

Proceedings of National Avian-Wind Power Planning Meeting

**Lakewood, Colorado
July 20-21, 1994**

Organized by
*National Renewable Energy Laboratory
U. S. Department of Energy
American Wind Energy Association
National Audubon Society
Electric Power Research Institute
Union of Concerned Scientists*

Meeting Facilitated by
*RESOLVE, Inc.
Washington, D. C.*

Proceeding Prepared by
*LGL Ltd., environmental research associates
King City, Ontario*



National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Managed by Midwest Research Institute
for the U.S. Department of Energy
under contract No. DE-AC36-83CH10093

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ABSTRACT

In recent years, bird deaths in wind power plants within the United States have become an important issue with economic, legal, policy and research dimensions. The National Avian-Wind Power Planning Meeting was convened to focus on the research aspects, particularly to (1) identify and prioritize key issues with respect to bird-wind turbine interactions, (2) define a research agenda to resolve scientific and technical issues, while (3) insuring transferability of results, (4) avoiding duplication and inadequate science, and (5) building consensus on approaches to the research needed to address the issues. The meeting was organized by groups with many perspectives on the issue: the National Renewable Energy Laboratory (NREL) and Department of Energy (DoE), American Wind Energy Association (AWEA), National Audubon Society (NAS), Electric Power Research Institute (EPRI), and Union of Concerned Scientists (UCS).

About 57 individuals representing these and other interested groups, plus various independent scientists with relevant expertise, met in Lakewood, Colorado, on 20-21 July 1994. They

- ▶ reviewed the status of wind power in the U.S.A.,
- ▶ developed lists of research questions,
- ▶ reviewed past and ongoing avian research at wind plants in the U.S.A. and Europe,
- ▶ discussed general design concepts for avian-wind power research, including both monitoring methods and the Adaptive Resource Management approach,
- ▶ discussed desirable components of an integrated national research program, and
- ▶ identified next steps that should be taken.

The meeting Proceedings volume includes a Meeting Summary section (p. 80ff) covering each of the above topics, plus a more detailed description of the presentations, discussions and conclusions on each topic.

Meeting attendees recommended that some of the technical issues identified at this meeting be taken up by a group with broader representation and mandate, including the economic, policy and legal ramifications. The National Wind Coordinating Committee's Avian Subcommittee may be an appropriate group to carry forward the work begun at this meeting. The overall goal might be to devise a process, incorporating scientific research as a major element, that would allow the wind industry to develop without the occurrence of an unacceptable number of bird deaths.

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PREFACE

In early 1994 representatives of the environmental community, academic community, wind energy industry, and federal and state governments agreed that it would be useful to convene a meeting

- ▶ to identify technical questions that need to be answered to better understand the interaction between wind power plants and avian species, and
- ▶ to discuss how to address these questions via scientific research.

These proceedings are the result of this meeting, called the National Avian - Wind Power Planning Meeting. The meeting successfully provided an overview of known data on this subject, and identified opportunities for additional research.

Parallel to this investigation into the technical questions surrounding avian/wind power interactions, a national collaborative was organized to address the sustainable commercialization of wind power. This committee, called the National Wind Coordinating Committee (NWCC), has an Avian Subcommittee. The Avian Subcommittee is building on the results of the National Avian - Wind Power Planning Meeting through additional workshops and the coordination of a national strategy for addressing avian/wind power interactions.

The organizers of the workshop hope this publication will be useful to the academic community, managers, and the public involved in wind development projects throughout the U.S. and internationally. Additionally, the organizers thank *all* the presenters and participants for their assistance in making the meeting a success.

GLOSSARY OF ACRONYMS

Numerous acronyms are mentioned in these Proceedings. Although most are spelled out when first mentioned, a Glossary may be of value to readers:

APLIC	Avian Power Line Interaction Committee
ARM	Adaptive Resource Management
AWEA	American Wind Energy Association
BACI	Before-After Control-Impact (a type of experimental design)
DoE	Department of Energy
EEI	Edison Electric Institute
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Agency
MW	megaWatt
NAS	National Audubon Society
NASA	National Aeronautics and Space Agency
NREL	National Renewable Energy Laboratory
NWCC	National Wind Coordinating Committee
PG&E	Pacific Gas and Electric
UCS	Union of Concerned Scientists
UWIG	Utility Wind Interest Group

INTRODUCTION

Wind power technology has advanced to the point that it is expected to grow rapidly and expand geographically in this decade. In recent years, bird deaths in wind power plants within the United States have become an important issue that must be addressed. This issue has a variety of dimensions, including economics, legalities, policy, and research.

