Impacts of avian collisions with wind power turbines: an overview of the modelling of cumulative risks posed by multiple wind farms

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1.0 INTRODUCTION

In Australia, assessments of the risk of bird and bat collisions with wind powered electricity turbines have been made for individual wind farms as part of the evaluation of new proposals for wind farms by regulatory agencies. However, assessment of the impacts of an individual wind farm may provide only a small part of the story where a significant bird or bat species has a wide distribution, or may move long distances, and can be subject to the impacts of collisions at multiple wind farms.

During 2005, Biosis Research was contracted by the Australian Government Department of Environment and Heritage to develop methodologies for modelling of the predicted cumulative risks posed to birds of collisions with turbines at multiple wind farms. Cumulative risk modelling was then undertaken for four birds, the Orange-bellied Parrot, Tasmanian Wedge-tailed Eagle, Swift Parrot and the Australian population of the White-bellied Sea-eagle (Smales 2005a, b; Smales and Muir 2005; Smales *et al*. 2005).

The present document provides an overview of the cumulative models we have developed, along with the rationale underlying the processes. In addition, the capacities and limitations of this modelling are outlined. Finally some recommendations are made with a view to improving the knowledge base required to make the process more widely applicable.

2.0 BACKGROUND TO MODELLING AS A TOOL IN RISK ASSESSMENT

The fundamental objective of modelling of risk is to provide a rigorous process by which probability can be assessed in a manner that can be replicated.

When making predictions of risk using a model, the rationale behind the predictions is explicitly stated in the mathematics of a model, which means that the logical consistency of the predictions can be easily evaluated. This is the case regardless of the type of model used.

The only real alternative to the use of a model is the use of subjective judgement to predict risks. Compared to subjective judgement, the explicit nature of inputs and rigour entailed in modelling makes models more open to analysis, criticism or modification when new information becomes available. Although there may be assumptions used and some arbitrary choices made when deciding on the structure and parameters of a model, these choices are stated explicitly when using a model but this is difficult to do when making subjective judgements. The assumptions underlying a model can be tested. Models can be used to help design data collection strategies. They can also help to resolve and avoid inconsistencies, and the rigorous analysis of data can help to clarify thoughts. Models are often also valuable for their heuristic capacities, by focussing attention on the important processes and parameters when assessing risks (Brook *et al*., 2002). These benefits are difficult, if not impossible to achieve with subjective judgement. Another drawback of subjective judgement is that it may lead to biased predictions of risk, and the biases vary unpredictably among people (Tversky and Kahneman, 1974; Ayton and Wright, 1994; Gigerenzer and Hoffrage, 1995; Anderson, 1998). The predictions of models tend to be less biased (Brook *et al*. 2000, McCarthy *et al*. 2004). There are thus considerable benefits to be gained by employing a model when assessing risk.

3.0 RISK TO BIRDS AND BATS OF COLLISIONS WITH WIND TURBINES

Modern wind powered electricity generators (wind turbines) consist of three essential structures: a tower, rotors and a nacelle. Turbines are usually arrayed in the landscape with little change to pre-existing land use and thus local populations of fauna are generally not expected to alter from the levels at which they existed prior to construction of a wind farm. Note that throughout this report we refer to 'birds' for simplicity, however much is equally applicable to a variety of bat species.

The principal risk to birds believed to be posed by turbines, is the potential for individuals to be killed as a result of collision with moving rotors. In Australia the majority of recently built and currently proposed commercial wind farms, use turbines with rotor diameters in the range of 60 to 90 metres. Rotational speeds are generally in the order of 14 to 18 rpm. Thus the tips of turbine rotors are usually travelling at speeds of between 200 and 300 km/h. In the design of current wind farms, turbines are usually micro-sited in such a way as to maximise wind values and to minimise turbulence from topographic features and other turbines. In practice, this means that there are usually large and variable spaces between turbines.

The rotors and nacelle of a turbine are moved in the horizontal plane around the fixed tower in order to face into the wind. The tower and nacelle are generally large, essentially stationary elements which we consider to present negligible collision risk to birds.

