

**Risk Assessment for Birds**  
**Flying Through Wind-Energy Developments**  
**In Southern Oaxaca, Mexico**

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## INTRODUCTION

This is a collision risk assessment for birds flying through wind-energy facilities in southern Oaxaca, Mexico. The risk assessment was to be based on bird count and behavior data already collected for existing wind-energy facilities in the area: the Acciona Eurus project, the EDF La Ventosa/La Mata project, and Central Eoloelectrica Piedra Larga. However, useful data sets were available only for the Acciona Eurus project during the fall and winter seasons. Collision probabilities for bird groups (by type and size) were based on Eurus fall and winter data, and then extrapolated to the other wind-energy facilities.

## METHODS

Adequate data tables were available with the Acciona Eurus reports for fall 2006 and 2007 (Campañas 1 and 6) and winter 2006-2007 (Campaña 2&3). Based on count data for the Chavarillo and Veracruz River of Raptors Hawkwatch sites (<http://hawkcount.org>), seasons were defined as:

Fall:	20 August - 20 November
Winter:	21 November – 19 February
Spring:	20 February – 20 May
Summer:	21 May – 19 August

Bird count data were assigned to groups based on bird type (i.e., raptor, vulture, waterbird, songbird, dove/pigeon, other) and size (small, medium, large). Bird sizes were based on wingspans as described in NGS (1999).

### *Passage Rate*

Passage rates were estimated for each bird group separately for Fall and Winter (the only two seasons with adequate data). For the Fall, two bird studies were conducted, Campaña 1 in 2006, and Campaña 6 in 2007. For the winter, only one study was conducted, Campañas 2 and 3 combined, in 2006 – 2007. Only birds estimated to be within rotor-swept heights were considered for the analysis. That is, non-flying birds and birds flying either above maximum rotor height or below minimum rotor height were considered not at risk of collision. Bird heights were estimated within categories. In Campaña 6, the categories that overlapped rotor-swept heights included B (30 m – 100 m) and C (101 m – 200 m). For this analysis, all birds within category B were assumed to be at risk of collision, while half of birds within category C were assumed to be at risk. We consider this to be a conservative assumption since maximum rotor height at Eurus is 115 m, and it is likely that fewer than half the birds observed in category C were actually flying below 115 m.

Seasonal passage rates were calculated by adjusting the observed counts by sampling effort. For each study (Campaña), sample effort was estimated using the both the proportion of daylight hours in which observations were made and the proportion of days in the season in which the study was conducted (Table 1). For instance, during the winter study (Campañas 2 and 3), we estimated that observations were made 4.5 hours per day for 10 days. Assuming a daylight period of 12 hours and a 91-day season (as defined above), then the proportion of daylight hours was  $4.5/12 = 0.375$  and the corresponding proportion of days was  $10/91 = 0.110$ . Thus, for a particular group/size class, if 100 birds were counted during the study, then the adjusted count, i.e., the estimated seasonal passage rate, was  $(10/0.375)/0.110 = 243$ . For the bird group/size class combinations common to both fall studies at Eurus, the two estimates of seasonal passage rate were averaged to obtain a single estimate for the fall season..

For evaluation of the EDF La Ventosa/La Mata project, we assumed that the passage rates for both Fall and Winter were the same as those estimated for the Eurus study. No adjustment was made for size of the wind project since the area covered by the project was unknown.

### ***Collision Probability***

Collision probability for each bird group/size class was estimated in two stages. In the first stage, Tucker's (1996) model was used to calculate the collision probability for a bird flying through a rotor. The overall collision probability for the wind project was estimated in the second stage, and for Acciona Eurus assumes the bird passes through three turbine strings or rows, while only one turbine string is assumed for the EDF project.