The National Avian-Wind Power Planning Meeting was convened to concentrate on the research dimension. The organizers and sponsors consisted of the National Renewable Energy Laboratory (NREL) and Department of Energy (DoE), American Wind Energy Association (AWEA), National Audubon Society (NAS), Electric Power Research Institute (EPRI), and Union of Concerned Scientists (UCS). Collectively, these groups represent a wide range of interests and perspectives. However, they share a common belief that it would be useful and timely to convene a meeting to initiate planning for a national, coordinated program of research on the avian-wind power issue.

Meeting Organizers, Facilitator and Proceedings

The meeting was organized by a Management Committee consisting of representatives from DoE, EPRI, NAS and UCS, supported by a Technical Committee with representatives of NREL, NAS and EPRI. Management Committee members were Jan Beyea (NAS), Earl Davis (EPRI), Ron Loose (DoE), and Mike Tennis (UCS), assisted by meeting facilitator Abby Arnold of RESOLVE Inc. Technical Committee members were Robert W. Thresher and Al Miller (NREL), Michael L. Morrison (University of Arizona, for NAS), and W. John Richardson (LGL Ltd., for EPRI).

The meeting was chaired by Bob Thresher of NREL, and facilitated by Abby Arnold of RESOLVE Inc. RESOLVE specializes in environmental conflict resolution. Ms. Arnold was assisted by Tim Wohlgenant and Morrissa Young, also of RESOLVE. That firm also had a major role in planning the meeting logistics.

The Proceedings were compiled and edited by W. John Richardson of LGL Ltd., based on Abstracts and other materials supplied by some Technical Presenters and on notes taken at the meeting. The draft Proceedings were reviewed by the organizers, Technical Presenters and Technical Participants, and were finalized taking their comments into account.

Meeting Participants

In planning the meeting, the organizers identified several principles that seemed desirable:

- ▶ discussion should focus on technical rather than policy issues;

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- ▶ participants should include scientists with research experience on bird-wind turbine issues and other closely related issues;
- ▶ participants should include additional scientists without previous involvement in these issues, but with good abilities to design research needed in order to address biological and environmental impact problems;
- ▶ the number of attendees should be small enough to allow effective discussion;
- ▶ because the technical and policy issues are interrelated, persons representing a wide spectrum of policy interests should be present.

It was obvious that, to accommodate a reasonable number of people from each interested group, 40 or more people would need to be invited. With that number of participants, discussion and consensus-building would be difficult. Therefore, the organizers decided to divide the meeting attendees into four categories: Technical Presenters, Technical Participants, Invited Participants, and Observers (Table 1). Appendix 1 provides full addresses and telephone and facsimile numbers for the meeting attendees.

Technical Presenters and **Technical Participants** included individuals, in most cases with a scientific or technical background, from the following organizations:

- ▶ American Wind Energy Association
- ▶ Edison Electric Institute
- ▶ Electric Power Research Institute
- ▶ Kenetech Windpower
- ▶ National Audubon Society
- ▶ National Biological Survey
- ▶ National Renewable Energy Laboratory
- ▶ Pacific Gas & Electric
- ▶ Union of Concerned Scientists
- ▶ U.S. Fish & Wildlife Service
- ▶ Wisconsin Department of Natural Resources

Representatives from these organizations were invited because of the nature and breadth of those organizations' involvement in avian interaction issues. In most cases, the invited representatives of these organizations were scientists or technical specialists with relevant technical expertise. The Technical Presenter/Technical Participant category also included several additional biologists from academic institutions and research firms, both within the United States and internationally. During the meeting, Technical Presenters and Technical Participants sat at a table. Technical Presenters gave prepared presentations, and Technical Presenters and Technical Participants led the discussion of these and other topics.

Additional individuals and group representatives were invited to attend as **Invited Participants**. These individuals represented utilities, firms, agencies and environmental groups. The objective was to obtain reasonable representation across the range of interested parties and geographic regions of the United States. The Invited Participants participated in the discussion of each major topic after a range of views had been presented by the Technical Presenters/Participants.