Clearly a risk of collision with rotors exists only when a bird is in flight within the rotor-swept-area, or may be affected by turbulence caused by rotors. Flight behaviours, including the heights at which birds fly, vary considerably between species. Many birds rarely, if ever, reach rotor-swept height, while others do so routinely and some frequently fly above that height. It is also the case that different types of flight, such as hovering, circling, vertical and horizontal flights made by different species of birds, and by birds engaged in different activities, may pose quite different risks of collision. Variations in visibility due to time of day or night and weather conditions are also likely to be influential in altering risk. For example, although little data are available, it seems likely that most collisions that do occur may be the result of a bird being struck by a rotor it did not see, rather than of a bird failing to avoid a visible turbine.

Significant bird mortality due to collisions with wind turbines is obviously not desirable and it is the intent of both the power generation industry and regulators representing the community to minimise it as far as possible. It should be noted, however, that in addition to windfarms, there are numerous other anthropogenic causes of fauna mortality, the great majority of which are entirely unquantified.

Of primary concern is the potential for windfarms to impact on populations of threatened birds and bats. Predictions of collision risk for those listed species are of principal interest in the decision-making process relating to the approval of new wind farms in Australia. To that end, collision risk modelling for some species has now been undertaken for a number of individual wind farm proposals.

However, assessment of the risk posed by individual wind farm proposals is of limited value if undertaken in isolation, when there are multiple new proposals across the range of some threatened or listed species. As part of this study, Biosis Research has now developed approaches to permit modelling of the cumulative risk that may be posed to key species by multiple wind farms. This document provides an outline of these cumulative modelling approaches and their underlying rationale.

4.0 COLLISION RISK MODELLING FOR INDIVIDUAL WIND FARMS

Modelling of cumulative risk is founded on the modelling of collision risk that is posed by individual wind farms. It requires initial modelling of risk for each wind farm within the range of the species of interest. For that purpose we have used the Biosis Research Deterministic Avian Collision Risk Assessment Model which is designed to determine the risk of bird-strike at individual wind farms.

No other wind farm avian collision risk model currently exists in Australia, and the Biosis Research model is more advanced than those that have been used overseas. The Biosis Research model has been developed in the context of Australian birds and has been tested on a range of wind farm proposals in Australia. The model has also been subject to independent peer review by Uniquest Pty. Ltd. (University of Queensland) (Pople 2005). The model has been constantly updated and improved over the last five years and now constitutes a unique and powerful tool for assessing the potential impacts of wind farms on birds. The model is the proprietary software of Biosis Research Pty. Ltd.

In usual practice, the model requires data on the site utilisation rates for each species being modelled, as collected during Point Count surveys on the site of a wind farm. These data provide inputs to the model that help characterise the activities of birds that might be at risk of collision with turbines. In the case where a species is believed to utilise a wind farm site, but data are not available because the species is not recorded during site surveys, or where data are too few and thus do not provide a reliable basis for extrapolation, a well informed scenario can be used.

The risk assessment modelling takes into account a combination of variables that are specific to a particular wind farm and its site, as well as relevant characteristics of bird species of concern that may occur in the vicinity. They include the following:

- The numbers of flights each bird species may make below rotor height, and for which just the lower portion of the turbine towers present a collision risk.
- The numbers of bird flights that may occur at heights within the zone swept by the turbine rotors, and for which the moving rotor blades present a collision risk.
- The numbers of movements-at-risk of collision. Usually this parameter is based upon the data recorded for each species during timed Point Count surveys, which are then extrapolated to determine an estimated number of movements-at-risk for each species for an entire year. Account is also taken of whether particular bird species are year-round residents or annual migrants that may be either seasonally resident or simply pass through the site.
- The mean area (m^2 per turbine) of the tower, nacelle and stationary rotor blades of a wind generator that present a risk to birds. A

multidirectional model can be used which allows for birds to move toward a turbine from any direction, or a unidirectional model can be used where bird flights are strongly directional, such as when birds are travelling along a topographic feature or are on migration. Thus the mean area presented by a turbine is determined to be between the maximum (where the direction of the bird is perpendicular to the plane of the rotor sweep) and the minimum (where the direction of the bird is parallel to the plane of the rotor sweep). The mean presented area is normally determined from turbine manufacturer's specifications provided for individual turbine makes and models.