### **Tucker Model for Individual Rotors**

Tucker's (1996) basic model treats rotor blades of wind turbines as 1-dimensional, having length only. This obvious simplification is considered justifiable because in most cases, the highest probabilities of collision occur on the leading edges of the blades rather than on the trailing surfaces. Tucker also described a 3-dimensional model that accounts for the trailing surfaces of blades, though this model requires more detailed information than is typically available from turbine manufacturers. For the 1-dimensional model, inputs include number of blades, angular velocity, wind velocity, rotor radius, axial induction factor, bird wingspan, bird aspect ratio (wingspan/body length), and bird flight velocity. Nearly all modern, horizontal axis turbines have 3 blades, and that is the case for the Eurus and EDF projects. For this analysis, wind velocity was assumed to be a constant 8 m/s, a reasonable value based on published data (Elliot et al. 2003).

Collision probabilities for the 1-dimensional model were calculated assuming downwind flight and bird air speeds of 5 m/s. Small and/or actively flying birds would likely have greater air speeds, while large and/or passively gliding birds would have lower air speeds. In general, 5 m/s is probably a conservative value, slower than most birds, and therefore likely to over-estimate

collision probability. In general, slower air speed leads to higher collision probability because the bird's residence time within the plane of the rotor is greater.

Pure, downwind flight is certainly an over-simplification because migrating birds may well fly at oblique angles to the wind, and – if the wind speed is not too great – they may fly upwind. All else being equal, downwind flight in the Tucker model yields lower collision probabilities than all other flight angles relative to wind direction. On the other hand, in downwind (and upwind) flight, the relative area presented by the rotor is maximal, such that a bird is more likely to encounter the rotor. Depending on turbine configuration within a wind park, birds flying at oblique angles to the wind may be less likely to encounter a rotor. Therefore, considering the joint probability of encountering a rotor *and* colliding with that rotor, the assumption of only downwind flight likely does not result in substantial under-estimation of overall collision probability.

The Tucker model was used to calculate average collision probability across the entire rotor and it was then assumed that all birds were exposed to this average probability. This simplified approach could either under-estimate or over-estimate overall risk of collision if the distribution of flight heights were non-uniform within rotor-swept heights. It seems likely that most birds do not have a uniform flight height distribution. However, the available data placed heights in broad categories (e.g., below, within, and above rotor heights), so it was not possible to estimate height distributions.

Collision probability for Tucker's 3-dimensional model is more realistic than the 1-dimensional representation of blades. In general, accounting for the 3-dimensional shapes of blades produces higher collision probabilities, though the differences depend on many factors such as flight speed and angle of approach. For this analysis, detailed blade specifications were not available so it was assumed that collision probability under the 3-dimensional model would be 20% higher than under the 1-dimensional model. That is average collision probability for each bird group was estimated using the 1-dimensional model and then simply multiplied by 1.2 to account for 3-dimensional blade structure. This adjustment was considered somewhat conservative, likely to over-estimate collision probability, because our prior experience with the Tucker model indicates that the average difference is nearly always less than 20% (typically, in the range 10% - 20%).

### **Turbine Strings and Overall Collision Probability**

The Tucker model yields collision probability for a bird passing through an individual rotor. To calculate overall collision probability for a wind park, it is necessary to account for turbine layout and the probability that a flight through the wind park will encounter a rotor. Wind parks were represented as a set of one or more parallel strings or rows of turbines. A bird approaching a wind park downwind would cross a turbine string. The bird might pass through the string successfully, either because it did not encounter any turbines, or because it flew through a rotor but was not struck. If no collision occurred, then the bird might cross another turbine string, and

so on. For each string, it was assumed that the rotor-swept area occupied 30% of the total frontal area of the string (a reasonable value based on typical turbine spacing within strings). Thus, a bird crossing the string would have a 30% chance of encountering a rotor. Furthermore, it was assumed that a bird encountering a rotor would avoid it with probability 0.95. This avoidance value is used by the Scottish Natural Heritage (<http://www.snh.org.uk/strategy/renewable/sr-we00a2.asp>) in their models of bird/turbine collisions when there is no other information available for bird avoidance behaviors. Thus, as implemented in our model, a bird crossing a turbine string would collide with probability  $p_S = 0.3 \times (1 - 0.95) \times p_T$ , where  $p_T$  is the probability calculated from the Tucker model, as described above.

