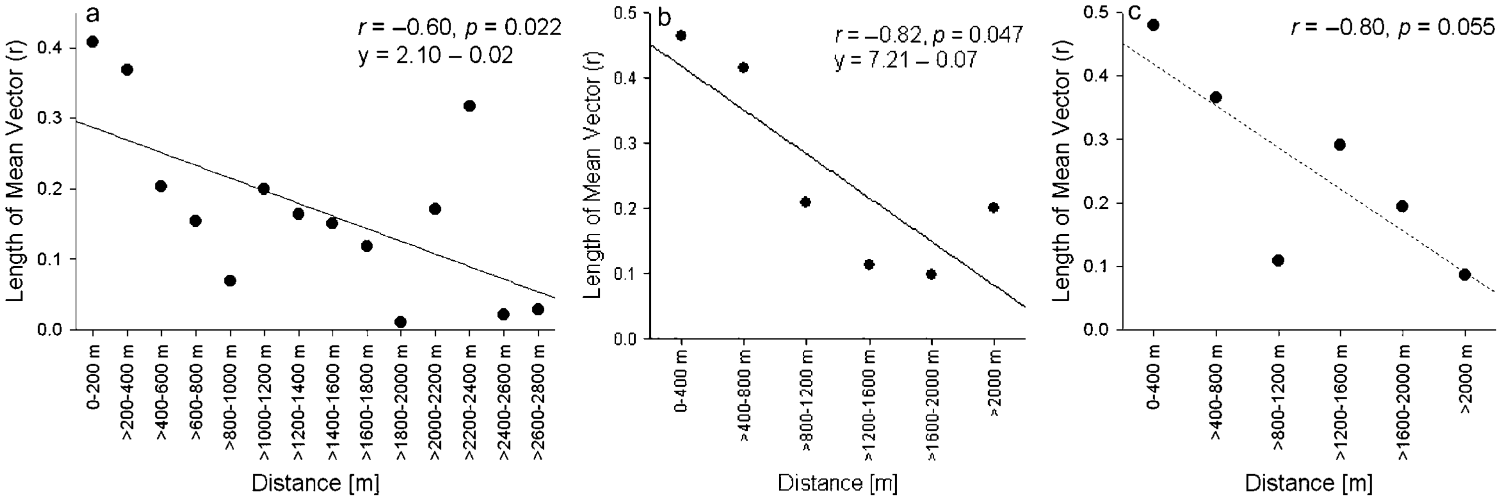

Figure 6. Effects of distance to power lines on length *r* of mean vectors of flight directions of Bustards after takeoff at three different study areas: ''Parndorfer Platte—Heideboden'' (a), ''Westliches Weinviertel'' (b) and ''Sandboden und Praterterrasse'' (c). In addition, results of linear regressions and regression functions (only for significant regressions) are provided. A trend which did not achieve a significant level is indicated by broken regression lines.