- The additional area (m^2 per turbine) presented by the movement of rotors during the potential flight of a bird through a turbine. This is determined according to the rotational speed of the turbine blades and the length and flight speed of the bird species in question. For instance in the case of a Vestas V90 turbine and a White-bellied Sea-eagle, the rotors are approximately 43 metres long and rotate at 16.1 rpm. The average length of the bird is 800 mm and it is assigned a flight speed of 60 km/h.
- A calculation, based on the layout and total number of turbines proposed for a wind farm, of the number of turbines likely to be encountered by a bird in any one flight. This differs according to whether turbines are aligned in a linear or a clustered array on the landscape.

Numerous values for all of the above parameters, form inputs to the model for each wind farm for which a collision risk is modelled.

This initial process of modelling for individual wind farms is a critical first-step in the cumulative modelling process because of the very wide distribution of existing and proposed wind farms across the country, and the consequent differences between their designs and layouts and the habitats, diversity and behaviour of the various bird species found in these areas. All these factors mean that the risk posed to birds varies considerably between individual wind farms.

The model also incorporates a measure of the estimated rate at which different species of birds might actively avoid collisions with wind turbines. For example, a 95% avoidance rate means that in one of every twenty flights a bird will take no action to avoid an obstacle in its path, while a 99% avoidance rate means that in one of every one hundred flights a bird will take no action to avoid such an obstacle. Modelled predictions of collision risk are determined for whatever avoidance rates are considered to be appropriate for a particular species, and these are often prescribed by regulatory authorities.

In the model, a collision is assumed to result in death of a bird.

It is also an important prerequisite that the number of birds comprising the population that interacts with each wind farm is either known or can be estimated. Results of the collision risk of a species are expressed in terms of the annual proportion of the species' population at a particular site that are predicted to survive encounters with wind turbines. In demographic terms this is the annual survivorship rate. The annual mortality rate is the simple inverse of annual survivorship rate.

5.0 CUMULATIVE COLLISION RISK MODELLING FOR MULTIPLE WIND FARMS

As indicated previously, the Biosis Research Deterministic Avian Collision Risk Assessment Model was modified as part of this study to create a Multi-site Risk Assessment Model, enabling the assessment of cumulative risk posed by multiple wind farms.

At present relatively few wind farms are operational in Australia. However a much larger number are in various stages of planning. For the purposes of modelling of cumulative impacts of turbine collisions on threatened bird species, we have included each existing or proposed wind farm for which sufficient information was available, across the distributional range of the species in question. This process involves the initial modelling of each wind farm, and results for each have been presented. This approach permits the cumulative model predictions to be adjusted at any time in the future to account for changes in the number, size (or other specifications) of planned wind farms. Note, however, that the cumulative model predictions provided to-date (Smales 2005a, b; Smales and Muir 2005; Smales *et al*. 2005) evaluate the total cumulative impact of all current and proposed wind farms, and therefore present a 'worst-case' scenario in which all of those wind farms for which planning had commenced in early 2005 are modelled as having a simultaneous impact.

In essence, the process of determining a predicted cumulative impact on a threatened or listed species involves combining the multiple impacts predicted for all of the relevant individual wind farms. However, some key differences between the ways in which different birds use their distributional ranges must be recognised and accounted for in the cumulative process.

In species that are sedentary through the course of their lives, the risk of colliding with turbines exists only for the portion(s) of the overall population whose home ranges coincide with wind farms. Thus, for example, adult Wedge-tailed Eagles *Aquila audax* in temperate south-eastern Australia generally reside permanently within quite stable home ranges (albeit that juveniles and subadults may be dispersive or more mobile). Accordingly, only those adult Wedge-tailed Eagles whose home ranges intersect with a wind farm, or farms, are at risk of collision. This means that the great majority of the adult population that is located elsewhere is at no risk at all.

Species that migrate seasonally from one part of their distributional range to another present a different situation for modelling purposes. Most of these species vacate one area, such as their breeding range, entirely for part of the year and take up seasonal residence elsewhere. Some of these species may migrate along quite narrow flyways and, outside of the breeding season, may move about within a non-breeding range. For such species it is possible that large portions, or even the entire population, might pass through multiple wind farm sites in the course of an annual migratory cycle. The Orange-bellied Parrot *Neophema chrysogaster* and Swift Parrot *Lathamus discolour* are examples of such migrants.

