IMPACTS OF WIND ENERGY DEVELOPMENTS ON BIRDS AND BATS: LOOKING INTO THE PROBLEM

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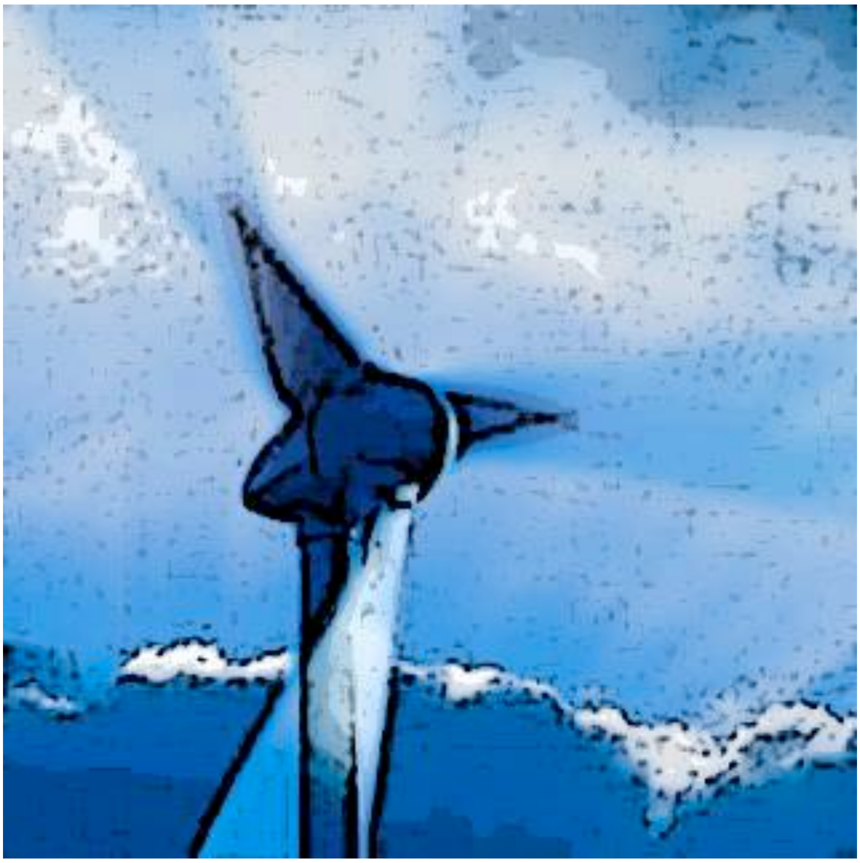

Executive Summary

Wind Energy is the fastest growing utility-scale renewable electricity generation. In the US in particular recent expansion has been very rapid, with the country becoming world leader in 2005 and boasting 16,818 MW by the end of 2007. By 2020 wind energy in the US could reach 2,158 MW or 3,856 MW depending on which projects are followed, and according to one study wind could supply 20% (300,000 MW) of the nations electricity needs by 2030.

The collisions of birds and bats with wind turbines has been noted since the 1970s, though only in light of the recent wind energy expansion has the problem been seriously recognised. Of the major studies recording bird strikes from wind turbines many quote collision rates per turbine from 0 to over 60 collision fatalities per year, which equals 0 to 20 birds per MW per year. Many bird species feature in the collision records, including gulls, raptors, such as griffon vulture, golden eagle, red kite, kestrels, and red-tailed hawks, though it is suggested that limited information existent on passerines collisions with wind turbines is probably due to a combination of fewer studies, lower detection rates, rapid scavenger removal.

Although the population level impacts are difficult to assess, studies of the Altamont Pass Wind Resource Area indicate further expansion is considered likely to lead to population decline unless adequate measures are taken to substantially reduce collision risk. Form the Tarifa and Smøla studies in is stressed that collision risk is highly site-specific and the Zeebrugge study highlights bird-specific behaviour as the cause. The important factors associated with elevated collision risk identified at onshore wind farms include topography, turbine location, design, and configuration, including spacing, and land use close to turbines, whereas off-shore wind farms, though difficult to assess, seem to have less of an impact.

Although in the US predicted annual avian mortality as a result of collisions with wind turbines amount to <0.01% of anthropogenically-caused avian deaths, in certain areas wind farms do seem to be acting as population sinks. It is suggested that with the expanding wind industry the bird declines, initially restricted to local populations of the most vulnerable species, could eventually lead to regional or even national population declines. Rough estimates show that by 2020 the number of birds killed annually could range from 300-400 to 3,000-5,700, though could rise to 300,000 by 2030. By contrast, the adverse impacts of climate change projects 15% to 37% of all bird and wildlife species to be “committed to extinction” by 2050.

The siting, or location, of a wind farm seems to be the single most important factor contributing to the risk of bird fatalities, though within wind farm design and layout also have an impact. Predicting and assessing the siting impact is seen to be the most important management tool. Additional mitigation options include feathering the turbines during high-risk periods, making the blades more visible, reducing the lighting, reducing the attractiveness of the areas around the turbines, and/or bird deterrents.

Bat fatalities only really gained attention after 2003, when an estimated 1,400-4,000 bats were killed at the Mountaineer Wind Energy Centre in West Virginia at rates

estimated above 30 per MW of installed capacity per year, which is well above the rates estimated for bird fatalities. Both US and European studies seem to suggest highly variable rates of mortality from 1 to 40 per MW per year in the US and from 1.5 to over 20 per turbine per year in the EU. Key findings from the studies reviewed include that most fatalities were dominated by lasiurine (migratory) species, with fatalities peaking in midsummer through autumn, though the specific local habitat influence has not yet been identified. It is also suggested that bat fatalities are highest during periods of low wind speeds, less than 6 m/sec, at which speeds wind turbines could be feathered as a potential mitigation option.

The peaking of bat fatalities during late summer and early autumn may be partially the result of exploratory activity, though additional factors, such as potential roost attraction, movement or sound attraction, or available prey, may help explain wind turbine-caused fatalities. Recent evidence suggests that bat fatalities is mainly caused by barotrauma, the rapid recompression experienced by bats due to changes in atmospheric pressure as the turbine blades rotate downward, in addition to direct rotor strike.

Although the data on bat fatalities at wind farms is still very sparse and sporadic, with, for example, no studies from Texas, which has the largest installed capacity of wind energy in the US, the population level impact is difficult to determine. Nonetheless, projected bat fatalities in the Mid-Atlantic Highlands could range from 33,000 to 110,000 annually by 2020. Furthermore, if the US supplies 20% of its electricity from wind by 2030, annual bat fatalities could be between 1,500,000 to 8,500,000 depending on the average number of deaths per MW installed.

In light of such potential impacts wind farm developers should take a number of impact mitigation steps, such as the five represented in the Californian Guidelines. These include preliminary site screening, permitting requirements and law compliance, a one-year pre-permitting assessment to determine the potential bird and bat impact of the site, impact analysis and mitigation, and finally operations monitoring for two years after the farm has been developed.

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List of Abbreviations

DOE – Department of Energy

EU – European Union

Ha – hectare

ITCs – investment tax credit

km – kilometre

m – metre

m/sec – metres per second

MW – megawatts

PTC – of production tax credit

RPSs – renewable power standards

US – United States

UV – ultra-violet

WWEA – World Wind Energy Association

Introduction

The US wind industry got its start in California during the 1970s, when the oil shortage increased the price of electricity generated from oil. The California wind industry benefited from federal and state investment tax credits (ITCs) as well as state-mandated standard utility contracts that guaranteed a satisfactory market price for wind power. By 1986, California had installed more than 1.2 GW of wind power, representing nearly 90% of global installations at that time[1].

Expiration of the federal ITC in 1985 and the California incentive in 1986 brought the growth of the US wind energy industry to an abrupt halt in the mid-1980s. Europe took the lead in wind energy, propelled by aggressive renewable energy policies enacted between 1974 and 1985. As the global industry continued to grow into the 1990s, technological advances led to significant increases in turbine power and productivity. Turbines installed in 1998 had an average capacity 7 to 10 times greater than that of the 1980s turbines, and the price of wind-generated electricity dropped by nearly 80%[2]. By 2000, Europe had more than 12,000 MW of installed wind power, versus only 2,500 MW in the United States, and Germany became the new international leader. With low natural gas prices and US utilities preoccupied by industry restructuring during the 1990s, the federal Energy Policy Act of production tax credit (PTC) enacted in 1992 did little to foster new wind installations until just before its expiration in June 1999. Nearly 700 MW of new wind generation were installed in the last year before the credit expired, which was more than in any previous 12-month period since 1985. After the PTC expired in 1999, it was extended for two brief periods, ending in 2003. It was then reinstated in late 2004. Although this intermittent policy support led to sporadic growth, business inefficiencies inherent in serving this choppy market inhibited investment and restrained market growth.

To promote renewable energy systems, many states began requiring electricity suppliers to obtain a small percentage of their supply from renewable energy sources, with percentages typically increasing over time. With Iowa and Texas leading the way, more than 20 states have followed suit with renewable power standards (RPSs), creating an environment for stable growth. After a decade of trailing Germany and Spain, the United States reestablished itself as the world leader in new wind energy in 2005. This resurgence is attributed to increasingly supportive policies, growing interest in renewable energy, and continued improvements in wind technology and performance. The United States retained its leadership of wind development in 2006 and, because of its very large wind resources, is likely to remain a major force in the highly competitive wind markets of the future.

According to the World Wind Energy Association[3], wind energy is currently the world's fastest-growing energy source on a percentage basis. Global wind power capacity has increased tenfold over the past decade, from 9,600 megawatt (MW) in 1998 to 93,800 MW at the end of 2007, which is more than 1% of the global

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[1] DOE 2008

[2] AWEA 2007

[3] WWEA 2008

electricity supply. 19,700 MW of new wind energy capacity were added in 2007, equalling a global growth rate of 26.6%. The US cumulative wind energy capacity reached 16,818 MW, with more than 5,000 new megawatts of wind installed in 2007. Wind contributed to more than 30% of the new US generation capacity in 2007, making it the second largest source of new power generation in the nation, surpassed only by natural gas. The US wind energy industry invested approximately $9 billion in new generating capacity in 2007, and has experienced a 30% annual growth rate in the last 5 years. A recent report by the US Department of Energy shows that wind power could potentially provide 20% of the nation's electricity by 2030, more than 300,000 MW[4] (Figure 1).

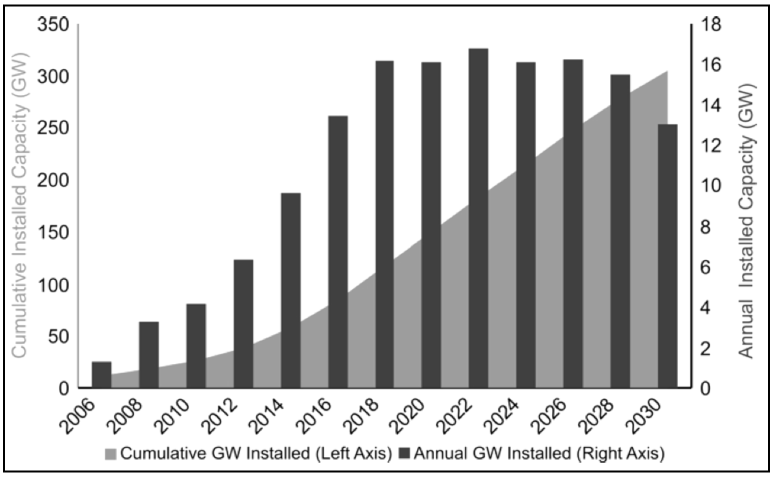

FIGURE 1: PROJECTED ANNUAL AND CUMULATIVE WIND INSTALLATIONS DEPLOYED IN THE US BY 2030. (SOURCE: DOE, 2008).

Taken together, politics, engineering and economics have converged to make wind power a truly viable alternative to conventional thermal or fossil fuel based power generation. However, while there are many environmental benefits associated with wind power, sites have the potential for environmental risks that need to be understood, minimized and mitigated. The most contentious issues include visual and wildlife impacts, specifically the impact to birds and bats. This study aims to summarise the knowledge on the bird and bat impact of wind farm development.

