Department of Environmental Affairs

environmental affairs

Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

Private Bag X 447· PRETORIA · 0001· Environment House · 473 Steve Biko Road · Arcadia · PRETORIA

DEA Reference: 14/12/16/3/3/2/826/AM1
Enquiries: Ms Samkelisiwe Dlamini
Telephone: (012) 399 9379 **E-mail:** SDlamini@henvironment.gov.za

Ms Jo-Anne Thomas
Savannah Environmental (Pty) Ltd
PO Box 148
SUNNINGHILL
2157

Telephone Number: (011) 656 3237
Email Address: joanne@savannhsa.com

PER E-MAIL / MAIL

Dear Ms Thomas

COMMENTS ON THE DRAFT REPORT FOR THE APPLICATION FOR AMENDMENT OF ENVIRONMENTAL AUTHORISATION ISSUED ON 25 JUL 2016 FOR THE 200MW GUNSFONTEIN WIND ENERGY FACILITY ON THE REMAINDER OF THE FARM FUNSFONTEIN 131 WITHIN THE KAROO HOOGLAND LOCAL MUNICIPALITY, NORTHERN CAPE PROVINCE.

The Environmental Authorisation (EA) for the above-mentioned project dated 25 July 2016, the appeal decision dated 17 January 2017 and 09 December 2017, and the application for amendment and the motivation reports received by the Department on 23 May 2019, refer.

The Department has the following comments on the abovementioned amendment application:

(a) Specific comments

(i) A layout plan showing the 90m set back line of all turbines must be included in the final report.
(ii) Confirmation that the specialist assessed and provided a motivation in terms of regulation 32 relating to all amendments applied for.

(b) Public participation

(i) Please ensure that comments from all relevant stakeholders are submitted to the Department with the final report. This includes but is not limited to the Western Cape Department of Environmental Affairs and Development Planning, the Department of Forestry and Fisheries (DAFF), the provincial Department of Agriculture, the South African Civil Aviation Authority (SACAA), the Department of Transport, the Laingsburg Local Municipality, the Department of Water and Sanitation (DWS), the South African National Roads Agency Limited (SANRAL), the South African Heritage Resources Agency (SAHRA), the Endangered Wildlife Trust (EWT), BirdLife SA, the Department of Mineral Resources, the Department of Rural Development and Land Reform, and the Department of Environmental Affairs: Directorate Biodiversity and Conservation.
(ii) A Comments and Response trail report (C&R) must be submitted with the final report. The C&R report must incorporate all comments for this application. The C&R report must be a separate document from the main report and the format must be in the table format. Please refrain from summarising comments

made by I&APs. All comments from I&APs must be copied verbatim and responded to clearly. Please note that a response such as "noted" is not regarded as an adequate response to I&AP's comments.

(iii) Please ensure that all issues raised and comments received during the circulation of the draft report from registered I&APs and organs of state which have jurisdiction in respect of the proposed activity are adequately addressed in the final report. Proof of correspondence with the various stakeholders must be included in the final report. Should you be unable to obtain comments, proof should be submitted to the Department of the attempts that were made to obtain comments. The Public Participation Process must be conducted in terms of Regulation 39, 40, 41, 42, 43 & 44 of the EIA Regulations 2014 as amended.

(iv) The final report must also indicate that this draft report has been subjected to a public participation process.

(c) Layout & Sensitivity Maps

(i) The final report must include an environmental sensitivity map indicating environmental sensitive areas and features identified during the assessment process.

(ii) The final report must include a map combining the final layout map superimposed (overlain) on the environmental sensitivity map.

(d) Specialist assessments

(i) The EAP must provide confirmation that all specialists were provided with the same request of proposed amendments as well as ensure that the terms of reference for all the identified specialist studies must include the following:

- A detailed description of the study's methodology; indication of the locations and descriptions of the development footprint, and all other associated infrastructures that they have assessed and are recommending for authorisations.
- Provide a detailed description of all limitations to the studies. All specialist studies must be conducted in the right season and providing that as a limitation will not be allowed.
- Please note that the Department considers a 'no-go' area, as an area where no development of any infrastructure is allowed; therefore, no development of associated infrastructure including access roads is allowed in the 'no-go' areas.
- Should the specialist definition of 'no-go' area differ from the Department's definition; this must be clearly indicated. The specialist must also indicate the 'no-go' area's buffer if applicable.
- All specialist studies must be final, and provide detailed/practical mitigation measures and recommendations, and must not recommend further studies to be completed post EA.
- Should specialists recommend specific mitigation measures for identified turbine positions, these must be clearly indicated.
- Clearly defined cumulative impacts and where possible the size of the identified impact must be quantified and indicated, i.e. hectares of cumulatively transformed land.
- A detailed process flow to indicate how the specialist's recommendations, mitigation measures and conclusions from the various similar developments in the area were taken into consideration in the assessment of cumulative impacts and when the conclusion and mitigation measures were drafted for this project.
- Identified cumulative impacts associated with the proposed development must be rated with the significance rating methodology used in the process.
- The significance rating must also inform the need and desirability of the proposed development.
- A cumulative impact environmental statement on whether the proposed development must proceed.

(ii) Should the appointed specialists specify contradicting recommendations, the EAP must clearly indicate the most reasonable recommendation and substantiate this with defendable reasons; and were necessary, include further expertise advice.

(e) <u>General</u>

Please ensure that all mitigation recommendations are in line with applicable and most recent guidelines.

Please note that in terms of Regulation 32 of EIA regulation 2014 as amended, the applicant is required within a specified timeframe to submit a report to this Department in light of the proposed amendments.

Further note that in terms of Regulation 45 of the EIA Regulations 2014 as amended, this application will lapse if the applicant fails to meet any of the timeframes prescribed in terms of the these Regulations, unless an extension has been granted in terms of Regulation 3(7).

You are hereby reminded of Section 24F of the National Environmental Management Act, Act No 107 of 1998, as amended, that no activity may commence prior to an environmental authorisation being granted by the Department.

Yours faithfully

Mr Sabelo Malaza
Chief Director: Integrated Environmental Authorisations
Department of Environmental Affairs
Signed by: Ms Pumeza Mngcita
Designation: Deputy Director: National Infrastructure Project
Date: 11/06/2019

cc:	Mr R Gordon	Gunstfontein Wind Farms (Pty) Ltd	Email: richard.gordon@aiimafrica.com/stephnie.kot@aced.co.za

Department of Water and Sanitation

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Private Bag X6101, Kimberley, 8300
28 Central Road, Beaconsfield Kimberley
Tel: (053) 836 7600, Fax: 086 547 2792

Enquiries: V. Ramugondo

Email: ramugondov@dws.gov.za
Reference:

Gunstfontein Wind Farm (PTY) LTD
P.O. Box 835
Constantia
7848

By Email/Registered Mail

Dear Mr. Jo-Anne Thomas/ Gideon Raath
Email: publicprocess@savannahsa.com

RE: MOTIVATION FOR AMENDMENT OF ENVIRONMENTAL AUTHORISATION FOR THE PROPOSED CONSTRUCTION OF GUNSTFONTEIN WIND ENERGY FACILITY AND ASSOCIATED INFRASTRUCTURE ON REMAINDER OF THE FARM GUNSTFONTEIN NO. 131, KAROO HOOGLAND LOCAL MUNICIPALITY, NORTHERN CAPE

Reference is hereby made to your motivation for Amendment of Environmental Authourisation for the proposed construction of Gunstfontein Wind Energy Facility and Associated Infrastructure. The proposed activity will take place within the Lower Orange Water Management Area. The reports compiled by Savannah Environmental (Pty) Ltd on behalf of Gunstfontein Wind Energy Facility (Pty) Ltd were presented to the Department of Water and Sanitation dated 03 July 2019.

1. COMMENTS

As mentioned in the report, the Department takes note that the proposed activity at the above mentioned location will include construction of Gunstfontein Wind Energy Facility and Associated Infrastructure. The Department has evaluated the said Amendment of Environmental Authourisation and has no objection to the approval of the report. However, the following should be addressed by the applicant.

a) It is apparent that the nature of activities the applicant is proposing to engage in has potential impacts on the environment and water resources, as the area of has various drainage lines.

b) Please note that the Department rates all perennial and non-perennial streams together with all dry river beds and natural drainage, wetlands, pans and associated riparian areas extremely sensitive to development.

c) Note that no activity may occur within the 100 m /1:100 year flood line of a river/drainage lines (whichever is furthest) and 500 m of a pan/wetland without authorisation from this Department;

d) You are advised to apply and obtain the water use authorisation prior to commencement of the proposed activities. An intent to apply for a water use authorisation should be sent to the Department;

e) Storm water must be diverted from the construction works and roads must be managed in such a manner as to disperse runoff and to prevent the concentration of storm water. Storm water control works must be constructed, operated and maintained in a sustainable manner throughout the project;

f) Any spillage of any hazardous materials including diesel that may occur during construction and operation must be reported immediately to our Department;

g) Increased runoff due to vegetation clearance and/or soil compaction must be managed, and storm water leaving the construction site must in no way be contaminated by any substance, whether such substance is a solid, liquid, vapour or gas or a combination thereof which is produced, used, stored, dumped or spilled on the premises;

h) The disposal of general waste and that of hazardous waste must be carried out in an environmentally safe way as to prevent and/or minimise the potential for pollution of water resources and collection of which should be done by an accredited waste collector. All applicable Sections of the National Environmental Management: Waste Act 59 of 2008 should be strictly adhered to;

i) A pre-consultation meeting can be arranged with the Department to advice on the water uses that are triggered by the activity which may require authorisation and relevant reports (before submission of the complete application to Department).

j) Please note that should you decide to continue with the proposed activity, a Risk Matrix has to be conducted by a Professional Scientist (registered with SACNASP as a professional member) and submitted to the Department in order to determine the impacts of the proposed activities on the watercourse.

k) A detailed layout plan needs to be submitted to the Department showing all the facilities in the proposed development including distance from the any watercourses. Details of the final design must also be included as soon as a decision has been made, as the details of this factor may influence the environmental impact both during the construction and operational phases of the project;

l) Sections 19 & 20 of the National Water Act, 1998 (Act No.36 of 1998) should be adhered to;

RE: MOTIVATION FOR AMENDMENT OF ENVIRONMENTAL AUTHORISATION FOR THE PROPOSED CONSTRUCTION OF GUNSTFONTEIN WIND ENERGY FACILITY AND ASSOCIATED INFRASTRUCTURE ON REMAINDER OF THE FARM GUNSTFONTEIN NO. 131, KAROO HOOGLAND LOCAL MUNICIPALITY, NORTHERN CAPE

This reply does not grant any exemption from the requirements of any applicable Act, Ordinance, Regulation or By-law.

This office reserves the right to revise initial comments and request additional information that may arise from correspondence and/or upon inspection.

Please note that any use of water without authorization is illegal as it is in contravention of the National Water Act and is punishable by law.

You may contact the Department should you have any enquiries.

Yours sincerely

ACTING DIRECTOR: INSTITUTIONAL ESTABLISHMENT
DATE: 11/07/2019

Eskom Holdings SOC Ltd

Savannah Public Process

From:	Savannah Public Process
Sent:	Monday, June 10, 2019 10:07 AM
To:	'John Geeringh'
Cc:	gideon@savannah.sa.com; Hermien Slabbert; Mabel Quinisile; 'nicolene@savannahsa.com'
Subject:	RE: Gunstfontein WEF: Notification of Application for Amendment to EA and Availability of Motivation Report

Dear John,

Please receive herewith acknowledgement of receipt of Eskom's comment on the Gunstfontein WEF Motivation Report.

Kind regards,

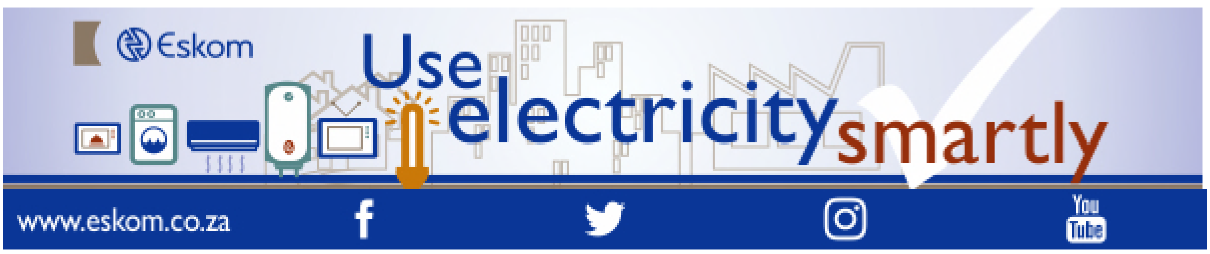
Nicolene Venter
Public Participation & Social Consultant | Savannah Environmental (Pty) Ltd
Tel: +27 (0)11 656 3237 | Cell: +27 (0)60 978 8396 | Fax: +27 (0)86 684 0547
SAWEA Award for Leading Environmental Consultant for Wind Projects in 2013 & 2015

From: John Geeringh <GeerinJH@eskom.co.za>
Sent: Monday, June 10, 2019 9:16 AM
To: Savannah Public Process <publicprocess@savannahsa.com>; Nicolene Venter <nicolene@savannahsa.com>; Mabel Quinisile <mabel@savannahsa.com>
Cc: gideon@savannah.sa.com
Subject: RE: Gunstfontein WEF: Notification of Application for Amendment to EA and Availability of Motivation Report

Please find attached Eskom requirements for developments at or near Eskom infrastructure. Please take note of the updated Setbacks document attached.

Regards

John Geeringh (Pr Sci Nat)
Senior Consultant Environmental Management
Group Capital Division: Land Development and Management
Megawatt Park, D1Y42, Maxwell Drive, Sunninghill, Sandton.
P O Box 1091, Johannesburg, 2000.
Tel: 011 516 7233
Cell: 083 632 7663
Fax: 086 661 4064
E-mail: john.geeringh@eskom.co.za



From: Savannah Public Process [mailto:publicprocess@savannahsa.com]
Sent: 31 May 2019 03:14 PM
To: nicolene@savannahsa.com; mabel@savannahsa.com
Cc: gideon@savannah.sa.com
Subject: Gunstfontein WEF: Notification of Application for Amendment to EA and Availability of Motivation Report

APPLICATION FOR AMENDMENT TO THE ENVIRONMENTAL AUTHORISATION:

GUNSTFONTEIN WIND ENERGY FACILITY AND ASSOCIATED INFRASTRUCTURE, NORTHERN CAPE PROVINCE

(DEA Ref.No.: 14/12/16/3/3/2/826)

- **Availability of Motivation Report for Review and Comment**

Dear Stakeholder and/or Interested and Affected Party,

Gunstfontein Wind Farm (Pty) Ltd received an Environmental Authorisation (EA) for the construction of Gunstfontein Wind Energy Facility (WEF) and associated infrastructure in the Northern Cape Province (DEA ref: 14/12/16/3/3/2/826 on the 25th of July 2016.

The draft Motivation Report is made available to registered Interested and Affected Parties (I&APs) for a 30-day review period from **Friday, 31 May 2019 to Tuesday, 02 July 2019.**

Please refer to the attached Notification Letter for further information.

Kind regards,

Nicolene Venter

Public Participation and Social Consultant | Savannah Environmental (Pty) Ltd
Tel: +27 (0)11 656 3237 | Fax: +27 (0)86 684 0547

SAWEA Award for Leading Environmental Consultant for Wind Projects in 2013 & 2015

Eskom requirements for work at or near Eskom infrastructure.

1. Eskom's rights and services must be acknowledged and respected at all times.

2. Eskom shall at all times retain unobstructed access to and egress from its servitudes.

3. Eskom's consent does not relieve the developer from obtaining the necessary statutory, land owner or municipal approvals.

4. Any cost incurred by Eskom as a result of non-compliance to any relevant environmental legislation will be charged to the developer.

5. If Eskom has to incur any expenditure in order to comply with statutory clearances or other regulations as a result of the developer's activities or because of the presence of his equipment or installation within the servitude restriction area, the developer shall pay such costs to Eskom on demand.

6. The use of explosives of any type within 500 metres of Eskom's services shall only occur with Eskom's previous written permission. If such permission is granted the developer must give at least fourteen working days prior notice of the commencement of blasting. This allows time for arrangements to be made for supervision and/or precautionary instructions to be issued in terms of the blasting process. It is advisable to make application separately in this regard.

7. Changes in ground level may not infringe statutory ground to conductor clearances or statutory visibility clearances. After any changes in ground level, the surface shall be rehabilitated and stabilised so as to prevent erosion. The measures taken shall be to Eskom's satisfaction.

8. Eskom shall not be liable for the death of or injury to any person or for the loss of or damage to any property whether as a result of the encroachment or of the use of the servitude area by the developer, his/her agent, contractors, employees, successors in title, and assignees. The developer indemnifies Eskom against loss, claims or damages including claims pertaining to consequential damages by third parties and whether as a result of damage to or interruption of or interference with Eskom's services or apparatus or otherwise. Eskom will not be held responsible for damage to the developer's equipment.

9. No mechanical equipment, including mechanical excavators or high lifting machinery, shall be used in the vicinity of Eskom's apparatus and/or services, without prior written permission having been granted by Eskom. If such permission is granted the developer must give at least seven working days' notice prior to the commencement of work. This allows time for arrangements to be made for supervision and/or precautionary instructions to be issued by the relevant Eskom Manager

   Note: Where and electrical outage is required, at least fourteen work days are required to arrange it.

10. Eskom's rights and duties in the servitude shall be accepted as having prior right at all times and shall not be obstructed or interfered with.

11. Under no circumstances shall rubble, earth or other material be dumped within the servitude restriction area. The developer shall maintain the area concerned to Eskom's satisfaction. The developer shall be liable to Eskom for the cost of any remedial action which has to be carried out by Eskom.

12. The clearances between Eskom's live electrical equipment and the proposed construction work shall be observed as stipulated by *Regulation 15* of the *Electrical Machinery Regulations of the Occupational Health and Safety Act, 1993 (Act 85 of 1993).*

13. Equipment shall be regarded electrically live and therefore dangerous at all times.

14. In spite of the restrictions stipulated by Regulation 15 of the Electrical Machinery Regulations of the Occupational Health and Safety Act, 1993 (Act 85 of 1993), as an additional safety precaution, Eskom will not approve the erection of houses, or structures occupied or frequented by human beings, under the power lines or within the servitude restriction area.

15. Eskom may stipulate any additional requirements to highlight any possible exposure to Customers or Public to coming into contact or be exposed to any dangers of Eskom plant.

16. It is required of the developer to familiarise himself with all safety hazards related to Electrical plant.

17. Any third party servitudes encroaching on Eskom servitudes shall be registered against Eskom's title deed at the developer's own cost. If such a servitude is brought into being, its existence should be endorsed on the Eskom servitude deed concerned, while the third party's servitude deed must also include the rights of the affected Eskom servitude.

John Geeringh (Pr Sci Nat)

Senior Consultant Environmental Management
Eskom GC: Land Development

Eskom	**SCOT**	**Technology**

Title:	**Renewable Energy Generation Plant Setbacks to Eskom Infrastructure**	Unique Identifier:	**240-65559775**
		Alternative Reference Number:	**N/A**
		Area of Applicability:	**Power Line Engineering**
		Documentation Type:	**Guideline**
		Revision:	**1**
		Total Pages:	**9**
		Next Review Date:	**N/A**
		Disclosure Classification:	**CONTROLLED DISCLOSURE**

Compiled by	**Approved by**	**Authorised by**
....	....	....
J W Chetty	**B Ntshuntsha**	**R A Vajeth**
Mechanical Engineer	**Chief Engineer (Lines)**	**Snr Manager (Lines) and SCOT/SC/ Chairperson**
Date: 23/11/2018	Date: 23/11/2018	Date: 16/11/2018

PCM Reference: 240-65132732 **LINE ENGINEERING SERVICES**
SCOT Study Committee Number/Name : **OVERHEAD LINES**

CONTENTS

FIGURES

EXECUTIVE SUMMARY

In recent decades, the use of wind turbines, concentrated solar plants and photovoltaic plants have been on the increase as it serves as an abundant source of energy. This document specifies setbacks for wind turbines and the reasons for these setbacks from infrastructure as well as setbacks for concentrated solar plants and photovoltaic plants. Setbacks for wind turbines employed in other countries were compared and a general setback to be used by Eskom was suggested for use with wind turbines and other renewable energy generation plants.

1. INTRODUCTION

During the last few decades, a large amount of wind turbines have been installed in wind farms to accommodate for the large demand of energy and depleting fossil fuels. Wind is one of the most abundant sources of renewable energy. Wind turbines harness the energy of this renewable resource for integration in electricity networks. The extraction of wind energy is its primary function and thus the aerodynamics of the wind turbine is important. There are many different types of wind turbines which will all exhibit different wind flow characteristics. The most common wind turbine used commercially is the Horizontal Axis Wind Turbine. Wind flow characteristics of this turbine are important to analyse as it may have an effect on surrounding infrastructure.

Wind turbines also cause large turbulence downwind that may affect existing infrastructure. Debris or parts of the turbine blade, in the case of a failure, may be tossed behind the turbine and may lead to damage of infrastructure in the wake path.

This document outlines the minimum distances that need to be introduced between a wind turbine and Eskom infrastructure to ensure that debris and / or turbulence would not negatively impact on the infrastructure.

Safety distances of wind turbines from other structures as implemented by other countries were also considered and the reasons for their selection were noted.

Concentrated solar plants and photovoltaic plants setbacks away from substations were also to be considered to prevent restricting possible power line access routes to the substation.

2. SUPPORTING CLAUSES

2.1 SCOPE

This document provides guidance on the safe distance that a wind turbine should be located from any Eskom power line or substation. The document specifies setback distances for transmission lines (220 kV to 765 kV), distribution lines (6.6 kV to 132 kV) and all Eskom substations. Setbacks for concentrated solar plants and photovoltaic plants are also specified away from substations.

2.1.1 Purpose

Setbacks for wind turbines and power lines / substations are required for various reasons. These include possible catastrophic failure of the turbine blade that may release fragments and which may be thrown onto nearby power lines that may result in damage with associated unplanned outages. Turbulence behind the turbine may affect helicopter flight during routine Eskom live line maintenance and inspections that may lead to safety risk of the aircraft / personnel. Concentrated solar plants and photovoltaic plants setback away from substations were required to prevent substations from being boxed in by these renewable generation plants limiting line route access to the substations.

2.1.2 Applicability

This document is applicable to the siting of all new and existing wind turbines, concentrated solar plants and photovoltaic plants near power lines and substations.

2.2 NORMATIVE/INFORMATIVE REFERENCES

2.2.1 Normative

1. http://www.envir.ee/orb.aw/class=file/action=preview/id=1170403/Hiiumaa+turbulence+impact+EMD.pdf.
2. http://www.energy.ca.gov/2005publications/CEC-500-2005-184/CEC-500-2005-184.PDF
3. http://www.adamscountywind.com/Revised%20Site/Windmills/Adams%20County%20Ordinance/Adams%20County%20Wind%20Ord.htm
4. http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=PA11R&RE=1&EE=1
5. http://www.wind-watch.org/documents/european-setbacks-minimum-distance-between-wind-turbines-and-habitations/
6. http://www.publications.parliament.uk/pa/ld201011/ldbills/017/11017.1-i.html
7. http://www.caw.ca/assets/pdf/Turbine_Safety_Report.pdf
8. Rogers J, Slegers N, Costello M. (2011) A method for defining wind turbine setback standards. Wind energy 10.1002/we.468

2.2.2 Informative

None

2.3 DEFINITIONS

Definition	Description
Setback	The minimum distance between a wind turbine and boundary line/dwelling/road/infrastructure/servitude etc.
Flicker	Effect caused when rotating wind turbine blades periodically cast shadows
Tip Height	The total height of the wind turbine ie. Hub height plus half rotor diameter (see Figure1)

2.3.1 Disclosure Classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 ABBREVIATIONS

Abbreviation	Description
None	

2.5 ROLES AND RESPONSIBILITIES

All personnel involved in the positioning wind turbines, concentrated solar plants and photovoltaic plants near power lines/substations must follow the setbacks outlined in this guideline.