As part of this study, Biosis Research developed an approach to cumulative modelling for both sedentary and migratory species. Other less predictable behaviour relating to the usage of habitats within a species' distributional range (such as nomadism) is a feature of some Australian birds, however, such behaviour does not occur in any of the species modelled as part of this cumulative risk assessment.

For sedentary, year-round resident species, the cumulative impact of collisions at wind farms on the entire species is simply the sum of the impact experienced by those parts of the population that are at risk of collisions. Thus, for modelling purposes, we first determined the annual survivorship rate for each species in question for each wind farm within that species' range. From those rates, we then calculated the mean survivorship rate for the portion of the population interacting with all existing and proposed wind farms. The mean is weighted according to the relative numbers of birds resident at the different wind farm sites. The cumulative impact of wind farm collisions on the entire population of the species was then found by multiplying the survivorship rate for the portion of the population at risk of collisions by the background annual survivorship rate affecting the entire population in the absence of any turbine collisions. The measure of *cumulative impact is the difference between the newly derived rate and the background survivorship rate* for the species.

For a migratory species, all or part of the population may encounter a number of wind farms during the course of its annual cycle. Accordingly, the cumulative impact of windfarms on that species is derived by assessing the probability of birds surviving their encounters with one wind farm after another, for as many wind farms as it is believed they might pass through within their distributional range. The survivorship rate for each wind farm provides a measure of the proportion of the population that survives annual encounters with that particular farm, and thus has the potential to encounter further wind farms within the species range. The cumulative species survivorship rate, for all wind farms in the species range, is thus the product of the survivorship rates of all relevant wind farms multiplied together.

If a species' population is segmented into various geographic portions during parts of the migration cycle, or only portions of the population will encounter particular wind farms, then this process may be applied only to the relevant portion(s) of the population and to applicable wind farms.

Similarly, a population of a migratory species may encounter wind farms during only a portion of its annual migratory cycle. The effect of turbine collisions will then be a seasonal one. For calculating this effect in terms of an annual survivorship rate, the process is no different from calculating it for the seasonal variations in survivorship that affect populations due to natural seasonal variables of climate, breeding and non-breeding behaviours, fluctuations in predator and prey numbers, and the like. However, it is important to determine the seasonal duration of the collision effect and factor it appropriately into the annual survivorship rate.

As for sedentary species, the cumulative population survivorship rate as affected by collisions at wind farms is multiplied by the background annual survivorship rate that effects the entire population in the absence of any turbine collisions. The measure of *cumulative impact is the difference between the newly derived rate and the background survivorship rate* for the species.

It is assumed that impacts of collision caused by an established wind farm on a bird population will function as a constant over time, provided the characteristics of the wind farms do not change. For this reason we use demographic rates (annual survivorship or mortality) to quantify impacts, because they are independent of population size and can be applied to determine the number of birds predicted to be killed, or to survive, for any given population size. Thus if the population size of the species in question alters over time then the number of birds killed would be expected to change proportional to the relevant survivorship rate. This is appropriate since wind farms being built now have operational life expectancies of about twenty years and bird populations may fluctuate over those timeframes. Where current population estimates are available (e.g. Orange-bellied Parrot, Tasmanian Wedge-tailed Eagle) the predicted altered survivorship rate due to collision with turbines has been converted into an expected mean number of annual mortalities for the current size of the population.

6.0 CRITICAL IMPACT DETERMINATION FOR THREATENED TAXA

The objective of this element of the assessment is to determine the level at which the predicted cumulative effect of collision is likely to cause a 'significant' impact on the population of the particular species being assessed. Simplistically, the objective is to provide information for a particular species from which a threshold risk can be determined, below which the predicted cumulative impact of collisions with wind turbines could be considered 'acceptable' and above which the impact could be considered to be 'unacceptable'.

