Modelled cumulative impacts on the White-bellied Sea-eagle of wind farms across the species' Australian range

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Ian Smales

White-bellied Sea-Eagle
Dave Watts

BIOSIS
RESEARCH

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BIOSIS RESEARCH Pty. Ltd. A.B.N. 65 006 175 097
Natural & Cultural Heritage Consultants

Melbourne: *38 Bertie Street Port Melbourne 3207*
Ph: (03) 9646 9499 Fax: (03) 9646 9242
email: melbourne@biosisresearch.com.au

Ballarat: *449 Doveton Street north, Ballarat VIC 3354*
Ph: (03) 5331 7000 Fax: (03) 5331 7033
email: ballarat@biosisresearch.com.au

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ABBREVIATIONS

DEH	Department of the Environment & Heritage
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999

CONTENTS

1.0 INTRODUCTION

1.1 Project Background

The White-bellied Sea-eagle *Haliaeetus leucogaster* is listed under provisions of the *Environment Protection and Biodiversity Conservation Act* (1999) for migratory species. The species has a world distribution from western India through south-east Asia to southern Australia. In Australia it is distributed around the coastline of most of Australia, including Tasmania and near-shore islands (Marchant and Higgins 1993). It also inhabits some larger river systems and large permanent inland waterbodies, such as major water-storage impoundments. The species' range includes a number of currently operating constructed wind power generation facilities (wind farms) and more facilities that are proposed.

Wind farms may pose a risk of collision to the White-bellied Sea-eagle since mortalities of various eagle species are known from wind farms in a variety of situations worldwide and large raptors have already been recorded as casualties of collision with turbines in Australia. The present project is specifically aimed at determining the cumulative risks posed by collision of sea-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 essential aim of the current project is to predict, the potential cumulative impacts of collision risk posed by 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 White-bellied Sea-eagle posed by such collisions.

Using data available for the White-bellied Sea-eagle, the Biosis Research collision model is utilised to determine the bird strike risk for the sea-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 (now Bluff Point and Studland Bay Wind Farms) 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 , Victoria, South Australia and recently in Fiji. It is applied here to determine levels of predicted risk to White-bellied Sea-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 2.4.4, 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 White-bellied Sea-eagles at four wind farms and is used here. For the other 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 White-bellied Sea-eagle the bird's length is set at 80 cm 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 White-bellied Sea-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. We also provide estimates of our predicted results in terms of the number of birds that might be affected annually.

1.1.4 The White-bellied Sea-eagle population

In Australia, the White-bellied Sea-eagle is distributed around the coastline of most of the continent, including Tasmania and near-shore islands (Blakers *et al.* 1984, Barrett *et al.* 2003, Marchant and Higgins 1993). It also inhabits some larger river systems and large permanent inland waterbodies, such as major water-storage impoundments. The species is less common along some portions of the coast such as western Victoria from around Port Phillip Bay to the South Australian border and along the Nullabor coast (Marchant and Higgins 1993). It may be absent altogether from some portions of the coastline. The species breeds throughout its coastal distribution and to a lesser extent near some inland waters.

Adult White-bellied Sea-eagles are believed to remain as year-round residents within home-ranges where they breed (Marchant and Higgins 1993). In common with other large eagles, it would seem likely that adults actively defend a relatively small breeding territory within the larger home-range. Breeding may not occur until birds are six years old (Marchant and Higgins 1993) and immatures are likely to be excluded from the core breeding territories of adults.

No estimate is available for the entire Australian population of the White-bellied Sea-eagle. Mooney (1986 in Marchant and Higgins 1993) provides an estimate of between 80 and 100 pairs around the Tasmanian coast, including Bass Strait islands. This equates to between 40 and 50 kilometres of coastline per pair for the 4,882 kilometres of Tasmanian coast including islands (Australian Bureau of Statistics). The entire Australian coastline, including islands, is 59,736 kilometres in length (Australian Bureau of Statistics). If we were to assume that two thirds of that length is suitable for White-bellied Sea-eagles, it would be expected to support between 790 and 990 pairs of birds at the density range reported for Tasmania. This approximation is for the number of territorial adult pairs in the population. In addition, the total population includes an annual cohort of juveniles and an unknown number of sub-adults. If these latter groups collectively equate to half the number of adults, the total population may be between 2000 and 3000 birds.

