A REVIEW of GOOSE COLLISIONS at OPERATING WIND FARMS and ESTIMATION of the GOOSE AVOIDANCE RATE

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SUMMARY

Bird survey data from six operating wind farms, of varying size and with varying levels of goose usage, are reviewed. All six wind farms show very low numbers of collisions between geese and the turbines, typically one goose collision per year per wind farm. This level of collisions is not significant in goose population terms.

The data are used in conjunction with a Collision Model to calculate a Goose Avoidance Rate of 99.93%.

Finally it is noted that the survey data for geese, taken in conjunction with similar data for Hen Harriers, raise questions about the validity of collision modelling.

1. INTRODUCTION

Scottish Natural Heritage (SNH) have developed, and refined, a model for predicting the risk to flying birds of collision with operating wind turbines[1]. The authors of the model acknowledge that the collision risk estimate it generates does not account for the likelihood that most birds will take action to avoid a collision, and that only a fraction of those that are in theory at risk, will actually collide.

The model may under certain circumstances be a useful tool in assessing the likely ornithological impacts of proposed wind farm developments, insofar as it provides in theory a quantitative basis for predicting likely effects on populations. However, such usefulness is only realised when the theoretical, no-avoidance, collision risk is corrected by an appropriate avoidance factor[2,3].

SNH have adopted a precautionary approach to avoidance factors, and advise that, although it is unreasonable to assume that collisions will be avoided on fewer than 95% of occasions, collision rates calculated on the basis of an avoidance factor that is higher than 95% should only be used where there is sufficient evidence to support such a factor.

To date only a small number of studies have estimated avoidance factors[4,5]. These studies have shown, with some unusual exceptions, that avoidance factors tend to be higher than 95%. To date, however, they have mainly focussed on raptor species.

In this study we estimate the Avoidance Rate for medium-large geese using published bird survey data from five operating wind farms in the USA (Stateline, Buffalo Ridge, Nine Canyons, Klondike and Top of Iowa) and one in Europe (Kreekrak). As far as we are aware these are the only wind farms that have both (a) significant levels of goose usage and (b) adequate survey data.

We begin in Section 2 by reviewing the survey data and in section 3 the Avoidance Rates are derived. Also in section 3 there is a brief comment on collision modelling.

(1) Band W., Madders M. & Whitfield P., In Press, *Developing Field and Analytical Methods to Assess Avian Collision Risk at Windfarms,* In de Lucas M., Janss G. & Ferrer M., (eds), *Birds and Wind Power,* Lynx Ediciones, Barcelona
(2) Chamberlain D., Freeman S., Rehfisch M.,Fox T. & Desholm M., 2005, *Appraisal of Scottish Natural Heritage's Wind Farm Collision Risk Mode,* BTO Research Report 401
(3) Madders M. & Whitfield D.P., 2006, *Upland Raptors and the Assessment of Wind Farm Impacts,* Ibis 148 p43-56
(4) Whitfield D.P. & Band W., In Preparation, *Estimates of Collision Avoidance Rates at Operational Wind Farms in the USA*
(5) Whitfield D. & Madders M., 2005, *A Review of the Impacts of Wind Farms on Hen Harriers,* Information Note 1, Natural Research Ltd.

2. SURVEY DATA

The survey data are summarised in Table 1. Before commenting on the survey data for individual wind farms we make two general comments, firstly regarding bird use and secondly regarding bird mortality.

Regarding bird use, the survey method employed for the American wind farms was to use topographical features to define a radius of approximately 800m around each vantage point. Within this 800m radius the number of birds seen was recorded for each species during a time interval that varied from 10 minutes to 1 hour. For ease of comparison, in Table 1 we have standardised the different surveys to a unit time of 1 hour. In general the surveys note the flight heights of the birds seen, hence they give the fraction of birds flying at rotor height, and this is also listed in Table 1.

Regarding mortality, mortality surveys do not in general discover all the bird corpses since (a) not all turbines (or more accurately the area under the turbines) are searched, particularly if it is a large wind farm and (b) scavengers may remove some corpses before they can be found, particularly if the interval between searches is long and (c) the searchers may miss some corpses, particularly if the search area includes water or dense vegetation. We refer to the combined effect of all these shortfalls as the Corpse Search Completeness, so for example a Corpse Search Completeness of 33% implies only 1 corpse would be expected to be found for every 3 collisions that occurred. For all the wind farms discussed in this study the Corpse Search Completeness was thoroughly investigated during the surveys and it is shown in Table 1, as is the number of corpses actually found at each wind farm.

2.1 Stateline Wind Farm

This is a very large wind farm situated on the Oregon-Washington border in the USA. It began operating in 2001 and consists of 454 Vestas V47 turbines, which have a hub height of 48.5m and rotor radius of 23.5m. In 2002 & 2003 a detailed survey[6] of bird use and bird mortality was carried out.