2.6 PROCESS FOR MONITORING

Approval by Eskom in writing.

2.7 RELATED/SUPPORTING DOCUMENTS

None

3. DOCUMENT CONTENT

3.1 INTERNATIONAL SETBACK COMPARISON

Wind Turbine setbacks employed by various countries were considered. It was found that setbacks were determined for various reasons that include noise, flicker, turbine blade failure and wind effects. The distances (setbacks) varied based on these factors and were influenced by the type of infrastructure

Wind turbine setbacks varied for roads, power lines, dwellings, buildings and property and it was noted that the largest setbacks were employed for reasons of noise and flicker related issues [1-7]. Very few countries specified setbacks for power lines.

The literature survey [1-7], yielded information about studies and experiments were conducted to determine the distance that a broken fragment from a wind turbine might be thrown. Even though of low probability of hitting a power line [$5.0x10^{-5}$ [8]], the distances recorded were significant [750m [8]]

Setbacks were thus introduced to prevent any damage to Eskom infrastructure.

Wind turbines may also cause changes in wind patterns with turbulent effects behind the hub. These actors dictate the wind turbine setbacks specified in this document.

Concentrated solar plants and photovoltaic plants also can limit access into the substation for power lines of all voltages. A setback distance must therefore be employed to prevent the substation from being boxed in by these generation plants. These setback distances are specified in this document.

3.2 ESKOM REQUIRED SETBACKS

A formal application must be sent to and accepted by Eskom if any of the below mentioned setback distances are infringed upon:

- Eskom requires a setback distance of 3 times the tip height of the wind turbine from the edge of the closest Eskom servitude (including vacant servitudes) for transmission lines (220kV to 765kV) and Substations.
- Eskom requires a setback distance of 1 times the tip height of the wind turbine from the edge of the closest Eskom servitude (including vacant servitudes) for distribution lines (66 kV to 132 kV) and Substations.
- An application must be send to Eskom regarding any proposed wind turbine, concentrated solar plants and photovoltaic activity within a 5 km radius of a substation for Eskom to comment on the application.
- Where concentrated solar plants and photovoltaic structures fall within a 2 km radius of the closest point of a transmission or distribution substation (66kV to 765kV), Eskom should be applied to for approval in writing during the planning phase of such plant or structures.
- Applicants must not position any wind turbine in the line of site between and two Eskom Radio Telecommunication masts. It must be proven that Eskom radio telecommunication systems (mainly microwave systems) will not be affected in any way by wind turbines.
- If the position or size of any turbine changes and subsequently infringes on any of the above stated setbacks, an application must be sent through to Eskom as per the point mentioned above.

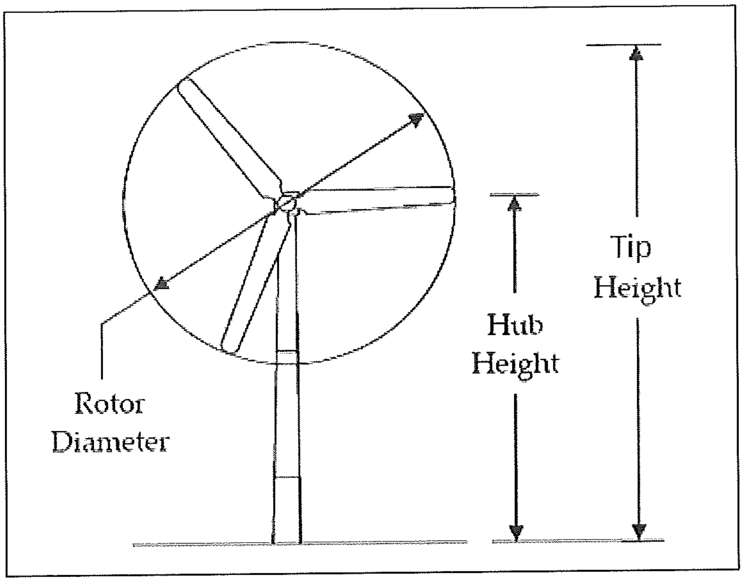


Figure 1: Horizontal Axis Wind Turbine [2]

4. AUTHORISATION

This document has been seen and accepted by:

Name & Surname	Designation
V Naidoo	Chief Engineer
Dr P H Pretorius	Electrical Specialist
J Geeringh	Snr Consultant Environ Mngt
B Haridass	Snr Consultant Engineer
R A Vajeth	Acting Snr Manager (Lines)

5. REVISIONS

Date	Rev.	Compiler	Remarks
November 2013	0	J W Chetty	First Publication - No renewable energy generation plant setback specification in existence
October 2018	1	JW Chetty	Modification to sub-section 3.2 to provide more clarity for application procedure

6. DEVELOPMENT TEAM

The following people were involved in the development of this document:

Jonathan W Chetty (Mechanical Engineer)

Vivendhra Naidoo (Chief Engineer)

Dr Pieter H Pretorius (Electrical Specialist)

John Geeringh (Snr Consultant Environ Mngt)

Bharat Haridass (Snr Consultant Engineer)

Riaz A Vajeth (Acting Snr Manager (Lines))

South African Heritage Resources Agency

an agency of the
Department of Arts and Culture

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South African Heritage Resources Agency | 111 Harrington Street | Cape Town
P.O. Box 4637 | Cape Town | 8001
www.sahra.org.za

Enquiries: Natasha Higgitt
Tel: 021 462 4502
Email: nhiggitt@sahra.org.za
CaseID: 8383

Date: Friday May 31, 2019

Final Comment

In terms of Section 38(4), 38(8) of the National Heritage Resources Act (Act 25 of 1999)

Attention: Gunstfontein Wind Farm (Pty) Ltd

The Oval
2nd Floor, Fernwood House
1 Oakdale Road
Newlands
Cape Town
7700

Project Name: Gunstfontein Wind Energy Facility, Northern Cape Province. Applicant: Gunstfontein Wind Farm (Pty) Ltd Proposed Activity: The development of a wind energy facility with a contracted capacity of up to 200MW and associated infrastructure including Wind turbines, concrete foundations to support the turbines, Cabling between the turbines, laydown areas, internal access roads, an on-site, buildings and dedicated areas for workshops, control systems, maintenance and storage with parking areas where required, and temporary construction compound and temporary site offices. Project Location: The proposed site is located ~20km south of Sutherland within the Karoo Hoogland Local Municipality, of the Namakwa District Municipality. The site development envelope includes the farms: Portion 1 of the farm Gunstfontein 131; Remainder of the farm Gunstfontein 131; Farm Boschmans Hoek 177, and Remainder of the farm Wolven Hoek 182.

Savannah Environmental have been appointed to conduct an Amendment Application for the authorised Gunstfontein Wind Energy Facility (WEF) near Sutherland, Northern Cape Province. A draft Amendment Motivation report has been submitted in terms of the National Environmental Management Act, No 107 of 1998 (NEMA), NEMA Environmental Impact Assessment (EIA) Regulations. The proposed amendments include the following:

- An increase in rotor diameter from 140 m up to 180 m;
- An increase in hub height from 120 m up to 150 m;
- The location, number and details of site access points has been altered;
- Several corrections to conditions;
- Amendment to the site layout with a reduced number of turbines (now 46 turbines);

an agency of the
Department of Arts and Culture

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South African Heritage Resources Agency | 111 Harrington Street | Cape Town
P.O. Box 4637 | Cape Town | 8001
www.sahra.org.za

Enquiries: Natasha Higgitt
Tel: 021 462 4502
Email: nhiggitt@sahra.org.za
CaseID: 8383

A heritage specific amendment includes the following:

- Amendment of condition 123 of the EA from “Pre-construction archaeological monitoring is required. The appointed archaeologist must keep a list documenting all identified farm infrastructure.” to “Pre-construction archaeological walkthrough is required unless confirmed otherwise by the archaeologist based on a desk-top assessment of the final layout. The holder must keep a list documenting all features of archaeological significance, identified by the archaeologist, which may be impacted by the development and which must be demarcated as no-go areas.

This amendment would entail a walk-through or desktop of the final layout by an archaeologist to ensure that all identified heritage resources are adequately avoided in the final micro-sited layout.

The change in the layout of the turbines and the impact to heritage resources is discussed in the report. The report notes the previous requirement from SAHRA that a no-go buffer zone of 1.6 km was to be adhered to from the Verlatenkloof pass. The new locations of the turbines comply with this requirement and will now be located more than 2 km from the pass, and therefore there will be no increase of impacts to heritage resources. Additionally, the proposed new layout will ensure a 100 m buffer between infrastructure and the uranium core occurrences identified as part of the palaeontological assessment.

The report notes the conditions provided in previous comments issued on the 18th March 2016 and 20th June 2016 which still apply to the development.

Final Comment

The SAHRA Archaeology, Palaeontology and Meteorites (APM) Unit has no objection to the overall proposed amendment to the authorised development.

With regards to the proposed amendment to condition 123, SAHRA requests that the amendment read as follows:

“Pre-construction archaeological walkthrough is required of the final layout. A report detailing the results of the walk-down must be submitted to SAHRA for comment. The holder must keep a list documenting all features of archaeological significance, identified by the archaeologist, which may be impacted by the development and which must be demarcated as no-go areas.”

Gunstfontein WEF

Our Ref:

an agency of the
Department of Arts and Culture

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CaseID: 8383

Date: Friday May 31, 2019

SAHRA **does not** accept the request that **either a walk-down or a desktop study** be undertaken. The final layout of the development must be physically inspected by a qualified archaeologist and a report must be submitted to SAHRA for comment.

The following additional conditions must be included in the Environmental Management Programme (EMPr) and completed should the Amended EA be granted:

- The Final Amendment Report and EMPr must be uploaded to the SAHRIS application for record purposes;
- If any evidence of archaeological sites or remains (e.g. remnants of stone-made structures, indigenous ceramics, bones, stone artefacts, ostrich eggshell fragments, charcoal and ash concentrations), fossils or other categories of heritage resources are found during the proposed development, SAHRA APM Unit (Natasha Higgitt/Phillip Hine 021 462 5402) must be alerted as per section 35(3) of the NHRA. If unmarked human burials are uncovered, the SAHRA Burial Grounds and Graves (BGG) Unit (Thingahangwi Tshivhase/Mimi Seetelo 012 320 8490), must be alerted immediately as per section 36(6) of the NHRA. A professional archaeologist or palaeontologist, depending on the nature of the finds, must be contracted as soon as possible to inspect the findings. If the newly discovered heritage resources prove to be of archaeological or palaeontological significance, a Phase 2 rescue operation may be required subject to permits issued by SAHRA;
- The decision regarding the Amended EA Application must be communicated to SAHRA and uploaded to the SAHRIS Case application.

Should you have any further queries, please contact the designated official using the case number quoted above in the case header.

Yours faithfully

Natasha Higgitt
Heritage Officer
South African Heritage Resources Agency

an agency of the
Department of Arts and Culture

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CaseID: 8383

Date: Friday May 31, 2019

Phillip Hine
Acting Manager: Archaeology, Palaeontology and Meteorites Unit
South African Heritage Resources Agency

ADMIN:
Direct URL to case: http://www.sahra.org.za/node/329604
(DEA, Ref: 14/12/16/3/3/2/826)

Terms & Conditions:

1. This approval does not exonerate the applicant from obtaining local authority approval or any other necessary approval for proposed work.
2. If any heritage resources, including graves or human remains, are encountered they must be reported to SAHRA immediately.
3. SAHRA reserves the right to request additional information as required.

South African Radio Astronomy Observatory

science & technology
Department: Science and Technology
REPUBLIC OF SOUTH AFRICA

NRF National Research Foundation | SARAO South African Radio Astronomy Observatory

Ms. Nicolene Venter
Savanah Environmental (Pty) Ltd

Email: publicprocess@savannahsa.com

Date: 01 July 2019

Dear Ms. Venter

Re: Gunstfontein Wind Energy Facility

SARAO has conducted a high level risk assessment of the proposed amendments to the above mentioned facility's Environmental Authorisation, in particular the increase in hub height from 120m to 150m.

Based on this assessment, we do not foresee that this amendment will increase the risk of electromagnetic interference on the SKA Infrastructure Territory. We do however request that we are kept informed of the developments of the project and that control measures are put in place to ensure that the total radiated EMI from the facility does not exceed the electric field strength of 78 dBμV/m when measured 10m from the facility in the direction of the SKA.

We wish you all the best with the project and our office remains open for further engagement on this matter.

Regards,

Mr Selaelo Matlhane
Spectrum & Telecommunication Manager
South African Radio Astronomy Observatory (SARAO)
Tel: 011 442 2434
Email: smatlhane@ska.ac.za

TECHNICAL REPORT

Gunstfontein Wind Energy Farm (Pty) Ltd

1. INTRODUCTION

Gunstfontein Wind Energy Farm received an Environmental Authorisation for the construction of wind energy facility and associated infrastructure on July 2016. The location of the facility in relation to the SKA Infrastructure territory is given in Figure 1, below. The developer has now applied for amendments of EA which includes the increase in the hub height from 120m to 150m. The purpose of this report is to assess if the change in the pathloss will increase the risk of interference on the SKA.

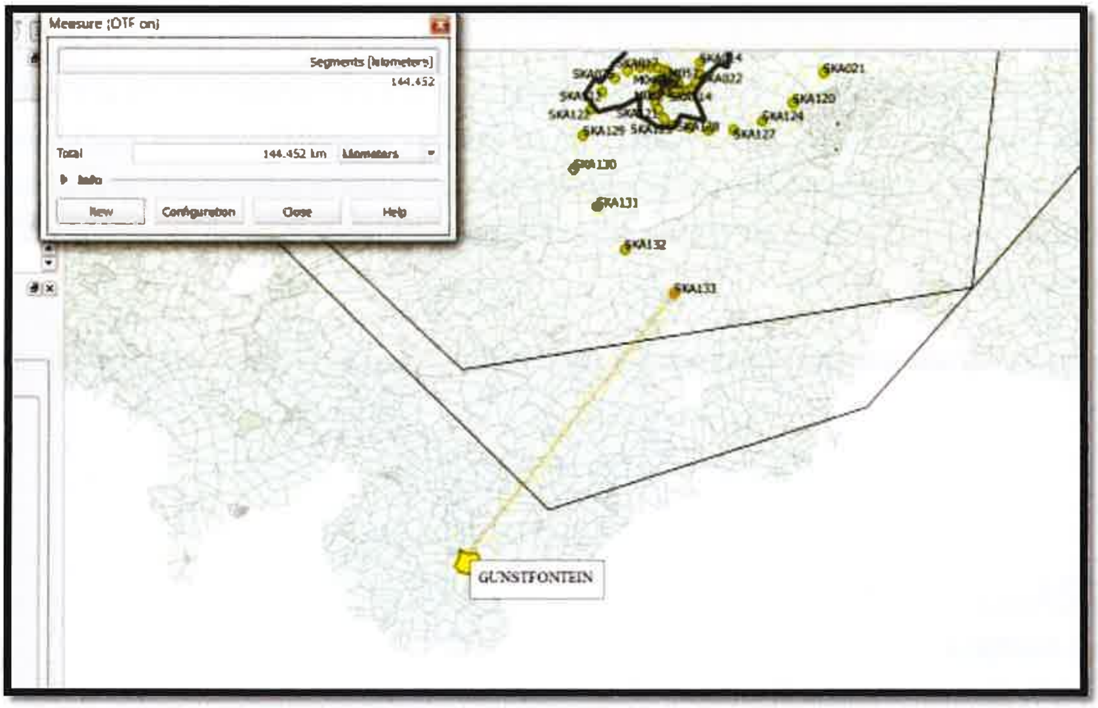

Figure 1: The location of Gunstfontein WEF in relation to the nearest SKA radio telescope.

2. Pathloss comparisons at 120m and at 150m hub height.

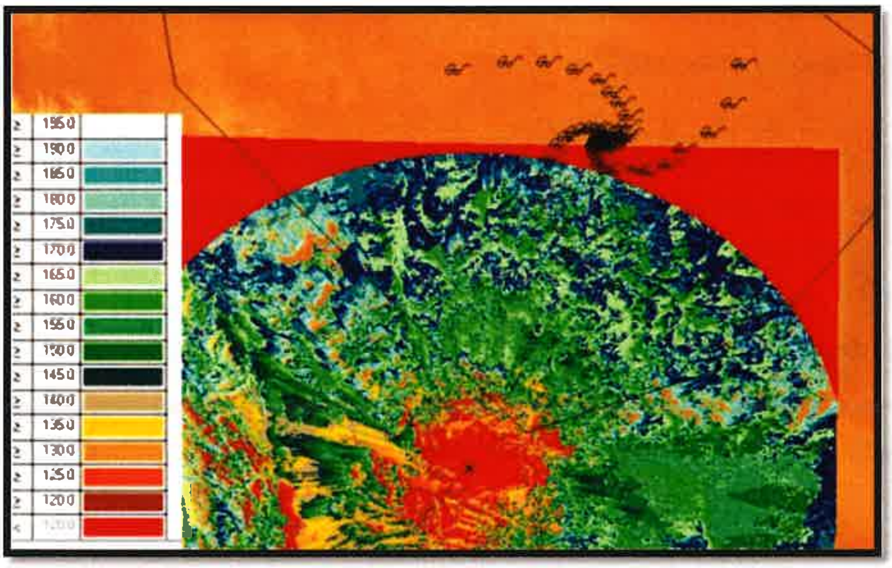

Figure 2: Pathloss simulations at a hub height of 120m

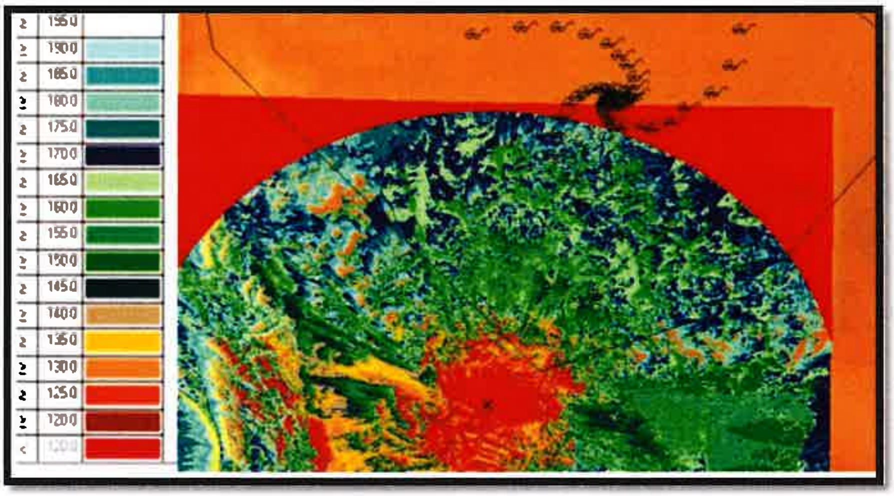

Figure 3: Pathloss simulations at hub height of 150m

3. Conclusions and Recommendations

As it can be seen from figure 1 and figure 2, the increase in hub height does not significantly decrease the pathloss between the wind energy facility and the SKA Infrastructure Territory. The pathloss between the facility and SKA133 at 120m hub height is 174 dB while at the hub height of 150m, the pathloss is 171 dB. Therefore, the increase in hub height from 120m to 150m does not significantly increase the risk of interference at the SKA. At this pathloss, radiated emission from the facility should be below 78 dBμV/m to comply with the Regulations.

It is recommended that the manager signs the attached letter to the developer of Gunstfontein Wind Energy Facility,

Written by:

Busang Sethole
Spectrum and Telecoms Analyst.

Interested and Affected Parties

Nicolene Venter

From: Frederik Stapelberg <fstapelberg@geoscience.org.za>
Sent: Friday, May 31, 2019 3:55 PM
To: Nicolene Venter
Subject: RE: Great Karoo WEF: Notification of Application for Amendment to EA and Availability of Motivation Report

Hallo Nicolene,

Neewat, ons het geen beswaar teen die verlenging nie.

Groete,

Frederik

Frederik Stapelberg (Pr. Sci. Nat.)
Engineering Geologist (Bellville Office)
Tel: +27 (0)21 943 6700/05 | **Cell:** +27 (0)84 490 7960
Email: fstapelberg@geoscience.org.za | **Website:** http://www.geoscience.org.za
Co Oos and Reed Steets, Bellville, South Africa, 0184
PO Box 572, Bellville, South Africa, 7535

Council for Geoscience

From: Nicolene Venter <nicolene@savannahsa.com>
Sent: Friday, May 31, 2019 1:38 PM
To: Nicolene Venter <nicolene@savannahsa.com>; Mabel Quinisile <mabel@savannahsa.com>
Cc: Gideon Raath <gideon@savannahsa.com>
Subject: Great Karoo WEF: Notification of Application for Amendment to EA and Availability of Motivation Report

APPLICATION FOR AMENDMENT TO THE ENVIRONMENTAL AUTHORISATION:
GREAT KAROO WIND ENERGY FACILITY AND ASSOCIATED INFRASTRUCTURE, NORTHERN CAPE PROVINCE
(DEA Ref.No.: 12/12/20/2370/3)

- **Availability of Motivation Report for Review and Comment**

Dear Stakeholder and/or Interested and Affected Party, Great Karoo Wind Farm (Pty) Ltd received an Environmental Authorisation (EA) for the construction of Great Karoo Wind Energy Facility (WEF) and associated infrastructure in the Northern Cape Province (DEA ref: 12/12/20/2370/3) on the 12th of August 2014 (as subsequently amended on 25 July 2016 and 5 May 2017).

The draft Motivation Report is made available to registered Interested and Affected Parties (I&APs) for a 30-day review period from **Friday, 31 May 2019** to **Tuesday, 02 July 2019**.

Please refer to the attached Notification Letter for further information.

Kind regards,

savannah environmental

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Nicolene Venter
Public Participation and Social Consultant

e: nicolene@savannahsa.com
c: +27 (0) 83 377 9112

SAWEA Award for Leading Environmental Consultant on Wind Projects in 2013 & 2015

EXECUTOR'S LETTER

MASTER OF THE HIGH COURT CAPE TOWN REFERENCE NO: 411/2013

DAVID CHRISTOPHER WOOTTON EXECUTOR
(ID no 570613 5140 082)

The Estate of the Late CATHARINA WILHELMINA WOOTTON
(ID no 220608 0165 08 8)
(08/06/1922 –17/04/1998)

MASTER OF THE HIGH COURT CAPE TOWN REFERENCE NO:17425/2011

DAVID CHRISTOPHER WOOTTON EXECUTOR
(ID no 570613 5140 082)

The Estate of the late JOHN LESLIE WOOTTON
(ID no 200711 5157 086)
(11/ 07/1920 --14/10/2011)

Re: Response to Letter from Savannah Environmental (Pty) Ltd Dated: 31st May 2019.

LETTER OF OBJECTION REGARDING THE WIND TURBINES UPGRADE AT GUNSFONTEIN FARM SUTHERLAND N CAPE.

Dear Sir/Madam,

1) References to the Impact of Wind Farms on Avian Species. Please see the following attached pdf files. The Internet has extensive Websites listing the problems and threats posed by wind farms to bird and bat populations.

2) I am conducting with the help of the MCSA (Mountain Club of South Africa), and other interested parties an ongoing survey of Malieschoek/De Kruis Farm. This is for "The Private Nature Reserve/Conservancy Malieschoek".

3) This is expected to take between 5 and 10 years minimum. And this is due to the enormous cyclical variations in the climate of the region.

4) As I have mentioned in previous letters to your selves. Your impact study has only been superficially done and is incomplete.

5) If you plan to change the original conditions of your application. Then I feel that you have to do a full re-assessment of the impact of the new sizes (wind turbines) that you plan to use.

6) These larger turbines are working with huge engineering forces. They do catch fire when the rotor brake fails. This also puts this very fragile environment at risk from being burnt out.