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[4] DOE 2008

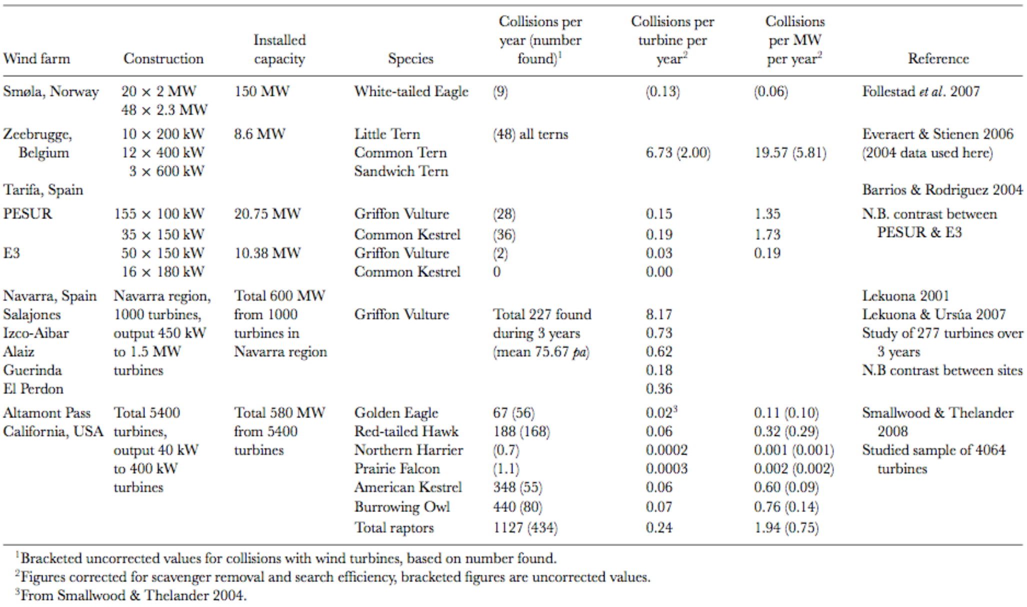
Impact of wind farm development on birds

Our understanding of the bird problem

Collision fatalities

Direct mortality at wind farms results from birds striking rotors, towers, nacelles, guy cables, power lines, and meteorological masts[5]. There is also evidence of birds being forced to the ground by turbulence created by the moving rotor[6]. The majority of studies have recorded low collision rates per turbine and often low levels of mortality overall, perhaps because many wind farms are situated away from concentrations of those bird species most vulnerable to collision[7]. Nonetheless, studies of the Altamont Pass in California[8], Tarifa in southern Spain[9], and Navarra in northern Spain[10] are frequently cited examples of problematic sites (Table 1). Despite the comparative wealth of literature, there are still relatively few peer-reviewed published papers on the subject of bird collisions at wind farms, and many uncertainties remain as to the level of effect, notably the likelihood of an impact on populations[11].

TABLE 1: COLLISION STATISTICS FOR A SUITE OF WIND FARM STUDY LOCATIONS ASSOCIATED WITH HIGH NUMBERS OF BIRD COLLISIONS (SOURCE: DREWITT & LANGSTON, 2008).



Wind farm	Construction	Installed capacity	Species	Collisions per year (number found)[1]	Collisions per turbine per year[2]	Collisions per MW per year[2]	Reference
Smøla, Norway	20 × 2 MW 48 × 2.3 MW	150 MW	White-tailed Eagle	(9)	(0.13)	(0.06)	Follestad *et al*. 2007
Zeebrugge, Belgium	10 × 200 kW	8.6 MW	Little Tern	(48) all terns			Everaert & Stienen 2006
	12 × 400 kW		Common Tern		6.73 (2.00)	19.57 (5.81)	(2004 data used here)
	3 × 600 kW		Sandwich Tern				
Tarifa, Spain							Barrios & Rodriguez 2004
PESUR	155 × 100 kW	20.75 MW	Griffon Vulture	(28)	0.15	1.35	N.B. contrast between PESUR & E3
	35 × 150 kW		Common Kestrel	(36)	0.19	1.73	
E3	50 × 150 kW	10.38 MW	Griffon Vulture	(2)	0.03	0.19	
	16 × 180 kW		Common Kestrel	0	0.00		
Navarra, Spain	Navarra region,	Total 600 MW					Lekuona 2001
Salajones	1000 turbines,	from 1000	Griffon Vulture	Total 227 found	8.17		Lekuona & Ursúa 2007
Izco-Aibar	output 450 kW	turbines in		during 3 years	0.73		Study of 277 turbines over
Alaiz	to 1.5 MW	Navarra region		(mean 75.67 *pa*)	0.62		3 years
Guerinda	turbines				0.18		N.B contrast between sites
El Perdon					0.36		
Altamont Pass California, USA	Total 5400 turbines, output 40 kW to 400 kW turbines	Total 580 MW from 5400 turbines	Golden Eagle	67 (56)	0.02[3]	0.11 (0.10)	Smallwood & Thelander 2008
			Red-tailed Hawk	188 (168)	0.06	0.32 (0.29)	Studied sample of 4064 turbines
			Northern Harrier	(0.7)	0.0002	0.001 (0.001)	
			Prairie Falcon	(1.1)	0.0003	0.002 (0.002)	
			American Kestrel	348 (55)	0.06	0.60 (0.09)	
			Burrowing Owl	440 (80)	0.07	0.76 (0.14)	
			Total raptors	1127 (434)	0.24	1.94 (0.75)	

[1] Bracketed uncorrected values for collisions with wind turbines, based on number found.
[2] Figures corrected for scavenger removal and search efficiency, bracketed figures are uncorrected values.
[3] From Smallwood & Thelander 2004.

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[5] Drewitt & Langston 2008

[6] Winkelman 1992b; Pettersson 2005

[7] e.g., reviews by Erickson et al. 2001; Langston & Pullan 2003; Percival 2005; Drewitt & Langston 2006

[8] e.g., Howell & DiDonato 1991; Orloff & Flannery 1992; Smallwood & Neher 2004; Smallwood & Thelander 2004, 2005; Thelander & Smallwood 2007

[9] Barrios & Rodriguez 2004, 2007; de Lucas et al. 2004

[10] Lekuona & Ursúa 2007

[11] Drewitt & Langston 2008

Of the major studies recording bird strikes from wind turbines many quote collision rates per turbine from zero to over 60 collision fatalities per wind turbine per year[12]. Although the lowest collision rates are associated with grassland and moorland sites and the highest are associated with mountain ridges and wetlands[13], it would be overly simplistic to state that collision risk is greater for some habitats than others without consideration of the species present and their abundance and usage of the area, combined with design features of the wind farm[14]. Many bird species feature in the collision records, including gulls, raptors, such as griffon vulture *Gyps fulvus*, golden eagle *Aquila chrysaetos*, red kite *Milvus milvus*, kestrels, and red-tailed hawks *Buteo jamaicensis*, and a wide variety of passerines, but most occur in low numbers[15] (Table 2).

As for the order *Passiformes*, which includes more than half of all bird species, the limited information existent on passerines collisions with wind turbines is probably due to a combination of fewer studies, lower detection rates, rapid scavenger removal[16], and possibly to lower actual collision rates, although this is difficult to establish. Nonetheless, nocturnally migrating passerines feature in the collision fatalities of several studies[17], and in Navarra, their fatalities peaked in September to October during the post-breeding migration, probably due to the addition of recently fledged young birds[18]. It may be that, as for other sources of collision mortality, the issue is lack of information rather than lack of effect, especially cumulatively from small numbers at many sites. The current scarcity of information means that it is impossible to know to what extent collisions with wind turbines add to the mortality of passerines from other sources[19].

By contrast, many studies have focused on raptors or other larger bird species, especially those of conservation concern. A predominantly low collision rate per turbine is apparent for raptors at a sample of wind farms in the United States[20] (Table 1). However, low collision rates per turbine can be misleading in situations where there are low numbers of collision fatalities and large numbers of turbines, of which Altamont Pass with a 0.02 collision rate for golden eagles per turbine per year is the prime example[21]. In view of the substantial increase in turbine size and energy output, a perhaps more comparable currency applied in recent studies is collision rate per megawatt (MW) of output. For the golden eagle example, the estimate is 0.115 ± 0.056 collision fatalities per MW, or 67 collision fatalities per year[22].

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[12] e.g., Winkelman 1992a; Musters et al. 1996; Still et al. 1996; Erickson et al. 2001; Langston & Pullan 2003; Hötker et al. 2006

[13] Hötker et al. 2006

[14] Drewitt & Langstron 2008

[15] e.g., Erickson et al. 2001; Hötker et al. 2006

[16] 10% within 8h, Winkelman 1989; ≤50% within 24 h, Winkelman 1992a; most within 1–3 days, Kerlinger et al. 2000; 70–80% within 2 days Lekuona & Ursúa 2007

[17] e.g., Johnson et al. 2000; Lekuona & Ursúa 2007

[18] Lekuona & Ursúa 2007

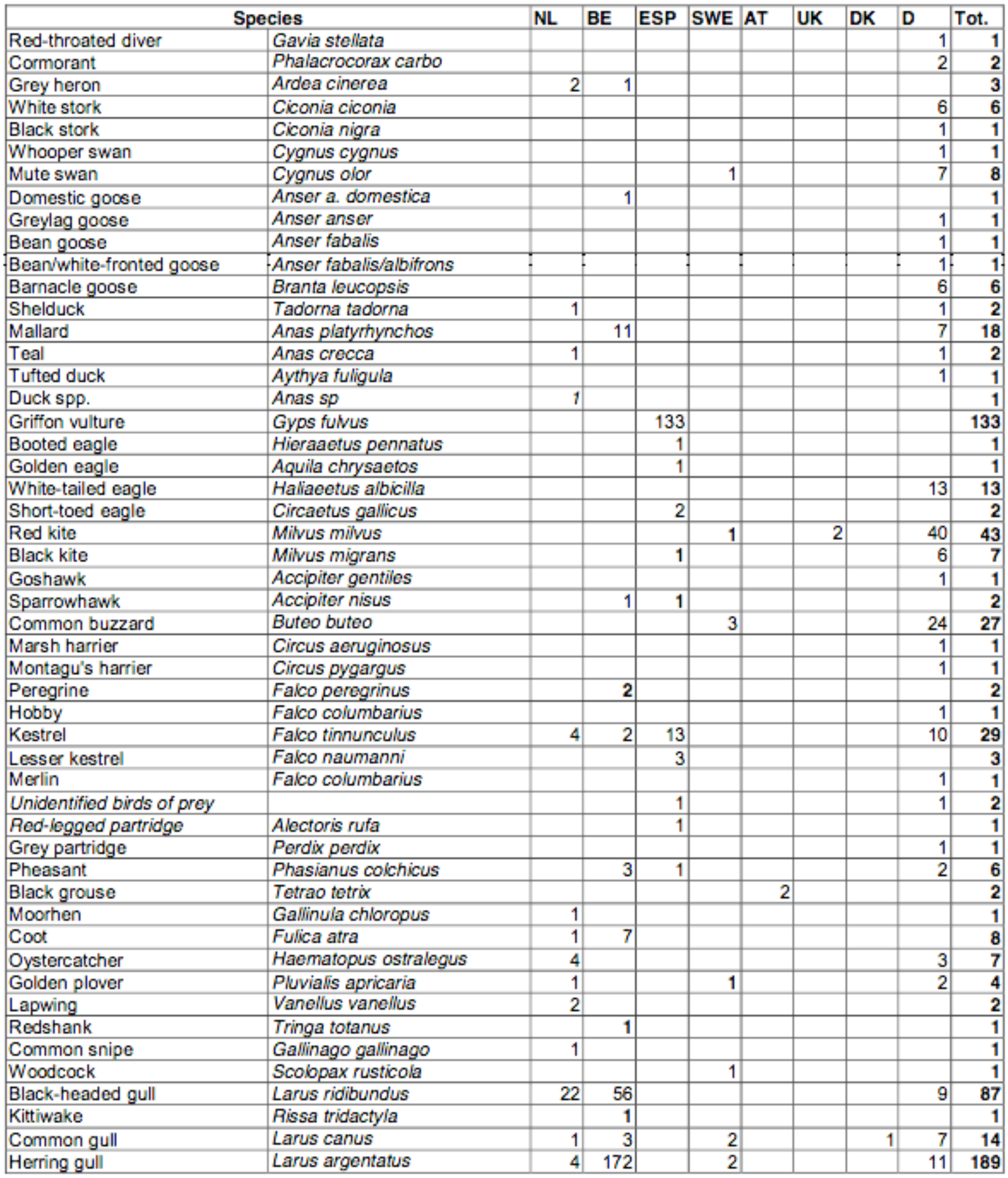
[19] Drewitt & Langstron 2008

[20] Erickson et al. 2001; Sterner et al. 2007

[21] Smallwood & Thelander 2004; Drewitt & Langstron 2008

[22] all quoted figures corrected for scavenger removal and search efficiency; Smallwood & Thelander 2008

Table 2: Number of bird collision victims found at wind farms in Europe. Data from Staatliche Vogelschutzwarte, LUA Brandenburg, T. Dürr, 06.09.2004 and from literature. NL: Netherlands; BE: Belgium; SEP: Spain; SWE: Sweden; AT: Austria; UK: Great Britain; DK: Denmark; D: Germany (as of July 2004) (Source: Hötker et al. 2006).



