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An appraisal of "A review of goose collisions at operating wind farms and estimation of the goose avoidance rate" by Fernley, J., Lowther, S. and Whitfield, P.

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A report by British Trust for Ornithology under contract to Scottish Natural Heritage

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Executive summary

1. BTO Scotland has been contracted by Scottish Natural Heritage to assess "A review of goose collisions at operating wind farms and estimation of the goose avoidance rate" by J. Fernley, S. Lowther, and P. Whitfield. In their report, Fernley *et al*. (2006) reviewed bird survey data from six operating wind farms to investigate goose collisions with turbines, and estimate the wind farm-avoidance rate exhibited by geese. Fernley *et al*. (2006) estimated avoidance rates for geese at four of these sites by dividing the actual observed mortality (the number of corpses found during corpse surveys, corrected for detection rates and scavenger rates) by the predicted number of collisions per year (based on bird-use survey data) and subtracting this from unity. This is the same principle that has been used to produce estimates of avoidance rates for other species.

2. True 'avoidance' is defined as the avoidance of a moving rotor by birds flying through the wind farm site. Estimates of avoidance rates are required to improve estimates of the rate of collision with wind farm turbines that would otherwise be calculated with the assumption of no avoidance. The ideal protocol for the estimation of avoidance rates is described (Section 1.4). As part of our assessment, the sites covered by Fernley *et al*. (2006) were reviewed against these criteria, and we verified the values as per the cited references. An evaluation of the formulae and calculations used to estimate avoidance rates was also made.

3. The ideal protocol for estimating avoidance rates was not achieved at any site. The flaws of each of the sites are summarised within the report (Section 2.7 and Table 2-2). No major discrepancies in the calculations of avoidance rates were identified. A small number of more minor adjustments were made, which are listed and justified in Section 3.2.

4. Fernley *et al*. (2006) calculated a mean avoidance rate of 99.93 %. Mean avoidance rate for Canada Goose was calculated in this report using two methods (see Section 3.2), producing estimates of 99.91 % and 99.89 %. These were lower than the value calculated by Fernley *et al*. (2006), suggesting increased collision rates of 1.22 to 1.51 times.

5. In these calculations, incidentally discovered fatalities were included. If fatalities found only during standardised searches were used, avoidance would have been calculated as 100 % at all sites. This suggests that the survey period for corpse searches, the number of search plots, and/or the frequency of searches need to be increased in order to observe these rare events, and produce reliable estimates of avoidance rates.

6. It is not easy to evaluate whether avoidance rates calculated based on data from Canada Goose are appropriate for the key geese species for which an environmental risk assessment might be required in Scotland (Bean Goose, Pink-footed Goose, White-fronted Goose, Greylag Goose and Barnacle Goose), and we endorse the comparative information reviewed by Patterson (2006) with respect to this issue. Further studies involving these species would help to confirm whether marked differences in avoidance rates occur between the individual goose species.

7. Since only four sites have been used to calculate avoidance rates, individual site variation from a number of factors may affect the estimates. It is difficult to evaluate the influence of these factors on goose avoidance rates at the sites and thus the relevance of the estimated avoidance rates to potential Scottish wind farm sites. Studies at a greater number of sites would obviously increase confidence in the measures of avoidance and provide further information on the main factors leading to site- (or goose species-) specific variation.

8. The review of goose avoidance rates by Fernley *et al*. (2006) is potentially valuable as species-specific estimates of avoidance and displacement rates are essential if the Band *et al*. (in press) collision-risk model is to be applied to help assess potential wind farm sites, and predict collision rates realistically. Whilst the available evidence points towards high wind farm avoidance by geese, insufficient data are available currently to estimate reliably values representative of all likely wind farms, or to ascertain

whether or not these values will always be greater than the 95 % avoidance currently assumed in SNH guidance. The data are currently not available to reliably estimate a value, or ascertain whether or not these values are likely to be greater than 95 % (the value currently assumed in SNH guidance). Further studies would: increase the reliability of the avoidance rate estimate; allow species variation in avoidance rates to be investigated; and further investigate the influence of weather on collisions. A range of further rigorous studies of goose displacement are also required to improve predictions of collision for proposed sites.

1. INTRODUCTION

BTO Scotland has been contracted by Scottish Natural Heritage (SNH) to assess "A review of goose collisions at operating wind farms and estimation of the goose avoidance rate" by J. Fernley, S. Lowther, and P. Whitfield; hereafter referred to as Fernley *et al*. (2006). In their report, Fernley *et al*. (2006) reviewed bird survey data from six operating wind farms (five in the USA, one in Europe) to investigate goose collisions with turbines, and estimate the wind farm-avoidance rate exhibited by geese.

1.1 Definition and calculation of avoidance measurements

The "avoidance" of wind farms by birds could occur at a range of distances, from a distance where the entire wind farm is avoided (Desholm & Kahlert 2005), to closer proximities where the blades of an individual turbine are avoided (Desholm *et al*. 2006). Band *et al*. (in press) defined the latter (avoidance of a moving rotor) as 'avoidance' and the former (complete avoidance of the footprint of an operational wind farm) as 'displacement'.

The measures of ornithological impact that are required in the Environmental Impact Assessment process need to be based on bird survey data collected at each particular site pre-construction. There is a requirement to interpret the information on the species, numbers and flight heights / behaviour of birds using the proposed wind farm footprint (and an appropriate buffer area) pre-construction to predict: (i) numbers likely to be killed by an operational wind farm on the site; and (ii) numbers that might avoid the wind farm area completely post-construction (i.e. those that would be "displaced"). Estimates of avoidance rates are required to improve predictions of the rate of bird collision with wind farm turbines that would otherwise be calculated with the assumption of no avoidance or displacement (Band *et al*. in press; Chamberlain *et al.* 2005, 2006). Estimates of avoidance rates have been produced for some other species (Whitfield & Madders 2005; Whitfield & Band in prep.) in addition to those suggested for geese in Fernley *et al.* (2006). Estimates of displacement are also required in order to predict the level of collision with wind farm turbines, since displacement will alter the amount of bird-use of a site between pre-construction and post-construction.

In order to estimate the extent to which birds avoid wind farms post-construction, data must be collected from operational wind farms. To estimate true avoidance (as defined by Band *et al.* in press), two principal parameters are needed: (i) an estimate of the number of bird deaths caused by collision with rotors in a given time period; and (ii) an estimate of the number of birds that were "at risk" in the same time period from which the observed number of fatalities occurred. Fernley *et al*. (2006) estimated avoidance rates for geese by dividing the actual observed mortality (the number of corpses found during corpse surveys, corrected for detection rates and scavenger rates) by the predicted number of collisions per year (based on bird-use survey data) and subtracting this from unity. This is the same principle used to produce estimates of avoidance rates for other species (Whitfield & Madders 2005; Whitfield & Band in prep.). The extent to which calculated "avoidance" represents true avoidance (as defined by Band *et al.*), as opposed to a combination of avoidance and possible displacement, depends on when the bird-use survey data were collected in relation to the timing of construction. These issues are considered further in sections 1.2-1.4 below.

1.2 Bird-use data requirements

To produce estimates of true avoidance, surveys of bird-use of a site post-construction are required (and these should be undertaken over the same representative period as surveys to search for dead birds). If numbers of birds from pre-construction surveys are used as the denominator when calculating mortality rates, then true avoidance rates are likely to be over-estimated because the construction of the wind farm may have caused displacement of some birds (i.e. fewer birds actually fly through the area of risk post-construction than would have been predicted from pre-construction bird-use surveys). However, in order to predict bird collision rates for proposed wind farm developments from pre-construction bird-use studies, knowledge of likely displacement is also required. If a lack of displacement is assumed, then predicted collision rates are likely to be over-estimated. Hence there is some rationale for deriving a combined "avoidance rate" (that includes both true avoidance and displacement) from existing studies: and this is achieved when "avoidance" is based on mortality rates post-construction as the numerator but bird-use data from the pre-construction phase as the denominator. A major assumption in this approach is that any change in bird-use of a site between the pre-construction and post-construction periods is due to displacement caused by the wind farm itself (and not other extrinsic factors). Given the availability of suitable datasets, we would advocate that true avoidance and displacement should be considered separately, so that clearer assessment can be made of: (i) variation in these across the available studies; and hence (ii) the extent to which the associated avoidance and displacement rates can be used to predict the impacts of other proposed wind farm developments.