7) I feel that, no matter what objections are put forward regarding this project. It is going to go ahead. All the effort that we have put into this wonderful place to preserve it for all future South Africans. Is now being put at serious risk? And this makes me sad.

Yours sincerely David C Wootton Dated: 25 June 2019.

David C Wootton, Malieschoek/De Kruis Farm, Sutherland, N. Cape, & Bergland Farm, Rustig Road, Brandwacht, Worcester, W. Cape
PO Box 5148, Heatlievale, 6851. Cell: 0711965985. E-mail: bergland@mb-net.co.za

PROCEEDINGS B

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Bird and bat species' global vulnerability to collision mortality at wind farms revealed through a trait-based assessment

Chris B. Thaxter[1,2], Graeme M. Buchanan[3], Jamie Carr[4], Stuart H. M. Butchart[5,7], Tim Newbold[6], Rhys E. Green[7,8], Joseph A. Tobias[9], Wendy B. Foden[10], Sue O'Brien[11] and James W. Pearce-Higgins[1,2,7]

[1]British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU, UK
[2]British Trust for Ornithology, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK
[3]RSPB Centre for Conservation Science, Royal Society for the Protection of Birds, 2 Lochside View, Edinburgh Park, Edinburgh EH12 9DH, UK
[4]International Union for Conservation of Nature, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK
[5]BirdLife International, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK
[6]Centre for Biodiversity and Environment Research, Department of Genetics, Evolution and Environment, University College London, Gower Street, London WC1E 6BT, UK
[7]Conservation Science Group, Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, UK
[8]RSPB Centre for Conservation Science, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK
[9]Department of Life Sciences, Imperial College London, Silwood Park, Buckhurst Road, Ascot SL5 7PY, UK
[10]Department of Botany and Zoology, University of Stellenbosch, P/Bag X1, Matieland 7602 Stellenbosch, South Africa
[11]Joint Nature Conservation Committee, Inverdee House, Baxter Street, Aberdeen AB11 9QA, UK

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Research

Check for updates

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http://dx.doi.org/10.1098/rspb.2017.0829

Received: 20 April 2017
Accepted: 9 August 2017

Subject Category:
Global change and conservation

Subject Areas:
ecology

Keywords:
biodiversity, climate change, impact, meta-analysis, phylogeny, renewable energy

Author for correspondence:
Chris B. Thaxter
e-mail: chris.thaxter@bto.org

Mitigation of anthropogenic climate change involves deployments of renewable energy worldwide, including wind farms, which can pose a significant collision risk to volant animals. Most studies into the collision risk between species and wind turbines, however, have taken place in industrialized countries. Potential effects for many locations and species therefore remain unclear. To redress this gap, we conducted a systematic literature review of recorded collisions between birds and bats and wind turbines within developed countries. We related collision rate to species-level traits and turbine characteristics to quantify the potential vulnerability of 9538 bird and 888 bat species globally. Avian collision rate was affected by migratory strategy, dispersal distance and habitat associations, and bat collision rates were influenced by dispersal distance. For birds and bats, larger turbine capacity (megawatts) increased collision rates; however, deploying a smaller number of large turbines with greater energy output reduced total collision risk per unit energy output, although bat mortality increased again with the largest turbines. Areas with high concentrations of vulnerable species were also identified, including migration corridors. Our results can therefore guide wind farm design and location to reduce the risk of large-scale animal mortality. This is the first quantitative global assessment of the relative collision vulnerability of species groups with wind turbines, providing valuable guidance for minimizing potentially serious negative impacts on biodiversity.

1. Introduction

In response to projected impacts of climate change on the environment, human society and health [1], political consensus at the 21st Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) led to agreement to hold the increase in global temperatures to below 2°C,

Electronic supplementary material is available online at https://dx.doi.org/10.6084/m9.figshare.c.3858520.

THE ROYAL SOCIETY PUBLISHING

above pre-industrial levels, and pursue efforts to limit the increase to 1.5°C [2]. Achieving this ambition depends on global emissions peaking around 2020, with negative emissions in the second half of this century [3], requiring large-scale and rapid deployment of renewable energy technologies. Wind farms are the most well-developed, cheapest, widely available and feasible renewable energy technologies for electricity generation [4], and are likely to form an important component of renewable electricity generation strategies.

Wind farms can have negative impacts upon biodiversity [5], including direct collision mortality, displacement from feeding or nesting areas, barrier effects to movement and habitat degradation or loss [6]. For volant species such as birds and bats, the risk of collision is a serious concern [5], and large numbers of birds and bats have been shown to be killed by turbines [5,7,8], particularly at aggregation sites, such as migratory bottlenecks or near breeding colonies [9]. It has been suggested anecdotally that some species groups, such as migratory bats, raptors and seabirds, may be particularly impacted [9,10], which may at least be partly linked to visual acuity [11].

Collision mortality with wind turbines may reduce populations, particularly of long-lived, slow-reproducing species [12,13] and wide-ranging or migratory species [12,14]. Consequently, there is an urgent need to quantify species' vulnerability across as wide a range of species and geography as possible. Further, a recent review highlighted most studies to date have focused on the developed world [5]. The need to identify species' vulnerability, however, is crucial for countries in the developing world, where wind farms may be rapidly deployed to achieve climate change mitigation targets. This paper describes analyses designed to improve our understanding of the factors influencing the collision vulnerability of species to onshore wind turbines, and to inform future wind farm location and design in areas and for species for which this has been little studied. We model the extent to which ecological, morphological and life-history traits are likely to influence encounter rates with turbines, accounting for variation in parameters that differ between studies. We also consider other factors, such as turbine size, that might affect the likelihood of collision [15,16], to examine the extent which wind farm design may reduce collision rates.

2. Material and methods

(a) Literature review and data structure

We conducted meta-analyses using Web of Science, Google Scholar© and Google© to search for peer- and non-peer-reviewed literature. Given the known differences in terminology for 'wind farms', we used the following search terms for birds: (bird* OR avian) AND wind AND (farm* OR energy OR windfarm* OR industry* OR wind-farm* OR park* OR development* OR facilit*). For bats, we repeated the search, replacing 'bird' and 'avian' terms with 'bat'. References reporting collision mortality were identified. Population-level impacts such as mortality rates were rarely available; instead most studies presented the numbers of collisions per species per turbine or per megawatt (MW). The following data were extracted: study reference, wind farm name, geographical location, species' identity, number of deaths, study duration, wind farm and turbine quantity, turbine size and study quality information (see below). In total, 133 studies for birds and 101 for bats reported collision rates. Of these, 88 bird and 87 bat studies were suitable for inclusion, and contained information from 93 and 134 onshore wind farm sites (electronic supplementary material, appendix A1, figure S1), respectively. Dominant land cover within a 5 km buffer of the centre point coordinate of wind farms was identified from GLC2000 [17]. References and further information on traits are given in electronic supplementary material, file S1 and data collection files S2.

(b) Study quality and site-specific information

The detectability of collision victims is affected by many factors, including frequency of mortality surveys, scavenger removal, observer skill and variation in encounter probability (detectability) between species [18–20], ground and habitat types and ecosystems. Studies varied in the extent to which they corrected for these factors, and did not provide sufficient information to produce a standardized collision rate metric [21,22]. Instead, we categorized studies based on quality as follows: (1) 'very low': no corrections; (2) 'low': correction for aspects of scavenger removal and observer skill, but detectability constant across species; (3) 'medium': as (2) but with multiple corrections for detectability for species' groupings, e.g. 'small bird' or 'large bird'; (4) 'high': species-specific corrections for main sources of error (electronic supplementary material, appendix A2). For bats, no distinctions were made for species groups, therefore a three-level variable was used, combining low and medium categories. Corrections for bat scavenger removal were sometimes based on proxy bird species, which might introduce bias.

The search area around turbines (hereafter, 'buffer area') may influence discovery of collision victims and so was included as a covariate (birds: mean $\pm$ 1 s.d., 2.1 $\pm$ 1.4 ha, range 0.1–8.6 ha; bats: 1.2 $\pm$ 1.1 ha, 0.1–8.1 ha). We included 'year' (birds: 1.8 $\pm$ 1.6 years, 1–10 years; bats: 1.4 $\pm$ 0.9 years, 1–5 years), and 'number of days' (birds: 281.7 $\pm$ 106.4 days, bats: 238.7 $\pm$ 110.1 days, range 42–365 days) as covariates to control for study duration. A binary factor separated peer- and non-peer-reviewed literature. As studies varied in the number of wind farms monitored, this was added as an additional covariate. Turbine size was included as a linear predictor, given its potential impact on mortality rate [12], here assessed as turbine MW output [9] (birds: 1.3 $\pm$ 0.7 MW, 0.2–2.5 MW; bats: 1.6 $\pm$ 0.6 MW, 0.5–3.0 MW).

(c) Species' traits

Traits for bird species were taken from the Birdlife International World Biodiversity Database [23] except wing morphology, which was measured directly from museum skins [24] (electronic supplementary material, appendix A3). Flightless species were excluded. Habitat, foraging strata and diet were specified using binary factors for each factor level. Migratory status and breeding dispersal distance, body size, clutch size, generation length and Kipp's distance (a measure of wing morphology related to manoeuvrability [25]) were also obtained.

To account for species potentially present, but not recorded in collision, we used spatial distribution polygons based on entire breeding ranges for birds [23] and bats [26] to generate species lists of 'pseudo-absences'. Although this approach may produce omission errors due to coarse data resolution [27], it allowed potential species' presences to be modelled. The frequency of collision may depend on local abundance, but such information was inconsistently reported. Therefore, we included global population size as a proxy, which is implicitly related to gross variation in density.

Bat trait data were extracted from the PanTHERIA database [28] but consideration of all traits simultaneously was not possible as data were available for subsets of species per trait. We therefore tested (i) population group size [28]; (ii) forearm length; (iii) body mass; (iv) litter size; (v) age of sexual maturity and (vi) gestation length. Body mass and forearm length were correlated ($R = 0.92$), so forearm length was excluded. As 96% of species were insectivorous [29], diet was not included. Dispersal distance (vii), use of tree roost sites (viii) and hibernation behaviour (ix) were obtained through field guides (e.g. [30]) and data portals [26,31,32]. For bats, current knowledge gaps and terminology differences between studies prevented migration from being separated from dispersal [32]. Maximum dispersal distance was defined as 'sedentary' less than 10 km, 'regional' 10–100 km and 'long-distance' 100+ km, the last probably equating to long-distance migration [32]. Binary variables were specified for tree roost site and hibernation. Traits 1, 5 and 6 were only available for a smaller proportion of species ($n = 36$), and were not significant ($p > 0.05$) when considered alongside the remaining traits. Therefore, we present models for traits 3, 4 and 7–9 for 67 species (see electronic supplementary material, appendices A3–A5).

(d) Phylogeny

To account for potential phylogenetic non-independence of data, we used bootstrapped estimates of phylogenetic relationships from the BirdTree database [33]. We generated 1000 random trees, reduced further into a single minimum consensus tree using a Python algorithm, taking a minimum of 50% support for branching events [34]. Seven different methods for generating trees were available for birds [33], providing seven alternative models. For bats, we used a phylogenetic tree within the R package 'ape' [35]. This tree had no bootstrapped estimates available, but species with available trait data were well represented (greater than 95%).

(e) Statistical analysis

Bayesian Markov chain Monte Carlo (MCMC) generalized linear mixed models were used to model the variation in collision rates, using the R package MCMCglmm [36,37]. Models were specified using a zero-adjusted Poisson error structure and a response of collisions per turbine, including the logarithm of the number of turbines surveyed as an offset; an R script for birds is provided in electronic supplementary data collection, files S2. Fixed effects were specified for species' traits, study quality and site-specific information (electronic supplementary material, table S1). To assess the effect of inserting pseudo-absences, we repeated our analysis based on recorded collisions, which produced similar results (electronic supplementary material, appendix A5). We therefore present results for models including pseudo-absences. Phylogenetic signals were included by specifying the 'tip label' of species names from the minimum consensus tree as a random effect [38], alongside a matrix inversely proportional to the covariance structure of 'tip label' [37]. Phylogenetic models were better fitting than those excluding phylogeny in all cases (dDIC < -2.0). Study ID was included as a random effect to account for repeated measurements of collisions per species and study. Uninformative priors were specified except for log(turbine) included as an informative prior to represent an offset. We specified 105 000 Monte Carlo iterations with a burn-in of 5000 and thinning of 100, to leave 1000 samples from the posterior distributions. The proportion of variance explained by fixed and random effects was examined [39] to generate conditional (fixed plus random effects) and marginal (fixed effects only) R^2 values. Significance of fixed effects was determined by whether 95% lower and upper credible intervals (LCL, UCL) drawn from the posterior distribution overlapped zero. For birds, model-averaged coefficients were computed across all seven phylogenetic models with equal weighting.

For birds, predicted numbers of collisions/turbine/year were generated from full models for 9568 species worldwide based on trait relationships. Predictions were generated marginal to the random effect of study ID, and were made at highest data quality level for a 365-d duration, equating to rates of collision per annum. Estimates for each species were treated as a final collision vulnerability index. For bats, full trait data were available for the 67 species modelled. To maximize the global generality of our predictions, we based predictions on phylogenetic correlation only (for 888 species) from a model including only study and site fixed effects (no-traits model). All modelling was conducted in R v. 3.3.1 [40]. Full predictions are given in electronic supplementary material, files S3 and S4.

For an independent check of correspondence, predicted vulnerability values were compared with a previous expert assessment of species' vulnerability to the threat of 'renewable energy' in the IUCN Red List (Threats Classification Scheme v. 3.2 [26]). Modelled predictions were summarized in 5% percentiles, and presented for those threatened species identified in the IUCN Red List. To assess whether threatened species may be more at risk of collisions than other species, we used a generalized linear model to test whether collision rates varied by Red List category (Least Concern, Near Threatened and 'Threatened', i.e. Vulnerable, Endangered or Critically Endangered) in interaction with taxon (bird versus bat), weighted by the reciprocal of collision rate error.

(f) Turbine capacity effects on bird and bat mortality

We generated predictions of mean collisions/turbine/year across all species for increasing turbine capacity, for the range of turbine sizes included in this review (0.1–2.5 MW). The number of turbines required to meet a hypothetical 10 MW energy demand were then multiplied by these estimates to investigate the mean number of predicted deaths per year across species for birds and bats with increasing turbine capacity.

(g) Spatial variation in vulnerability to wind energy

Spatial variation in the potential impact of turbines on collision rates was mapped globally, based on the predicted occurrence of species within a grid (resolution, 5 km $\times$ 5 km), derived from overlaps with species range maps [23]. For birds and bats, the MCMC posterior predictions for each species were extracted. The predicted collision rates for each species that occurred in a 5 km cell (v_i) were summed across all species ($v_1 + v_2 + v_3 \dots v_{ij}$), up to the total number j occuring in that cell. A mean cumulative value, with 95% credible intervals, was then generated and mapped as a 'vulnerability' surface for birds and bats. Spatial data processing was undertaken in SAS v. 9.3 (SAS Institute Inc.) and ArcMap v. 9.3.

3. Results

(a) Data summary

A total of 362 bird and 31 bat species were recorded as collision victims with 407 and 41 further bird and bat species included as pseudo-absences. Data were obtained from 16 countries for birds and 12 countries for bats. The dataset was spatially biased to North America (birds, 64.0%, bats 48.6%) and Europe (birds, 31.0%, bats 50.6%), although South Africa, Japan, Australia and New Zealand were represented (electronic supplementary material, appendix A1, figure S1). In total, 36% of studies were in forests and 29% were in agricultural areas (e.g. artificial landscapes) with fewer in shrub (9%) and grassland (14%) landscapes. Agricultural land cover was over-represented in the review compared with global land cover (17%), whereas shrub (21%) and grassland (26%) were under-represented and forest was sampled approximately in proportion (37%) (electronic supplementary material, appendix A4).

(b) Study quality and site-specific variables

Studies that had not corrected for carcass detection probability (birds 'very low'; bats 'low') or the size of birds (low),

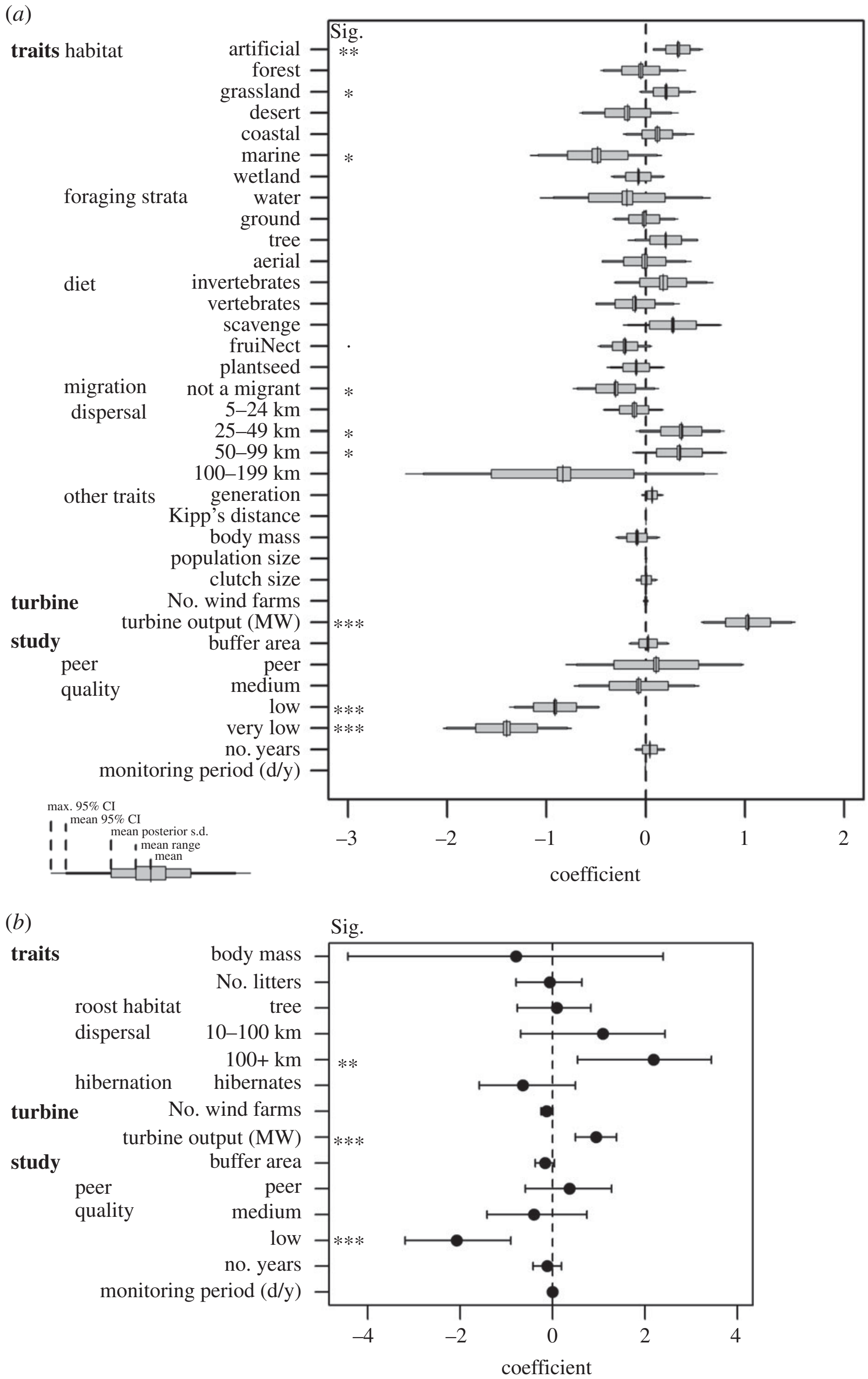

Figure 1. Coefficients from MCMCglmm models for (*a*) birds, and (*b*) bats. For birds, model-averaged coefficients are presented from seven models using alternative phylogenetic reconstruction methods, presenting (i) mean posterior predictions averaged, (ii) range of mean estimates, (iii) posterior standard deviations averaged, (iv) mean 95% credible intervals (CIs) and (v) maximum 95% CIs. For bats, the posterior mean estimate, and lower and upper 95% CIs, are given from the single trait-based model; the significance of each term (Sig.) is presented using the maximum level of significance attained ($.p < 0.1$; $*p < 0.05$, $**p < 0.01$; $***p < 0.001$).

significantly underestimated the number of collisions compared with studies that had made such corrections ($p < 0.001$ in all cases, figure 1; see also electronic supplementary material, tables S3 and S4). By contrast, 'high' and 'medium' quality levels were not significantly different from the average (figure 1, $p > 0.05$). There was no residual variation explained by peer-and non-peer-review studies, buffer area, number of wind farms and study duration in days or years, after accounting for overall study-level variation using random effects ($p > 0.05$). There was, however, a strong positive correlation between turbine capacity (MW) and collisions per turbine (figure 1, $p < 0.01$ in all models).

(c) Species' traits

For birds, habitat association was an important predictor of collision rates (figure 1*a*, electronic supplementary material, tables S3 and S4). Species using artificial (such as farmland and urban areas) and grassland habitats had significantly higher collision rates than species not using these habitats ($p < 0.01$ in all cases). Species using marine habitats had significantly lower collision rates than species not using marine environments, probably influenced by a paucity of data for offshore wind farms. Species feeding on fruit and nectar had lower collision rates than species with other diets. Diet and foraging strata had smaller effects than habitat, with

Table 1. Summary of MCMCglmm model fits, assessed using pseudo-R^2 values, for birds (model-average across seven phylogenetic models, electronic supplementary material, table S2) and bats.

		marginal: fixed effects		conditional: random ID + phylo		conditional: random ID	
taxa	model type	mean	posterior mode (95% CI)	mean	posterior mode (95% CI)	mean	posterior mode (95% CI)
birds	traits model	0.46	0.45 (0.35–0.56)	0.85	0.85 (0.82–0.88)	0.66	0.65 (0.57–0.72)
bats	traits model	0.30	0.30 (0.11–0.50)	0.84	0.83 (0.77–0.92)	0.58	0.64 (0.37–0.75)
bats	no-traits model	0.19	0.08 (0.04–0.42)	0.88	0.87 (0.81–0.95)	0.39	0.39 (0.16–0.62)

coefficients being mostly non-significant (figure 1*a*). Migrants exhibited higher estimated collision rates than non-migrants (figure 1). One model gave significant support to migratory status (electronic supplementary material, appendix A5), and the direction of the effect was consistent across all models, but the mean effect size across models just overlapped zero. Species with median dispersal rates of 25–49 km or 50–99 km had significantly higher estimated collision rates from some models than those dispersing smallest (less than 25 km) or longest distances (greater than 100 km).

For bats, species dispersing furthest had significantly greater collision rates than sedentary species (figure 1), but roost site and hibernation were not significant predictors (figure 1). When fitted without dispersal, however, tree-roosting species had significantly higher collision rates than other species (electronic supplementary material, appendix A5).

(d) Model fit

The marginal R^2 explained by fixed effects was 0.46 for birds, and for bats it was 0.30 for the trait-based model and 0.19 for the no-traits model (table 1). For birds, the phylogenetic models produced similar β-coefficients (figure 1, electronic supplementary material, appendices A4 and A5, tables S3 and S4). Phylogeny explained a high proportion of variance in all models (table 1). Effective sample sizes greater than 200 and diagnostic plots indicated that autocorrelation within MCMC chains was appropriately accounted for.

(e) Model predictions

For birds, 936 species had collision rates of more than 0.046 collisions/turbine/yr (90% quartile), of which 174 species were Accipitriformes (figure 2), 57% of species in that order. Accipitriformes had the highest predicted collision rates of any taxonomic order (0.073 ± 0.064 s.d. collisions/turbine/year, mean lower credible interval less than 0.001, mean upper credible interval, 0.288). Mean predictions were also high for Bucerotiformes, Ciconiformes and Charadriiformes, whereas Galbuliformes and Coraciiformes were among the lowest, and waterbirds such as Anseriformes and Galliformes and Passeriformes songbirds also had smaller than average predictions (figure 2).

