Orange-bellied Parrot
Dave Watts

Modelled cumulative impacts on the Orange-bellied Parrot of wind farms across the species' range in south-eastern Australia

December 2005

Ian Smales, Stuart Muir and Charles Meredith

BIOSIS
RESEARCH

Report for
Department of Environment and Heritage

Modelled cumulative impacts on the Orange-bellied Parrot of wind farms across the species' range in south-eastern Australia

December 2005

Ian Smales[1], Stuart Muir[2] and Charles Meredith[1]

[1] Biosis Research Pty. Ltd.
[2] SymboliX

Project no. 4857

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

ACKNOWLEDGEMENTS

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

SymboliX
- Dr Elizabeth Stark

Orange-bellied Parrot Recovery Team
- Mark Holdsworth – for generous provision of comprehensive census and demographic data for the Orange-bellied Parrot population

UniQuest Pty Ltd (University of Queensland)
- Dr Tony Pople – for review and valuable comments on an initial draft of the cumulative impacts assessment component of this report

Department of the Environment & Heritage, Canberra
- Wayne Furler
- Malcolm Forbes
- Nick Gascoigne
- Chris Murphy

Biosis Research Pty. Ltd.
- Dr Bob Baird

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

CONTENTS

Male Orange-bellied Parrot **(photo I. Smales)**

1.0 INTRODUCTION

1.1 Project Background

The Orange-bellied Parrot *Neophema chrysogaster* is listed as Endangered under provisions of the EPBC Act for threatened species. The species migrates annually between Tasmania and the coast of south-eastern mainland states of Australia. Current population estimates indicate that the population numbers fewer than 200 birds. The species range coincides with a number of recently constructed wind power generation facilities (wind farms) and more facilities are proposed. The wind farms may pose a risk of collision to the parrot as bird mortalities are known from wind farms in a variety of situations worldwide.

The project has two essential aims:

1. To predict, based upon the extant population of Orange-bellied Parrots, 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 Orange-bellied Parrot posed by such collisions.

2. To determine a suitable assessment to provide an estimate of the level at which predicted collision is likely to present concerns for the Orange-bellied Parrot 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 Orange-bellied Parrot, the Biosis Research collision model is utilised to determine the bird strike risk for the parrot'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

(Meredith *et al.* 2000). 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 Orange-bellied Parrots 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 2.4.2, 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 stationary tower below rotor height, and
2. the turbine components within the height area swept by turbine rotors

We consider that birds will avoid collision with the stationary tower below rotor height in all but the most exceptional circumstances and model for 99% avoidance rate in that height zone. For the zone within rotor-swept height (encompassing rotors, upper portion of tower and nacelle) 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, as is the case for the present project. 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 for each bird species below rotor height, and for which just the lower portion of turbine towers present a collision risk.
- The numbers of bird flights 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 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 Orange-bellied Parrot the bird's length is set at 200 mm and its flight speed at 60 kmh.

- 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 Orange-bellied Parrots, of both individual wind farms and of the cumulative impacts of them all, 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 known demographic values for the current population of the species, including the numbers of birds known to exist and the 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.

Assessment of critical impact levels on the Orange-bellied Parrot population was undertaken using Population Viability Analysis (PVA) (Shaffer 1981). PVA outcomes are routinely measured in terms of increase or decrease in the probability of extinction of the subject species. Thus our critical impact evaluation is quantified in terms of changes to extinction risk that the cumulative effects of wind turbine collisions might have on the Orange-bellied Parrot population.

1.1.4 Orange-bellied Parrot population size and dispersion

Population estimates for the entire known population of the Orange-bellied Parrot are based on detailed demographic data for the entire known population kindly supplied to us by Mark Holdsworth (Orange-bellied Parrot Recovery Team and DPIWE) (Table 1). The census data covers the period from the breeding season of 1998/99 to the breeding season of 2004/05. Estimates are based on re-sightings records of banded and unbanded adults and juveniles during the period from spring 1998 to autumn 2005 in the breeding range at Melaleuca, and a former natural breeding site at Birch's Inlet, where birds have been reintroduced in recent years in Tasmania. A ratio of banded to unbanded birds for each year has been used to derive estimates, based on the sum of the two components over the seven years, for mean total size of the annual population minimum (immediate pre-breeding season in spring) and annual maximum (immediate post-breeding season). The annual maximum and minimum population sizes coincide with the autumn and spring migrations of Orange-bellied Parrots. Mean annual minimum (spring) population was 99 birds (SD = 10.22) and mean annual maximum (autumn) population was 200 birds (SD = 21.02).

Table 1 Annual minimum and maximum Orange-bellied Parrot population estimates based on numbers of birds at commencement and conclusion of breeding seasons at Melaleuca and Birch's Inlet (data supplied by Orange-bellied Parrot Recovery Team Nov 2005)

Breeding season	Estimated annual total population in spring (annual minimum population)	Estimated annual total population in autumn (annual maximum population)	Annual number of birds died
1998/99	**83**	**184**	**102**
1999/00	**96**	**220**	**124**
2000/01	**107**	**171**	**64**
2001/02	**108**	**229**	**121**
2002/03	**110**	**212**	**103**
2003/04	**95**	**189**	**94**
2004/05*	**92**	**194**	**102**
mean	**99**	**200**	**101**
SD	**10.22**	**21.02**	**19.74**

Note that these figures include an average of 32 (SD 9.48) Orange-bellied Parrots bred in captivity and released in spring of each of the six years since 1999 as part of the recovery effort for the species. Their mortality rate immediately after release in Tasmania has been substantially higher than that of the natural population. Thus the number of Orange-bellied Parrots that undertake the subsequent autumn migration to the mainland is believed to have generally been fewer than the maximum autumn mean of 200 birds comprising the entire population. Nonetheless, given that it is feasible that disappearance of some of those birds could be ascribed to migration rather than mortality, we used 200 as the average annual maximum in the population for the purposes of modelling.

Whilst the numbers of Orange-bellied Parrots comprising the breeding population and annual numbers of offspring are quite well known and appear to have remained relatively stable over recent years, the mainland distribution of the population during the non-breeding period remains largely unknown. The numbers of parrots reported as utilising the few well known regular locations on the mainland account for just a small fraction of the breeding population. In addition, the numbers of birds reported from those sites have declined over recent years. Clearly, a very significant portion of the population must be spending the winter period at sites that remain to be discovered.

1.1.5 Orange-bellied Parrot migration

The Orange-bellied Parrot migrates annually between its breeding range in south-west Tasmania and the coastal mainland of Victoria, South Australia and New South Wales. This annual process involves both regular migratory movements through a very large geographic range and variable periods of residence by portions of the population at different locations across the range. The timing of migratory movements is well known from annual arrival and departures dates from key locations. However, actual migratory movements have rarely been documented for a number of reasons, including the following:

- the very few birds in the extant population,
- the small numbers of ornithologists able to competently identify the species,
- difficulties of terrain and access along much of the west coast of Tasmania,
- the fact that part of the route is across Bass Strait,
- a long distance of coastline in both Tasmania and the mainland along

which birds could depart or arrive,

- uncertainty about the winter destination(s) of the majority of the population and,
- the possibility some migration occurring at night.

It is known that the annual migration cycle commences after the breeding season, with parrots moving north from south-west Tasmania in March/April and birds appearing then in north-west Tasmania, adjacent islands and King Island. Shortly thereafter birds appear at locations along the coast of central and western Victoria and eastern South Australia. A very few individuals are reported in some years from coastal eastern Victoria and even southern NSW. A small portion of the known breeding population utilises traditional locations on the mainland during parts of each year whilst they are on the mainland. These locations include western Port Phillip Bay, especially near Point Wilson, Swan Island and nearby locations around Queenscliff and Lake Connewarre on the Bellarine Peninsula, and the Yambuk estuary in Victoria. In South Australia some birds have been sighted fairly routinely although not altogether predictably, from places like Carpenters Rocks, Picanninie Ponds and the coastal side of Canunda National Park. Occasional birds are reported from a host of other places along the coastline from west of Adelaide almost to Sydney.

The parrots disappear from most mainland locations during September and this coincides with birds appearing in south-western Tasmania. On this leg of the migration, birds are not generally reported from Bass Strait islands or north-western Tasmania and it is assumed that the southward migration proceeds rapidly, possibly taking only one or two days of travel.

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 Orange-bellied Parrots, 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 Orange-bellied Parrot migrates annually between its breeding range in south-west Tasmania and the coastal mainland of Victoria, South Australia and New South Wales. This annual process involves both regular migratory movements through a very large geographic range and variable periods of residence by portions of the population at different locations across the range. Throughout the entire distributional range of the species are a number of current and proposed wind farms which may present a collision risk to the birds. The likelihood of the entire Orange-bellied Parrot population, or parts of it encountering and/or colliding with turbines is considered likely to differ according to a wide range of variables of particular wind farms and of the numbers and behaviours of the parrots. In essence, the approach taken here to modelling of potential cumulative impacts on the population has been as follows:

- First, the possible impact of each wind farm on the Orange-bellied Parrot has been modelled on the basis of available information about that particular farm and an informed scenario of how part or all of the parrot's population might interact with the wind farm annually. The impact is expressed as a mortality rate (annual probability of parrots being killed by the particular wind farm). The inverse of annual mortality is an annual survivorship rate (annual probability of parrots surviving encounters with the wind farm).

- Given that parts, or all, of the population of a migratory species such as the Orange-bellied Parrot may encounter a number of wind farms during the course of its annual cycle, the cumulative effects are derived, in essence, by assessing the probability (*P*) of parrots surviving their encounters with one wind farm after another. The survivorship rate (*S*) of each wind farm provides a measure of the proportion of the population that survives annual encounters with that particular farm and thus has the potential to encounter another wind farm, and so forth sequentially through the geographic spread of wind farms within the range of the species. The probable population survivorship rate for multiple wind farms that may be encountered, is thus found by multiplying the survivorship rates of wind farms together. i.e the annual population survivorship of all wind farms within a particular range equates to = $P(S_1)P(S_2)P(S3)....P(S_N)$.