Regarding bird use, Table 11 of the Report shows there were an average of 0.141 Canada Geese per 10 mins per circle of radius 800m. No information is given in the Report about the flight heights of the birds.

Regarding mortality, 1 Canada Goose corpse was found during the 2 year survey. The Corpse Search Completeness for Stateline was investigated thoroughly by the surveyors and is described in detail in the Report. They concluded that for large birds it was 24%[7] implying that an estimated 4 goose collisions actually occurred during the 2 year survey.

(6) Erickson W., Jeffrey J., Kronner K. and Bay K., 2004, *Stateline Wind Project Wildlife Monitoring,* Report available from www.west-inc.com.
(7) The Corpse Search Completeness may be obtained by comparing the actual number of corpses found during the survey with the surveyors final estimate of mortality due to the wind farm. From section 4.6.2 on p16 of the Report, 50 large bird corpses were found during the 2 year survey. Also from this section, the surveyors estimate that the number of large bird fatalities will be 0.23 birds per turbine per year. For 454 turbines for 2 years this gives a total number of fatalities of 209, hence the Corpse Search Completeness is 50 / 209 = 0.24.

2.2 Buffalo Ridge Wind Farm

This is a very large wind farm in Minnesota, USA. In total it consists of 354 turbines. Phase 1, which began operating in 1994, consists of 73 Kenetech 33 Turbines, which have a hub height of 36m and a rotor radius of 16.5m. Phase 2, which began operating in 1998, consists of 143 Zond 750 Turbines and Phase 3, which began operating in 1999, consists of 138 Zond 750 Turbines. The Zond turbines have a hub height of 50m and a rotor radius of 24m.

Between 1996 and 1999 a detailed survey[8] of bird use and bird mortality was carried out. Each year the survey covered 8 months, beginning on March 16 and ending on November 15.

Regarding bird use, the survey found that 2 species of geese used the wind farm area in large numbers, Canada Geese and Snow Geese. Appendix E of the Report gives mean numbers per hour per circle of radius 800m for both species and Appendix G of the Report gives information about the flight heights, again for both species.

Regarding mortality, no goose corpses were found during the 4 year survey. As with Stateline the Corpse Search Completeness was investigated thoroughly by the surveyors who concluded that for large birds it was 18%[9].

Finally it is noted that an earlier mortality survey[10] at Buffalo Ridge searched 50 of the 73 Phase I turbines at 7 day intervals between April 1994 and December 1995 and found no goose corpses.

2.3 Top of Iowa Wind Farm

This is a large wind farm in Iowa, USA that began operating in 2001. It consists of 89 NEG Micon 900kW turbines, which have a hub height of 72m and a rotor radius of 26m. A bird survey[11] was carried out at the wind farm from April 15 to December 15 2003 and from March 24 to December 10 2004.

(8) Johnson G., Erickson W., Strickland M., Shepherd M. & Shepherd D., 2000, *Avian Monitoring Studies at the Buffalo Ridge Wind Resource Area: Results of a 4Year Study,* Report available from www.west-inc.com.
(9) The methodology used is the same as for Stateline, hence from Table 22 of the Report, 13 large bird corpses were actually found during the survey (being the waterfowl, waterbirds, upland gamebirds, raptors and shorebirds). From Table 27 of the Report the surveyors final estimate of the number of large bird fatalities during the survey period is 71 (being 14 in Phase 1 and 57 in Phase 2). Hence the Corpse Search Completeness is 13 / 71 = 0.18.
(10) Osborn R.G., Higgins K.F., Usgaard R.E., Dieter C.D. & Neiger R.G., 2000, *Bird Mortality Associated with Wind Turbines at the Buffalo Ridge Wind Resource Area,* Am. Mid. Nat. 143 p41-52.
(11) Jain A., 2005, *Bird and Bat Behaviour at a Northern Iowa Wind Farm,* Masters Thesis, Dept of Ecology & Evolutionary Biology, Iowa State University (this report can be obtained by request to rkoford@iastate.edu

Regarding bird use, no detailed bird use observations were reported. However Chapter 2 of the Report notes that there are 3 Wildfowl Reserves within 1 to 5 kms of the wind farm and these Wildfowl Reserves attract up to 40,000 Canada Geese each year. Furthermore, the primary vegetation type of the wind farm area is corn fields which are attractive feeding for the geese and in Chapter 2 of the Report it is stated that "Canada Geese used the wind farm area in high numbers during the fall". It is also noted in Chapter 4 that goose use of fields with and without turbines did not differ significantly.

Regarding mortality, no goose corpses were found during the 2 year survey. The Corpse Search Completeness was again investigated thoroughly and it was estimated to be 5.6%[12], however this was for all birds and generally it is much higher for large birds, such as geese. In particular we note that:
(i) because the search frequency was every 2 days scavenger removal was relatively low, the authors estimate between 5% and 7%.
(ii) the search efficiency was estimated by the authors to be between 70% and 77% but these trials only involved sparrows and for large birds like geese it will be higher.
(iii) the main reasons the Corpse Search Completeness is so low are because (a) only 26 out of 89 turbines were searched and (b) the search area around each turbine was only 30% of the potential search area, but by the time of the year geese were using the wind farm the crops had been harvested so the actual area visible to the searchers, particularly for a large bird corpse, would have been considerably larger than 30%.