For bats, the most vulnerable families containing greater than 10 species/family included Molossidae and Hipposideridae, while Rhinolophidae were among the least vulnerable (figure 3). The largest family, Vespertilionidae, had high collision rates (0.718 ± 0.586 s.d., 294 species) and included the five bat species most vulnerable to collision (electronic supplementary material, appendix A6).

In total, 57 bird species (including 31 Accipitriformes) were identified as threatened by 'renewable energy' [26], of which 43 species (75%) were above the 75% percentile of our collision predictions (electronic supplementary material, table S6). All of the 31 Accipitriformes were above the 75% percentile, and 26 (84%) were ranked above the 90% percentile. After accounting for a significantly greater collision rate for bats than birds ($\chi^2 = 510.30$, $p < 0.001$), there was no residual variation explained by IUCN Red List category ($\chi^2 = 0.63$, $p = 0.73$), or among categories constituting the broader 'threatened' category (Vulnerable, Endangered or Critically Endangered) ($\chi^2 = 0.19$, $p = 0.91$, electronic supplementary material, appendix A7).

(f) Relationships between turbine size and mortality

For birds and bats, larger turbines were associated with increased collision rates (figure 1). A greater number of small turbines, however, resulted in higher predicted mortality rates (figure 4) than a smaller number of large turbines per wind farm unit energy output. Using 1000-0.01 MW turbines resulted in the largest estimated number of bird and bat fatalities; thereafter the numbers decreased exponentially up to approximately 1.2 MW, where the relationship for birds contined to decline up to 2.5 MW turbines (posterior means, LCL–UCL 0.8, 0.5–1.1). By contrast, the mortality for bats increased again from 14 (8–21) bats with 1.2 MW turbines, to 24 (12–40) bats with 2.5 MW turbines (figure 4).

(g) Spatial variation in vulnerability to wind energy

The greatest numbers of vulnerable bird species occurred along coastal and migratory pathways in the eastern and southwestern USA, the central American isthmus from Mexico to Panama, Northern Andes, Rift Valley of East Africa and the Himalayas. For bats, the greatest number of collisions was predicted in North America (figure 5).

4. Discussion

Previous studies into the collision risk of birds with terrestrial wind farms have documented a high risk for Accipitriformes (raptors and birds of prey) [41,42]. Further studies have suggested that raptors, migratory soaring birds and waterbirds may be particularly vulnerable [9,43–45].

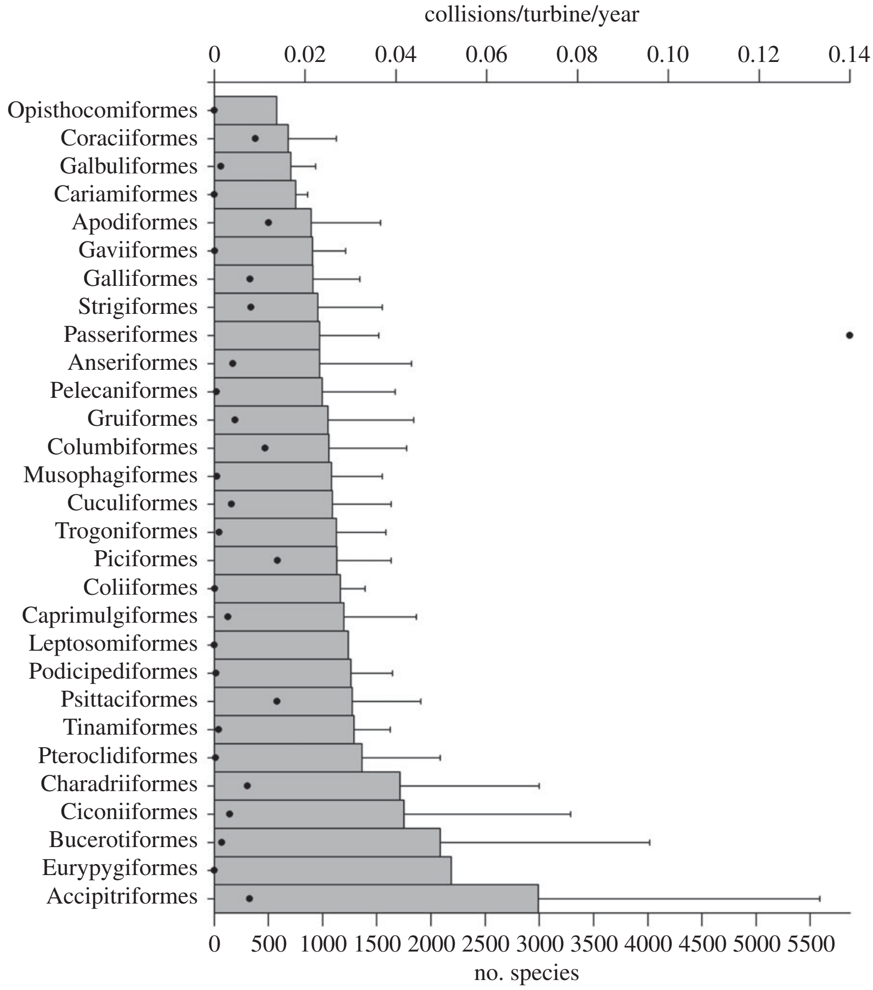

Figure 2. Predictions of mean collisions per turbine (per year) (±s.d.) for bird orders (9568 species) from the posterior distributions of MCMCglmm models, ordered by mean predictions; numbers of species per order are shown by black dots.

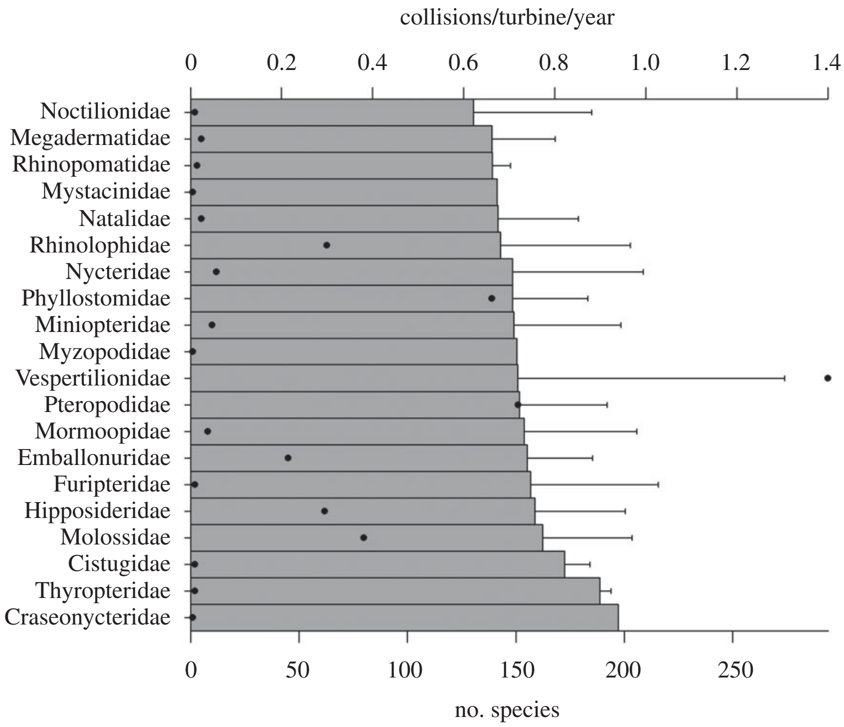

Figure 3. Predictions of mean collisions per turbine (per year) (±s.d.) for bat families (888 species) from the posterior distributions of MCMCglmm models, ordered by mean predictions; numbers of species per family are shown by black dots.

Similarly, our study showed that Accipitriformes had the highest rates of collision. Among other orders, Bucerotiformes (hornbills and hoopoes), Ciconiformes (storks and herons) and some Charadriiformes (shorebirds) were also vulnerable, but notably many waterbirds (e.g. Anseriformes) were not.

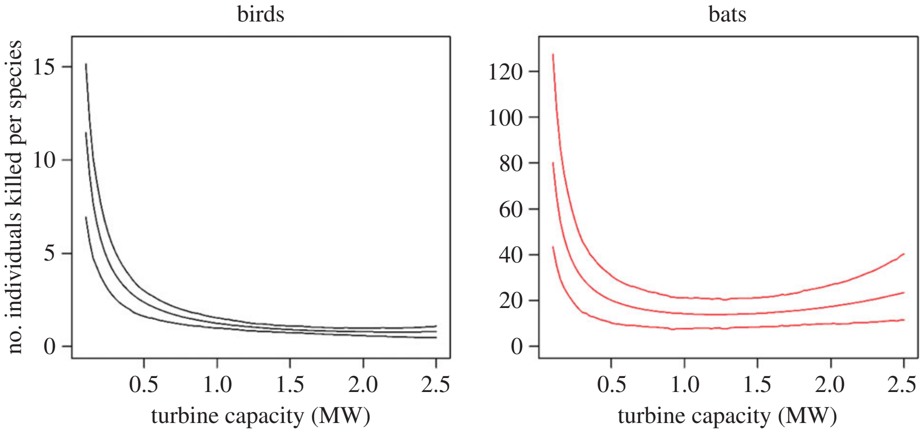

Figure 4. The mean total mortality rate across species for a hypothetical 10 MW wind farm, shown in relation to individual turbine capacities (which in turn require different numbers of wind turbines to meet the same capacity). Lines represent posterior means and 95% upper and lower credible intervals.

Although there was less variation in predicted mortality between bat families (figure 3), a small number of Vespertilionidae species were associated with relatively high rates of collision, as also found in a recent review [8]. Our models predicted higher collision rates for bats than birds, as reported elsewhere [15], which adds to the literature emphasizing the risk that wind farms pose to bat populations [7,8,14].

For birds, vulnerability to collision was related to habitat, migratory status and dispersal distance. High collision rates for species associated with agricultural habitats may reflect the disproportionate number of wind farms from agricultural landscapes in our sample. Species associated with these human-modified habitats, however, may be less likely to avoid wind farms than those occupying natural landscapes [46], while our results suggest that grassland species may also be more vulnerable to collision.

Migratory species are often suggested as being vulnerable to collision with wind farms [44], for which our results are supportive. Previous work has suggested high rates of collision with wind turbines at avian migratory bottlenecks [9,41,42], and for migratory bats in North America [8,47], suggesting migration may outweigh the greater exposure time of residents to wind turbines [41].

Wind farms may have significant meta-population-level impacts [45], for example on species with large home ranges and moderate rates of dispersal [12]. The link, however, between dispersal distance and collision rate across multiple species has not previously been identified, and demonstrates that bird species dispersing short or very long distances may have reduced vulnerability to collision compared with species dispersing intermediate distances. Those species dispersing furthest may exhibit unmeasured traits of flight behaviour, such as flight height rendering them less susceptible to collision, but the large uncertainty in the effect emphasizes that further study is needed. For bats, long-distance dispersers had the highest collision rates, but certainty of behaviour for many species tempers our ability to draw firm conclusions. Tree-roosting bat species were frequently recorded in collision, potentially through attraction mechanisms [48], although this effect was weaker than dispersal. Overall, these findings emphasize the need to consider cumulative impacts of wind farms on populations, particularly for migrants and wide-ranging species.

Our vulnerability estimates may not reflect population-level impacts, to understand which requires further consideration of population demography and other impact metrics [22,45]. However, our findings may be problematic in terms of species conservation, as the species groups with the greatest rate of collision tended to be *k*-selected species with low fecundity and late ages of maturity, and most sensitive to impacts of additional mortality [49,50], such as Accipitriformes, Bucerotiformes, Ciconiformes and Charadriiformes for birds, and a range of bat species. Avoiding placement of wind farms in areas with populations or high concentrations of such species, such as coastal areas and migratory flyways (figure 5), would reduce potential impacts of wind farms on biodiversity. Although some passerine families (e.g. Motacillidae) and species (e.g. European starling, *Sturnus vulgaris*) had high predicted rates of collision, their *r*-selected life-histories and relatively high abundances make it less likely that large population-level effects would arise, as population growth rate is less sensitive to reductions in adult survival [49].

Although as comprehensive as possible, our study has some limitations. First, data were largely from well-studied parts of Europe and North America. While our results can be used to infer potential collision risk for species in other parts of the world, uncertainty arises when extrapolating to understudied regions and taxa. This was particularly the case for bats, where studies were exclusively from temperate northern latitudes with low species diversity. More geographically widespread studies, from the tropics and from countries with rapidly growing wind industries (such as India and China), are required to feed into meta-analyses like ours. In the absence of such studies, our estimated collision rates should help indicate vulnerable species in these areas. Second, collision rate data were not available from offshore wind farms. Only 5% of studies recorded collisions with marine species at coastal wind farms, and further work is needed to estimate their vulnerability to offshore wind turbines [51]. Third, trait information for bats was less comprehensive than for birds, meaning it was not possible to extrapolate from a trait-based model globally in the same manner. We also note the strong geographical variation in predicted bat mortality rates between North America and Europe (figure 5), and suggest further work is required to test whether this effect is real. Fourth, although we corrected for data quality, inevitably some variation will not be captured by our classification; for example, corrections for unsearchable portions of the survey area were not always reported. Fifth, our

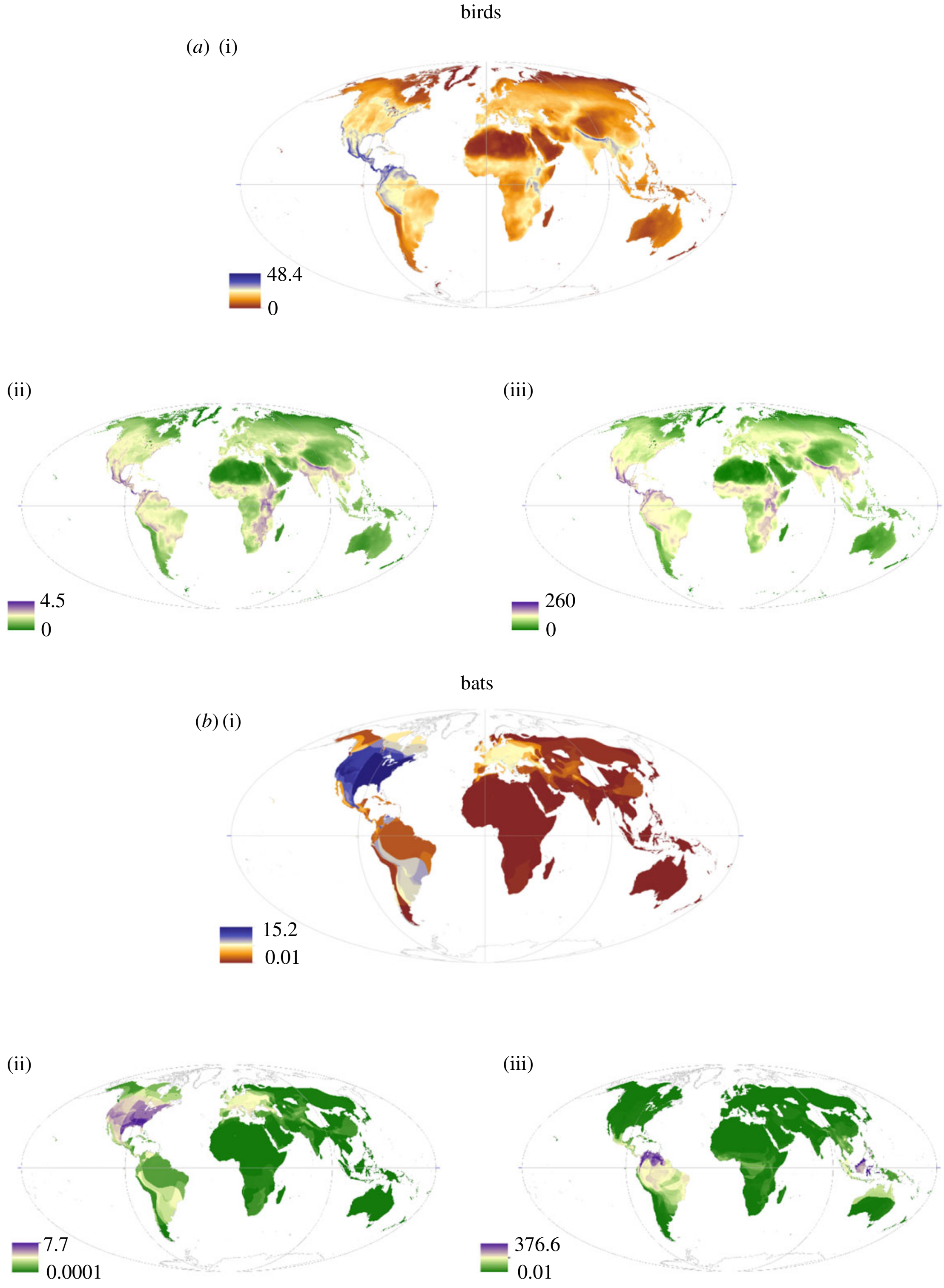

Figure 5. Worldwide distribution of (*a*(*i*–iii)) bird and (*b*(*i*–iii)) bat species' vulnerability to wind farm collisions, based on summing vulnerability of each species that occurs at each point, according to species range maps for (*a*(*i*),*b*(*i*)) mean across species, and lower and upper (*a*(ii),*b*(ii) and *a*(iii),*b*(iii)) credible intervals from MCMCglmm models (for details of data manipulation and calculations behind these maps, see methods).

study metric focused on a measured impact after collision with turbines, reflecting both initial sensitivity and current exposure. Our study, however, did not include future potential to habituate (adaptability), necessitating caution when translating our findings more broadly. Finally, our list of species putatively present at a wind farm was derived from broad-scale distribution polygons, and so may have included false negatives [27].

Given the recent dramatic increases in wind energy generating capacity in parts of the world where wind farms have not previously been deployed [52], and probably continued increases to meet climate change mitigation targets, wind farms pose an increasing threat to bird and bat species worldwide. Our study can be used to mitigate this risk in two ways. First, although uncertain, our species-level predictions of collision rates provide a useful starting point for scoping potential impacts of wind farms on species where collision risk has not been studied. New wind developments should preferably be in areas with low concentrations of species vulnerable to collision. Our results can help identify locations based on the distribution of vulnerable species, which alongside habitat restrictions on wind farm development, such as in forested areas, can be used to minimize the risk of negative biodiversity impact. Although country and regional maps [53,54] should be developed to help identify local hotspots, our global vulnerability maps (figure 5) are a useful starting point, suggesting key areas and migratory pathways where collision may occur. The agreement between our predictions and species classified by the IUCN Red List as being threatened by 'renewable energy' suggests an emerging consensus for key taxa.

Second, there was a strong positive relationship between wind turbine capacity and collision rate per turbine. The strength of this relationship, however, was insufficient to offset the reduced number of turbines required per unit energy generation with larger turbines, at least for birds. Therefore, to minimize bird collisions, wind farm electricity generation capacity should be met through deploying fewer, large turbines, rather than many smaller ones, supporting suggestions for marine birds [16]. For bats, an optimum turbine size of approximately 1.25 MW may minimize collision risk, with the largest turbines associated with a disproportionately high collision rate, but we again caution that model certainty for bats was low for the reasons outlined. More research is required to understand the relationship between collision risk and turbine size for larger (and more efficient) turbines, and how this may vary between habitats.

5. Conclusion

This study is the first global quantitative assessment from the published literature of the relative vulnerability of different species groups to wind farms. Wind farms have the potential to benefit biodiversity through their contribution to climate change mitigation, but our results emphasize the global nature of the potential risks to biodiversity involved, which needs to be accounted for through appropriate wind turbine design and planning, if those risks are to be minimized.

Data accessibility. Supporting data are available on the Dryad Digital Repository: The collision rate data for bird and bat species obtained from the literature is available at: http://dx.doi.org/10.5061/dryad.h9s55 [55].

Authors' contributions. C.B.T., J.W.P.-H., G.M.B., J.C., S.H.M.B., T.N. and R.E.G. conceived and designed the study. C.B.T. conducted the literature review and carried out the meta-analysis, J.C., S.H.M.B. and J.A.T. extracted and provided data for analysis, and G.M.B. produced mapped outputs from statistical models. C.B.T. and J.W.P.-H. drafted the manuscript, and conceived appropriate testing and statistical procedures, under the guidance of all authors, and an independent project advisory group, including W.B.F. and S.O'B. All authors edited the manuscript and gave their approval for publication.

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Impacts of wind farms on birds: a review

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Impacts of wind farms on birds: a review

Ralph G. Powlesland

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Impacts of wind farms on birds: a review

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ABSTRACT

The impacts of wind farms on New Zealand bird species and populations are unknown. This document reviews available literature on the impacts of onshore wind farms on birds, based on studies in other countries. A key finding is that wind farms tend to have variable effects on bird populations, which can be species-, season- and/or site-specific. The impacts include collision fatalities, habitat loss and disturbance resulting in displacement. The main factors that contribute to collision fatalities are proximity to areas of high bird density or frequency of movements (migration routes, staging areas, wintering areas), bird species (some are more prone to collision or displacement than others), landscape features that concentrate bird movement, and poor weather conditions. In many instances, the numbers of carcasses reported are likely to be underestimates, as they are often based only on found carcasses, without accounting for scavenging and searcher efficiency. Habitat loss as a result of wind farm construction seems to have a minor impact on birds, as typically only 2–5% of the total wind farm area is taken up by turbines, buildings and roads. However, the cumulative loss of sensitive or rare habitats may be significant, especially if multiple large developments are sited at locations of high bird use. Disturbance of birds as a result of wind farm development may arise from increased activity of people at the site, and/or the presence, motion and noise of turbines. The level of disturbance to birds has been shown to vary, depending on the availability of alternative feeding or breeding habitat. Although some of the findings from this review may be relevant to the New Zealand situation, it is important to realise that each wind farm tends to be different as a result of topography, weather, habitats, land use, bird species and turbine characteristics.

Keywords: wind farm, turbine, review, collision fatalities, habitat loss, displacement, migration routes, weather, lighting, mitigation

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1. Introduction

The levels of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere have become the focus of international concern, being linked to observed and predicted climate change. Atmospheric CO_2 concentrations were approximately constant until the industrial era began in about 1750. Since then, they have risen by around 35% and are currently increasing at 0.4% per annum on average (Ashby 2004). Most of the increase is thought to have come from burning of fossil fuels. Most governments now accept that climate change is a reality and that it presents serious environmental threats, including threats to human health, food production and biodiversity. The Kyoto Protocol was established under the United Nations Framework Convention on Climate Change as an international response to the climate change issue. The New Zealand Government ratified the Kyoto Protocol in December 2002.

The Kyoto Protocol commits New Zealand to reduce greenhouse gas emissions by at least 5% of 1990 levels between 2008 and 2012. Renewable sources of energy offer an opportunity to reduce the deleterious environmental impacts of climate change arising from over-reliance on fossil fuels. Of the most advanced renewable technologies, wind energy is set to make a modest contribution to energy generation in many countries. Already, some state governments in the USA are setting targets for large utilities to purchase a minimum proportion of their electricity from renewable sources (Nijhuis 2006), and the UK Government has set a specific target to derive 10% of energy from renewable sources by 2010, of which 7–8% will be from wind energy, and has set a goal of doubling that by 2020 (Drewitt & Langston 2006; Morley 2006). In contrast, in 2007 the New Zealand Government said it aimed to have 90% of electricity generated from renewable resources, such as wind and hydro power, by 2025 (www.stuff.co.nz/print/4217358a7693.html; viewed 27 August 2008).

New Zealand probably has the best overall accessible wind resource of any nation (Ashby 2004). Large parts of New Zealand have good mean wind speeds for generation year round (Parliamentary Commissioner for the Environment 2006: figure 3.1). However, a wind turbine with a rated capacity of 1 MW will not produce that output all the time, due to variation in wind speeds. Worldwide in 2002, the average capacity factor was 23%, i.e. the amount of electricity produced by turbines was equivalent to them operating at 23% of their rated capacity. By comparison, capacity factors achieved so far in New Zealand are 40–50% (Ashby 2004). Major providers in the energy industry see wind as being able to supply up to 20% of New Zealand's energy needs safely, economically and reliably within the next 10 years (Rodgers 2006).

