BAT DEATHS AND WIND TURBINES - A REVIEW OF CURRENT KNOWLEDGE, AND OF THE INFORMATION AVAILABLE IN THE DATABASE FOR GERMANY

Tobias DÜRR & Lothar BACH

Abstract

The present paper deals with bat mortality in Germany due to the action of wind turbines (up to now, 10 species in Germany and 15 in Europe) which is known at the present. According to the studies conducted in Brandenburg and Saxony it appears that most dead bats are found at the end of summer and during the autumn migration, a fact that is not statistically confirmed by the irregular checks carried out throughout the year and which should be considered only as an indication. About 93% of all the victims were found between the dispersal of the breeding colonies and the end of the autumn migration (August- September). 89% of the fatalities were around turbines whose towers were less than 100 m from wooded landscape features (woods and hedgerows). Because of the heterogeneity of the data, no difference in effect has been noted among the diverse types of wind turbines - all can be responsible for the death of bats. It appears obviously that the siting of the turbines has a direct influence on the number of bats killed. The possible reasons for this mortality are discussed here, but they are still largely unexplained and need more specific research. To this end a protocol for future comparative studies is presented.

1 Introduction

Until the 1990s only isolated dead birds were found under wind turbines. Up to that time wind parks were only set up in open landscape near the coast, and nobody thought of the potential risk for bats. To start with then, the connection between bat mortality and wind turbines was only a well-founded supposition (Bach et al 1999, Rahmel et al. 1999), but the risk for these animals has now been proved through numerous findings in Germany and elsewhere. The first evidence of bat mortality due to wind turbines was published in Australia in the 70s (Hall & Richards 1972). Much later Osborne et al (1996) mentioned bat bodies found under wind turbines, this time in Minnesota (USA). After these discoveries, made by chance during research into the death of birds, the studies were intensified and now most data about bat mortality comes from the USA (Anonymous 1999, Johnson et al. 2000, Johnson in press, Johnson et al. 2003, Keeley et al. 2001).

Until recently there were very few studies in Germany about bat behaviour (Rahmel et al. 1999, Bach 2001, 2002) and collisions with wind turbines. The publication by Vierhaus (2000) of the first dead bat found in Germany in 1998 at first went unnoticed. In 1999 Heddergott started systematically to research death by collision in Thuringia. His data has yet to be published. Only a summary is available and the original data is not accessible and cannot be verified. But the mortality figures published in 2001 by Dürr triggered an avalanche. Since 2002 all published and known data on birds and bats are recorded in a national databank for mortality by wind turbines which is situated at the Landesamt Brandenburg (Staatliche Vogelschutzwarte).

In this paper we attempt to analyse the possible relationship between known victims and the numerous parameters of the wind turbines involved (axle height, rotor diameter and total height). We also try to establish a possible relationship between the distance of the WT from the nearest wooded feature that bats might use as a foraging habitat, or as a linear landmark for orientation while commuting or migrating.

2 Bat fatalities at wind turbines in Germany and Europe

The German databank shows that up to now 207 bats from 10 species have been killed by wind turbines in 8 different states in Germany (Tab.1)

Tab.1: Bats killed by WTs in Germany (BB = Brandenburg, SAH = Saxony-Anhalt, SN = Saxony, TH = Thuringia, SH = Schleswig-Holstein, BY = Bavaria, NRW = North Rhine-Westphalen, RP = Rhineland-Palatine, NDS = Lower Saxony (Vauk *et al.* 1990) (state as on 31.08.2004).

Species		BB	SAH	SN	TH	SH	BY	NRW	RP	NDS	Total
Nyctalus noctula	Noctule bat	39	1	20	54	3	1	1			118
Nyctalus leisleri	Leisler's bat	5	1	1	3						10
Eptesicus serotinus	Serotine bat	2			2	1		1			6
Vespertilio murinus	Parti-coloured bat	1		7							8
Myotis myotis	Greater mouse-eared bat			7							7
Myotis daubentonii	Daubenton's bat	1									1
Plecotus austriacus	Grey long-eared bat	1									1
Pipistrellus pipistrellus	Common pipistrelle	15	2	6	2						25
Pipistrellus nathusii	Nathusius' pipistrelle	17	1	23	2			1			44
Pipistrellus pygmaeus	Soprano pipistrelle	1									1
Pipistrellus sp.	Pipistrelle sp.	4				14					18
Chiroptera sp.	Chiroptera sp.		2						2		4
TOTAL		85	5	59	70	18	1	3	2	0	243

The information from Thuringia (70 victims from 6 species) goes back to M. Heddergott's findings in Eichsfeld from 1999 to 2001. At present this data is still insufficiently documented, but the circumstances of Heddergott's findings leave no doubt as to its veracity. The 7 dead Greater Mouse-eared bats (*Myotis myotis*) are the only individuals of this species found in Germany under wind turbines and up to now the only dead *Myotis* spec. killed at European wind farms[1]. Unfortunately this data was orally communicated and up to now it has been impossible to see the dead animals. According to Dürr, the data is perfectly believable, but we are convinced that the figures for the Greater Mouse-eared bat must be considered with caution in the absence of the bodies.

The findings from Schleswig-Holstein come exclusively from unsystematic checks at several wind farms in late summer and autumn 2003 by M. & M. Göttsche; they concern 3 Noctule bats (*Nyctalus noctula*) and a large number of *Pipistrellus* spec. We still do not have the precise identification results of one particular specimen. Data is also missing for those German states not mentioned in the table and for those with low figures. This missing data may be simply due to lack of registration[2]. In Lower Saxony and Schleswig-Holstein a total of 9 wind farm sites along the coast were checked in 1989 and 1990 (Vauk *et al.* 1990).