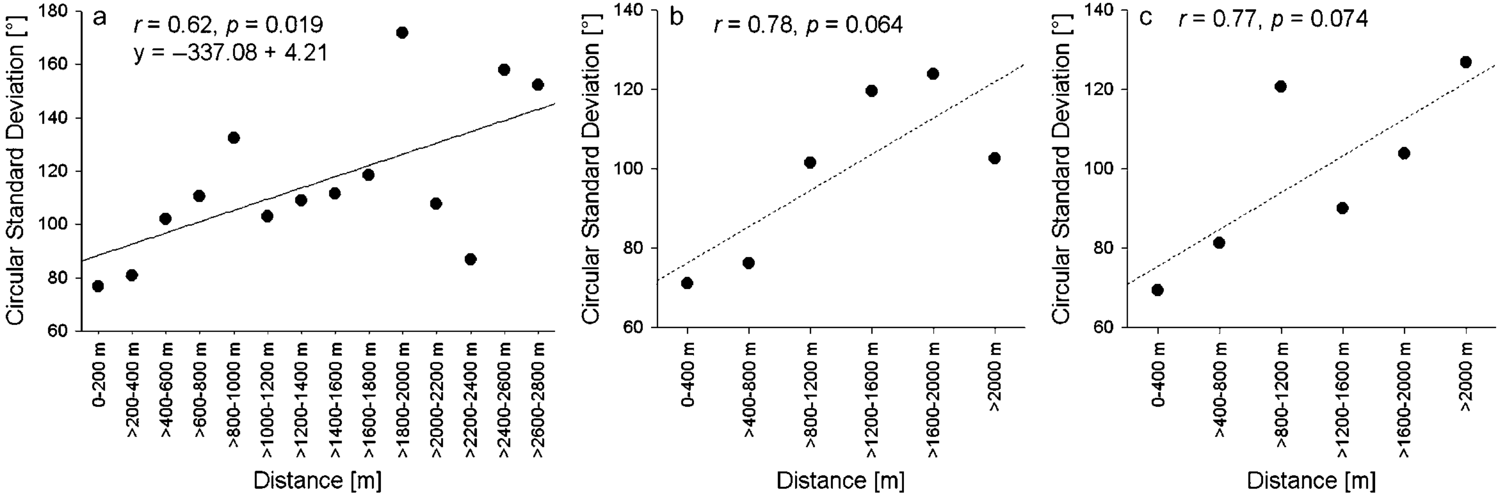

Figure 7. Effects of distance to power lines on circular standard deviations of flight directions of Bustards after takeoff at three different study areas: ''Parndorfer Platte–Heideboden'' (a), ''Westliches Weinviertel'' (b) and ''Sandboden und Praterterrasse'' (c). In addition, results of linear regressions and regression functions (only for significant regressions) are provided. A trend which did not achieve a significant level is indicated by broken regression lines.

et al. 2004). However, the likelihood of collision mortality can differ depending on the location of man-made structures. A greater risk of collision was observed when such artificial structures were placed on or near areas regularly used by large numbers of feeding, breeding, or roosting birds, or on local flight paths, such as those between foraging and nesting or roosting areas (Faanes 1987, Everaert and Stienen 2007).

Our study demonstrates that beside the collision risk, power lines have a high potential to result in habitat loss in a similar way to wind turbines which can reduce the habitat for foraging and breeding waterfowl (Osborn *et al.* 1998, Larsen and Madsen 2000, Guillemette and Larsen 2002).

Our finding has important implications for the conservation of the relatively small populations of Great Bustards at the western margin of the Pannonian distribution range of the species. Such small marginal populations are particularly at risk of local extinction as documented for Spanish Great Bustards (Alonso and Alonso 1996, Lane and Alonso 2001). Although the adaptation of flight routes after take-off in response to nearby power lines may reduce the risk of collision, such man-made structures most likely have severe consequences for the spatial movements of Great Bustards within the entire landscape and particularly between potentially suitable breeding and foraging habitats. Furthermore, there are likely significant effects on the time and energy budget of birds moving between different locations to visit feeding, breeding and, in the case of the Great Bustard, courtship sites. Therefore spatial movements of bustard populations have to be carefully monitored and considered when planning new power lines around or between breeding and wintering grounds of this highly endangered species. Marking is a compromise to reduce the collision risk, but marked power lines influence flight directions more strongly than unmarked power lines (Alonso *et al.* 1994). We therefore recommend ''undergrounding'' of cables instead of marking power lines, because this should eliminate every negative effect of the power line on birds.

Acknowledgements

We would like to give our special thanks to more than 700 people involved in conservation projects for the West-Pannonian Great Bustard population. The three LIFE Projects ''Cross-border Protection of the Great Bustard in Austria'' (LIFE05 NAT/A/000077), www.grosstrappe.at; ''Conservation of *Otis tarda* in Hungary'' (LIFE04 NAT/HU/000109), www.tuzok.hu; ''Conservation of *Otis tarda* in Slovakia'' (LIFE05 NAT/SK/000115), www.dropy.sk, are supported by the EU, many project partners and co-financiers. Additional EU co-financed projects are supported by the Austrian Federal Ministry for Agriculture, Forestry, Environment and Water management (BMLFUW), the regional governments of Lower Austria and Burgenland. Without this support the time-intensive work for the conservation of the entire West-Pannonian Great Bustard population during recent years would not have been possible. We are grateful to Björn Beckmann for proofreading a first draft of the manuscript. Rainer Raab would like to extend his special thanks to his PhD supervisor Hans Winkler. We also like to thank Olivier Combreau for helpful comments which significantly improved the manuscript.

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Received 30 November 2009; revision accepted 7 July 2010;
Published online 11 August 2010