Unfortunately, although wind power is a cleaner option for energy production, its impact on wildlife remains unclear. In New Zealand and Australia, developers often voluntarily commission wildlife surveys before beginning construction, but studies often span inadequate time periods, details are rarely made public and robust results from impact surveys following construction have not been reported. Although some state governments in the USA have established permitting processes and guidelines for wind farm development, monitoring remains weak and haphazard (Nijhuis 2006). Thus, conservationists and scientists often find themselves in a difficult situation. As Nijhuis (2006) asked, 'How can they support and encourage the rapid spread of wind power, our most promising source of clean, renewable energy, while ensuring that the industry minimises its damage to birds and other wildlife?'.

As a result of concern over the negative impacts that wind-energy developments could have on wildlife, especially threatened species, efforts have been increasing to avoid establishing new developments at locations that are likely to pose significant risks to birds, and to accurately quantify the impacts of wind farms on birds at existing wind farm sites (Percival 2005; Morrison et al. 2007).

In New Zealand, energy production by wind farms is still in a much earlier stage of development than in Europe and North America. However, it is poised for rapid expansion, to make a significant contribution to total energy production. Thus, this is an opportune time to learn from the observed effects that wind farms have had on birds elsewhere. In some areas, wind farms have had adverse impacts on birds, e.g. 1143 carcasses of more than 40 species, including threatened species, were found following searches around 4075 turbines at the Altamont Pass Wind Resource Area, California, USA, during May 1998 – May 2003 (Smallwood & Thelander 2004). However, many wind farms exist where recorded bird mortality has been non-existent or minimal, including facilities in Africa, Asia, Europe, Australia, Canada, USA and South America (Kingsley & Whittam 2005). For example, in the UK, there have been no significant[1] ornithological problems reported at wind farms, despite there being some 101 wind farms in operation comprising about 1234 turbines with a capacity of 979 MW in 2005 (Drewitt & Langston 2006), mainly because they are sited away from important bird populations (Percival 2005). Therefore, the challenge in New Zealand is to identify which species are likely to be adversely affected by wind farms, the locations at which adverse impacts are most likely, and the particular features of the environment and wind farm structures that increase the risks to birds, so that adverse effects can be appropriately avoided, remedied or mitigated in a way that meets the purpose of the Resource Management Act (Anon. 1991).

This report reviews literature, both published and unpublished, about the impacts of wind farms on birds. The review was undertaken at the request of the Corporate Services Group of the Department of Conservation to provide background information on the topic for the Group and other Department staff dealing with consent applications for the building of wind farms by New Zealand wind energy generators. This report includes information about features of wind farms that may contribute to impacts on birds, collision fatalities, disturbance leading to displacement, loss of or damage to habitat, and barrier effects. It is restricted mainly to the impacts of onshore wind farms as, at present, most wind farms throughout the world are onshore facilities, and although offshore wind farms are likely to make up a significant part of the future wind farm development in Europe with further technological advances, no offshore facilities are currently present in New Zealand. Many reports referred to in this review were commissioned for particular purposes and have not been through a peer-review process. However, because of the paucity of published studies on the impacts of wind farms on bird populations, much information in this review emanates from these non-peer-reviewed unpublished reports. Thus, I recommend caution about drawing firm conclusions from the results provided in these reports.

Common and scientific names for New Zealand bird species used in this document follow those of Turbott (1990).

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[1] Throughout this report, 'significant' is used either in a statistical sense or to refer to an impact on a species that occurs at the population level.

2. Features of wind farms that may contribute to impacts on birds

A number of features of wind farms may contribute to their impacts on birds and their populations. These include the scale of wind farms, wind farm configuration, construction and operation, turbine design and dimensions, lighting, blade speed and motion smear, associated structures, and landscape features.

2.1 SCALE OF WIND FARMS

There is little relationship between the scale of a wind farm and the amount of bird mortality that has occurred (Kingsley & Whittam 2005; Percival 2005). A large, appropriately sited wind farm may kill fewer birds than a small, poorly sited one. Considered in isolation, it is unlikely that small numbers of fatalities per year at a wind farm would be considered significant, unless some of those fatalities were of threatened species, in which case impacts might occur at the population level (although it should be noted that cumulative effects of small numbers of fatalities at two or more wind farms may be sufficent to result in population impacts). In contrast, a large facility may kill many birds in total, thus impacting at the population level, especially when threatened species are involved. Even relatively small increases in mortality rates may be significant for populations of some birds, especially long-lived species with generally low annual productivity and slow maturity, and particularly when already rare (Percival 2000; Langston & Pullan 2003; Everaert & Stienen 2007), e.g. blue duck (*Hymenolaimus malacorhynchos*) and kaka (*Nestor meridionalis*). When considering potential impact, it is important to consider the average effect of each turbine, the cumulative effect of the total number of turbines and associated structures (overhead power lines, meteorological masts; see section 2.4) on a farm, and even the cumulative impact of other wind farms in the range of a bird population, particularly where rare or threatened species are concerned (Australian Wind Energy Association 2002; Everaert & Stienen 2007).

As the area of the farm increases (density of turbines remaining constant), the potential for adverse effects, other than fatalities, also increases. Large facilities may cause more bird habitat to be lost or compromised, so that foraging and breeding birds may be more inclined to avoid the area. Even in New Zealand, a large wind farm can occupy many square kilometres in area: e.g. Hawke's Bay wind farm near Napier—75 turbines, 30.0 km^2; Project West Wind near Wellington—62 turbines, 55.8 km^2; Project Hayes near the Lammermoor Range, Otago—176 turbines, 92 km^2. Percival (2005) considered that direct habitat loss from wind farm construction was usually small-scale and unlikely to have a significant impact on bird populations. However, a considerable proportion of habitat may be lost if a particularly scarce and important habitat type was affected, or if there was potential for the effects to extend into the wider area (e.g. through disrupting the hydrology of a wetland).

2.2 WIND FARM CONFIGURATION, CONSTRUCTION AND OPERATION

The configuration of turbines at onshore facilities is most often dictated by the wind resource, and thus far no one has examined how overall wind farm configuration may affect birds. Percival (2001) considered that, in general, spacing between turbines should be greater than 200 m in order to avoid inhibiting bird movement (barrier effect). This recommended distance is also often the amount of spacing required by industry to reduce wake effects of large turbines on neighbouring turbines (Kingsley & Whittam 2005). However, spacing turbines widely in an attempt to reduce the likelihood of blocking bird movement may potentially increase the area from which birds will be displaced by disturbance. Given that most New Zealand operational and planned wind farms occur on open/modified landscapes (habitat occupied mainly by common and widespread bird species), the displacement of such bird species from portions of a wind farm is unlikely to have population consequences.

Although it has been suggested that some species are more disturbed by clusters of turbines than strings, clusters may be more advantageous, as mortality could subsequently be reduced (Percival 2001). For large projects, a possible solution is to provide wide corridors between clusters of closely spaced turbines (Langston & Pullan 2003). Winkelman (1992b) also considered that wind farm layout was probably an important determinant of collision risk, arguing that a (dense) cluster of turbines was potentially less damaging for wintering, feeding and possibly breeding birds, because it tended to dissuade them from flying amongst the turbines. Larsen & Madsen's (2000) study of foraging geese supported this. However, for migrants, Winkelman (1992b) considered that a line formation parallel to the main flight direction or a loose cluster was the best arrangement.

The high degree of disturbance normally associated with construction of a wind farm is temporary. The time taken to construct a wind farm is dependent upon several factors, including the scale of the project, the terrain and climate. However, construction typically takes 9–18 months (Kingsley & Whittam 2005), making it likely that some of this time will coincide with bird breeding. Construction usually begins with the development of roads, followed by the excavation and pouring of the concrete foundations for the towers. Typically, this is followed by digging trenches and burial of underground electrical cables where soil conditions allow. Substations and any other buildings are then built, and lastly the turbines are assembled and tested. The erection of a turbine usually takes 1 day.

As most wind farms are completely automated, disturbance by people at a site is minimal once construction is complete, with only a few on-site personnel required on an occasional basis. However, some wind farms are promoted as tourist sites (e.g. Meridian Energy's Te Apiti wind farm on Saddle Road, near the Manawatu Gorge), which may result in substantial human disturbance. The activities associated with decommissioning of turbines could also disturb birds at the site.

Although wind energy is considered 'clean and green', it does produce waste materials during all phases of a facility's life (construction, operation and decommissioning). Potential pollutants include various lubricants that are used in the turbines, such as gearbox oils, hydraulic fluids and insulating fluids. These materials pose little threat to birds if handled appropriately, but contamination can arise from spills during routine maintenance and fluid leaks if the turbines are not regularly inspected. Decommissioning creates a great deal of waste, as all of the turbines must be dismantled, any above-ground wires removed, and any other equipment and waste removed from the site and disposed of appropriately.

2.3 TURBINES

2.3.1 Design and dimensions

Most commercial-scale wind turbines consist of a three-bladed rotor that rotates around a horizontal hub facing upwind in front of the generator and tower (Fig. 1). Most towers these days are of tubular steel construction and are bolted to a concrete foundation. Blades are made of fibreglass or wood epoxy. The hub is connected to a gearbox and generator, which are all located in the nacelle. The tower of a large wind turbine may have an internal elevator to transport workers to the nacelle for maintenance. The nacelle on top of the tower contains a generator turned by the blades, which in turn produces electricity.

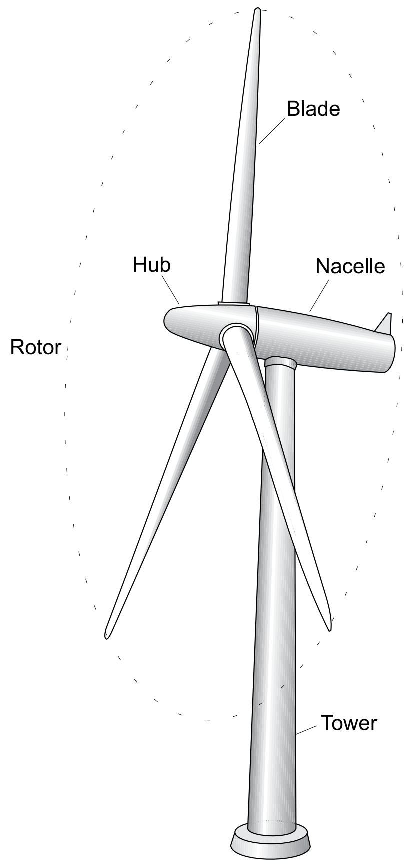

Figure 1. Basic features of a wind turbine.

As wind-power generation has developed and the associated technologies advanced, rotor diameters and tower heights have increased and are likely to continue to do so, as taller towers allow turbines to intercept wind that is less turbulent. During the 1980s, relatively short turbine towers were installed, with few exceeding 18 m in height (Kingsley & Whittam 2005). In contrast, typical tower heights today for commercial-scale turbines (1–2 MW capacity) are 80–100 m. The length of the blade is usually about half the height of the tower (Ashby 2004), making the tallest turbines in New Zealand about 150 m in total height (Meridian Energy Ltd 2007). Experience with communication towers and skyscrapers in the USA suggests that turbines of this height have the potential to interact more frequently with migratory birds (Kingsley & Whittam 2005). However, it is unknown whether turbines greater than 150 m in height in New Zealand would cause increased bird mortality.

Small turbines are often used in remote areas, where they meet the electricity needs of a settlement, field station or family. These turbines often have tubular or lattice towers, and range between 18 m and 40 m in height. They also tend to be variable speed turbines with quickly turning blades (usually 10–50 revolutions per minute (rpm), but can be as great as 300 rpm). Typically, the use of such turbines would be on a small scale, and their effect on birds is likely to be reduced if sited correctly.

Laboratory research has indicated that high contrast patterns on turbine blades (McIsaac 2001) or a single black blade paired with two white blades may reduce collision risk by increasing the visibility of the rotating blades (Hodos et al. 2001, cited in Sterner 2002). However, it is not known to what extent these features might avert collisions, especially in conditions of poor visibility. Furthermore, such measures may be unacceptable on landscape grounds.

Wind turbines can be mounted on either lattice or tubular steel towers. In the past, it was believed that lattice-type towers encouraged raptor perching, which led to increased mortality (Percival 2000). However, recent research suggests that the specific type of turbine does not influence the flight, perching behaviour or rate of collisions of raptors. Rather, it is the placement of turbines within the landscape that appears to be the major factor influencing raptor behaviour and death (Morrison et al. 2007).

2.3.2 Lighting

In general, turbines are required to have some form of lighting, either individually or collectively as a wind farm. The lighting specifications differ between countries. In New Zealand, the lighting required has been specified by the Civil Aviation Authority of New Zealand (CAA) on a case-by-case basis. Generally, each turbine in New Zealand at either end of a line has a light, but more may be required to have lights depending on factors such as proximity to an airport and low-level flight zones. The lights are usually medium-intensity obstruction lights, and they have to be installed and operated in a way that minimises their visibility at ground level. As a result, low-intensity steady red lights are used that are directed upwards (shielded downwards) and installed on top of the nacelle. To minimise the risk of the lighting causing problems for wildlife, white lighting is not allowed.

Lit turbines can attract birds, thereby potentially increasing the risk of collision, especially in conditions of poor visibility (Winkelman 1992b). There have been large mortality events at a variety of lit structures in the USA as a result of nocturnal-migrant songbirds being disorientated by lights when forced to fly at low altitude by rain and mist (Langston & Pullan 2003; Kingsley & Whittam 2005). Erickson et al. (2001) suggested that lighting was the single most critical attractant for nocturnal migrants[2], leading to collisions with tall structures. Various explanations have been put forward for the apparent attraction of birds, especially nocturnally migrating passerines, to artificial lights (Avery et al. 1976; Verheijen 1985), though none of these has been conclusively established. Perhaps the most plausible relates to a 'trapping effect' of light rather than actual attraction (Avery et al. 1976): on entering an illuminated area, especially on a foggy night, passing migrants are reluctant to leave; on approaching the edge of the illuminated area, they are hesitant to fly into the darkness beyond, and instead fly back towards

[2] Migration refers to the regular seasonal journeys undertaken by many species of birds, often between breeding and wintering sites. It includes movements within national boundaries and between countries.

the light. Solid or blinking red lights seem to attract birds more than white strobes, which flash every 1–3 seconds (Ogden 1996; Sterner 2002). Therefore, the trapping effect could be minimised by reducing the intensity of the light to a minimum, and having the intervals between flashes as long as possible (Hotker at al. 2006; Huppop et al. 2006). It has been suggested that the hazard of lighting attracting or trapping nocturnally active birds could be reduced by shielding, but this needs to be tested to ensure that it meets the requirements of navigational safety and does not introduce an unacceptable collision risk for birds. The issue of these lights attracting or confusing nocturnally migrating birds and resulting in them colliding with turbines has been a concern for wildlife agencies, and therefore needs to be considered in detail when assessing risk.

Mass mortality of birds involving thousands during one night has occurred at some communication towers in the USA. For example, an estimated 30 000 birds representing 56 species were killed at the Eau Claire tower, Wisconsin, on the nights of 18 and 19 September 1963 (Kemper 1964). Generally, such large-scale mortality events have almost exclusively occurred at guyed and lit communication towers greater than 150–180 m (500–600 feet) in height (Avery et al. 1980; Kerlinger 2000). The number of nocturnal migrants reported dead at North American wind turbines is a small fraction of the number killed by communication towers (Kerlinger 2004). Similarly, none of the wind turbine studies in the USA listed in Erickson et al. (2002) reported large or significant numbers of nocturnal migrants colliding with wind turbines, and some reported no collisions; the reported fatality incidents mostly involved collisions of single birds. The reason so few nocturnal migrants have been found to collide with wind turbines to date compared with tall communication towers is likely related to the shorter height of wind turbines, their lack of guy wires and their minimal lighting (Avery et al. 1980; Kerlinger 2000).

2.3.3 Blade speed and motion smear

The rotor on a 1.5 MW capacity turbine turns at a speed of about 19 rpm. In contrast, smaller machines, such as the 225 kW Brooklyn turbine, turn at 40–45 rpm (Ashby 2004). To avoid damage, turbines automatically shut off when the wind reaches a speed of about 25 m/s (c. 90 km/h).

There are several reasons why birds may collide with wind turbines during conditions of good visibility, with the most obvious being that they are unable to detect the spinning blades. Two hypotheses, applying mainly to raptors, have been suggested to explain this. The first is motion smear, or motion blur, which occurs when an object moves with increasing speed, becoming progressively more blurred. This phenomenon is apparent at the tips of turbine blades because the speed at the tip is much greater than at the base of the blade, so that the eye is unable to detect the individual revolutions (although it is not clear whether this perceived problem is based on human vision or bird vision). The second hypothesis is the inability of birds to divide their attention between hunting and monitoring the horizon for obstacles. Hodos (2003) considered it likely that hunting raptors are able to focus on both the ground and the horizon, as their eyes have two foveal regions, one for frontal vision and the other for looking down. However, observations of hunting raptors by L. Barea (Department of Conservation, pers. comm. 15 February 2008) suggest that for at least some of the time birds cannot use the two fovea at the same time, as they become so focussed on the ground they are searching or prey they are pursuing that they sometimes fail to see objects in front of them, such as power lines, resulting in collisions. Therefore, although motion smear is considered by some to be the main reason birds collide with moving turbine blades during good visibility (McIsaac 2001; Hodos 2003), it is probably not the only reason.

To date, most studies of the effects of turbine blades on bird mortality have been based on older, variable-speed turbines. These turbines, which have c. 3-m-long blades, can have very high blade speeds of over 60 rpm, making motion smear an important issue. However, wind turbine technology has changed significantly, such that the c. 11-m-long blades of large turbines (> 1 MW) now rotate at a much slower speed of 15–30 rpm. Even though the tips of the 11-m blades revolve faster than those of 3-m blades, the longer blades seem to be more visible to birds (Kingsley & Whittam 2005), lessening the potential risk of collision. Nonetheless, no studies to date have examined the effect of slower blade revolution on birds (Kingsley & Whittam 2005).

All new wind energy developments should ensure that blade revolutions per minute are minimised, to avoid motion smear and promote blade visibility during the day. Laboratory research indicates that applying certain designs to turbine blades will enhance the ability of birds to see rotating blades, and thus potentially reduce fatalities (see McIsaac 2001: figure 9 for design examples).

2.4 ASSOCIATED STRUCTURES

The following structures, which may occur at wind farms, have been responsible for avian fatalities: overhead wires (power transmission and distribution lines), guy wires, lighting and uninsulated electrical equipment.

Based on fatality rates reported in other studies, Erickson et al. (2001) estimated that tens of thousands to 174 million bird fatalities occur in the USA each year due to collision with overhead wires. Several groups of birds appear to be susceptible to collision with wires, most notably waterfowl, shorebirds and raptors (Curtis 1977; Anderson 1978; Olsen & Olsen 1980). Although waterfowl and shorebirds seem to avoid turbines, as evident by the low recorded incidence of fatal collisions involving these groups of birds (Percival 2005), significant numbers have been known to collide with associated power lines, especially when located near wetlands (Anderson 1978; Moorehead & Epstein 1985, cited in Kingsley & Whittam 2005). At a power plant in Illinois, 200–400 waterfowl (0.2–0.4% of the peak number present) were killed each autumn during 1973–1975 as a result of colliding with overhead power lines (Anderson 1978). However, it is important to keep in mind the fact that impacts are site- and species-specific, and there are no data for New Zealand situations.

The maximum number of bird fatalities reported at a wind farm is a recently reported event that involved 27 birds at three turbines and a substation (Kerlinger 2003). The event occurred on a foggy night and was, in all probability, caused by four sodium vapour lamps that were mounted on the substation, which was near the middle of the turbines (Kerns & Kerlinger 2004), as once the substation lamps were turned off, no subsequent multiple fatalities occurred (Kerlinger 2003). At another wind farm, 14 fresh carcasses (all passerines) were found underneath two adjacent turbines (Johnson et al. 2002). Although carcass searches were conducted at 14-day intervals at the site, a severe thunderstorm during the night before the search was suspected to have forced the migrating birds to fly at a lower than normal altitude and into the turbines.

Although evidence from US studies suggests that nocturnal bird migration typically occurs at heights above most wind farm structures (see section 5.2.3), collisions still occur with structures less than 100 m in height (Avery et al. 1980). For example, Wylie (1977) found 73 dead birds representing 21 species at an unlit fire tower following a night of fog and rain. The 30-m tower stood on a ridge at c. 800 m a.s.l. It was considered that the inclement weather and the tower being on a ridge at high elevation contributed to the mortality, even though the tower was unlit and relatively short. This example emphasises the site- and weather-specific nature of some occurrences. Therefore, the altitude at which nocturnal migrants, such as waders, fly in New Zealand during different weather conditions needs to be determined for species of concern.

Another possible risk to birds is electrocution from perching on uninsulated equipment. For example, the 'Falcons for Grapes Project' in Marlborough released 19 young falcons (*Falco novaeseelandiae*) in vineyards of the Wairau Plain during 2005/06, of which five were electrocuted during their first few months of flight as a result of perching on uninsulated transformers (www.falconsforgrapes.org; viewed 4 September 2008). However, transformers on wind farms are large and insulated, and the conductors, which are uninsulated, are well spaced from anything that could earth them, making electrocution of a perched bird in such circumstances impossible (S. Faulkner, Connell Wagner Ltd, pers. comm. 30 January 2008).

Reducing the amount of above-ground wire at wind farms will reduce the potential risk of collision to birds in the area. However, it is not always practical to place cables underground. Furthermore, in areas where the risk of bird collision is low and where sensitive habitat exists, the placement of wires underground may cause more damage to local bird populations through habitat destruction than overhead wires would cause through collisions. Where it is unavoidable to have above-ground wires at a wind farm, bird deflectors (brightly coloured plastic balls) should be attached to wires, to alert birds to their presence. However, these will only work during the day.

2.5 LANDSCAPE FEATURES

Physical features on the landscape can strongly influence bird movement and behaviour. For example, diurnal migrants tend to follow coasts, shorelines of lakes, rivers, ridges and other linear features (Richardson 2000). During the day, peninsulas and islands can host concentrations of nocturnal migrants that have been migrating over large bodies of water, and coastal islands and headlands provide essential resting and feeding habitat during layover times for these birds. Islands of habitat (plantations) can act in a similar fashion, concentrating migrants in otherwise hostile environments, such as in open agricultural landscapes and in industrial areas. Thus, the placement of turbines close to prominent landscape features may positively or negatively influence the number of birds moving through a wind farm, particularly migrants and wetland species.

3. Weather conditions and collision fatalities

Many studies have shown that certain weather conditions (e.g. strong winds that affect the ability to control flight manoeuvrability, or reduced visibility) increase the occurrence of collisions with artificial structures, especially communication towers (Case et al. 1965; Seets & Bohlen 1977; Elkins 2004). The majority of collisions at wind farms have involved single birds (Kingsley & Whittam 2005), and even in poor weather conditions there have been very few multiple bird kills reported. The greatest mortality reported in North America on a single night was 27 birds, which occurred at the Mountaineer site in West Virginia on a foggy night, the birds being found at three turbines and a brightly lit substation (Kerlinger 2003). Another large mortality event at a North American wind farm was of 14 birds found at two adjacent turbines, which occurred during a severe thunderstorm (Erickson et al. 2001). Mortality events of such magnitude are rare phenomena, but can occur during periods of poor weather. Winkelman (1989, cited in Percival 2003; 1992a) showed that most collision fatalities at two sites in The Netherlands were found following nights with poor flight and visibility conditions.