It seems there will be a large number of victims wherever the siting of the wind turbines is in conflict with the foraging airspace of some high flying bats (*Eptesicus serotinus, Vespertilio murinus, Nyctalus noctula, Nyctalus leisleri* and also to a lesser extent *Pipistrellus pipistrellus* and *Eptesicus nilssonii*) as described by Rahmel *et al.* (1999). For the Northern bat (*Eptesicus nilssonii*) mortality is still unproved in Germany and no doubt is related to the very limited distribution area of the species in this country and the lack of corresponding

---

[1] At the date of the translation, other dead *Myotis* spec. have been found

[2] At the date of translation two more investigations are finished or in progress: Brinkmann et al. (2005) Baden-Württemberg, Hermanns mündl. Mecklenburg-Vorpommern

studies in the area. But Ahlén (2002) considered this species to be the most common victim around wind turbines in Southern Sweden. In Germany the migratory species *Nyctalus noctula* (47,8%) and *Pipistrellus nathusii* (19,3%) were found particularly often. Together they represent two thirds (67,1%) of all victims. On two sites *Vespertilio murinus* have been killed by wind turbines (3,9%). Isolated findings (each one 2,4%) concern *Nyctalus leisleri* and *Eptesicus serotinus* and one *Pipistrellus pygmaeus* and *Plecotus austriacus*. The percentage of *Pipistrellus pipistrellus* is surprisingly high (9,8%) and if we consider the total of all individuals belonging to the genus *Pipistrellus*, they represent 31,5% of all findings.

Tab. 2: Bat fatalities at wind farms in Europe (X = species found but no figure available)

Species		Germany	Sweden	Spain	Total
Nyctalus lasiopterus	Greater noctule			X	>1
Nyctalus noctula	Noctule	118	1	X	>100
Nyctalus leisleri	Leisler's bat	10	-	-	>5
Eptesicus serotinus	Serotine	6	-	X	>5
Eptesicus nilssonii	Northern bat	-	8	-	8
Vespertilio murinus	Parti-coloured bat	8	1	-	9
Tadarida teniotis	European free-tailed bat			X	
Myotis myotis	Greater Mouse-eared bat	7			7
Myotis daubentonii	Daubenton's bat	1			1
Pipistrellus pipistrellus	Pipistrelle bat	25	1	X +1	>22
Pipistrellus nathusii	Nathusius' pipistrelle	44	5	-	45
Pipistrellus pygmaeus	Soprano pipistrelle	1	1	X	2
Pipistrellus kuhlii	Kuhl's pipistrelle			X	>1
Pipistrellus sp.	Pipistrelle spec.	18			17
Hypsugo savii	Savi's pipistrelle			X+1	>1
Plecotus austriacus	Grey Long-eared bat	1			1
Chiroptera sp.	Chiroptera spec.	4	30	14	48
TOTAL		243	47	22	277

In the rest of Europe there are very few results of studies and most are unpublished (Tab. 2). In Spain, up to the year 2000, about 20 bats were found dead on one wind farm (Alcade 2003, Artazcoz pers. comm), mainly *Pipistrellus kuhlii* but also *Pipistrellus pipistrellus, P. pygmaeus*, *Hypsugo savii* and *Eptesicus serotinus* as well as *Nyctalus noctula* and *N. leisleri*. Lekuona (2001) made available the results of studies of different wind farms in Navarra (Spain), revealing the death of one *Pipistrellus pipistrellus* at Izco Airbar wind farm and one *Hypsugo savii* at Salajones wind farm. Dubourg-Savage (pers. comm.) announced that in France also the first dead bats had been reported under wind turbines, but precise data was not then available.

On Gotland (Sweden), about 30 dead bats were found in 1999 under one solitary wind turbine. They were probably *Nyctalus noctula*. The only other survey of different wind farms and solitary wind turbines in Southern Sweden in 2002 resulted in findings of dead *Eptesicus nilssonii*, *Pipistrellus nathusii*, *Nyctalus noctula, Pipistrellus pygmaeus* and *Vespertilio murinus* (Ahlén 2002), the Northern bat (*E. nilssonii*) being the most common victim. Apart from these findings, no other data from Europe has reached us.

3 Frequency of findings

Since 2001 wind turbine checks are carried out in Brandenburg and the results recorded in the central databank of the Staatliche Vogelschutzwarte (Tab. 3). The majority of wind farms were monitored for a minimum of 2 years, and some for 3 years, checked at random dates throughout the year. However the majority of checks took place between the end of March and the end of May and between the end of July and the end of October. The intervals between the controls were irregular and varied between yearly, weekly (March to October) and fortnightly (November to February). They averaged out at no more than 5 per WT per year. The following wind farms were surveyed (see also Annex 1): Bredow, Bückwitz, Eichfelder Damm, Jacobsdorf, Klessen-Görne, Ketzin, Lietzow, Markau, Michelsdorf, Nackel, Nahmitz, Nauen, Netzen, Prützke, Sieversdorf, Tremmen, Wernikow, Wernitz, Zachow.

Tab. 4 presents Förster's analysis (2004) of the number of dead bats found. Taking all the surveys into consideration, we find higher mortality than in Brandenburg (Tab. 3). The maximum was 11 bats found under just one wind turbine. These high figures can be explained by the fact that the resources put into the survey were more than twice those in Brandenburg. In addition the majority of checks took place only during the season when most fatalities occur (Tab. 3 + 4). Unlike Brandenburg, in Saxony no searching for victims was done during the six winter months when bat activity is reduced to a minimum. On some wind farms in Brandenburg (some findings) or in Saxony (Förster 2004), during certain years at least, no dead bats were found at all during random checks. These checks were for the most part not continuous (Brandenburg) or took place only during a few weeks or months (Saxony). The studies in Brandenburg and Saxony made it very likely that dead bats are missed, by the mere fact that they did not cover the whole activity cycle of the bats. This was also partly the case for the studies in coastal areas. The data must therefore be considered with great care. But even on wind farms where dead bats have been found, animals were not lying under every wind turbine. Other factors probably play a role, such as the activity of predators, the type of WT, or their distance from the nearest wooded feature, etc. (see below).

To get a better idea of the problem, in September and December 2003 the Staatliche Vogelschutzwarte of Brandenburg made tests on several wind farms to evaluate how long it would take for 1-day chicks to disappear if left on the ground (Dürr 2004). Predators, human and agricultural activity contributed to the rapid disappearance of most chicks within a week (83% in September, 42% in December). But these results have to be interpreted with caution, knowing the taste of carnivores for chick flesh. Many bats were found mummified and despite their state of decomposition had been unnoticed or spurned by the carnivores. We know of no single case of a bat showing traces of being bitten by a mammal, though there were signs of insect activity. On the other hand the teeth marks of mammal were regularly observed on dead birds. Chick flesh may therefore be compared to small bird flesh, but not to the flesh of bats with its strong smell.