Some studies have estimated avoidance rates using bird-use data collected during construction. This is clearly risky as displacement may be increased at that time (potentially even more so than when the turbines are operational) due to disturbance from construction activities. Such estimates might be irrelevant to functioning wind farms, but the resulting measure of avoidance / displacement is likely to be conservative (an underestimate).

The use of bird-use data collected from outside the actual wind farm site is obviously risky in that consistency of bird-use between areas must be assumed. If data are collected off-site and post-construction, bird-use of these areas may also be influenced by birds avoiding the main wind farm area: the off-site survey areas may also be avoided (particularly if close to the actual footprint), leading to under-estimates of avoidance; alternatively, the off-site survey areas might accommodate birds that are avoiding the main wind farm area, leading to over-estimates of avoidance.

Ideally, bird-use data should be collected throughout the year (or across the entire part of the year during which the species under consideration occurs in the area), so that a mean annual value of bird-use can be estimated, and used to estimate mean annual avoidance. Ideally, bird-use data should also be collected in all weather conditions, and during the night (using radar, for example): this is because avoidance estimates should be representative of usual conditions, and particular environmental conditions that might render the particular species under consideration at more risk of collision (e.g. hours of darkness, poor visibility, strong winds) should be adequately sampled.

1.3 Bird mortality data requirements

A rigorous estimate of bird mortality is essential for the calculation of, and strongly affects, avoidance rates. Bird mortality should be estimated by carrying out systematic searches for corpses of the species in question at operating wind farms, once construction has been completed. Ideally these searches should be carried out at the same time as the post-construction bird-use data are collected and similar quality criteria apply (section 1.2): corpse searches (and validation work) should cover the whole year (or the periods when the species in question is present in the area) and searches should be regular enough to cover all weather conditions in a representative manner.

It is essential that factors that influence the recovery of corpses are dealt with within the design of these mortality surveys, including the rate of losses to scavengers and the ability of observers to detect corpses. These issues are generally addressed using some form of experimental scattering of corpses and assessment of the rates at which these are removed by scavengers and detected by observers across a study area that is representative if the wind farm site. Both scavenging rate and detection rate are used to produce an estimate of "corpse search completeness", which can then be used to correct the number of observed corpses to produce estimates of mortality. Investigations into scavenger and detection rates should use corpses of a similar size to the species in question (in this case goose species). If smaller corpses are used, for example, this can lead to underestimates of both scavenger and detection rates, since scavengers and observers may be more likely to miss a smaller item. This would lead to underestimates of corpse search completeness, overestimates of mortality and therefore conservative estimates (underestimates) of avoidance rate.

The assessments of mortality rate should also ideally consider any mortality due to the wind farm against background mortality from other causes. This could involve either corpse searches carried out pre-construction or, ideally, careful post-mortem of carcasses to assess cause of death. If mortality is attributed to the wind farm but is actually due to other cases, avoidance will be under-estimated, although the discrepancy is likely to be very small given existing knowledge of geese. The use of mortality data collected during the construction phase is inappropriate because it is likely to underestimate the number of potential fatalities from an operating wind farm, and hence lead to overestimation of avoidance rate.

1.4 Ideal data requirements

The ideal data requirements for the calculation of avoidance rates are summarised as:

- Bird-use survey data collected post-construction and on-site, during all appropriate months for at least a year, in all weather conditions, and including the night;
- Estimates of flight height made during the bird-use surveys to produce estimates of the proportion flying at collision height;
- Corpse searches undertaken post-construction and on-site, during all appropriate months for at least a year, and all weather conditions; and including some estimate of base-line mortality; and
- Appropriate scavenger and detection rate calibration surveys, using birds of an appropriate size.

These were the principal criteria against which the sites reviewed by Fernley *et al*. (2006) were compared in this assessment. In estimating bird avoidance rates to use in this applied context, the precautionary approach should be used as a guiding principle. For each of the wind farm sites, this approach is tested, looking at whether any assumptions made are likely to have resulted in (particularly) underestimation but also overestimation of avoidance rates.

1.5 Sites reviewed by Fernley *et al*. (2006)

The six operating wind farms reviewed by Fernley *et al.* (2006) were:

- Stateline wind farm (454 turbines, located in Umatilla County, Oregon and Walla Walla County, Washington, USA (Erickson *et al.* 2004);
- Buffalo Ridge wind farm (358 turbines), located in Minnesota, USA (Johnson *et al*. 2000; Osborn *et al*. 2000);
- Top of Iowa wind farm (89 turbines), located in Worth County, Iowa, USA (Jain 2005);
- Klondike wind farm (16 turbines), located in Sherman County, Oregon, USA (Johnson *et al*. 2002a, 2003);
- Nine Canyons wind farm (37 turbines), located in Benton County, Washington, USA (Erickson *et al*. 2003a); and
- Kreekrak wind farm (5 turbines), located in the province of Zeeland, Netherlands (Musters *et al*. 1995).

The goose species observed at the above sites were Snow Goose *Anser caerulescens*, Canada Goose *Branta canadensis* and Brent Goose *B. bernicla*.

1.6 Aims

As part of this appraisal of Fernley *et al.* (2006), the following aspects of each of the six wind farm sites were investigated:

1. The timing of, and methodology used for, data collection (for both bird-use and corpse searches) and whether the information provided by Fernley *et al*. (2006) was correct as per the cited references (Section 2).
2. Whether the formulae used to estimate avoidance rates were correct, an evaluation of the assumptions used, and verification that the calculations were made correctly (Section 3.1).
3. Calculation of avoidance rates (Section 3.2).
4. Whether the estimated avoidance rates are relevant to Scottish situations (Section 4.1).

1.7 Abbreviations

In this report, the following abbreviations were used:

- A = avoidance rate;
- c = the mean distance a bird is expected to fly over a circle of known radius, r;
- CSR = the corpse search completeness; the proportion of corpses from the whole site estimated to have been located during the mortality searches;
- f_{RH} = the fraction of recorded birds flying at rotor height (RH);
- L = mean length of bird species in question;
- $N_{BIRD\text{-}USE}$ = the number of birds recorded during bird-use surveys, per hour per circle of 800 m;
- N_{COLL} = the number of collisions predicted per year with no avoidance or displacement, calculated as the product of $N_{ENCOUNTERS}$ and P_{COLL}.
- N_{CORPSE} = the number of goose corpses found during the corpse searches, corrected for corpse search completeness;
- $N_{ENCOUNTERS}$ = the number of occasions in a year that a bird encounters a wind turbine;
- $N_{FATALITIES}$ = the number of goose corpses found during the corpse searches;
- $N_{FLIGHTS}$ = the number of bird flights per year across the survey plot at rotor swept height;
- N_{TURBS} = the number of turbines;
- P = mean rotation period of the wind turbine;
- P_{COLL} = the probability that a bird that flies through the sweep of a wind turbine will collide with a rotor blade;
- P_{TURB} = the probability that a bird that flies through the survey plot will encounter a wind turbine;
- r = the length of the radius of the view area used for bird-use observations;
- R = rotor radius (m);
- RH = rotor height (m);
- V = mean flight velocity of bird species in question.

2. REVIEW OF SURVEY DATA

The formulae, used by Fernley *et al.* (2006) to estimate goose avoidance rates, require the following parameters from each of the six wind farm sites: $N_{BIRD-USE}$, f_{RH}, RH, N_{TURBS}, R, $N_{FATALITIES}$ and CSR. The values provided by Fernley *et al*. (2006), for each wind farm site, are given in Table 2-1.

2.1 Stateline wind farm

The Stateline wind farm was constructed in multiple stages in 2001 and 2002 (Erickson *et al*. 2004). Surveys were carried out in all months between July 2001 and December 2003 (Erickson *et al*. 2004). The bird-use surveys were carried out either immediately before or immediately after the corpse surveys. All surveys were undertaken at operating wind turbines, but those carried out during 2001 and 2002 coincided with construction elsewhere on the site. The effect of any disturbance from this construction work is difficult to evaluate since the site is large (approximately 9 miles by 6 miles). Corpse searches were undertaken 16-17 times per year at each plot (Erickson *et al*. 2004). A search for other relevant literature was made, and the resulting report (Erickson *et al*. 2003b) did not contain any additional relevant information.