Taking all these matters into account we believe a conservative estimate of the Corpse Search Completeness for geese would be 25%.

2.4 Klondike Wind Farm

This wind farm is in Oregon, USA and consists of 16 Enron 1.5MW turbines, which have a hub height of 65m and a rotor radius of 35m. It began operating in January 2002. Beginning in April 2001 there was a one year bird use survey[13] and from February 2002 there was a 1 year bird mortality survey[14] at the site.

Regarding bird use, there are two problems with the survey data. Firstly figure 1 of the Baseline Ecology Report shows that the survey used seven Vantage Points, two of which were close to the wind farm and the other five were approximately four miles away, at the site of a proposed extension to the wind farm. The Report does not break the survey data down between Vantage Points. Secondly, during the winter of the survey the wind farm was under construction, hence there could have been disturbance at the two Vantage Points close to the wind farm at the time of year which corresponds to the peak presence of geese.

(12) The methodology used is the same as or Stateline, hence from Chapter 2, Section 4.1 of the Report, 7 bird corpses were actually found during the survey. Also from this section the surveyors final estimate of bird fatalities during the survey period is 125 birds, hence a Corpse Search Completeness of 7 / 125 = 5.6%.
(13) Johnson G., Erickson W & Bay K., 2002, *Baseline Ecological Studies for the Klondike Wind Project,* Report available from www.west-inc.com.
(14) Johnson G., Erickson W., White J. and McKinney R., 2003, *Avian and Bat Mortality during the first year of operation at the Klondike Wind Project,* Report available from www.west-inc.com.

On the other hand, p16 of the Report states that "Canada Geese used all portions of the area sampled" which suggests the data from the five Vantage Points at the site of the proposed extension would be reasonably representative of bird use at the wind farm. Also the data from these five Vantage Points would not have been affected by any construction disturbance.

Clearly these bird use data are not ideal and when estimating Avoidance Rates, in the next section, tests will be run to quantify the effect of this uncertainty. Table 5 of the Baseline Ecology Report lists the number of waterfowl (all of which are Canada Geese – p1 of the Report) per 30 mins per circle of 800m radius and Table 7 gives information about flight heights.

Regarding mortality, 2 Canada Geese corpses were found during the 1 year survey. The Corpse Search Completeness was investigated thoroughly and from Table 3 of the Mortality Report it is estimated to be 49% for large birds, so the 2 corpses found imply an estimated 4 goose collisions per year.

2.5 Nine Canyons Wind Farm

This wind farm is in Washington, USA and Phase I consists of 37 Bonus 1.3MW turbines, which have a hub height of 60m and a rotor radius of 31m. It began operating in September 2002. Subsequently, and after the surveys discussed below had been completed, Phase II of the wind farm was completed which added a further 12 turbines.

Immediately following the start of operations at the wind farm there was a 1 year mortality survey[15]. No goose corpses were found. The Corpse Search Completeness was investigated thoroughly and from Table 4 of the Report it was estimated to be 80% for large birds.

Before the start of operations a bird use survey[16] was carried out but we were unable to obtain a copy of this Report. However, a review article[17] lists waterfowl use of the site as 0.42 birds per 20 mins per circle of radius 800m. Nine Canyons is very close to both the Klondike and Stateline wind farms and at both these wind farms waterfowl were exclusively Canada Geese. We assume this is also true for Nine Canyons. No information is given regarding the fraction of goose flights at rotor height.

(15) Erickson W.P., Gritski B. & Kronner K., 2003, *Nine Canyon Wind Project Avian and Bat Monitoring Report.* Report Available from www.west-inc.com
(16) West Inc & Northwest Wildlife Consultancy Inc, 2001, *Wildlife Baseline Study for the Nine Canyon Wind Project,* Technical Report prepared for Energy Northwest.
(17) Erickson W.P., Johnson G., Young D., Strickland D., Good R., Bourassa M., Bay K. & Sernka K., 2002, *Synthesis and Comparison of Baseline Avian and Bat Use, Raptor Nesting and Mortality Information from Proposed and Existing Wind Developments,* Report Available from www.west-inc.com

2.6 Kreekrak Wind Farm

This wind farm is situated in Zeeland in the Netherlands and Phase I consisted of five 250kW turbines with a hub height of 30m and a rotor radius of 12.5m. The wind farm began operating in April 1990 and for the first year of it's operation a bird survey[18] was carried out.

Regarding bird use, no detailed observations were made. However the wind farm is situated at the mouth of an estuary and on p11 of the Report it is stated that "the Kreekrak area is frequently visited by ducks, geese, cormorants……". It is also noted in the Report that regular diurnal movements across the wind farm site, between roosting and feeding sites, occurred in many of the species recorded in the Report.