Table 1. List of Attendees, National Avian-Wind Power Planning Meeting

Attendee	Affiliation	Role
Amidaneau, Debbie	NREL	Observer
Anderson, Dick	California Energy Commission	Invited Participant
Arapkiles, Tina	Sierra Club	Observer
Arnold, Abby	RESOLVE, Inc.	Facilitator
Bain, Don	Oregon Dept. of Energy	Observer
Beyea, Jan	National Audubon Society	Technical Presenter
Bouchard, David C.	Central & South West Services	Observer
Brower, Mike	Union of Concerned Scientists	Technical Participant
Byrne, Sheila	PG&E	Technical Presenter
Cade, Tom	Boise State Raptor Center/Kenetech	Technical Presenter
Campbell, Lennox H.	RSPB, Gr. Britain	Observer
Carey, Christopher	Oregon Dept. of Fish & Wildlife	Observer
Colson, Ed	AWEA	Technical Participant
Curry, Dick	Kenetech Windpower	Technical Participant
Davies, Al	Zond Systems, Inc.	Invited Participant
Davis, Earl	EPRI	Technical Participant
Davis, Holly	NREL	Observer
Davis, Laura	NREL	Observer
DeMeo, Ed	EPRI	Technical Presenter
Dunlop, John	AWEA—Great Plains Reg. Off.	Observer
Feinstein, Art	Golden Gate Audubon Society, Bay Area	Invited Participant
Flynn, John	DoE/HQ	Invited Participant
Fuller, Mark	National Biol. Survey	Technical Participant
Gauthreaux, Sid	Clemson University	Technical Presenter
Harmata, Alan R.	Montana State University	Observer
Haugh, John	Bureau of Land Management	Invited Participant
Hock, Susan	NREL	Observer
Hunt, Grainger	Univ. of Calif. Santa Cruz—PBRC	Technical Participant
Jamison, Van	Montana Natural Resources Dept.	Invited Participant
Kendall, Bill	USFWS—Migratory Bird Management	Technical Participant
Kingsbury, Marcia D.	Naval Facil. Eng. Serv. Center	Observer
Letto, Jay	Audubon Regional Representative, WA	Invited Participant
Loose, Ron	DoE/HQ	Invited Participant
Martí, Ramón	Sociedad Española de Ornitología	Observer
Marvin, Mike	AWEA	Invited Participant
Mayer, Larry	Statistical Consultant	Technical Participant
Mazelis, Joel	Edison Electric Institute	Technical Participant
McEwen, Gail	Oregon Dept. of Fish & Wildlife	Observer
Miller, Al	NREL	Observer
Mitchell, Diane	Consulting Biologist	Technical Participant
Monahan, Mike	Univ. of Denver	Observer
Morrison, Mike	U. of Arizona and National Audubon Society	Technical Presenter
Nudds, Tom	U. of Guelph, Canada	Technical Presenter
Olmstead, Paul	Sacramento Mun. Utility Dist.	Observer
Osieck, Eduard	Netherlands Soc. Prot. Birds	Observer
Poulos, Pete	USFWS—Migratory Bird Management	Observer
Richardson, John	LGL Ltd., Canada (for EPRI)	Technical Participant
Sharp, Lynn	Woodward-Clyde Consultants	Observer
Stanley, Tom	National Biol. Survey	Technical Participant
Strickland, Dale	WEST	Observer
Thompson, Michael	Spectrum Sciences & Software	Technical Participant
Thresher, Bob	NREL	Program Chair
Turner, Bob	National Audubon Society	Technical Participant
Ugoretz, Steve	Wisconsin Dept. Natural Resources	Technical Participant
Winkelman, Johanna	Dutch DLO-Inst. Forestry & Nature Manage.	Technical Presenter
Wohlgenant, Tim	RESOLVE, Inc.	Recorder
Young, Morrissa	RESOLVE, Inc.	Assistant to Facilitator

All other persons who expressed an interest in attending the meeting were accommodated as *Observers*. They, like other categories of attendees, included people from a variety of backgrounds including federal and state agencies, utilities, industry, consulting firms, universities, and environmental groups—mostly from the United States but some from Europe. Observers were encouraged to interact with other meeting participants during breaks.

Introductory Comments by Organizers

National Audubon Society

On behalf of the National Audubon Society (NAS), Jan Beyea noted that NAS and many local Audubon chapters are very concerned about the effects of wind turbines on birds. The primary NAS concern is the potential impacts of wind plant-related bird mortality¹ on bird populations. However, there is also concern about any unnecessary deaths of individual birds, whether or not these bird deaths have population consequences.