Species		**NL**	**BE**	**ESP**	**SWE**	**AT**	**UK**	**DK**	**D**	**Tot.**
Red-throated diver	*Gavia stellata*								1	**1**
Cormorant	*Phalacrocorax carbo*								2	**2**
Grey heron	*Ardea cinerea*	2	1							**3**
White stork	*Ciconia ciconia*								6	**6**
Black stork	*Ciconia nigra*								1	**1**
Whooper swan	*Cygnus cygnus*								1	**1**
Mute swan	*Cygnus olor*				1				7	**8**
Domestic goose	*Anser a. domestica*		1							**1**
Greylag goose	*Anser anser*								1	**1**
Bean goose	*Anser fabalis*								1	**1**
Bean/white-fronted goose	*Anser fabalis/albifrons*								1	**1**
Barnacle goose	*Branta leucopsis*								6	**6**
Shelduck	*Tadorna tadorna*	1							1	**2**
Mallard	*Anas platyrhynchos*		11						7	**18**
Teal	*Anas crecca*	1							1	**2**
Tufted duck	*Aythya fuligula*								1	**1**
Duck spp.	*Anas sp*	*1*								**1**
Griffon vulture	*Gyps fulvus*			133						**133**
Booted eagle	*Hieraaetus pennatus*			1						**1**
Golden eagle	*Aquila chrysaetos*			1						**1**
White-tailed eagle	*Haliaeetus albicilla*								13	**13**
Short-toed eagle	*Circaetus gallicus*			2						**2**
Red kite	*Milvus milvus*				**1**		2		40	**43**
Black kite	*Milvus migrans*			**1**					6	**7**
Goshawk	*Accipiter gentiles*								1	**1**
Sparrowhawk	*Accipiter nisus*		1	**1**						**2**
Common buzzard	*Buteo buteo*				3				24	**27**
Marsh harrier	*Circus aeruginosus*								1	**1**
Montagu's harrier	*Circus pygargus*								1	**1**
Peregrine	*Falco peregrinus*		**2**							**2**
Hobby	*Falco columbarius*								1	**1**
Kestrel	*Falco tinnunculus*	4	2	13					10	**29**
Lesser kestrel	*Falco naumanni*			3						**3**
Merlin	*Falco columbarius*								1	**1**
Unidentified birds of prey				1					1	**2**
Red-legged partridge	*Alectoris rufa*			1						**1**
Grey partridge	*Perdix perdix*								1	**1**
Pheasant	*Phasianus colchicus*		3	1					2	**6**
Black grouse	*Tetrao tetrix*					2				**2**
Moorhen	*Gallinula chloropus*	1								**1**
Coot	*Fulica atra*	1	7							**8**
Oystercatcher	*Haematopus ostralegus*	4							3	**7**
Golden plover	*Pluvialis apricaria*	1			**1**				2	**4**
Lapwing	*Vanellus vanellus*	2								**2**
Redshank	*Tringa totanus*		**1**							**1**
Common snipe	*Gallinago gallinago*	1								**1**
Woodcock	*Scolopax rusticola*				1					**1**
Black-headed gull	*Larus ridibundus*	22	56						9	**87**
Kittiwake	*Rissa tridactyla*		**1**							**1**
Common gull	*Larus canus*	1	3		2			1	7	**14**
Herring gull	*Larus argentatus*	4	172		2				11	**189**

	Species	**NL**	**BE**	**ESP**	**SWE**	**AT**	**UK**	**DK**	**D**	**Tot.**
Lesser black-backed gull	*Larus fuscus*		44						1	**45**
Great black-backed gull	*Larus marinus*		6							**7**
Gull sp.	*Larus sp*	*2*			2				1	**5**
Common tern	*Sterna hirundo*		**8**							**8**
Little tern	*Sterna albifrons*		**4**							**4**
Guillemot	*Uria aalge*								1	**1**
Eagle owl	*Bubo bubo*			**3**					4	**7**
Woodpigeon	*Columba palumbus*	1	5	1	1				4	**12**
Stock dove	*Columba oenas*		**1**							**1**
Rock/feral dove	*Columba livia*		*9*						4	**13**
Pigeon sp.		*1*		2						**3**
Swift	*Apus apus*		2	1	3				8	**14**
Cuckoo	*Cuculus canorus*			1						**1**
Great spotted woodpecker	*Dendrocopos major*								1	**1**
House martin	*Delichon urbica*			1	**6**				1	**8**
Barn swallow	*Hirundo rustica*			**1**	1					**2**
White wagtail	*Motacilla alba*	1	1						1	**3**
Yellow wagtail	*Motacilla flava*								1	**1**
Woodlark	*Lullula arborea*			5						**5**
Crested lark	*Galerida cristata*			1						**1**
Skylark	*Alauda arvensis*			**2**					6	**8**
Tawny pipit	*Anthus campestris*			2						**2**
Robin	*Erithacus rubecula*	1	1	5					1	**8**
Marsh warbler	*Acrocephalus palustris*								1	**1**
Willow warbler	*Phylloscopus trochilus*				1				1	**2**
Pied flycatcher	*Ficedula hypoleuca*								2	**2**
Black redstart	*Phoenicurus ochrorus*			2						**2**
Whinchat	*Saxicola rubetra*								1	**1**
Stonechat	*Saxicola torquata*			1						**1**
Redwing	*Turdus iliacus*							1	1	**2**
Blackbird	*Turdus merula*		1	3	4				1	**9**
Song thrush	*Turdus philomelos*	1	4		**1**					**6**
Fieldfare	*Turdus pilaris*	1							1	**2**
Unidentified thrush	Turdus	*1*								**0 [1]**
Goldcrest	*Regulus regulus*		1						1	**2**
Firecrest	*Regulus ignicapillus*			**1**					1	**2**
Regulus sp.	*Regulus*	*3*								**3**
Whitethroat	*Sylvia communis*			1						**1**
Blackcap	*Sylvia atricapilla*			4						**4**
Great tit	*Parus major*								1	**1**
Magpie	*Pica pica*		1						1	**2**
Jackdaw	*Corvus monedula*	1								**1**
Raven	*Corvus corax*								9	**9**
Rook	*Corvus frugilegus*				1				1	**2**
Carrion crow	*Corvus corone*		1		1				3	**5**
Crow sp.	*Corvus sp*								1	**1**
Starling	*Sturnus vulgaris*	14	9						5	**28**
Corn bunting	*Emberiza calandra*								9	**9**
Yellowhammer	*Emberiza citrinella*								1	**1**
Tree sparrow	*Passer montanus*								1	**1**
House sparrow	*Passer domesticus*	3							1	**4**
Greenfinch	*Carduelis chloris*								2	**2**
Goldfinch	*Carduelis carduelis*	1								**1**
Chaffinch	*Fringilla coelebs*			1	1			1		**3**
Linnet	*Carduelis cannabina*			**3**				1		**4**
Common crossbill	*Loxia curvirostra*			1						**1**
Unidentified birds	*Aves sp*			**4**						**4**
Total		**77**	**359**	**204**	**33**	**2**	**2**	**4**	**248**	**829**

Although it is difficult to determine the impact of wind energy on bird populations, as compared with the impact on individuals, research on golden eagles in a 30 km radius around the Altamont Pass Wind Resource Area may offer some insight. A high proportion, 42%, of fatalities in this area, which records one of the highest breeding densities in the world, are due to collisions with wind turbines[23]. Fatalities were relatively higher for subadults and nonbreeding adults, which spend a lot of time hunting within the wind farm area. Population models indicated that maintenance of the breeding population was dependent on immigration[24], and hence a further expansion of wind energy in Altamont Pass is considered likely to lead to population decline unless adequate measures are taken to substantially reduce collision risk[25].

The high impact studies (Table 1) illustrate the potential for heightened collision risk at locations with high levels of activity by bird species that also display behaviours that predispose them to fatal collision with wind turbines[26]. Several of these species are also of conservation concern and subject to special legislative protection, for example the Migratory Bird Treaty Act, Bald Eagle and Golden Eagle Protection Act, and Endangered Species Act in the United States and the Habitats Directives of the European Union. Further more, although collision mortality individually, even at some of these sites, may not lead to population declines, there may be a cumulative impact of elevated mortality across multiple wind farms[27]. According to Drewitt & Langstron wind farms were high bird mortality has been recorded may also act as ecological sinks, whereby territories vacated as a result of collision mortality may become occupied by birds from outside the area on a repeated basis, as replacements also suffer an increased risk of collision mortality.

The problem sites in detail

At Altamont Pass and Tarifa, where the highest recorded collision rates for raptors have been recorded (Table 1), a number of different causal factors are highlighted, including super-abundant prey, high densities of activity, topographical bottlenecks, and certain aspects of raptor behaviour such as pursuit flights, hunting, territorial disputes, and soaring on thermals or rising winds on slope[28]. The highest-risk turbines are thought to be those situated on steeper, windward slopes and in canyons, and also on ridge saddles[29]. Unfortunately such areas are also the primary locations sought for wind energy generation, because the highest wind strengths are at the break of slope at ridge tops[30], and hence wind turbine in these areas can be especially problematic, leading to high levels of collision mortality for species that frequently use rising winds to gain elevation[31]. Collisions of raptors at Altamont Pass included golden eagles, red-tailed hawks, American kestrels *Falco sparverius*, and burrowing owls *Athene cunicularia*, all of which spent more time flying close to the turbines than

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[23] Hunt 2002; Hunt & Hunt 2006

[24] ibid

[25] Smallwood & Neher 2004

[26] Drewitt & Langstron 2008

[27] ibid

[28] Barrios & Rodriguez 2004, 2007; Smallwood & Neher 2004; Smallwood & Thelander 2004, 2005; Thelander & Smallwood 2007

[29] Orloff & Flannery 1992; Barrios & Rodriguez 2004, 2007; Smallwood & Thelander 2004, 2005; Thelander & Smallwood 2007

[30] Drewitt & Langstron 2008

[31] Barrios & Rodriguez 2004; Smallwood & Thelander 2004, 2005

would be expected by chance, at least in part because of prey availability[32]. Northern harriers *Circus cyaneus* and prairie falcons *Falco mexicanus* also spent a disproportionate amount of flying time within 50 m of the turbines, but few were found to collide with the rotors.

At Tarifa, despite close proximity to a major migration bottleneck at the Straits of Gibraltar, collisions recorded were mainly of resident griffon vultures and common kestrels *Falco tinnunculus*[33]. The majority of observed flights by birds migrating through the area were considered to be at low risk of collision because there was a low frequency of passage between the turbines. Most birds flew at a higher elevation than the rotor-swept area, and lower altitude flights coincided mainly with very low wind speeds, when the turbines were not operational. The interaction between initial flight height, on entering the wind farm, and wind speed was a highly significant determinant of collision risk for vultures[34]. Collisions by vultures at Tarifa occurred during daylight, in good visibility, and light winds, when the birds were flying low as they entered the observation zone within 250 m of a turbine[35]. The high-risk period was when the vultures left their roost and were using rising winds on sloping ground to gain height and manoeuvrability, which brought them close to ridge-wind turbines.

The contrasting collision risk documented for griffon vultures at different wind farms around Tarifa[36] demonstrates the site-specificity of collision risk. The collisions by common kestrels occurred at turbines in open habitats, and the risk was thought to be associated with hunting habitat preferences. The authors concluded that wind-relief interactions influenced collision risk, mediated by the birds' flight behaviour[37]. Similarly, at Navarra in northern Spain, raptors accounted for the majority of collision fatalities, with griffon vultures most numerous[38], where once again there was a pronounced difference in the collision mortality of vultures at the different wind farms studied[39].

Another site that has recorded relatively high levels of collision mortality among raptors is Smøla in Norway[40] (Table 1). Preconstruction, there were an estimated 19 breeding pairs of resident white-tailed eagles *Haliaeetus albicilla* in the area comprising the wind farm plus a 2 km buffer zone. Bird usage of the area included displays and territorial disputes by breeding birds, commuting flights between nesting and off-shore feeding areas, gatherings of soaring and roosting birds, and migration along the Norwegian coast. Ten fatal collisions of white-tailed eagles were recorded between August 2005, when the wind farm became fully operational, and September 2006[41], and more have occurred subsequently[42]. This figure is likely to represent the minimum number of collisions, because prior to February 2006, with no formal searches, dead birds were incidental finds. Breeding adults and fledged juveniles were among the deaths, including three of the five young fledged within the wind farm and

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[32] Smallwood & Thelander 2004; Smallwood 2006, 2007; Thelander & Smallwood 2007

[33] Barrios & Rodriguez 2004, 2007

[34] ibid

[35] Barrios & Rodriguez 2004

[36] Barrios & Rodriguez 2004; de Lucas et al. 2004

[37] Barrios & Rodriguez 2004, 2007

[38] Lekuona & Ursúa 2007

[39] ibid

[40] Follestad et al. 2007

[41] ibid

[42] Drewitt & Langstron 2008

buffer zone in 2005, and in a spike of fatalities record four were recorded in just one week in late April to early May 2006[43].