	2001	2002	2003	Total
Number of wind farms checked	8	15	18	19
Number of wind turbines checked	38	79	147	156
Number of checks	66	394	550	1010
Checks/WT/year	1.74	4.99	3.74	3.83
Bats found (n)	5	11	20	36
Number of bats/check	0,08	0,03	0,04	0,04

Tab. 3 : Wind turbine surveys in Brandenburg and bat mortality (Total = total number of checked wind farms and solitary turbines)

	2002	2003	Total
Number of wind farms checked	5	10	12
Number of wind turbines checked	34	61	95
Number of checks	418	347	765
Checks/WT/year	12.29	5.69	8.05
Bats found (n)	37	24	61
Number of bats/check	0.09	0.07	0.08

Tab. 4 : Wind turbine checks in High Lusatia (Saxony) from Trapp *et al.* (2002) and Förster (2004)

4 Seasonal distribution of findings

Fig.1 shows the seasonal distribution of 49 dead bats found in Brandenburg. Here we must take into account the fact that the search for dead bats is not evenly distributed throughout the year. For the purpose of this study, we have analysed data from the central mortality file concerning 1367checks for a total of 201 wind turbines. During the winter months from December to February no bat has been found during 156 checks. In spring (March to May) 271 checks were carried out and 3 bats (0,011 ind./control) found. In summer (June to August) 484 controls revealed 27 dead bats (0,056 ind./control). In autumn (September to November) 455 checks were carried out and 19 bats (0,042 ind/control) were found. Therefore for the period under consideration (2001-2003) 0,04 bat per check was found. The numbers differ slightly from the data in Tab. 3 which only shows information coming from the studies realised directly by the Staatliche Vogelschutzwarte.

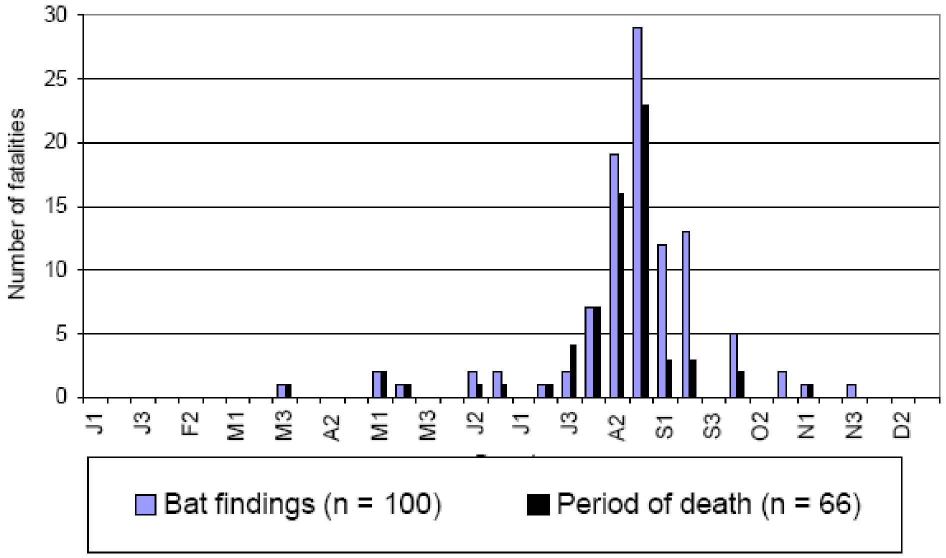

Fig.1 Bat fatalities at wind turbines in Brandenburg

5 Distance between wind turbines and wooded structures

To determine if landscape features around wind turbines play a role in bat mortality, the distance of wind turbines responsible for bat fatalities from forest edges, hedgerows and/or other types of wooded structures has been analysed (fig. 2). Unfortunately we do not have data for WT sites with no bat mortality (see above). It is clear that most animals (36 individuals, 77%) were found under turbines which were less than 50 m from trees. As each bat species reacts differently to landscape features, there should be differences in the correlation between fatalities under the turbine and its distance from the nearest trees, and data for the 44 victims should therefore be presented by species. It is however necessary to take into account the fact that the sampling number per species is very low. As expected, mortality of *Pipistrellus* spec. was mostly near trees and there were only very few differences between *Pipistrellus nathusii* and *Pipistrellus pipistrellus*. But for the Noctule bat, mortality at wind turbines occurred also at a mean distance of 200 m and as far as 600 m from woods. A surprising finding was that of a Serotine bat (*Eptesicus serotinus*) killed by a WT which was 700 m away from the nearest wood.

6 Influence of the type of wind turbine

As the different types of wind turbines (axle height, rotor diameter) may have a different effect on the occurrence of bat fatalities, this will be analysed in detail. A total of 113 fatalities have been analysed: 51 from Brandenburg, 59 from Saxony, 2 from Rhineland-Palatinate, and 1 from North Rhine-Westphalia. As complete information was not available in every case, slight differences occur in the size of samples (number of WTs checked, number of checks per WT). For the purposes of this analysis we must also take into account the fact that the season, the exact position and the site environment, sometimes unknown to the authors, play an important part in the results of the findings and therefore in the classification of the wind turbine types. For this reason the data must be considered as no more than a rough outline! In general an average number of 1 dead bat was found for every 25 checks.