2.2 Model inputs

Inputs to the model have been determined to specifically assess the possible cumulative effects upon the Orange-bellied Parrot population posed by twenty-three existing and proposed wind farms, through the entire range of the species' natural distribution. 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 of fifteen of the relevant wind farms have been undertaken previously by Biosis Research and of at least two additional sites by other workers. Results of all of those studies were checked to determine the known usage of each site by Orange-bellied Parrots. The species has been recorded at, or within close proximity to, only three of the wind farm sites (Studland Bay (Woolnorth Lot 2) in Tasmania and Nirranda South and Yambuk in Victoria) and those records are of only one or two birds at each of those locations. Orange-bellied Parrots have not been reported from any of the other sites, albeit they are known to occur quite close to some of them. As a consequence, modelling using actual utilisation rates for the species was not considered possible or reliable for any of the twenty-three sites. Thus scenarios to represent the interactions of Orange-bellied Parrots with each wind farm were used.

The specific scenario developed for each wind farm site was determined from knowledge of the size of the Orange-bellied Parrot population and its geographic and temporal use of its distributional range. Considerable gaps in knowledge of the species exist, particularly with regard to the whereabouts of the majority of the population outside of the annual breeding season, despite extensive efforts undertaken under the auspices of the Orange-bellied Parrot Recovery Team. Where assumptions were made in the absence of empirical information, we have used what we believe are valid judgements based on what is known. Parameters specific to each site were used to account for seasonal variation in the population of Orange-bellied Parrots and behaviours of parrots.

We have used a precautionary approach to input assumptions to modelling. For instance, Orange-bellied Parrots have not been recorded at twenty of the 23 wind farm sites under consideration despite active searching for them at most of the sites. One or two sightings of individuals have been made at the other three sites. Thus there is no informative empirical data about actual numbers or variation in numbers of birds that might reside at any site. However we have modelled on the basis that numbers of birds do spend time at the great majority of sites. The modelling here thus exceeds all actual experience. Similarly, we have modelled for birds to remain present within single mainland wind farm locations for six months - which is the longest possible duration in the annual cycle of the species that birds could remain at such a site - and longer than any birds have ever been recorded to remain at any winter location. We have intentionally adopted this approach in an attempt 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 twenty-three wind farms considered here, eight are built and currently in operation (Breamlea, Codrington, King Island Huxley Hill Stage 1, King Island Huxley Hill Stage 2, Bluff Point (Woolnorth Lot 1), Lake Bonney Stage 1, Canunda, Toora (DEH data)). Yambuk is currently under construction and a further fourteen are not yet constructed but fall within categories (i) or (ii) of Section 1.1, above.

Key to the collision risk posed by a wind farm to Orange-bellied Parrots are both the specifications of turbines proposed to be used and configuration of turbines on the landscape.

2.3.1 Turbines

The model of turbine in use, 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.

As far as we were able to determine, nine different models of turbine are currently in operation, or are proposed to be built at the twenty-three wind farms considered here. For three potential wind farms (Kongorong, Nirranda South and 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 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 2 provides information about turbines in use, or proposed for the twenty-three wind farms assessed here.

Table 2 Details of the twenty-three wind farms assessed.

Windfarm	EPBC referral number (where applicable)	POINT_X	POINT_Y	Number of turbines	Turbine model
Heemskirk	2002/678	145.121	-41.833	53	Vestas V90
Jim's Plain	2003/1162	144.838	-40.847	20	*Vestas V90
Studland Bay (Woolnorth Lot 2)	2000/12	144.925	-40.785	25	Vestas V90
Bluff Point (Woolnorth Lot 1)	2000/12	144.925	-40.785	37	Vestas V66 1.75MW
King Is. Huxley Hill Stage 1		143.893	-39.942	3	Nordex 0.25MW
King Is. Huxley Hill Stage 2	2002/570	143.893	-39.942	2	Vestas [V52 - 850] 0.85MW
Nirranda	2001/471	142.741	-38.524	28	NEG Micron 1.65MW
Nirranda South	2002/763	142.788	-38.561	40	* Vestas V66
Codrington		142.383	-38.174	14	AN Bonus 1.3MW
Yambuk	2000/18	141.625	-38.390	20	NEG Micron 1.65MW
Portland 3 Capes combined	2000/18			100	NEG Micron 1.65MW
Green Point	2001/529	140.883	-38.030	18	Vestas V90
Kongorong	2002/568	140.499	-37.939	20	*Vestas V90

Windfarm	EPBC referral number (where applicable)	POINT_X	POINT_Y	Number of turbines	Turbine model
Canunda	2002/691	140.400	-37.767	23	Vestas V80 2.0MW
Lake Bonney Stage 1	2001/265	140.067	-37.417	46	Vestas V66 1.75MW
Lake Bonney Stage 2	2004/1630	140.359	-37.688	53	Vestas V90
Breamlea		144.602	-38.247	1	Westwind 60kW
Wonthaggi	2002/820	145.561	-38.614	6	REPower each turbine 2MW
Bald Hills	2002/730	145.946	-38.751	52	REPower each turbine 2MW
Dollar	2003/1110	146.166	-38.568	60	NEG Micron 1.65MW
Toora		146.407	-38.652	12	Vestas V66 1.75MW

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

Manufacturer's specifications for wind turbine models were used to calculate attributes of each of the nine models. 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 parrots, was calculated from specification data for both the static elements (tower and nacelle) and moving components (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 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 correlated to any particular wind direction and it is thus assumed that a bird is equally likely to encounter a turbine from any direction. Strongly directional movements are made by Orange-bellied Parrots during their annual migrations, however the number of such flights is an extremely small proportion of the total number of flights made by the birds during the course of a year. For the modelling undertaken here, we are assuming that birds are resident in the vicinity of most wind farms for periods of some months during which their flights are multi-directional. Hence the use of a mean turbine area is the appropriate approach.

The area presented by a turbine does differ 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 of an Orange-bellied Parrot is included in calculations of the presented area.

Turbine 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 minimum 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 Orange-bellied Parrots

2.4.1 Flight heights of Orange-bellied Parrots

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. Whilst a variety of turbine types are involved in this assessment, the lowest point swept by rotors for the majority of them is approximately 33 metres above the ground. The largest turbines (Vestas V90) 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. Very few data for Orange-bellied Parrots are available since the species has very rarely been recorded. However, a larger body of data has been obtained for the closely related Blue-winged Parrot *Neophema chrysostoma*. This indicates that *Neophemas* do fly within the rotor-swept-height at times although the very great majority of recorded flights are from below that zone. Flight behaviour, including height, is likely to vary according to the activity being undertaken. Parrots moving about a location in the course of routine foraging generally seem to do so at quite low heights whilst less frequent movements between sites, between feeding and roosting areas and on migration may be higher. We have assigned 25% of flights to the rotor-swept zone and 75% to the zone below rotor height. This is conservative when compared with our data for Blue-winged Parrots, in which a larger percentage of flights have generally been below rotor-swept height.

2.4.2 Avoidance by Orange-bellied Parrots 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 relate to the area presented by moving turbine components (the area of rotors plus 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. In should 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 most birds in 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 unlikely for some species in certain conditions.

It would seem likely that avoidance by a species with the flight characteristics of the Orange-bellied Parrot would generally be close to 100% in most conditions, but it may decrease in conditions of poor visibility, resulting in the average (mean) avoidance rate, being less than 100%. Migrating birds usually do not fly when visibility is reduced by fog or rain (Richardson 1998, Tulp et al. 1999). However, some individuals of some species do fly under these conditions and this can lead to increased collision risk. This occurs due to a decreased level of control individual birds have of their flight in very windy conditions or reduced visibility in fog/mist events (Richardson 1998). In respect of Orange-bellied Parrots specifically, there are no data, however, anecdotal evidence indicates that birds generally do not migrate in storm weather and the southward migration occurs in fine north-westerly weather conditions (Mark Holdsworth pers. comm.). This is consistent with migration behaviour as observed in birds generally (Richardson 1998). 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 Orange-bellied Parrots will have avoidance rates in the 95%-100% range.

2.4.3 Modelling of Orange-bellied Parrot migration and population size

Records of Orange-bellied Parrots across the species' range are strongly correlated with proximity to the coast. Virtually no records exist of the species further than five kilometres inland and by far the majority are within two kilometres of the coast. For the purposes of modelling, we have 'confined' the movements of parrots to a two-kilometre wide strip that is the length of the geographic range of the parrot and incorporates all of the relevant wind farms. In the model this does not mean that birds cannot interact with inland wind farms, but it artificially constrains the population to a strip of a width that appears to be realistic. This parameter of the model can thus only serve to overestimate risk to parrots by not 'allowing' them to fly outside of a zone which contains the wind farms.

The migration pattern and population dispersion of the Orange-bellied Parrot differ considerably according to geographic regions. For the purposes of modelling here they are considered according to the following regions:

Region 1: South-western Tasmania, where no wind farms are proposed,

Region 2: West coastal Tasmania from Cape Sorell to Sandy Cape, where it is considered likely that the entire population migrates twice annually (autumn and spring) along the coastal strip. Currently, one wind farm is proposed and under assessment for this region.

Region 3: North-western Tasmania and western Bass Strait islands, through which the entire population is believed to pass twice annually on migration and in which a portion of the population is known to reside for some days or weeks during the northward, autumn migration. Three wind farms are operational and a further two are proposed (one listed as 'Approved' and one as 'Approval not Required' under EPBC Act) in this region.

Region 4: Coastal Victoria, eastern South Australia and southern NSW, where the entire population is believed to be dispersed during the non-breeding season. It is considered likely that birds migrating from Tasmania make their landfall somewhere in the vicinity of Cape Otway, from where portions of the population disperse to the east and to the west. Within this region, birds may be resident for variable periods at particular locations and movements may occur over parts or all of the mainland range. Throughout this region, five wind farms are operational, one is under construction and a further eleven are proposed (six listed as 'Approved', three as 'Approval not Required', and two currently being assessed under the EPBC Act).