At the port of East Zeebrugge, in Belgium, a wind farm comprising 25 small wind turbines (200–600 kW) is situated along the harbour wall in a linear array[44]. A high proportion of Belgium's breeding common terns, Sandwich terns *Sterna sandvicensis*, and little terns *S. albifrons*, and a significant proportion of their western European biogeographical populations, breed at Zeebrugge. Corpse searches were conducted minimally weekly or twice weekly, and at greater during the terns' breeding season, and the numbers of terns found dead under the seaward turbines were 48 in 2004 and 51 in 2005. Equivalent figures for gulls were 54 in 2004 and 37 in 2005[45]. Only obvious or highly probable collision fatalities, based on the type of injuries, were included in the estimates of collision mortality and searches were confined to land. Collision records were corrected for search area (including corpses lost in the sea), search efficiency, and scavenging, following the approach advocated by Winkelman[46], resulting in collision mortality of terns estimated at 168 (1.57 per day) and 161 (1.51 per day) in 2004 and 2005 respectively, and the majority in May to July when breeding terns were feeding chicks. Over 90% of the recorded collisions were with four turbines that intercept the main foraging flights of terns from their breeding colony. All recorded collisions were of adults, most coinciding with wind directions perpendicular to the line of turbines. In all the collisions were estimated to represent additional mortality of 1.5% annually for little tern, 1.8–3.7% for common tern, and 0.6–0.7% for Sandwich tern at Zeebrugge[47].

The Zeebrugge observations recorded most flights below 50 m, that is, at or below the rotor-swept height, with a high proportion below 15 m. The collision probability for the terns flying at rotor height was low, at 0.1% or less, and a significant correlation was found between the number of breeding pairs of terns and the number of collision fatalities over the period 2001–2005[48], implying that the terns were not deterred by the objects across their flight path. Early in the breeding season they avoided the turbines, but, as the imperative to provision chicks took priority, they later flew by the most direct route, which increased their collision risk and actual collisions with the wind turbines. This observation is similar to that made by Henderson and colleagues with respect to foraging terns and collision with power lines[49].

Underlying factors for the collisions

The factors contributing to the high collision rates for raptors in Altamont Pass were identified as features of turbine structure and spacing, location of turbines in relation to local topography, aspects of management associated with the wind farms, and season[50]. Collision risk tended to increase with height of turbine and rotor diameter, and, notably for golden eagles, risk was greatest at more isolated turbines and those

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[43] Follestad et al. 2007
[44] Everaert & Stienen 2006
[45] ibid
[46] Winkelman 1992a
[47] Everaert & Stienen 2006
[48] ibid
[49] Drewitt & Langstron 2008
[50] Smallwood & Thelander 2004; Smallwood et al. 2006; Thelander & Smallwood 2007

turbines with lower blade reach[51]. Most of the eagle deaths are associated with particular turbine strings and turbines at the ends of rows or edges of clusters[52]. Rock piles around turbine bases attracted small mammals and so provided a source of food for raptors. Further more, cattle tended to congregate around turbine bases and their dung attracted grasshoppers, another important food source for American kestrels and burrowing owls in particular[53].

Slow to intermediate blade tip speeds were associated with collision mortality of raptors[54], which may be due, at least in part, to "motion smear"[55], causing the image to blur as the bird approaches close to the moving rotors. Lattice towers were originally thought to pose a greater collision risk than tubular tower[56], but more recent studies suggest that there is no appreciable difference between the two[57]. Turbine size tends to increase with increased MW rating, but collision risk does not necessarily increase with increased size of wind turbine[58], and hence "repowering" old wind farms to the same capacity with newer, larger turbines would reduce the negative impact on birds. If however the wind farm is expanded 1.5 fold when "repowering" the negative impact on birds and bats dominate and doubling the capacity increases the negative impact of wind farms[59]. Furthermore, this rule may not hold for bats, which record exponential increases in fatalities with increasing turbine tower height[60].

In summary, important factors associated with elevated collision risk identified to date at onshore wind farms include topography, turbine location, design, and configuration, including spacing, and land use close to turbines[61]. In particular there is a significant interaction between the prevailing wind and topography for raptors, notably associated with slopes and ridges[62]. When siting a wind farm all these factors need to be considered in light of the local bird population and their flight behaviour and thereby minimise the impact of the wind turbines.

Offshore Wind Farms

Although offshore studies are more difficult, due to the limitations of deploying remote monitoring techniques[63], there is evidence of avoidance from studies at several offshore wind farms, notably by migrating common eiders *Somateria mollissima*[64], the most frequently studied species. In the western Baltic, for example, birds' avoidance response from Nysted wind farm was initiated at greater distance from the wind farm during daylight (≤3 km) than at night (≤1 km)[65]. It would seem therefore

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[51] Smallwood & Thelander 2004; Thelander & Smallwood 2007
[52] Orloff & Flannery 1992; Smallwood & Thelander 2004; Thelander & Smallwood 2007
[53] Drewitt & Langstron 2008
[54] Smallwood & Thelander 2004
[55] Winkelman 1992c; Hodos 2003
[56] Orloff & Flannery 1992
[57] Barrios & Rodriguez 2004; Smallwood & Neher 2004
[58] Smallwood & Thelander 2004; Hötker et al. 2006
[59] Hötker et al. 2006
[60] Barclay et al. 2007
[61] Barrios & Rodriguez 2004; Smallwood & Thelander 2004; Dorin & Spiegel 2005; Sterner et al. 2007; Drewitt & Langstron 2008
[62] Barrios & Rodriguez 2004; Smallwood & Neher 2004
[63] Drewitt & Langstron 2008
[64] Kahlert et al. 2004; Desholm & Kahlert 2005; Pettersson 2005
[65] Desholm & Kahlert 2005

that birds were able to see obstacles at greater distances in daylight and so take earlier avoidance action, though the radar monitoring proved to be difficult and there was no account for weather in the study[66]. It can be theorised that deteriorating weather conditions that force birds to fly at low altitude or to settle on the water increase the risk of collision in areas occupied by wind turbines. Nonetheless, out of 235,136 migrating sea ducks only 47 individuals were predicted to collide with the wind turbine rotor-blades, equivalent to an overall mean collision risk of 1.4 collisions per turbine per year, or 0.02% of the total number of birds passing the turbines[67]. This figure lies within the published collision estimates for other wind farms worldwide, which in general are low, i.e. between 0 to over 60 collision fatalities per wind turbine per year[68].

Such a low fatality record is supported by another study involving radar and visual observations at two small offshore wind farms in the southern Kalmar Sound, Sweden, which found that collisions were rare, though a recorded collision observation by individuals in a flock of common eiders is quite telling[69]. The flock of around 310 eiders, in V-formation, flew past an outer turbine when several individuals in the outer flank, and therefore the rear, of the flock struck the rotating blade on its downward trajectory or were caught in the associated turbulence. Four birds were observed to fall into the water, of which at least two flew out and at least one was killed. This is a useful observation in providing evidence of the mechanism for collision or turbulence effects associated with wind turbines.

The broader picture

Erickson et al.[70] shows that, compared to other causes of mortality among birds, the effect of wind power is relatively minor. While these authors acknowledge that determining the extent of wildlife mortality due to collisions with structures such as power lines, buildings, communication towers, or wind plants is a difficult sampling and estimation problem their work indicates that, at least in the US, predicted annual avian mortality as a result of collisions with wind turbines amount to <0.01% of anthropogenically-caused avian deaths. Well-publicised reports of bird deaths at sites, including the Altamont Pass near San Francisco and Tarifa in southern Spain, therefore appear to be exceptions rather than the rule.

Nonetheless, the Altamont Pass study does show that a high level of collision mortality has reduced productivity in the local population to the point where it effectively acts as a sink, depending on immigration for its maintenance[71]. Other recent studies of local populations of birds of prey affected by wind turbines have, in some cases, revealed similarly high levels of mortality[72]. Although population effects have yet to be detected, there are indications of wind farms acting as sinks in some of

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[66] Drewitt & Langstron 2008

[67] Desholm 2006

[68] e.g., Winkelman 1992a; Musters et al. 1996; Still et al. 1996; Erickson et al. 2001; Langston & Pullan 2003; Hötker et al. 2006

[69] Pettersson 2005

[70] Erickson et al. 2001

[71] Hunt 2002; Hunt & Hunt 2006

[72] e.g., Follestad et al. 2007; Lekuona & Ursúa 2007

these cases[73]. Other species, besides birds of prey, such as the terns in Everaert & Stienen[74] Zeebrugge study, also may have population level impacts from wind turbines. Here the 1.5% estimated additional mortality for the two species is well above the 0.5% suggested as an additional mortality level above which the population could be seriously impacted[75]. Particularly wildfowl *Anseriformes* and waders *Charadriiformes* seem to be vulnerable to population declines according to a meta-analysis of 19 globally-distributed wind farms, though in general the evidence-base for windfarm impacts on birds is still rather poor[76].

Drewitt & Langstron[77] estimate that at a minimum several hundred million birds are killed annually by collisions with power lines, communication towers, windows and wind turbines in the United States alone. Though this death toll is still a relatively minor component of the overall mortality levels, and mortality due to other factors, such as habitat loss and degradation, predation, and adverse weather conditions, is much greater, the progressive deployment of such structures will certainly have its future impact on birds. They suggest that initially, perhaps, declines will be restricted to local populations of the most vulnerable species, as suggested by some of the studies reviewed, but eventually these local impacts will rise and could lead to regional or even national population declines[78].

If for each new MW of wind power on average an additional bird dies every year, by 2030 this could result in 300,000 more collisions annually, under a target of supplying 20% of the US' electricity from wind power. Similarly, by 2020 annual bird death could range from a mere 300-400 to 3,000-5,700, depending on the installed wind capacity, 2,158 MW or 3,856 MW according to different wind development projections, and depending on the average bird death per MW, from 0.1 to 1.5 (Table 1). Alternatively, if climate change is not prevented, in the long-term, under a mid-range climate warming scenario, 15% to 37% of all bird and wildlife species will be "committed to extinction" by 2050[79]. For montane Queensland forests, for example, the extinction risk of birds is dominated by climate change, with 7-10% and 49-72% predicted extinction for minimum and maximum climate scenarios, respectively. In South Africa a mid-range climate change scenario would raise the risk of bird extinctions to 28-32% by 2050. Another US study found that depending on the global climate model used, as many as 78 bird species are projected to decrease by at least 25 percent, while as many as 33 species are projected to increase in abundance by at least 25 percent in the eastern U.S[80].

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[73] Drewitt & Langstron 2008
[74] Everaert & Stienen 2006
[75] Drewitt & Langstron 2008
[76] Stewart et al. 2007
[77] Drewitt & Langstron 2008
[78] ibid
[79] Thomas et al. 2004
[80] Matthews et al. 2004

Avoidance guidelines

The single most important factor in controlling collision impacts seems to be location, though selecting the site for constructing a wind turbine is often subject to a range of constraints. Drewitt & Langstron[81] highlight a number of best-practice steps for a range of different structures birds could collide with:

- Wind farms, power lines, fences, and communication towers should be located away from wetlands and other areas where large numbers of vulnerable birds concentrate to nest, feed, or roost, known migratory or daily flight routes, and especially areas that support scarce and threatened species.
- For structures requiring lighting for aviation and shipping safety, the minimum amount required by the relevant regulations should be used. Unless the regulations dictate otherwise, only the lowest intensity intermittent lighting, with the minimum number of flashes per minute, should be employed at night. Where possible, downward deflection of lights, other than those for aircraft safety, is recommended.
- All unnecessary lights in tall buildings should be extinguished, at least from 11 pm until dawn, and the use of external floodlighting should be avoided during migration periods. Where lights must be left on at night, alternatives, such as motion-sensitive lighting, low-intensity lighting, and desk lamps, should be adopted.
- Where floodlighting is required (e.g., billboards), the light beam should be directed downward from above rather than pointing upward toward the sky.
- Security lighting for on-ground facilities should be shielded to keep light pollution to a minimum.
- Structures no longer in use (e.g., wind turbines, communication towers, fences) or considered obsolete should be promptly removed.