A comparison between the information contained within the cited reference for the Stateline wind farm (Erickson *et al.* 2004), and values provided by Fernley *et al*. (2006) (Table 2-1), follows:

- $N_{BIRD-USE}$ was as provided by Erickson *et al.* (2004).
- f_{RH} was not given by Erickson *et al.* (2004). To estimate f_{RH}, Fernley *et al*. (2006) assumed that the fraction of geese flying at rotor height would be similar to that of Buffalo Ridge due to similar habitat (predominantly agricultural land) and similar sized turbines.
- RH was as provided by Erickson *et al.* (2004).
- The value for N_{TURBS} used by Fernley *et al*. (2006) was the total number in operation at the end of construction, which took place in 2001 and 2002 (Erickson *et al.* 2004). The bird surveys were carried out between July 2001 and December 2003, which included part of the construction period. The number of turbines in operation during the bird surveys was therefore less than the value used by Fernley *et al*. (2006), but the actual number can not be calculated from the available reports (Erickson *et al*. 2003b, 2004).
- R was as provided by Erickson *et al.* (2004).
- $N_{FATALITIES}$ reported by Fernley *et al*. (2006) was one Canada Goose. Erickson *et al.* (2004) reported this fatality as an incidental discovery, rather than found during standardised searches. Since the corpse was found incidentally, this could suggest that standardised searches were too infrequent (16-17 times per year; CSR of 24 %) to adequately detect infrequent fatalities.
- CSR was estimated for large birds by Fernley *et al*. (2006) using values provided by Erickson *et al.* (2004). This incorporated estimates of detection rates and scavenger rates, both estimated using appropriately-sized birds. Erickson *et al*. (2004) also provided confidence intervals for the estimate of annual large bird fatalities per turbine (90 % CIs: 0.17 to 0.29; equates to approximate 95 % CIs of 0.16 to 0.30), a value used by Fernley *et al.* (2006) to calculate CSR. 95 % confidence for CSR can therefore be estimated as 18-34 % (mean = 24 %).

2.2 Buffalo Ridge wind farm

The Buffalo Ridge wind farm was constructed in three phases: Phase I was completed in 1994, Phase II in 1998, and Phase III in 1999 (Johnson *et al.* 2000). Bird-use surveys were carried out, within the wind farm area, between 15 March and 15 November in the four years between 1996 and 1999 (Johnson *et al.* 2000). Bird-use surveys in the Phase I area were undertaken at operating wind turbines. Bird-use surveys in the Phase II and III areas were undertaken pre-construction, during construction and post-construction. The effect of any disturbance from this construction work is difficult to evaluate since the site is large (approximately 20 miles by 15 miles). Corpse searches were carried out weekly between April 1994 and

December 1995 (Osborn *et al.* 2000), and at two-week intervals between 15 March and 15 November in the four years between 1996 and 1999 (Johnson *et al.* 2000). These were undertaken at operating wind turbines, plus during pre-construction to provide background mortality rates; the latter were not used in producing $N_{FATALITIES}$ or CSR. A search for other relevant literature was made, and the resulting papers (Osborn *et al*. 1998; Johnson *et al*. 2002b) did not contain any additional relevant information.

A comparison between the information contained within the cited references for the Buffalo Ridge wind farm (Johnson *et al.* 2000; Osborn *et al.* 2000), and values provided by Fernley *et al.* (2006) (Table 2-1), follows:

- The values for $N_{BIRD\text{-}USE}$ were as provided by Johnson *et al.* (2000).
- The values for f_{RH} were as provided by Johnson *et al.* (2000).
- RH was 19.5 to 52.5 m for Phase I turbines, and either 26 to 74 m or 27 to 73 m for Phase II and Phase III turbines (Johnson *et al*. 2000). To produce f_{RH} for Phase II turbines, RH of 26 to 74 m was used by Johnson *et al*. (2000). There being two slightly different-sized turbines was unlikely to greatly affect the estimation of f_{RH} once inaccuracies of estimating flight heights are taken into account.
- The values for N_{TURBS} were as provided by Johnson *et al.* (2000).
- R was as provided by Johnson *et al.* (2000) for Phase I turbines. For Phase II turbines, R was either 23 m or 24 m (Johnson *et al*. 2000); 24 m was given by Fernley *et al*. (2006).
- $N_{FATALITIES}$ was as provided by Johnson *et al*. (2000) and Osborn *et al*. (2000). One Canada Goose fatality was found during the searches, but the probable cause of death was predation according to Johnson *et al*. (2000), so was not included by Fernley *et al*. (2006). This was included in a review of goose collisions (Patterson 2006), however.
- CSR was estimated for large birds by Fernley *et al*. (2006), using values provided by Johnson *et al*. (2000). This incorporated estimates of detection rates and scavenger rates, both estimated using appropriately-sized birds.

2.3 Top of Iowa wind farm

Construction of the Top of Iowa wind farm was completed in December 2001 (Jain 2005). The measure of bird-use collected at this site was not used by Fernley *et al.* (2006) as the methodology differed from that used at other sites: point counts were made within a 100 m radius view area (Jain 2005) rather than an 800 m radius. Corpse searches were carried out every two days from 15 April to 15 December 2003, and 15 March to 15 December 2004 (Jain 2005). All surveys were undertaken at operating wind turbines. A search for other relevant literature was made, and the resulting reports (Koford *et al*. 2004, 2005) did not contain any additional relevant information.

A comparison between the information contained within the cited reference for the Top of Iowa wind farm (Jain 2005), and values provided by Fernley *et al*. (2006) (Table 2-1), follows:

- Jain (2005) estimated bird-use only by using point counts of birds within 100 m radius, which were not used by Fernley *et al*. (2006), so values for $N_{BIRD\text{-}USE}$ and f_{RH} were not available.
- N_{TURBS} was as provided by Jain (2005).
- R was as provided by Jain (2005).
- $N_{FATALITIES}$ was as provided by Jain (2005).
- CSR was estimated by Fernley *et al*. (2006) using values provided by Jain *et al.* (2005). This incorporates estimates of detection rates and scavenger rates. Scavenger rates were estimated using House Sparrow *Passer domesticus*, Mallard *Anas platyrhynchos* and Canada Goose carcases, but the figure presented was an overall estimate, not for the geese only. Detection rates were estimated using House Sparrow carcasses only. Discussion is made by Fernley *et al*. (2006) as to the appropriateness of this value of CSR (5.6 %) for geese, since detection rates and scavenger rates were estimated using small carcases, and these rates are likely to be higher for geese due to their large size. For their calculations, Fernley *et al*. (2006) used a higher estimate of CSR. CSR was not

needed in the calculations for this wind farm, however, since $N_{FATALITIES} = 0$, so this discussion was not evaluated here.

2.4 Klondike wind farm

Construction of the Klondike wind farm took place in the winter of 2001/2002, being completed in January 2002 (Johnson *et al*. 2002a, 2003). Bird-use surveys were carried out for one year from April 2001 (Johnson *et al*. 2002a). Two of the seven vantage points were within the wind farm area, whilst the other five were between 2 to 4 miles away. The bird-use surveys were carried out during pre-construction, construction and post-construction periods. Corpse searches were carried out at intervals of approximately 28-30 days, for one year from February 2002 (a total of 13 searches per plot), around operating wind turbines (Johnson *et al*. 2003). No other reports / papers were found in a search for other relevant literature.

A comparison between the information contained within the cited references for the Klondike wind farm (Johnson *et al.* 2002a, 2003), and values provided by Fernley *et al.* (2006) (Table 2-1), follows:

- It was not clear how Fernley *et al*. (2006) calculated their value for $N_{BIRD-USE}$, and this value could not be replicated. Johnson *et al.* (2002a) provides the mean number of Canada Geese observed per 30 min per circle of 800 m radius for the four seasons (Table 4; spring: 0, summer: 0.44, fall: 1.79, winter: 17.41). These values can be multiplied by the number of surveys conducted in each season (Table 3; spring: 9, summer: 13, fall: 10, winter: 20), summed (0 + 5.7 + 17.9 + 348.2 = 371.8), divided by the total number of surveys (52) conducted, and multiplied by two to produce a value for $N_{BIRD-USE}$ (per hour) of 14.3; a value of 13.86 was provided by Fernley *et al*. (2006).
- f_{RH} for Canada Goose was as provided by Johnson *et al.* (2002a).
- RH was 30-100 m (Johnson *et al.* 2002a).
- N_{TURBS} was as provided by Johnson *et al.* (2002a, 2003).
- R was 35.2 m (Johnson *et al.* 2002a; c.f. 35 m, as provided by Fernley *et al*. 2006).
- $N_{FATALITIES}$ reported by Fernley *et al*. (2006) was two Canada Geese. Johnson *et al.* (2003) reported these fatalities as incidental discoveries, rather than found during standardised searches. Since the corpses were found incidentally, this could suggest that standardised searches were too infrequent (13 times per year; CSR of 49 %) to adequately detect infrequent fatalities.
- CSR was estimated for large birds by Fernley *et al*. (2006) using values provided by Johnson *et al.* (2003). This incorporated estimates of detection rates and scavenger rates, both estimated using appropriately-sized birds. Johnson *et al*. (2003) also provided confidence intervals for the total mortality estimate ($N_{FATALITIES} \times$ CSR; 90 % CIs: 2 to 12.0).