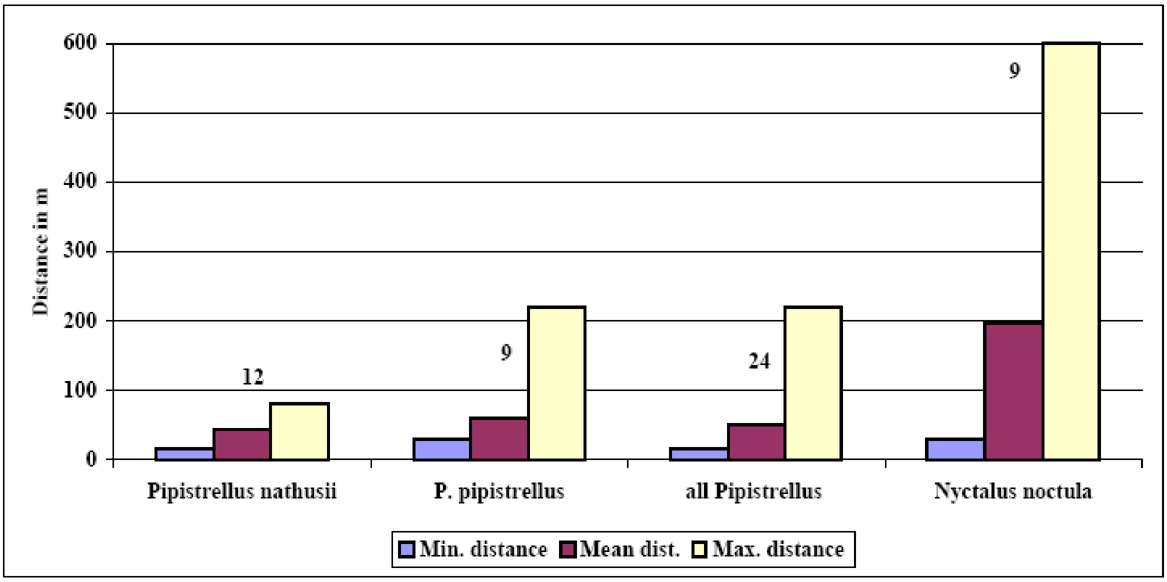

Fig.2 : Distance of WTs with bat fatalities from the nearest wood or hedgerow (n= number of analysed findings)

7 Rotor axle height

The distribution of bat fatalities for the 292 checked wind turbines (2982 controls) with a rotor axle between 31 and 110 m in height (fig.3) shows that bat mortality occurs at all types of wind turbine with an axle height of over 51 m. No mortality occurred when the rotor axle was lower than 50 m.

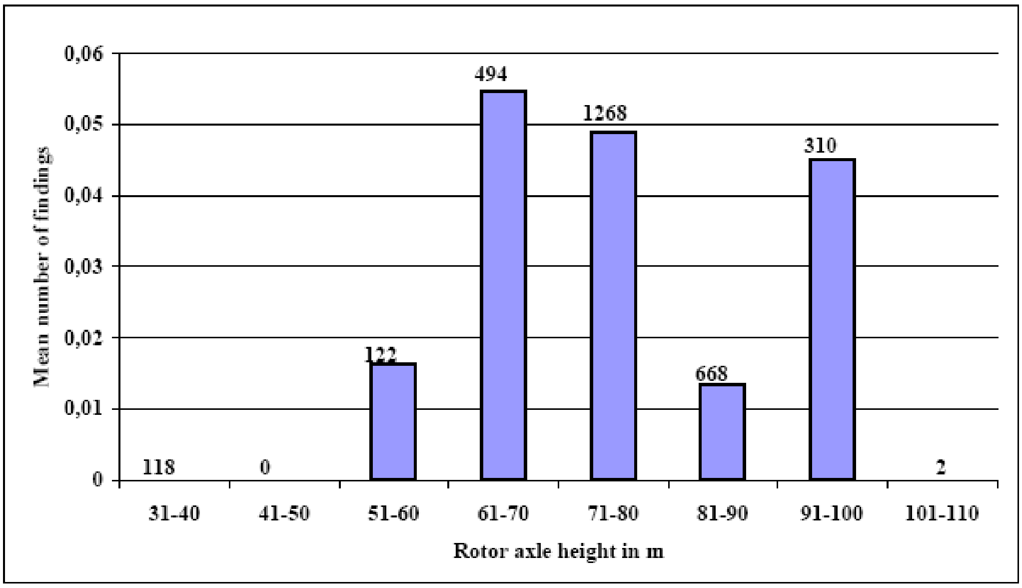

Fig.3 : Distribution of 113 bat fatalities in relation to axle height (292 WTs, n = number of controls)

8 Rotor diameter

The measurements of the rotor diameter of 291 wind turbines were noted for 2981 checks. The distribution of victims shows that deaths occur with nearly every size of rotor between 21 and 90 m (fig. 4). Only for the largest rotors was no victim recorded, but only 6 controls for these were carried out (and it takes 25 checks to find 1 dead bat, see above).

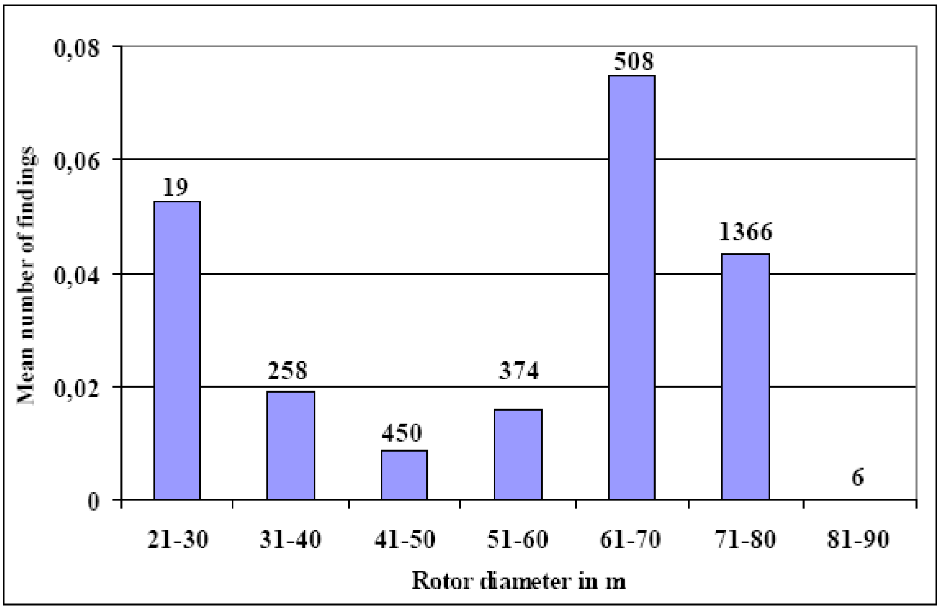

Fig. 4 : Distribution of 113 bat fatalities according to rotor diameter (3291 WTs, n = number of controls

9 Discussion

For 3 years now the phenomenon of bat mortality through wind farms has been discussed in Germany. Up to now it has not been possible to identify the real reasons for these losses. Reasons mentioned in discussion are

- the siting of the wind farm

- the immediate surroundings of the wind turbines
- the type of wind turbine
- the season when dead bats are found
- the reason for the collisions.

It is probably a combination of several factors which contributes to mortality. We will try here to shed some light on these different factors.