Within these four regions a scenario was developed and modelled to ascertain a potential survivorship rate for Orange-bellied Parrots for each wind farm with which it was deemed likely that parrots might interact. A scenario was determined to reflect potential population size that might be resident in the vicinity of the particular wind farm, annual period during which it might be resident, number of annual migratory movements and numbers of parrots that might interact with the wind farm during those movements. The actual numbers of Orange-bellied Parrots and frequency of their movements for any given wind farm are unknown and, especially for the mainland, it is not clear to what extent the population might be segmented or alternatively how widely the total population ranges. Hence, we have estimated population sizes for each wind farm such that when summed they equal the total known population. Modelled assumptions about numbers of birds that might interact with any given wind farm were informed, where possible, by known usage of key locations by the species.

From the discussion above (Section 1.1.4) it is apparent that some aspects of the Orange-bellied Parrot's migration and population size are quantifiable and can thus be modelled directly. However, a range of other aspects are not known and, for the purposes of modelling, require assumptions to be made.

Movements by birds that are resident in the vicinity of wind farms for variable periods of time are modelled for the likelihood that they may be made in any compass direction (see Section 2.3.1, above), since actual usage patterns are not known for any of the sites.

Region 1

No consideration of Region 1 is required for the present modelling as no wind farms are proposed for the region.

Region 2

In Region 2 a single large wind farm, the Heemskirk Wind Farm, is proposed. For this region we have modelled on the assumption that the entire population may make two passes through the site of the wind farm, once on the autumn and once on the spring migration. Mean population estimates of the Orange-bellied Parrot population for the two migrations are 200 in autumn and 99 in spring (Section 1.1.4). Thus a mean value of 150 parrots was modelled as making the two flights through the wind farm.

Region 3

For Region 3 it is known that the entire population passes through the general area during both autumn and spring migrations. As for Region 2, allowance was made for a margin of overestimation of potential risk and thus a mean value of 150 parrots was modelled as making the two migratory movements through the region. Some or all of the population is known to spend a period of some days or weeks within the region during the course of the autumn migration only. Knowledge of the availability of habitat at all sites and records from detailed investigations of bird utilisation of the two Woolnorth sites, allowed some site-specific assumptions to be made.

The two operating wind farms on King Island are considered to be on habitat inappropriate for the species. In addition, records of regular occurrence, in which a portion of the parrot population usually spends some weeks in autumn on the island, are from elsewhere on the island. Hence, no potential impacts on the parrot are considered likely to be posed by the two wind farms and modelling was not undertaken for them.

During extensive field investigations at the Woolnorth Lot 1 site no Orange-bellied Parrots have been recorded and again the habitat seems unsuited to the species. No part of the population is believed to reside in the vicinity of the farm for any length of time. Nevertheless, it is possible that the entire population could pass directly through the site unnoticed during its migration. Hence we have modelled for the possibility of the entire population (mean of 150 birds) annually making two migratory passes through the site.

For both Studland Bay (Woolnorth Lot 2), which has been investigated on-site, and Jim's Plain, where no studies have been undertaken, we have modelled for the possibility of one third of the population spending two weeks resident at the sites during autumn, one third of the population annually making two migratory passes through the sites and the remaining third bypassing the site altogether. The number of movements made by resident birds was set at two per day for two weeks, based on the concept that such birds might fly through the wind farm in question during daily flights to and from roost and foraging locations.

Region 4

In Region 4, the Dollar and Toora wind farms in South Gippsland are considered not to offer habitat suitable for the species and to be too far from suitable habitat to warrant modelling. Hence, no potential impacts on the parrot are considered likely to be posed by those farms and modelling was not undertaken for them.

No wind farm in this region occupies the entire coastal strip available to the species, but each encompasses a portion of that zone. Thus the number of parrots modelled as interacting with each wind farm, either during a period of residence locally or during migration through the area, has been estimated on the basis that part of the population will fly through the site and another part will bypass the wind farm.

A number of locations within this region do not directly offer suitable habitat and are geographically positioned such that it would seem unlikely that Orange-bellied Parrots would reside at the particular location for any length of time. In those instances we have modelled for the possibility of a portion of the population annually making two migratory passes through the site.

Various other sites are within close proximity of appropriate habitats where portions of the parrot's population are recorded, but none are known to be inhabited themselves by long-term resident birds. In those cases we have modelled for the possibility that a portion of the population is resident close to the site for six months of the year. The number of movements made by such resident birds was set at two per day for an entire six months, based on the concept that such birds might fly through the wind farm in question during daily flights to and from roost and foraging locations. A further portion of the population is modelled as annually making two migratory passes through the site.

The numbers of parrots modelled as either resident or migrating through sites within Region 4 are based on the concept that the entire population migrating from Tasmania in autumn makes a landfall in the area between Cape Otway and the Bellarine Peninsula. We have assumed that half of the population then moves eastward along the coastline whilst the remaining half moves westward. For the modelling of cumulative impacts of multiple wind farms we make a distinction between these two sub-populations (see below Section 2.4.4). We refer to these sub-regions and populations as Region 4W (the portion from Cape Otway to the western extremity of the species' distribution in South Australia), and Region 4E (the portion from Cape Otway to the eastern extremity of the species' distribution in NSW). As each location where birds are known to reside for part of the non-breeding period is encountered during the migration into the mainland range by the two sub-populations we have assumed that a number of birds take up residence there whilst the rest of the birds continue eastward or westward. Thus the number of birds continuing to travel further is modelled as becoming sequentially less as birds take up residence along the route. For Region 4 we have modelled for a total of 95 birds in a western sub-population and 95 in an eastern sub-population that may interact with turbines. This total of 190 birds equates to 95% of the entire mean autumn population of Orange-bellied Parrots recorded during the seven years between 1998/99 and 2004/05 and models for that portion of the population all having some interaction with wind turbines.

The Orange-bellied Parrot scenario modelled for each wind farm is outlined in Table 3.

Table 3 **Scenario modelled for Orange-bellied Parrot use of wind farms**

					Population sizes (number of birds) modelled		
Wind farm	**Region**	**Bird utilisation studied at the site**	**Orange-bellied Parrots &/or Blue-winged Parrots recorded?**	**Types and annual duration of Orange-bellied Parrot interaction with windfarm modelled**	**Resident population for 6 months (autumn - spring, mainland**	**Resident population for 2 weeks (autumn, NW Tas.)**	**Passage migrant population (2 x passes thru site per annum)**
Heemskirk	2	Yes	Very few OBPs, few BWPs	Possible migration passage only	0	0	150
Jim's Plain	3	No		Potential residency by part of population for 2 weeks + migration passage by additional portion of population	0	50	50
Studland Bay (Woolnorth Lot 2)	3	Yes	Very few OBPs, some BWPs	Potential residency by part of population for 2 weeks + migration passage by additional portion of population	0	50	50
Bluff Point (Woolnorth Lot 1)	3	Yes	No OBPs, few BWPs	Possible migration passage only	0	0	150
King Is Huxley Hill Stage 1	3	No		Distant from habitat. Not relevant to model	N/A	N/A	N/A
King Is Huxley Hill Stage 2	3	No		Distant from habitat. Not relevant to model	N/A	N/A	N/A
Nirranda	4W	Yes	Very few OBPs, few BWPs	Potential residency by part of population for 6 months + migration passage by additional portion of population	5	0	45

					Population sizes (number of birds) modelled		
Wind farm	**Region**	**Bird utilisation studied at the site**	**Orange-bellied Parrots &/or Blue-winged Parrots recorded?**	**Types and annual duration of Orange-bellied Parrot interaction with windfarm modelled**	**Resident population for 6 months (autumn - spring, mainland**	**Resident population for 2 weeks (autumn, NW Tas.)**	**Passage migrant population (2 x passes thru site per annum)**
Nirranda South	4W	Yes	No OBPs, few BWPs	Potential residency by part of population for 6 months + migration passage by additional portion of population	5	0	45
Codrington	4W	Yes	No OBPs, few BWPs	Potential residency by part of population for 6 months + migration passage by additional portion of population	10	0	35
Yambuk	4W	Yes	Few OBPs, few BWPs	Potential residency by part of population for 6 months + migration passage by additional portion of population	10	0	25
Portland 3 Capes combined	4W	Yes	No OBPs, few BWPs	Possible migration passage only	0	0	25
Green Point	4W	Yes	No OBPs, numbers of BWPs	Potential residency by part of population for 6 months + migration passage by additional portion of population	5	0	10
Kongorong	4W	No		Potential residency by part of population for 6 months + migration passage by additional portion of population	5	0	10
Canunda	4W	No		Possible migration passage only	0	0	10
Lake Bonney Stage 1	4W	Yes	Neither spp recorded	Possible migration passage only	0	0	10

Wind farm	Region	Bird utilisation studied at the site	Orange-bellied Parrots &/or Blue-winged Parrots recorded?	Types and annual duration of Orange-bellied Parrot interaction with windfarm modelled	Population sizes (number of birds) modelled		
					Resident population for 6 months (autumn - spring, mainland	Resident population for 2 weeks (autumn, NW Tas.)	Passage migrant population (2 x passes thru site per annum)
Lake Bonney Stage 2	4W	Yes	Neither spp recorded	Possible migration passage only	0	0	10
Breamlea	4E	No		Potential residency by part of population for 6 months + migration passage by additional portion of population	2	0	0
Wonthaggi	4E	Yes	Neither spp recorded	Potential residency by part of population for 6 months + migration passage by additional portion of population	0	0	20
Bald Hills	4E	Yes	No OBPs, few BWPs	Possible migration passage only	0	0	15
Dollar	4E	Yes	No OBPs, few BWPs	Distant from habitat. Not relevant to model	N/A	N/A	N/A
Toora	4E	No		Distant from habitat. Not relevant to model	N/A	N/A	N/A

2.4.4 Modelling of cumulative impacts relevant to subpopulations

In assessing the cumulative impacts of wind farms it is plausible to argue that all birds in the Orange-bellied Parrot population could encounter wind farms in western Tasmania and Bass Strait islands, as outlined above (Section 2.4.3 Regions 2 and 3). However, it appears unlikely that the entire Orange-bellied Parrot population would face risks from all of the wind farms distributed across the large mainland range in a given year. In order to account for this in modelling of cumulative impacts we have assessed the mainland range as two separate subregions (Region 4W and Region 4E, see Section 2.4.3). This concept allows modelling without the unrealistic assumption that every bird is at risk from every wind farm. The survivorship rate for the overall mainland range is thus found by first determining the survivorship rate for each subregion (i.e. the product of survivorship values of all wind farms within each subregion - see also Section 2.1 and Appendix 1). Since we have modelled population dispersion on the basis that each of these subregions accommodates half of the entire population, the survivorship rate for the two subregions is next halved and the two resulting values are then summed to obtain the overall value for the mainland (Region 4). Finally, that value is multiplied by the overall survivorship rate for Regions 2 and 3 to obtain the survivorship rate for the entire twenty-three wind farms across the species' total range.