2.5 Nine Canyons wind farm

Commercial operation of the Nine Canyons wind farm began in September 2002 (Erickson *et al*. 2003a). Bird-use surveys were carried out for two years (Erickson *et al*. 2002), apparently prior to commencement of operations (Fernley *et al.* 2006), which could have included the construction period. Corpse surveys were carried out, twice monthly, for one year from September 2002, around operating wind turbines (Erickson *et al*. 2003a). No other reports / papers were found in a search for other relevant literature.

A comparison between the information contained within the cited reference for the Nine Canyons wind farm (Erickson *et al*. 2003a), and values provided by Fernley *et al*. (2006) (Table 2-1), follows:

- Fernley *et al*. (2006) used summary data on mean use of "waterfowl and waterbirds" from Erickson *et al.* (2002) to estimate $N_{BIRD-USE}$. The value provided by Erickson *et al*. (2002) is a mean of 0.424 birds per 20 min in a search area of 800 m radius. This provides a value for $N_{BIRD-USE}$ (per hour) of 1.27 (c.f. 1.26, calculated by Fernley *et al.* 2006). Fernley *et al.* (2006) assumed that the proportion of Canada Geese amongst waterfowl and waterbirds is similar at Nine Canyons wind farm to Klondike wind farm (99.98 %; Johnson *et al*. 2003) and Stateline wind farm (73 %; Erickson *et al*. 2004) and so concluded that these were likely to be exclusively Canada Geese. This assumption is likely to lead to a reduction in the overall avoidance rate estimate, but only by a very small amount (*ca.* 0.001 %).

- f_{RH} was not given by Erickson *et al.* (2002). To estimate f_{RH}, Fernley *et al*. (2006) estimated the fraction of geese flying at rotor height as an average of Stateline and Klondike wind farms, due to close proximity and similar vegetation type, and the turbines at Nine Canyons being intermediate in size between the other two sites. It should be noted, however, that f_{RH} for Stateline wind farm was itself estimated, based on the value for Buffalo Ridge wind farm.
- RH was 29-91 m (Erickson *et al.* 2003a).
- N_{TURBS} was as provided by Erickson *et al.* (2003a).
- R was as provided by Erickson *et al.* (2003a).
- $N_{FATALITIES}$ was as provided by Erickson *et al.* (2003a).
- CSR was estimated for large birds by Fernley *et al*. (2006) using values provided by Erickson *et al.* (2003). This incorporated estimates of detection rates and scavenger rates, both estimated using appropriately-sized birds.

2.6 Kreekrak wind farm

Commercial operation of the Kreekrak wind farm began in April 1990 (Musters *et al*. 1995). No surveys of bird-use were carried out (Musters *et al*. 1995). Corpse searches were carried out every two days under operating wind turbines between 28 April 1990 and 29 April 1991 (Musters *et al*. 1995). A search for other relevant literature was made, and the resulting paper (Musters *et al*. 1996) did not check any additional relevant information.

A comparison between the information contained within the cited reference for the Kreekrak wind farm (Erickson *et al*. 2003), and values provided by Fernley *et al*. (2006) (Table 2-1), follows:

- As stated by Fernley *et al*. (2006), Musters *et al.* (1995) did not investigate bird-use of the study area, so values for $N_{BIRD\text{-}USE}$ and f_{RH} were not available.
- N_{TURBS} was as provided by Musters *et al.* (1995).
- R was provided by Musters *et al.* (1995).
- $N_{FATALITIES}$ was as provided by Musters *et al.* (1995).
- CSR was estimated for large birds by Fernley *et al*. (2006) using values provided by Musters *et al.* (1995). This incorporated estimates of detection rates and scavenger rates, both estimated using appropriately-sized birds.

2.7 Summary of the six sites

A summary of the important points from each site (Table 2-2) follows:

- At Stateline wind farm, both the bird-use and corpse surveys were carried out throughout the year, for 2.5 years, and within the site at operating wind turbines, but some of the surveys were undertaken whilst construction took place elsewhere on the site. f_{RH} was estimated, rather than being based on data from this site. The only goose fatality reported at the site was an incidental discovery, rather than being found during standardised searches. The inclusion of this individual provides an underestimate of CSR, and leads to a conservative (underestimate) of avoidance rate. The detection and scavenger rates were both estimated using appropriately-sized birds.
- At Buffalo Ridge wind farm, the bird-use surveys were carried out during four years within the site, but excluded fours months of the winter period, and were undertaken during construction and post-construction as well as pre-construction. The corpse surveys were carried out at operating wind turbines within the site, during four years excluding four months of the winter period, and a 21 month-period including one winter. At this site, CSR was estimated as being relatively low (18 %), which as pointed out by Fernley *et al.* (2006), may mean "*the true avoidance rate is less than 100 %*". The detection and scavenger rates were both estimated using appropriately-sized birds.

- At Top of Iowa wind farm, bird-use surveys were not carried out using methods used at the other sites. The corpse surveys were carried out at operating wind turbines within the site for two periods of eight and nine months, but excluded the winter periods. The detection and scavenger rates were not estimated using appropriately-sized birds.
- At Klondike wind farm, bird-use surveys were carried out over a one year period, which included construction and post-construction as well as pre-construction, and only two of the seven vantage points were within the site. It is difficult to evaluate whether bird-use off the site would be applicable to within the site; a major flaw to this particular study. The corpse surveys were carried out at operating wind turbines within the site over a one year period. The only goose fatalities reported at the site were incidental discoveries, rather than being found during standardised searches. The inclusion of these individuals provides an underestimate of CSR, and leads to a conservative (underestimate) of avoidance rate. The detection and scavenger rates were both estimated using appropriately-sized birds.
- At Nine Canyons wind farm, bird-use surveys were carried out within the site for two full years, which could have included some of the construction period. Corpse surveys were carried out at operating wind turbines within the site for a full year. f_{RH} was estimated, rather than being based on data from this site. The detection and scavenger rates were both estimated using appropriately-sized birds.
- At Kreekrak wind farm, no bird-use surveys were carried out, but the corpse surveys were undertaken at operating wind turbines within the site for one full year. The detection and scavenger rates were both estimated using appropriately-sized birds.

In summary, the ideal situation for estimating avoidance rates (bird-use survey data collected on-site and post-construction, and corpse surveys carried out on-site and post-construction, and survey work covering all months) was not achieved at any site. At the four sites where bird-use surveys were undertaken (Stateline, Buffalo Ridge, Klondike and Nine Canyons wind farms), at least some surveying took place during construction, all months were covered at two sites only, one site included off-site estimates, and night estimates were not made for any site. At all six wind farm sites, corpse surveys were undertaken on-site and post-construction, and the surveying at all but one site covered all months.

At two of the four sites where bird-use surveys were undertaken, Stateline and Nine Canyons wind farms, f_{RH} was estimated, rather than being based on data from the site in question. The estimates of goose flight height were based on data from only two sites: Buffalo Ridge and Klondike wind farms. It is difficult to evaluate whether flight heights from Buffalo Ridge and Klondike wind farms are applicable to Stateline and Nine Canyons wind farms, since there may be variation in flight heights between sites (see review in Patterson 2006).

Of the wind farm sites at which both bird-use and corpse surveys were undertaken, two of these found no goose fatalities that were thought to be attributable to collision with wind farm structures: Buffalo Ridge and Nine Canyons wind farms. At Buffalo Ridge wind farm, however, the CSR was low (18 %), which could have resulted in fatalities being missed, leading to an overestimate of avoidance rate. It is difficult to evaluate this possibility in terms of estimating the number of fatalities that may have been missed, if any. The effect of increasing N_{CORPSE} at each of the four sites (Stateline, Buffalo Ridge, Klondike and Nine Canyons wind farms) is investigated in Section 3.2.