For multiple turbine strings, each crossing was assumed to be independent, i.e., not affected by having successfully crossed any previous turbine strings. Thus, for  $n$  turbine strings, the overall probability of collision was calculated as  $(1 - p_S)^{n-1} \times p_S$ . For Eurus, it was assumed that on average birds would cross 3 turbine strings. Of course, some birds flying through Eurus would cross more than 3 strings, but other possible flight paths would cross only 1 or 2 strings. EDF was represented by a single turbine string.

### **Population Impacts**

To evaluate population-level impacts, predicted fatalities for bird groups were compared to population estimates as available from Birdlife International (<http://www.birdlife.org/datazone/index.html>).

## **RESULTS and DISCUSSION**

### ***Collision Probabilities and Predicted Fatality Rates***

Collision probabilities based on Tucker's (1996) model and accounting for turbine configuration, wind velocity, bird wingspan and aspect ratio, and bird flight velocity were highest for large raptors, large vultures, and large waterbirds (0.12, 0.11, and 0.12, respectively; Table 2). Large bird categories had wingspans over 150 cm. Large raptors consisted of golden eagle (*Aquila chrysaetos*) and osprey (*Pandion haliaetus*). Large vultures were represented by turkey vulture (*Cathartes aura*), and large waterbirds consisted of great blue heron (*Ardea herodias*), magnificent frigatebird (*Fregata magnificens*), wood stork (*Mycteria americana*), and American white pelican (*Pelecanus erythrorhynchos*). Small songbirds (0.01), small doves/pigeons (0.02), and small other birds (0.02) with wingspans less than 100 cm had the lowest collision probabilities (Table 2).

Fatalities were predicted for Fall and Winter separately due to variation in bird passage rates during the migration and non-migration seasons. For the Fall season at the Eurus project, fatalities are predicted to be highest for small songbirds (37 fatalities) and large vultures (32

fatalities; Table 3). Small doves/pigeons had eight predicted fatalities, large waterbirds had three predicted fatalities, and all other groups had one fatality each for the Fall season (Table 3).

During the Winter season at the Eurus project, large vultures had the most fatalities (five), small waterbirds had three, medium vultures had two, and all other groups had one fatality each during winter (Table 4).

Fatalities were predicted for the EDF La Ventosa-La Mata project using passage rates and collision probabilities calculated from the Eurus data, and adjusted based on EDF turbine numbers and dimensions (Tables 5, 6). For the Fall season at the EDF project, small songbirds had the highest predicted fatalities (13), followed by large vultures (11), small doves/pigeons and large waterbirds (three each), and all other groups had one fatality each during the Fall season (Table 5).

During the Winter season at the EDF project, large vultures were predicted to have two fatalities and all other groups were predicted to have one fatality each (Table 6).

### ***Population-Level Impacts***

Population-level impacts were based on global population estimates available from Birdlife International (<http://www.birdlife.org/datazone/index.html>). Some population estimates for relatively well-studied species are fairly precise, and may be assumed to be accurate. Other species are not well-studied and population estimates are available only as a wide range. Since collision probabilities and predicted fatality rates were calculated only to the level of large groups based on taxonomy and wingspan, population impact estimates can be applied only to these groups. Population impact estimates were further separated by season and project due to the different collision rates.

The highest population impact was to large vultures (turkey vulture) in the fall at the Acciona Eurus project where 0.0006% of the vulture population was predicted to collide with turbines (Table 7). Large vultures had the highest estimated population impacts the Eurus project in winter (0.0001%; Table 8), and at the EDF project in winter (0.00004%; Table 10). Waterbirds had the highest estimated population impacts at the EDF project in fall (0.0005%; Table 9). Songbirds had the lowest predicted population impacts at the Eurus project in winter and the EDF project in both seasons; small other birds had the lowest impact estimate at Eurus in fall (Tables 7-10).