This is an extremely rough approximation and takes no account of inland waters that are known to support some birds nor of some coastal regions where densities may be considerably higher such as the Gippsland Lakes, Victoria and some island groups (see citations in Marchant and Higgins 1993). Nonetheless, it provides an order-of-magnitude estimation for the Australian population.

Breeding adults occupy their 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 likely that home-ranges would be occupied throughout the adult life of White-bellied Sea-eagles.

Bilney and Emison (1983 in Marchant and Higgins 1993) have documented an average of 0.8 young produced per occupied territory per annum in Victoria. Juveniles remain within their parents' territories for the first few months of life. Dispersal of non-breeding birds has not been investigated thoroughly, although some long-distance movements by a few of such birds have been recorded (Marchant and Higgins 1993).

2.0 METHODS: CUMULATIVE IMPACTS MODELLING

Methods are presented here for the aim of the project - to predict, based upon the extant population of White-bellied Sea-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).

Resident White-bellied Sea-eagles, including adult parents and their first-year offspring, are sedentary and, for the purposes of modelling, such birds are thus considered to have a probability of interacting with only one wind farm throughout the course of a given year. It is feasible that, in common with other eagles such as *Aquila* species, adult White-bellied Sea-eagles are likely to maintain a home range, within which a smaller core breeding territory is actively defended during the breeding season, whilst conspecifics are generally tolerated within the larger home range.

Immature birds disperse from natal territories and some may move long distances (Marchant and Higgins 1993). However, no data exists about patterns or frequency of movements made by such birds, although there does not appear to be evidence suggesting that immature White-bellied Sea-eagles make long-distance movements away from the coast or large watercourses. There is no information to suggest that they are likely to make numerous movements through multiple wind farm sites. In the absence of evidence to the contrary, it seems logical to assume that immature White-bellied Sea-eagles would generally disperse from their natal territories to take up residence in nearby coastal environments. Areas utilised by immature birds may be exclusive of the core territories of breeding pairs and may not provide all of the resources necessary for successful reproduction. Thus for the purposes of modelling, it has been assumed that all birds, whether immature or birds of breeding age, should be modelled as essentially sedentary residents of coastal habitats.

Modelling for the cumulative effects of collisions with wind turbines by White-bellied Sea-eagles thus has assumed that all birds can interact with a single wind farm during the course of any given year. The mathematical approach is therefore as outlined in Appendix 1, where the number of wind farms that a given bird can encounter is set at one.

Initially, the possible impact of each wind farm on the White-bellied Sea-eagle is modelled on the basis of available information about that particular wind farm or an informed scenario of how part of the sea-eagle's total population might interact with the wind farm annually. The impact is expressed as a mortality rate (annual probability of sea-eagles being killed by the particular wind farm) for that part of the sea-eagle population. Based on the number of individuals that are assumed to be at risk of collision at each wind farm, the predicted number of White-bellied Sea-eagle fatalities per annum is calculated from the mortality rate (the direct inverse of survivorship rate) for that site.

The cumulative risk is subsequently determined as the number of birds that the scenario modelling predicts might be killed due to collisions with turbines, on average per annum, at all wind farms across the species' range. This provides an indication of the level of cumulative impact on the entire population of White-bellied Sea-eagles.

A background annual survivorship rate, that effects the entire population in the absence of impacts of wind farms, is not known. However, if or when that is determined, the turbine collision mortality rate for the population can be multiplied by the background rate to show the predicted change in population-wide mortality that modelling predicts will occur due to collisions with turbines across the species' range. Since collision effects are considered to be constant over time, the adjusted mortality rate will be applicable regardless of the White-bellied Sea-eagle population size.

2.2 Model inputs

Inputs to the model have been determined to specifically assess the possible cumulative effects upon the White-bellied Sea-eagle population posed by existing and proposed wind farms, through the entire range of the species' Australian distribution.

Sea-eagles are known from some inland areas and are known to breed along some rivers, particularly in a central portion of the Murray River and associated Riverina waterways. However, inland wind farm locations do not coincide with those environments. The distribution of White-bellied Sea-eagles overlaps with wind farm locations only in close proximity to the coast, which is where the great majority of existing and proposed wind farms are located. In all, fifty-six wind farms are considered likely to be encountered by the species and are considered in modelling undertaken here. The species has been recorded at, or within close proximity to, a number of these sites.

Field investigations of the utilisation by birds of many wind farms in south-eastern Australia, including Tasmania, have been undertaken previously by Biosis Research or other workers. From the results of those studies, documented usage by White-bellied Sea-eagles was available for four sites, all in Tasmania (Bluff Point, Heemskirk, Mussleroe and Studland Bay). Utilisation rates recorded from those locations were used to develop scenarios for modelling of the possible interactions of White-bellied Sea-eagles with all fifty-six wind farms.