National Audubon is very pleased to be involved in this collaborative effort to understand and resolve the avian-wind power issues. NAS hopes that, during this meeting, representatives of the different interests can set aside their respective policy positions and focus on technical issues. This should facilitate a process in which scientists and engineers can work together to gain the knowledge necessary to resolve the issues.

American Wind Energy Association

On behalf of the American Wind Energy Association (AWEA), Mike Marvin noted that participation in this meeting is an important initiative for the wind power industry, including individual companies and their trade association. This industry has for many years seen itself as providing an environmentally responsible approach to the generation of electrical energy in a renewable manner. Given these environmental benefits, the existence of even one environmental issue is a real concern to AWEA.

AWEA believes that an expanded research effort is necessary in order to address this issue. AWEA has been taking steps to encourage increased funding for avian-wind power research, and expects that there will be increases in the funding devoted to this issue by both government agencies and industry. On-going industry research permits implementation of research-based recommendations for modifications, where appropriate, in subsequent phases of wind power projects. The modular nature of wind developments provides an opportunity to assess the effects of wind plant construction and operation on the surrounding

¹ Meeting attendees recognized that the term "mortality" is widely used in a loose fashion to mean "deaths". The term is often used in this loose manner in these Proceedings. Strictly speaking, measurements of mortality are rates, representing the number of bird deaths within defined spatial and temporal bounds.

environment. It will be important to focus the expanded research effort on the most important questions. This meeting can help achieve that focus. On its own initiative, AWEA is compiling an international database listing the studies done on this topic. Mr. Marvin concluded by noting that the wind power industry began largely because of environmental concerns about other forms of energy generation. The wind power industry wants to continue operating in partnership with environmental groups.

Electric Power Research Institute

Earl Davis of the Electric Power Research Institute (EPRI) noted that EPRI is a Research and Development organization serving most of the electric utility industry in the United States. EPRI focuses on developing, evaluating, and deploying technologies appropriate for the electrical utilities. EPRI believes that, near the end of this decade, some generating plants will need to be retired, and anticipates that there will be an increasing demand for electricity. For these reasons, EPRI believes that there will be a need for new generating facilities, and that wind power plants could be an important part of new generation. Therefore, it is important that concerns about bird fatalities at wind plants be resolved. Scientific research will be necessary to resolve the concerns. This research should be done in a well-planned and coordinated manner in order to resolve the existing issues in a comprehensive and convincing way. EPRI hopes that this collaborative meeting will make significant advances toward that objective.

Union of Concerned Scientists

On behalf of the Union of Concerned Scientists (UCS), Mike Brower noted that UCS supports the development of wind power but also focuses on environmental concerns. UCS is involved in collaborative programs to promote wind power in the Midwest and in New England. However, UCS recognizes that there are environmental concerns associated with wind power development. These include not only the avian issues, but also concerns about the effects of road construction, tree felling, and visual impacts. UCS believes that, in addressing these issues, it is important to involve all interested parties. This has not always been done in the past. Research is needed to improve understanding and agreement concerning the most appropriate areas and methods for wind power development, and about areas that should not be developed. Without a cooperative approach, there will be a legacy of confrontation that will benefit neither industry nor the cause of environmental protection.

Objectives of the Meeting

The initial invitations stated that the overall goal of the meeting

"...is to define a research program that addresses wind power-related avian mortality issues. This research program should investigate both individual site impacts and national cumulative impacts.

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"To reach this goal, the meeting intends to (1) identify and prioritize key issues with respect to bird-wind turbine interactions, (2) define a research agenda to resolve scientific and technical issues, while (3) insuring transferability of results, (4) avoid duplication and inadequate science, and (5) build consensus on approaches to the research needed to address the issues."

At the start of the meeting, a more specific list of meeting objectives was proposed by the meeting Chairman, Bob Thresher, and accepted by the participants:

- ▶ to help all parties understand the principal interests and concerns of one another;
- ▶ to identify and where possible prioritize the key scientific and technical questions regarding avian-wind interactions at wind power plants;
- ▶ to define and where possible prioritize research projects to address the questions identified;
- ▶ to identify research study requirements (e.g. time frame, resources and challenges associated with particular research proposals);
- ▶ if there is time, to develop consensus on a national research plan and establish priorities were possible; and
- ▶ define possible next steps.