### ***Population Implications***

Overall mortality rates for birds are not always well known. For raptors, adult mortality appears to vary widely and fall between 9-90%, based on published reports for *Buteo buteo* (Kenward et al. 2000), accipiters (Kirschbaum 2004), *Falco cherrug* (Wink et al. 1999), *Coragyps atratus* (Blackwell et al. 2007), *Cathartes aura* (Campbell et al. 2005), *Pandion haliaetus* (Henny and

Wight 1969), and *Aquila chrysaetos* (Kochert et al. 2002). For *Pelecanus erythrorhynchus*, adult mortality rates are about 79% (Knopf and Evans 2004).

The Scottish National Heritage standard describes unacceptable levels of mortality as more than 1% of background mortality. To conservatively evaluate potential mortality at the project in Oaxaca, we can use the lower range of the population estimate with the lower range of mortality. For large vultures (*Cathartes aura*), the population estimate is 5 million birds, according to Birdlife International. If minimum annual population mortality is 9%, then approximately 450,000 vultures die per year; 1% of that is 4,500 birds, and predicted fatalities at the Acciona Eurus project and EDF project fall well below 4,500 large vultures. Application of this standard to the other bird types, based on estimated population sizes and predicted fatality number, indicates that no other bird type is at risk of having more than 1% of general mortality occur at the Eurus or EDF projects.

### ***Limitations***

As noted above, there was very limited bird data available for the EDF wind project. Therefore, we assumed that the same bird groups observed at Eurus would pass through EDF, and furthermore, that the passage rates would be the same through both wind parks. If different birds occur at EDF and/or passage rates are different, then the results reported in Tables 5, 6, 9, and 10 will be inaccurate. However, it is not possible for us to specify the degree of accuracy in either our assumptions or in the results.

To re-iterate, the validity of extrapolation to other conditions (whether other seasons or other wind projects) depends on the similarities in bird groups and their passage rates. Uncertainty in the results necessarily increases with such extrapolation. Aside from EDF, we have not extrapolated conditions at Eurus to other wind projects in the region because of the greater uncertainty and because there was insufficient time for processing the additional information from these projects.

In all assessments of risk, it would be helpful to include estimates of uncertainty, such as confidence intervals, along with point estimates of collision probability and predicted fatalities. However, for this analysis, the data are very sparse. Obtaining point estimates has required many assumptions, and for each of these assumptions it is difficult if not impossible to quantify the associated uncertainty. Therefore, propagating the uncertainties through the entire chain of reasoning to the final estimates of fatalities is not possible, in any *quantifiable* sense.

Nonetheless, a *qualitative* assessment of uncertainty is possible. It is our opinion that the margin of error associated with each point estimate in Tables 3 – 10 is substantial. Again, the large uncertainty is a consequence of imperfect data and a greatly simplified collision model based on many assumptions. However, this situation can be improved in the future by additional data obtained using rigorous, well-documented sampling methods. With better information on bird

use within the region, as well as better information on turbine design and wind park layout, it will be possible to conduct a more quantitative assessment of risk and the associated uncertainty.

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**Table 1. Survey effort during Campanas 1, 2&3, and 6.**

	<b>Camp. 1 (Fall 2006)</b>	<b>Camp 2&amp;3 (Winter 06-07)</b>	<b>Camp 6 (Fall 2007)</b>
Days Surveyed	12-14, Oct; 16-23 Oct 2006	Dec 9-13, 2006; Feb 1-5, 2007	28 Aug - 22 Nov 07
Sampling Effort	2 points; time of day surveys conducted is unclear ("morning", "afternoon"); assuming 900hrs-19:00hrs based on times of obs = 83% of daylight hours	9 points; 30 min each; (37.5% daylight hours)	2 points; Point 1 28 Aug-29 Oct; Point 2 30 Oct-22 Nov; obs all day (7:00-19:00 hours) (100% hours)

**Table 2. Bird groups and rotor collision probability estimated from Tucker (1996) model.**

<b>Bird Group</b>	<b>Size Class</b>	<b>Wingspan (m)</b>	<b>Collision Probability</b>
Dove/Pigeon	Small	0.3	0.0175
Other	Small	0.3	0.0175
Raptor	Small	0.5	0.0292
Raptor	Medium	1.25	0.0731
Raptor	Large	2	0.1169
Songbird	Small	0.25	0.0146
Vulture	Medium	1.4	0.0818
Vulture	Large	1.8	0.1052
Waterbird	Small	0.9	0.0526
Waterbird	Medium	1.15	0.0672
Waterbird	Large	2	0.1169

