Modelled cumulative impacts on the Tasmanian Wedge-tailed Eagle of wind farms across the species' range

September 2005

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Tasmanian Wedge-tailed Eagle
Dave Watts

Report for
Department of Environment and Heritage

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Project no. 4857

ACKNOWLEDGEMENTS

Biosis Research wishes to acknowledge the contribution of the following people and organisations in undertaking this study:

Department of the Environment & Heritage, Canberra

- Wayne Furler
- Malcolm Forbes
- Nick Gascoigne
- Chris Murphy

Biosis Research Pty. Ltd.

- Dr Charles Meredith
- Dr Bob Baird

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- Dr Elizabeth Stark

ABBREVIATIONS

DEH	Department of the Environment & Heritage
DPIWE	Department of Primary Industries, Water and Environment, Tasmania
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999

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1.0 INTRODUCTION

1.1 Project Background

The Tasmanian Wedge-tailed Eagle *Aquila audax fleayi* is listed as Endangered under provisions of the *Environment Protection and Biodiversity Conservation Act* (1999) for threatened species. The subspecies is distributed across most of Tasmania and some of its offshore islands, but is believed to be in slow decline (Bell and Mooney 1999, Garnett and Crowley 2000). The subspecies range includes a number of recently constructed wind power generation facilities (wind farms) and more facilities are proposed.

Wind farms may pose a risk of collision to the eagle as bird mortalities are known from wind farms in a variety of situations worldwide and a few Wedge-tailed Eagles have already been recorded as casualties of collision with turbines in Tasmania and elsewhere in Australia. The present project is specifically aimed at determining the cumulative risks posed by collision of eagles with wind turbines. A variety of associated impacts of wind farm developments may affect bird populations. They include direct loss of habitat due to constructed facilities and roads; alienation of habitat caused by disturbance during construction and on-going operation; and potential for electrocution and collisions with overhead distribution lines. These latter impacts are not addressed as part of the present project.

The project has two essential aims:

1. To predict, based upon the extant population of Tasmanian Wedge-tailed Eagles, the potential cumulative impacts of collision risk posed by a number of wind farms across the range of the species distribution. The project utilises bird collision risk modelling to generate assessments of the cumulative risk to the endangered Tasmanian Wedge-tailed Eagle posed by such collisions.

2. To determine a suitable assessment to provide an estimate of the level at which predicted collision (and hence number of turbines or presented area of turbines) is likely to present concerns for the Tasmanian Wedge-tailed Eagle population. We term this ‘critical impact level’.

The cumulative modelling was undertaken for the species using the Biosis Research avian collision risk model. The assessment is based on existing and currently proposed wind farm sites.

Using data available for the Tasmanian Wedge-tailed Eagle, the Biosis Research collision model is utilised to determine the bird strike risk for the eagle’s population from the wind farms in the following categories, as at 30th May 2005, within the species range:

(i) already constructed or approved;

(ii) referred under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and:

. determined to be not a controlled action (NCA);

. determined to be not a controlled action manner specified (NCA-MS);

. approved under the EPBC Act; and

. proposed and currently being assessed for a determination under the EPBC Act.

1.1.1 Risk modelling

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, 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. Compared to subjective judgement, this makes models more open to analysis, criticism and modification when new information becomes available. Although there may be assumptions used and some arbitrary choices when deciding on the structure and parameters of a model, these choices are stated explicitly when using a model but are difficult to disclose when making subjective judgements. Assessments based on subjective judgement can give the illusion that they are not scientifically rigorous (Burgman 2000), regardless of whether they are or not. The assumptions underlying a model can be tested. Models can be used to help design data collection strategies. They can help to resolve and avoid inconsistencies, and the rigorous analysis of data can help to clarify thoughts. Models are often most 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.

Biosis Research's Avian Collision Risk Assessment Model is designed to determine the risk of birdstrike at individual wind farms. This model has been modified to create a Multi-site Risk Assessment Model, enabling the assessment of cumulative risk from multiple wind farms. No other windfarm 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, and has been subject to independent peer review by Uniquest Pty. Ltd. (University of Queensland). It 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.

1.1.2 Overview of Collision Risk Modelling for individual wind farms

In order to quantify levels of potential risk to birds of collision with turbines, Biosis Research Pty Ltd developed a detailed method for the assessment of deterministic collision risk, initially for the Woolnorth Wind Farm in Tasmania. This model has continued to be used for a variety of operating wind farms as further data has been obtained and has also been used to assess the potential impacts of wind farms at a number of further potential sites in Tasmania, Victoria, South Australia and recently in Fiji. It is applied here to determine levels of predicted risk to Tasmanian Wedge-tailed Eagles from individual wind farms.

The model provides a measure of the potential risk at different rates at which birds might avoid collisions. For example, a 95% avoidance rate means that in one of every twenty flights a bird would hit an obstacle in its path. Clearly, birds have vastly better avoidance capacity than this and it is well established overseas that even collision-prone bird species avoid collisions with wind generators on most occasions (see Section 2.4.6, below).

In the modelling undertaken for the present project we divide the risk into two height zones according to components of wind turbine structures. These are:

1. the zone between the ground and lowest height swept by turbine rotors, and
2. the height zone swept by turbine rotors

We consider that birds will avoid collision with the stationary components of a turbine in all but the most exceptional circumstances and model for 99% avoidance rate in the height zone below rotor height. For the height zone swept by rotors we provide predictions for movements at risk for each of 95%, 98% and 99% avoidance rates.

In usual practice the model requires data on the *utilisation rates* of each species being modelled, as collected during Point Count surveys on-site. This data provides inputs to the model regarding activities of birds that might be at risk of collision with turbines. Where data is not available because a species is not recorded from a site, or where data are too few and is thus an unreliable basis for extrapolation, a well informed scenario can be used. In the case of the present project, data has been obtained for Tasmanian Wedge-tailed Eagles at four of the seven wind farms and is used here. For the other three wind-farms scenarios are modelled, based on available information about the sites and experience from similar sites. The risk assessment accounts for a combination of variables that are specific to the particular wind farm and to birds that inhabit the vicinity.

They include the following:

- The numbers of flights made by the species below rotor height, and for which just the lower portion of turbine towers present a collision risk.

- The numbers of flights made by the species at heights within the zone swept by turbine rotors, and for which the upper portion of towers, nacelles and rotors present a collision risk.

- The numbers of movements-at-risk of collision. Usually this parameter is as recorded for each species during timed Point Counts, which are then extrapolated to determine an estimated number of movements-at-risk for each species for an entire year. Account is taken of whether particular bird species are year-round residents or are present for a portion of the year as annual migrants.

- The mean area of tower (m^2 per turbine), nacelle and stationary rotor blades of a wind generator that present a risk to birds. The multidirectional model used here allows for birds to move toward a turbine from any direction. Thus the mean area presented by a turbine is 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 determined from turbine specifications supplied to Biosis Research 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 length and flight speed of the bird species in question. In the case of the Tasmanian Wedge-tailed Eagle the bird's length is set at 950 mm and its flight speed at 60 km/h.

- A calculation, based on the total number of turbines proposed for the wind farm, of the number of turbines likely to be encountered by a bird in any one flight. This differs according to whether turbines form a linear or a clustered array on the landscape.

A value, or values, for each of the parameters above forms an input to the model for each wind farm for which collision risk is modelled.

1.1.3 Presentation of results

All collisions are assumed to result in death of a bird or birds. Results produced from modelling of the collision risk to Tasmanian Wedge-tailed Eagles, of both individual wind farms and of the cumulative impacts of multiple wind farms, are generally expressed here in terms of the annual proportion of the known population of the species that are predicted to survive encounters with wind turbines. On the basis of published demographic values for the current population of the species, including the numbers of birds known to exist and the mean annual mortality rate that is believed to be affecting the population in the absence of wind farm collisions, we also provide estimates of our predicted results in terms of the number of birds that might be affected annually.

2.0 METHODS: CUMULATIVE IMPACTS MODELLING

Methods are presented here for the first aim of the project - to predict, based upon the extant population of Tasmanian Wedge-tailed Eagles, the potential cumulative impacts of collision risk posed by a number of wind farms across the range of the species distribution.

The modelling outlined here assesses the potential risks to a bird population of collision with wind-driven electricity turbines. Other potential impacts, such as loss of habitat, increased disturbance, or other effects that may result from wind farms are not encompassed by this assessment.

2.1 Mathematical approach to cumulative impacts modelling

The mathematical approach to modelling of the potential cumulative impacts on bird populations used, along with its rationale, is provided in Appendix 1 (*Cumulative Wind Farm Effects Modelling* by Dr. Stuart Muir).

The Tasmanian Wedge-tailed Eagle is confined to Tasmania, where it occupies the majority of the state, including a number of small offshore islands (Brothers *et al.* 2001) and larger Bass Strait islands. However, the species breeds through a portion, but not all, of this range. Wedge-tailed Eagles are believed to remain as year-round residents only within home-ranges occupied by breeding birds. The portion of the population comprised of non-breeding adults between one and four years of age is believed to be nomadic over the greater range across the state. Such birds may overlap with the home-ranges of breeding birds in areas where they occur.

Since resident birds, including adult parents and their first-year offspring, are sedentary, such birds are considered to have a probability of interacting with only one wind farm throughout the course of a given year. It is possible that nomadic birds may move through more than one wind farm site during the course of a year, however, no data exists about movements of such birds and it is therefore assumed for the purpose of this project that they are essential random.

Modelling for the cumulative effects of collisions with wind turbines for resident birds is effectively as outlined in the mathematical model (Appendix 1), where they can interact with a single wind farm. As mentioned above, there is no real basis on which to determine a number of wind farms which nomadic birds might encounter. We considered an option of assessing the probability of nomadic birds encountering a series of wind farms as relative to the proportions of the entire range (the area of Tasmania) that is occupied by various wind farms.