The specific scenario developed for each wind farm site was also informed from published information about the density and dispersion of White-bellied Sea-eagles around the Australian coastline.

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 wind farms considered here, twenty-nine are built and currently in operation. The remaining twenty-seven wind farms are proposed and fall within categories (i) or (ii) of Section 1.1, above. Specific attributes of each wind farm were provided by DEH and were augmented, where required, from our own investigations. Included in this assessment are a number of very small wind 'farms' and thirteen installations of single, small turbines. These have been included where they appear to be situated within prime coastal habitats for sea-eagles and, because there are a number of them across the entire range, the cumulative risk they may pose to the species should not be ignored.

Bird utilisation data collected by Biosis Research at a variety of wind farms and observations made during numerous assessments for other purposes, indicates that White-bellied Sea-eagles residing in coastal locations are almost entirely confined to a narrow zone and are rarely sighted more than 500 metres inland. Key to the collision risk posed by a wind farm to White-bellied Sea-eagles are both the specifications of turbines proposed to be used and configuration of turbines on the landscape. Details of the fifty-six wind farms considered are shown in Table 1 and Figure 1.

Table 1 Details of the fifty-six wind farms assessed.

Wind farm	EPBC referral number (where applicable)	Position co-ordinates		Number of turbines	Turbine model
10 Mile Lagoon, WA		121.76	-33.89	9	Vestas V27
9 Mile Beach, WA		121.78	-33.9	6	Enercon 600 kW
Albany, WA		117.82	-35.07	12	Enercon E66
Bluff Point, Tas	12	144.92	-40.78	37	Vestas V66
Breamlea, Vic	439	144.6	-38.25	1	Westwind 0.60 MW
Bremer Bay, WA		119.38	-34.39	1	Enercon 600 kW
Canunda, SA	691	140.4	-37.77	23	Vestas V80
Cape Barren Is, Tas		148.03	-40.38	1	Westwind 10kW
Cape Bridgewater, Vic	18	141.38	-38.37	40	NEG Micon NM82
Cape Nelson, Vic	18	141.54	-38.42	39	NEG Micon NM82
Cape Sir William Grant, Vic	19	141.62	-38.39	21	NEG Micon NM82
Cathedral Rocks, SA		134.85	-34.72	33	*Vestas V90
Codrington, Vic	1929	141.97	-38.28	14	AN Bonus 1.3 MW
Denham, WA		113.53	-25.93	3	Enercon E30 230kW
Denmark, WA	2105	117.32	-35.07	4	0.6 MW
Emu Downs, WA		115.01	-30.22	48	Vestas V82 1.65MW
Exmouth, WA		114.1	-22.08	3	20 kW
Flinders Island, Tas		148.09	-40.04	2	Nordex 0.6 & 0.125 MW
Fraser Is, Qld		153.21	-24.73	1	Westwind 10kW
Fremantle, WA	933	115.75	-32.06	8	*Vestas V90
Gabo Is, Vic		149.92	-37.57	1	Westwind 10kW
Green Point, SA	529	140.88	-38.03	18	Vestas V90
Heemskirk, Tas	678	145.12	-41.83	53	Vestas V90
Hopetoun, Wa		120.12	-33.85	1	Enercon 600 kW
Kemmiss Hill Road, SA	1611	138.48	-35.46	15	*Vestas V90
King Is Huxley Hill Stages 1 & 2, Tas	570	143.89	-39.94	3	Nordex 0.25 MW & Vestas V52
Kongorong, SA	568	140.5	-37.94	20	*Vestas V90
Kooragang, NSW		151.68	-32.97	1	Vestas V52
Lake Bonney Stage 1, SA	265	140.07	-37.42	46	Vestas V66
Lake Bonney Stage 2, SA	1630	140.36	-37.69	53	Vestas V90
Mallacoota, Vic		149.75	-37.56	1	Westwind 10kW
Mount Millar, SA		136.71	-33.64	35	Enercon E70 2 MW
Mumbida stg 1, WA		114.68	-28.89	50	Enercon 600 kW
Mussleroe, Tas		148.00	-40.80	46	Vestas V90 on low tower
Myponga, SA		138.41	-35.36	20	Vestas V66
Nirranda South, Vic	763	142.79	-38.56	40	*Vestas V66