For the purposes of this meeting, consensus was taken to mean that "all participants at the table can live with a decision being considered".

Process Guidelines

The Facilitator reviewed the draft Agenda circulated before the meeting (Table 2). There were no suggestions for changes. The first day of the meeting consisted largely of prepared presentations, summarized starting on page 9. (More detailed versions of some presentations and background materials appear in Appendix 2, p. 100ff.) The second day included additional presentations but was largely devoted to discussion.

Meeting attendees were asked to hand in, during the first day of the meeting, their suggestions concerning specific research projects. A form was provided to each attendee, requesting information about the suggested research question, research needed, research design, time frame, and estimated cost. These forms were collated by the meeting organizers and discussed on the second day. Appendix 3 (p. 141ff) summarizes these suggestions.

The Facilitator then proposed the following procedural guidelines, and they were accepted by the meeting participants:

- ▶ Honor agenda, or modify it by consensus;
- ▶ Attempt to make comments as constructive as possible;
- ▶ Attempt to be as responsive to direct questions as possible;
- ▶ Respect time for Invited Participants' comments at times identified by Facilitator;
- ▶ General good faith commitment to make this meeting as productive as possible.

Table 2. Meeting Agenda. The following is the draft agenda circulated before the meeting and accepted by the attendees at the start of the meeting.

Wednesday July 20, 1994

8:15-9:00 am I. Introduction

- | | | |
|----|--|-----------------------|
| A. | Welcome and Introductions
- Meeting organizers introductory comments
- Participant introductions | Abby Arnold, RESOLVE |
| B. | Goals, objectives, and products | Robert Thresher, NREL |
| C. | Meeting format | |

9:00-9:45 II. Wind Technology Overview (*Presentation and Discussion*)

- | | | |
|----|---|----------------|
| A. | Wind Power: status, role, capabilities | Ed DeMeo, EPRI |
| B. | Projected growth of the wind power industry | |

9:45-12:00 III. Avian Mortality Questions at Wind Power Plants (*Presentation and Discussion*)
(*Including break*)

- | | | |
|----|---|-------------------------|
| A. | Review and discussion of Preliminary Avian Questions List | Mike Morrison, NAS/UofA |
| B. | Additions to avian questions | |
| C. | Prioritization of identified questions | |

12:00-1:30 LUNCH

1:30-3:30 pm IV. Factors that Contribute to Avian Mortality in Relation to Wind Power
(*Presentation and Discussion*)

- | | | |
|----|---|--|
| A. | The history of wind-related avian research. | Sid Gauthreaux, Clemson U./EPRI |
| B. | Status of current avian-wind power studies | |
| 1. | Industry research | Tom Cade, Chairman, Kenetech Avian Research Task Force |
| 2. | Government and Public Sector Research | Bob Thresher, NREL |
| C. | European avian-wind power and related research. | J.E. Winkelman, Dutch DLO—
Inst. Forest. & Nat. Manage. |
| D. | Lessons from utility structure environmental impacts. | Sheila Byrne, PG&E |

3:30-3:45 BREAK

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Table 2 (continued). Meeting agenda.

-
- 3:45-5:30 V. Designs for Avian-Wind Power Research (*Presentation and Discussion*)
- A. Research areas to address the questions identified Sid Gauthreaux
1. Identify research areas (i.e.: mortality, population, physiology, siting . . .)
 2. Identify study requirements (i.e.: accuracy, time frame, etc.)
 3. Identify constraints and limitations (\$, time, statistical)

5:30 pm Van service back to Doubletree Hotel
Dinner on own in Lakewood/Denver area

Thursday, July 21, 1994

8:15-11:00am V. **Designs for Avian-Wind Power Research** (*Presentation and Discussion*)
(continued)

- B. Study outlines and approaches from participants Bob Thresher, NREL
(worksheet results)
- C. Conceptual framework: Integration of Mike Morrison, NAS/UofA
diverse studies. Tom Nudds, Univ. of Guelph

11:00-12:00 VI. **Defining an Integrated Plan for Avian Research Questions.** (*Presentation and Discussion*)

- A. Development of a national research agenda Jan Beyea, NAS
for addressing avian questions associated with
wind power facilities.
- What are the appropriate research agenda categories?;
 - What criteria should we use to prioritize the research studies?
 - Which research studies ought to be conducted under each category?
 - What is the recommended priority to be started first, second, third.