For wind farms more specifically there are many suggested mitigation measures, although most have yet to be tested to determine their effectiveness[82]. Suggested mitigation techniques range from general strategies (e.g., avoid locations used heavily by migrating bats and birds) to specific ones (e.g., reduce motion smear by painting the blades). Of all though, Careful location of wind farms is key to minimising negative effects on birds, especially those of high conservation concern[83]. For example, Madders and Whitfield[84] consider that “spatial models that attempt to predict areas of greatest sensitivity for birds at the landscape scale can be useful design tools, enabling developments to be located so as to minimise the potential effects on identified key species”. Barrios and Rodriguez[85] recommended that detailed observations of the flight behaviour of species susceptible to collision, together with mapping of migration routes, are necessary precursors to the selection of wind farm locations in particular. In the United Kingdom, a map of areas in which bird sensitivities are most likely to arise has been produced for Scotland[86] (figure 2),

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[81] Drewitt & Langstron 2008

[82] NWCC 2007

[83] Drewitt and Langston, 2006; Stewart et al., 2007; Langston et al., 2006

[84] Madders and Whitfield 2006

[85] Barrios and Rodriguez 2004, 2007

[86] Bright et al. 2008

where a greater incidence of bird sensitivities is shown in northwest Scotland, particularly in the Highlands, Western and Northern Isles. The bird species with the greatest overlap with all proposed and existing wind farms in Scotland were bean goose *Anser fabalis*, red kite *Milvus milvus* and hen harrier *Circus cyaneus*. Constraints mapping, combining the bird sensitivity map with factors such as wind speed, technical feasibility and cost, could be used by planners and developers to identify preferred areas for wind farm development within a region[87]. The Highland Renewable Energy Strategy is an example of this[88].

FIGURE 2: COMPOSITE SENSITIVITY MAP OF SCOTLAND FOR LOCATION OF ONSHORE WIND FARMS WITH RESPECT TO A SUITE OF SENSITIVE BIRD SPECIES (SOURCE: BRIGHT ET AL., 2008)

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[87] ibid

[88] Aquatera 2006

A notable drastic measure suggested to reduce the impact of wind turbines on birds is their temporary shutdown or feathering during periods of particularly high bird activity[89], especially in migration bottlenecks, such as mountain passes, migration staging areas, and near breeding or wintering concentrations, including wetlands[90]. Specific examples of proposed shutdowns include Altamont Pass[91], the Isthmus of Tehuantepec in Mexico, where migrating birds that have crossed the Gulf of Mexico are funneled or stopover to roost[92], and Zeebrugge Harbour[93], though naturally such activity would reduce the electrical power output of the wind farms, and hence, raise their cost.

More effective mitigation options would include adjusting the design and layout of wind farms accordingly. Besides their location one option, for example, is to cluster turbines close together, allowing for minimal inter-turbine spacing, so as to encourage flocks of birds to fly around them rather than among them[94]. In southern Spain turbine clusters are thought to be avoided by migrating birds[95]. Additionally, the provision of flight corridors between turbine clusters would be helpful in minimizing collision risk[96]. Orientation of turbine rows parallel to the main direction of flight, rather than intercepting main flight paths, is also likely to reduce collision risk, especially where there is large-scale bird movement in a predominant axis[97], for example between breeding colonies and marine feeding areas or tide-related movements between coastal feeding areas and roosts. Setting back turbines from cliff edges or positioning turbines on the prevailing leeward side of ridges is recommended to reduce the hazard posed to soaring raptors using rising winds on steep slopes[98].

Increasing the visibility of rotating blades to birds has been proposed, notably using the Hodos scheme of alternate black and white stripes along the blades[99], but this requires field testing. The use of ultraviolet paint or lighting has also been suggested as potentially helpful in alerting birds to the presence of the rotors while not increasing the visibility for humans, but results of limited trials to date are equivocal[100], probably due to different species' sensitivities to different UV wavelengths[101].

Minimal use of lighting, consistent with the obligatory requirements for navigation and aviation, is likely to reduce collision risk by both reducing the attraction of potential prey, for example insects, and, depending on the light intensity, reducing the likelihood of disorientation of birds[102]. Other measures to avoid attractions to wind farms could include anchoring turbine bases with materials that do not provide

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[89] Hoover & Morrison 2005
[90] Drewitt & Langstron 2008
[91] Smallwood & Thelander 2004
[92] Drewitt & Langstron 2008
[93] Everaert & Stienen 2006
[94] eg., Winkelman 1992a
[95] Lucas et al. 2005
[96] Drewitt & Langston 2006
[97] Drewitt & Langston 2008
[98] Smallwood & Neher 2004; Smallwood & Thelander 2004; Johnson et al. 2007
[99] Hodos et al. 2001; Hodos 2003; Smallwood & Thelander 2005; Johnson et al. 2007
[100] e.g., Young et al. 2003
[101] Johnson et al. 2007
[102] Drewitt & Langston 2008

opportunities for burrowing mammals to colonize, exclusion of livestock from the immediate surroundings of turbines, and using alternative management of the vegetation may remove the attractiveness to birds of high-risk areas close to the rotors[103]. Effective scaring techniques may make the wind farm area unsuitable for birds and so equate to habitat loss[104].

Bird deterrents that have been suggested as possible mitigation include the use of scaring devices, such as recordings of birds' alarm calls. This is likely to be of limited and only short-term effectiveness and unacceptably intrusive close to human habitation[105]. Radar-activation of deterrents[106] or of possible risk-reduction measures, such as turbine shutdown, has the potential advantage that it can be initiated when a hazardous situation is developing, as birds approach, though these are yet to be tested. Marking ground wires associated with electric transmission networks necessary for wind farms proves to also be a useful bird deterrent[107].

Monitoring highlights

A nearly universal design and execution problem among the studies reviewed was the lack of adequate descriptions of reference (control) and impact sites. Most studies lacked descriptions of "original conditions" as derived either from data and literature or from baseline studies[108]. To adequately assess impacts, conditions before and after the activity in question need to be compared, however, this is often difficult give the fact that there may be inadequate time to collect these data over several seasons and that any one year might represent an extreme of a normal range[109]. A single season's or year's data may not really represent conditions. There is therefore a need for an organised and coordinated monitoring of a much larger, stratified sample of structures, not just those known or perceived to cause high levels of mortality. Drewitt & Langston[110] further state that post-construction monitoring programs should be agreed for new developments, through planning or license conditions, to assess the level of mortality caused by developments, both individually and cumulatively. Monitoring is also needed to test the effectiveness of mitigation measures and to increase the understanding of what causes avian collisions, so that new, effective solutions can be devised and employed.

Monitoring of actual collisions is problematic[111], because they are generally infrequent events, and relying on visual observations alone is too time-consuming and impractical. Most on-shore studies rely on corpse searches, but because of the limitations of the method it has to be assumed that the corpses found represent the minimum number of actual fatalities. Collision searches require strict protocols including calibration for search effort, removal by scavengers, observer efficiency, corpse detectability, and nonfatal collisions, or "crippling bias," when injured birds

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[103] e.g., Smallwood & Thelander 2004, 2005
[104] Drewitt & Langston 2008
[105] ibid
[106] e.g., Stevens et al. 2000; Ronconi et al. 2004
[107] Alonso et al. 1994
[108] Hötker et al. 2006; Drewitt & Langston 2008
[109] Drewitt & Langston 2008
[110] ibid
[111] Winkelman 1992a; Barrios & Rodriguez 2004

can move at least 2 km away from the point of impact[112]. The use of dogs to search for corpses is a helpful development, which could be employed more widely[113].

Corpse removal can dramatically affect estimates of mortality, with an extreme recording of scavengers taking up to 70–80% of collision victims in a study[114]. Lekuona[115], working at Navarra in northern Spain, found evidence of scavenger activity at 89.8% of 88 griffon vulture carcasses, in contrast with Barrios and Rodriguez[116] who found persistence rates of several months at Tarifa and so assumed that all larger dead birds were found. This exposes the need for scavenger activity to be assessed at each study site to avoid erroneous assumptions about whether or not all collision fatalities, of small or large birds, are found[117]. Similarly, search effectiveness has to be controlled for and monitored, especially for variable vegetation (with season and by site) and terrain.

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[112] e.g., Winkelman 1992a; Bevanger 1999; Anderson et al. 1999; Morrison et al. 2007; Smallwood 2007
[113] Bevanger 1999; Arnett 2006
[114] Lekuona & Ursúa 2007
[115] ibid
[116] Barrios and Rodriguez 2004
[117] Drewitt & Langston 2008

Impact of wind farm development on bats

Our understanding of the problem

Collision fatalities

Fatalities of bats have been recorded at wind facilities worldwide, including Australia[118], North America[119], and Europe[120]. First records of bat fatalities are from Australia in 1972[121], with small numbers recorded in the United States since – at wind energy projects in California during avian fatality searches[122]. However it was not until 2003, when an estimated 1,400–4,000 bats were killed at the Mountaineer Wind Energy Centre in West Virginia[123], that bat fatalities at wind energy facilities started to gain more attention. High bat fatalities, at rates of over 30 per MW per year, continued at the Mountaineer facility in 2004, and large kills also have been reported at facilities in Pennsylvania and Tennessee in the U.S.[124]. Although bats collide with other tall anthropogenic structures, the frequency and magnitude of fatalities is much lower than those observed at wind turbines[125]. Such records at wind fatalities raise concerns about potential impacts on bat populations at a time when many species of bats are known or suspected to be in decline and extensive planning and development of wind energy is increasing worldwide[126].

In their review of 19 different wind energy facilities in the US Arnett et al.[127] found that estimates of bat fatalities were highest at wind energy facilities located on forested ridges in the eastern United States, at 15.1 to 41.1 bats per MW installed capacity per year[128], and lowest in the Rocky Mountain and Pacific Northwest regions, 0.8 to 8.6 bats per MW per year (Figure 3). They do caution though that their reported bat fatalities are based on very variable studies, with diverse monitoring lengths and intensities. Variation in bat fatality records were noted among sites in the upper Midwestern US where estimates range from 0.2 bats to 8.7 bats/MW, and in south-western Alberta, Canada, where 3 sites that had similar vegetation and topographic composition and that were in proximity to one another showed dramatically different estimates of bat fatalities. Similarly, bat fatalities collected in 2005 at the Summerview facility were estimated to be 14.1 times greater, on average, than at the other 2 nearby facilities, and high fatalities were again recorded at Summerview in 2006[129]. The bat fatality estimate from the only study conducted in south-central US was less than 1 bat/MW, but only 2 searches were performed at each turbine in May and June for each of 2 years of study[130]. The European studies have

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[118] Hall & Richards 1972
[119] Johnson et al. 2003, 2004; Fiedler 2004; Arnett 2006
[120] Ahlen 2007, Bach & Rahmel 2004, Dürr & Bach 2004, Brinkman 2006
[121] Hall & Richards 1972
[122] Orloff and Flannery 1992, Thelander & Rugge 2000
[123] Kerns & Kerlinger 2004
[124] Fiedler 2004, Arnett 2006
[125] Arnett 2006, Cryan & Veilleux 2007
[126] DOE 2007, Kunz et al. 2007
[127] Arnett et al. 2008
[128] Kunz et al. 2007
[129] Anett et al. 2008
[130] Piorkowski 2006

also noted the high variability of bat fatalities at their wind turbines, from 1.5[131] to 16.6-27.9 in 2004 and 9.4-15.6 in 2005[132], to over 20 bats per turbine per year[133].

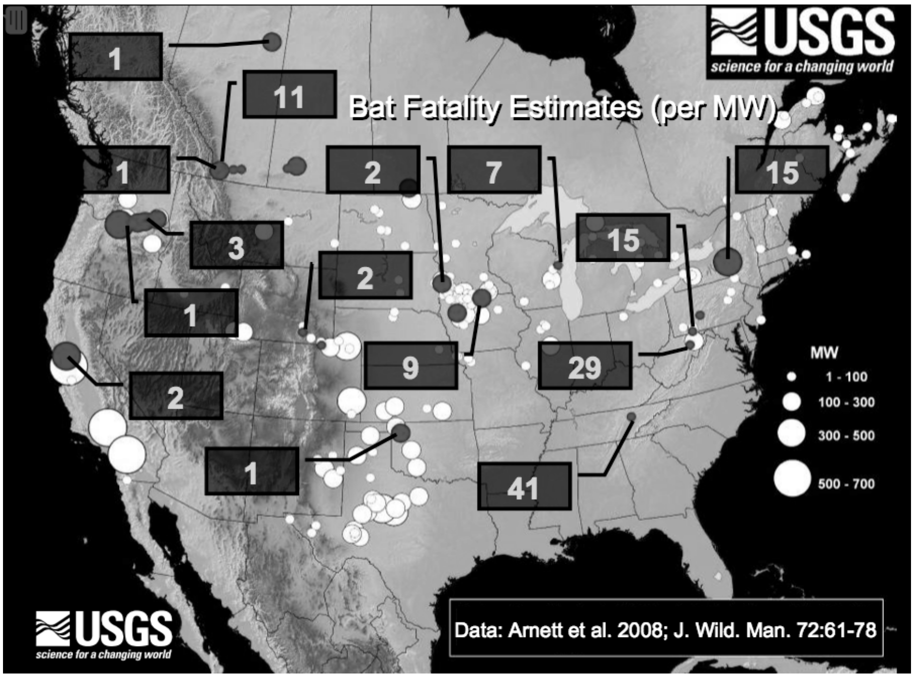

FIGURE 3. ESTIMATES OF MEAN BAT FATALITIES PER MEGAWATT (MW) CAPACITY FOR 15 WIND FACILITIES IN NORTH AMERICA, 1996–2006, OVERLAYED ON PROJECTED MW WIND FARM DEVELOPMENT (SOURCE: ARNETT ET AL. 2008)

Anett et al.[134] identified 5 key unifying patterns associated with bat fatalities at wind facilities among the studies they reviewed, which generally were consistent with findings reported from wind facilities in Europe[135]:

1) Fatalities were heavily skewed toward migratory bats and were dominated by lasiurine species in most studies.
2) Studies consistently reported peak of turbine collision fatality in midsummer through autumn from all studies in North America.
3) Fatalities were not concentrated at individual turbines (i.e., fatalities were distributed among turbines at facilities), and current studies have not identified consistent relationships with habitat variables (e.g., distance to water).
4) Red-strobe lights recommended by the FAA did not influence bat fatality.
5) Bat fatalities were highest during periods of low wind speed, and they were related to weather variables associated with the passage of weather fronts.