Wind farm	EPBC referral number (where applicab le)	Position co-ordinates		Number of turbines	Turbine model
Nirranda, Vic	471	142.74	-38.52	28	NEG Micon NM82
North Keppel Is, Qld		150.90	-23.08	1	*Westwind 10kW
Pt Hicks, Vic		149.27	-37.80	1	Westwind 10kW
Rottnest Is, WA		115.53	-31.99	1	Enercon 600 kW
Sheringa, SA	503	135 11'	-33 55'	95	*Vestas V90
Starfish Hill, SA		138.16	-35.57	23	NEG Micon NM64C 1.5 MW
Studland Bay, Tas	12	144.92	-40.78	25	Vestas V90
Swan Valley, WA		116.00	-31.83	2	*Westwind 10kW
Thursday Is, Qld		142.22	-10.59	2	Vestas 225kW
Toora, Vic	1109	146.41	-38.65	12	Vestas V66
Tortoise Head, Vic		145.29	-38.39	1	Westwind 10kW
Troubridge Point, SA		136.99	-35.16	15	*Vestas V90
Tungetta Hill & Loch Well Beach, SA		135	-33	55	NEC Micon 900 kW
Vincent North (She Oak Flat), SA	1001	137.86	-34.70	36	Vestas V82 1.65MW
Waitpinga, SA	1359	138 32'	-35 37'	23	*Vestas V90
Walkaway Alinta, WA		114.80	-28.94	54	Vestas NM 82 1.65MW
Wattle Point, SA		137.73	-35.13	55	Vestas V82 1.65MW
Wilsons Promontory, Vic		146.37	-39.13	1	Westwind 10kW
Wonthaggi, Vic	820	145.56	-38.61	6	REPower 2 MW
Yambuk, Vic	18	141.62	-38.39	20	NEG Micon NM82

* denotes turbine type used for modelling particular wind farm where manufacturer and model of turbine not specified

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 twenty different models of turbine are currently in operation, or are proposed to be built at the wind farms considered here. For a few potential wind farms (noted by an asterisk in Table 1) 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 those instances 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. Table 1 provides information about turbines in use, or proposed for the wind farms assessed here.

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 sea-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. Hence, 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 White-bellied Sea-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 White-bellied Sea-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 White-bellied Sea-eagles

2.4.1 Size and flight speed of White-bellied Sea-eagles

White-bellied Sea-eagles are approximately 75 - 85 cm in length (Marchant and Higgins 1993) and were modelled here as 80 cm long. Average flight speed of the species was estimated from observations of birds and was modelled as 60 km/h. These two factors were used to determine the time it would take for a bird to fly through the danger zone of moving rotors. This was incorporated into calculation of the amount of rotor travel that would be involved in an encounter and hence contributed to determination of the area of turbine presented to the bird.

2.4.2 Flight heights of White-bellied Sea-eagles

The height at which birds fly within a wind farm is clearly relevant to the likelihood of collision with turbines. This is due to the different heights of turbine components and of collision risks they present to birds. The moving rotors of a turbine are considered to present a greater risk than is the stationary tower. By way of example, the largest turbines involved in this assessment (Vestas V90 on 78 metre-high tower) sweep up to approximately 123 metres above the ground. The height zone swept by rotors (in the case of Vesta V90 between 33 and 123 metres height) is considered to represent the zone of greatest danger to flying birds.

In studies of the utilisation of wind farm sites by birds through south-eastern Australia, we have consistently evaluated the height of each flight recorded during standard point counts. The heights of 160 movements by White-bellied Sea-eagles, within 120 metres of the ground, have been recorded by Biosis Research at four wind farm sites. Of those, 30% were within 30 metres of the ground and 70% were between 30 and 120 metres of the ground. This body of flight-height data was used as a basis for determining scenarios for the proportion of sea-eagle flights that might occur relative to the dimensions of particular types of turbines at sites for which no data exists.

For each wind farm modelled a number of sea-eagle flights are allocated to each of 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).

2.4.3 Population size and movements of White-bellied Sea-eagles at wind farm sites

Specific investigations have not been undertaken into the population dynamics of White-bellied Sea-eagles inhabiting any wind farm sites in Australia, or elsewhere, so there is little 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 information collected during bird utilisation studies undertaken by Biosis Research at four wind farm sites where White-bellied Sea-eagles occur (Bluff Point, Heemskirk, Mussleroe and Studland Bay). The basis for assessment of the number of birds present at a site was the maximum number of individual birds sighted at any one time, or identifiable as individuals from differences in plumage.