A meaningful way to accomplish this is to determine the level of impact on the population that would significantly increase the probability of extinction risk for the population. Population Viability Analysis (PVA) (Schaffer 1981) was used as part of this study as it is a widely accepted modelling tool used for this kind of analysis. The PVA program VORTEX 9.51 (Lacy 2005) was used to examine the degree of increased extinction risk posed to birds resulting from increased mortality due to collisions with wind turbines, as predicted by our modelling of the cumulative effects of wind farms across the species' range. The VORTEX model used is an individualistic, stochastic model, accounting for life-stages and various mortality risks.

It has been possible to undertake this analysis only for species for which comprehensive census data and demographic values are available. Population and demographic values resulting from long-term investigations of subject species were used for inputs to the PVA model.

In the absence of empirical data about actual impacts on the species, any evaluation of what constitutes a critical level of impact on an endangered or listed species, is necessarily subjective and arbitrary. Nevertheless, for the purposes of this study, the approach was adopted whereby scenarios in the PVA model were re-run, increasing the environmental mortality each time. This approach allowed us to determine where the cumulative effects of turbine collisions began to have a measurable and significant effect on extinction probability. Thus our critical impact evaluation is quantified in terms of changes to extinction risk that the cumulative effects of wind turbine collisions might have on a particular species' population.

7.0 CAPACITIES AND LIMITATIONS OF CUMULATIVE COLLISION RISK MODELLING

The cumulative risk model is considered to be a sophisticated and powerful tool that it is very capable of providing appropriate assessments of the collision risk for particular species associated with multiple wind turbines at different sites.

For sedentary bird species there is a clear value in making determinations about the potential impact of turbine collisions at the population level, rather than assessing individual wind farms in isolation. This situation is even more applicable for migratory species, where large portions of the species population may encounter multiple wind farms. The results of cumulative impact modelling for sedentary species can be generated and interpreted in a relatively straightforward way, as impacts can generally be expected to be felt by local segments of the population-at-large. The cumulative model is, however, of perhaps greater value in assessing cumulative risk for migrant species, whose entire populations may move very widely and the evaluation of the risk is somewhat less intuitive than it is for sedentary species.

The main limitation in the modelling approach relates to the quality and quantity of data available for use as inputs to the model. Principally, this limitation relates to data on bird behaviour and characteristics rather than on that for wind farms or turbines, for which engineering specifications generally provide the values required for modelling. Available data relating to bird behaviour and life cycle characteristics are generally much poorer. Wherever good data are available, such as the comprehensive values for Orange-bellied Parrot population parameters provided by the Orange-bellied Parrot Recovery Team, they have been used. However, this situation is not the case for most parameters for the majority of threatened or listed species and empirical data, at the fine level of detail required for modelling purposes, are simply not available. Accordingly, assumptions are typically required to be made for almost all variables relating to birds - including population numbers, numbers of movements they make, heights and speeds at which they fly, and the timing and likelihood that species might inhabit or visit a particular site.

Investigation of bird usage of proposed wind farm sites is generally a pre-requisite to the approval process for these developments, however, comprehensive bird utilisation data, spanning a full range of seasonal and climatic variables, are available for very few wind farm sites in Australia. For most proposed wind farms no data have been collected at all.

Other than a single short investigation at one wind farm (Meredith *et al*. 2002), no comprehensive investigation of bird or bat avoidance behaviour has been made at any wind farm in Australia. Thus for the great majority of wind farms included in this study informed assumptions are required to be used as inputs to modelling process. This is not a limitation of cumulative modelling *per se* but must be acknowledged. Also, this situation is not likely to improve significantly in the short-term.

Uncommon species, or those that visit a region rarely, may easily be missed during site surveys. Furthermore, the level of our knowledge of bird distributions is not sufficiently detailed for us to be entirely certain how likely it is that some species will utilise a particular site. The collective ornithological knowledge within Australia is certainly not comprehensive enough at this time to provide reliable information about the frequency or numbers of a particular species that might use most sites where wind farms are proposed to be built. Given this limitation, there is usually no alternative but to make informed assumptions for modelling purposes.