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 Orange-bellied Parrot collisions with wind turbines is to determine a level of risk posed by each individual wind farm. Results from this process also allow assessments 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 4. It has been necessary to calculate and show these values to seven 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 4 Modelled survivorship rates for wind farms presenting a collision risk to Orange-bellied Parrots

Wind farm	Survivorship rate at 95% avoidance rate	Survivorship rate at 98% avoidance rate	Survivorship rate at 99% avoidance rate
Regions 2 and 3			
Heemskirk	0.9999702	0.9999799	0.9999832
Jim's Plain	0.9999368	0.9999574	0.9999643
Woolnorth Lot 2	0.9999293	0.9999524	0.9999600
Woolnorth Lot 1	0.9999641	0.9999718	0.9999744
Region 4W			
Nirranda	0.9986540	0.9989850	0.9990960
Nirranda South	0.9984370	0.9988000	0.9989210
Codrington	0.9980340	0.9984910	0.9986430
Yambuk	0.9970040	0.9977410	0.9979860
Portland 3 Capes	0.9998727	0.9999041	0.9999145

Wind farm	Survivorship rate at 95% avoidance rate	Survivorship rate at 98% avoidance rate	Survivorship rate at 99% avoidance rate
Green Point	0.9955140	0.9969750	0.9974620
Kongorong	0.9952720	0.9968110	0.9973250
Canunda	0.9999301	0.9999489	0.9999552
Lake Bonney Stage 1	0.9999200	0.9999372	0.9999429
Lake Bonney Stage 2	0.9999405	0.9995990	0.9999664
Region 4E			
Breamlea	0.9997710	0.9997810	0.9997850
Wonthaggi	0.9999288	0.9999502	0.9999574
Bald Hills	0.9999001	0.9999294	0.9999392

3.2 Estimated cumulative impacts across the range of the Orange-bellied Parrot

The cumulative products of survivorship rates determined for all wind farms across the regions of the Orange-bellied Parrot's range are provided in Table 5.

Table 5 **Cumulative survivorship values for the Orange-bellied Parrot population from potential collision risk posed by 17 wind farms in south-eastern Australia**

Survivorship rate at 95% avoidance rate	Survivorship rate at 98% avoidance rate	Survivorship rate at 99% avoidance rate
0.9910	**0.9933**	**0.9944**

3.2.1 Impacts on Orange-bellied Parrot annual survivorship

In order to assess the potential impact of altered survivorship rates that may be imposed on the Orange-bellied Parrot population by collisions with wind turbines it is first necessary to know the natural, background survivorship rate.

Comprehensive population data for Orange-bellied Parrots for the period from 1998/99 to 2004/05 has been provided to us by the Recovery Team (M. Holdsworth pers. comm. 2005). From that data we have determined survivorship values from the portion of the population comprised of individually colour-banded birds in the wild population, including reintroduced birds known to have survived beyond a first migration. Use of this portion of the population permits the most accurate calculation of survivorship values.

The data for this portion of the population indicates that the mean annual survivorship rate (calculated for each year and then averaged) was 0.68 (SD = 0.10) (i.e. on average 68% of the population survive from one year to the next) for the period from 1998/99 to 2004/05 (Table 6).

McCarthy (1995) found that the annual survivorship of the wild Orange-bellied Parrot population was 0.59 (i.e. 59% of the population surviving from one year to the next). Data for the period from 1998/99 to 2004/05 thus indicates a higher background annual survivorship rate than that calculated by McCarthy for the period prior to 1995.

Orange-bellied Parrots are sedentary during the six month long annual breeding period in south-western Tasmania where there is no risk of interactions with wind farms. Hence, only the six-month period from autumn until spring, when collisions with wind turbines could occur, is relevant to determination of the background survival rate for the species for our purposes. The available data does not provide sufficient detail to determine actual survival rates for different portions of the birds' annual cycle. Thus a constant year-round rate is assumed here for all post-fledgling birds in the population. On that basis the data gives us a background survival rate of 0.82 (SD = 0.07) for the six-month period during which birds are at risk of turbine collisions. The value is shown to four significant figures in Table 6 for the purpose of further calculations, below.

Table 6 **Population and demographic values for the banded component of the Orange-bellied Parrot population 1998/99 – 2004/05**

Breeding season	Annual population minimum [total pre-breeding season population]	Annual population maximum [total post-breeding season population]	Annual survivorship rate	Six-monthly (Autumn - Spring) survivorship rate
1998/99	83	106	0.7784	0.8823
1999/00	64	97	0.6568	0.8105
2000/01	81	96	0.8448	0.9191
2001/02	59	121	0.4909	0.7006
2002/03	73	108	0.6752	0.8217
2003/04	69	108	0.6375	0.7984
2004/05	68	96	0.7038	0.8389
mean	**71**	**105**	**0.6839**	**0.8245**
SD	8.58	9.13	0.10	0.07

The effect on the Orange-bellied Parrot population of survivorship values calculated here for cumulative impacts of collision risk may be determined by multiplying the background six-monthly survivorship rate by wind farm survivorship rates.

Thus, for the case of 95% avoidance rate, the cumulative effect equals 0.8170 (0.8245 x 0.9910). The equivalent annual rate for 98% avoidance rate equals 0.8189 (0.8245 x 0.9933) and for 99% avoidance rate equals 0.8198 (0.8245 x 0.9944).

In summary, it is predicted from the cumulative effects modelling process that the overall mean survival rate for the Orange-bellied Parrot may be expected to drop from a background environmental rate of 0.8245 to 0.8170, 0.8189 or 0.8198 for turbine avoidance rates of 95%, 98% and 99% respectively. These changes correspond to increases of 0.009, 0.007 or 0.006 in mortality rate.

It will immediately be seen that the rates of survivorship of turbine collisions at wind farms, predicted by our cumulative modelling, will alter survivorship rates of the Orange-bellied Parrot population from the existing background rate to only a very small degree. For all avoidance rates we have modelled, the predicted change in survivorship rates are approximately one order of magnitude less than the annual variation in the background rate as indicated by the standard deviations for background survivorship rates (Table 6).

3.2.2 Predicted Orange-bellied Parrot mortalities

A number of birds that might be killed annually by the predicted cumulative effects of collisions with wind turbines can be determined by multiplying the mean annual number of Orange-bellied Parrots that might interact with wind turbines by the predicted annual cumulative mortality rate. Note that the mortality rate is simply the inverse of the survivorship of rate.

The mean population size used here is 150 birds (i.e. equals the mean of the annual population maximum and minimum (200 + 99)/2 = 149.5) see Section 1.1.4).

For the case of 95% avoidance rate, the predicted annual cumulative mortality rate from wind turbine collisions equals 0.0090 (i.e. the inverse of the predicted annual cumulative survivorship rate (1 - 0.9910 = 0.0090). The annual number of mortalities thus equates to 1.35 birds (i.e. 150 x 0.0090 = 1.35).

For the case of 98% avoidance rate, the predicted annual cumulative mortality rate from wind turbine collisions equals 0.0067 (i.e. the inverse of the predicted annual cumulative survivorship rate (1 - 0.9933 = 0.0067). The annual number of mortalities thus equates to 1.01 birds (i.e. 150 x 0.0067 = 1.005).

For the case of 99% avoidance rate, the predicted annual cumulative mortality rate from wind turbine collisions equals 0.0056 (i.e. the inverse of the predicted annual cumulative survivorship rate (1 - 0.9944 = 0.0056). The annual number of mortalities thus equates to 0.84 birds (i.e. 150 x 0.0056 = 0.8400).

In the entire Orange-bellied Parrot population, an average of 101 Orange-bellied Parrots have died annually in the period from 1998/99 to 2004/05 (Table 1). However the actual number has varied from 64 to 124 (SD = 19.74). Predictions of the current modelling suggest that between 1.35 and 0.84 additional parrot mortalities might result annually from the cumulative effects of wind turbine collisions across the species range if all potential wind farms were to be built. We consider that a collision avoidance rate for the species will be 99% or higher. Thus the additional mortality predicted for the cumulative effects of turbine collisions for wind farms within the range of the Orange-bellied Parrot is likely to result in the additional death of less than one bird per annum.

In a review of an early draft of this report (Pople 2005) it was suggested that compensatory mortality might be expected to ameliorate the effects of collisions at wind farms due to density dependent regulation of the population. In other words, birds that might fatally collide with turbines may have been birds that would have died anyway or their death might improve the survival probability of other birds. However, in order to demonstrate that the population is regulated in a density dependent fashion it would first be necessary to show that it is at equilibrium. We do not suggest that density dependence might not regulate the population, but we are not aware of any demonstrable evidence that this is the case and it is difficult to substantiate for almost any natural population (Krebs 1995). Certainly the population is now limited by a variety of influences, possibly including its fidelity to traditional relict breeding and overwintering locations and the resources provided at those sites. However such mechanistic regulators of the population do not of themselves provide evidence of density dependence. Indeed the Orange-bellied Parrot population's substantial decline since European settlement has occurred for largely unknown reasons and current influences are also largely unknown. Despite relative stability of the population for the seven years of data we have here, the data for the period since 1999 follows some population growth resulting from initiation and continuing supplementation of the population by way of reintroductions. The reintroductions into apparently suitable former habitat at Birch's Inlet actually provide an experimental indication that the population is not presently operating at a habitat carrying capacity and may not currently be regulated in a density dependent fashion.