Regarding mortality, one Brent Goose corpse was found during the year long survey. Because the wind farm is on a dyke some bird corpses fell on land, and had a very high probability of being found, and some fell in the water, and had a consequently much smaller probability of being found. The Corpse Search Completeness was investigated very thoroughly, considering both the corpses that fell on land and in the water, and was estimated at 65% for large birds (p18 of the Report) so the single corpse found implies approximately 2 collisions per year.

2.7 Summary

The survey data are summarised in Table 1 and it can be seen that only 4 goose collisions have been recorded in over 9 years of surveys at 6 different wind farms where there were many thousands of goose flights. Taking into account the Corpse Search Completeness it is estimated that 10 collisions actually occurred (4 at Stateline, 4 at Klondike and 2 at Kreekrak) or equivalently an average of just over 1 goose collision per year per wind farm. These results suggest that geese are not prone to collision with turbines and any mortality so caused is most unlikely to be influential at the population level.

An alternative way of looking at this is to consider the contrary proposition, i.e. that wind farms do cause significant goose mortality. If there was only one survey showing negligible mortality then this could be dismissed as a freak result. However there are six surveys all showing negligible mortality and it is not credible to claim six out of six freak results.

It may be argued that because the Corpse Search Completeness is relatively low at the larger wind farms, for example 18% at Buffalo Ridge, some collisions may have occurred but no corpse found. This is a valid point since a Corpse Search Completeness of 18% implies that on average only 1 corpse would be found for every 5 or 6 collisions, so it is possible that some collisions will have gone unrecorded. However there are two points to consider, firstly even if the number of collisions at Buffalo Ridge is not zero it is likely to be small. Secondly, with this kind of probabilistic argument it must also be borne in mind that there are six wind farms in the present study. The number of corpses may be under-recorded, relative to the corpse search completeness, at one wind farm but over-recorded, relative to the corpse search completeness, at another wind farm. Averaged over the six wind farms the effects will tend to cancel out.

(18) Musters C., Noordervliet M. and Ter Keurs W., 1995, *Bird Casualties and Wind Turbines near the Kreekrak Sluices of Zeeland,* (this report can be obtained by request to musters@cml.leidenuniv.nl

3 AVOIDANCE RATES

The approach we adopt to estimating Avoidance Rates is to use the survey data on bird use plus a collision model to estimate the predicted number of collisions at each wind farm. This can then be compared with the actual number of collisions found at that wind farm to derive an Avoidance Rate.

The collision model we use is a formulation of the Band Model[19] specifically to fit with the survey methodology used at the American wind farms. The surveys give information about the number of birds seen within an 800m radius circle but not their flight times or flight distances. For a bird seen flying within the 800m radius circle the total distance that bird may fly will be between 0m and 1600m, assuming it flies in a straight line across the circle. Simple trigonometry shows that the average distance is not 800m, as may at first be thought, but 1600 x π/4 = 1257m. It can be argued that if the bird lands part way across the circle, for example to feed, then this decreases the distance flown. But geese typically will circle a site before landing and this increases the distance flown. The effect of varying this average distance of 1257m will be discussed in section 3.6.

The probability that a bird flight through the survey plot will encounter a turbine, P_{TURB}, can be expressed as

$$P_{TURB} = \frac{\text{Collision Volume}}{\text{Survey Plot Volume}}$$

$$= \frac{1257 \times \pi R^2}{\pi 800^2 \times 2R}$$

$$= 0.000982 \times R$$

where R is the rotor radius. The total number of encounters per year, $N_{ENCOUNTERS}$, will depend on both the number of turbines, N_{TURBS}, and the number of bird flights per year across the survey plot at rotor swept height, $N_{FLIGHTS}$. This is given by

$$N_{FLIGHTS} = N_{BIRD\text{-}USE} \times f_{RH} \times (12 \times 365)$$

$$= 4380 \times N_{BIRD\text{-}USE} \times f_{RH}$$

where $N_{BIRD\text{-}USE}$ = the bird use per hour per circle of 800m radius and f_{RH} = the fraction of birds flying at rotor height. Both of these quantities come from the survey data and are listed in Table 1. It is also assumed that, averaged over the year[20], there are 12 goose flying hours per day. Since geese fly at night this underestimates the number of flying hours, however, this is likely to be largely offset by the fact that turbines are idle for typically10% ~15% of the year due to either very low or very high wind and maintenance activity.

(19) Band W., 2000, *Windfarms and Birds: Calculating a Theoretical Collision Risk assuming No Avoidance*, SNH Guidance

(20) Although geese were not present year round at any of the wind farms studied, estimates of bird use have been calculated on an annual basis for all the wind farms since some studies presented the data only on an annual basis.