On the basis of the information from those wind farms, it appears that any one site is likely to be part of the home range of a single pair of adult birds. A home-range is expected to be occupied year-round by an adult pair and, on average, for a few months by less than one juvenile. Almost all wind farms cover an area that is considerably smaller than the expected home-range of such a family group. Therefore the majority of wind farms have been modelled for the possibility of three birds interacting with turbines throughout a given year (Table 2).

It is possible that larger wind farms may intersect the home-ranges of two family groups. Taking this possibility into account, larger wind farms have been modelled for the possibility of six birds interacting with turbines throughout a given year (Table 2).

As outlined in Section 2.1, it has been assumed for modelling purposes that immature birds occupy habitat at the same density as that at which home-ranges of breeding pairs are occupied.

We have assumed that development of a wind farm does not alienate the area from further use by sea-eagles. This is considered to be the case because previous land uses at all currently operating wind farm sites in Australia, are believed to have continued and pre-existing habitat values have remained largely unaltered following construction of facilities. It is also the case that White-bellied Sea-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 White-bellied Sea-eagles. We do not consider that collisions are likely to result in heightened avoidance behaviours on the part of survivors. 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 sea-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 sea-eagle behaviours, including avoidance rates for sea-eagles encountering turbines, will remain constant over time.

In studies of the utilisation of wind farm sites by birds through south-eastern Australia, the number of flights made by birds has been recorded during standard point counts. Thus we have data for the numbers of movements-at-risk of collision made by White-bellied Sea-eagles at the Bluff Point, Heemskirk, Mussleroe and Studland Bay wind farm sites where Biosis Research has undertaken such investigations. In order to determine possible numbers of movements that might be made by sea-eagles at other locations, data from those four sites has been averaged and then extrapolated to determine an estimated number of movements-at-risk made by the species at each site for an entire year. It is recognised that the basis for these estimations is a small pool of data from limited locations which may not be representative of the wide range of wind farm sites under consideration and is thus somewhat arbitrary. However, it is considered best to base scenario modelling on the only available data rather than on none at all.

The numbers of birds and number of flights per annum at risk of collision with turbines that have been used in modelling for each site are shown in Table 2.

Table 2 Scenario modelled for White-bellied Sea-eagle use of wind farms

Wind farm	Population size (number of birds) modelled	Number of annual movements at risk per bird per annum modelled
10 Mile Lagoon, WA	3	330
9 Mile Beach, WA	3	330
Albany, WA	3	330
Bluff Point, Tas	6	660
Breamlea, Vic	3	330
Bremer Bay, WA	3	330
Canunda, SA	6	660
Cape Barren Is, Tas	3	330
Cape Bridgewater, Vic	3	330
Cape Nelson, Vic	3	330
Cape Sir William Grant, Vic	3	330
Cathedral Rocks, SA	3	330
Codrington, Vic	3	330
Denham, WA	3	330
Denmark, WA	3	330
Emu Downs, WA	6	660
Exmouth, WA	3	330
Flinders Island, Tas	3	330
Fraser Is, Qld	3	330
Fremantle, WA	3	330
Gabo Is, Vic	3	330
Green Point, SA	3	330
Heemskirk, Tas	6	660
Hopetoun, Wa	3	330
Kemmiss Hill Road, SA	3	330
King Is Huxley Hill Stages 1 & 2, Tas	3	330
Kongorong, SA	3	330
Kooragang, NSW	3	330
Lake Bonney Stage 1, SA	6	660
Lake Bonney Stage 2, SA	6	660
Mallacoota, Vic	3	330
Mount Millar, SA	6	660
Mumbida stg 1, WA	6	660
Mussleroe, Tas	6	660
Myponga, SA	3	330
Nirranda South, Vic	3	330
Nirranda, Vic	3	330
North Keppel Is, Qld	3	330
Pt Hicks, Vic	3	330
Rottnest Is, WA	3	330
Sheringa, SA	6	660
Starfish Hill, SA	6	660
Studland Bay, Tas	6	660
Swan Valley, WA	3	330
Thursday Is, Qld	3	330
Toora, Vic	3	330
Tortoise Head, Vic	3	330
Troubridge Point, SA	3	330
Tungetta Hill & Loch Well Beach, SA	6	660
Vincent North (She Oak Flat), SA	6	660
Waitpinga, SA	6	660

Wind farm	Population size (number of birds) modelled	Number of annual movements at risk per bird per annum modelled
Walkaway Alinta, WA	6	660
Wattle Point, SA	6	660
Wilsons Promontory, Vic	3	330
Wonthaggi, Vic	3	330
Yambuk, Vic	3	330

2.4.4 Avoidance by White-bellied Sea-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, 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 White-bellied Sea-eagle would generally be in the range of 95% to 100% in most conditions. Sea-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 raptors in Australia is that of Meredith *et al.* (2002) who investigated avian avoidance of turbines at the Codrington wind farm in Victoria. They documented 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 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 White-bellied Sea-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 White-bellied Sea-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.