However, the proportional areas are extremely small and we considered that this might underestimate potential risk, especially if nomadic birds are more concentrated into some regions than others. On balance, we determined that a more parsimonious approach was to assume that nomadic birds might be modelled as though they were resident within wind farm sites throughout a given year at a rate proportional to the percentage of nomadic birds that comprise the overall population. This approach is considered more likely to introduce some slight overestimate of risk than an underestimate.

Initially, the possible impact of each wind farm on the Tasmanian Wedge-tailed Eagle is modelled on the basis of available information about that particular wind farm or an informed scenario of how part of the eagle's total population might interact with the wind farm annually. The impact is expressed as a mortality rate (annual probability of eagles being killed by the particular wind farm) for that part of the eagle population. The inverse of annual mortality is an annual survivorship rate (annual probability of eagles surviving encounters with the wind farm).

The cumulative impacts of all wind farms across the subspecies' range is subsequently determined as the mean of the combined survivorship rates for Tasmanian Wedge-tailed Eagles interacting with all wind farms. The mean is weighted according to the relative numbers of birds modelled for the different sites. Cumulative impact is expressed as a mortality rate (annual probability of eagles being killed at all wind farms involved) for the combined portion of the total eagle population interacting with all of the wind farms. The inverse of annual mortality is an annual survivorship rate (annual probability of eagles surviving encounters with all wind farms). This survivorship rate is multiplied by the background annual survivorship rate that effects the entire population in the absence of any impacts of wind farms. The result indicates the cumulative impact of wind farm collisions on the entire population of the Tasmanian Wedge-tailed Eagle.

2.2 Model inputs

Inputs to the model have been determined to specifically assess the possible cumulative effects upon the Tasmanian Wedge-tailed Eagle population posed by seven existing and proposed wind farms, through the entire range of the subspecies' natural distribution. The subspecies has been recorded at, or within close proximity to, all of the seven wind farms under consideration here. Specific attributes of each wind farm were provided by DEH and were augmented, where required, from our own investigations.

Field investigations of the utilisation by birds at four of the relevant wind farms have been undertaken previously by Biosis Research. Results of those studies were used here to determine the usage of those sites by Tasmanian Wedge-tailed Eagles. For the remaining three sites we have used a scenario for each based on informed assumptions about similarity of the particular location to sites for which we do have data.

Where assumptions were made in the absence of empirical information, we have used what we believe are valid judgements based on what is known and have attempted to err, if at all, on the basis of over- rather than underestimation of potential risks to the species.

2.3 Parameters of wind farms

Of the eight wind farms considered here, four are built and currently in operation (King Island Huxley Hill Stage 1, King Island Huxley Hill Stage 2, Woolnorth Lot 1, Flinders Island (DEH data)). The remaining four wind farms are proposed (Heemskirk, Mussleroe, Jim's Plain, Woolnorth Lot 2) and fall within the categories outlined at (i) and (ii) in Section 1.1, above. Hereafter we treat the two stages of the Huxley Hill wind farm as one site.

Key to the collision risk posed by a wind farm to Tasmanian Wedge-tailed Eagles are both the specifications of turbines in use or proposed to be used and configuration of turbines on the landscape.

2.3.1 Turbines

The model of turbine in operation, or proposed to be used, at the various wind farms differ. The specific attributes of turbines are incorporated into the model since the different turbine types present different collision risks to birds. Differences are due to such things as the size ('presented area') of the structure that a bird might strike and such specifics as operational rotor speed and percentage of time that rotors are likely to turn, as dictated by variables of appropriate wind speed and maintenance downtime.

At least four different models of turbine are currently in operation, or are proposed to be built at the eight wind farms considered here. The current proposal for the Mussleroe wind farm will utilise Vestas V90 turbines installed on reduced height towers and specifications for these were provided by Hydro Tasmania. For one potential wind farm (Jim's Plain) we were not able to obtain a clear indication of the turbine type proposed to be used as it appeared that proponents have not yet determined which they might use. In this instance we modelled for a turbine type most likely to be used based on the total generating capacity planned for and from industry trends in the type of turbines being proposed. We were not supplied with specifications of the two rather old turbines on Flinders Island and were unable to obtain them. Hence we modelled for a turbine type for which we have specifications with a slightly larger generating capacity than the actual turbines. Similarly, for the two stages of Huxley Hill wind farm on King Island we were unable to obtain full specifications for the three older generation turbines installed for Stage 1. Thus we used the specifications of the slightly larger machines comprising Stage 2 for the entire farm of five turbines and hereafter evaluate the entire installation as one wind farm. Table 1 provides information about turbine type used in modelling for the various wind farms assessed here.

Table 1 **Details of the wind farms assessed.**

Windfarm	EPBC referral number (where applicable)	POINT_X	POINT_Y	Number of turbines	Turbine type used for risk modelling
Mussleroe	2002/683	148.09	-40.04	46	Vestas V90 (low tower)
Heemskirk	2002/678	145.121	-41.833	53	Vestas V90
Jim's Plain	2003/1162	144.838	-40.847	20	Vestas V90
Woolnorth Lot 1	2000/12	144.925	-40.785	37	Vestas V66 1.75 MW
Woolnorth Lot 2	2000/12	144.925	-40.785	25	Vestas V90
King Is Huxley Hill	2002/570	143.893	-39.942	5	Vestas [V52 - 850] 0.85 MW
Flinders Island		148.09	-40.04	2	Nordex 0.125 MW

Manufacturer's specifications for wind turbine models were used to calculate attributes of each of them. Sixteen dimensions for each turbine, in combination with rotor speed, were input to the model. The mean presented area [m^2] of each turbine, that presents a collision risk to eagles, was calculated from specification data for both the static elements (all physical components of a turbine, including tower, nacelle, rotors) and the dynamic components (accounting for the movement of rotors) of each turbine structure.

The plane of a wind turbine rotor pivots in a 360° horizontal arc around the turbine tower in order to face into the wind direction. The area presenting a collision risk to a bird flying in a particular direction may thus vary from a maximum, in which the rotor plane is at 90° to the direction in which the bird is travelling, to a minimum in which the rotor plane is parallel with the travel direction of the bird.

To account for this variable, specifications for turbine types were used to calculate a *mean* area that each turbine presents to birds. The use of a mean turbine area is appropriate when the flights of birds are not biased toward any particular compass direction and it is thus assumed that a bird is equally likely to encounter a turbine from any direction. The flights of Wedge-tailed Eagles in the vicinity of the relevant wind farms are multi-directional and the use of a mean turbine area is thus the appropriate approach.

The area presented by a turbine also differs according to whether the rotors are stationary or are in motion. When turbines are operational and rotors are in motion, the area swept by the rotors during passage of a bird the size and speed of a Tasmanian Wedge-tailed Eagle is included in calculations of the presented area.

Turbines rotors do not turn when wind speed is too low (usually below about 4 m/sec) and are braked and feathered to prevent them from turning if it is too high (usually in excess of about 25m/sec), and during maintenance. During such times only the static area of each turbine presents a collision risk. To account for the difference in mean area presented by operational and non-operational turbines a percentage of downtime is an input to the model.

2.3.2 Turbine number and configuration

Two principal components of the collision risk represented by a particular wind farm are the number of turbines at the site and way in which they are positioned relative to each other in the landscape.

The number of turbines at each site is a simple parameter input to the model.

The layout of turbines relative to each other, in combination with the lengths and directions of flights that birds make, affects the number of turbines that a bird might be likely to encounter at the site. In relation to this, a linear array entailing a single row of turbines is quite different from a cluster of turbines. This factor is taken into account as a parameter input that can be varied according to the known layout array of each wind farm modelled.

2.4 Parameters of Tasmanian Wedge-tailed Eagles

2.4.1 The Tasmanian Wedge-tailed Eagle population

In order to assess the potential cumulative impacts of collisions with wind turbines on the Tasmanian Wedge-tailed Eagle population an initial review was required to determine a number of aspects of the population for use in our analyses. These included the overall size of the population, relevant information about variable densities of the subspecies across its range and the potential influences of nomadic and residential behaviours of different age-classes of the birds. A population viability analysis for the Tasmanian Wedge-tailed Eagle population inhabiting the Forestry Tasmania Bass District has recently been undertaken by Bekessy *et al.* (2004). Their work provides the most comprehensive and up-to-date collation of information about demographics of the entire Tasmanian Wedge-tailed Eagle population. In general, we have used demographic values they provide both directly and to derive additional values required for our analysis. However, we note that population and demographic estimates provided by various primary authors differ somewhat. We have relied on our own judgement of these various estimates, particularly with regard to overall population size.

Population size and density

Tasmanian Wedge-tailed Eagles occupy most of the state (Bryant and Jackson 1999, Barrett *et al*. 2003). Various estimates of the size and densities of the population of Tasmanian Wedge-tailed Eagles have been published in recent years (Bell and Mooney 1999, Garnett and Crowley 2000, Bekessy *et al*. 2004).

Total population estimates range from ‘an adult population of less than 440’ (Bell and Mooney 1999), to ‘750 territorial birds’ (= breeding adults) (Bekessy *et al*. 2004).

Bell and Mooney (1999) cite density estimates varying from a maximum of one pair per 20 – 30 km^2 in lowland eastern and northern Tasmania to one pair per 1,200 km^2 in southern and western parts of the state. Bekessy *et al*. (2004) cite Mooney and Holdsworth (1991) and Bell and Mooney (1999) for values of 50 – 100 km^2 in lowland eastern and northern Tasmania to one pair per 1,200 km^2 in southern and western parts of the state. Since the species is a top-order predator and scavenger, densities are likely to correlate very directly with productivity of habitats the birds occupy.