Hence,

$$N_{ENCOUNTERS} = N_{FLIGHTS} \times N_{TURBS} \times P_{TURB}$$

$$= 4.30 \times N_{BIRD\text{-}USE} \times f_{RH} \times N_{TURBS} \times R$$

Writing N_{COLL} as the predicted number of collisions per year assuming no avoidance, then

$$N_{COLL} = N_{ENCOUNTERS} \times P_{COLL}$$

$$= 4.30 \times N_{BIRD\text{-}USE} \times f_{RH} \times N_{TURBS} \times R \times P_{COLL} \qquad (1)$$

where P_{COLL} = the probability that a bird flight that encounters a turbine will collide with a rotor blade. This collision probability is calculated in the Appendix for the different turbines found at the wind farms.

Finally, the Avoidance Rate, A, is given by

$$A = 1.0 - N_{CORPSE} / N_{COLL} \qquad (2)$$

Where N_{CORPSE} is the "gross" number of corpses found during the mortality survey, that is the number of corpses actually found corrected for the Corpse Search Completeness. Both the number of corpses actually found and the Corpse Search Completeness are shown in Table 1.

3.1 Buffalo Ridge Wind Farm

Since the surveys found no goose corpses then the Avoidance Rate is by definition 100%. As noted earlier, it may be argued that because the corpse search completeness is relatively low, 18%, a small number of collisions may have occurred even though no corpses were found, and therefore the true Avoidance Rate is less than 100%.

To investigate this effect we have used eqn (1) to calculate the number of collisions assuming no avoidance at Buffalo Ridge. We obtain a total of 4420 goose collisions during the 4 year survey, being 2040 for Phase I, 2053 for Phase II and 327 for Phase III. Of the 4420 collisions 3685 are Canada Geese and 735 are Snow Geese. Assuming a small number of collisions actually occurred but no corpses were found we obtain the following Avoidance Rates from eqn (2): for 1 collision A = 99.98%, for 2 collisions A = 99.95%, etc. In other words the effect is, as expected, very small and the Avoidance Rate is a robust quantity.

3.2 Stateline Wind Farm

The bird use survey at Stateline did not note the flight heights of the birds. If the geese seen during the survey were migratory and seen when passing over the wind farm then they may all have been at flight heights above the rotors. However, on the basis of the similarity of the vegetation at Stateline to that of Klondike (principally agricultural land) and the geographical proximity of Klondike, we have assumed that use is similar and the birds seen were not always flying over the wind farm[13,14].

At Klondike the fraction of Canada Geese flying at rotor height was 0.60 but the rotors at Klondike have a larger radius of 35m, compared to the 23.5m at Stateline. At Buffalo Ridge, also with predominantly agricultural land, where the rotors have a similar radius of 24m, the fraction of Canada Geese flying at rotor height was 0.38. We adopt a value of 0.38 but we will consider the effect of changes in this parameter.

From eqn (1) we obtain N_{COLL} = 4317 during the 2 year survey. Since N_{CORPSE} = 4 then eqn (2) gives A = 99.91%. If we reduce the fraction of birds flying at rotor height by one third then A becomes 99.86% which shows that, like Buffalo Ridge, the Stateline Avoidance Rate is a robust quantity.

3.3 Klondike Wind Farm

Eqn (1) gives N_{COLL} = 2253 and with N_{CORPSE} = 4, after correcting for the Corpse Search Completeness, we obtain A = 99.82% from eqn (2).

As discussed in section 2.4, the main source of uncertainty in this calculation is the number of geese flying within the wind farm. If we reduce the bird use by one third then A becomes 99.73% and therefore, as for Buffalo Ridge and Stateline, the Klondike Avoidance Rate is a robust quantity.

3.4 Nine Canyons Wind Farm

The bird use survey at Nine Canyons did not record flight heights. We note that Nine Canyons is geographically close to both Klondike and Stateline and the vegetation type is similar. The turbines at Nine Canyons have rotors of radius 31m, intermediate between Stateline, 23.5m, and Klondike, 35m. The fraction of birds at rotor height for Stateline was 38% and for Klondike 60% and we adopt 50% for Nine Canyons.

From eqn (1) we then obtain N_{COLL} = 384. Given there were no corpses found A = 100%. The relatively high value of the Corpse Search Completeness, 80%, for this site means we can have a reasonable degree of confidence that no collisions occurred.

3,5 Top of Iowa and Kreekrak Wind Farms

The lack of bird use survey data means that we cannot calculate N_{COLL} and hence formally we cannot estimate the Avoidance Rates for these two wind farms. It may be argued that for Top of Iowa there were no corpses found therefore A = 100%. This reasoning introduces a bias, in the sense that for wind farms without bird use data we can only determine Avoidance Rates when they are 100%.