Table 2-1. Data on $N_{BIRD\text{-}USE}$, f_{RH}, RH, N_{TURBS}, R, $N_{FATALITIES}$ and CSR, as provided by Fernley *et al*. (2006).

Site	$N_{BIRD\text{-}USE}$	f_{RH}	RH	N_{TURBS}	R	$N_{FATALITIES}$	CSR	Species
Stateline	0.85	unknown	27-72	454	23.5	1	24%	Canada Goose
Buffalo Ridge – Phase I	1.99	0.37	19.5-52.5	73	16.5	0	18%	Canada Goose
Buffalo Ridge – Phase II	2.49	0.38	26-74	143	24.0	0	18%	Canada Goose
Buffalo Ridge – Phase III	0.68	0.38	26-74	138	24.0	0	18%	Canada Goose
Buffalo Ridge – Phase I	3.08	0.06	19.5-52.5	73	16.5	0	18%	Snow Goose
Buffalo Ridge – Phase II	0.53	0.19	26-74	143	24.0	0	18%	Snow Goose
Buffalo Ridge – Phase III	1.42	0.19	26-74	138	24.0	0	18%	Snow Goose
Top of Iowa	unknown	unknown	46-98	89	26.0	0	25%	Canada Goose
Klondike	13.86	0.60	30-100	16	35.0	2	49%	Canada Goose
Nine Canyons	1.26	unknown	29-91	37	31.0	0	80%	Canada Goose
Kreekrak	unknown	unknown	17.5-42.5	5	12.5	1	65%	Brent Goose

Table 2-2. Checklist of methodological ideals for the six wind farm sites.

	Stateline	Buffalo Ridge	Top of Iowa	Klondike	Nine Canyons	Kreekrak
Bird-use searches: post-construction?	✓	✗	✗	✓	✗	✗
Bird-use searches: avoiding construction period?	✗	✗	✗	✗	✗	✗
Bird-use searches: on-site?	✓	✓	✗	✗	✓	✗
Bird-use searches: during all months?	✓	✗	✗	✓	✓	✗
Bird-use searches: at least one year?	✓	✓	✗	✓	✓	✗
Bird-use searches: includes night?	✗	✗	✗	✗	✗	✗
Estimates of flight height?	✗	✓	✗	✓	✗	✗
Corpse searches: post-construction?	✓	✓	✓	✓	✓	✓
Corpse searches: avoiding construction period?	✗	✓	✓	✓	✓	✓
Corpse searches: on-site?	✓	✓	✓	✓	✓	✓
Corpse searches: during all months?	✓	✓	✗	✓	✓	✓
Corpse searches: at least one year?	✓	✓	✓	✓	✓	✓
Corpse searches: base-line mortality?	✗	✓	✓	✗	✗	✓
Detection searches: birds of appropriate size?	✓	✓	✗	✓	✓	✓
Scavenger searches: birds of appropriate size?	✓	✓	✗	✓	✓	✓

3. EVALUATION OF FORMULAE AND CALCULATIONS

3.1 Evaluation of formulae

The bird-use surveys, carried out at Stateline, Buffalo Ridge, Klondike and Nine Canyons wind farms, counted the numbers of birds seen within an 800 m radius circle, but did not estimate flight times or flight lengths. Fernley *et al*. (2006) first calculated the mean distance a bird is expected to fly over a circle of 800 m radius, assuming direct non-stop flight (equation [1]). This simplifying assumption is not likely to be far from the case for migrating geese. There may be cases where the flight-line through the viewing circle is increased, due to circling birds for example, but this would lead to a conservative (underestimate) of avoidance rate.

$$c = 2 \times r \times \pi / 4$$
$$= r \times \pi / 2 \qquad \text{equation [1]}$$

Fernley *et al*. (2006) provided no explanation on how this equation is derived, other than saying simple trigonometry was used. Correspondence from John Fernley (Appendix 1) provided some explanation as to how equation [1] was derived. An assumption made in these calculations would seem to be that the birds are crossing the circle in the same direction (i.e. parallel to each other). An alternative view would be to take the assumption that the birds are entering the circle, and then crossing it in a random direction. With the latter assumption, our calculations show the mean distance should be calculated using equation [2]; see Appendix 2 for an explanation. It should be noted that John Fernley's view is that equation [1] is the only method for calculating the mean flight distance over a circle (Appendix 3); a mathematician would be required to assess which approach is most 'correct'. The difference in resulting avoidance rate in using either equation [1] or [2] is discussed in Section 3.2.

$$c = 4 \times r / \pi \qquad \text{equation [2]}$$

Using equation [1], the mean distance across an 800 m radius circle = 400π m = 1256.6 m. Using equation [2], the mean distance across an 800 m radius circle = 3200/π m = 1018.6 m. Which of the above assumptions best reflects the true situation is questionable. As such, avoidance rates have been calculated using both equations so that any resulting variation can be examined.

Fernley *et al.* (2006) then go on to calculate N_{COLL}, using equations [3] to [7].

$$P_{TURB} = (c \times \pi \times R^2) / (\pi \times 800^2 \times 2 \times R)$$
$$= c \times R / 1280000 \qquad \text{equation [3]}$$

$$N_{FLIGHTS} = 12 \times 365 \times N_{BIRD\text{-}USE} \times f_{RH}$$
$$= 4380 \times N_{BIRD\text{-}USE} \times f_{RH} \qquad \text{equation [4]}$$

In the calculation of $N_{FLIGHTS}$, it is assumed by Fernley *et al*. (2006) that there are twelve flying hours per day. As Fernley *et al.* (2006) states, this underestimates the number of flying hours as geese also fly at night. Night-time activity at the sites has not been evaluated, however, so it is difficult to estimate an appropriate value for number of daily flying hours. It should be noted that use of twelve hours is likely to produce a conservative (underestimate) of avoidance rate, but as Fernley *et al.* (2006) states, this is likely to be at least partially offset by turbines being idle for periods (typically 10-15 % of year, according for Fernley *et al*. 2006) due to either very low or very high winds, and maintenance activities.

$$N_{ENCOUNTERS} = N_{FLIGHTS} \times N_{TURB} \times P_{TURB}$$
$$= 4380 \times N_{BIRD\text{-}USE} \times f_{RH} \times N_{TURB} \times c \times R / 1280000$$
$$= 219 \times N_{BIRD\text{-}USE} \times f_{RH} \times N_{TURBS} \times c \times R / 64000$$
$$\text{equation [5]}$$

It should be highlighted that values of $N_{BIRD\text{-}USE}$ were estimated only from day-time observations of bird activity. Since geese also fly at night, these values may be underestimated. Again, since night-time activity at the sites has not been evaluated, however, night-time values cannot be estimated. This is also likely to produce a conservative (underestimate) of avoidance rate.

$$P_{COLL} = [3 \times (L + (0.01 \times R)) / (P \times V)] + 0.055 \qquad \text{equation [6]}$$

It was unclear from Fernley *et al*. (2006) how equation [6] was derived. Relationships between mean chord value and rotor radius, and mean thickness of rotor blade and rotor radius, were apparently used to produce the equation, but it is not obvious where these relationships are in the cited reference (Berry & Lockard 2002). The values provided by Fernley *et al.* (2006) for V for each turbine type were not verified since references were not provided.

It should be noted that in their calculations of collision risk, Fernley *et al*. (2006) used a method that differed from the Band *et al.* (in prep.) method recommended by SNH (Whitfield *et al*. 2005). Whilst Fernley *et al*. (2006) showed these methods do not differ greatly in their estimates of P_{COLL}, consistency in methods used should be encouraged. Given that most studies calculate collision risk using the Band *et al*. (in prep.) method, and estimates of avoidance rate have been produced already for other species using this method (Whitfield & Madders 2005; Whitfield & Band in prep.), using this method may have been more appropriate.