The most consistent theme of US studies is that bat fatality is dominated by migratory bats – 75% were foliage-roosting, eastern red bats *Lasiurus borealis*, hoary bats

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[131] Göttsche & Göbel 2007
[132] Brinkmann et al. 2006
[133] Dürr 2007
[134] Anett et al. 2008
[135] Dürr and Bach 2004, Brinkmann et al. 2006, Dürr 2007

Lasiurus cinereus, and tree cavity-dwelling silver-haired bats *Lasionycteris noctivagans*[136]. They were killed during midsummer through autumn in North America, coinciding with the southward migration patterns of the bats. Similarly, of 15 species of bats reported as fatalities at wind facilities in Europe, of which 10 sites were in Germany, most were migratory species, such as 2 species of *Nyctalus* and *Pipistrellus nathussi*, and most were killed in midsummer and autumn[137]. This is a pattern that coincides with records of migrating bats striking other anthropogenic structures and their arrival at migration stopovers[138]. In the UK by contrast the long distance bat migrants do not exist, but it is thought that bats migrate regionally for food and shelter, and hence are also at risk of being killed by wind turbines[139].

Johnson[140] reported that, in open prairie and farmland, bat fatalities seemed to be low during the maternity season; only 66 of the 1,628 reported fatalities (4.1%) occurred between 15 May and 15 July. At several wind energy facilities studied to date, low fatalities were documented during the maternity season, even though relatively large numbers of bats were present in the area[141]. Most of these wind energy facilities were in open areas such as crop fields, grasslands, and shrub steppe, and mating bats may be more prone to collision at wind farms constructed in bat foraging habitats, such as those constructed in forested areas. Johnson et al.[142] contended that it was unlikely resident bats would spend significant amounts of time foraging near turbines in crop fields or pastures, but that may not be the case for species such as Brazilian free-tail bats that are well known to use agricultural areas for foraging[143]. Roughly equal numbers of Mexican free-tail carcasses were discovered beneath turbines in forest, crop, and mixed grass prairie habitats at one facility in Oklahoma[144].

Fatality timing and causes

Movement of migratory bats into new areas during late summer and early autumn may be partially the result of exploratory activity[145], and the temporal pattern of bat fatality could simply be related to increased bat activity before and during migration[146]. Some migratory species may summer in areas where they are colliding with turbines as well. Little brown bats and eastern pipistrelles are known to migrate several hundred kilometers to hibernate and autumn transient colonies form as early as August, peaking in September or October[147], a period that corresponds with high fatalities documented at some wind energy facilities that Anett et al.[148] reviewed. European studies also seem to confirm the peaking of collisions in late summer/beginning of autumn[149]. Factors such as potential roost attraction, movement

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[136] Kunz et al. 2007
[137] Dürr 2006, Brinkmann et al. 2006
[138] Cryan and Brown 2007
[139] Cohen, K., RPS, personal communication.
[140] Johnson et al. 2004
[141] Howe et al. 2002, Johnson et al. 2003, Fiedler 2004
[142] Johnson et al. 2004
[143] Cleveland et al. 2006
[144] Piorkowski 2006
[145] Cryan 2003
[146] Arnett et al. 2008
[147] Johnson et al. 2004
[148] Anett et al. 2008
[149] Dürr 2007, Traxler et al. 2004

or sound attraction, or available prey may explain wind turbine-caused fatalities in species such as big brown bats and little brown *myotis*. Some species of bats are known to night-roost, and many species hawk for insect prey[150], possibly supporting the roost attraction hypothesis for explaining deaths of species other than lasiurines.

Higher fatalities during migration could be related to reduced echolocation and flight capabilities of juvenile bats[151]. However, little is known about use of echolocation during migration, and evidence suggests that bats are somehow attracted to turbines and that fatality is not a random event[152]. Kunz et al.[153] discussed several hypotheses as to why bats may be attracted to and killed by turbines. It is possible that migrating tree-roosting species perceive turbines as possible roost trees and investigate them upon encounter[154]. Thermal images of bats attempting to land or actually landing on stationary blades and the turbine mast generally support the roost attraction hypothesis[155], but the ultimate attraction to ridge top sites where turbines are located might be the availability of insect prey[156], which may be clustered in the swirling wake of wind turbines (Figure 4). Modifications of landscapes during installation of wind energy facilities, including the construction of roads and power-line corridors, and removal of trees to create clearings (usually 0.5–2.0 ha) around each turbine site may create favorable conditions for the aerial insects upon which most insectivorous bats feed. Bats that migrate, commute, or forage along linear landscapes may be at increased risk of encountering and being killed by wind turbines[157].

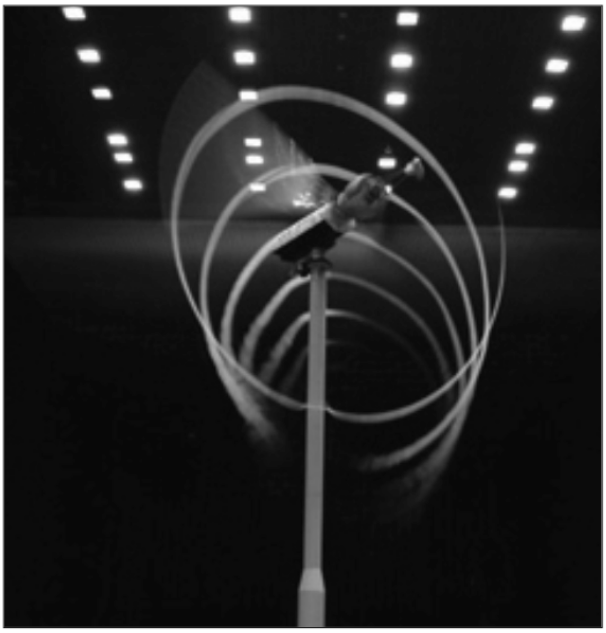

FIGURE 4: BLADE-TIP VORTICES CREATED BY MOVING ROTOR BLADES IN A WIND TUNNEL ILLUSTRATE THE SWIRLING WAKE THAT TRAILS DOWNWIND FROM AN OPERATING WIND TURBINE. (SOURCE: KUNTZ ET AL. 2007)

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[150] ibid

[151] ibid

[152] Horn et al. 2008

[153] Kunz et al. (2007)

[154] Arnett 2006, Kunz et al. 2007, Horn et al. 2008

[155] Kunz et al. 2007

[156] Horn et al. 2008

[157] Kunz et al. 2007

Although it is clear that bats are struck and killed directly by turning rotor blades[158], recent evidence indicated that barotrauma, the rapid recompression experienced by bats due to changes in atmospheric pressure as the turbine blades rotate downward[159], may be the over-riding cause for death. Baerwald et al.[160] found that 90% of hoary *Lasiurus cinereus* and silver-haired *Lasionycteris noctivagans* bats killed at a wind energy facility in south-western Alberta, Canada, had internal hemorrhaging consistent with barotrauma. The majority of those recorded, 57%, had no external injuries, indicating that the cause of death was due to barotrauma. Although the pressure reduction required to cause the type of internal injuries Baerwald et al.[161] observed in bats is unknown, pressure drop in the blade-tip vortex is in the range of 5–10, levels sufficient to cause serious damage to various mammals. Bird deaths at wind farms have not been attributed to barotrauma, though their respiratory anatomy probably makes them less susceptible to changes in pressure. Bats have large lungs and hearts, high blood oxygen-carrying capacity, and blood-gas barriers thinner than those of terrestrial mammals changes, which suggests they are particularly susceptible to barotraumas[162].

The broader picture

Although post-construction monitoring has been conducted at wind facilities in North America for more than a decade, relatively few studies have focused on bats, and some states and regions have very poor or no data on bat fatalities. For example, Texas, which has the largest installed capacity of wind energy in the continental United States, has no data on wildlife fatalities from any of its facilities[163]. Only one study from California, the state with the second highest installed capacity of wind energy, reported bat fatality estimates that were corrected for field bias, although the corrections were based on one trial in December with only 8 bat carcasses[164]. Potential population effects of wind turbine-related bat fatality remain unknown from available studies[165]. For many species, especially foliage and tree-roosting lasiurines that are most frequently killed, no quantitative information regarding long-term population trends can be drawn from existing data, in part because detection probabilities cannot be determined from current sampling methods[166].

Given our current, though admittedly minor, state of knowledge and the projected future development of wind energy facilities in the United States, the potential for significant cumulative population impacts to bats is an important concern[167]. Based on estimates of installed capacity and the limitations and assumptions with respect to fatality rates, projected annual fatalities of bats in the Mid-Atlantic Highlands in the eastern United States could range from 33,017 to 61,935 (2,158 MW installed capacity, based on National Renewable Energy Laboratory projections) or from

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[158] Horn et al. 2008
[159] Kunz et al. 2007
[160] Baerwald et al. 2008
[161] ibid
[162] ibid
[163] Arnett et al. 2008
[164] Kerlinger et al. 2006
[165] Kunz et al. 2007
[166] Arnett et al. 2008
[167] Kunz et al. 2007

58,997 to 110,667 (3,856 MW installed capacity based PMJ electric grid operator interconnection queue) bats per year by 2020 in just this one region (National Research Council 2007). These estimates would result in the cumulative death of 9500 to 32000 hoary bats, 11500 to 38000 eastern red bats, and 1500 to 6000 silver-haired by 2020[168].

Furthermore, if 20% of the US electricity is supplied form wind farms by 2030, the potential number of deaths could be as high as 8,400,000 annually at a death rate of 28 bats per MW, 4,500,000 annually at a death rate of 15 bats per MW, or 1,500,000 annually at a death rate of 5 bats per MW. These projections, although hypothetical, should be of particular concern for species of migratory tree bats that experience the highest fatalities at wind energy facilities in North America. Arnett et al.[169] believe that because many bat populations are believed to be in decline, and because there are long-lived and have exceptionally slow reproducing (and hence population growth) rates, some species could be pushed to threatened or endangered status resulting proximately, ultimately, or independently of wind energy development. Conversely, with more than 1,100 species worldwide, bats account for nearly a quarter of all mammals, and under climate change scenarios mammals, which are already highly threatened by extinction, are thought to become even more vulnerable[170].

Avoidance guidelines

Results from studies reviewed do not reveal consistent patterns to assist with macro (facility-scale) or micro (turbine-scale)-siting decisions to avoid bat fatalities, though many of the issues discussed for birds hold true for bats. Additionally, the studies that addressed relationships between bat fatalities and weather patterns found that most bats were killed on nights with low wind speed, <6 m/sec[171]. Curtailing operations during low wind periods, particularly in late summer and autumn, could reduce bat fatality substantially. For example, at the Meyersdale and Mountaineer facilities bat fatality would have been reduced by 82% and 85%, respectively, had turbines not been operating on nights when mean wind speed was less than 6 m/sec from 1 August to 13 September 2004[172].

It has further been suggested that different states of bat activity must be investigated. Unlike bird migratory patterns, the behaviour and movement of bats is still not really known, and hence there is really little empirical evidence to determine what represents "appropriate siting"[173]. There is a particular need to understand the migration patterns of bats, over water[174] and on land, under different weather conditions, in particular at different wind strengths[175], as well as during different seasons. The fundamental question of why bats are attracted to wind turbines also needs further investigation[176].