3.6 Summary

For the four wind farms for which an Avoidance Rate could be determined (Buffalo Ridge, Stateline, Klondike and Nine Canyons) the values are 100%, 99.91%, 99.82% & 100%. The mean of these four values is 99.93%. As discussed at the beginning of section 3, the method we have used assumes that at all four wind farms the average distance flown by the geese seen during the surveys is 1257m. To illustrate the level of uncertainty introduced by this assumption we note that changing this distance by one third changes the mean Avoidance Rate to 99.90% or 99.95%. As with the individual Avoidance Rates, the mean Avoidance Rate is also a robust quantity.

Further support for this relatively high value of Avoidance Rate comes from the low number of collisions found at two other wind farms, Top of Iowa (0 collisions in 2 years of corpse surveys) and Kreekrak (2 collisions in a 1 year corpse survey). It is also worth noting that whilst the main species at the wind farms were Canada Geese, at Buffalo Ridge the 100% avoidance applied to both Canada and Snow Geese and at Kreekrak the low number of collisions were for Brent Geese.

Of the several biases associated with searches for carcasses[21], the studies reviewed in this report accounted for all except for those birds which were fatally injured by a turbine but died outwith the search area. We are not aware of any study which has attempted to examine this factor, and most seem to assume that it will be negligible on the basis of the skew and kurtosis in the distribution of carcasses with distance from turbine. It is possible that this factor is more significant for large birds since death may be less likely to be instantaneous, however, given the low mortality documented close to turbines, it is unlikely that it would markedly affect estimates of avoidance rates. It must also be noted that while deaths away from the search area would decrease estimated avoidance rates, the observation methods employed by the reviewed studies are also likely to have underestimated goose activity[3] thereby increasing estimated avoidance rates.

There is no reason to suppose that the six wind farms we have studied were not representative of the types of conditions which may be found at UK wind farms where geese may be present. The studies involved both birds stopping over on passage and wintering, and situations where birds were moving from roost sites to feeding sites, which typically included the wind farm area. Given goose behaviour generally, birds were also likely to be active at night (even though nocturnal observations of activity were not collected) and in a range of weather conditions (e.g. the casualties at Klondike appeared to occur during a period of fog and rain[14]). The finding that geese appear to be highly adept at avoiding collision is also supported by a recent study at an offshore wind farm[22].

(21) Gauthreaux, S.A., 1995, *Standardised Assessment and Monitoring Protocols,* Proceedings of the National Avian-Wind Power Planning Meeting, Denver, Colorado, 20-21 July 1994, p53-59. report Available from www.nationalwind.org/pubs
(22) Desholm M. & Kahlert J., 2005, *Avian Collisions at an Offshore Wind Farm,* Biology Letters 1, p296-298

As noted in the Introduction of this Report, SNH recommend a ‘precautionary’ Avoidance Rate of 95% should be used where there is insufficient evidence to justify a higher value. In our opinion that evidence now exists for geese, as can be seen below where we compare the predicted number of collisions at various Avoidance Rates with the actual number of collisions for Nine Canyons, Klondike, Stateline and Buffalo Ridge.

	Predicted Collisions at Avoidance Rates of				Actual
	95%	99%	99.5%	99.9%	Collisions
Nine Canyons	19	4	2	0.4	0
Klondike	113	23	11	2.3	4
Stateline	216	43	22	4.3	4
Buffalo Ridge	221	44	22	4.4	0
TOTAL	569	114	57	11.4	8

Two points are apparent, the first and most obvious is that the survey data do not provide support for an Avoidance Rate of 95% (or even 99% or 99.5%).

The second point is more subtle but arguably more fundamental. If we look at the trend of the numbers it can be seen that collision modelling predicts a clear increase in the number of collisions as we go from Nine Canyons to Klondike and finally to Stateline and Buffalo Ridge. The actual number of collisions shows no such trend, albeit this conclusion is based on a rather small sample of wind farms. However, a similar result was also found for Hen Harriers[5] based on a larger sample of wind farms. The reason for this lack of correlation is a matter for conjecture but it seems that the behaviour of birds in reality is rather different than assumed in collision modelling. Taken together the results for Hen Harriers and Geese raise doubts about a fundamental assumption of the method, i.e. that collision mortality increases with bird activity.

Table 1 The Survey Data

Windfarm	Bird Use[a]	Fraction at Rotor Height	Number Turbines	Radius	Number Corpses Found	Corpse Search Completeness[b]	Number Yrs Survey
Buffalo Ridge							
Phase I	1.99 / 3.08[c]	0.37 / 0.06[c]	73	16.5m	0	18%	4[d]
Phase II	2.49 / 0.53[c]	0.38 / 0.19[c]	143	24.0m	0	18%	1.5[d]
Phase III	0.68 / 1.42[c]	0.38 / 0.19[c]	138	24.0m	0	18%	0.5[d]
Stateline	0.85	not known	454	23.5m	1	24%	2
Top of Iowa	not known	not known	89	26.0m	0	25%	2[e]
Nine Canyons	1.26	not known	37	31.0m	0	80%	1
Klondike	13.86	0.60	16	35.0m	2	49%	1
Kreekrak	not known	not known	5	12.5m	1	65%	1