In their calculations of P_{COLL}, Fernley *et al*. (2006) provided values for the mean length and flight velocity of Canada Goose and Snow Goose. It should be noted that Canada Geese vary greatly in size depending on their race (Cramp 1977), which would affect both mean length and flight velocity. The races observed at the wind farm sites were not recorded, however. Fernley *et al*. (2006) used values for flight speed, for both Canada Goose and Snow Goose, based on measures of the air speed of migrating Canada Geese (Wege & Raveling 1984). It is unclear why the air speed measure (17 ms^{-1}) was used, rather than the ground speed measure (23.1 ms^{-1}; Wege & Raveling 1984), when a measure relative to the wind turbine (i.e. the ground) was required. This latter value was used, plus data from Bellrose & Crompton (1981), to calculate a mean flight speed (weighted for sample sizes) of 19.3 ms^{-1}. For Snow Goose, data were taken from Bellrose & Crompton (1981) to calculate a mean flight speed (weighted for sample sizes) of 22.4 ms^{-1}. It is also unclear where Fernley *et al*. (2006) obtained their values for mean length. The midpoints of values provided by Cramp (1977) are 72.5 (65-80) cm for Snow Goose and 83 (56-110) cm for Canada Goose (c.f. 73 cm and 84 cm used by Fernley *et al*. 2006).

$$\begin{aligned} N_{COLL} &= N_{ENCOUNTERS} \times P_{COLL} \\ &= 219 \times N_{BIRD\text{-}USE} \times f_{RH} \times N_{TURBS} \times c \times R \times P_{COLL} / 64000 \end{aligned} \qquad \text{equation [7]}$$

$$A = 100 \times (1 - (N_{CORPSE} \text{ (per year)} / N_{COLL})) \qquad \text{equation [8]}$$

In working out the average avoidance rate, Fernley *et al*. (2006) calculated avoidance rate, using equation [8], for each wind farm site, and took a mean. A more appropriate method would be to calculate mean collision rate by dividing mean N_{CORPSE} by mean N_{COLL} (Cochran 1977), and subtracting the result from unity. This latter method gives a greater weighting to sites with greater bird-use.

3.2. Avoidance rate calculation

The following estimates of avoidance rates are based on the four wind farm sites at which both bird-use and corpse surveys were carried out (Stateline, Buffalo Ridge, Klondike and Nine Canyons wind farms). Top of Iowa and Kreekrak wind farms have been excluded since data were not available for bird-use. I agree with Fernley *et al*. (2006) that, even though the avoidance rate at the Top of Iowa could be assumed to be 100 % since no goose fatalities were found, the use of this site would introduce a bias in that for wind farms without bird-use data, avoidance rates can only be determined when they are 100 %.

In the following calculations, there are some differences between our methodology and that of Fernley *et al*. (2006):

- For L of Canada Goose, the midpoints of values provided by Cramp (1977) were used as it was unclear where Fernley *et al*. (2006) obtained their values.
- For V of Canada Goose, additional data from Bellrose & Crompton (1981) were used to calculate a mean flight speed (weighted for sample sizes).
- In working out the average avoidance rate, mean collision rate was calculated by dividing mean N_{CORPSE} by mean N_{COLL} (Cochran 1977), and subtracting the result from unity. This method gives a greater weighting to sites with greater bird-use. Using this method, N_{COLL} and N_{CORPSE} were both summed for the three Buffalo Ridge sites (Phase I, Phase II and Phase III).
- Since Snow Goose was recorded at one site only (Buffalo Ridge wind farm), the data for this species was not included in the calculation of avoidance rate. This therefore produces a value specific to Canada Goose.
- For Klondike wind farm, a value of 14.4 was used for $N_{BIRD\text{-}USE}$ rather than the value of 13.86 used by Fernley *et al*. (2006), since the latter value could not be replicated (Section 2.4).
- For Klondike wind farm, a value of 35.2 was used for R, rather than the value of 35 m used by Fernley *et al*. (2006), since the former was the value proved by Johnson *et al*. (2002a).
- For Nine Canyons wind farm, a value of 1.27 was used for $N_{BIRD\text{-}USE}$ rather than the value of 1.26 used by Fernley *et al*. (2006), since the latter value could not be replicated (Section 2.5).

Fernley *et al*. (2006) calculated a mean avoidance rate of 99.93 % (Stateline wind farm: 99.91 %; Buffalo Ridge wind farm: 100 %; Klondike wind farm: 99.82 %; and Nine Canyons wind farm: 100 %). I have calculated mean avoidance rate for Canada Goose using two methods (equations [1] and [2]) of calculating the mean distance through an 800 m radius vantage point viewing area. Using equation [1], mean Canada Goose avoidance rate was calculated as 99.91 % (Stateline wind farm: 99.89 %; Buffalo Ridge wind farm: 100 %; Klondike wind farm: 99.81 %; and Nine Canyons wind farm: 100 %). Using equation [2], mean Canada Goose avoidance rate was calculated as 99.89 % (Stateline wind farm: 99.87 %; Buffalo Ridge wind farm: 100 %; Klondike wind farm: 99.77 %; and Nine Canyons wind farm: 100 %). Both equations [1] and [2] resulted in similar estimates of avoidance rate. These were lower than the value calculated by Fernley *et al*. (2006): our figures suggest collision rates of 1.22 to 1.51 times greater than those of Fernley *et al*. (2006). These values are summarised in Table 3.2-1.

It is important to note that in these calculations (Table 3.2-1) I have followed Fernley *et al*. (2006) in including the incidentally-discovered fatalities at Stateline and Klondike wind farms. If these had not been included, avoidance would have been calculated as 100 % at all sites. This suggests that the survey period for corpse searches, the number of search plots, and/or the frequency of searches need to be increased in order to observe these rare events, and produce reliable estimates of avoidance rates.

Investigating the use of the two different methods for estimating the mean distance across an 800 m circle (equations [1] and [2]), the effect on mean avoidance rate was small: 99.91 using equation [1] and 99.89 using equation [2] (Table 3.2-1). This small amount of variation is unlikely to be important, compared to bigger questions of sample size and applicability (Section 4.1).

Confidence intervals were calculated for CSR for both Stateline and Klondike wind farms – 95 % confidence intervals for Stateline wind farm and 90 % confidence intervals for Klondike wind farm. It should be noted that if 95 % confidence intervals had been derived for Klondike wind farm, rather than 90 %, the intervals would have been slightly wider. The upper and lower values of these stated intervals were used to investigate the impact on avoidance rates for the two sites, and mean avoidance rate (Table 3.2-1). The mean avoidance rates using these values were 99.82 to 99.95 using equation [1], and 99.79 to 99.94 using equation [2].

To investigate the possibility that corpses were not detected, and the effect of CSR being relatively low for some sites (Buffalo Ridge wind farm especially), N_{CORPSE} was increased by ten for each site, to look at the effect of there being up to ten unfound corpses, on each of the avoidance rate estimates. The mean avoidance rate value for Stateline wind farm decreased from 99.89 % to 99.64 % using equation [1], and 99.87 % to 99.55 % using equation [2] (Table 3.2-2). The mean avoidance rate value for Buffalo Ridge wind farm decreased from 100.00 % to 99.70 % or 99.63 %, using equation [1] and equation [2] respectively (Table 3.2-2). The mean avoidance rate value for Klondike wind farm decreased from 99.81 % to 99.35 % using equation [1], and 99.77 % to 99.20 % using equation [2] (Table 3.2-2). The mean avoidance rate value for Nine Canyons wind farm decreased from 100.00 % to 96.76 % or 96.26 %, using equation [1] and equation [2] respectively (Table 3.2-2). The avoidance rate estimate for this latter site was the most sensitive due to N_{COLL} being relatively small. A total of ten unfound corpses at any site would decrease overall avoidance rates from 99.91 % to 99.81 % using equation [1], and from 99.89 % to 99.77 % using equation [2], producing an estimate of 2.20 times more goose collisions.

Table 3.2-1. Estimates of Canada Goose avoidance rates for four wind farm sites, and the calculated means. Three methods are used: those of Fernley *et al*. (2006); and the methods described in Section 3.1, either using equations [1] or [2] to estimate the distance across the bird-use viewing circle. The comparisons are of 'mean collision rate', compared to the value obtained from the Fernley *et al*. (2006) calculations.

	Fernley *et al*. (2006)	Equation [1]	Equation [2]
Stateline	99.91	99.89 (99.86-99.93)	99.87 (99.83-99.91)
Buffalo Ridge	100.00	100.00	100.00
Klondike	99.82	99.81 (99.44-99.91)	99.77 (99.31-99.89)
Nine Canyons	100.00	100.00	100.00
Mean avoidance rate	99.93	99.91 (99.82-99.95)	99.89 (99.79-99.94)
Mean collision rate	0.07	0.08 (0.05-0.18)	0.10 (0.06-0.21)
Comparison	1.00×	1.22× (0.72-2.56)	1.51× (0.89-3.16)

Table 3.2-2. The effect on the site avoidance rate estimates, for Canada Goose, of increasing N_{CORPSE} by ten. Two methods of estimating the distance across the bird-use viewing circle were used: equation [1] (eq. [1]) and equation [2] (eq. [2]).