The first wind farms were built along the coast at the end of the 1980s. They consisted of wind turbines which in most cases had a rotor axle height of under 40 m. The first intensive study of existing wind farms was made by VAUK *et al.* (1990), commissioned by the BMFT. The aim of this work was to measure the possible effects on bird populations but mammals and even bats had also to be taken into account, but to a lesser extent. From this point of view 9 wind farms were partially studied for 17 months. It was found that the wind turbines were always responsible for bird fatalities. But as these wind farms were situated in open landscape without hedges (except in Bredstedt, North Friesland, where a hedge came close to wind turbines), there was no hint of negative impact on bats and none was found dead or injured. Nor were any dead bats found during other studies of bird mortality, no dead bat was discovered (e.g. Bremerhaven [SCHERNER 1999] where 2 wind turbines were placed at the confluence of the Lune and the Weser, near a clarification plant). But things changed when wind turbines started to appear inland in habitats with more varied and richer landscape (RAHMEL *et al.* 1999).

At the same time intensive studies were carried out in the USA, looking for bird fatalities on 14 wind farms of different sizes. The results showed that unexpectedly there were even higher numbers of dead bats than there were dead birds (JOHNSON et al 2000, KEELEY 2001). It was estimated that, depending on the siting, there are between 5 and 319 dead bats/wind farm/year. Even more meaningful is the estimated mortality per turbine on 7 wind farms which fluctuates from 0.07 to 10.0, with a mean value of about 2.42 dead bats/WT/year (JOHNSON in press). In general bat mortality concerned 61% of *Lasiurus cinereus* and 17% of *Lasiurus borealis*, two high-flying species that can be compared with the European species of the genera *Nyctalus*. The four other species found were less numerous and were bats which usually forage in heights less than 10 m (BARCLAY 1984, FENTON & BELL 1979). More recent American studies underline that species usually known to be low-flying ones are also often victims of collision with WTs (BOONE, pers. comm.). These studies have revealed 475 dead bats at just one wind farm of 44 turbines from April to November 2003 (weekly checks). BOONE estimated the number of bats which have been killed there during 2003 of about 3000 individuals. Results of comparable studies carried out over a period of at least 1 year are being processed in Germany at the moment (MÖCKEL and WIESMER, pers. comm.). The analysis of German studies that we presented here show that in Europe also highflying species are not the only bats affected, although they represent the majority of the victims, but that species which forage near structures, such as Long-eared bats (*Plecotus* spec.) are also concerned.

Do the features of the surrounding landscape therefore play a part in the risk of collision for bats? A first analysis of the available data shows that dead *Pipistrellus nathusii* and *Pipistrellus pipistrellus* usually appeared around wind turbines which were close to hedgerows. In the case of *Nyctalus*, the results are, as expected, less obvious; the mean distance between turbines with Noctule bat fatalaties and the nearest copse was about 197 m (max. 600 m). These results were confirmed by a swedish study (AHLÉN 2002), but major research is needed to confirm these statements. After a careful interpretation of the rather sparse data available, a distance of 150 m between the tower base of the wind turbines and the copse features would clearly lead to a decrease in bat mortality, as 89% of the recorded findings are related to turbines built less than 100 m from hedgerows or forest edges.

Another factor that might affect bat mortality is the type of wind turbine. Previously it had been thought that especially small turbines could have a bigger impact on bats (RAHMEL et al 1999). Today this seems no longer to be the case. The data analysed for this study shows that bats are also killed by tall WTs with almost any length of blade. As no other statistically comparable studies are available, no conclusion can be drawn here about the effects that different types of wind turbines may have. On the other hand, it may be supposed that the siting of the wind farms is crucial. For example, VAUK *et al.* (1990) could not find dead bats (see above) during their surveys on wind farms with small turbines that were situated along the coast in large open areas, but bat mortality was not expected there due to the bareness of the landscape. It is the development of taller wind turbines which has allowed the wind industry to develop inland sites where the landscape is more variable and rich of structures. This error of judgement is probably due to the fact that at present little is known about the flight heights of bats when they are out of range of ultrasonic detectors. In addition, there is our lack of knowledge about how collisions occur, whether if they happen during foraging, commuting or even searching for a roost within the turbine (see below). In the american list of victims there were also some bat species whose ecology could be compared to the European *Myotis mystacinus/brandtii* (e.g. Little brown bat, *Myotis luciferus*) or to *Myotis nattereri* (e.g. Long-eared bat, *Myotis septentrionalis*), which are not thought to be a species which forage typically high in the sky.

All European and American studies have one point in common: most bat fatalities were found during the migration period in late summer and more especially during the period of autumn migration (ALCADE, pers. comm., JOHNSON *et al.* 2000, JOHNSON *et al.* 2003, HEDDERGOTT pers. comm.). Dead bat findings in the USA were almost synchronous to the German findings (JOHNSON *et al.* 2003). But up to this moment this has to be regarded with caution as for many German studies it was not always obvious if the period of research covered the full season of bat activity or was concentrated during the autumn migration, as in Saxony (TRAPP *et al.* 2002, FÖRSTER 2004). In 1367 checks in Brandenburg (see above) which include every month except January, dead bats were found from the beginning of May to the end of November. The number of fatalities clearly increased at the beginning of August and reached a peak at the end of August. After mid-September only, occasional findings were recorded. Beside the temporal aspect, it is evident that in Germany also the species that were most often found are migratory bats (AHLÉN 1997, AHLÉN *et al.* 2002, JOHNSON in press, PETERSONS 1990).

During the last decades an enormous amount of knowledge has been obtained on bird migration, especially about migratory routes, physiology and orientation, but in the case of bats there are very serious gaps in our knowledge. Apart from the work on the ability of homing of bats (GRIFFIN 1970, MERKEL 1980) and a study from the 1970s on possible receptors in bats for magnetic fields (BUCHLER & WASILEWSKI 1985), there are neither studies about the orientation of migrating bats, flight heights nor migration physiology. There is also only a rudimentary knowledge of migration routes (AHLÉN 1997, AHLÉN *et al.* 2002, PETERSONS 1990).