Notes: (a) Bird Use is the number of birds seen per hour per circle of radius 800m averaged over the year. Where bird use has been tabulated by season in the original reference the annual average has been formed, weighted by the number of days per season.
(b) Corpse Search Completeness is defined in section 2
(c) The first number is for Canada Geese and the second number for Snow Geese
(d) The survey at Buffalo Ridge only covered 8 months per year, from March 16 to November 15
(e) The survey at Top of Iowa only covered 8 months per year, from April 15 to December

Appendix - The Calculation of Collision Probabilities

The calculation of probabilities for bird – wind turbine collisions is a complex three dimensional problem. In order to solve the problem the Band Model[19] reduces it to one dimension by assuming that all bird flights are perpendicular to the rotor swept area (in reality flights may approach the turbines from any angle in the horizontal and vertical planes and by ignoring this angular dependence two dimensions are dropped).

A method for solving the full three dimensional problem is being developed[23]and preliminary results show significant differences compared to the one dimensional case. However, since so much work in the UK is based on the Band Model, then for the purposes of the present study the method has been reduced to one dimension to make it comparable to the Band Model.

If the rotor blades are assumed for the moment to have negligible width, then the probability, P_{COLL}, that a bird flying through the rotor swept area will suffer a collision is given by

$$P_{COLL} = \frac{\text{time taken for the bird to fly through the rotor swept area}}{\text{time taken for the rotor blades to traverse the entire rotor swept area}}$$

with the simplifying assumption that all bird flights are perpendicular to the rotor swept area, then the time taken for the bird to fly through the rotor swept area is given by $(L + T) / V$ where L is the mean length of the bird, V its mean flight velocity and T the mean thickness of the rotor blade. The time taken for the rotor blades to traverse the entire rotor swept area is P/3 where P is the mean rotation period of the turbine and the factor 3 is for a 3-blade turbine, hence

$$P_{COLL} = \frac{3\,(L + T)}{P\,V}$$

In reality the rotor blades have a finite width or chord. The surface area of the rotor blade may be approximated as a rectangle that has a length = R, the radius of the blade, and a width = C, the mean value of the chord. There will be then an additional term to include in the collision probability given by $3CR/\pi R^2 = 3C/\pi R$, where as before the factor 3 assumes a 3-blade turbine. Thus

$$P_{COLL} = \frac{3\,(L + T)}{P\,V} + \frac{0.95\,C}{R}$$

From generic studies of turbine blades it appears that, for modern 3-blade turbines, the mean thickness of the rotor blade and the mean chord do not vary greatly when expressed as a function of the rotor radius[24,25] hence to a first approximation this equation may be simplified to

$$P_{COLL} = \frac{3\,(L + 0.01R)}{P\,V} + 0.055 \qquad (1)$$

(23) Fernley J., 2006, *The Calculation of Collision Risk for Birds and Wind Turbines,* In Preparation
(24) Piggott H., 1997, *Windpower Workshop,* The Centre for Alternative Technologies
(25) TPI Composites Inc, 2002, *Parametric Study for Large Wind Turbine Blades*, Report Available from www.sandia.gov/wind

As shown below, eqn (1) is of comparable accuracy to the Band Model and since it is computationally easier (a single equation with 4 parameters compared to a spread sheet with 10 parameters, some of which – maximum chord, chord profile, mean pitch angle and pitch angle profile - are technical details of the blade design and are therefore commercially sensitive information which we found turbine manufacturers were reluctant to divulge) we use eqn (1) in this Report.

Comparison with the Band Model

There are several differences between the Band Model and our model, however, before discussing these differences we note that both methods make the same crucial simplifying assumption, namely that bird flights are always perpendicular to the rotor swept area. This reduces a three dimensional problem to one dimension and hence makes it easier to solve. It does of course also introduce an error and preliminary work[23] suggests that the 3-D probabilities are significantly larger than the 1-D probabilities. To a large extent this is offset since a 3-D treatment of the problem leads to a reduction in the number of bird flights encountering the turbines[19]. The residual effect is estimated to be a 0% - 25% increase, depending on the ratio of wingspan to length of the bird, in the number of predicted collisions. As noted earlier the work on the 3-D case is preliminary but it is mentioned here in order to give an estimate of the level of uncertainty in the 1-D collision probability calculations by both the Band Model and our model.

As regards the differences between the 1-D collision probability calculations by the Band Model and our model, there are three of these: the treatment of the rotor blade thickness (which our model includes but the Band Model does not) and the treatment of the rotor blade depth and the wingspan of the bird (which the Band Model includes but our model does not).

Dealing firstly with the rotor blade, because a rotor blade tapers from leading edge to trailing edge, the thickness of the blade is always a factor, hence it is explicitly included in our model. The Band Model instead treats the blade depth, which implicitly includes the blade thickness. However the blade depth is only a factor if the time taken for the blade to travel a distance C cosγ is less than the time taken for the bird to fly a distance C sinγ, where C is the blade chord and γ the blade pitch angle.