Bekessy *et al*. (2004) provide the most recent overview of available information about population size and density relevant to the present assessment. Information they provide is summarised in Table 2.

Table 2 Summary of population size and density information for Tasmanian Wedge-tailed Eagles adapted from Bekessy *et al.*

Maximum total population of Tasmanian Wedge-tailed Eagles	1500
Number of territorial birds (breeding adults)	750
Number of non-territorial birds (juveniles, immatures & non-territorial adults	750
Density of Wedge-tailed Eagles eastern and northern Tasmania	1 pair/50 - 100 km2
Density of Wedge-tailed Eagles southern and western Tasmania	1 pair/1,200 km2

Territoriality, social and site fidelity

Breeding adults occupy home-ranges year-round and generally maintain life-long monogamous pair bonds. The death of a partner may be followed by the survivor re-pairing (Marchant and Higgins 1993). It appears usual for home-ranges to be occupied throughout the adult life of Wedge-tailed Eagles and, whilst various nest sites may be used in different years, a given nest may be re-used for many years and even by subsequent generations of birds. During the breeding season adult pairs concentrate their activities on a nesting territory, which is a core portion of the year-round home-range.

Age-related movement behaviour

During the first year of life, juveniles remain within their parents' territories. As the subsequent breeding season approaches, immature birds move away from natal territories and from that age, eagles join a non-breeding component of the population until forming partnerships and themselves becoming breeders at about five years of age. Dispersal of non-breeding birds in Tasmania has not been investigated, although long-distance movements by such birds have been recorded from the mainland subspecies and it is thus possible that non-breeders ('floaters') may wander widely over the state (Olsen 1995, Bekessy *et al*. 2004).

It seems likely that more productive areas of the state, where high densities of Wedge-tailed Eagles occur are also areas where breeding territories are concentrated. The distribution of breeding records across the state is provided by Bryant and Jackson (1999). In regions inhabited by breeding birds, the home-ranges of resident breeding birds may overlap with areas used by non-breeding birds (Olsen 1995, Bekessy *et al*. 2004), although it is expected that residents would not normally tolerate non-breeders within their core nesting territories. Conversely, areas of low densities of birds are likely to be inhabited principally by non-breeders. If that assumption is correct, then breeding territories may be rare in the south and west of Tasmania, where non-breeding birds may predominate, albeit at low occupancy rates. Marchant and Higgins (1993) indicate that breeding occurs on Flinders Island in the Furneaux Group, but that whilst birds are recorded from King Island, no breeding is known to occur there, so we presume that birds there are nomadic non-breeders.

Additional demographic data

A variety of demographic information for the subspecies, additional to population size and density, is provided by Bekessy *et al*. (2004) and is summarized in Tables 3 and 4 below.

Table 3 Demographic values for Tasmanian Wedge-tailed Eagles adapted from Bekessy *et al.* (2004).

Estimated number of territories within Tasmania	363
Approx. proportion of territories annually producing chicks	0.5
Average annual number of chicks per successful territory	1.07
Fecundity per breeding female	0.531
Nestling period	Hatch - 11 or 12 weeks
Juvenile period	12 weeks - 1 year of age
Average age at first breeding	5 years
Reproductive lifespan	15 - 20 years
‘Usual lifespan'	20 - 25 years

Bell and Mooney (1999) provide minimum mortality rates for three life-stages. Those rates were incorporated into a refined set of rates for eight life-stages used by Bekessy *et al*. (2004).

Table 4 Mortality rates for life-stages of Tasmanian Wedge-tailed Eagles (adapted from Table 10.1 of Bekessy *et al.*) and derived survivorship rates

Life-stage	Average mortality rate	Derived survivorship rate
Chick	10%	90%
Juvenile	50%	50%
Immature 1	30%	70%
Immature 2	25%	75%
Immature 3	20%	80%
Immature 4	10%	90%
Non-breeding Adult	5%	95%
Breeding Adult	5%	95%

2.4.2 Determining population values used for modelling

We have used the demographic information, summarized above, as the basis for creation of a static life-table for the Tasmanian Wedge-tailed Eagle population (Krebs 1978) (Table 5). In essence it provides a cross-section of the age structure of the population. The life-table was used to ascertain putative values required for our modelling that were not explicitly provided by previous authors, including the proportions of the population that are breeders and non-breeders. It was also used to provide the population estimate for our modelling purposes and to determine the background mean annual survivorship rate of the population against which to measure the predicted impacts of collision risk.

Table 5 Putative life-table for Tasmanian Wedge-tailed Eagle population based on life-history and survivorship attributes provided by Bekessy *et al.* (2004)

Age of life-stage increment (years)	Life stage	Life-stage survivorship rate (Sx)	Annual survivorship rate (Sx)	Cumulative cohort survivorship rate (Sx)	Mean number of individuals annually survive life-stage in Tas. Population	Life stage duration (months)
0	Hatch	1.00		1.00	194	
0 - 0.22	Chick	0.90		0.90	175	2.6
0.22 – 1	Juvenile	0.50	0.45	0.45	87	9.4
1 – 2	Immature 1	0.70	0.70	0.32	61	12
2 – 3	Immature 2	0.75	0.75	0.24	46	12
3 – 4	Immature 3	0.80	0.80	0.19	37	12
4 – 5	Immature 4	0.90	0.90	0.17	33	12
5 – 6	Adult 1	0.95	0.95	0.16	31	12
6 – 7	Adult 2	0.95	0.95	0.15	30	12
7 – 8	Adult 3	0.95	0.95	0.15	28	12
8 – 9	Adult 4	0.95	0.95	0.14	27	12
9 – 10	Adult 5	0.95	0.95	0.13	26	12
10 – 11	Adult 6	0.95	0.95	0.13	24	12
11 – 12	Adult 7	0.95	0.95	0.12	23	12
12 – 13	Adult 8	0.95	0.95	0.11	22	12
13 – 14	Adult 9	0.95	0.95	0.11	21	12
14 – 15	Adult 10	0.95	0.95	0.10	20	12
15 – 16	Adult 11	0.95	0.95	0.10	19	12
16 – 17	Adult 12	0.95	0.95	0.09	18	12

17 – 18	Adult 13	0.95	0.95	0.09	17	12
18 – 19	Adult 14	0.95	0.95	0.08	16	12
19 – 20	Adult 15	0.95	0.95	0.08	15	12
20 – 21	Adult 16	0.95	0.95	0.07	15	12
21 – 22	Adult 17	0.95	0.95	0.07	14	12
22 – 23	Adult 18	0.95	0.95	0.07	13	12
23 – 24	Adult 19	0.95	0.95	0.06	12	12
24 – 25	Adult 20	0	0	0.00	0	12
Annual maximum Tasmanian population based on life-table						**742**
Mean population annual survivorship rate (Sx)						**0.8660**
Portion of total population (post-fledging birds) that are floaters (1 - 4 years of age)						**0.24**
Mean number floaters in population (1 – 4 years of age)						**177**

Bekessy *et al.* state that 'usual lifespan' of Tasmanian Wedge-tailed Eagles is 20 – 25 years. We have thus truncated the life-table to a maximum longevity of 25 years.

Cumulative cohort survivorship rates are derived from the product of the incremental survivorship rates of all preceding annual age-classes in a population (S_x = finite rate of survival during the time interval x to $x + 1$ (Krebs 1978)).

We have used a mean number of 194 chicks annually hatched in the entire population. This is derived from detailed values, as provided by Bekessy *et al.* (2004), for the total estimate of Tasmanian Wedge-tailed Eagle breeding territories (= 363); the percentage of those that are successful annually (~50%); and the mean number of chicks hatched per successful female (= 1.07). We have used these values, which would appear to be based on more detailed estimates, rather then the, "approximately 140 pairs breed successfully each year" that Bekessy *et al*. cite elsewhere (p. 219).

Note, that the life-stage survivorship rates and longevity attributes provided by Bekessy *et al.* (2004), in combination with the number of chicks produced per annum as we have determined it, indicates a mean annual maximum population estimate for Tasmanian Wedge-tailed Eagles of 742 birds. This is the maximum number of eagles that are suggested would be of flying age and is comprised of the combined estimates of 390 adults, 175 fledglings and 177 birds aged 1 – 4 years. It excludes chicks prior to fledging and juveniles which are encompassed within each annual cohort of fledglings.

This total is considerably lower than the 1500 birds in the population suggested by Bekessy *et al.* although it is derived entirely from values they provide. The number of adults suggested by the life-table does not equate with the 363 breeding pairs on which it is based. This would seem to indicate that published population estimates or demographic rates are not entirely accurate. A smaller annual cohort of chicks, based on 140 successful breeding pairs, would suggest an even lower total population. We have not attempted to reconcile these differences, but note that they are indicative of the kinds of difficulties in population estimates that are available even for a large and conspicuous species that is relatively easy to study. Despite that, in the absence of other information, we have based our modelling on this most recently available information.

Values from the life-table indicate that approximately 24% of the population is comprised of non-breeding adult birds aged 1 – 4 years. This constitutes the nomadic portion of the population.

2.4.3 Populations of Tasmanian Wedge-tailed Eagles at wind farm sites

Specific investigations have not been undertaken into the population dynamics of Tasmanian Wedge-tailed Eagles inhabiting any wind farm sites in Tasmania so there is no empirical data about the number of birds using sites. In order to provide necessary inputs about the number of birds that might interact with turbines at any given site, and consequently across all sites, we have made assumptions about the number of birds involved based on available information about relative regional densities of the wider Tasmanian population of the species (see 2.4.1 *The Tasmanian Wedge-tailed Eagle population*). That has been further informed by knowledge of habitats at particular sites and their potential influence on densities of the bird; by local knowledge, where available; and by information gleaned during bird utilisation studies at a number of the sites. The latter includes the relative frequencies of observing Wedge-tailed Eagles and the maximum numbers of individuals observed on any one occasion at any of the relevant wind farm sites.