**Table 3. Overall collision probabilities and predicted fatalities for Fall Season, Acciona Eurus wind project.**

Bird Group	Size Class	2006 (Campaña 1)		2007 (Campaña 6)		Average Passage Rate	Collision Probability	Predicted Fatalities
		Count	Seasonal Passage Rate	Count	Seasonal Passage Rate			
Dove/Pigeon	Small			7647	9771	9771	0.00079	8
Other	Small			404	516	516	0.00079	1
Raptor	Small			131	167	167	0.00131	1
Raptor	Medium	10	101	111	142	121	0.00328	1
Raptor	Large			1	1	1	0.00525	1
Songbird	Small			4269 3	54552	54552	0.00066	37
Vulture	Large	1008	10158	2542	3248	6703	0.00473	32
Waterbird	Small			164	210	210	0.00237	1
Waterbird	Medium			48	61	61	0.00302	1
Waterbird	Large			301	385	385	0.00525	3

**Table 4. Overall collision probabilities and predicted fatalities for Winter Season, Acciona Eurus wind project.**

<b>Bird Group</b>	<b>Size Class</b>	<b>Count</b>	<b>Seasonal Passage Rate</b>	<b>Collision Probability</b>	<b>Predicted Fatalities</b>
Dove/Pigeon	Small	13	315	0.00079	1
Other	Small	14	340	0.00079	1
Raptor	Small	1	24	0.00131	1
Raptor	Medium	10	243	0.00328	1
Songbird	Small	9	218	0.00066	1
Vulture	Medium	18	437	0.00368	2
Vulture	Large	40	971	0.00473	5
Waterbird	Small	38	922	0.00237	3

**Table 5. Overall collision probabilities and predicted fatalities for Fall Season, EDF wind project.**

<b>Bird Group</b>	<b>Size Class</b>	<b>Seasonal Passage Rate</b>	<b>Collision Probability</b>	<b>Predicted Fatalities</b>
Dove/Pigeon	Small	9771	0.00026	3
Other	Small	516	0.00026	1
Raptor	Small	167	0.00044	1
Raptor	Medium	121	0.00110	1
Raptor	Large	1	0.00525	1
Songbird	Small	54552	0.00022	13
Vulture	Large	6703	0.00158	11
Waterbird	Small	210	0.00079	1
Waterbird	Medium	61	0.00101	1
Waterbird	Large	385	0.00525	3

**Table 6. Overall collision probabilities and predicted fatalities for Winter Season, EDF wind project.**

<b>Bird Group</b>	<b>Size Class</b>	<b>Seasonal Passage Rate</b>	<b>Collision Probability</b>	<b>Predicted Fatalities</b>
Dove/Pigeon	Small	315	0.00026	1
Other	Small	340	0.00026	1
Raptor	Small	24	0.00044	1
Raptor	Medium	243	0.00110	1
Songbird	Small	218	0.00022	1
Vulture	Medium	437	0.00123	1
Vulture	Large	971	0.00158	2
Waterbird	Small	922	0.00079	1

**Table 7. Population estimates and predicted population impacts for Fall Season, Acciona Eurus wind project.**

<b>Bird Group</b>	<b>Size Class</b>	<b>Total Popn. Estimate</b>	<b>Collision Probability</b>	<b>Predicted Fatalities</b>	<b>% of Popn. Impacted</b>
Dove/Pigeon	Small	171,000,000 – 201,000,000	0.00079	8	0.0000040 – 0.0000047
Other	Small	82,050,000 – 95,549,997	0.00079	1	0.0000010 – 0.0000012
Raptor	Small	17,690,000 – 22,189,999	0.00131	1	0.0000045 – 0.0000083
Raptor	Medium	12,040,000 – 12,489,999	0.00328	1	0.0000080 – 0.0000083
Raptor	Large	670,000	0.00525	1	0.0001493
Songbird	Small	1,950,720,000 – 2,014,649,993	0.00066	37	0.0000018 – 0.0000019
Vulture	Large	5,000,000	0.00473	32	0.0006400
Waterbird	Small	20,040,000 – 33,089,999	0.00237	1	0.0000030 – 0.0000050
Waterbird	Medium	2,335,000 – 2,515,000	0.00302	1	0.0000398 – 0.0000428
Waterbird	Large	542,500 – 634,500	0.00525	3	0.0004728 – 0.0005530