	Stateline		Buffalo Ridge		Klondike		Nine Canyons	
ΔN_{CORPSE}	Eq. [1]	Eq. [2]	Eq. [1]	Eq. [2]	Eq. [1]	Eq. [2]	Eq. [1]	Eq. [2]
0	99.89	99.87	100.00	100.00	99.81	99.77	100	100
+1	99.87	99.83	99.97	99.96	99.76	99.71	99.70	99.63
+2	99.84	99.80	99.94	99.93	99.72	99.65	99.39	99.25
+3	99.82	99.77	99.91	99.89	99.67	99.59	99.09	99.88
+4	99.79	99.74	99.88	99.85	99.63	99.54	98.79	98.50
+5	99.76	99.71	99.85	99.82	99.58	99.48	98.49	98.13
+6	99.74	99.68	99.82	99.78	99.53	99.42	98.18	97.76
+7	99.71	99.65	99.79	99.74	99.49	99.37	97.88	97.38
+8	99.69	99.62	99.76	99.71	99.44	99.31	97.58	97.01
+9	99.66	99.58	99.73	99.67	99.39	99.25	97.27	96.64
+10	99.64	99.55	99.70	99.63	99.35	99.20	96.97	96.26

4. DISCUSSION

4.1 Applicability to Scottish situation

In Scotland, the key goose species for which an environmental risk assessment might be required are Bean Goose *Anser fabalis*, Pink-footed Goose *A. brachyrhynchus*, White-fronted Goose *A. albifrons*, Greylag Goose *A. anser* and Barnacle Goose *Branta leucopsis*. It is not easy to evaluate whether avoidance rates, largely calculated using data from Canada Geese, are wholly appropriate for the above species. Patterson (2006) provides a comprehensive review of the relevant comparative information that is available currently.

Given that only four sites have been used by Fernley *et al*. (2006) to calculate avoidance rates, it is difficult to investigate the degree of between-site variation, which is important for interpreting the avoidance rates in relation to proposed sites for development in Scotland. Such variation in avoidance rates may arise between sites from:

- Topography of the site, which may affect flight-lines and flight-heights used by the geese.
- Weather conditions, such as frequencies of fog, low cloud or heavy rain, which may affect detection of the wind farm by geese. At the Klondike wind farm, the only recorded goose collisions occurred on a foggy, rainy night (Johnston *et al*. 2003).
- Numbers of geese using the site and surrounding area, such that avoidance rates may be density-dependent.
- Proximity to goose roosting- and feeding- sites, which are likely to affect flight behaviour.
- Seasonality in site-use: for example, avoidance at a site used regularly across the winter may differ from that at a site where large numbers of geese occur on passage over a relatively short time period.
- The effect of habituation to wind farms over time.

It is difficult to evaluate the influence of these factors on goose avoidance rates at the sites covered by Fernley *et al*. (2006); and how appropriate these sites are for comparisons to be made to Scottish sites. A greater number of sites would increase the likelihood of sites covering a range of each of these factors to be included, so that a more representative measure of avoidance could be calculated.

The accuracy of collision rates would have been increased if the survey period for corpse searches, number of search plots, or the frequency of searches had been higher, given that these appear to be rare events. This would have been particularly relevant for sites with relatively low CSRs, such as Buffalo Ridge wind farm. An increase in the number of search plots at Stateline and Klondike wind farms would have increased the likelihood of the Canada Goose fatalities being found during standardised searches.

4.2 Conclusions

The review of goose avoidance rates by Fernley *et al*. (2006) is potentially valuable as species-specific estimates of avoidance and displacement rates are essential if the Band *et al*. (in press) collision-risk model is to be applied to help assess potential wind farm sites, and predict collision rates realistically (Chamberlain *et al.* 2005, 2006). Further estimates of avoidance rates should be encouraged to build on those estimated for other species (Whitfield & Madders 2005; Whitfield & Band in prep.).

In a review of literature, there are reports of goose collisions (six Barnacle Geese and two Bean Geese) at wind farm sites in Germany (Durr 2004 in Kingsley & Whittam 2005). However, there is no information available on bird-use of the sites by these two species from which to calculate collision rates / avoidance. In a separate review, there were six other studies on mortality rates of geese at wind farms in Europe, and two in North America, each with mortality rates reported as zero (Patterson 2006). The geese present at the European sites include Bean Goose, Pink-footed Goose, White-fronted Goose, Greylag Goose and Barnacle Goose.

The studies reviewed by Fernley *et al.* (2006) cannot be used to produce reliable estimates of goose avoidance rates. This is due to the very small number of sites (four) and, critically, flaws in the protocols used at the sites, such as:

- data being collected during site construction;
- not all months being covered by some studies; and
- the use of data collected off-site.

A number of other questionable assumptions also had to be made by Fernley *et al.* (2006), although most of these would have resulted in conservative (underestimates) of avoidance rates.

The studies on geese available currently do suggest that avoidance at wind farms is high, and each study is consistent in this, as are the studies reviewed by Patterson (2006); although the latter review did not attempt to estimate actual avoidance rates. An assessment of the additional studies reviewed by Patterson (2006) and Kingsley & Whittam (2005) would identify whether data from these sites could be used to estimate additional avoidance rates. Insufficient data are available currently to estimate reliably values representative of all likely wind farms, or to ascertain whether or not these values will always be greater than the 95 % avoidance currently assumed in SNH guidance (Band *et al*. in press). Further studies will increase the reliability of the avoidance rate estimate, and allow species variation in avoidance rates to be investigated. Further work is also required to investigate the influence of weather on collisions, as avoidance rates are likely to decrease during conditions such as fog or low cloud. A range of further rigorous studies of goose displacement are also required to improve predictions of collision for proposed sites, since displacement will alter the amount of bird-use at a site between pre-construction and post-construction.

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Appendix 1. Correspondence from John Fernley (7 October 2006) with explanations for his calculation of mean distance flown by a bird over a circle of radius of r m (equation 1).

What you have done is take a simple average of $2r\cos(\varphi)$ over $0 < \varphi < 90$ and this is fine if all values of φ contribute equally. In this case they do not.

Working in terms of the drawing you sent me the segment, perpendicular to the direction of flight, on the surface of the circle for a given increment $\Delta\varphi$ has length $2r\cos(\varphi)\,\Delta\varphi$

For small values of φ, close to 0, this is approximately $2r\,\Delta\varphi$.

For larger values of φ, close to 90, this tends to zero.

In other words the chords at small φ contribute more than those at larger φ and hence the average needs to be weighted by $\cos(\varphi)$. I find this rather difficult to explain in words – perhaps the easiest way of understanding it in terms of your drawing is to imagine birds flying into the circle along the chord line you have drawn. As they come in from the top of the page towards 6 o'clock on the circle (chord line is vertical, small values of φ) then the apparent length of the segment of the circle that they cross, i.e. perpendicular to their line of flight, is quite large for a given angular increment $\Delta\varphi$. As they come in from the right-hand side of the paper towards 6 o'clock on the circle (chord line tends to the horizontal, larger values of φ) then the apparent length of the segment of the circle that they cross, i.e. perpendicular to their line of flight, is quite small for the same angular increment $\Delta\varphi$.

I think an easy way to verify this is with a different drawing, basically the one I suggested to you in the previous e-mail, where you draw onto the circle a series of parallel lines, equally spaced from each other, going across the circle. If you do around ten or so lines and then actually measure them you can see that the average is close to ¾ of the diameter. As you draw more equally spaced lines then the average gets closer to the true value of 0.785.

Anyway if you include this weighting by $\cos(\varphi)$ and then take the average you have

Mean chord $= \int 2r\cos^2(\varphi)\,d\varphi \;/\; \int \cos(\varphi)\,d\varphi \quad = \quad 2r\int \cos^2(\varphi)\,d\varphi$

Where the integral runs from 0 to 90. Now $\cos^2(\varphi) = ½\,(1 + \cos(2\varphi))$, thus

Mean Chord $= r\int (1 + \cos(2\varphi))\,d\varphi = r\,[\,\varphi + 0.5 \times \sin(2\varphi)\,]$

And $\sin(2\varphi)$ is zero for both $\varphi = \pi/2$ and $\varphi = 0$ thus

Mean Chord $= \pi r/2 = 1257$m

Appendix 2. Explanation of calculation of mean distance flown by a bird over a circle of radius of r m (equation 2).