The Wedge-tailed Eagle population is comprised of two components whose movement behaviours relative to a particular site are likely to differ. These are territory residents, including breeding adults and their first-year offspring, and nomadic non-breeders aged between approximately one and five years. We have therefore had to determine how to appropriately model for these two sectors of the population in modelling of both collision risk for individual wind farms and subsequently of the cumulative impacts of multiple wind farms.

The numbers of Tasmanian Wedge-tailed Eagles that we have considered are likely to be resident in the area of each wind farm, based on the considerations above, is shown in Table 6 (Section 2.4.5). In order to account for a level of uncertainty, we have attempted to err toward modelling for a higher level of risk and have assumed that the territories of more than one pair may intersect within the site of any given wind farm. Thus for every location where breeding birds might occur we have modelled for the possibility that a minimum of two pairs and their juvenile offspring may interact with turbines on the site.

Based on the 24% of the overall population that was determined to be nomadic, we have added that percentage to the number of residents believed to be present at the majority of wind farm sites. At two sites where resident breeding birds are considered unlikely to exist (Heemskirk and Huxley Hill), we have modelled on the basis of two non-breeding birds being present at all times. Numbers of non-breeding birds at each site are provided in Table 6. The rationale for modelling of the presence of nomadic birds is outlined above (2.4 *Mathematical approach to cumulative impacts modelling*).

The combined total of Tasmanian Wedge-tailed Eagles modelled as having potential to interact with turbines at each wind farm is shown in Table 6.

We have assumed that development of a wind farm does not alienate the area from further use by eagles. This is considered to be the case because previous land uses at all current wind farm sites in southern Australia, including Tasmania, have continued and pre-existing habitat values have remained largely unaltered following construction of facilities. It is also the case that Wedge-tailed Eagles are known to continue to occupy operational wind farm sites in southern Australia, including the large Bluff Point Wind Farm (formerly Woolnorth Lot 1) in Tasmania.

It is also assumed that mortalities due to collisions with turbines do not alter usage, or occupancy of wind farm sites by Tasmanian Wedge-tailed Eagles. We do not consider that collisions are likely to result in heightened avoidance behaviours on the part of survivors. The closest analogy in our view are motor vehicle collisions involving Wedge-tailed Eagles and we are not aware of any suggestion that fatal accidents result in changed behaviours on the part of surviving birds. In the short-term there may be a period of months before an individual bird that is killed might be replaced in a local population. However we do not consider that the presence of a wind farm or the incidence of collision is likely to materially alter the rate at which dead eagles will be replaced from that which occurs elsewhere.

Following the rational outlined above, we have modelled the effects of collisions on the basis that occupancy rates of wind farm sites and eagle behaviours, including avoidance rates for eagles encountering turbines, will remain constant over time.

2.4.4 Frequency and heights of flights by Tasmanian Wedge-tailed Eagles

In studies of the utilisation of wind farm sites by birds through south-eastern Australia, the number of flights and height of each flight made by birds has been recorded during standard point counts. Thus we have data for utilisation by Tasmanian Wedge-tailed Eagles of the Mussleroe, Woolnorth Lot 1, Woolnorth Lot 2 and Heemskirk wind farm sites where Biosis Research has undertaken such investigations. These data provide the parameter inputs used here that are specific to those wind farm locations.

We do not have data for utilisation by Tasmanian Wedge-tailed Eagles of the Jim's Plain, Flinders Island and Huxley Hill sites. In order to model for those sites we have used a scenario for each based on informed assumptions about similarity of the particular location to sites for which we do have data. Thus we have modelled the Jim's Plain site on the basis that it is biogeographically close to the Woolnorth sites and have assumed that utilisation might equate with those recorded at Woolnorth Lot 2, which has higher rates than Woolnorth Lot 1. Similarly, Flinders Island has been modelled on the basis of its biogeographic proximity to the Mussleroe site. Tasmanian Wedge-tailed Eagles are known from King Island but are not known to breed there. Hence, we have assumed that utilisation rates for the Huxley Hill site may be most similar to those recorded at the Heemskirk location which is also in a region believed to be inhabited by few, if any, breeding birds.

Frequency of Wedge-tailed Eagle flights

The numbers of movements-at-risk of collision has been determined from the number of Wedge-tailed Eagle flights recorded during timed point count records at wind farms where they have been undertaken (Mussleroe, Woolnorth Lot 1, Woolnorth Lot 2 and Heemskirk). This parameter is then extrapolated to determine an estimated number of movements-at-risk for each species for an entire year.

For sites where the number of flights has not been collected or was not available (Jim's Plain, Flinders Island and Huxley Hill), we have used a scenario for each based on informed assumptions about similarity of the particular location to sites for which we do have data, as outlined above (Section 2.5).

The numbers of flights per annum at risk of collision with turbines that have been used in modelling for each site are the sum of the numbers of flights shown for the two height zones in Table 6.

Relative heights of Wedge-tailed Eagle flights

The height at which birds fly within a wind farm is relevant to the likelihood of collision with turbines due to the different heights of turbine components and different collision risks they present to birds. The moving rotors of a turbine are considered to present a greater risk than are the static elements of the machine. A variety of turbine types are involved in this assessment, but by way of example, the rotors of the largest turbines (Vestas V90) on a standard height tower, sweep a 90 metre deep height zone between 33 and 123 metres above the ground. This rotor-swept-zone is considered to represent an area of greater danger to flying birds than is the stationary tower below rotor-swept height.

As part of our studies of bird utilisation at the Mussleroe, Woolnorth Lot 1, Woolnorth Lot 2 and Heemskirk wind farm sites we have recorded the height of each flight made by birds observed during standard point counts. These data are allocated to the two height zones in which birds may interact with turbines:

- the zone between the ground and the lowest point swept by rotors, and
- the zone between the lowest and highest point swept by rotors (the rotor-swept-zone).

The proportion of flights recorded from the two height zones vary considerably between the four sites, but are consistent in that the majority of flights were from rotor-swept-height at all of them (Table 6).

Flight height data has not been collected or was not available for the remaining three sites, Jim’s Plain, Flinders Island and Huxley Hill. In order to model for those sites we have used a scenario for each based on informed assumptions about similarity of the particular location to sites for which we do have data, as outlined above (Section 2.5).

2.4.5 Parameters modelled for Tasmanian Wedge-tailed Eagles at wind farm sites

The data or scenario for Tasmanian Wedge-tailed Eagle modelled for each wind farm is outlined in Table 6.

Table 6 Inputs modelled for Tasmanian Wedge-tailed Eagle use of wind farms

Wind farm	Number of flight records from below rotor-swept-zone	Number of flight records from within rotor-swept-zone	Total minutes of observations	Putative number of residents (breeding age adults + juveniles) modelled	Putative number of floaters (1- 4 year old non-breeders)	Modelled population total for site
Mussleroe [A]	3	29	8100	6	1.44	7.44
Heemskirk [A]	1	7	11610	0	2	2
Jim's Plain [B]	Modelled as for Woolnorth Lot 2			6	1.44	7.44
Woolnorth Lot 1 [A]	11	32	11315	9	2.16	11.16
Woolnorth Lot 2 [A]	32	45	14805	6	1.44	7.44
King Is Huxley Hill [B]	Modelled as for Heemskirk			0	2	2
Flinders Island [B]	Modelled as for Mussleroe			6	1.44	7.44
		Total		**33**	**11.9**	**44.9**

[A] = All values from site-specific data

[B] = Scenario based on similar site

2.4.6 Avoidance by Tasmanian Wedge-tailed Eagles of wind turbines

Note that in modelling of the cumulative impacts of collision, any collision caused by a bird striking, or being struck by, a turbine, is assumed to result in death of the bird.

The use of the term 'avoidance' here refers to how birds respond when they encounter a wind turbine, that is, the rate at which birds attempt to avoid colliding with the structures.

At the request of DEH, three avoidance rates are modelled: 95%, 98% and 99%. Given that static elements of a turbine (tower, nacelle, etc.) are stationary and highly visible, we take the approach of modelling the likely avoidance rate of the area presented by these parts as 99% in all scenarios. The three variable avoidance rates that are modelled here relate to the area in which the sweeping motion of rotors is considered to present a higher risk. They are calculated as the area swept by rotors during the passage of a bird at a given flight speed. Complete lack of avoidance (0%) is behaviour that has not been observed in any study of bird interactions with wind turbines and would be analogous to birds flying blindly without responding to any objects within their environments. It should be noted that 99% avoidance rate means that for every 100 flight made by a bird it will make one in which it takes no evasive action to avoid collision with a turbine. In real terms this equates to avoidance behaviour that is considerably lower than that shown by many species of birds under most circumstances. Absolute avoidance behaviour (100%) has been documented for some species and may be a reasonable approximation for many species in good conditions, but is unlikely for some species in certain conditions.

For all bird groups, specific avoidance rates measured to date are:

1. Directly observed avoidance rates (i.e. observations of birds passing through a turbine array, but showing active avoidance of collisions):

- 100% - Barnacle, Greylag, White-fronted Geese, Sweden (Percival 1998);
- 100% - range of species (Common Starling, Straw-necked Ibis, Australian Magpie, Australian Raven, Little Raven, European Goldfinch, White-fronted Chat, Skylark, Black-shouldered Kite, Brown Goshawk, Richards Pipit, Magpielark, Nankeen Kestrel, White-faced Heron, Brown Songlark, Wedge-tailed Eagle, Swamp Harrier, Brown Falcon, Collared Sparrowhawk, egret sp., White Ibis), Codrington, Victoria (Meredith *et al.* 2002);
- 99% - migrating birds, Holland (diurnal and nocturnal data) (Winkelman 1992);
- 99.9% - gulls, Belgium (Everaert *et al.* 2002, in Langston & Pullan 2002);
- 99.8% - Common Terns, Belgium (Everaert *et al.* 2002, in Langston & Pullan 2003);
- 97.5% - waterfowl and waders, Holland (Winkelman 1992, 1994);
- 87% - waterfowl and waders at night, Holland (Winkelman 1990).