3.2.3 Conclusion: Predicted Cumulative Impacts

The cumulative impacts of collision with turbines on the population of Orange-bellied Parrots predicted by the modelling undertaken here are small and it is highly likely that their effects would be masked by normal fluctuations that occur in the population due to natural environmental variables.

Mortality of Orange-bellied Parrots due to collisions with turbines may be very small – even barely noticeable - compared with natural mortality, however, we are of the view that it is nonetheless a negative impact on the species and should be offset by mitigation and conservation measures. That is preferable to assuming that density dependent regulation of the population will offset losses or that it might prevent potential growth of the population initiated by positive mitigation measures.

4.0 METHODS: CRITICAL IMPACT LEVEL

The objective of this element is to determine a suitable estimation of the level at which predicted cumulative effects of collision is likely to present concerns for the Orange-bellied Parrot population.

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 Orange-bellied Parrot resulting from increased mortality due to collisions with wind turbines as predicted by our modelling of the cumulative effects of wind farms across the species' range. The VORTEX model used is an individualistic, stochastic model, accounting for life-stages and various mortality risks. It was possible to undertake this analysis for the Orange-bellied Parrot only because comprehensive census data for population has been obtained by the Orange-bellied Parrot Recovery Program since 1998 (Holdsworth, pers. comm.) and was made available to us. Population and demographic values from the data were used for input to the PVA model. A life-table was constructed from these to derive life-expectancy values.

In the absence of empirical data about actual impacts on the species, any evaluation of what constitutes a critical level of impact on an endangered 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

The modelling assumed that there is a single Orange-bellied Parrot population of an initial population size of 99 birds (i.e. the recent mean population size at the commencement of annual breeding seasons). A stable age distribution was used and a sex ratio of 3 males : 2 females was used.

Simulations were run for 100 years and for 1000 iterations per scenario.

Environmental variation in reproduction and mortality was considered to be concordant. An upper habitat carrying capacity of 500 Orange-bellied Parrots was used.

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

The parrots were defined as monogamous, but capable of re-pairing rapidly after the death of a previous partner. It was assumed that the age of first breeding was at one year and was the same for both males and females. Maximum breeding age for both sexes was set at a mean of ten years of age (Table 7).

Table 7 **Putative life-table for Orange-bellied Parrot population based on life-history and survivorship attributes provided by Orange-bellied Parrot Recovery Team (2005).**

Age of life-stage increment (years)	Life stage	Annual survivorship rate (*Sx*)	Cumulative cohort survivorship rate *(Sx)*	Mean number of individuals of annual cohort surviving
hatch				101
0 - 1	Juvenile *S*	0.50	0.50	51
1 - 2	Adult 1 *S*	0.68	0.34	34
2 - 3	Adult 2 *S*	0.68	0.23	23
3 - 4	Adult 3 *S*	0.68	0.16	16
4 - 5	Adult 4 *S*	0.68	0.11	11
5 - 6	Adult 5 *S*	0.68	0.07	7
6 - 7	Adult 6 *S*	0.68	0.05	5
7 - 8	Adult 7 *S*	0.68	0.03	3
8 - 9	Adult 8 *S*	0.68	0.02	2
9 - 10	Adult 9 *S*	0.68	0.02	2
10 - 11	Adult 10 *S*	0.68	0.01	1
11 - 12	Adult 11 *S*	0.68	0.01	1
12 - 13	Adult 12 *S*	0.68	0.00	0

Annual survivorship rate for both sexes from hatch to one year of age was 0.50. For all adults it was 0.68. Environmental variation in annual survivorship for all ages and both sexes was set at 0.10 (Table 6).

Based on data supplied, fecundity rates used for those females producing progeny were:

6.00 percent of females produce 1 progeny in an average year
10.00 percent of females produce 2 progeny in an average year
24.00 percent of females produce 3 progeny in an average year
33.00 percent of females produce 4 progeny in an average year
23.00 percent of females produce 5 progeny in an average year
4.00 percent of females produce 6 progeny in an average year

Deterministic population growth rate values are critical for understanding the observed dynamics. (see Section 5.0 Results and Discussion: PVA Modelling of Critical Impact Assessment for discussion). The relevant values are:

r = 0.043
lambda = 1.044
R_0 = 1.129
Generation time for females and males = 2.82 years.

No information was available about the possible influences of negative stochastic effects such wildfire, storm events during migrations or disease nor of unpredictable positive events like eruptions of favoured foods. Likewise, we were not able to incorporate any effects of inbreeding depression on a small population, or the influences of 'harvest' of birds into a captive population and of supplementation through reintroductions.

4.1.2 Incorporating the effects of wind farm collisions

Whilst Orange-bellied Parrot densities vary considerably across the species' range, our objective was to provide a critical impact evaluation for the cumulative impact of all relevant wind farms. Hence the *cumulative* impact value predicted for all wind farms combined, for each avoidance rate (see *3.2 Estimated cumulative impacts across the range of the Orange-bellied Parrot*) was used in PVA modelling.

4.1.3 Finding a Critical Level of impact on the Orange-bellied Parrot

In 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. 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 'Baseline' model, which represents the population as it is currently functioning. 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

The following findings of Population Viability Analyses are drawn from two data sets: the Baseline and the Critical Level scenarios.

The Baseline scenario models the current observed environment for Orange-bellied Parrots as described in the Recovery Team data supplied by Mark Holdsworth. We then ran a further three scenarios, corresponding to the Cumulative Wind Turbine Collision effects results calculated for 95%, 98% and 99% avoidance rates respectively.

PVA modelling found that the risk of extinction is affected to varying degrees by the introduction of collision risks predicted by our modelling of the cumulative impacts for the twenty-three wind farms assessed here.

As can be seen in Figure 1, the probability of extinction immediately increases from the Baseline scenario when we add the cumulative effects of wind farm collisions, at any of the three avoidance rates, into the model.

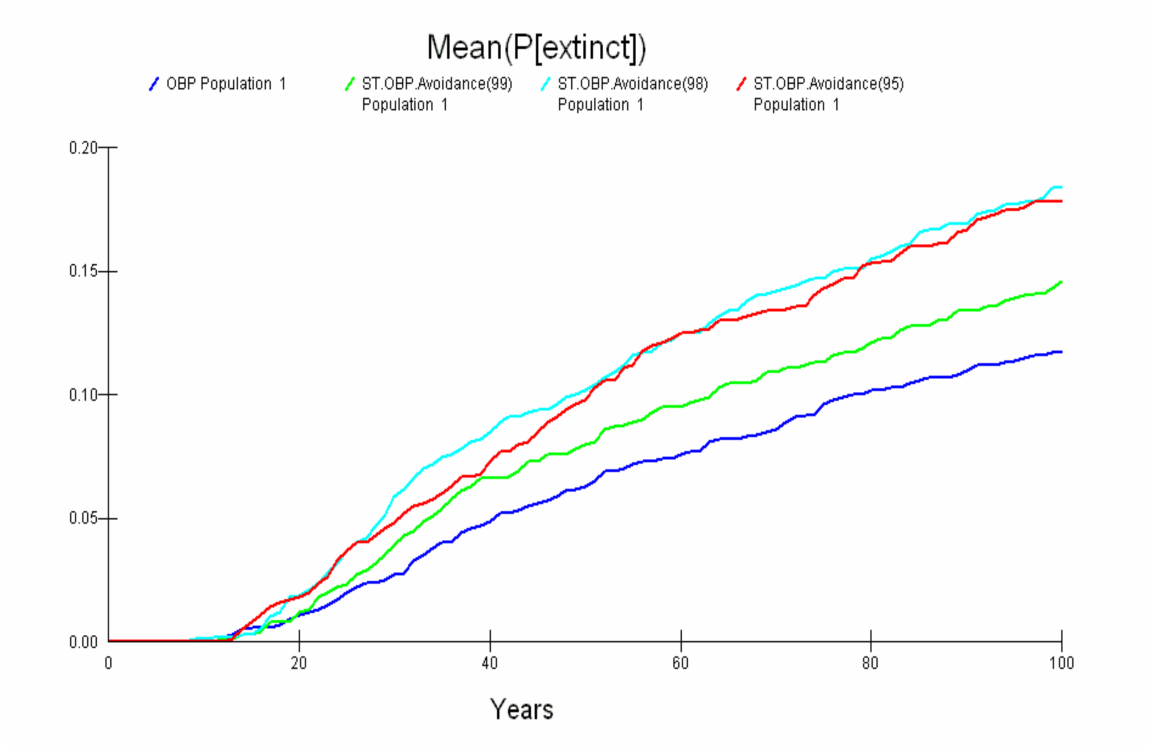

Figure 1 Probability of extinction of the Orange-bellied Parrot for Baseline (blue) and Cumulative Wind Turbine Collision results calculated for 95%, 98% and 99% avoidance.

Figure 2 displays the standard error bars over the same data, clearly showing that the separation between the Baseline case and the 99% avoidance of the current and proposed wind farms is a real effect.