The mean distance flown by a bird over a circle of radius of r m can be calculated by working out the mean length of a chord (Figure 1)

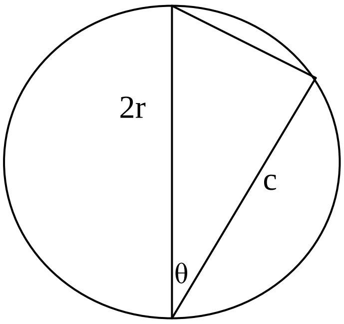

Figure 1. A circle with chord c, diameter of 2r, and angle between the chord and diameter of θ. θ can vary between 0 and π/2 radians.

A length of a chord is given by $c = 2r \times \cos\theta$

Mean chord length $= 1 / (\pi/2 - 0) \times \int [2r \times \cos\theta]$ (with integral limits of 0 to π/2)

$= (2 / \pi) \times 2r \times \int \cos\theta$ (with integral limits of 0 to π/2)

$= (4r / \pi) \times (\sin \pi/2 - \sin 0)$

$= (4r / \pi) \times (1 - 0)$

$= 4r / \pi$

Appendix 3. Correspondence from John Fernley (10 October 2006) with disagreement over calculation of the mean distance flown by a bird over a circle of radius of r m, being dependent on bird behaviour.

Dear Chris,

the difference in our calculated values of the average chord length has got nothing to do with assumptions about bird behaviour. This is a straightforward matter of trigonometry - what is the average value of the chord of a circle? The answer is $\pi \times r / 2$ which in the present case works out at 1257m.

It's a difficult one to explain, and I appear not to have been successful in so doing!

The picture of having a series of equally spaced parallel lines makes it easy to check just by drawing the lines and then measuring them. This is perfectly general because the lines can of course be at any orientation (north-south or east-west etc).

The picture you have of flights all originating from the same point gives the same result as the parallel lines picture but is more complicated because you have to account for both the chord length and the length of the segment on the surface of the circle perpendicular to the chord, and this latter quantity varies with angle (in the parallel line picture this quantity is a constant).

Regards John.

Appendix 4. Spreadsheet used to calculation avoidance rates. The shaded columns are inputted values; other columns are calculated. See Section 3.1 for methods.

Fernley *et al*. (2006)		R	$N_{BIRD-USE}$	f_{RH}	N_{TURB}	L	P	V	years	$N_{FATALITIES}$	CSR	P_{TURB}	$N_{FLIGHTS}$	$N_{ENCOUNTERS}$	P_{COLL}	N_{COLL}	N_{COLL} 2	N_{CORPSE}	A	Means
Stateline	Canada Goose	23.5	0.85	0.38	454	0.84	2.11	17	2	1	24	0.023077	1414.74	14818.1741	0.144908	2147.272	4294.544	4.166667	99.90298	99.90298
Buffalo Ridge Phase 1	Canada Goose	16.5	1.99	0.37	73	0.84	1.67	17	2.666667	0	18	0.016203	3224.994	3813.555405	0.161199	614.7427	1639.314	0	100	
Buffalo Ridge Phase 2	Canada Goose	24	2.49	0.38	143	0.84	2.45	17	1	0	18	0.023568	4144.356	13963.64112	0.132791	1854.247	1854.247	0	100	
Buffalo Ridge Phase 3	Canada Goose	24	0.68	0.38	138	0.84	2.45	17	0.333333	0	18	0.023568	1131.792	3680.02944	0.132791	488.6752	162.8917	0	100	
Buffalo Ridge Phase 1	Snow Goose	16.5	3.08	0.06	73	0.73	1.67	17	2.666667	0	18	0.016203	809.424	957.14388	0.149576	143.1653	381.7742	0	100	
Buffalo Ridge Phase 2	Snow Goose	24	0.53	0.19	143	0.73	2.45	17	1	0	18	0.023568	441.066	1486.09032	0.124868	185.565	185.565	0	100	
Buffalo Ridge Phase 3	Snow Goose	24	1.42	0.19	138	0.73	2.45	17	0.333333	0	18	0.023568	1181.724	3842.38368	0.124868	479.7906	159.9302	0	100	100
Top of Iowa	Canada Goose	26			89	0.84		17	2	0	25	0.025532	0	0				0		
Klondike	Canada Goose	35	13.86	0.6	16	0.84	3.7	17	1	2	49	0.03437	36424.08	20024.928	0.111757	2237.921	2237.921	4.081633	99.81761	99.81761
Nine Canyons	Canada Goose	31	1.26	0.5	37	0.84	3.53	17	1	0	80	0.030442	2759.4	3107.223	0.11249	349.5328	349.5328	0	100	100
Kreekrak	Brent Goose	12.5			5				1	1	65	0.012275	0	0				1.538462		
																				99.89165

Pendlebury (2006): equation [1]		R	$N_{BIRD-USE}$	f_{RH}	N_{TURB}	L	P	V	years	$N_{FATALITIES}$	CSR	P_{TURB}	$N_{FLIGHTS}$	$N_{ENCOUNTERS}$	P_{COLL}	N_{COLL}	N_{COLL} 2	N_{CORPSE}	A	Means
Stateline	Canada Goose	23.5	0.846	0.38	454	0.83	2.11	19.29371	2	1	23.43237	0.023071	1408.082	14748.63019	0.133482	1968.684	3937.367	4.2676	99.89161	99.89161
Buffalo Ridge Phase 1	Canada Goose	16.5	1.986667	0.37	73	0.83	1.67	19.29371	2.666667	0	18.30986	0.016199	3219.592	3807.216244	0.147643	562.1084	1498.956	0	100	
Buffalo Ridge Phase 2	Canada Goose	24	2.486667	0.38	143	0.83	2.45	19.29371	1	0	18.30986	0.023562	4138.808	13945.12655	0.122908	1713.973	1713.973	0	100	
Buffalo Ridge Phase 3	Canada Goose	24	0.68	0.38	138	0.83	2.45	19.29371	0.333333	0	18.30986	0.023562	1131.792	3680.076517	0.122908	452.3122	150.7707	0	100	100
Top of Iowa	Canada Goose	26			89	0.83		19.29371	1.6	0	25	0.025525	0	0				0		
Klondike	Canada Goose	35	14.3	0.6	16	0.83	3.7	19.29371	1	2	48.78049	0.034361	37580.4	20660.9043	0.104589	2160.904	2160.904	4.1	99.81026	99.81026
Nine Canyons	Canada Goose	31	1.272	0.5	37	0.83	3.53	19.29371	1	0	80	0.030434	2785.68	3136.855728	0.105215	330.0451	330.0451	0	100	100
																				99.91455

Pendlebury (2006): equation [2]		R	$N_{BIRD-USE}$	f_{RH}	N_{TURB}	L	P	V	years	$N_{FATALITIES}$	CSR	P_{TURB}	$N_{FLIGHTS}$	$N_{ENCOUNTERS}$	P_{COLL}	N_{COLL}	N_{COLL} 2	N_{CORPSE}	A	Means
Stateline	Canada Goose	23.5	0.846	0.38	454	0.83	2.11	19.29371	2	1	23.43237	0.018701	1408.082	11954.78899	0.133482	1595.755	3191.51	4.2676	99.86628	99.86628
Buffalo Ridge Phase 1	Canada Goose	16.5	1.986667	0.37	73	0.83	1.67	19.29371	2.666667	0	18.30986	0.01313	3219.592	3086.013158	0.147643	455.6279	1215.008	0	100	
Buffalo Ridge Phase 2	Canada Goose	24	2.486667	0.38	143	0.83	2.45	19.29371	1	0	18.30986	0.019099	4138.808	11303.49349	0.122908	1389.294	1389.294	0	100	
Buffalo Ridge Phase 3	Canada Goose	24	0.68	0.38	138	0.83	2.45	19.29371	0.333333	0	18.30986	0.019099	1131.792	2982.957581	0.122908	366.6304	122.2101	0	100	100
Top of Iowa	Canada Goose	26			89	0.83		19.29371	1.6	0	25	0.02069	0	0				0		
Klondike	Canada Goose	35	14.3	0.6	16	0.83	3.7	19.29371	1	2	48.78049	0.027852	37580.4	16747.09774	0.104589	1751.563	1751.563	4.1	99.76592	99.76592
Nine Canyons	Canada Goose	31	1.272	0.5	37	0.83	3.53	19.29371	1	0	80	0.024669	2785.68	2542.639407	0.105215	267.5245	267.5245	0	100	100
																				99.89458