2. Calculated avoidance rates (i.e. recorded fatalities compared with measured utilisation rates – these are more accurately considered as survival rates of birds passing through a wind farm, but they give an indirect estimate of avoidance rate):

- 100% - waterfowl, Yukon, Canada (Mossop 1997);

- 100% - raptors, Yukon (ibid);
- 99% - Australian Magpie, Skylark, Codrington Victoria (Meredith *et al.* 2002);
- 99% - waterfowl, waders, cormorants, UK (Percival 2001);
- >95% - Brown Falcon, Victoria [Codrington] (Meredith *et al.* 2002).

Based on the experience cited above, it is reasonable to conclude that an avoidance rate of 99% or greater is typical for daylight and normal weather. The only measured avoidance rate of nocturnal flights is 87% (Winkelman 1990). While other sources conclude that birds' avoidance behaviour differs between night and day, they do not provide actual avoidance rates. Radar studies record 100% avoidance in most cases, but where a "reduction" in avoidance has been noted, corresponding avoidance rates have not been provided (Dirksen *et al.* 1996). These sources suggest that at night, birds are more cautious about flying into a wind farm area, but have potentially lower rates of avoidance if they do enter a wind farm. Since 87% is the only avoidance rate figure available for conditions of poor visibility (e.g. night, fog), and in the absence of any other empirical data this is most reasonable to use as a lower bound on ecologically reasonable rates.

It would seem likely that avoidance by a species with the flight characteristics of the Tasmanian Wedge-tailed Eagle would generally be in the range of 95% to 100% in most conditions. Eagles may fly infrequently when visibility is reduced by fog or rain, however some individuals of some species do fly under these conditions and this can lead to increased collision risk. They are highly unlikely to fly during the hours of darkness. Data from overseas, based on findings of bird carcasses, demonstrates that large raptors do collide with turbines. However, empirical data about avoidance rates requires investigations that assess the actual behaviours of birds when they are confronted by turbines. Such studies for raptors have rarely been attempted and the only research into this question for the Wedge-tailed Eagle is that of Meredith *et al.* (2002) who investigated avian avoidance of turbines at the Codrington wind farm in Victoria. They documented just three instances of Wedge-tailed Eagles flying in the vicinity of the wind farm and the birds avoided collision in each case. In a recent investigation of collision risk for the closely related Golden Eagle *Aquila chrysaetos* for the proposed Lewis Wind Farm in Scotland, Coates (2004) modelled for avoidance rates of between 95% and 99.9%. He considered that, '… the actual level of avoidance is most likely to lie within the upper part of this range, that is, around 99.0 to 99.5%". Overall, considering the range of species sampled in Australia and overseas, the consistency in avoidance rates and the absence of any documented cases lower then 95%, it is appropriate to assume that Tasmanian Wedge-tailed Eagles will have avoidance rates in the 95% - 100% range. Nonetheless, we recommend that this is a key area requiring further soundly based investigation within operational wind farms.

3.0 RESULTS: CUMULATIVE IMPACTS MODELLING

3.1 Estimated impacts from modelling of individual wind farms

The initial stage for modelling the cumulative risk of Tasmanian Wedge-tailed Eagle collisions with wind turbines is to determine a level of risk posed by each individual wind farm. Results from this process also allow assessment to be made of the effects of any single wind farm or of any combination of farms. For the purposes of evaluating the potential impacts of current or future proposals to build wind farms this component of the process provides a valuable tool.

Predicted risk of collisions is expressed as a mean annual survivorship rate which represents the proportion of the population that is expected to survive all encounters with turbines at a given wind farm during the course of a year. Modelled survivorship rates for relevant wind farms are shown in Table 7. It has been necessary to calculate and show these values to four significant numbers in order for differences between them to be detected. It is important that this is not to be misinterpreted to indicate any level of 'accuracy' in the predicted results.

Table 7 Modelled survivorship rates for wind farms presenting a collision risk to Tasmanian Wedge-tailed Eagles

Windfarm	Survivorship rate at 95% avoidance rate	Survivorship rate at 98% avoidance rate	Survivorship rate at 99% avoidance rate
Mussleroe	0.8621	0.9248	0.9467
Heemskirk	0.9118	0.9524	0.9663
Jim's Plain	0.9269	0.9595	0.9706
Woolnorth Lot 1	0.9628	0.9783	0.9835
Woolnorth Lot 2	0.9187	0.9548	0.9672
King Is Huxley Hill	0.9793	0.9891	0.9924
Flinders Island	0.9881	0.9932	0.9948

3.2 Estimated cumulative impacts across the range of the Tasmanian Wedge-tailed Eagle

No empirical values for annual variations in population numbers nor for any variables of demographic parameters influencing the population were available. Clearly environmental variables and stochastic events have effects on the Tasmanian Wedge-tailed Eagle population, however in the absence of any known values and for simplicity of presentation, we have not assigned arbitrary coefficients of variation. Therefore, in the following results and discussion mean values are used throughout, but may be viewed as indicative only. Annual variations in all values will occur and may have considerable influence on population numbers used here and on predictions derived from them.

The total number of Wedge-tailed Eagles modelled as interacting annually with all seven wind farms under consideration here is 45 (2.4.5 *Parameters modelled for Tasmanian Wedge-tailed Eagles at wind farm sites*). This equates to 6% of the entire Tasmanian population of 742 Wedge-tailed Eagles (as derived from the life-table) that is at risk of collisions with wind turbines.

The weighted mean survivorship rates determined for the cumulative impacts of collisions at all wind farms across the Tasmanian Wedge-tailed Eagle's range are provided in Table 8.

Table 8 **Cumulative survivorship values for the Tasmanian Wedge-tailed Eagle population from potential collision risk posed by seven wind farms in Tasmania**

Survivorship rate at 95% avoidance rate	Survivorship rate at 98% avoidance rate	Survivorship rate at 99% avoidance rate
0.9355	0.9642	0.9741

3.2.1 Impacts on Tasmanian Wedge-tailed Eagle annual survivorship

In order to assess the potential impact of altered survivorship rates that may be imposed on the Tasmanian Wedge-tailed Eagle population by collisions with wind turbines it is first necessary to know the background survivorship rate that affects the population in the absence of any impacts of wind farm collision.

A mean annual background survivorship rate of 0.8660 (i.e. 86.60% of the population surviving from one year to the next) was obtained from the life-table constructed from previously published rates for life-stages of the Tasmanian

Wedge-tailed Eagle population (see 2.4.2 *Determining population values used for modelling*).

The effect of survivorship values for cumulative impacts of collision risk on the portion of the Tasmanian Wedge-tailed Eagle population that interacts with wind farms is found by multiplying the background by wind farm survivorship rates.

Thus, for the case of 95% avoidance rate, the cumulative effect equals 0.8102 (0.8660 x 0.9355). The equivalent annual rate for 98% avoidance rate equals 0.8350 (0.8660 x 0.9642) and for 99% avoidance rate equals 0.8436 (0.8660 x 0.9741). Note that these altered survivorship rates affect only the 6% of the population that are modelled as coming into contact with wind farms in any year, while the remaining 94% of the population continue to experience the background rate.

We can also determine an overall cumulative impact of the seven wind farms on the entire subspecies. To do so we compare the effect of background survivorship of the entire population in the absence of wind farms, with the combined effects of that rate affecting the 94% of the population that do not interact with turbines on the seven wind farms and the predicted increased rate affecting the 6% of the population that does interact with them.

The background rate for the entire population indicates that a mean of 642.23 birds survive each year (742 x 0.8660). Of 94% (697 birds) of the population surviving at the mean annual background rate, 603.26 (697 x 0.8660) would be expected to survive per annum.

For 95% collision avoidance rate, of 6% (45 birds) of the population affected by the survival rate for wind farms, 36.46 (45 x 0.8102) would be expected to survive each year. The sum of these two components of the overall population is 640.06 birds. Expressed in terms of the effect on annual survivorship rates of the entire population, this predicts an overall decrease from 0.8660 to 0.8631.

For 98% collision avoidance rate, of 6% (45 birds) of the population affected by the survival rate for wind farms, 37.58 (45 x 0.8350) would be expected to survive each year. The sum of these two components of the overall population is 641.18 birds. Expressed in terms of the effect on annual survivorship rates of the entire population, this predicts an overall decrease from 0.8660 to 0.8646.

For 99% collision avoidance rate, of 6% (45 birds) of the population affected by the survival rate for wind farms, 37.96 (45 x 0.8436) would be expected to survive each year. The sum of these two components of the overall population is 641.22 birds. Expressed in terms of the effect on annual survivorship rates of the entire population, this predicts an overall decrease from 0.8660 to 0.8646, which is no different from that predicted for 98% avoidance.

3.2.2 Predicted Tasmanian Wedge-tailed Eagle mortalities

A number of birds that might be killed annually by the predicted cumulative effects of turbine collisions for all seven wind farms can be determined by comparing the number of individuals utilising the wind farm sites that would be expected to die at the background mortality rate with the number expected to die at the rate predicted for wind farms. The total population of Wedge-tailed Eagles modelled as interacting annually with all seven wind farms under consideration here is 45 (2.4.5 *Parameters modelled for Tasmanian Wedge-tailed Eagles at wind farm sites*). Note that mortality rate is simply the inverse of survivorship of rate. See Section 3.2.1 *Impacts on Tasmanian Wedge-tailed Eagle annual survivorship* for survivorship rates calculated for the three different rates of collision avoidance modelled.