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 White-bellied Sea-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.

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 3. It has been necessary to calculate and show these values to five significant numbers in order for differences between them to be detected. It is important that this is not misinterpreted to indicate any level of 'accuracy' in the predicted results.

Table 3 Modelled survivorship rates for wind farms presenting a collision risk to White-bellied Sea-eagles

Windfarm	Survivorship rate at 95% avoidance rate	Survivorship rate at 98% avoidance rate	Survivorship rate at 99% avoidance rate
10 Mile Lagoon, WA	0.99364	0.99628	0.99716
9 Mile Beach, WA	0.99657	0.99801	0.99849
Albany, WA	0.99515	0.99719	0.99787
Bluff Point, Tas	0.98929	0.99359	0.99151
Breamlea, Vic	0.99997	0.99998	0.99998

Windfarm	Survivorship rate at 95% avoidance rate	Survivorship rate at 98% avoidance rate	Survivorship rate at 99% avoidance rate
Bremer Bay, WA	0.99860	0.99919	0.99938
Canunda, SA	0.98879	0.99358	0.99519
Cape Barren Is, Tas	0.99996	0.99998	0.99999
Cape Bridgewater, Vic	0.98665	0.99218	0.99403
Cape Nelson, Vic	0.98681	0.99228	0.99411
Cape Sir William Grant, Vic	0.99031	0.99433	0.99567
Cathedral Rocks, SA	0.98327	0.99084	0.99337
Codrington, Vic	0.99255	0.99565	0.99668
Denham, WA	0.99267	0.99585	0.99692
Denmark, WA	0.99719	0.99837	0.99877
Emu Downs, WA	0.98538	0.99144	0.99346
Exmouth, WA	0.99994	0.99997	0.99998
Flinders Island, Tas	0.99815	0.99887	0.99911
Fraser Is, Qld	0.99996	0.99998	0.99999
Fremantle, WA	0.99173	0.99548	0.99673
Gabo Is, Vic	0.99996	0.99998	0.99999
Green Point, SA	0.98762	0.99322	0.99510
Heemskirk, Tas	0.98468	0.99153	0.99383
Hopetoun, Wa	0.99993	0.99995	0.99996
Kemmiss Hill Road, SA	0.98869	0.99381	0.99553
King Is Huxley Hill Stages 1 & 2, Tas	0.99515	0.99733	0.99806
Kongorong, SA	0.98695	0.99286	0.99484
Kooragang, NSW	0.99783	0.99881	0.99913
Lake Bonney Stage 1, SA	0.98806	0.99286	0.99446
Lake Bonney Stage 2, SA	0.97885	0.98840	0.99161
Mallacoota, Vic	0.99996	0.99998	0.99999
Mount Millar, SA	0.99834	0.99858	0.99866
Mumbida stg 1, WA	0.99012	0.99427	0.99565
Mussleroe, Tas	0.97780	0.98790	0.99129

Windfarm	Survivorship rate at 95% avoidance rate	Survivorship rate at 98% avoidance rate	Survivorship rate at 99% avoidance rate
Myponga, SA	0.99211	0.99528	0.99634
Nirranda South, Vic	0.98882	0.99345	0.99500
Nirranda, Vic	0.98784	0.99293	0.99463
North Keppel Is, Qld	0.99996	0.99998	0.99999
Pt Hicks, Vic	0.99996	0.99998	0.99999
Rottnest Is, WA	0.99860	0.99919	0.99938
Sheringa, SA	0.97178	0.98450	0.98878
Starfish Hill, SA	0.98986	0.99406	0.99547
Studland Bay, Tas	0.98543	0.99202	0.99423
Swan Valley, WA	0.99996	0.99998	0.99999
Thursday Is, Qld	0.99707	0.99829	0.99869
Toora, Vic	0.99389	0.99634	0.99717
Tortoise Head, Vic	0.99996	0.99998	0.99999
Troubridge Point, SA	0.98869	0.99381	0.99553
Tungetta Hill & Loch Well Beach, SA	0.98436	0.99084	0.99300
Vincent North (She Oak Flat), SA	0.98733	0.99258	0.99434
Waitpinga, SA	0.98602	0.99234	0.99446
Walkaway Alinta, WA	0.98450	0.99092	0.99307
Wattle Point, SA	0.98436	0.99084	0.99300
Wilsons Promontory, Vic	0.99996	0.99998	0.99999
Wonthaggi, Vic	0.99374	0.99653	0.99745
Yambuk, Vic	0.99054	0.99446	0.99578