Up to this day the reason for collisions with wind turbines or other man-made structures (radio masts etc.) is not understood (OSBORN *et al.* 1996, JOHNSON *et al.* 2003). According to VAN GELDER (1956) bat collisions with such structures occur during migration and "unfriendly" weather, like bird mortality. However the "bad weather theory" could not be confirmed later (CRAWFORD & BAKER 1981), and studies on wind farms brought no evidence of this (JOHNSON et al 2003, AHLÉN 2002). On the other hand during the studies on American wind plants, many bats have been killed by wind turbines but not by the weather towers of the respective wind plants (JOHNSON, e-mail). It seems, that during migration, bats are less likely to navigate by ultrasound, preferring other methods of orientation (CRAWFORD & BAKER 1981, EKLÖF 2003, GRIFFIN 1970, MUELLER 1966, VAN GELDER 1956). It is assumed that during migration, bats orientate by visual means, though this is unconfirmed. On a wind farm in Wyoming, for example, only 20 ultrasonic signals of *Lasiurus cinereus* have been recorded at wind turbines, but the species represented 88% of the victims. On the other hand in Minnesota the mortality rate could be correlated to bat activity deduced from echolocation. Off course visual orientation allows them to see the turbines in time, but is their eyesight good enough, in the prevailing light conditions, to spot the rotating blades and identify it as a danger? Furthermore, during migration the animals cross regions that they do not know as well as their summer foraging habitats. The combination of these phenomena implies then that obstacles such as wind turbines will be perceived, either too late or not at all. But then the question arises why the percentage of dead bats is so much higher than the percentage of dead birds?

The results presented here, as well as the list of species found in Europe and in the USA show that migration is not the only reason for bat mortality, as a series of non-migratory species is also to be found among the victims, and fatalities occur also, even to a lesser extent, at the beginning of the summer. It means that other factors must play a role. With a thermal imaging camera, AHLÉN (2002) observed on Gotland that e.g. Northern bats (*Eptesicus nilssonii*) were foraging in autumn around rotors and nacelles. During foraging one Northern bat was fatally hit by a blade. The reason for this behaviour was the presence around the nacelle of warm air which attracted insects from the much cooler surrounding environment. This phenomenon is to be expected mainly in the autumn. Bats are real opportunists when it comes to feeding and will take advantage in the short term of this abundant food supply. We cannot agree with HENSEN'S theory (in press) that this phenomenon only occurs on warm nights, thus explaining the high mortality rate in August. There is no particular concentration of insects round the nacelle on warm nights, which means that bats have no incentive to forage around it. The explanation is rather that during warm nights flying insects reach higher altitudes and get stuck on the slowly rotating blades. The nacelle temperature should not have much influence on the mortality of insects on the blades as these sweep continuously through the air. It is possible that this behaviour plays a part in areas where bats congregate in autumn. During detector controls at one wind plant in the USA, similar behaviour has been noted, but no dead bat has been found. At all other wind farms there was evidence of bats passing through but none of foraging bats (JOHNSON in press).

The main cause of death to be discussed is direct collision with the blades. This is borne out by the numerous broken bones and wounds on the patagium shown by the animals that we have examined. These wounds are caused by collision with a blade or by air turbulence (see AHLÉN 2002); they are not bruises inflicted by moving parts inside the nacelle (see below). Neither the bat's ability to orientate by sight nor by ultrasound can realy explain the many recorded fatalities. In principle bats can detect wind turbines. They can react to movements in the air. They have been seen taking evasive action when pursued by hobbies or peregrine falcons (*Falco subbuteo* and *Falco peregrinus*) (SÖMMER & HAENSEL 2003). But they may underestimate the speed of the blades and therefore the danger. This estimation would become more difficult with the increase of rotor diameter as the speed of the blade tips increases accordingly. This may be another reason for the high mortality rate found with longer blades. It is possible that bats perceive only one blade in movement without noticing the next one coming from above or from underneath.

Another kind of mortality, not yet studied in detail but involving a large number of deaths by implosion, seems to be caused by low pressure fields (e.g. when a blade passes close to the tower, or as a result of the huge difference in pressure between the front and the rear of the blades). In the findings from Saxony published by TRAPP *et al.* (2002), about 20% of the bats had very oily fur. This could also be explained by contact with the hydraulic oil of the turbine, or possibly by the presence of oil particles in the air around the nacelle. No other "very oily" bats have been recorded in other studies. Up to now it has been assumed that bat implosion in low pressure fields would cause the "body fat" to ooze through the skin pores, thus giving the animals an oily appearance. The results of the analysis of the Saxony animals by ZINKE in the Oberlausitz Museum at Kamenz make poisoning by hydraulic oil very improbable. This analysis shows that death was due to low pressure fields (FÖRSTER, pers. comm.). On the other hand quite a lot of animals with no external wounds show internal haemorrhaging whose origin could also be explained by the fact that the animals came too close to low pressure fields. This phenomenon obviously awaits a definitive explanation!

Another kind of accident could result from bats trying to find a roost within the nacelle (AHLÉN 2002, HENSEN in press). Using credible technical parameters HENSEN launched a debate based on the fact that the majority of fatalities occurred during the least windy period (August). Thus Noctule bats (*Nyctalus noctula*) looking for a roost inside the nacelle seem indeed to succumb to injuries inflicted by the gearbox of the turbine. But the use of the nacelle as a roost seems still to be an exceptional occurrence as only a single finding of a bruised bat has been reported (see above). It is however possible that searching for a roost in wind turbines ends in death because, strangely enough, the majority of fatalities start when colonies disperse and the search begins for temporary roosts.

Apart from these obvious cases, we have little information on the reasons for bat mortality. This is true especially for all estimates of the impact on bat populations. It is even more difficult because we do not know whether the victims are resident bats or migrating ones. And in the latter case we know very little about the phenomenon of bat migration and even less about their numbers (see above).

10 Conclusion

The unsatisfactory state of our knowledge of the real factors which result in bat mortality demands immediate investigation to establish these factors. This can only be achieved by a close co-operation with the wind turbine industry (manufacturers and power generating companies). We must investigate more closely not only the siting but also the weather conditions and the technical parameters of the different wind farms. All the findings must be documented as precisely as possible, all the information being forwarded to the central databank. To set up a uniform method of documenting the victims, we have formulated a questionnaire (.ppt-file) which may be obtained from the Staatliche Vogelschutzwarte of Brandenburg.

JOHNSON et al (2003) found 54% of the victims within a radius of 10 m, 43% within 10-20m and only 0.5% > 50 m. The data from Germany are slightly different (90% of all victims < 30 m). This could be due to the type of wind turbines installed in Germany as they are much taller and have appreciably longer blades.