12:00-1:30pm LUNCH

1:30-2:30 VI. **Defining an Integrated Plan for Avian Research Questions.** (continued)

- B. Defining an information dissemination process
1. Proceedings from this meeting.
 2. Collaboration among groups.
 3. Future Workshops
 4. Coordination with NWCC Avian Subcommittee

2:30-2:45 BREAK

2:45-5:30 VII. **Next steps to be taken**

WIND TECHNOLOGY OVERVIEW

E.A. DeMeo of the Electric Power Research Institute summarized the

- ▶ status and potential of the wind power industry in the United States,
- ▶ Utility-EPRI-DoE Wind Turbine Verification Program, and
- ▶ activities of the Utility Wind Interest Group (UWIG) and the National Wind Coordinating Committee (NWCC).

The following is an expanded version of his Abstract, incorporating copies of his slides plus additional points that arose during the presentation and discussion

Wind Power Status and Utility Activities

by
E.A. DeMeo, EPRI²

Electricity generation from the power in the wind is becoming a commercial reality in many parts of the United States with good winds. After a decade of growth and maturation in California, wind power is now expanding across the United States with major new wind plants in operation, construction or advanced planning in Washington, Wyoming, Minnesota, Texas, Iowa, Maine, Vermont, New York, and elsewhere. In California, installed capacity totals some 1,600 MW, and an additional 500-1,000 MW of capacity is under discussion. In parts of the U.S.A. outside California, about 50 MW of capacity has been installed, about 250 MW of additional capacity is now at the permitting or construction stages, and at least 500 MW of further capacity has been proposed (slides 8,9). Overall, about 1 to 2 billion ($1-2 \times 10^9$) dollars of investment is under discussion. Wind power is the only newly-emerging renewable technology for power generation that has reached the threshold of widespread commercial application.

Several forces are joining to encourage the growth in wind power. (1) Costs of generating equipment have dropped markedly over the past decade, making wind power competitive with conventional power generation in many cases. Also, the reliability of wind power plants has become very high. The energy cost in constant dollars has diminished from the early-1990s to today. EPRI believes that energy cost in constant dollars will further decline in the late 1990s and beyond (slide 4). Likewise, the project installed cost, currently about \$800/kW, is expected to continue to decline gradually (slide 11). (2) Wind power has substantial environmental benefits relative to conventional power plants. There are no air or water emissions during operation. (3) Improved understanding of wind resources has uncovered a huge potential in many parts of the U.S. that could supply a substantial portion of the country's requirements for electricity. The wind resource is especially great in the Great Plains (slide 5).

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In recognition of this potential, a Utility Wind Interest Group (UWIG) was established several years ago to understand and communicate the status of wind power from the perspective of the electric utility industry (slides 6,7).

The U.S. wind turbine supplier industry is expanding. One major player is actively developing several hundred megawatts of new capacity in several states. Several other firms with an established business base in California are expanding the geographic and technological scope of their operations (slide 10). Many of these firms are receiving technical and financial support from the DoE/NREL advanced wind turbine development program and/or a joint DoE/EPRI wind turbine performance verification program (slides 12-14). This verification program provides risk-shared funding to conduct operational tests of about 20 turbines of a given type. This program is designed to expand utility experience with wind power, evaluate new turbine designs, and establish a bridge between tests of 1 or 2 prototype turbines and commercial-scale operation of hundreds of machines. Round 1 of this program will involve tests in Texas and Vermont.

Meanwhile, there is much activity in Europe as well, where most governments have wind development programs and incentives. About 1,000 MW of capacity are in place now, and there are plans for about 4,000 MW of capacity by the end of the decade. There are a number of European wind turbine manufacturers. Some of these are developing technologically innovative equipment. European-built turbines continue to be installed in the U.S.A.

The continued expansion of wind power will require successful resolution of a number of key issues (slide 15). For example, many windy sites are distant from population centers, requiring lengthy transmission lines through areas that are often environmentally sensitive. The intermittent nature of wind presents challenges in integrating wind-generated power into a network that must supply reliable power at all times. The UWIG has recently initiated an expansion of its scope to address wind resource validation and utility-integration issues. On another front, concerns have been raised in some locations over reported collisions between wind turbines and migratory birds.