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[168] ibid

[169] Arnett et al. 2008

[170] Thomas et al. 2004; Isaac 2008

[171] Arnett 2006; Rodrigues et al. 2008

[172] Arnett et al. 2008

[173] ibid

[174] Ahlén et al. 2007

[175] Arnett et al. 2008

[176] Kunz et al. 2007

Monitoring highlights

Although daunting, developing methods to assess populations and ways of investigating relationships between bat abundance and fatality risks at local and regional scales should be a priority[177]. The perfect monitoring protocol has as of yet not been determined and a number of bat monitoring mechanisms are being suggest, including hand held or automated bat detectors, radio-tracking whenever necessary and also trapping in forests or highly structured areas only. The height at which such recordings are done seems crucial, though difficult to administer, with some ideas highlighting the use of radar in combination with bat detectors at different altitudes and night vision equipment[178], though this all gets very expensive.

In contrast to bird fatalities studies, bats are smaller and seem to have quite high rates of predation, which would indicate that higher corps search frequencies should be applied[179]. Furthermore, a study highlighted by Arnett et al.[180] shows that the use of dogs for corpse searches may be more effective. Dog/handler and human searchers' efficiency varied considerably between the two sites; the dog team found 71% of the carcasses at Mountaineer and 81% at Meyersdale, compared with 42% and 14% for the human searchers, respectively. Dog and human searchers' efficiency also varied considerably with distance from the turbine and visibility.

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[177] Arnett et al. 2008; Rodrigues et al. 2008
[178] Rodrigues et al. 2008
[179] Arnett et al. 2008
[180] ibid

Guidance on minimising impact of wind farm development

In order to reduce the impact of wind farm development on birds and bats a number of steps need to be completed, as outlined by the California Guidelines[181], where five main steps are highlighted:

1. Preliminary site screening

Site screening is the first step to assess biological resource issues and potential impacts associated with wind development at a proposed site and to develop a "pre-permitting" study plan. It consists of a reconnaissance field survey and a desktop effort to collect data about the site from databases, reports from nearby projects, agencies, and local experts. Based on the site reconnaissance and review of existing data, a preliminary list of impact questions can be developed, including which species are likely to occur at the site and which are likely to be affected by the project. The site's sensitivity will determine what kind of species-specific data should be collected and determine the kinds of studies the developer should conduct during the pre-permitting assessment to adequately evaluate a wind energy project's potential impacts to birds and bats.

2. Permitting requirements and compliance with laws

Permitting of wind energy projects should be in line with the state and federal laws. For a Californian case the following laws would have to be abided to:

- State laws: California Environmental Quality Act and Fish and Game Code Wildlife Protection Laws
- Federal laws: National Environmental Policy Act, Federal Endangered Species Act, Migratory Bird Treaty Act, Bald and Golden Eagle Protection Act.

3. Pre-permitting assessment methods

With information from the preliminary site assessment, proposed project sites can be grouped into one of four categories to provide a general framework for determining the duration and intensity of study needed for pre-permitting and operations monitoring. The categories are as follows, each requiring different amounts of pre and post-construction monitoring:

Category 1: Project Sites with Available Wind-Wildlife Data

- Existing foundation of data on bird and bat use and potential impacts from nearby similar projects.

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[181] California Energy Commission 2007

- Infill development, “repowering” projects, and those near existing wind facilities for which there is little uncertainty as to the level of impacts.
- Projects may not need a full year of pre-permitting studies to answer questions about potential collision risk because of the availability of existing data.

Category 2: Project Sites with Little Existing Information and No Indicators of High Wildlife Impacts

- No obvious “red flags” – known occurrences of special-status species or high levels of fatalities at nearby wind facilities
- Pre-permitting surveys should last a minimum of one year to document how birds and bats use a site during spring, summer, autumn, and winter.

Category 3: Project Sites with High or Uncertain Potential for Wildlife Impacts

- Projects with high levels of bird and/or bat use or considerable uncertainty regarding bird and bat use
- Pre-permitting studies in excess of one year may be necessary

Category 4: Project Sites Inappropriate for Wind Development

- Wind development should not be considered on land protected by local, state, or federal government as: designated wilderness areas, national parks or monuments, state parks, regional parks, and wildlife or nature reserves.
- Sites for which existing data indicate unacceptable risk of bird or bat fatalities

The standardised data collection method for diurnal birds is the bird use count; most projects will also need raptor nest searches. Depending on characteristics of a proposed project site and the bird species potentially affected by the project, additional pre-permitting study methods may be necessary. Bird use counts are modified point counts that involves an observer recording bird detections from a single vantage point for a specified period, usually 30 minutes once a week for a year, covering most weather conditions. Sampling sites should have unobstructed views of the surrounding terrain, should be about 1.6 km apart, and cover areas of the proposed project site. The number and species of birds observed, the distance from bird to observer, the flight height above ground and environmental variable should be recorded. Behaviour, such as soaring, contour hunting and flapping flight, should be recorded at short, 30 second, intervals. Raptor nest searches provide information for micrositing decisions, to aid in estimating impacts, to establish an appropriately sized non-disturbance buffer around nesting territory and to develop compensatory migration measures if needed. Suitable habitat should be searched during the breading season, at least 2.6 km in radius around the proposed project site, thought this may be reduced if the raptors recorded have small home ranges.

For bats, monitoring with specialised acoustic systems is recommended to determine the presence and activity levels of resident and migratory bats at proposed project sites. If defensible, site-specific data are available indicating that the project is unlikely to pose a risk to bats acoustic monitoring may not be warranted. Other bat research tools are available to complement the information form acoustic surveys but are not recommended on every project. Monitoring should be for a full year and environmental variables, such as temperature, precipitation and wind speed should be noted too, as not much is known about bat behaviour and migration.

For nocturnal migratory birds, conduct additional studies as needed if characteristics of the project site and surrounding areas potentially pose a high risk of collision to migrating songbirds and other species. Primary tools available to study nocturnal birds include radar, acoustic monitoring, visual monitoring but no standardised recommendations on duration or frequency of sampling or study design are provided.

4. Impact analysis and mitigation

The following elements in site selection and turbine layout and in developing infrastructure for the facility should be considered:

- Minimize fragmentation and habitat disturbance.
- Establish buffer zones to minimize collision hazards (for example, avoiding placement of turbines within 100 meters of a riparian area).
- Reduce impacts with appropriate turbine design and layout.
- Reduce artificial habitat for prey at turbine base area.
- Avoid lighting that attracts birds and bats.
- Minimize power line impacts by placing lines under ground whenever possible.
- Avoid using structures with guy wires.
- Decommission non-operational turbines.

If avoidance and minimization measures are insufficient compensation measures can be considered. The compensation must be biologically based, reasonable, and provide certainty in terms of the funds that will be expanded and certainty that the mitigation will continue to provide biological resource value over the life of the project. The following list would have to be considered in developing compensatory mitigation:

- Offsite conservation and protection of essential habitat
    - Nesting and breeding areas
    - Foraging habitat
    - Roosting or wintering areas
    - Migratory rest areas
    - Habitat corridors and linkages
- Offsite habitat conservation and habitat restoration
    - Restored habitat function
    - Increased carrying capacity
- Offsite habitat enhancement
    - Predator control programmes
    - Exotic/invasive species removal

Lastly, operations impact mitigation can be performed, though this tends to only occur, if the level of fatalities at a project site was unanticipated at project origination and permitting, and therefore measures included in the permit have become inadequate to avoid, minimise or compensate for bat or bird fatalities. In extreme cases, if the additional impact monitored cannot be met through additional compensatory action, project operators may need to consider operational and facility changes as habitat modification, seasonal changes to cut speed, limited and periodic feathering of wind turbines during low wind nights, seasonal shutdowns, or removal of problem turbines. See Appendix 1 for more detail on the options available.

5. Operations monitoring

Operations monitoring, also known as post-construction monitoring, involves searching for bird and bat carcasses under turbines to determine fatality rates and collecting data on bird use at the project site. At a minimum the primary objective for operations monitoring are:

- Whether estimated fatality rates from the pre-permitting assessment were reasonably accurate
- Whether the avoidance, minimisation and mitigation measures implemented for the project were adequate or whether additional corrective action or compensatory mitigation is warranted
- Whether overall bird and bat fatality rates are low, moderate, or high relative to other projects.

Duration

Category 2 and 3 projects will need two years carcass count data to assess whether pre-permitting impact estimates were accurate, to evaluate the effectiveness of mitigation measures and capture variability between years. One year of bird count data is also recommended for Category 2 and 3 projects. Category 1 projects may need only one year of operations monitoring, whereby reduced monitoring in the second year is only allowed if the first year provides scientifically defensible data documenting that fatality rates were as expected and similar to those of nearby projects. Data from the first year should be evaluated to guide the second year monitoring effort, such as more emphasis on turbines and habitat types, where impacts were noted to be higher and/or seasons when impacts were higher.

Number of Carcass Search Plots

About 30 % of the turbines in a wind farm should be sampled.

Search plot Size

Search width should be equal to the maximum rotor tip height, e.g. for a 120m turbine with rotor tip height, the spread of searched area, as a rectangle, square or circle, should be 60m in either direction form the turbine base. This may have to be altered in order to ensure that the searched area encompass approximately 80% of the carcasses.

Search Protocol

Trained and tested searchers should search a standardised 6m transect, looking 3m either side of them, though this may have to be adjusted as necessary, depending on vegetation and topographic conditions.

Frequency of Searches

Searches should be conducted every two weeks for two years, but may have to be adjusted according to carcass removal rates (more frequent under higher rates), target species, terrain, and other site-specific conditions.

Searcher efficiency Trials

These are to be conducted seasonally during operations monitoring. Test each searcher by planting carcasses of species likely to occur in the project area within the search plots and monitor searcher detection rates. Geo-reference the planted carcasses by global positioning system (GPS) and mark them in a fashion undetectable to the searcher. Test new searchers when they are added to the search team.

Carcass Removal Trials

These are to be conducted seasonally during operations monitoring. Place carcasses in known locations in the search plots and monitor to determine removal rate. Check planted carcasses at least every day for a minimum of the first three days and thereafter at intervals determined by results from pilot scavenger trials. Where possible use fresh carcasses of different sized birds and bats likely to occur in the project.

Bird and Bat Metrics

Record bird and bat fatalities per MW of installed capacity per year and fatalities per rotor-swept square meter per year. Analyse data according to different bird groups, e.g. raptors or passerines.

Bird Use Counts

Category 2 and 3 projects should conduct one year of bird use counts during project operation to characterise bird species composition abundance and behaviour. They should be consistent with the pre-permitting studies, but may be tailored to address specific issues.

Bat Acoustic Monitoring

Standard scientific report format in operations monitoring reports should be followed, and should provide enough detail to allow agency and peer-reviews to evaluate the methods used.

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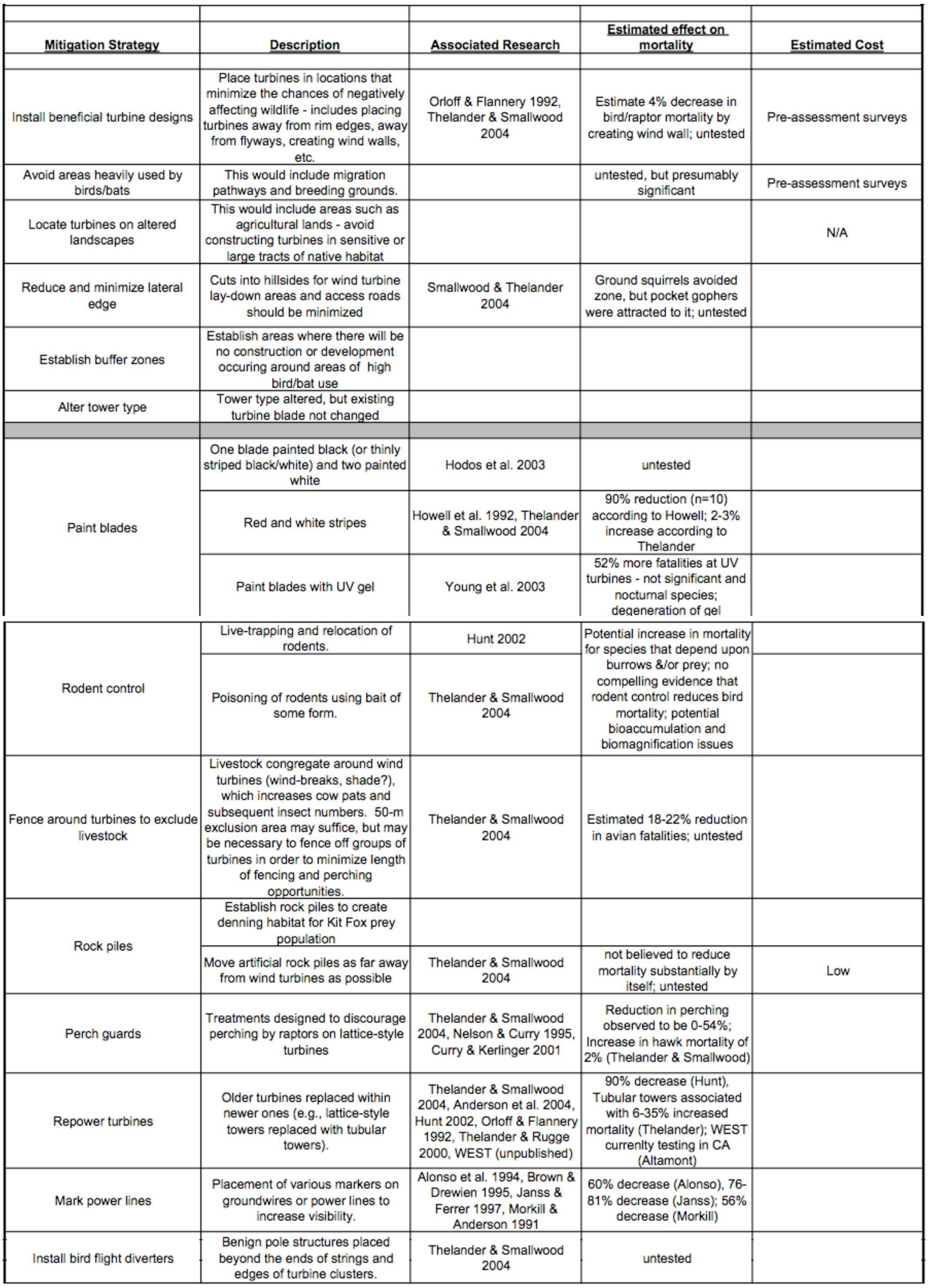
Appendix 1: Mitigation Options