**Table 8. Population estimates and predicted population impacts for Winter Season, Acciona Eurus wind project.**

<b>Bird Group</b>	<b>Size Class</b>	<b>Total Popn. Estimate</b>	<b>Collision Probability</b>	<b>Predicted Fatalities</b>	<b>% of Popn. Impacted</b>
Dove/Pigeon	Small	171,000,000 – 201,000,000	0.00079	1	0.0000005 – 0.0000006
Other	Small	82,050,000 – 95,549,997	0.00079	1	0.0000010 – 0.0000012
Raptor	Small	17,690,000 – 22,189,999	0.00131	1	0.0000045 – 0.0000057
Raptor	Medium	12,040,000 – 12,489,999	0.00328	1	0.0000080 – 0.0000083
Songbird	Small	1,950,720,000 – 2,014,649,993	0.00066	1	0.0000001 or less
Vulture	Medium	20,000,000	0.00368	2	0.0000100
Vulture	Large	5,000,000	0.00473	5	0.0001000
Waterbird	Small	20,040,000 – 33,089,999	0.00237	3	0.0000090 – 0.0000150

**Table 9. Population estimates and predicted population impacts for Fall Season, EDF wind project.**

<b>Bird Group</b>	<b>Size Class</b>	<b>Total Popn. Estimate</b>	<b>Collision Probability</b>	<b>Predicted Fatalities</b>	<b>% of Popn. Impacted</b>
Dove/Pigeon	Small	171,000,000 – 201,000,000	0.00026	3	0.0000015 – 0.0000018
Other	Small	82,050,000 – 95,549,997	0.00026	1	0.0000010 – 0.0000012
Raptor	Small	17,690,000 – 22,189,999	0.00044	1	0.0000045 – 0.0000057
Raptor	Medium	12,040,000 – 12,489,999	0.00110	1	0.0000080 – 0.0000083
Raptor	Large	670,000	0.00525	1	0.0001493
Songbird	Small	1,950,720,000 – 2,014,649,993	0.00022	13	0.0000006 – 0.0000007
Vulture	Large	5,000,000	0.00158	11	0.0002200
Waterbird	Small	20,040,000 – 33,089,999	0.00079	1	0.0000030 – 0.0000050
Waterbird	Medium	2,335,000 – 2,515,000	0.00101	1	0.0000398 – 0.0000428
Waterbird	Large	542,500 – 634,500	0.00525	3	0.0004728 – 0.0005530

**Table 10. Population estimates and predicted population impacts for Winter Season, EDF wind project.**

<b>Bird Group</b>	<b>Size Class</b>	<b>Total Popn. Estimate</b>	<b>Collision Probability</b>	<b>Predicted Fatalities</b>	<b>% of Popn. Impacted</b>
Dove/Pigeon	Small	171,000,000 – 201,000,000	0.00026	1	0.0000005 – 0.0000006
Other	Small	82,050,000 – 95,549,997	0.00026	1	0.0000010 – 0.0000012
Raptor	Small	17,690,000 – 22,189,999	0.00044	1	0.0000045 – 0.0000057
Raptor	Medium	12,040,000 – 12,489,999	0.00110	1	0.0000080 – 0.0000083
Songbird	Small	1,950,720,000 – 2,014,649,993	0.00022	1	0.0000001 or less
Vulture	Medium	20,000,000	0.00123	1	0.0000050
Vulture	Large	5,000,000	0.00158	2	0.0000400
Waterbird	Small	20,040,000 – 33,089,999	0.00079	1	0.0000030 – 0.0000050