The background annual mortality rate equals 0.1340 (i.e. the inverse of the predicted annual cumulative survivorship rate (1 - 0.8660 = 0.1340). The annual number of background mortalities occurring within the population of Wedge-tailed Eagles modelled as interacting annually with all seven wind farms thus equates to 6.03 birds (i.e. 45 x 0.1340 = 6.030).

For the case of 95% avoidance rate, the predicted annual cumulative mortality rate from wind turbine collisions equals 0.1898 (i.e. the inverse of the predicted annual cumulative survivorship rate (1 - 0.8102 = 0.1898). The annual number of mortalities thus equates to 8.54 birds (i.e 45 x 0.1898 = 8.541). The increase in mortalities of the entire Tasmanian Wedge-tailed Eagle population due to the cumulative effects of collisions at 95% avoidance rate, is thus predicted to average approximately 2.5 birds per annum (8.54 – 6.03 = 2.51).

For the case of 98% avoidance rate, the predicted annual cumulative mortality rate from wind turbine collisions equals 0.1650 (i.e. the inverse of the predicted annual cumulative survivorship rate (1 - 0.8350 = 0.1650). The annual number of mortalities thus equates to 7.43 birds (i.e 45 x 0.1650 = 7.425). The increase in mortalities of the entire Tasmanian Wedge-tailed Eagle population due to the cumulative effects of collisions at 98% avoidance rate, is thus predicted to average approximately 1.4 birds per annum (7.43 – 6.03 = 1.40).

For the case of 99% avoidance rate, the predicted annual cumulative mortality rate from wind turbine collisions equals 0.1564 (i.e. the inverse of the predicted annual cumulative survivorship rate (1 - 0.8436 = 0.1564). The annual number of mortalities thus equates to 7.04 birds (i.e 45 x 0.1564 = 7.038). The increase in mortalities of the entire Tasmanian Wedge-tailed Eagle population due to the cumulative effects of collisions at 99% avoidance rate, is thus predicted to average approximately 1.0 birds per annum (7.04 – 6.03 = 1.01).

We consider that a collision avoidance rate for the species is likely to be 99% or higher. Thus the additional mortality predicted for the cumulative effects of turbine collisions for wind farms within the range of the Tasmanian Wedge-tailed Eagle is likely to result in the additional death of approximately one bird per annum.

3.2.3 Conclusion

The cumulative impacts of collision with turbines on the overall population of Tasmanian Wedge-tailed Eagles, predicted by the modelling for current and presently proposed wind farms within the species' range, are very small and it is thus highly likely that their effects would be masked by normal fluctuations in the population due to natural environmental variables. However, mortality due to turbine collision is a negative impact on the species that would be expected to increase further if the number of wind farms continues to grow (see also Section 5.0 *Results and Discussion: PVA Modelling Of Critical Impact Assessment*).

Effects of wind farm developments on eagle populations, other than collisions with turbines, such as direct and indirect losses of habitat are not encompassed by the assessment here. Collisions with other wind farm infrastructure like transmission poles and lines may present particular risks for eagles. We recognise that the cumulative impacts of a variety of such aspects of wind farms may have adverse effects on the Tasmanian Wedge-tailed Eagle population additional to those modelled here.

4.0 METHODS: DETERMINING CRITICAL IMPACT LEVEL

The objective of this element was to determine a suitable assessment for providing an estimate of the level at which predicted collision is likely to present concerns for the Tasmanian Wedge-tailed Eagle population. Ideally, a critical impact level should be measured in terms of presented area of turbines (m^2). Such a value could conceivably be converted into a number of turbines of any particular type, or into a matrix of both turbine numbers and types.

One method is to use a Population Viability Analysis (PVA) to assess the level of impact on the population that would significantly increase the probability of extinction risk to the population. Simplistically, the objective would be to determine a threshold extinction risk below which the impact of predicted collisions with wind turbines would be considered ‘acceptable’ and above which the impact would be considered to be ‘unacceptable’.

We have used the Population Viability Analysis tool, VORTEX (v9.51), to examine the difference in extinction risk posed to the Tasmanian Wedge-tailed Eagle resulting from increased mortality due to collisions with wind turbines as predicted by our modelling of the cumulative effects of wind farms in Tasmania. The VORTEX model used is an individualistic, stochastic model, accounting for life-stages and various mortality risks. It was possible to undertake this analysis for the Tasmanian Wedge-tailed Eagle only because a recent PVA has been undertaken to assess the potential impacts of forestry practices on a regional portion of the population (Bekessy *et al.* 2004) and it provided values for most of the population parameters required. Where derived values were required, the base data provided by Bekessy *et al.* permitted us to construct a life-table in order to calculate required values.

In the absence of empirical data, any evaluation of what constitutes a critical level of impact on an endangered species or population, will necessarily be subjective and arbitrary and we are not in a position to mandate a threshold level for ‘acceptable’ risk. Nevertheless, by re-running scenarios, increasing the environmental mortality each time, we were able to determine where the cumulative effects of wind farms (under the refinements and assumptions of our greatly simplified PVA – see below) began to make a measurable and significant effect.

4.1.1 Assumptions and inputs to the VORTEX PVA model

Extinction was defined as occurring in a simulation if the population was reduced to only one gender.

The population was modelled as homogenous over the entire suitable habitat range. We are aware that densities of Wedge-tailed Eagles do vary considerably across the species' range in Tasmania (Mooney and Holdsworth (1991), Bell and Mooney (1999)). But we were not able to take this factor into account in PVA modelling since the proportions of the population that exist at different densities have not been quantified. However, this will mean that wind farms situated in different parts of the range would present different levels of risk to the population. Hence a single measure of risk is not entirely applicable across the species' range and this complicates the notion of determining a single suitably applicable threshold that would constitute a critical impact level.

The eagles were defined as long-term monogamous, with a maximum breeding age of 25 years. It was assumed that the age of first breeding was the same for both males and females, and was set at 5 years. The maximum progeny per cycle was set at two, although with a 98% likelihood of only one offspring. The sex ratio at birth was assumed to be equal.

The mean annual fecundity of adult females was set at 0.531 (Bekessy *et al.* 2004), with an environmental variation allowing for a 95% confidence interval for the rate of between 0.425 and 0.637.

No distinction in demographic values was drawn between the sexes, and the following table of mortality rates (Table 9) was derived from the life table we constructed (2.4.2 *Determining population values used for modelling*).

Table 9 **Mortality rates and standard deviations for life-stages used in PVA modelling of extinction risks posed by predicted collisions with wind turbines on Tasmanian Wedge-tailed Eagles**

Life Stage	Mortality	Standard Deviation due to Environmental Variance
0-1 Year	0.55	0.20
1-2 Years	0.30	0.03
2-3 Years	0.25	0.03
3-4 Years	0.20	0.03
4-5 Years	0.10	0.03
5+ Years	0.05	0.03
25+ Years	1.00	0.00

The initial population was assumed to be 700 individuals, with a maximum environmental carrying capacity of 1500 individuals. It should be noted that in the 20000 simulation runs used to generate the following findings, not a single run met this carrying capacity barrier. It was assumed that carrying capacity was static for the 200 years of the simulation run, meaning that no habitat loss (or creation) was modelled.

There was assumed to be a correlation between the environmental variation in good breeding years, and years conducive to higher survival rate.

The focus of this model was to highlight the difference in survivorship rate/extinction probability between different scenarios hence we did not model the species' recovery rate, or the ability to recover from any stochastic catastrophe. In the absence of input values and the interests of clarity, we did not model genetic effects or density dependent breeding effects. There was no account made in this modelling for either harvest, or supplementation of the population.

A run of 5000 iterations, modelling the population over 200 years, was completed for the background configuration detailed above. The data from this was collated, and the mean extinction was used to generate a probability of extinction.

4.1.2 Incorporating the effects of wind farm collisions

From the cumulative effects modelling process, it was predicted that the overall survival rate for the Tasmanian Wedge-tailed Eagle may be expected to drop from a background environmental rate of 0.8660 to 0.8646. This corresponds to a 0.001% increase in mortality rate. As wind farms are assumed to be non-discriminating in their risk, this 0.001% increase in mortality was applied across all of the life stages. Environmental variation and all other factors were kept the same as previously. Another 5000 scenarios were run to model the predicted cumulative effects of wind farm collisions, and the mean outputs were compared with the outputs of the previous 'background' model.

4.1.3 Assessment of significant impacts

It order to ascertain a point at which the effects of collisions at a number of wind farms begin to make a measurable and significant effect on the extinction risk to the population, we re-ran the wind farm scenario a number of times increasing the environmental mortality each time. This process, under the refinements and assumptions of this very simplified PVA, permitted us to determine a level at which heightened mortality began to significantly increase the probability of extinction risk.

5.0 RESULTS AND DISCUSSION: PVA MODELLING OF CRITICAL IMPACT ASSESSMENT

PVA modelling found that the risk of extinction is not affected to any significant level by the introduction of collision risks predicted by our modelling of the cumulative impacts for the seven wind farms assessed here.

Comparing the two P(Extinct) curves generated for extinction risk in the absence of the seven wind farms and with the seven wind farms (i.e. with a mortality rate increase of 1.001 over the base scenario) (Figure 1), a slight increase in extinction risk can be identified for the data set containing wind farm effects. However the standard error associated with each curve clearly overlaps the other, indicating that there is no significant difference. In fact, the median year of extinction for both scenarios is identical, supporting the argument of no significant effect.