This matrix compares the economic costs of certain mitigation strategies with the estimated effect on mortality of that strategy. The mitigation strategies presented in Column A came from both mitigation research and existing policies and guidelines. Column B briefly describes what the mitigation strategy encompasses. Associated Research is presented in Column C and shows existing or current research that has tested the mitigation strategy; the results of that research (in terms of effectiveness) are presented in Column D. Finally, Column E presents the estimated costs of the mitigation strategy. (Source: NWCC 2007)



Mitigation Strategy	Description	Associated Research	Estimated effect on mortality	Estimated Cost
Install beneficial turbine designs	Place turbines in locations that minimize the chances of negatively affecting wildlife - includes placing turbines away from rim edges, away from flyways, creating wind walls, etc.	Orloff & Flannery 1992, Thelander & Smallwood 2004	Estimate 4% decrease in bird/raptor mortality by creating wind wall; untested	Pre-assessment surveys
Avoid areas heavily used by birds/bats	This would include migration pathways and breeding grounds.		untested, but presumably significant	Pre-assessment surveys
Locate turbines on altered landscapes	This would include areas such as agricultural lands - avoid constructing turbines in sensitive or large tracts of native habitat			N/A
Reduce and minimize lateral edge	Cuts into hillsides for wind turbine lay-down areas and access roads should be minimized	Smallwood & Thelander 2004	Ground squirrels avoided zone, but pocket gophers were attracted to it; untested	
Establish buffer zones	Establish areas where there will be no construction or development occuring around areas of high bird/bat use			
Alter tower type	Tower type altered, but existing turbine blade not changed			
Paint blades	One blade painted black (or thinly striped black/white) and two painted white	Hodos et al. 2003	untested	
	Red and white stripes	Howell et al. 1992, Thelander & Smallwood 2004	90% reduction (n=10) according to Howell; 2-3% increase according to Thelander	
	Paint blades with UV gel	Young et al. 2003	52% more fatalities at UV turbines - not significant and nocturnal species; degeneration of gel	
Rodent control	Live-trapping and relocation of rodents.	Hunt 2002	Potential increase in mortality for species that depend upon burrows &/or prey; no compelling evidence that rodent control reduces bird mortality; potential bioaccumulation and biomagnification issues	
	Poisoning of rodents using bait of some form.	Thelander & Smallwood 2004		
Fence around turbines to exclude livestock	Livestock congregate around wind turbines (wind-breaks, shade?), which increases cow pats and subsequent insect numbers. 50-m exclusion area may suffice, but may be necessary to fence off groups of turbines in order to minimize length of fencing and perching opportunities.	Thelander & Smallwood 2004	Estimated 18-22% reduction in avian fatalities; untested	
Rock piles	Establish rock piles to create denning habitat for Kit Fox prey population			
	Move artificial rock piles as far away from wind turbines as possible	Thelander & Smallwood 2004	not believed to reduce mortality substantially by itself; untested	Low
Perch guards	Treatments designed to discourage perching by raptors on lattice-style turbines	Thelander & Smallwood 2004, Nelson & Curry 1995, Curry & Kerlinger 2001	Reduction in perching observed to be 0-54%; Increase in hawk mortality of 2% (Thelander & Smallwood)	
Repower turbines	Older turbines replaced within newer ones (e.g., lattice-style towers replaced with tubular towers).	Thelander & Smallwood 2004, Anderson et al. 2004, Hunt 2002, Orloff & Flannery 1992, Thelander & Rugge 2000, WEST (unpublished)	90% decrease (Hunt), Tubular towers associated with 6-35% increased mortality (Thelander); WEST currenlty testing in CA (Altamont)	
Mark power lines	Placement of various markers on groundwires or power lines to increase visibility.	Alonso et al. 1994, Brown & Drewien 1995, Janss & Ferrer 1997, Morkill & Anderson 1991	60% decrease (Alonso), 76-81% decrease (Janss); 56% decrease (Morkill)	
Install bird flight diverters	Benign pole structures placed beyond the ends of strings and edges of turbine clusters.	Thelander & Smallwood 2004	untested	

Provide alternative perches	Establishment of alternative perches in order to attract birds away from turbines.	Thelander & Smallwood 2004	untested	
Barricade the rotor plane	Erection of barriers to keep birds from flying into moving blades.	Thelander & Smallwood 2004	untested	believed to be overwhelmingly costly & impractical
Accoustic deterrents	Modifying the acoustic signatures of turbine blades in order to make them more audible to birds/bats.	Dooling 2002, Arnett et al. 2005, Szewczak & Arnett (unpublished)	acoustic signatures for birds untested; sonar "jamming" testing in progress	associated costs for decreasing bat fatalities believed high
Retrofit turbine-tower pads				
Reduce availability of carrion	Remove carcasses to discourage scavengers from approaching turbines		untested	
Minimize number of lit turbines		Johnson et al. 2003, Erickson et al. 2004, Huppop et al. 2006, Arnett et al. 2005	lighting did not appear to affect bats/birds (Johnson, Erickson, Arnett); lights observed to cause disorientation and be attractant - needs to be field tested (Huppop)	save $
Avoid sodium vapor lights		Kerlinger & Kerns 2004	47.8% decrease after lights were turned off	
Synchronize lighting	Lights on turbines should flash at same time.	Larwood 2005	untested (only looked at effects on pilots)	N/A
Relocate selected turbines	Dependent upon species/location. Relocation of turbines that cause disproportionately large numbers of fatalities (i.e. isolated turbines, turbines in canyons).	Hoover 2002, Hoover et al. 2005, Thelander & Smallwood 2004, WEST (unpublished)	2-5% decrease in bird/raptor mortality by removing isolated turbine (Thelander); 100% decrease in GOEA mortality from turbines by removing from canyon (Hoover); WEST currenlty testing in CA (Altamont)	
Coordinate timing of operational turbines				
Remove derelict and non-operating turbines	Evidence suggests raptors are killed disproportionately more often by turbines adjacent to broken ones.	Thelander & Smallwood 2004	5-9% increase in mortality at or next to derelict turbines	
Suspend operation during high risk periods	Dependent upon species/location. Includes combinations of adverse weather, high migration, high/low winds, and topography.	Arnett et al. 2005, Hoover 2002, Hoover et al. 2005, Barrios & Rodriquez 2004, Huppop et al. 2006, Sherwell (unpublished), Villegas-Patraca et al. (unpublished), WEST (unpublished)	Currently being tested by Sherwell in MD, WEST in CA (Altamont), and Villegas-Patraca in Mexico.	
Repower using turbines with high rotor planes	Rotor planes should be no lower than 29m above the ground.	Thelander & Smallwood 2004	untested	
Acquire off-site conservation easements	Improving habitat/wildlife population by purchasing/improving habitat in another location.	USFWS (Ron Reynolds contact) unpublished		
Reestablish nesting/maternity areas	Any bird/bat nesting/maternity areas that are disturbed by the construction/operation of the turbines should be reestablished.			

Appendix 2: Studies in Progress

McNew, L.B., et al. (In progress) *Effects of Wind Power Development on the Demography of the Greater Prairie Chicken.*
This study is examining the impacts of wind development on lek attendance, mating behavior, habitat use, dispersal, and demographic performance of Greater Prairie Chickens. A before-after control-impact, or BACI, design with three replicates of paired study sites will be used to assess potential impacts of wind development on prairie- chicken demography. Focal population studies will occur at the Elk River II site in Butler County, Kansas, in Year 1 and expand to three sites in Years 2-4. Birds will be captured and radio-marked at leks during the 2006-2009 breeding seasons for this study. Treatment and reference sites will be monitored simultaneously during three phases of wind power development: predevelopment, construction, and operation.

Schroeder, M.A., et al. (In progress*) Effects of Wind Power Development on Sage Grouse.*
This study is examining the effect of wind power generation on sagebrush steppe habitat, specifically that of the sage grouse. The hypothesis is that the 'footprint' of wind power generation in the sagebrush steppe is far larger than previously believed because of the spread of noxious weeds and exotic plants, habitat loss and fragmentation, and fatality risk due to predation and collision with turbines, powerlines, fences and vehicles. Additional disturbance and noise caused by wind farms is also of concern in relation to sage grouse populations.

Sherwell, J. (In progress) *Developing a Mitigation Strategy for Bat Impacts from Windpower Development in Maryland.*
This study presents a model that has been established to aid in the development of mitigation strategies for bats at wind farms in Maryland along the Appalachian Mountains. Two mitigation scenarios were investigated: one in which suboptimum tip speed ratios is explored, the other in which rotation rate is managed from a low value up to a threshold value, above which the optimum tip speed ratio is established. Results suggest that low wind speed curtailment can significantly reduce the risk of bat collisions. This study has been conducted, but results have not yet been published and economic consequences have not yet been explored.

Szewczak, J., and E.B. Arnett. (In progress) *Evaluation of Acoustic Deterrents to Reduce Bat Fatality at Wind Facilities.*
This study was based on earlier observations that bats avoided areas featuring high-intensity ultrasounds; it sought to determine whether high-intensity ultrasounds deterred bats from wind turbines. The hypothesis is that, above some threshold, bats will show avoidance because they can't hear anything but the sound emitting from the deterrence device. Only preliminary results from laboratory and field tests are currently available.

Villegas-Patraca, Rafael et al. (In progress) *Impact and Potential Conflicts of Wind Power Generation on Raptor Migration in Tehuantepec Isthmus, Mexico.*

Several companies will be developing the largest wind-farm facilities in Latin-American over the next five years in the Isthmus of Tehuantepec in Oaxaca, Mexico. During three field work seasons, more than four million migratory raptors were found around the potential sites for the wind-farm. The majority of these birds were Turkey Vultures, Swainson Hawks and Broadwing Hawks flying at heights less than 120m. There is a potential high risk that birds will collide with the wind turbines within a range of 72-130m high in operation because this area is one of the most important bird migration routes in the world. This study will monitor the effects of a mitigation strategy to shut down the turbines for 3 weeks during Broad- winged Hawk, Mississippi Kite, and Swainson's Hawk migration on avian mortality and economic performance. This study hasn't begun yet.

Ruiz, J.L. (in progress). *An assessment of the bird mortality of a windfarm located in Zaragoza.*
Study assessing the bird mortality of a windfarm located in Zaragoza, 300 km northwest of Madrid, since it began operating 5 years ago. Every march an annual report is produced that is sent to the environmental administration for control. Winkelman's (1992a) formula is used to calculate the estimated rate of bird deaths using the data from the detection and predation rates. Preliminary results over the years indicate the estimated annual bird deaths per turbine for the farms being 0.6, 0.6 and 0.25 for small, medium and large birds respectively. Trend lines of estimated mortality for size groups are calculated as: Small: $y = -0{,}723x + 12{,}64$ ($R^2 = 0{,}021$); Medium: $y = 0{,}142x + 2{,}676$ ($R^2 = 0{,}012$); Large: $y = 0{,}05x + 4{,}1$ ($R^2 = 0{,}000$).

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