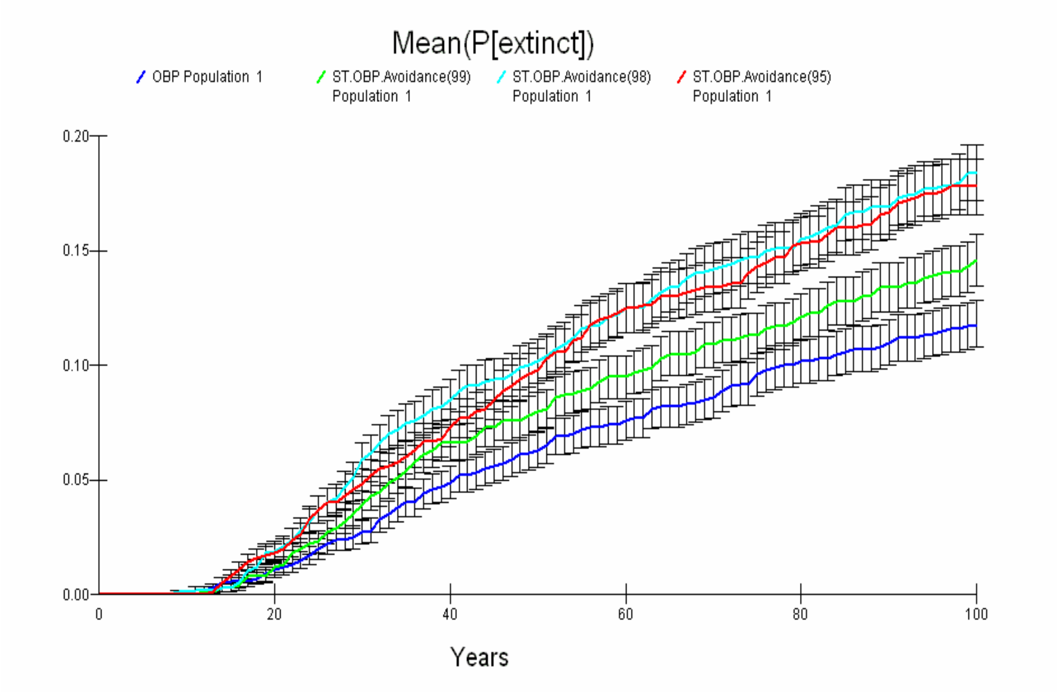

Figure 2 **Probability of extinction of the Orange-bellied Parrot for Baseline (blue) and Cumulative Wind Turbine Collision results calculated for 95%, 98% and 99% avoidance with Error Bars shown.**

The following few charts highlight the large amount of spread in the simulated population numbers, with the error bars corresponding to 66% confidence. The apparent plateau is driven by the population truncation as it reaches the proposed site capacity of 500 individuals.

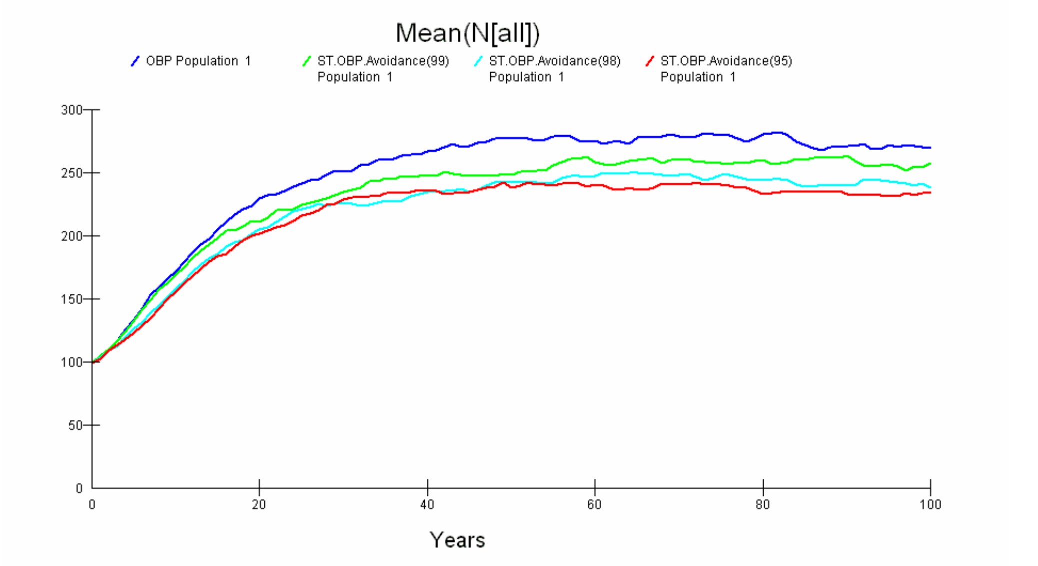

Figure 3 **Mean predicted population size of the Orange-bellied Parrot over time for Baseline (blue) and Cumulative Wind Turbine Collision results calculated for 95%, 98% and 99% avoidance.**

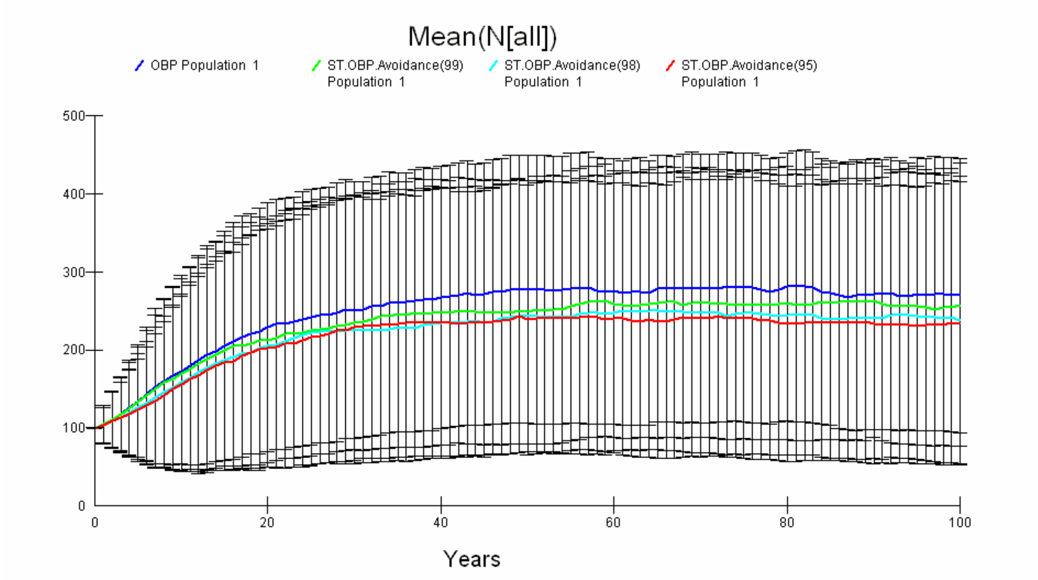

Figure 4 **Mean predicted population size of the Orange-bellied Parrot over time for Baseline (blue) and Cumulative Wind Turbine Collision results calculated for 95%, 98% and 99% avoidance with Error Bars shown.**

This distribution of population possibilities is explained by examining the deterministic drivers of the population.

The most significant of these is the deterministic “r” value (Figure 5), which controls the (exponential) growth of any natural system. As we can see, the Baseline case exhibits an “r” = of only 0.043. This value is critical because, should it become negative, no environmental variations can conspire to save the species from impending extinction. Any additional stresses placed on the population, can be seen to immediately reduce this value. What makes the population so dynamic, is the effect of the Environmental Variations, which contribute around 0.23, or 5 times the baseline deterministic value. This means that the population is almost completely dominated by environmental variation.

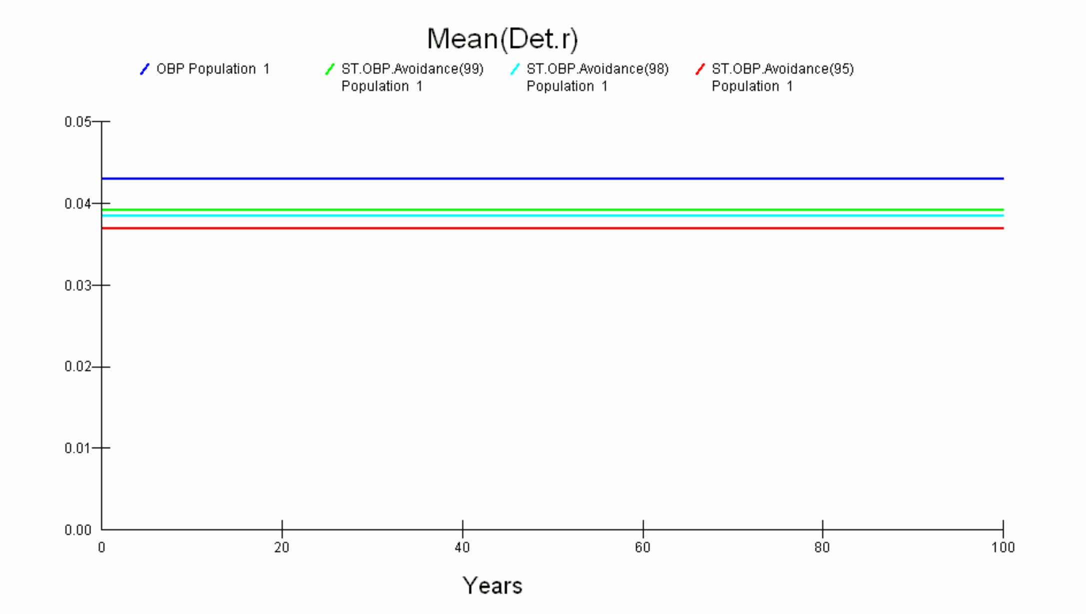

Figure 5 Deterministic "r" values for the Orange-bellied Parrot over time for Baseline (blue) and Cumulative Wind Turbine Collision results calculated for 95%, 98% and 99% avoidance.

Environmental variations are shown in the chart of Stochastic "r" (Figure 6). This indicates how the normal variation frequently tips the growth rate negative. The average for the current environment remains positive, albeit only just.

An "r" value of 0.04 means that for an average year, we expect the population to grow by about 4%, or in this case, 4 individuals. Once we add environmental effects, the average value drops to closer to 0.02, meaning average years only supply two individuals to the population (assuming a population of around 100).

Thus the continued survival of the species is currently very precariously balanced.