4. Possible bird and wind turbine interactions

4.1 COLLISION FATALITIES

Direct mortality at wind farms results from birds striking revolving blades, towers, nacelles, and associated powerlines and meteorological masts. There is also evidence of birds being violently forced to the ground by turbulence behind the turbine created by the moving blades (Winkelman 1992a; Drewitt & Langston 2008).

Two wind farm areas have become synonymous with collision fatalities: Altamont Pass in California and Tarifa in southern Spain. Large numbers of raptors have collided with turbines at these sites, including substantial numbers of golden eagles (*Aquila chrysaetos*) at Altamont (Thelander et al. 2003), and griffon vultures (*Gyps fulvus*) at Tarifa (Barrios & Rodriguez 2004), both of which are long-lived species with low reproductive outputs. While the numbers of collisions per turbine at Altamont and Tarifa have been relatively low (considerably less than 1 bird per turbine per year for each), the total number of collisions has been significant, as a result of the large number of turbines (c. 7000 at Altamont and c. 700 at Tarifa). Also, and of particular importance, both sites support important food resources that attract raptors, resulting in birds of these species foraging within the collision-risk zone of turbines (Thelander et al. 2003). Thus, in both areas, the scale and siting of the wind farms are inappropriate given the species' behaviour (large soaring species with poor flight manoeuvrability), which makes them vulnerable to colliding with turbines, and their demographics, which make their populations vulnerable to small increases in mortality (Percival 2005).

Most other studies completed to date suggest low numbers of bird fatalities at wind farms (Australian Wind Energy Association 2002; Kingsley & Whittam 2005; Percival 2005). No other 'Altamont-type' problems have been reported elsewhere in North America (Erickson et al. 2001; Kingsley & Whittam 2005). Likewise, studies at upland sites in the UK have generally reported extremely low collision rates (< 0.1/turbine/year), with some finding no collisions at all (Meek et al. 1993; Percival 2005), probably reflecting the generally low bird densities present in these areas. In comparison, studies of bird collisions at coastal wind farms have generally reported higher numbers of collisions, which may reflect higher bird densities at coastal sites (Percival 2005), or greater frequency of bird movements at such sites. For example, studies at Blyth Harbour, Northumberland (Painter et al. 1999), and at Zeebrugger Harbour, Belgium (Everaert et al. 2002; Everaert & Stienen 2007), revealed collision rates greater than one bird per turbine per year, with most casualties at both sites being terns and gulls. Again, these results stress the importance of site characteristics.

Unfortunately, in many instances these numbers are likely to be underestimates, as they are often based only on found corpses, without accounting for scavenging and searcher efficiency. Several studies have indicated rapid removal of carcasses by scavengers (Langston & Pullan 2003). For example, in the USA, Kerlinger et al. (2000) found that most passerine carcasses disappeared within 3 days, but that large carcasses remained for at least 1–2 months. Search efficiency of observers was also shown to be variable, with only 25% of small birds (passerines) being found, but 75% of medium-sized carcasses (ducks) and all large carcasses (large raptors) being found (Kerlinger et al. 2000). In another study at Buffalo Ridge, USA, it was found that scavengers removed 39% of carcasses within 7 days (Osborn et al. 2000) and observers had a search efficiency of 79% in grasslands and cropped land. These and other studies highlight the potential for underestimating collision rates, particularly for passerines, and the consequent need to correct measures of collision rates for the confounding variables through experimental work (Smallwood 2007).

The following figures provide an indication of the range of collision fatalities per turbine per year from a variety of studies. Except for figures reported by the American National Wind Coordinating Committee (2004), it is not known whether these values have been corrected for scavenging rate and/or search efficiency. An estimated mean of 2.3 birds have been killed per turbine per year in parts of the USA outside California (based on 12 studies), with rates varying from 0.63 (agricultural site) to 10.00 (fragmented mountain forest site) (National Wind Coordinating Committee 2004). The number of collision fatalities in different onshore European wind farms has varied from less than one bird per turbine per year up to 125 birds per turbine per year (Langston & Pullan 2003; Percival 2005; Everaert & Stienen 2007). The results from 48 studies summarised by Percival (2005) indicated that most wind farms have resulted in less than one fatality per turbine per year: 10 studies resulted in no carcasses being found, 24 of < 0.1 fatalities/turbine/year, 7 of 0.1–1 fatalities/turbine/year, 5 of 1–10 fatalities/turbine/year, and two of > 10 fatalities/turbine/year.

Erickson et al. (2001) estimated that 33 000 birds would be killed by wind turbines in the USA in 2001 (based on an average of 2.2 fatalities/turbine/year where scavenging rate and searcher efficiency had been taken into account, and a projection of 15 000 operational turbines), 26 600 of which would be killed in California (where the Altamont Pass wind farms occur). These estimates were based on ten studies of 0.4 to 3.7 years' duration during 1988–2001. Although this may seem to be a large number of bird deaths, the impact is relatively small compared to the millions of birds that die annually due to collision with transmission lines, vehicles, buildings and communication towers. For example, it is estimated that 80 million birds are killed on US roads each year (Erickson et al. 2001, 2002). However, it should be remembered that this may be partially due to the relative scarcity of wind farms in the landscape at present compared with other structures (Evans 2004), as can be seen by breaking down mortality with other structures on a per structure basis. For example, using the numbers provided by Erickson et al. (2001), it appears that roads result in 9–12 bird deaths/km/year, buildings and windows result in 1–10 bird deaths/structure/year, and communication towers result in 50–625 bird deaths/tower/year. As wind power becomes more popular and wind farms become more abundant, collision numbers will increase. Indeed, given current documented average mortality rates of about 2 bird deaths/turbine/year, the projected impact of turbines in the USA could be in the range of 1–5 million birds per year by 2025, if large numbers of wind turbines become part of the landscape (Evans 2004). This makes proper siting imperative to help reduce bird mortality and therefore population effects.

An important issue is whether or not the collision fatalities at wind farms are sufficiently great in number to cause population declines. Even when collision rates per turbine are low, collision mortality at a wind farm may be considered high, especially when composed of hundreds or thousands of turbines (Langston & Pullan 2003). The cumulative mortality from multiple wind farms may also contribute to population declines in susceptible species, such as soaring raptors (Hunt et al. 1998). Furthermore, even relatively small increases in mortality rates may have a significant impact on some populations of birds, such as a threatened species, or a long-lived species with low annual productivity and slow maturity (Langston & Pullan 2003), such as many New Zealand waders, particularly when adults are killed.

The strongest evidence of collision mortality affecting populations comes from studies of particularly vulnerable species that are present in relatively high numbers in the vicinity of wind turbines. The most vulnerable species appear to be those highly susceptible to collision and with low productivity (e.g. large raptors, seabirds), making them less able to compensate for increased levels of adult mortality. For example, a long-term study of golden eagles at Altamont Pass, California, showed that the incidence of collision mortality had reduced productivity in the local population to the point were it had become a sink, dependent on immigration for its maintenance (Hunt & Hunt 2006). Similarly, evidence from a study of nesting terns at Zeebrugge, Belgium, estimated additional mortality of at least 1.5% for two species as a result of colliding with turbines as they returned to their nests (Everaert & Stienen 2006). Dierschke et al. (2003, cited in Drewitt & Langston 2008) suggested that such increases in mortality of greater than 0.5% could have serious population impacts.

There appear to be four main (and often interacting) factors that contribute to avian mortality at a particular wind farm site (Kingsley & Whittam 2005):

1. **Density of birds**: In general, there are more opportunities for birds to collide with turbines when there is an abundance of birds or high frequency of movements. This does not mean that high bird density or frequency of movements necessarily translates into greater bird mortality; a direct relationship between the number of birds in an area and collision rate has only been documented by one study (Everaert 2003).
2. **Bird species**: Particular species or groups of birds appear to be particularly prone to collision with structures such as wind turbines. These groups include swans and ducks (Anseriformes), raptors (Accipitridae), particularly large soaring species, owls (Strigiformes), and nocturnally migrating passerines (Thelander & Rugge 2000; Erickson et al. 2001; Langston & Pullan 2003; Stewart et al. 2004). See section 5 for further discussion.
3. **Landscape features**: Some landforms at wind farm sites, such as ridges, steep slopes, saddles and valleys, may increase the degree of interaction between turbines and birds using or moving through an area, although some debate exists around this point (Barrios & Rodriguez 2004; Smallwood & Thelander 2004; Drewitt & Langston 2008). The presence of other landforms, such as peninsulas and shorelines, can funnel diurnal bird movement, which may also affect collision rates, although this has yet to be studied. These features can combine with high bird abundance to create high collision risk.

4. **Poor weather conditions**: At many sites, collisions by nocturnal migrants tend to occur during episodes of poor weather with low visibility. Although most examples appear to be isolated incidents, weather conditions should be kept in mind if a wind farm is being proposed in an area that has a large number of poor visibility days (< 200 m visibility) during spring and autumn (periods of migration), and has other confounding factors (e.g. large numbers of nocturnal migrants and landform features such as ridges present). See section 3 for further discussion.

It is difficult to determine the potential magnitude of wind turbine-related bird fatalities at New Zealand wind farms by extrapolating from studies elsewhere, because there is no information available about the rate of collision fatalities at New Zealand wind farms where the removal of carcasses by scavengers or the efficiency of observers at locating carcasses have been quantified. Also, as far as I am aware, no studies have modelled collision risk for birds at New Zealand wind farms. Therefore, there is an urgent need for comparative data from New Zealand wind farms to determine the extent to which native species, particularly threatened species, are being killed. It is also important that the mistakes made at Altamont and Tarifa are not repeated in New Zealand, and that the characteristics of the bird populations at proposed wind farm locations are determined, and potential problem sites identified and avoided. This is crucial when planning New Zealand wind farms, given the infancy of the industry and lack of robust data from which to make predictions.

4.2 HABITAT LOSS

Wind farm development will result in habitat loss for birds (Percival 2000). Land will be taken up by turbine bases and access roads, and secondary effects, such as altered hydrology, are possible. In the UK, habitat loss or damage as a result of wind farm infrastructure is not generally perceived to be a major concern for birds outside designated sites of national and international importance for biodiversity (Percival 2005). Typically, actual habitat loss only amounts to 2–5% of the total development area (Fox et al. 2006), and careful positioning of turbine bases and routing of access roads, together with the use of proven restoration techniques, should ensure that any loss is minimised. However, the cumulative loss of or damage to sensitive habitats may be significant, especially if multiple large developments are sited at locations of high bird use. Furthermore, direct habitat loss may be additive to displacement.

The scale of habitat loss, together with the availability and quality of other suitable habitats that can accommodate displaced birds, and the conservation status of those birds, will determine whether or not there is an adverse impact on populations (Anon. 2006). The possibility that wintering birds might habituate to wind farm structures has been suggested (Langston & Pullan 2003), but there is little evidence and few studies of long enough duration to show this (Stewart et al. 2004; Drewitt & Langston 2006). Differences in behaviour between residents and migrants have been observed in some studies (Kingsley & Whittam 2005; Drewitt & Langston 2006), but not in others (Langston & Pullan 2003; Percival 2005). Unfortunately, very few conclusive studies are available because most lack well-designed procedures incorporating observations both before and after construction (e.g. Ketzenberg et al. 2002). Furthermore, very few studies have taken into account differences between diurnal and nocturnal behaviour, only assessing daytime activity (Anon. 2006). This is inadequate for those species, including many in New Zealand, that are active at night, and which may behave quite differently at night compared with by day.

4.3 DISTURBANCE AND DISPLACEMENT

Although collision rates have been the primary focus of research and monitoring in North America, the effects of disturbance may have a greater impact on birds (Stewart et al. 2004; Kingsley & Whittam 2005), and yet this is the least studied aspect of wind farm impacts on birds. Behavioural research on disturbance impacts is lacking for some bird groups. However, the available information suggests that some groups of birds (e.g. seaducks) may be more sensitive to disturbance from wind farms than others (Percival 2005; Drewitt & Langston 2006).

Disturbance and displacement may arise from increased activity by people at a wind farm during construction and maintenance, as well as from improved road access as a result of the wind farm development, especially in areas where there was little human activity before the wind farm existed. Roads may also improve access for predators of ground-dwelling or ground-nesting birds, such as wandering dogs (*Canis lupus*), possums (*Trichosurus vulpecula*) and hedgehogs (*Erinaceus europaeus*). The presence and noise of turbines may deter birds from using an area close to these.

Some studies appear to show little or no behavioural impact of wind turbines on various bird species. In some cases, this apparent lack of evidence may be an artefact of such things as the type and intensity of monitoring. However, in Britain the majority of recent studies have also found no disturbance effects (Percival 2000, 2005) and there is an increasing body of evidence that wind farms generally do not affect bird distribution. For example, no significant adverse effect was reported on birds breeding in upland sites at Bryn Tytli, Carno or Cemmaes in Wales, at Ovenden Moor in the south Pennines, or at Windy Standard in southwest Scotland (Percival 2000). The Ovenden study showed how useful longer term monitoring programmes can be, as the 23-turbine wind farm was constructed following 2 years of breeding-bird surveys that had shown that the site held good numbers of upland birds, particularly golden plover (*Pluvialis apricaria*). The wind farm was constructed in 1993 and further surveys were carried out in 1995 and again in 1997, to determine the effects on these birds and their populations. Whilst numbers in a nearby control area remained constant, numbers at Ovenden actually increased (Percival 2000). The distribution of the birds suggested that they were unaffected by the wind farm; there was no significant difference in distribution pattern in relation to the turbine positions, and no evidence of any disturbance zone. Similarly, Thomas (1999, cited in Percival 2005), who surveyed breeding birds at ten wind farms in England and Wales, found no significant disturbance effects on any species, including curlew (*Numenius arquata*), lapwing (*Vanellus vanellus*), meadow pipit (*Anthus pratensis*) and skylark (*Alauda arvensis*).

In other studies, a reduction in bird numbers has been reported as far as 600 m from turbines outside the breeding season, and up to 300 m from turbines during the breeding season (Percival 2005). Such variation was found during two studies on the barnacle goose (*Branta leucopsis*) population. The first study, which was carried out on the birds' spring staging grounds in Sweden, where they fed in close proximity to wind turbines (to within 25 m), found no significant disturbance effect (Percival 1998). However, the second study of the same population on their wintering grounds in Germany found that few geese fed within 350 m of turbines, and there was a reduction in numbers up to 600 m from the turbines (Kowallik & Borbach-Jaene 2001). The most likely explanation for such different results is that geese avoid turbines when there is easy access to alternative feeding habitat, but will be less selective when resources are limited (Percival 2005). Similar results of birds becoming more tolerant of disturbance as resources become scarcer have been found in other studies of disturbance of wintering waterfowl (Percival 1993), and studies to date have shown that substantial displacement by wind turbines seems to have occurred primarily in farmland habitats, where there would typically be alternative feeding areas within easy reach (Percival 2005). Other results suggest that disturbance can lead to reduced breeding productivity (Madsen 1995), reduced survival or a reduction in available habitat (Woodfield & Langston 2004, cited in Percival 2005), so disturbance may be significant for some species in certain situations.

Studies of birds' responses to turbines at night, using thermal and passive imaging equipment plus radar, revealed that more flight reactions occurred with headwinds (87%) than with tailwinds (29%) (Winkelman 1992b). Winkelman's (1992b) observations in daylight indicated that over 75% of all reactions took place within 100 m of the turbines, with ducks reacting at the greatest distance and passerines reacting closest to wind turbines. Flights were mainly at the height of turbines (up to 50 m) at sunrise during dispersal from nocturnal roosts to feeding areas, at the end of nocturnal and start of diurnal migrations and, to some extent, at sunset as flights to roost and nocturnal migration started (Winkelman 1995). In comparison, observed flight reactions to wind turbines in Schleswig-Holstein, Germany, indicated that waders, terns and waterfowl reacted 200–500 m from the turbines, whereas gulls reacted at a distance of 100–150 m (Koop 1997). Gulls and waders increased their flight height or changed direction to fly over or around turbines, whilst waterfowl manoeuvred to fly between turbines. Observations of diurnal flight behaviour by gulls and common terns (*Sterna hirundo*) at two sites found that they flew between the turbines to and from their breeding colonies and marine feeding areas (van den Bergh et al. 2002; Everaert 2003). Breeding adults tend to fly much closer to structures when making frequent flights to feed chicks than at other times, and they may sustain collisions as a consequence (Everaert 2003; Everaert & Stienen 2007).

Relatively long lines of turbines or large wind farms can become important barriers to the local or seasonal movements of birds (Langston & Pullan 2003). The effect of birds altering their local flight paths or migration routes to avoid a wind farm is a form of displacement. This effect is of concern because it may result in increased energy expenditure when birds have to fly further to avoid a large array of turbines, and it may disrupt linkages between distant feeding, roosting, moulting and breeding areas (Drewitt & Langston 2006). The magnitude of the effect will depend on species, type of bird movement, flight height, distance between rows of turbines, layout and operational status of turbines, time of day, and wind force and direction. The impact can range from a slight 'check' in flight direction, height or speed, through to significant diversions that may reduce the numbers of birds using areas beyond the wind farm (Drewitt & Langston 2006).

Several studies have shown that some species alter their route to avoid flying through wind farms, e.g. tufted duck (*Aythya fuligula*) and common pochard (*Aythya ferina*) at Lely in The Netherlands (Dirksen et al. 1998). While this may reduce collision risk, it could result in the wind farm acting as a barrier to bird movements. However, such effects are not universal; for example, at Zeebrugge, large numbers of birds regularly fly through a wind farm without diverting around it (Everaert et al. 2002), and van der Bergh et al. (2002) and Everaert & Stienen (2007) concluded that a line of turbines did not act as a barrier to the daily flight paths of breeding gulls and terns. In contrast, studies of bird movements in response to offshore developments have recorded waterfowl taking avoidance action between 100 m and 3000 m from turbines (Christensen et al. 2004; Kahlert et al. 2004a, b). These findings highlight the species- and site-specific nature of wind farm impacts on birds.

Some birds will fly between turbine rows, as seen with common eider (*Somateria mollissima*) at Nysted, where the turbines were 480 m apart (Kahlert et al. 2004b). However, their ability to do so will depend on the distance between turbines. Although evidence for this type of response is limited, these observations have implications for wind farm design. Generally, spacing between turbines at onshore wind farms is recommended to be a minimum of 200 m apart to avoid inhibiting bird movements (Percival 2001). This recommended distance is often the minimum spacing required by industry to reduce wake effects of large turbines on neighbouring turbines (Kingsley & Whittam 2005).

For a small wind farm (< 10 turbines), the ecological consequences of any barrier are unlikely to be a problem, with minimal diversion distances involved. For larger sites, however, the barrier effect has the potential to be more important. Thus, it is important to consider new wind farm proposals on a case-by-case basis, and to assess the patterns of resource availability and the potential loss through disturbance for each. However, it should be noted that a review of the literature suggests that none of the barrier effects identified so far have had significant impacts on populations (Drewitt & Langston 2006).

5. Observed impacts of wind farms on various groups of birds

5.1 HABITAT GROUPINGS

The following is a review of the impacts of wind farms on various groups of birds, largely in relation to the main habitat type they occupy. For each group, findings from other countries are related back to the New Zealand situation, particularly where relevant to a New Zealand species.

5.1.1 Waterbirds

Waterbirds include species that are typical of terrestrial wetland habitats, including ponds, lakes and rivers. This category excludes seabirds, waterfowl and shorebirds, which are discussed separately. Waterbirds of New Zealand include grebes, shags, herons, egrets, rails, gulls and terns.

There have been few reports of waterbird fatalities resulting from collision impacts at wind farms, but in many cases the methods used to detect them have been imprecise (see section 4.1). Gulls and terns have been identified as being especially vulnerable to mortality due to wind turbines because they often fly within the height of the rotor sweep zone (Langston & Pullan 2003). However, despite their perceived vulnerability, very low numbers of gulls and terns have been reported as colliding with turbines, with the exception of three sites in Belgium (Everaert 2003; Everaert & Stienen 2007). At one of these sites, Zeebrugge, Everaert & Stienen (2007) calculated that the mean number of collision fatalities (mainly gulls and terns) per turbine per year in 2004 and 2005 was 20.9 and 19.1 birds, respectively, after taking into account the number of dead birds found under turbines and the correction factors for available search area, search efficiency and scavenging.

There is little information available regarding the behavioural impacts of turbines sited near wetlands on waterbirds. Wind farms could have a marked negative impact on waterbirds where a significant proportion of a local resource, such as nesting or foraging habitat, is no longer available because turbines were placed on or too close to it (Percival 2001). Some species feed close to their breeding colonies, while others may forage some distance away (shags, gulls, terns). More research is needed to examine the potential effects of disturbance caused by wind turbines on waterbirds, particularly colonial nesting waterbirds.

The black shag (*Phalacrocorax carbo*) and cattle egret (*Bubulcus ibis*) are the only species of waterbirds occurring in New Zealand that were listed by Kingsley & Whittam (2005) as having been found fatally injured after colliding with a wind turbine. However, Kingsley & Whittam (2005) did list representatives from several genera that are represented in New Zealand: *Larus* (gulls), *Sterna* (terns), *Ardea* (herons) and *Nycticorax* (night heron). Three such waterbird species occasionally forage over pasture near wetlands and are threatened (Hitchmough et al. 2007): the red-billed gull (*Larus novaehollandiae*) (gradual decline), black-billed gull (*Larus bulleri*) (serious decline), and black-fronted tern (*Sterna albostriata*) (nationally endangered). Therefore, any wind farms sited in pastureland that may have deleterious impacts on the populations of these three species would be of concern.

5.1.2 Seabirds (order Procellariiformes)

I have not found any records of Procellariiformes being killed as a result of collision with wind turbines, or offshore wind farms resulting in their displacement. This probably reflects both the fact that in the Northern Hemisphere, where most wind farms occur, there is little overlap in the distribution of such seabirds and wind farms, and the difficulty of locating seabirds killed by collision at offshore wind farms. Even so, Procellariiformes, particularly the larger species, may be just as vulnerable to turbine collision fatalities as soaring raptors, because these seabirds are adapted to sustained high-speed flight with slow manoeuvrability in unobstructed environments. In addition, many have delayed maturity and low productivity, making their populations sensitive to increased mortality.

I am not aware of any applications to develop offshore wind farms about New Zealand. However, there have been applications and investigations for the establishment of wind farms at coastal sites (see Appendix 1). A few colonies of Procellariiformes remain on the main islands of New Zealand. Most occur on headlands or coastal cliffs, e.g. royal albatross (*Diomedea epomophora*) at Taiaroa Head near Dunedin; small colonies of the sooty shearwater (*Puffinus griseus*) on Banks Peninsula, Cape Wanbrow near Oamaru, and headlands along the Otago coast and west coast of the South Island; and small colonies of the grey-faced petrel (*Pterodroma macroptera*) on scattered headlands of the northern North Island as far south as New Plymouth on the west coast and Gisborne on the east coast. Birds from these coastal colonies are unlikely to be impacted by wind farms unless turbines are erected within a kilometre or so of their colonies. Two species fly some distance inland to their colonies: the nationally endangered Hutton's shearwater (*Puffinus huttoni*), which flies to the Seaward Kaikoura Range, and the range restricted Westland Petrel (*Procellaria westlandica*), which flies to the coastal foothills of the Paparoa Range. Obviously, any turbines erected in the flight paths of these two species, both of which have restricted colony distributions, would be highly likely to result in collision fatalities. In addition, both species fly to and from their colonies at night, particularly around dusk and dawn. It has been found that nocturnal seabirds, especially fledglings, can become disorientated, especially during periods of fog, and are then prone to being attracted to artificial lights, such as street lights. Thus, lighting on turbines would increase the risk of collision for these nocturnally active seabirds if wind farms were sited near their colonies or on routes between the sea and their colonies.