If V_{BIRD} = the flight velocity of the bird and V_{BLADE} = the linear velocity of the rotor blade then the above condition may be expressed as

$$C \sin\gamma \ / \ V_{BIRD} \quad > \quad C \cos\gamma \ / \ V_{BLADE}$$

$$V_{BLADE} \ \times \ \tan\gamma \quad > \quad V_{BIRD} \qquad (2)$$

Both V_{BLADE} and γ vary along the length of the rotor blade. V_{BLADE} is straightforward to estimate but the variation in pitch angle is considered by the turbine manufacturers to be commercially sensitive information which, as noted earlier, we found them reluctant to divulge, however, from generic turbine blade studies[24,25] it appears that inequality (2) would never be satisfied - although V_{BLADE} increases outward along the blade, γ decreases outward and the combination of the two is always less than any realistic bird velocity. Thus by working with the blade depth, which it would appear is never a factor, the Band Model effectively ignores the blade thickness. It is straightforward to show, using eqn (1), that neglect of blade thickness causes an underestimate of between 10% - 30%, depending mainly on the size of the turbine, in the collision probability.

Considering next the wingspan of the bird our model ignores this since it greatly complicates the analysis and the effect is not significant. This can be understood as follows, if L and W are respectively the length and wingspan of the bird and T is the thickness of the rotor blade then for the wingspan of the bird to be a factor the time taken for the bird to fly a distance (L + T) must be less than the time taken for the blade to travel a distance W, which is equivalent to the following condition

$$W \,/\, V_{BLADE} \quad > \quad (L + T) \,/\, V_{BIRD}$$

$$V_{BIRD} \quad > \quad V_{BLADE} \;\; x \;\; (L + T) \,/\, W \qquad (3)$$

Both V_{BLADE} and T vary along the radius of the rotor blade. As before, V_{BLADE} is straightforward to estimate but T is commercially sensitive information which, as noted earlier, the turbine manufacturers were reluctant to divulge, however, the generic studies[24,25] suggest that inequality (3) is only satisfied relatively close to the hub – although V_{BLADE} decreases inwards along the blade, T increases inwards and for any realistic bird velocity and size, inequality (3) is only satisfied in the inner quarter (or less) of the blade. Since the rotor swept area is proportional to R^2 then the inner quarter (or less) of the rotor blade only contributes one-sixteenth (or much less) of the total area and thus has a low weight in the final solution. More detailed numerical tests show that neglect of the wingspan causes an underestimate of collision probabilities of between 0% - 5%.

Test Cases

Band[19] gives a worked example and taking the values from that example;
Bird – mean length and mean flight velocity 0.82m and 13 m/s.
Turbine – mean rotation period and radius 2.97 secs and 26m
With these values eqn (1) gives $P_{COLL} = 0.139$, compared to the value 0.131 given by the Band Model.

Three other randomly selected examples were also tested, two from Band, Madders & Whitfield[1] and one from the Ornithological Assessment for a proposed wind farm at Largie[26]. The total of four examples show differences, defined as the collision probability calculated from eqn (1) minus the collision probability calculated from the Band Model, of 6%, 14%, 16% & 26%. The mean value of this difference is 15%, in the sense that eqn (1) predicts larger collision probabilities. This is as expected given the different treatment of blade thickness by the two models, as discussed previously.

As a final comment on collision probabilities, we note that the Avoidance Rates derived in the body of this paper are extremely robust with respect to changes in the collision probabilities. For example, a change in the collision probabilities of ±20% would only change the Avoidance Rates from 100%, 99.90%, 99.80% to 100%, 99.92% or 99.88%, 99.84% or 99.76% respectively.

(26) Percival S., 2004, *Proposed Wind Farm at Largie Estate: Ornithological Assessment,* Report Prepared for Ecogen Ltd

Collision Probabilities for Buffalo Ridge, Stateline, Klondike and Nine Canyons

	Canada Goose	Snow Goose
Birds - Mean length and Flight Velocity[27]	0.84m, 17m/s	0.73m, 17m/s
Turbines[28] - mean rotation period and radius		
Kenetech 33	1.67secs, 16.5m	
Zond 750	2.45secs, 24.0m	
Vestas 47	2.11secs, 23.5m	
Bonus 1.3MW	3.53secs, 31.0m	
Enron 1.5MW	3.70secs, 35.0m	
Collision Probability using eqn (1)		
Kenetech 33	0.161	0.150
Zond 750	0.133	0.125
Vestas 47	0.145	na
Bonus 1.3MW	0.112	na
Enron 1.5MW	0.112	na

(27) Wege M. & Raveling G., 1984, *Flight Speed and Directional Responses to Wind by Migrating Canada Geese,* Auk 101, p342-8
(28) Data from Manufacturers