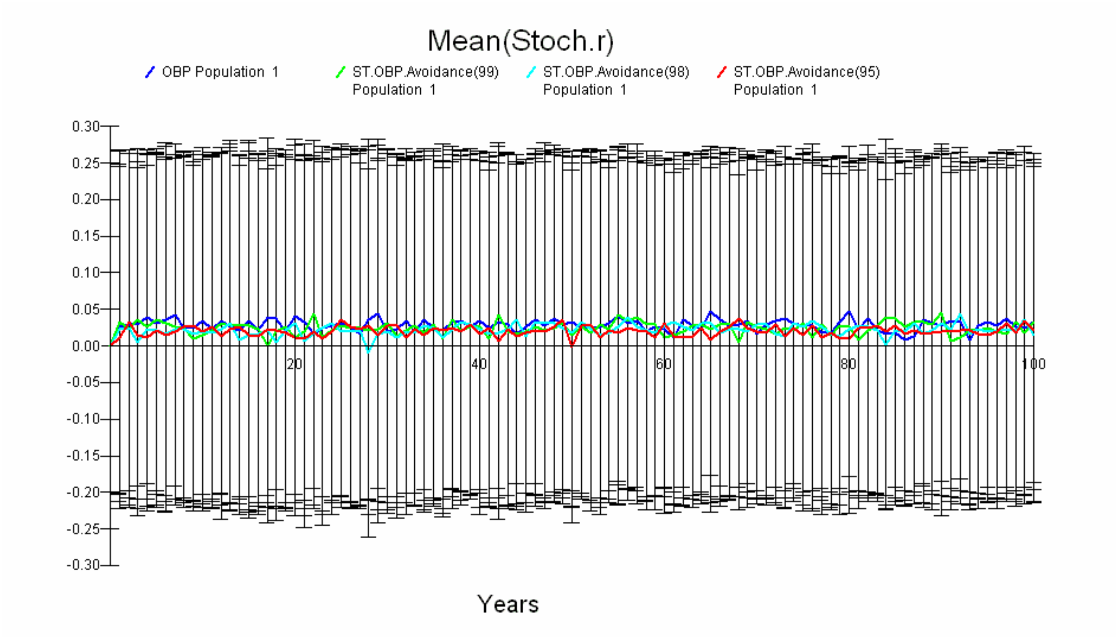

Figure 6 Stochastic "r" values for the Orange-bellied Parrot over time for Baseline (blue) and Cumulative Wind Turbine Collision results calculated for 95%, 98% and 99% avoidance.

To highlight and interpret this component of the model, the ratio of the standard deviation of the growth rate to the deterministic value implies that 42% of years will result in a population decline. This in turn means that only around one in five years will actually result in a net population growth (two bad years, two good years to recover, and the final year to actually move forward).

5.1.1 Finding a Critical Level

Technically, and numerically, the critical level of environmental risk is when the deterministic "r" drops to a negative value. In order to find the Critical Level, the PVA model was run using incremental increases of 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.10, 0.15 and 0.20 of the Baseline environmental risk. These are shown sequentially as "Critical Level (1)", "Critical Level (2)", …."Critical Level (10)", in Figure 7. It can be seen that the deterministic "r" drops to a negative value critical level at around 0.05 increase ("Critical Level (5)"), over the current observed risk to the birds from their environment. However, it should also be noted that large variation in population numbers is possible for this and any of the other levels modelled (Figure 8).

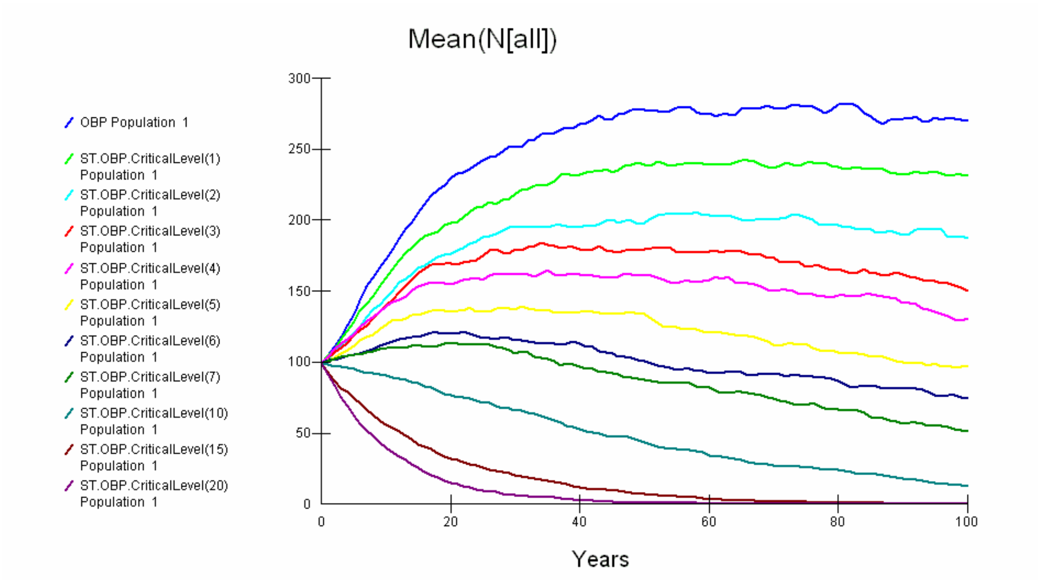

Figure 7 Incremental increases of 0.1 – 0.20 environmental risk (Deterministic "r") values above those currently operating (shown as Baseline (blue)) for the Orange-bellied Parrot population over time.

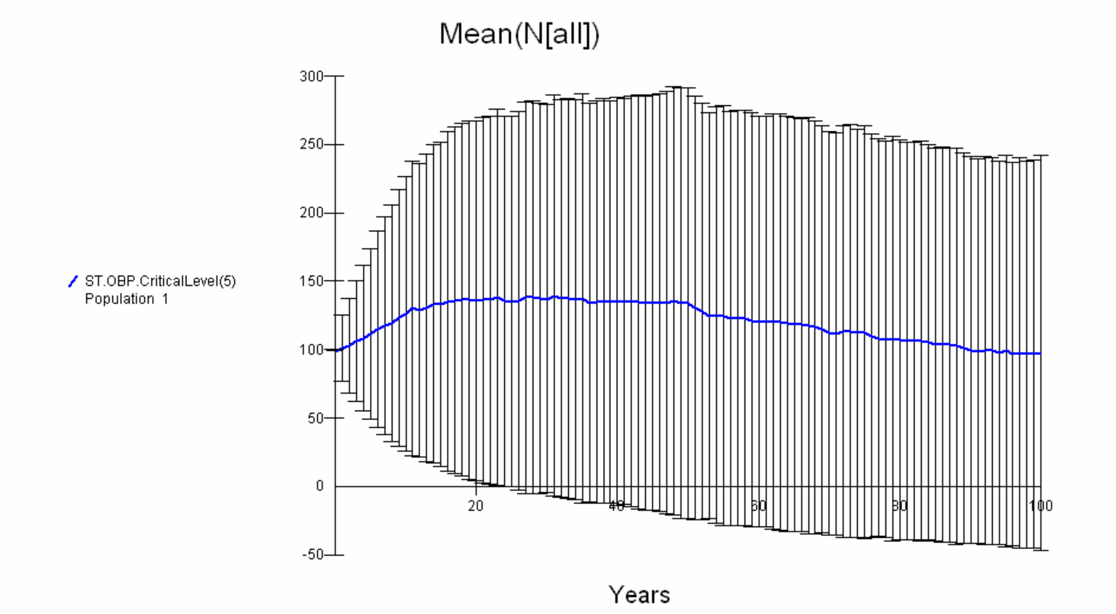

Figure 8 Variation in population size (error bars) for an increases of 0.5 environmental risk (Deterministic "r") value above current for the Orange-bellied Parrot population over time.

To find the critical value, we can use either of the following methods, both of which indicate an increase in background environmental risk of 0.05 will result in the loss of the species. It should be noted that at the current levels, the species only enjoys population growth, minimal as it is, 60% of the time, implying a one-year-in-five net growth. Any increase in risk to this species, such as the effects of catastrophes or genetic inbreeding, will reduce this tenuous hold. As it stands, an unmodelled event occurring once every five years may reduce the species growth rate to zero or negative.

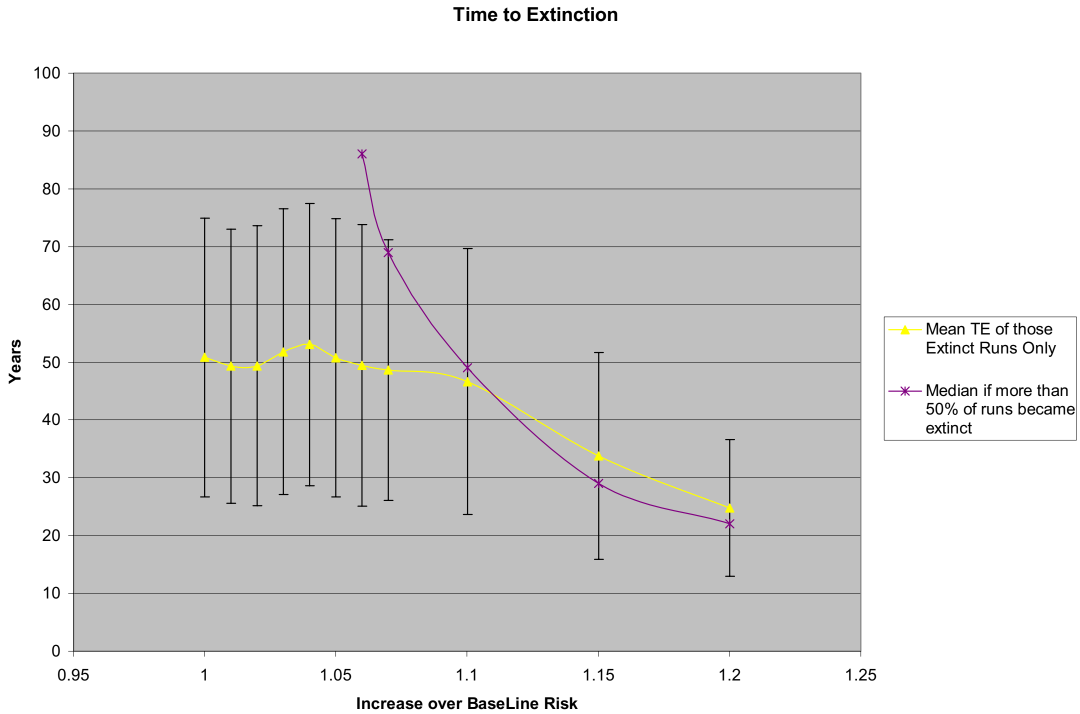

Figure 9 Modelled mean and median times to extinction as environmental risk is incrementally increased above current "Baseline" (1.0).