11 Proposal for checking bat mortality at wind turbines

As shown above, bat mortality occurs around all types of wind turbines and in various regions of Germany and Europe. Until now, as the victims were found mainly by accident and/or during semi-systematic studies, no definite conclusion can be drawn about the influence of particular types of wind turbine, their distance from wooded areas etc. However, such conclusions must be reached if we are going to be able to deal with the problem of bat mortality and e.g. to react in case of impact regulations. It is only if the problem of bat mortality is studied systematically that we will be able to look for solutions.

All this means that in future we should spend less time on unsystematic and occasional collecting of dead bats under wind turbines – that bat mortality exists has already been proved – but systematic studies using consistent methods must be realised in the different regions of Germany. We must also launch some experimental studies to find out how bats recognise the presence of WTs and investigate the phenomenon of bat migration, especially their migratory routes.

How should a research project of bat mortality be set up? The aim is not only to document the death of bats, but also to find out if the following factors have an influence:

- the different types of turbines
- the general environment (distance from copes, water, waste dumps, foraging habitats, etc.)
- the siting of the turbines (migration route, proximity of roosts and foraging habitats, etc.)
- the season,

Above all the aim is to find out if WT may have an influence on bat populations. In each case it is important, in addition to the collecting of victims, to evaluate bat activity around the wind farm. Only then will it be really possible to compare different studies.

Species		BB	SAH	SN	TH	SH	BY	NRW	RP	NDS	Total
Nyctalus noctula	Noctule bat	39	1	20	54	3	1	1			118
Nyctalus leisleri	Leisler's bat	5	1	1	3						10
Eptesicus serotinus	Serotine bat	2			2	1		1			6
Vespertilio murinus	Parti-coloured bat	1		7							8
Myotis myotis	Greater mouse-eared bat			7							7
Myotis daubentonii	Daubenton's bat	1									1
Plecotus austriacus	Grey long-eared bat	1									1
Pipistrellus pipistrellus	Common pipistrelle	15	2	6	2						25
Pipistrellus nathusii	Nathusius' pipistrelle	17	1	23	2			1			44
Pipistrellus pygmaeus	Soprano pipistrelle	1									1
Pipistrellus sp.	Pipistrelle sp.	4				14					18
Chiroptera sp.	Chiroptera sp.		2						2		4
TOTAL		85	5	59	70	18	1	3	2	0	243

12 Draft protocol for studying bat mortality (search for victims)

12.1 General remarks

When it comes to choosing the study areas one should ascertain that bat data collected before the construction of the turbines is available for the region. The studies must account all regions of Germany and the most diverse habitats (open land, landscapes with hedges, forest) and all the different types of turbines.

The method used for each study must be described in detail. This means also describing very carefully the study area, the types of wind turbines, the siting of each and the method and intensity of the search (person or person + dog) etc It should be noted that the use of different persons during the search phase may result in discrepancies in discovery rates. And it is important that all studies cover the whole "summer season" from April to October.

12.2 Profile of the study

Bat activity

Bat activity must be monitored according to the method described by RAHMEL *et al.* (2004) for the impact assessment. This means 7 all-night surveys (April-September) to assess resident bat populations and 16 half-night surveys to study the bat migration. Automatic recording units ("automatical bat registration boxes") must also be used (see RAHMEL *et al.* 2004).

Search for victims
From April to mid-October all wind turbines must be checked once a week in the early morning looking for dead bats. Each study area should have a minimum of 10-15 turbines. At least 5 WTs must be checked every morning, the radius of the search area being the radius of the blades + 50 m. For each wind turbine, individual protocols should be written with site description, findings, etc.. If possible searches should be combined with nights when bat activity is being monitored.

13 Acknowledgements

For the communication of their findings data we are particularly obliged to T. Blohm, R. Brinkmann, D. Dolch, A. Ewert, A. Fölling, F. Förster, M & M. Göttsche, R. Günter, M. Heddergott, M. Heiss, M. Hirt, L. Ittermann, L. Manzke, R. Möckel, G. Nessing, M. Putze, R. Reifenrath, P. Schonert, H. Trapp and P. Wiesner. We express our thanks to D. Dolch (Nature Conservation Station of Zippelsförde) who verified a great number of findings from Brandenburg. We also thank the services for the protection against emissions in Brandenburg/Havel, Cottbus, Frankfurt/Oder, Neuruppin and Wünsdorf for their excellent support in our search for the data related to the types of different wind turbines. Without forgetting P. Burkhardt and U. Rahmel for their comments on our script.

14 References

AHLEN, I. (1997): Migratory behaviour of bats at south Swedish coasts. - Z. Säugetierk. 62: 375-380.

AHLEN, I. (2002): Fladdermöss och fäglar dödade av vindkraftverk. - Fauna och Flora 97(3):14-22

ALCALDE, J.T. (2003). Impacto de los parques eolicos sobre las poblaciones de murciélagos. - Barbastella 2: 3-6.

ANONYMUS (1999): Abstract of windpower-related mortality at Buffalo Ridge, Minnesota 1996-1999. - unveröff. Manuskript: 4 S..

BACH, L. (2001): Fledermäuse und Windenergienutzung – reale Probleme oder Einbildung? - Vogelkdl. Ber. Niedersachs. 33: 119-124.

BACH, L., R. BRINKMANN, H. LIMPENS, U. RAHMEL, M. REICHENBACH & A. ROSCHEN (1999): Bewertung und planerische Umsetzung von Fledermausdaten im Rahmen der Windkraftplanung. - Bremer Beiträge für Naturkunde und Naturschutz 4: 162-170.

BARCLAY, R.M.R. (1984): Observations on the migration, ecology and behaviour of bats at Delta Marsh, Manitoba. – Can. Field Nat. 98:331-336.

BRINKMANN, R., H. SCHAUER-WEISSHAHN & F. BONTADINA (2005): Untersuchungen zu möglichen betriebsbedingten Auswirkungen von Windkraftanlagen auf

Fledermäuse im Regierungsbezirk Freiburg – unveröff. Gutachten

BUCHLER, E.R. & P.J. WASILEWSKI (1985): Magnetic remanence in bats. – in: KIRSCHVINK, J.L., D.S. CRAWFORD, R.L. & W.W. BAKER (1981): Bats killed at a north Florida Television tower: a 25-year record. – J. Mammal. 62: 651-652.