Obviously it is equally important to have good information about species population size and demographic characteristics in order to accurately quantify the level of impact windfarms may have on a particularly species. However, such detailed population data are available for relatively few Australian birds (Smales 2004), and even estimates of total population size are rarely based on comprehensive census data. Lack of information about actual, or even estimated, population size means that cumulative modelling is not feasible for many bird and bat species, regardless of whether they are listed or not. While this factor is not a limitation of the cumulative modelling process, it does limit its applicability to a broad range of species. It is somewhat ironic that the more reduced and concentrated a population becomes, the more accurately it can be counted and otherwise investigated. Thus quite precise population and demographic data are available for some particularly endangered species like the Orange-bellied Parrot, and have allowed those parameters of modelling to be undertaken with a relatively high degree of precision.

In an independent review undertaken by Pople (2005) of the cumulative risk assessment modelling for the Orange-bellied Parrot , the modelling process itself was agreed to be sound. The main points raised, however, related to the assumptions used about aspects of the bird's population and its utilisation of proposed windfarm sites. Clearly the accuracy of the assumptions used as inputs to the model will effect the accuracy of any predicted outcomes, and we have taken great care to ensure that any assumptions used are based on the best available information.

Within the overall distributional range of most wide-ranging bird species, population density varies in accord with local variables in environmental resources. If a wind farm is situated in an area where a naturally high density of a bird species occurs, such as key breeding or feeding sites, then it is possible that mortalities due to collisions could create a local population 'sink' which could have a widespread impact on the species. In the modelling undertaken in this study, this aspect has been accounted for in the assumptions used in the scenarios developed for the various wind farms. However, in common with all bird data used as inputs, there is considerable potential to refine these assumptions if better data becomes available.

A deterministic approach to modelling cumulative impacts has been used in our studies. Many of the parameters used in the model (such as natural changes in bird population sizes, annual variables in turbine operation due to weather, etc), will in reality be subject to natural stochastic variation. However, no data were available to provide a basis for estimating variables for such parameters. Therefore this study has we have been constrained to using single ‘average’ values as inputs which represent a measure of central tendency for the assumptions modelled. As a consequence, predicted outcomes are also expressed as single, representative values.

8.0 RECOMMENDATIONS

The greatest improvement in terms of modelling the impacts of wind-turbine collision risk to birds and bats (and as a consequence to modelling cumulative impacts on species), will come from better information about the utilisation of proposed wind farm sites and the behaviour of birds and bats when they are within the proximity of turbines.

8.1 Bird utilisation of wind farm sites

It is recommended that emphasis be placed on improving the understanding of how key species utilise wind farm sites. Relevant information can be obtained from utilisation studies targeted at key species, which should be carried out at all proposed wind farm sites where initial investigations demonstrate the presence of key species, or where habitat for these species occurs.

Key species/groups include:

- all threatened species for which little data presently exists,
- all species which are rarely recorded,
- all species which exist naturally at relatively low densities,
- waders and seabirds,
- species that are active during the hours of darkness,
- all bats,
- larger birds such as eagles, cranes, swans, geese and pelicans.

Currently data are too few for threatened species, all species that are rarely recorded, and all groups which exist naturally at relatively low densities, such raptors. Also, few data currently exist for some particular groups such as waders and seabirds at coastal locations. Little information has been collected about bird usage at night and some groups are certainly active during the hours of darkness. Usage by all bats is poorly understood. As a general rule, larger birds would appear likely to have higher risk of collisions, as eagles, cranes, swans, geese and pelicans frequently fly at rotor-swept-height. A combination of their large size and flight behaviours would appear to increase their probability of collision with wind turbines.

8.2 Turbine avoidance behaviour by birds

Little is currently known about real avoidance rates exhibited by different species – and this is a significant constraint to predictive modelling. This information can only be obtained by the accumulation of data from well designed investigations at operational wind farms, and will entail the observation of the behaviour of birds when they encounter turbines.

It is strongly recommended that further study of this aspect be undertaken. Typically, at least three different avoidance rates are used in modelling collision risk for individual wind farms (as well as in this cumulative risk assessment). It is then left for a subjective judgement to be made about which rate is the most appropriate for a particular species. Predictive modelling of collision risks would be improved by removing this uncertainty. It would be valuable to pursue such research, both for its value to improvements in predictive modelling and because public perceptions about collisions may be considerably improved by the results obtained from soundly based research into this question.

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