Resolution of these issues will require careful, reasoned discussion and teamwork among the major sectors of our society that will be affected by the growth and use of wind power. There are many stakeholders, not just the utilities and turbine producers. To provide a forum for broader discussion and a catalyst for the needed teamwork, a new group has recently formed. Called the National Wind Coordinating Committee (NWCC), this group includes representation from the electric utility, environmental, consumer advocate, regulatory, government, and manufacturing sectors (slides 16-19). The group's aim is to ensure the responsible use of wind power in the U.S. Toward this end, the NWCC will identify issues that impact the use of wind power, establish dialogue among key stakeholders, and catalyze appropriate activities. The group's ultimate vision is a self-sustaining commercial market for wind power. (By self-sustaining, the NWCC means that it is environmentally, ecologically, economically, and politically sustainable.)

The NWCC is in the process of establishing several subcommittees, including one to deal with avian issues (slide 20). The Avian Subcommittee is expected to review the outcome of the present meeting and to make recommendations regarding implementation of this meeting's technical recommendations. Appendix 2A provides a more detailed description of the formation and perspective of the NWCC.

In the subsequent *discussion*, it was noted that no one expects the U.S. wind resource to be fully developed in the foreseeable future, but there is much potential for long-term development. At present, the U.S. produces 700,000 to 800,000 MW of electricity. AWEA hopes that the U.S. wind turbine capacity will increase from the present 2,000 MW to 10,000 MW by the year 2000 and to 50,000 MW by 2020. EPRI's vision is that 10% of the U.S. electricity requirements might ultimately be met by wind power—comparable to the proportion met by hydro-electricity now. It was suggested that 100,000 to 200,000 MW might be the upper limit of the available wind resource in the U.S.A.

At present, about 15,000 wind turbines are installed in the U.S.A., producing about 2,000 MW. Most existing turbines have lower generation capacity than current-design turbines. To reach 10,000 MW of capacity by the year 2000 would require about 16,000 new wind turbines of present design. If the upper limit on the wind resource is 100,000-200,000 MW, the upper limit on the number of wind turbines that would be needed in the U.S.A. would be about 200,000 to 400,000 units of present design. Power generated per turbine has, however, increased about ten-fold in the past decade.

It was noted that, although wind power has environmental benefits in comparison with some other methods of power generation, it also has environmental costs, including but not limited to bird fatalities. Meeting participants agreed that environmental issues other than bird fatalities need to be considered, e.g. in Environmental Assessments, but are beyond the scope of this meeting.

Some participants noted that plans for rapid expansion of the wind power industry provide a unique opportunity to do carefully planned tests of wind plant effects on birds, including well-controlled pre- vs. post-construction comparisons. Ideally, studies at different wind plants should be done in a coordinated way such that different wind plants form experimental replicates. By installing two or more different types of wind turbines in each wind plant and monitoring effects on birds, one could achieve a "split-plot" experimental design. These tests could be implemented in an Adaptive Resource Management framework (see p. 59).

The participants discussed the amount of land occupied or affected by turbines. It was suggested that, at least in California, wind turbines and associated infrastructure (including roads) typically occupy about 5% of the land area of a wind plant, increasing to a maximum of about 10% in steep terrain. However, more of the area could be affected indirectly, e.g. through effects on the prey available in the area as a whole. EPRI estimates that a typical wind plant produces about 20 MW per square mile. The Altamont wind plants include over 7,000 turbines on 80 square miles of rangeland. It was noted that road

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Outline

Status Summary
Wind Resource Potential
Utility Wind Interest Group
Nationwide Wind Activity
Wind Industry Overview
Turbine Verification Program
Unresolved Issues
National Wind Coordinating Committee

2

Current Situation

Wind at threshold of significant utility-scale use nationally
Substantial utility deployment activity underway and planned
Hardware available
– one major domestic supplier
– several strong players overseas
– several players emerging in U.S.
Wind can begin to show measurable environmental benefits