3.2 Estimated cumulative impacts across the range of the White-bellied Sea-eagle

The total number of White-bellied Sea-eagles modelled as interacting annually with all fifty-six wind farms under consideration here is 219 (*2.4.3 Population size and movements of White-bellied Sea-eagles at wind farm sites*).

The mean survivorship rates determined for the cumulative impacts of collisions on this portion of the entire sea-eagle population at fifty-six wind farms across the bird's range are provided in Table 4.

Table 4 Cumulative survivorship values for the White-bellied Sea-eagle population from potential collision risk posed by fifty-six wind farms in the species' range

Survivorship rate at 95% avoidance rate	Survivorship rate at 98% avoidance rate	Survivorship rate at 99% avoidance rate
0.99188	**0.99537**	**0.99648**

3.2.1 Impacts on White-bellied Sea-eagle annual survivorship

In order to assess the potential impact of altered survivorship rates that may be imposed on the White-bellied Sea-eagle population by collisions with wind turbines it will first be necessary to know the background survivorship rate that affects the population in the absence of any impacts of wind farm collision. Unfortunately, this has not been determined for the species. If or when it is, it can be multiplied by the cumulative collision risk survivorship rates predicted by the modelling and shown in Table 4, for the portion of the total population that is assumed to interact with wind farms. Since collision effects are considered to function as a constant over time, the adjusted mortality rate will be applicable regardless of the White-bellied Sea-eagle population size.

3.2.2 Predicted White-bellied Sea-eagle mortalities

The number of White-bellied Sea-eagles that the model predicts might be killed on average per annum at each wind farm, according to the three avoidance rates modelled, are shown in Table 5. A total number of birds predicted to be killed annually by the cumulative effects of turbine collisions across the species' range is determined by summing the number of fatalities predicted for each avoidance rate for all thirty-five wind farms, and is shown as a total in Table 5.

Table 5 **Predicted average annual number of White-bellied Sea-eagle mortalities due to collisions with wind turbines**

Windfarm	Number of deaths at 95% avoidance rate	Number of deaths at 98% avoidance rate	Number of deaths at 99% avoidance rate
10 Mile Lagoon, WA	0.01907	0.01115	0.00851
9 Mile Beach, WA	0.01030	0.00597	0.00452
Albany, WA	0.01030	0.00597	0.00452
Bluff Point, Tas	0.06427	0.03846	0.02983
Breamlea, Vic	0.00008	0.00007	0.00006
Bremer Bay, WA	0.00421	0.00244	0.00185
Canunda, SA	0.06728	0.03849	0.02887
Cape Barren Is, Tas	0.00011	0.00005	0.00003
Cape Bridgewater, Vic	0.04006	0.02346	0.01791
Cape Nelson, Vic	0.03956	0.02317	0.01768
Cape Sir William Grant, Vic	0.02908	0.01702	0.01299
Cathedral Rocks, SA	0.05018	0.02749	0.01989
Codrington, Vic	0.02236	0.01306	0.00995
Denham, WA	0.02199	0.01244	0.00925
Denmark, WA	0.00842	0.00488	0.00369
Emu Downs, WA	0.08770	0.05138	0.03922
Exmouth, WA	0.00017	0.00008	0.00005
Flinders Island, Tas	0.00555	0.00338	0.00266
Fraser Is, Qld	0.00011	0.00005	0.00003
Fremantle, WA	0.02481	0.01357	0.00981
Gabo Is, Vic	0.00011	0.00005	0.00003
Green Point, SA	0.03714	0.02033	0.01470
Heemskirk, Tas	0.09194	0.05082	0.03705
Hopetoun, Wa	0.00022	0.00014	0.00012
Kemmiss Hill Road, SA	0.03392	0.01856	0.01342
King Is Huxley Hill Stages 1 & 2, Tas	0.01455	0.00801	0.00582
Kongorong, SA	0.03914	0.02142	0.01549