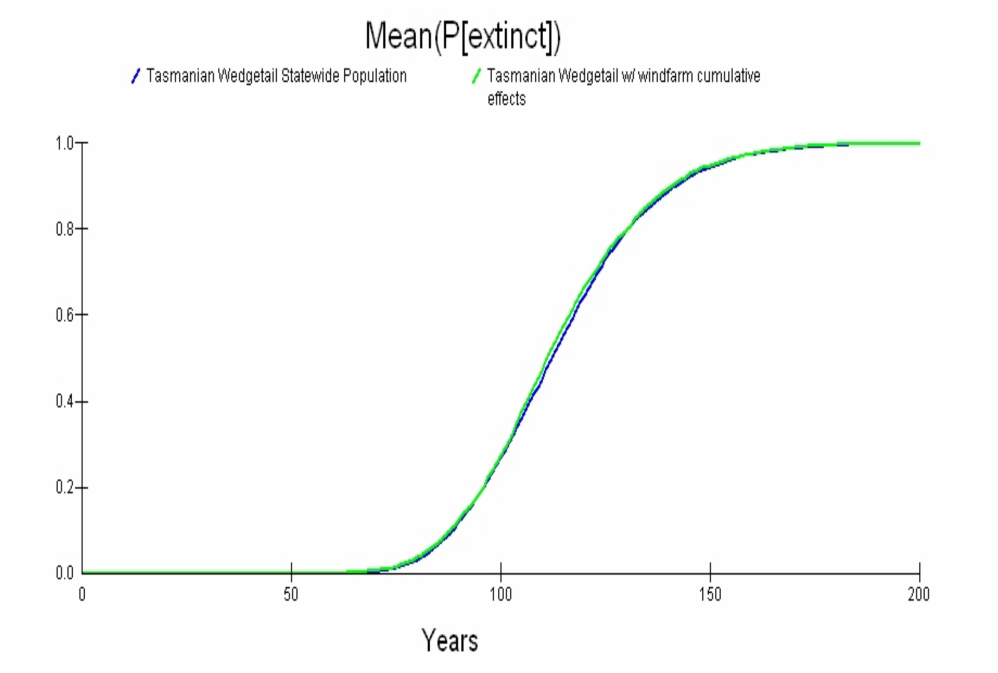

Figure 1

Examining the same curves with the Standard error bars overlain (Figure 2), it can be seen that there is no significance to the slight difference between the two curves.

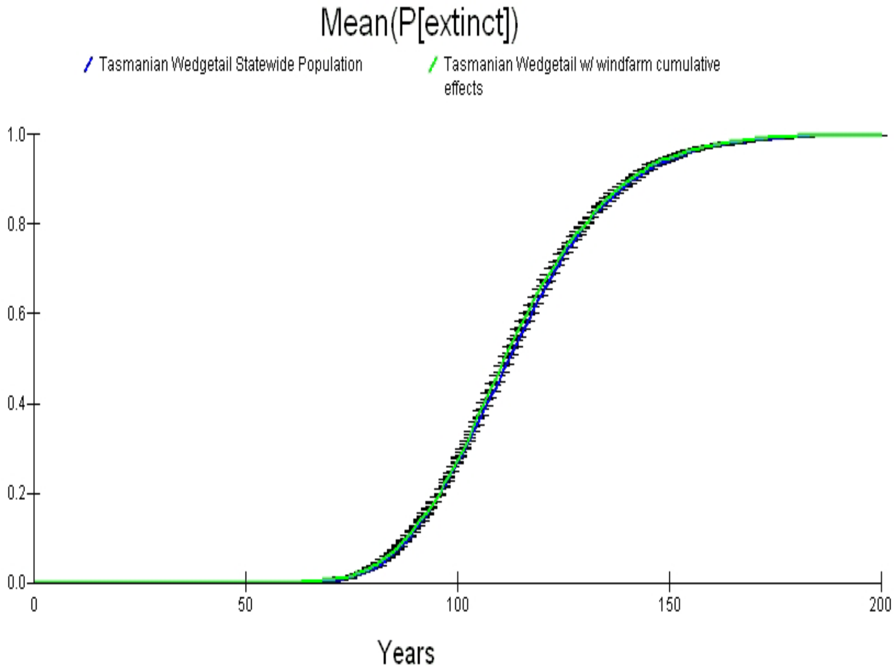

Figure 2

The model was re-run using the same scenarios but with incrementally increased mortality each time with a view to determining a point at which the effects of collisions at a number of wind farms begin to make a measurable and significant effect on the extinction risk to the population. Hence, it was run with for 1.005, 1.0075, 1.01 and 1.02 times the background mortality. This generated the family of curves shown in Figure 3.

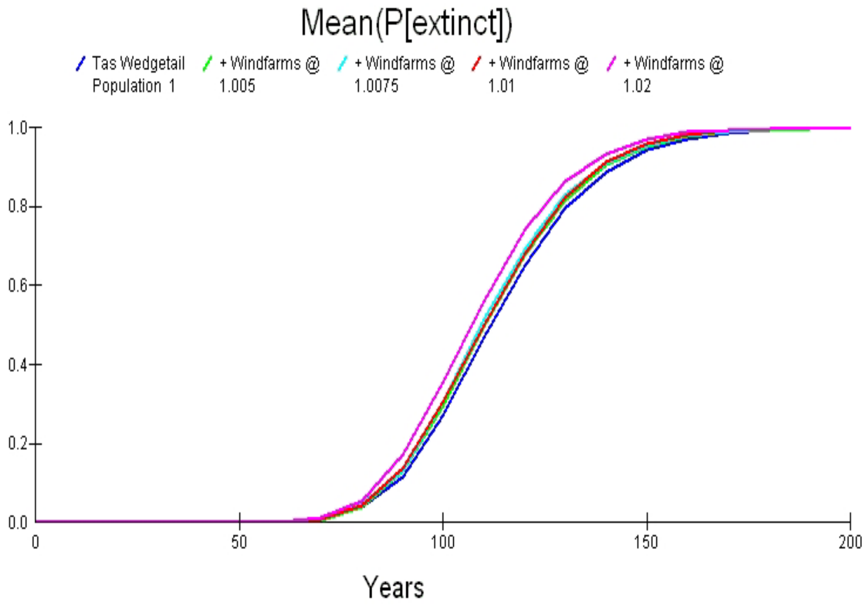

Figure 3

It is at the 1.005 level, or an increase of 0.5% to the background mortality rate that a difference in the models can first start to be resolved. It should be noted here that the increase of 0.75% actually shows a greater chance of extinction than increasing the background mortality by a whole percentage point. This serves to highlight the level of caution we should have in using the model for such fine analysis.

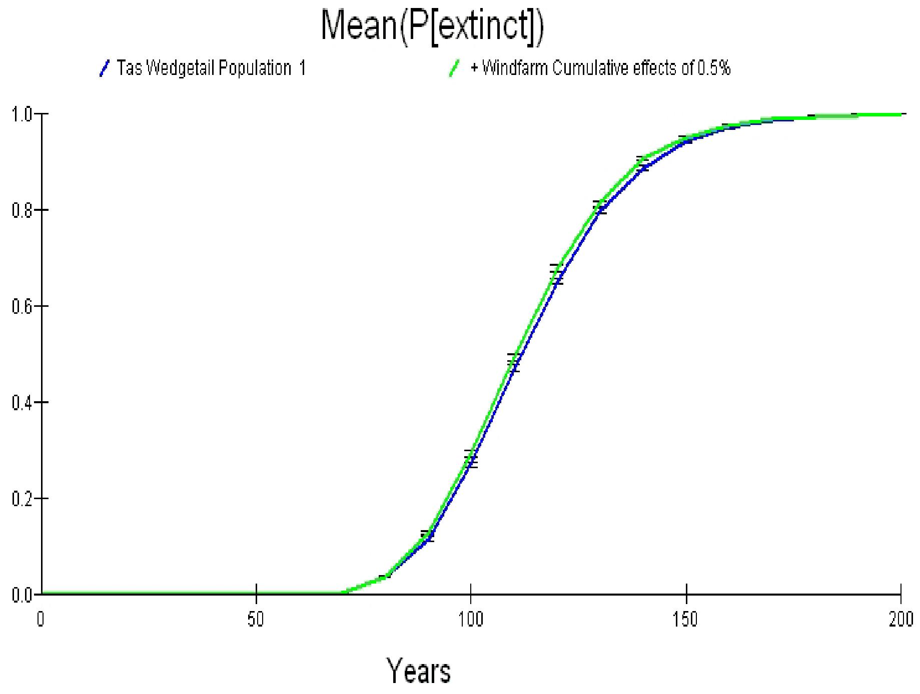

Figure 4

Showing the error bars, we can see that they just begin to separate at the 0.5% level (Figure 4).

If we examine the mean numbers of individuals predicted for any given time we can see that all curves are well and truly within each other's band of confidence (Figure 5).