5.1.3 Waterfowl

The effects of wind turbines on waterfowl (e.g. ducks, shelducks, geese and swans) have been examined at a few wind farms, particularly in Europe. Even though waterfowl are regarded as prone to collision with turbines (Langston & Pullan 2003), the presence of large numbers of waterfowl near wind farms does not necessarily mean that large numbers of fatalities will eventuate (Erickson et al. 2002; Kingsley & Whittam 2005). In some cases, seaducks are believed to have learned to avoid turbines, resulting in fewer collisions over time (Percival 2001). Sites in the USA with year-round waterfowl use reported the most fatalities of dabbling ducks (Anatinae) (Erickson et al. 2002), and at these sites waterfowl made up 10–20% of all fatalities (Erickson et al. 2002). However, numbers of fatalities were still low, especially in relation to the number of ducks that used the areas. Moorehead & Epstein (1985, cited in Kingsley & Whittam 2005) identified large wetland birds, such as geese and cranes, as being especially susceptible to collisions with wind farm installations. They emphasised that collision potential varied with a number of factors (weather, terrain, turbine placement, and rotor design and speed), and identified the provision of visual cues and the selection of sites outside critical areas among their recommended mitigation measures.

Disturbance is an important factor to consider when siting a wind farm near significant waterfowl areas. The most comprehensive study of the effect of wind turbines on waterfowl took place in Denmark and involved a modern, 10-turbine offshore facility in an area where large numbers of common eider (*Somateria mollissima*) and black scoter (*Melanitta nigra*) fed. It was found that these diving ducks exhibited avoidance behaviour towards the turbines, which was accentuated in poor weather (Guillemette et al. 1999; Tulp et al. 1999). Eiders generally avoided flying or landing within 100 m of the turbines, and avoided flying between turbines that were spaced less than 200 m apart, preferring to fly around the outer turbines. Similarly, two diving duck species, common pochard and tufted duck, were tracked at night using radar and were found to avoid flying near turbines, passing around the outer turbines instead (Larsson 1994; Dirksen et al. 1998). In a meta-analysis of 19 studies into the effects of wind farms on bird abundance, Stewart et al. (2004) found that wind farms seemed to reduce the abundance of many bird species and that Anseriformes (swans, geese, ducks) experienced greater declines than other bird groups, suggesting that a precautionary approach should be adopted to wind farm developments near aggregations of Anseriformes.

The observations of avoidance behaviour are not restricted to studies at offshore wind farms. In the Yukon, a single turbine was placed at the edge of a river valley, past which large numbers of waterfowl migrated. No collisions were recorded, but the birds avoided flying close to the turbine (Mossop 1998). Amongst waterfowl, reactions to onshore wind turbines appear to be species-specific, with even closely related species showing very different reactions. For example, pink-footed geese (*Anser brachyrhynchus*) were reluctant to forage within c. 100 m of turbines in Denmark (Larsen & Madsen 2000), whereas barnacle geese (*Branta leucopsis*) in Sweden foraged to within 25 m of the structures (Percival 2005).

The Canada goose (*Branta canadensis*), domestic goose (*Anser anser*), mallard (*Anas platyrhynchos*) and mute swan (*Cygnus olor*) are waterfowl species that occur in New Zealand and were listed by Kingsley & Whittam (2005) as having been found fatally injured after colliding with wind turbines. In addition, the following genera are represented in the mortality list of Kingsley & Whittam (2005), all of which have members in New Zealand: *Podiceps* (Australasian crested grebe *P. cristatus*), *Tadorna* (paradise shelduck *T. variegata*) and *Aythya* (New Zealand scaup *A. novaeseelandiae*).

5.1.4 Shorebirds

In North America, observed mortality of shorebirds (waders) at wind farms has been low (Kingsley & Whittam 2005), possibly because few sites are located in shorebird habitat. In contrast, Stewart et al. (2004) found that wind farms can have a negative impact on the abundance of shorebirds, and advocated a precautionary approach to wind farm development at coastal sites where aggregations of shorebirds occur. This result was derived from a meta-analysis of six studies: two in the USA, and one each in Germany, The Netherlands, Scotland and England.

Each species of shorebird appears to have a different threshold to disturbance. For example, at Blyth Harbour wind farm in the UK, purple sandpipers (*Calidris maritima*) did not seem to be disturbed by either the construction process or the operation of wind turbines (Lowther 2000). In contrast, studies in The Netherlands and Denmark examining the effect of turbines near important staging areas for many shorebird species found that the birds avoided the turbines and were at a relatively low risk of collision (Pedersen & Poulson 1991, cited in Drewitt & Langston 2006; Dirksen et al. 1998). Some studies have shown that shorebirds avoid turbines up to 500 m away (Winkelman 1995), while others have shown no significant effect on shorebird distribution (Thomas 1999, cited in Percival 2005). It is not known whether this inconsistency in behaviour between species is related to the abundance and proximity of alternative suitable habitat: a species may be more likely to move away from turbines if there is ample suitable habitat nearby.

The pied oystercatcher (*Haematopus ostralegus*) is the only shorebird species that occurs in New Zealand that was listed by Kingsley & Whittam (2005) as having been found fatally injured after colliding with wind turbines. Other genera that are represented in the mortality lists and have representatives in New Zealand are *Charadrius* (dotterels) and *Pluvialis* (plovers). Many endemic and native shorebirds occur in New Zealand. Given the threatened status of some endemic species (Hitchmough et al. 2007) and our lack of knowledge about their vulnerability to wind farm developments, a precautionary approach should be taken when considering any wind farm developments in shorebird habitats and along their migration routes.

5.1.5 Diurnal raptors

Collision has been the focus of raptor studies at wind farms, due to the high collision rates observed at a small number of sites. One study at Altamont, California, USA, which involved observations and carcass searches over six seasons and covered c. 16% of the 7000 turbines, found 183 dead birds (0.05 birds per turbine per year), 65% of which were raptors (Orloff & Flannery 1992). Of these deaths, 55% were attributed to turbine collisions, 8% to electrocution and 11% to wire collision; for 26%, the cause of death could not be determined (Orloff & Flannery 1992). There has also been significant raptor mortality at Tarifa, Spain (0.34 birds per turbine per year) (Percival 2003). This site is near the Strait of Gibraltar, and forms a bottleneck that concentrates bird migration between Europe and Africa in the Mediterranean basin; at least 30 000 raptors and large numbers of storks pass through the area each autumn (Marti 1995). There are several wind farms in the area, with a total of

268 older-style turbines (lattice tower, with a relatively fast rotor speed) in operation (Marti 1995). Many bird collisions with the turbines have been recorded, including an estimated 106 deaths in a single year, most of which occurred on days with high visibility (Marti & Barrios 1995, cited in Kingsley & Whittam 2005). However, a subsequent study at a different wind farm at Tarifa resulted in only two carcasses being found over 14 months, suggesting that death rates can vary with year and wind farm (Janss 2000).

Very few raptor fatalities have been reported at other sites. In parts of the USA outside California, raptors comprised only 2.7% of turbine-related deaths (Erickson et al. 2001; Kerlinger 2001). However, even though this percentage seems small, an increase in mortality of greater than 0.5% could have a serious impact on a population of long-lived raptors with low productivity (Dierschke et al. 2003, cited in Drewitt & Langston 2008).

The most important factor that influences raptor collision rate appears to be topography, in particular elevation and the presence of ridges and slopes (Anderson et al. 2000; Morrison et al. 2007). The low numbers of raptor fatalities observed at the majority of wind farms is most likely due to improved siting of turbines, away from problem topography and high raptor concentrations. It has been speculated that the construction of tubular (as opposed to the lattice type) towers and slower rotor speeds may also have helped to lower raptor fatalities, but no studies to date have shown a significant relationship between mortality levels and turbine type (Anderson et al. 2000). Percival (2003) considered that the high mortality at Altamont and Tarifa resulted from a combination of sensitive species (soaring raptors) flying through the area in large numbers (important feeding areas and migration route, respectively), and turbine layout (hundreds in densely packed formation) and design (lattice towers attractive to raptors as perches).

There is no information available on how raptors react behaviourally to turbines (Kingsley & Whittam 2005).

Although no raptor species that occur in New Zealand are represented in the mortality list of Kingsley & Whittam (2005), the genera *Circus* and *Falco* are present in the list, both of which have representatives in New Zealand (Australasian harrier *C. approximans* and New Zealand falcon *F. novaeseelandiae*). Species of nocturnal raptors (owls) are also represented in the list of birds reported to have collided with wind turbines (Kingsley & Whittam 2005).

5.1.6 Landbirds

Amongst the landbirds, passerines are the group most commonly affected by wind farms in parts of North America outside California. Protected passerines comprise 78% of all fatalities documented at wind farms in the USA (Erickson et al. 2001). This proportion would be even greater if it included unprotected species, such as the starling (*Sturnus vulgaris*) and house sparrow (*Passer domesticus*). Grassland bird species with aerial courtship displays, such as the horned lark (*Eremophila alpestris*), appear to be particularly prone to collisions with turbines, as they fly high enough when displaying to collide with turbines (Kerlinger & Dowdell 2003). However, during migration most passerines fly at night and at an altitude in good weather (1000–1500 m; Alerstam 1990) that takes them well above turbine height.

The greatest threat from wind farms to migrant passerines in North America was found to be habitat loss (Kingsley & Whittam 2005). In contrast, the impact of turbines on forest-nesting passerines was found to be low, with several nesting in the forest within 20–30 m of the turbines, although a few species were found to avoid clearings where turbines were located, and some appeared to move further into the forest (Kerlinger 2003). However, since there has only been one study to date into the effect of wind turbines on forest-nesting birds, more studies are needed to understand these effects.

Turbines may displace some grassland species of landbirds. Leddy et al. (1999) found that there were fewer nesting grassland birds within 100–200 m of turbines than beyond, and densities decreased by more than 50% within c. 50 m of turbines. In contrast, Devereux et al. (2008) found that the distribution of four functional groups of wintering farmland birds (granivores, corvids, gamebirds and the skylark *Alauda arvensis*) was unaffected by turbines in East Anglia, England (in 150-m-wide blocks), at distances ranging from 0 m to 750 m. They also measured occurrence in areas 0–75 m and 75–150 m from the turbines, and found no evidence that the four functional groups of farmland birds avoided areas close to turbines.

Gamebirds (pheasants and quail in New Zealand), which are a subset of the landbirds group, are vulnerable to habitat destruction and fragmentation, and disturbance of local breeding populations as a result of human-induced changes in the landscape, such as wind farm developments (see Kingsley & Whittam 2005). In North America, much of the remaining suitable habitat for gamebird species is located in remote areas or where topography makes agriculture difficult. Some of these sites may be suitable for wind farms, and so turbines and associated structures could adversely affect sensitive and vulnerable gamebird species (Kingsley & Whittam 2005). In agreement with this conclusion is the finding of Devereux et al. (2008) that the distribution of the pheasant (*Phasianus colchicus*) was negatively effected by turbines. S.M. Percival (Ecology Consulting, pers. comm., 5 March 2008) considered that there is a low risk of gamebirds colliding with turbine towers.

The feral pigeon (*Columba livia*), rook (*Corvus frugilegus*), skylark (*Alauda arvensis*), blackbird (*Turdus merula*), song thrush (*Turdus philomelos*), starling, chaffinch (*Fringilla coelebs*), greenfinch (*Carduelis chloris*) and house sparrow are landbird species that occur in New Zealand and were listed by Kingsley & Whittam (2005) as having been found fatally injured after colliding with wind turbines. In addition, the genera *Hirundo* and *Anthus* are represented in their mortality list, both of which have representative species in New Zealand (welcome swallow *H. tahitica* and New Zealand pipit *A. novaeseelandiae*). Most species mentioned above are introduced and none are threatened.

The California quail (*Callipepla californica*), chukor (*Alectoris chukar*) and pheasant (*Phasianus colchicus*) are gamebird species that occur in New Zealand and were listed by Kingsley & Whittam (2005) as having been found fatally injured after collision with wind turbines. All of these gamebirds were introduced to New Zealand, and all except the chukor are widely distributed (Heather & Robertson 2005).

5.2 SEASONAL GROUPS

5.2.1 Breeding birds

In general, birds breeding near wind turbines have been reported to have lower collision rates than non-residents (Kingsley & Whittam 2005). In part, this is probably because local birds become familiar with turbines, whereas individuals passing through the area would not have that familiarity and may be unable to detect turbines before a collision occurs if weather conditions are poor, e.g. during fog. However, wind farms are likely to have a greater impact on breeding birds as a result of habitat loss, obstruction of regular flight paths, disturbance by people servicing turbines and obstruction to important feeding areas (particularly important in coastal areas).

Bird productivity (breeding success) does not appear to be negatively affected at many wind farms. For example, in one study, mean productivity at a 66-turbine site, was the same as in surrounding areas (Guyonne & Clave 2000, cited in Kingsley & Whittam 2005). However, few such studies have been carried out (Kingsley & Whittam 2005).

Reduced breeding bird populations were noted at a few wind farms where breeding habitat was destroyed during installation of turbines, and where people and vehicles were continuously present in the area (Percival et al. 1999, cited in Percival 2000). It has also been found that many grassland birds avoid nesting within 100–200 m of turbines (Leddy et al. 1999). Ketzenberg et al. (2002) investigated the breeding densities and spatial distribution of the common skylark (*Alauda arvensis*) and some species of breeding waders (Eurasian oystercatcher *Haematopus ostralegus*, northern lapwing *Vanellus vanellus*, common redshank *Tringa totanus* and black-tailed godwit *Limosa limosa*) before and after installation of wind farms in four coastal areas in Lower Saxony, Germany. They found no consistent pattern in the change in number of breeding pairs following construction, with some decreases but also some increases: for some species of waders, the numbers increased near wind turbines because of the change in farming practice post-construction, emphasising the need to consider other changes contemporary with wind farm development. Similarly, there was no significant difference in numbers of breeding pairs of ducks (Anatinae), waders (Charadriiformes), Arctic skua (*Stercorarius parasiticus*), gulls (Laridae) and small passerines between the year of installation of a 3-turbine cluster and the subsequent 8 years at Burgar Hill, Orkney Islands (Meek et al. 1993).

Many seabirds, including coastal species such as gulls and terns, are readily disturbed by the activities of people near their breeding colonies, so that the presence of turbines may cause the abandonment of a site. Although I am not aware of studies that support this suggestion, it is of note that English Nature (the UK government agency that promoted the conservation of wildlife until 2006, when it was integrated into Natural England) recommended that turbines should not be located within 20 km of sensitive or important colonies of seabirds (e.g. albatrosses, petrels, shearwaters), and should not be within 1 km of sensitive or important gull or tern colonies (Percival 2001).

5.2.2 Wintering birds

The numbers and movements of sedentary species remain much the same year round, particularly for most forest-dwelling and open-country species. However, physical or biological factors, such as localised habitat and/or food supplies, may act to concentrate birds such as waterfowl and shorebirds. Thus, depending on the site of a wind farm, bird densities in the vicinity may remain much the same, increase or decrease during winter. For example, studies at Urk, The Netherlands, found reductions in density within a wind farm area in winter for four duck species (mallard *Anas platyrhynchos*, tufted duck *Aythya fuligula*, common pochard *A. farina* and common goldeneye *Bucephala clangula*), which extended to 300 m away from the farm (Winkelman 1989, cited in Percival 2003). In contrast, there was little or no effect on great-crested grebe (*Podiceps cristatus*), Eurasian coot (*Fulica atra*) or common gull (*Larus canus*), and increased numbers of black-headed gulls (*Larus ridibundus*) and greater scaup (*Aythya marila*). At Blyth Harbour wind farm, UK, great cormorants (*Phalacrocorax carbo*) were temporarily displaced from their roost during construction, but returned once the farm was operational. Numbers of great cormorants, common eiders (*Somateria mollissima*), purple sandpipers and gulls were comparable before and after construction (Still et al. 1995, cited in Langston & Pullan 2003). This wind farm is sited in a commercial harbour and comprises nine turbines built at 200-m intervals along the estuary's breakwater. The harbour is a Site of Special Scientific Interest because it hosts a large winter roost of the purple sandpiper, and the estuary it protects adjoins a Ramsar site.

Wind farm layout can also affect avoidance behaviour. For example, for pink-footed geese, the avoidance distance was c. 100 m for lines of turbines, compared with c. 200 m for clusters of turbines, and geese did not enter the area between turbines arranged in a cluster (Larsen & Madsen 2000).

5.2.3 Migrating birds

Although long-distance movements of birds can occur in any month, the periods of peak migration in New Zealand occur in spring, summer and autumn (Dowding & Moore 2006; Williams et al. 2006). Different species, and possibly different age and sex categories of the same species, migrate through the same area during different periods. Migration can also occur in winter, e.g. northward movements following unusually severe southerly storms that bring snow to sea level. In summer, there can also be movements of subadult birds or failed breeders from nesting areas to staging areas (coastal sites), or to wintering sites further north. Thus, the pattern and timing of migration can be highly unpredictable (Kingsley & Whittam 2005). The broader the spatial and temporal scale, the more predictable migration movements appear, but with regard to a particular local area on a given day, it is very difficult to predict whether migrants will be present (Mabey 2004).

Meteorological conditions can have a large influence on the numbers of birds involved in migration. In Canada, numbers of birds migrating have been shown to vary 10-fold or even 100-fold from one day or night to the next, depending largely on weather (Richardson 2000). A bird may migrate several hundred kilometres in a day or night when the weather is favourable, and then may not migrate for several days when the weather is poor (Richardson 2000). Migrant numbers appear to be greater at times with (or following) light tail winds than when winds are strongly opposing. Such winds allow birds to travel a given distance more quickly and with less energy expenditure than would be required while flying into a headwind (Richardson 2000). There is also a close interaction between migration and other weather variables such as temperature, humidity and pressure, and it is not well established which specific variables cue birds to migrate rather than remain on the ground (Richardson 2000).

In the case of migrants, flights once underway tend to be at high altitude, well above turbine height, to maximise flight and energy efficiency. Birds wait for suitable conditions before embarking on migration, but may be forced to lower their flight altitude if they encounter bad weather during migration (Newton 2007). Therefore, migrants are at risk of collision with wind farms mainly during takeoff and descent, when their flight paths take them through the height range of the rotor-sweep zone (Drewitt & Langston 2008).

Many collisions reported at wind farms in North America involve migrating birds. For example, Johnson et al. (2002) noted that 71% of carcasses were migrants. Sites in different regions differ in the magnitude of bird migration and the influences on this migration. For example, in western North America, there is little evidence that tall human-made structures kill large numbers of night-migrating birds (Evans 2003), whereas this is a well-documented phenomenon in eastern North America. The reason for this regional difference is unclear, although it may be due to lower densities of nocturnal migrants in the west, or differing meteorological conditions leading to different avian behaviour. Whatever the reason, this is an important point that must be considered when comparing mortality studies from sites outside the general area of a proposed wind farm.

Inclement weather can increase the risk of migrant collision with wind farm structures. For example, a cloud ceiling that drops to near or below the height of turbines will affect high-altitude migration, inducing migrants to move at or below treetop level, and therefore increasing the probability of collisions with tall obstacles (Robbins 2002; Langston & Pullan 2003; Kingsley & Whittam 2005). Drizzle and fog impair visibility, and cause birds to fly at lower altitudes and follow topographical cues. The combination of such weather with lighting at wind farms may attract migrating birds, and so increase the collision rate. Thus, if there is a high proportion of foggy days during a period of migration at a proposed wind farm site that is on a migration route, there is likely to be an increased risk of collision.

Wind farms situated on prominent landforms can also represent greater potential risks to migrating birds. Features that rise abruptly in the landscape, such as high ridges and mountains, can influence bird movements, and if wind farms are sited at high elevations, turbines may end up at a height that enters the altitudinal strata typically used by migrants. For example, the turbine rotor sweep zone of 100-m towers located on a ridge 200 m above the surrounding landscape are effectively 300 m in the air and at an altitude where nocturnal migrants may be flying (Kingsley & Whittam 2005).

Diurnal migrants

Some groups of birds, e.g. raptors, are principally diurnal migrants (Kingsley & Whittam 2005). Diurnal migrants that use thermals (rising warm air caused by the sun heating the earth) to reach their preferred altitude do so to facilitate soaring and conserve energy. As a result, the number of such migrants tends to decline in the late morning and through the afternoon. Diurnal migrants can be more constrained by topographical features than nocturnal migrants, and tend to concentrate along linear features, such as coastlines, rivers, ridges and valleys (Richardson 2000). Birds will often divert by as much as 45° from their preferred course in order to fly along such a 'leading line' (Richardson 2000). The greatest concentration of birds often occurs at these features when there is a crosswind relative to that feature. Therefore, the placement of wind farms on such topographical features may result in interactions with diurnal migrants.

Nocturnal migrants

Many bird species migrate at night (e.g. grebes, ducks, rails, waders, cuckoos). There are three main reasons why birds flying at night collide with wind turbines, and these are often inter-related: height of the structure (and the landform it is located on), lighting and weather (Kingsley & Whittam 2005) (see sections 2.3.2 and 3). The flight heights of nocturnal migrants are quite variable and not well understood, even in North America and Europe (Kingsley & Whittam 2005). According to Kerlinger (1995, 2000), the majority of migrants fly between 90 m and 900 m a.g.l. (above ground level), with small numbers flying above 1500 m a.g.l., and few below 150–180 m a.g.l., except during landing and takeoff. Able (1999) stated that most nocturnal migrant songbirds usually flew below 600 m when over land. Cooper (2004) found that 16% of migrants flew at or below turbine height (< 125 m), with most passing at 250–750 m. Similarly, Richardson (2000) believed that most nocturnal migrants flew well above turbine height (50–1000 m a.g.l.). These data suggest that only a small percentage of nocturnal migrants passing over a wind farm with tall turbines (150 m) would fly within the rotor sweep zone. However, migration altitudes are affected by weather, with birds tending to fly lower when heading into opposing winds than when flying with tailwinds. Therefore, numbers of migrating birds flying at turbine height may be as great or even greater when winds are opposing than when they are following, even though total numbers aloft tend to be much reduced with opposing winds (Kingsley & Whittam 2005). Poor weather (cloud and rain) increases the effect of lighting and also lowers the flight altitude of migrants, so that greater numbers fly at turbine height.

Many UK and North American nocturnal migrants continue to migrate for at least part of the day, but do so at lower altitudes, tending to stay within 20–30 m of the ground (within or near vegetation) to avoid predation (Kingsley & Whittam 2005). On a typical day during migration, birds move between higher and lower altitudes at dawn and dusk, and it is during these times that birds may be at risk of colliding with wind farm structures (Richardson 2000; Langston & Pullan 2003). At daybreak, or just before it, nocturnal migrants drop rapidly from higher altitudes (> 200 m) and fly at or above treetop level (< 200 m) until they find a suitable location for landing, features of which will depend on the conditions and the requirements of the individual birds (Kerlinger 1995).

There appears to have been only one comprehensive study calculating the collision risk for nocturnal migrant birds (Winkelman 1992a). This was performed in The Netherlands, and collision risk was calculated by means of observed collisions (using thermal image intensifiers). The results showed a high nocturnal collision probability, with 1 in 40 (2.5%) birds passing at rotor height. Daily searches for collision fatalities during the migration periods, together with systematic field observations of passing birds, could lead to a better picture of the behaviour and collision risk of birds (Everaert & Stienen 2007). The use of night vision devices and/or radar, and thermal image intensifiers are regarded as necessities (Everaert & Stienen 2007).

Staging areas

Some types of migrants, such as shorebirds and waterfowl, flock at restricted areas of suitable habitat while resting and feeding between migratory flights. These 'staging areas' are often lakes, marshes, estuaries, mud flats or other areas that can provide food and/or shelter for large numbers of birds (Richardson 2000). Once a migrant decides to stop, it is constrained by the availability of habitat and resources within the local landscape. Stopover sites are not necessarily large expanses of high-quality habitat, such as mudflats where thousands or millions of birds congregate; they can also include marginal habitat when nothing else is available in the immediate area. For example, a flock may be forced to land and stopover at a marginal site during bad weather (Mabey 2004).