DÜRR, T. (2001): Fledermäuse als Opfer von Windkraftanlagen. – Naturschutz und Landschaftspflege in Brandenburg 10: 182.

EKLÖF, J. (2003): Vision in echolocating bats. – Dissertation an der Univ. Göteborg: 106 S..
FENTON, M.B. & G.P. BELL. (1979): Echolocation and feeding behaviour in four species of Myotis (Chiroptera). - Can. J. Zool. 57: 1271-1277.

FÖRSTER, F. (2004): Windkraftanlagen und Fledermausschutz in der Oberlausitz. Manuskript zum Tagungsband der Fachtagung „Kommen die Vögel und Fledermäuse unter die Wind(räder)?“, 17./18.11.2003, TU Dresden: 15 S.

GRIFFIN, D.R. (1970): Migration and homing in bats. – in: WIMSATT, W.A. (Hrsg.): Biology of bats. – Academic Press, New York: 233-264.

HALL, L.S. & G.C. RICHARDS (1972): Notes on Tadarida australis (Chiroptera: Molossidae). - Australian Mammalogy 1: 46.

HENSEN, F. (im Druck). Gedanken und Arbeitshypothesen zur Fledermausverträglichkeit von Windenergieanlagen.

JOHNSON, G.D., W.P. ERICKSON, M.D. STRICKLAND, M.F. SHEPHERD & D.A. SHEPHERD (2000): Avian monitoring studies at the Buffalo Ridge, Minnesota Wind Resource Area: Results of a 4-year study. – unveröff. Bericht der Northern States Power Company, Minnesota: 262 pp.

JOHNSON, G.D., W.P. ERICKSON, M.D. STRICKLAND, M.F. SHEPHERD & D.A. SHEPHERD (2003): Mortality of bats at a Large-scale wind power development at Buffalo Ridge, Minnesota. – Am. Midl. Nat.150: 332-342.

JOHNSON, G.D. (in pres.): What is known and not known about impacts on bats? –
Proceedings of the avian interactions with wind power structures, Lackson Hole, Wyoming,

KEELEY, B.W., S. UGORETZ & D. STRICKLAND (2001): Bat Ecology and Wind Turbine Considerations. – in: NATIONAL WIND COORDINATING COMMITTEE (Hrsg.) National Avian-Wind Power Planning Meeting 4, Washington, D.C.: 135-146.

KUGELSCHAFTER, K. & A. ROSCHEN (2004, i. d. Bd.): Wieso verunglücken Fledermäuse an Windkraftanlagen - eine theoretische Annäherung an eine komplexe Thematik - Bremer Beiträge für Naturkunde und Naturschutz, Band

LEKUONA, J. M. (2001): Uso del Espacio por la Avifauna y Control de la mortalidad de Aves y Murciélagos en Los Parques Eolicos de Navarra durante un Ciclo anual. Direccion General de Medio Ambiente Departmento de Medio Ambiente, Ordenacion del Territorio y Vivienda. Gobierno de Navarra: 1-147.

MERKEL, F.W. (1980): Orientierung im Tierreich. - Grundbegriffe der modernen Biologie 15, Gustav Fischer Verlag, Stuttgart.

MUELLER, H.C. (1966): Homing and distance-orientation in bats. – Z. Tierpsychol. 23: 403-421.

OSBORNE, R.G., K.F. HIGGINS, C.D. DIETER & R.E. USGAARD (1996): Bat collisions with wind turbines in Southwestern Minnesota. - Bat Research News 37: 105-108.

PETERSONS, G. (1990): Die Rauhhautfledermaus, *Pipistrellus nathusii* (Keyserling u. Blasius, 1839), in Lettland: Vorkommen, Phänologie und Migration. - Nyctalus 3: 81-98.

RAHMEL, U., L. BACH, R. BRINKMANN, C. DENSE, H. LIMPENS, G. MÄSCHER, M.
REICHENBACH & A. ROSCHEN (1999): Windkraftplanung und Fledermäuse. Konfliktfelder und Hinweise zur Erfassungsmethodik. – Bremer Beiträge für Naturkunde und
Naturschutz, Band 4: 155-161.

RAHMEL, U., R. BRINKMANN, H. LIMPENS, & A. ROSCHEN (2004, i. d. Bd.): Windenergieanlagen und Fledermäuse – Hinweise zur Erfassungsmethodik. – Bremer Beiträge für Naturkunde und Naturschutz, Band

SCHERNER, E. R.. (1999): Windkraftanlagen und „wertgebende Vogelbestände“ bei Bremerhaven: Realität oder Realsatire? – Beitr. Naturk. Niedersachsen 52 (4): 121-156.

SÖMMER, P. & J. HAENSEL (2003): Fledermäuse als Beute von Taggreifvögeln – überraschende neue Befunde besonders für die beiden schnellsten deutschen Falkenarten. Nyctalus (N.F.), Berlin (9) 1: 61-78.

TRAPP, H., D. FABIAN, F. FÖRSTER & O. ZINKE (2002): Fledermausverluste in einem Windpark der Oberlausitz. – Naturschutzarbeit in Sachsen 44: 53-56.

VAN GELDER, R.G. (1956): Echo-location failure in migratory bats. - Transactions of Kansas Academy of Science 59: 220-222.

VAUK, G., M. BÖTTGER, T. CLEMENS, G. GROTE, G. HARTMANN, E. HARTWIG, C. LAMMEN u. E. VAUK-HENTZELT (1990): Biolog.-ökol. Begleituntersuchung zum Bau und Betrieb von WEA. Endbericht. NNA-Ber. (3) Sonderheft: 3-124.

VIERHAUS, H. (2000): Neues von unseren Fledermäusen. - ABU Info 24 (1): 58-60.

Authors:

Tobias Dürr
Landesumweltamt Brandenburg
Staatliche Vogelschutzwarte
Buckower Dorfstr. 34
14715 Nennhausen
E-mail(c/o): Torsten.langgemach@lua.brandenburg.de

Lothar Bach
Hamfhofsweg 125 b
28357 Bremen
E-mail: lotharbach@aol.com

Translation from the German
Marie-Jo Dubourg-Savage (July 2005)
E-mail: mjo.ds@club-internet.fr