Figure 9 shows the Time to Extinction (TE) predicted from the PVA. The yellow curve is the mean time for any runs in the scenario testing which actually became extinct. We show the more robust median TE only when more than 50% of the models resulted in an extinction. Both these curves show a change in behaviour at an increase of 0.05 – 0.06 over the baseline case.

This is driven by the deterministic growth factor, shown in Figure 10.

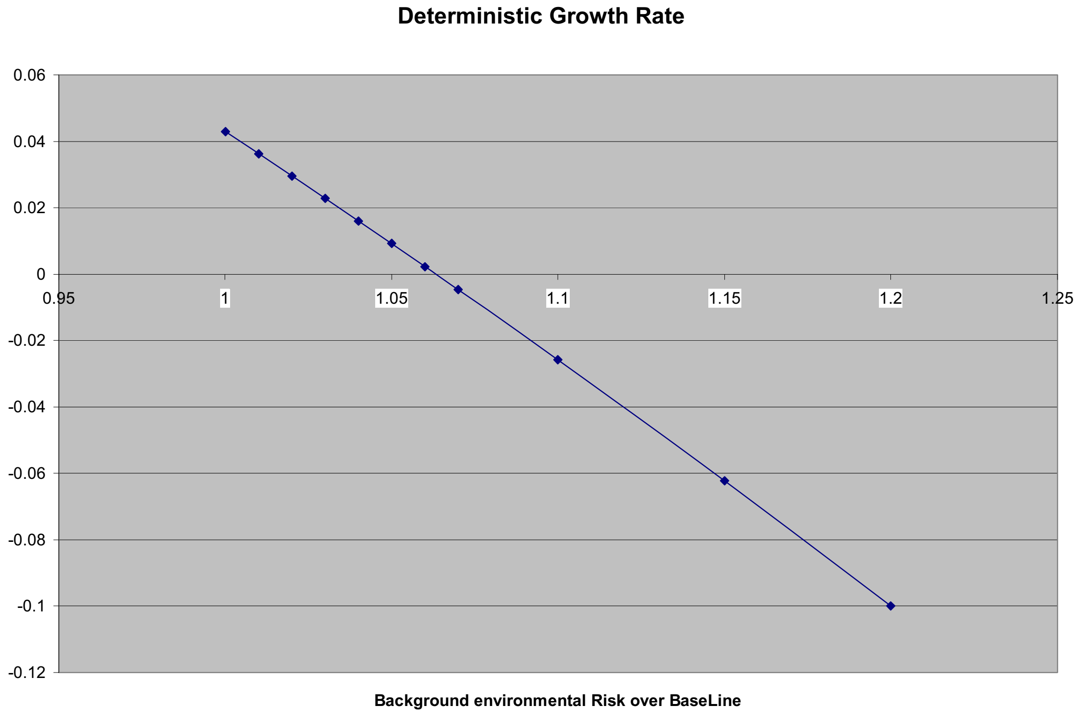

Figure 10 Deterministic growth rate for the Orange-bellied Parrot population as environmental risk is incrementally increased above current "Baseline" (1.0).

5.1.2 Caveats and Conclusions.

PVA modelling should only really be used as a comparative tool, to assess the relative effects of different management strategies. However, in this particular case, we believe that the quality of data is good enough and consistent enough to draw the conclusions above.

The exclusion of some environmental effects, such as catastrophes, from this model highlights the tenuous balance of the species. The current and proposed levels of wind farms within its habitat do not significantly affect the chance of survival, although the clear dominance of the environmental variation (in which wind farms are included) upon the system is noted. Although technically capable of withstanding an increase to about 0.05 times current levels of environmental risk (after which extinction is predicted to be inevitable), this figure does not allow room for the effects of sporadic events, nor the stochastic conspiring of a run of "bad" years, which would potentially be the ultimate cause of extinction of the species.

Modelling of the cumulative impacts of turbine collisions at twenty-three wind farms predicts an increases in mortality rates in the range of between 0.006 and 0.009 above current levels, dependant upon turbine avoidance rate (see Section 3.2.1). PVA modelling predicts that extinction risks for Orange-bellied Parrots would increase slightly as a result of such increases in mortality rates, as shown in Figures 1 and 2. PVA modelling indicates that extinction risk will increase to the point where it is an inevitable outcome if environmental risk, such as mortality rates, increase to about 0.05 times above current levels.

Of vital concern for the Orange-bellied Parrot, is the fact that PVA modelling utilising the most up-to-date and comprehensive population information indicates that the species has a very high probability of going extinct within about 50 years *in the absence of any mortality due to wind turbine collisions*. Despite the best efforts of the Orange-bellied Parrot Recovery effort, there are clearly substantive factors that are presently largely preventing growth of the population and placing it at very significant risk of extinction. Our modelling did not have information available from which to incorporate frequency or magnitude of stochastic environmental events such as wildfire, disease or storm events, nor adverse genetic consequences of small population size. Without doubt such factors must have adverse effects on the population that increase the risks of its extinction over and above results shown by our PVA modelling.

The Orange-bellied Parrot is clearly in a very tenuous predicament caused by an array of both identified and unknown factors. Our modelling suggests that the cumulative mortality of Orange-bellied Parrots that is likely to result from turbine collisions at current and proposed wind farms across its range will be very small at the population level. PVA modelling of this cumulative effect indicates that it would increase the probability of extinction if it were to continue over timeframes substantially longer than the average expected life of current wind farms.

Given that the Orange-bellied Parrot is predicted to have an extremely high probability of extinction in its current situation, almost any negative impact on the species could be sufficient to tip the balance against its continued existence. In this context it may be argued that any avoidable deleterious effect - even the very minor predicted impacts of turbine collisions - should be prevented. Our analyses suggest that such action will have extremely limited beneficial value to conservation of the parrot without addressing very much greater adverse effects that are currently operating against it.

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.

REFERENCES

Brook B.W., Burgman M.A., Akçakaya H.R., O'Grady J.J., Frankham R., 2002. *Critiques of PVA ask the wrong questions: throwing the heuristic baby out with the numerical bath water*. Conserv. Biol. 16, 262-263.

Burgman M.A., 2000. *Population viability analysis for bird conservation: prediction, heuristics, monitoring and psychology*. Emu, 100, 347-353.

Everaet, J., Devos, K. & Kyuijken, E. 2002. *Windturbines en vogels in Vlaanderen: Voorlopige onderzoeksreultaten en buitenlandse bevindingen [Wind turbines and birds in Flanders (Belgium): Preliminary study results in a European context].* Instituut voor Natuurbehoud, Report R. 2002.03, Brussels.

Henderson, I.G., Langston, R.H.W. & Clark, N.A. 1996. *The response of Common Terns Sterna hirundo to power lines: an assessment of risk in relation to breeding commitment, age and wind speed.* Biological Conservation 77: 185-192

Krebs, C. J. 1995. *Two Paradigms of Population Regulation.* Wildlife Research 22: 1 – 10.

Langston, R.H.W. & Pullan, J.D. 2002. *Windfarms and birds: an analysis of the effects of windfarms on birds, and guidance on environmental assessment criteria and site selection issues*. Bern Convention. Convention on the Conservation of European Wildlife and Natural habitats, Strasbourg, France.

McCarthy M.A., 1995. *Stochastic population models for wildlife management*. PhD Thesis. University of Melbourne.

Meredith, C., Saunders, D. and Timewell, C. 2000. *Avifauna monitoring update – proposed north-west Tasmania wind farm*. Biosis Research Pty. Ltd. Report to Hydro-electric Corporation.

Meredith, C., Venosta, M. & Ressom, R. 2002, *Codrington Wind Farm Avian Avoidance Behaviour Report.* Biosis Research Pty. Ltd. Report to Pacific Hydro Pty. Ltd.

Mossop, D.H. 1997. *Five years of monitoring bird strike potential at a Mountain-Top Wind Turbine, Yukon Territory.* Annual Canadian Wind Energy Conference and Exhibition. Pp. 197-211. Yukon Energy Corporation, Whitehorse, Yukon, Canada.

Percival, S. 1998. *Beinn Churlaich, Islay, Proposed Wind Cluster - On Geese and Turbines.* Supplementary Precognition to Board of Inquiry

Percival, S.M. 2001. *Assessment of the Effects of Offshore Wind Farms on Birds.* Consultancy Report to UK Department of Technology and Industry. Ecology Consulting, University of Sunderland, Sunderland, UK.

Pople. T. 2005. *Review of the BIOSIS modelling of the cumulative impacts of windfarms on the orange-bellied parrot.* Report to Department of Environment and Heritage.

Richardson, W.J. 1998. *Bird Migration and Wind Turbines: Migration Timing, Flight Behavior, and Collision Risk.* Pp 132-140. In: Proceedings of the National Avian - Wind Power Planning Meeting IV. San Diego, California, May 1998.

Schaffer, M. L. 1981. *Minimum population sizes for species conservation.* Bioscience 31: 131 – 134.

Tulp, I., Schekkerman, H., Larsen, J., van der Winden, J., van de Haterd, R.J.W., van Horssen, P., Dirksen, S. & Spaans, A.L. 1999. *Nocturnal flight activity of sea ducks near the windfarm Tuno Knob in the Kattegat.* Bureau Waardenburg, Culemborg

Winkleman, J.E. 1990. *Nocturnal collision risks for and behaviour of birds approaching a rotor in operation in the experimental wind park near Oosterbierum, Friesland, The Netherlands.* English summary. Rijksinstituut voor Natuurbeheer, Arnheim. RIN-Rapport 90/17.

Winkelman, J.E. 1992. *The impact of the Sep wind Park near Oosterbierum (Fr.), The Netherlands on birds. 2. nocturnal collision victims.* RIN-Rapport 92/3. Rijksinstitut voor Natuurbeheer, Arnhem, The Netherlands.

Winkelman, J.E. 1994. *Bird/wind turbine investigations in Europe.* National Avian-Wind power planning meeting. Pp. 43-47.