At staging areas, flights of migrants are often concentrated into corridors when the birds are either taking off or approaching to land (Richardson 2000). The flight height of these migrants is often at the height of wind turbines. Some birds, like swans, typically climb only very gradually, and may remain low for a considerable distance after takeoff from the stopover area, while other birds climb more rapidly (Richardson 2000). Therefore, the distance from the stopover area within which flight altitudes will be low enough to be at risk of collisions with turbines will depend on the species (Kingsley & Whittam 2005).

Collision with wind farm structures is not the only potential effect on migrating birds. Disturbance can also affect migrants if turbines are located near important staging areas. Additionally, the alteration or destruction of habitat used by birds during migration can also contribute to adverse environmental effects.

6. Mitigation of impacts

The most useful way to ensure minimal negative effects of wind farms on birds is to choose an appropriate site. However, a number of mitigation measures have been suggested to reduce collision fatalities at operational wind farms, although it must be emphasised that most have yet to be tested to determine their effectiveness.

Mitigation may involve on-site and/or off-site measures. Temporary shutdowns of turbines during periods of high bird activity, especially at migration bottlenecks and staging areas, and near breeding or wintering concentrations, have been proposed (Smallwood & Thelander 2004; Everaert & Stienen 2007; Hotker et al. 2006). Since turbine shutdown has yet to be routinely implemented, it is not known to what extent it would reduce collision fatalities, although stationary blades are likely to pose less of a risk to flying birds than rotating blades (Drewitt & Langston 2008). However, because collisions also occur with turbine towers, this does not remove the need to avoid siting wind farms on migration routes or at other sites where concentrations of species vulnerable to collisions occur. In this regard, it is of note that in response to a 2004 lawsuit filed against the Altamont turbine operators (California, USA) over raptor kills, wind-power companies and local county officials agreed to shut down half the turbines during winter months, and permanently remove 100 turbines over 5 years (Nijhuis 2006).

It has been suggested that scaring devices, such as playback of alarm calls, could be used as a deterrent (Drewitt & Langston 2008). However, this is likely to be of short-term effectiveness and unacceptably intrusive close to human habitation. Radar- or audio-activation of possible risk-reduction measures, such as alarm calls or turbine shutdown, has the potential advantage that it could be initiated when a hazardous situation is developing, as birds approach (Evans 2000; Drewitt & Langston 2008). However, given that such scaring devices have not been trialled at wind farms, much development and testing would be required before they could be accepted as an effective method for deterring bird species from wind farms in New Zealand.

It has been proposed that the visibility of rotating blades to birds could be increased by having high contrast patterns on blades (McIsaac 2001; Hodos 2003). This proposal requires field testing, but even if it reduced collision risk, such obvious turbine blades visible from urban areas may not be acceptable to the general populous (Langston & Pullan 2003). The use of ultraviolet paint has also been suggested as potentially helpful in alerting birds to the presence of rotors while not increasing their visibility to people (Drewitt & Langston 2008). However, results from limited trials have been equivocal, perhaps because of different species' sensitivities to different UV wavelengths (Hotker et al. 2006).

Smallwood & Thelander (2004) found that turbines at the ends of lines and edges of clusters killed disproportionately more birds, and so hypothesised that a pair of poles could serve as dummy turbines beyond the end of lines and edges of clusters. These poles would be placed 5–10 m apart, just beyond the rotor plane of the end turbine and upward to the maximum height of the rotor. These ‘flight diverters’ would be expected to encourage birds to fly around or over the operating turbines (Smallwood & Thelander 2004). Another suggestion to overcome this problem is to relocate turbines that kill disproportionately more birds because of where they are located (Langston & Pullan 2003).

Another suggested mitigation measure could involve adjusting turbine tower height to minimise collision rates (Anderson et al. 1999; Hotker et al. 2006). Taller or shorter towers could expose fewer birds to collision, although little research has been conducted on this factor. It would require detailed knowledge of the variability of flight altitude of species prone to collision mortality at the site to determine whether such an adjustment would be effective.

Reducing collision mortality of resident species could involve making the site unsuitable for use by birds or a specific bird species through changes in habitat (Anderson et al. 1999). This action has been effective in reducing bird abundance on grassed airfields, where mown swards were made unsuitable to foraging and roosting species by being left to grow long (> 230 mm) (Caithness et al. 1967).

Off-site mitigation can involve actions taken to increase the security of at-risk species at sites away from wind farms (Percival 2003; Smallwood & Thelander 2004; Kuvlesky et al. 2007). This might involve creating or improving habitat near a wind farm to encourage birds to use it rather than the wind farm site. An alternative procedure could involve management to improve adult survival or fledgling production, e.g. by carrying out mammalian predator control for New Zealand species (Ashby 2004). Ideally, where an assessment has quantified the level of adverse effect on a bird population, there may be an opportunity to carry out management to mitigate against such effects (Percival 2003).

An essential aspect of any mitigation measure would be to monitor its impact and test its effectiveness in either reducing collision fatalities or increasing numbers of individuals above those lost to collision fatalities.

7. New Zealand wind farms and their impact on birds

During 2007, wind generation capacity in New Zealand almost doubled to 322 MW, representing 2.2% of total electricity generation (New Zealand Wind Energy Association 2008). Installed wind generation capacity is expected to grow to 494 MW by the end of 2009, and to supply up to 20% of New Zealand's energy needs by 2020 (Rodgers 2006). Lists of operational and proposed wind farms are provided in Appendix 1.

As far as I am aware, there has been no report of carcass searches made at New Zealand wind farms using a scientifically robust methodology. Instead, reports only include anecdotal information. For example, in a popular article, Rodgers (2006) noted that the only fatality at the Brooklyn turbine in more than 10 years of operation was a blackbird, and that 'elsewhere the deaths of a few magpies, gulls and blackbirds have been recorded' (Rodgers 2006: 111). Similarly, ten deaths (all magpies *Gymnorhina tibicen*) have been recorded at the Tararua wind farm, while at Te Apiti five magpies and one kingfisher (*Halcyon sancta*) died during 2004–06 (Clutha District Council 2007). Thus, post-construction monitoring at New Zealand wind farms to date has been inadequate with regard to searches for birds killed as a result of collision with turbines. Maintenance workers are requested to document carcasses they encounter during their work (Seaton 2007). However, this is unlikely to turn up many carcasses unless large birds are killed, because carcasses can be lost due to scavenging, carcasses of small birds can be concealed in vegetation, and untrained personnel, lacking a systematic survey effort, find fewer carcasses than trained staff (Morrison et al. 2007). Since even a low impact can have significant implications for a threatened species' population viability, concerted efforts need to be made to improve post-construction monitoring at wind farms in New Zealand.

I am not aware of any reports or published papers detailing the effects of habitat loss or disturbance on bird populations at New Zealand wind farms.

8. Conclusions

A number of key findings have come from this literature review:

- The effects of wind farms on birds are variable, and can be species-, season- and site-specific. Thus, how applicable the information and conclusions provided in this review are to the New Zealand situation is unknown. Although the general conclusions from studies elsewhere may be pertinent to the New Zealand situation, we need to carry out research at New Zealand wind farms to have confidence in their applicability, particularly with regard to species impacts.
- The four main factors that contribute to collision fatalities at a wind farm are high densities of birds or frequency of movements through it, presence of species prone to collision with turbines, landscape features that concentrate bird movement, and poor weather conditions.
- Species groups that are most prone to collision fatalities at wind farms in Europe and North America are herons and allies, swans, geese, ducks, large soaring raptors, gulls, terns, owls, and nocturnal migrant passerines.
- While carcass numbers found at wind farms have been documented, these will underestimate fatalities unless a systematic methodology is used, including taking into account scavenger rate and searcher efficiency.
- Loss of or damage to habitat as a result of wind farm construction (roads, turbines, buildings) tends to be a minor impact, unless sensitive or rare habitats are involved, or habitat management at the site changes as a result of the development.
- Disturbance of birds as a result of wind farm development and operation may arise from increased activity of people and/or the presence, motion or noise of turbines. Disturbance may lead to displacement or exclusion of birds from areas of suitable habitat. The degree of disturbance can be highly variable, depending on the bird species, wind farm layout and availability of alternative habitat nearby.
- The choice of an appropriate site for a wind farm is the most useful way to ensure minimal negative effects on birds.
- The amount and extent of ecological baseline data collected at a proposed wind farm site should be determined on a case-by-case basis. A minimum of 3 years of detailed investigation should be carried out to determine which bird species use the site, and how and when they use the site.
- Any detailed study should ensure that seasonal, annual and weather variables are suitably investigated, particularly if a site is found to be used by a species that is threatened or likely to be at risk of disturbance or collision by an operational wind farm.
- Wind farm layout is probably important in reducing disturbance and collision risk to birds. It has been suggested that wide corridors between clusters of closely spaced turbines is the most appropriate layout to minimise collision fatalities and prevent barrier effects for both resident and migrant birds. However, a line formation parallel to the main flight direction of migrants has also been suggested.

- Wind farm developments should ensure that blade revolutions per minute are as low as possible, to avoid motion smear and thus promote blade visibility during the day.
- Bright white lighting is regarded as the main attractant of nocturnally active birds leading to collision with tall buildings, so its use should be avoided at wind farms. Ideally, the intensity of lighting should be minimal and be white and flashing, with the interval between flashes being as long as possible. In New Zealand, the lighting required on turbines is specified by the Civil Aviation Authority on a case-by-case basis.
- Although a number of on-site mitigation measures have been suggested to reduce collision fatalities at operational wind farms (e.g. temporary shutdown of turbines, bird scaring devices, high contrast patterns or UV paint on blades, flight-diverter poles, and adjustments to tower height), almost all have yet to be tested in the field to determine their effectiveness; therefore, these should be considered with caution. Off-site mitigation measures could involve habitat management to encourage birds to use sites away from wind farms and/or to improve adult survival or fledgling production.
- Post-construction monitoring at New Zealand wind farms has been inadequate to accurately determine bird fatalities as a result of collision with turbines because neither systematic search procedures nor trained staff have been used. Fatalities have been reported to involve magpies, gulls, blackbirds and a kingfisher, but these results are probably not indicative of the full range of species killed.

Although some of the findings from studies in other countries described above are applicable to New Zealand wind farms, some are not (e.g. there are no large soaring raptors in New Zealand). In addition, each wind farm site tends to be a little different from any other because of variation in topography, weather, habitats, land use and bird species present. Furthermore, our ability to draw conclusions from the review information is constrained because of changing technology, such as turbines becoming taller, having tubular steel bases rather than being of a lattice construction, and having a slower rotor speed. All of these factors need to be considered when investigating possible impacts of wind farm proposals on New Zealand birds. Pre-construction assessments with regard to birds should always be carried out, but the complexity of the assessment required will depend on various attributes of the site, such as the bird species present, their threat status, collision risk, and vulnerability to disturbance. Post-construction assessments should always be carried out when threatened or vulnerable species are likely to be using the site, or population impacts are likely to occur.

Due to a paucity of studies, it has not been possible to relate habitat type to likely wind farm impacts on birds in New Zealand. However, it is probable that the ideal habitat for wind farms in New Zealand, from an ecological perspective, is pastureland some distance from native forest, wetland or the coast, where it has been shown that the site is not on a migration route. This is because pastureland is largely inhabited by native bird species that are widespread and common (e.g. Australasian harrier, black-backed gull *Larus dominicanus* and paradise shelduck), and therefore are unlikely to be impacted significantly by disturbance and occasional collision fatalities.

There are major gaps in our knowledge with regard to impacts of New Zealand wind farms on birds. For example, it is not known to what extent each species is prone to wind farm development (collision, disturbance, barrier effect), which species are suffering collision fatalities, which routes are taken by migrants, how fixed these routes are in relation to varying weather conditions and time of travel (northward to wintering sites, southward to breeding sites), and the extent to which each species is able to avoid collision with turbines. Given that much effort and funding will go into establishing wind farms in New Zealand over the next 10–20 years (Parliamentary Commissioner for the Environment 2006), much effort also needs to go into filling gaps in our knowledge to ensure that wind farms are sited appropriately with regard to New Zealand bird species.

9. Recommendations

9.1 BIRD MIGRATION

The published literature on bird migration is considerable; however, much of the information is very general and relates to the Northern Hemisphere. Specific information relating to migration routes, timing and prevalence of nocturnal movements for New Zealand species is lacking (Williams et al. 2006). The following questions, in particular, need answering in relation to New Zealand birds and possible impacts of wind farms on their populations:

- Are there identifiable migration routes that should be avoided when siting wind farms?
- Do migrant birds follow or concentrate their flights along ridges, mountains, coastal margins, waterways and/or through saddles?
- At what heights do diurnal and nocturnal migrants fly during various weather conditions?
- What fatalities of migrant species are occurring at New Zealand wind farms (location of wind farm, species involved, numbers and months of occurrence)?
- How successful are birds in New Zealand at avoiding collisions with wind turbines when involved in nocturnal migration during various weather conditions?
- How will any cumulative detrimental impact (as collision fatalities) at more than one wind farm on a species during migration be monitored and considered when there is a further proposal for a wind farm along the migration route?

The issue of identifying important migration routes in New Zealand is a crucial one. It may be informative to overlay a map of annual median wind speed (which would suggest where most wind farms will be located) with likely migration routes and significant bird habitats (e.g. estuaries, freshwater wetlands) of New Zealand bird species. This information would enable a developer of a wind farm to determine whether the prospective site is on the route taken by any migratory species and whether a species' flight characteristics would make it vulnerable to collision with turbines. The following would be required for this project:

- Mapped routes for each species involved in migration.
- Information about the migration of these species, including timing, altitude of flight in relation to weather conditions, total number of migrants and flock size (mean and range).

While various sources provide information on the timing of migration, and departure and destination locations for some species (volumes 1–4 of the Handbook of Australian, New Zealand and Antarctic birds (Marchant & Higgins 1990, 1993; Higgins & Davies 1996; Higgins 1999); Dowding & Moore 2006; Williams et al. 2006), additional field studies would be required to provide much of this information. For example, information on migration routes would require telemetry studies, and determination of flight statistics (e.g. altitude, flock size) would require the use of marine and/or meteorological radar scans (Kingsley & Whittam 2005; Sun 2007).

With suitable siting (lack of tall structures and complex landforms nearby) and in conjunction with computer-assisted data processing, the latest marine radar units can apparently reliably detect small birds (starling (*Sturnus vulgaris*) size) at a range of 3 nautical miles horizontally (5.6 km) and up to 1500 m vertically, and medium to large birds (gulls, harriers) or flocks of smaller birds out to 6 nautical miles (11.1 km) and up to 3000 m vertically. This equipment would be useful where there are large resident populations or significant seasonal bird movements that require quantification for risk modelling. When used in conjunction with audio recordings and observers, these systems can identify species, range, direction of movement, speed of flight and altitude (if vertical and horizontal radars are combined), and can provide highly accurate records of each bird's or flock's flight path across the landscape. However, the radar is not able to determine the number of individuals in a flock or identify the species when used on its own (Fuller 2008; S. Fuller, Boffa Miskell, pers. comm., 24 October 2008). Meteorological radars can be used on a broader scale to determine the relative size and direction of migrating flocks. Also, the development of PTTs (platform transmitter terminal, satellite transmitter) or GPS (global positioning system) tags may allow barometric pressure or temperature to be measured, which would give an estimate of flight altitude. Before embarking on this migration research, it is important that New Zealand prioritises the order in which New Zealand at-risk species will be investigated.

9.2 COLLISION FATALITIES

Protocols for monitoring collision fatalities and analysing the results have been developed (Anderson et al. 1999), but have not been used at New Zealand wind farms in a systematic way that takes account of searcher efficiency, scavenger activity, habitat type and cause of death. The present information for New Zealand wind farms is inadequate to assess which species have died as a result of collisions with turbines and the number killed per turbine per annum. Therefore, it is important that New Zealand researchers collate information on species impacted and mortality rates at several New Zealand wind farms in various habitat types using the internationally accepted protocols that have been developed to detect collision fatalities.

9.3 AVOIDANCE RATE

Collision risk models have been developed to predict the theoretical numbers of birds that would collide with wind turbines at a proposed wind farm in the absence of any avoidance behaviour (Tucker 1996; Band et al. 2006). In order to make realistic predictions about the number of collisions that may actually occur, the inclusion of various avoidance rates (proportion of flights that might, in theory, result in successful avoidance) has been advocated: 95% by Scottish Natural Heritage (2008) and 97–99% by Percival (2007). Avoidance estimates should include species that continue to fly during conditions of poor visibility, when their ability to detect and avoid operating turbines is likely to be much reduced (Madders & Whitfield 2006). The precise estimation of collision and avoidance rates has proven difficult to determine because the frequency of such events is generally very low. Nevertheless, there is an urgent need for studies to determine avoidance rates of New Zealand birds. New technologies to achieve this are currently being developed, including the use of infra-red video cameras to monitor collisions (Percival 2007). Until avoidance rates have been determined for New Zealand species, a precautionary approach should be adopted, whereby 95% avoidance is assumed when calculating collision risk.

9.4 COLLABORATIVE RESEARCH

A collaborative approach to the research required into the impacts of wind farms on New Zealand's birds should be adopted, including in the development of research programmes, data collection and analyses, and funding. The various parties involved in the research should include wind-power generators, regulatory bodies that are promoting the use of wind energy (central government) and deciding the merits of particular sites (regional government and local authorities), and the Department of Conservation, whose responsibilities include the conservation of New Zealand's indigenous flora and fauna that may be impacted by wind farm developments. Since the membership of the New Zealand Wind Energy Association (NZWEA, www.windenergy.org.nz; viewed 24 October 2008) includes most businesses involved in wind-energy generation, including site development, service industries (law, finance and consulting), construction, engineering and generation, this seems to be the appropriate body to promote such a collaborative research programme among wind-energy businesses.

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Appendix 1

OPERATIONAL AND PROPOSED WIND FARMS IN NEW ZEALAND

A1.1 Operational wind farms

The following operational wind farms are listed in order of construction (Ashby 2004; Rodgers 2006; www.windenergy.org.nz, viewed 7 October 2008):

- Brooklyn, Wellington: a single 225 kW turbine, erected in 1993 by Meridian Energy.
- Hau Nui stage 1 near Martinborough: seven turbines each of 550 kW capacity (3.85 MW), erected in 1996 by Genesis Energy.
- Tararua stage 1 near Palmerston North: 48 turbines each of 660 kW capacity (31.7 MW), erected in 1999 by TrustPower.
- Gebbies Pass near Lyttelton: a single 500 kW turbine, erected in 2003 by Windflow Technology.
- Tararua stage 2 near Palmerston North: a further 55 turbines each of 660 kW capacity (36.6 MW), erected in 2003/04 by TrustPower.
- Te Apiti near Palmerston North: 55 turbines each of 1.65 MW capacity (90.7 MW), erected in 2003/04 by Meridian Energy.
- Hau Nui stage 2 near Martinborough: a further eight turbines each of 600 kW capacity (4.8 MW), erected in 2004 by Genesis Energy.
- Southbridge near Geraldine: one turbine of 100 kW capacity, erected in 2005 by Energy3.
- Te Rere Hau stage 1 near Palmerston North: five turbines each of 500 kW capacity (2.5 MW), erected in 2006 by New Zealand Windfarms Ltd.
- White Hills near Mossburn: 29 turbines each of 2 MW capacity (58 MW), erected in 2006/07 by Meridian Energy.
- Tararua stage 3 near Palmerston North: a further 31 turbines each of 3 MW (93 MW), erected in 2006/07 by TrustPower.
- Te Rere Hau stage 2 near Palmerston North: 14 turbines each of 500 kW capacity (7 MW), erected in 2007/08 by New Zealand Windfarms Ltd.
- Project West Wind near Makara: Meridian Energy has been given approval to erect 62 turbines each of 2.3 MW (142.6 MW). Under construction, and is expected to be fully commissioned by late 2009.

A1.2 Proposed wind farms

Planned farms for which resource consent has been granted or applied for, and for which preliminary investigations are underway are as follows:

- Titiokura near Napier: Unison / Hydro Tasmania has been granted approval for stage 1 (16 turbines, 48 MW), but construction is on hold at present.
- Te Waka near Napier: 111 MW. On being declined by the Environment Court, this application was modified by the developers (three turbines removed) and awaits a hearing by the Environment Court after being called in by the Ministry for the Environment.
- Hawke's Bay near Napier: Wind Farm Developments, Hallblock Resources Ltd & Lowe Family Interests have been granted approval for 75 turbines each of 3 MW, awaiting construction.
- Taumatatotara near Te Anga, King Country: approval granted by council to Ventus for a 20 MW wind farm in June 2006, awaiting construction.
- Awhitu Peninsula near Waiuku: resource consent granted by the Environment Court to Genesis Energy to build 19 turbines each of 1.0 MW turbines, but construction on hold at present.
- Teviot Valley east of Roxburgh, central Otago: resource consent granted in 2007 to Pioneer Generation to construct a 1.5 MW (three 0.5 MW turbines) wind farm at Horseshoe Bend on the Teviot River. Awaiting construction (this apparently depends on availability of second-hand turbines).
- Lake Mahinerangi of inland Otago: following feedback to a resource consent application for a 200 MW wind farm (up to 100 turbines), TrustPower submitted a revised application for a smaller wind farm in December 2006. Awaiting outcome of an appeal to the Environment Court.
- Taharoa C near Kawhia: 42 turbines (100 MW) to be erected by Taharoa C Incorporation and PowerCoast; consent was granted in August 2006, but has been appealed.
- Project Hayes of inland Otago: Meridian Energy has been given approval to erect 176 turbines (1.8–3.6 MW turbines, 630 MW in total) adjacent to the Lammermoor Range, awaiting construction. May be appealed in the Environment Court.
- Motorimu near Shannon: resource consent application lodged by Allco Australia to build 127 turbines of 500 kW each; local council commissioners gave approval to erect 75 (109.7 MW), but has been appealed.
- Te Uku near Raglan: resource consent application lodged by WEL Networks for an 84 MW wind farm.
- Epakauri on the Northland west coast: resource consent application lodged by Meridian Energy for 18 turbines each of 2.74 MW (49.3 MW) on land administered by the Department of Conservation, and surrounding farmland.
- Kaiwera Downs near Gore, Southland: TrustPower applied in November 2007 for resource consent for a 240 MW wind farm (up to 83 turbines).
- Puketiro near Upper Hutt: the Greater Wellington Regional Council applied to dedicate land to a wind farm in June 2005. In 2006, RES NZ Ltd was awarded the tender, and is now monitoring wind at the site. They propose to erect about 50 turbines each of 2–3 MW capacity. Expected to lodge for resource consent in 2009.

- Project Mill Creek in Ohariu Valley near Wellington: Meridian Energy has lodged resource consent applications for the project (31 turbines each of 2.3 MW capacity, 71 MW combined capacity).
- Project Central Wind near Waiouru: preliminary investigation by Meridian Energy for a wind farm of 51 turbines.
- Hauauru ma raki, Waikato Wind Farm, between Port Waikato and Raglan: consent application being prepared by Contact Wind Ltd for a wind farm consisting of up to 220 turbines with a capacity of 540 MW in total (turbines up to 3 MW and up to 150 m high at blade tip).
- Turitea near Palmerston North: feasibility study being carried out by Mighty River Power and Palmerston North City Council for a 120 MW wind farm.
- Rock and Pillar Gorge in Otago: feasibility study being carried out by Windpower for a 25 MW wind farm.
- Waverley near Wanganui: a wind farm of 135 MW is under investigation by Allco Wind.

How do wind farms impact on birds?

Wind generation is poised for rapid expansion in New Zealand, being expected to supply up to 20% of New Zealand's energy needs by 2020. However, nothing is known about the likely impacts of wind farms on our bird populations. This literature review shows that the main impacts of wind farms on birds in other countries include collision fatalities, habitat loss and disturbance. A key finding is that wind farms have variable effects on birds, depending on species, season and site, and no two wind farms are the same, making it difficult to generalise from studies carried out in other countries. Therefore, it is imperative that we gain more information about the New Zealand situation.

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New Zealand Government