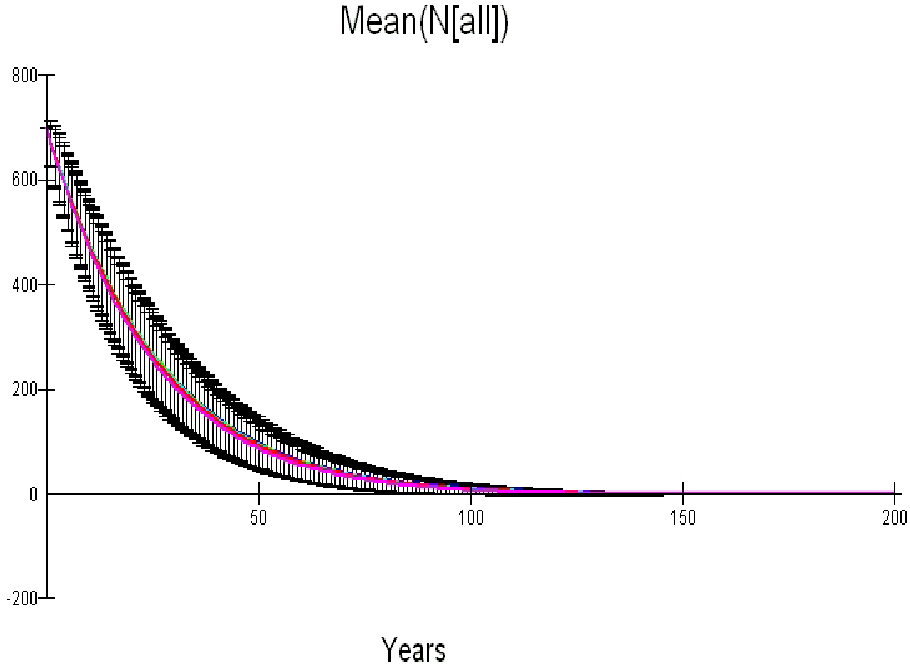

Figure 5

5.1.1 Conclusion and caveats

Predicted risk of extinction for Tasmanian Wedge-tailed Eagles of the modelled cumulative impacts of the seven wind farms (i.e. an expected 0.001 increase in mortality) is not significantly different from that indicated for the population in the absence of those wind farms. *PVA modelling predicted a significant difference in extinction risk only when the mortality rate increased to five times that level.* On this basis it could be predicted that a significant impact on the Tasmanian Wedge-tailed Eagle population, over and above the existing variable mortality due to current environmental conditions, might occur only if collisions with turbines occur at a considerably higher rate than they are predicted to by our modelling for seven existing and currently proposed wind farms.

However, we offer this assessment derived from PVA modelling with strong reservations. Using the PVA model in this way places incredible faith in its representation. We have used the PVA model in the most appropriate setting, as an aid to comparison of two scenarios. Unfortunately, the actual data entered to the PVA model is simplistic as it does not account for catastrophes, significant events, or a full range of potential environmental variables. These factors aside, the simple PVA as it is used here can highlight the extent to which collisions with turbines at that the wind farm sites can be expected to affect the likelihood of survival. By removing the environmental factors described above, we reduce the variability of the population, and increase the sensitivity of the population to background environmental mortality rates. This will result in a slight overstatement of the sensitivity to cumulative effects of wind farms on the probability of survival.

APPENDICES

APPENDIX 1

Cumulative Wind Farm Effects Modelling

Cumulative Wind Farm Effects Modelling

Approach and Justification

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SymboliX
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June 10, 2005

Abstract

The method to combine the individual wind-farm site assessments into a cumulative effects model is described. It is shown that this is done by multiplying all the individual site survival probabilities for each species together. i.e Survival chance = $P(S_1)P(S_2)P(S_3)P(S_4)\dots P(S_N)$

1 Introduction

Previous windfarm modelling has resulted in a measure of risk of bird-turbine interactions. It inherently relied on the assumption that the bird interacted with the site of the farm, and proceeded to generate a measure of the probability of birdstrike through calculations of presented areas of turbine and assumptions and observations of bird movements.

To approximate cumulative effects of multiple windfarms on the risk of strike, we need to remove the assumption that the bird is already interacting with the site. Having done this, we must account for the probabilities of interacting with a given farm site, and then incorporate the risk of strike associated with that farm. We then can proceed to calculate the survival rate of a bird population residing or moving through a region with resident windfarms.

2 Mechanics

This section is provided to allow for subsequent auditing of the process. Due to its technical nature, it may be skimmed by the non-technical reader.

2.0.1 Definitions

- *"region"* At this stage we only refer to a *region* to allow the distinction between "home-ranges" and "habitats." Appropriate choices for what these regions represent will need to be made at a later stage.
- N the number of wind farm sites found within the region of interest
- *"site"* A particular wind farm, consisting of turbines standing on some of the region
- B_i the event of a birdstrike associated with site i
- A_i the event of a bird interacting with site i
- S_i the event of survival of an interaction with site i
- $P(C)$ a measure of the probability of an event, C, occurring

Note: The development of the method requires that all mortality risk assessments be converted to survival chance. This is due to the impossibility of a struck bird going on to either be struck again, or to survive the next interaction. Only survivors can continue to interact.

2.1 Estimating Individual Site Risk ($P(B_i|A_i)$)

As stated previously, the previous wind farm risk assessments have concentrated on the risk of strike, *given that the bird is flying through the site.*

Using the definitions of section 2.0.1, this is written as

$$P(B_i|A_i), \tag{1}$$

and read as *the probability of strike (event B_i), given that the bird is already on site (event A_i).*

A measure of this risk can be obtained one of two ways. Assuming there is a significant population (defined to be large enough that the loss of a single bird will not be significant and another individual will replace it) then

$$\frac{\text{Movements at Risk}}{\text{Total Yearly Movements}} \tag{2}$$

can be used. Using this ratio implicitly assumes that the site population is comparable to the number of observed movements. This may result in a significant under estimate of risk.

If the population is small, then the mortality rate should be taken from the earlier model's measure of corpse numbers per year, and expressed as

$$\frac{\text{Expected corpses per year}}{\text{Population}}. \tag{3}$$

The later form, if population data is available, is the preferred form. This is both for completeness as well as ease of implementation. If the actual population is known to be small but site residency is unknown, it is better to estimate site population, or enter the habitat population, than to rely on the movements at risk approximation which could well be two orders of magnitude below actual risk.

2.2 Estimating the chance of surviving a site

To estimate the chance of surviving a site, we need both the probability of never visiting ($P(A')$) and the chance of visiting, but not being struck ($P(B'|A)$). As there are only three possibilities,

1. Visiting and *not* being struck,
2. Visiting and *being* struck,
3. and Not visiting at all

the easiest estimation of this risk is to calculate the risk of visiting and being struck, and subtract this value from unity.

The probability of visiting *and* being struck is given by,

$$P(A_i \cap B_i) = P(A_i)P(B_i|A_i) \tag{4}$$

The chance of surviving site i is then given by

$$P((A_i \cap B_i)') = P(S_i) = 1 - P(A_i)P(B_i|A_i) \tag{5}$$

Note: Earlier, non-cumulative models assumed that $P(A) = 1$

The previous section (2.1) dealt with derivation of the second term. The first term ($P(A_i)$) can be approximated a number of ways. These are detailed next.

2.3 Estimating the chance of visiting a site ($P(A_i)$)

Previous modelling successfully avoided the issue of the physical size of the windfarm site through its implementation of the observational data. Unfortunately, there does not appear to be any way to avoid incorporating this measure into the model at this stage.

The chances of visiting a given site can be generated by measuring the interaction between a region and the site. This is most naturally done by comparing areas of the site relative to the region. This assumes that there is no reason for visiting or avoiding the site relative to any other area of the region. It may be appropriate to adjust this value if the site is a significant habitat or food source likely to attract visits. Conversely, if the site is barren, $P(A_i)$ might be adjusted downwards to account for this. Without accurate data on visitation habits, the following estimates are safe and realistic by assuming a homogenous region.

A basic measure of this probability is given by

$$P(A_i) = \frac{\text{Area of site}}{\text{Area of region}} \tag{6}$$

This approximation is most appropriate for sedentary species, where the relevant region is the home range, not the habitat.

The form indicated above may also be used for migratory species. If it is to be used for a migratory species, the region appropriate becomes the habitat area. Should the species be using a narrow corridor, this form will be an underestimate of risk.

For a migratory species using a corridor, $P(A_i)$, is better approximated by taking the widest projection of the farm site (orthogonal to the corridor), and dividing through by the width of the migratory corridor at that location. i.e

$$P(A_i) = \frac{\text{width of site}}{\text{width of corridor}}. \tag{7}$$

This removes the possibility of birds flying around a farm placed in the corridor, without ever "passing" it. This eventuality is possible for sedentary species, who are free to roam in arcs whilst avoiding the actual site.

2.4 Cumulative effect of N sites

Having generated the chance of surviving site i's existence
$(P(S_i) = 1 - P(A_i)P(B_i|A_i))$,
we need to know the likelihood of surviving all N sites in the region.

This is given by

$$P(S_1 \cap S_2 \cap S_3 \cap \ldots). \tag{8}$$

As surviving any one of the windfarm sites in the region is independent of surviving any other site, this simplifies to

$$\begin{aligned} P(S_{1\ldots N}) &= P(S_1)P(S_2)P(S_3)\ldots && (9)\\ &= \Pi_i^N P(S_i) && (10) \end{aligned}$$

3 Summary

The derivation of cumulative effects takes into account the varying individual risk presented by each wind farm in a given region. This information can be taken directly from the previously prepared reports on each site. Extra information required to perform this calculation is:

For sedentary species : relative areas of home ranges and site areas occupied by windfarms/turbines

For migratory species : effective blockage of corridors by windfarm sites.

3.1 Calculation steps

To calculate the cumulative effect on the survival rate of a species:

1. Identify the sites relevant to each species
2. Estimate the mortality rate for each site ($P(B_i|A_i)$). This can be done either through the movements at risk, or mortality (corpse) rate found on the summary pages. (See Section 2.2)
3. Determine an appropriate chance of site visitation, $P(A_i)$. (See Section 2.3)
   Note: If the home range of a sedentary species is significantly smaller than the habitat, then average, representative values for these probabilities may be calculated and substituted.

4. Determine the survival rate of each site via $1 - P(A_i)P(B_i|A_i)$.
5. Multiply all the survival rates of each site relevant to the species together.
   Note: If using average properties (as discussed in the previous point), raise the average probability to the power of the number of sites relevant to the size of the home range.

The resultant figure is a chance of survival for the species as a result of the residency of windfarms in the habitat or corridor. A figure of unity (1) indicates no individual will ever be struck. Zero (0) indicates complete loss of the population.

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