Windfarm	Number of deaths at 95% avoidance rate	Number of deaths at 98% avoidance rate	Number of deaths at 99% avoidance rate
Kooragang, NSW	0.00652	0.00358	0.00260
Lake Bonney Stage 1, SA	0.07162	0.04287	0.03325
Lake Bonney Stage 2, SA	0.12691	0.06959	0.05036
Mallacoota, Vic	0.00011	0.00005	0.00003
Mount Millar, SA	0.00997	0.00850	0.00801
Mumbida stg 1, WA	0.05930	0.03441	0.02608
Mussleroe, Tas	0.13321	0.07258	0.05224
Myponga, SA	0.02366	0.01415	0.01097
Nirranda South, Vic	0.03355	0.01964	0.01499
Nirranda, Vic	0.03647	0.02122	0.01612
North Keppel Is, Qld	0.00011	0.00005	0.00003
Pt Hicks, Vic	0.00011	0.00005	0.00003
Rottnest Is, WA	0.00421	0.00244	0.00185
Sheringa, SA	0.16930	0.09299	0.06733
Starfish Hill, SA	0.06085	0.03561	0.02718
Studland Bay, Tas	0.08745	0.04788	0.03464
Swan Valley, WA	0.00011	0.00005	0.00003
Thursday Is, Qld	0.00880	0.00514	0.00392
Toora, Vic	0.01834	0.01097	0.00850
Tortoise Head, Vic	0.00011	0.00005	0.00003
Troubridge Point, SA	0.03392	0.01856	0.01342
Tungetta Hill & Loch Well Beach, SA	0.09383	0.05498	0.04197
Vincent North (She Oak Flat), SA	0.07603	0.04452	0.03398
Waitpinga, SA	0.08390	0.04593	0.03322
Walkaway Alinta, WA	0.09298	0.05448	0.04159
Wattle Point, SA	0.09383	0.05498	0.04197
Wilsons Promontory, Vic	0.00011	0.00005	0.00003
Wonthaggi, Vic	0.01877	0.01042	0.00764
Yambuk, Vic	0.02838	0.01661	0.01267

Windfarm	Number of deaths at 95% avoidance rate	Number of deaths at 98% avoidance rate	Number of deaths at 99% avoidance rate
Total predicted deaths	**2.09513**	**1.19430**	**0.89272**

Thus for the scenarios modelled here, a cumulative total of between 0.9 and 2.1 White-bellied Sea-eagles per year are predicted to be killed by collisions at all of the sites the population is likely to encounter within its natural range. From the admittedly limited, but accumulating, information about bird avoidance of wind turbines, particularly for large raptors, we consider that the higher avoidance rates modelled here are the most likely to represent the avoidance capacities of White-bellied Sea-eagles. Thus the lower annual mortalities predicted are considered to be the closest to what might occur in reality.

3.2.3 Conclusion

The cumulative impacts of collision with turbines on the overall population of White-bellied Sea-eagles, predicted by the modelling for all current and presently proposed wind farms within the species' range are provided. Results for the range of avoidance rates modelled, predict an average of between slightly less than one and slightly more than two sea-eagles may be killed due to wind turbine collisions every year.

It is recognised that assumptions about numbers of White-bellied Sea-eagles and numbers of their movements used in the modelling are necessarily arbitrary since there is relatively few empirical data on which to base them. It is therefore possible that they may not reflect reality for all of the fifty-six wind farms encompassed by the modelling. Based on knowledge of the species, it can be assumed that predictions of the present modelling are as accurate as can be currently made.

We consider it important that further investigations of White-bellied Sea-eagles at wind farm sites should be made in order to better validate modelled predictions. Additional data for utilisation rates of sites by the species will assist, as will studies that document the actual avoidance behaviours of birds in flight within functioning wind farms.

APPENDICES

APPENDIX 1
Cumulative Wind Farm Effects Modelling

Cumulative Wind Farm Effects Modelling

Approach and Justification

Stuart Muir
SymboliX
for
Biosis Research Pty. Ltd

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 = $P(S_1)P(S_2)P(S_3)P(S_4)\ldots P(S_N)$

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

$$P(S_{1\ldots N}) = P(S_1)P(S_2)P(S_3)\ldots \tag{9}$$

$$= \Pi_i^N P(S_i) \tag{10}$$

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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