3

U.S. Experience Base In Wind

Some 1600 MW installed in California

Some 50 MW installed elsewhere

A number of utility-scale projects in negotiations or planning

- Northwest
- North Central
- New England

Several smaller-scale tests in operation or planning

- New York
- Texas

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Energy Cost

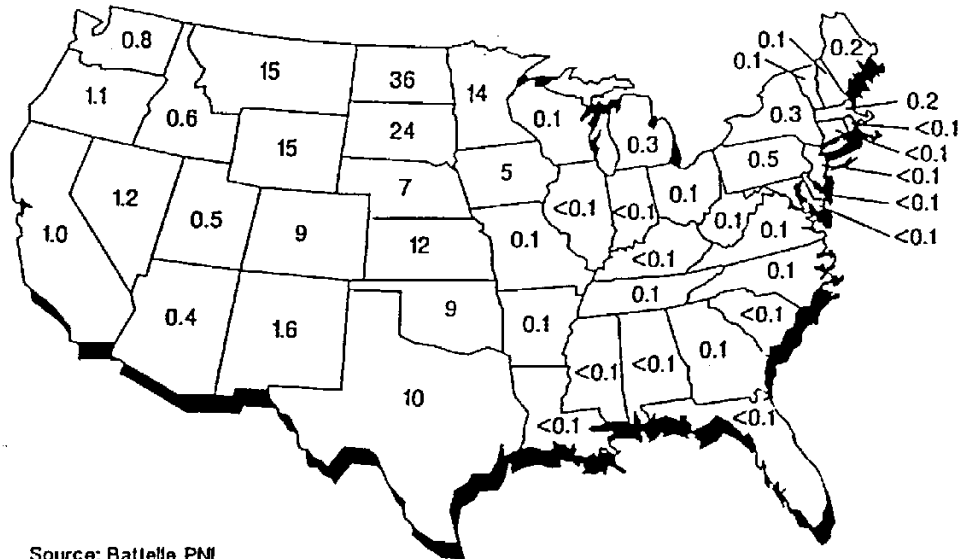
(1993 constant dollars)

Early 1990s:	7-9¢/kWh	good winds ¹
Mid 1990s:	5-6¢/kWh	good winds ¹
Late 1990s:	5¢/kWh	moderate winds ²
Early 2000s:	4¢/kWh	moderate winds ²

1 16 mph annual average at hub height

2 13 mph annual average at hub height

5 **WIND RESOURCE POTENTIAL**
Percent of Contiguous States' Electricity Needs (1990)



Source: Battelle PNL

0072.01

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Utility Wind Interest Group (UWIG)

Formed by utilities mid 1989 with DOE and EPRI support

Current membership: 13 utilities

Mission: Expedite appropriate integration of wind power for utility applications

Strategy: Understand and communicate status and issues

- experience exchange
- wind industry interactions
- brochures and seminars

Seven brochures published; several in process

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UWIG Expansion Rationale

Forum for utility issues discussion

Focus for key wind activities

- resource assessment
- environmental issues
- integration issues
- status assessment
- outreach

Accelerated use of wind nearly certain

- help define the acceleration process

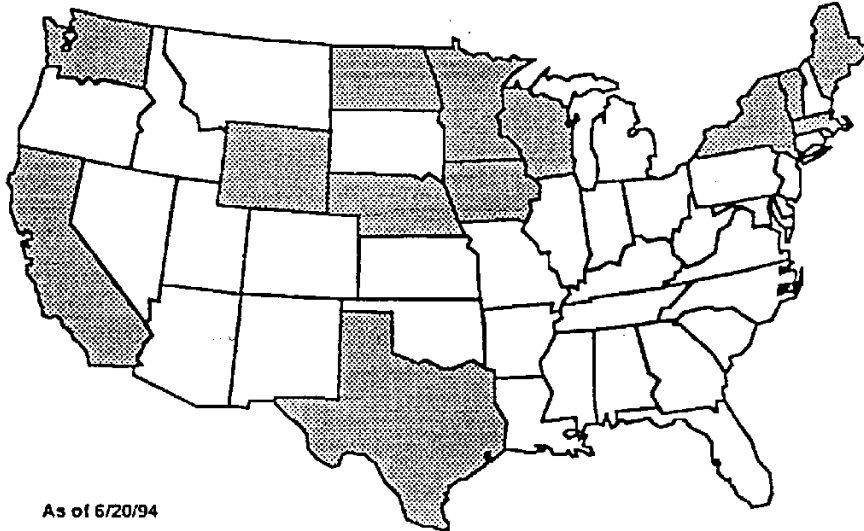
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Wind Projects Outside California

<u>State</u>	<u>Construction-Operational</u>	<u>Announced</u>
HI	11.3 MW	10.0 MW
IA	0.4	153.2
ME	1.5	33.5
MN	25.8	tbd
NY	0.7	tbd
TX	7.8	250.0
VT	8.2	0.0
WA	105.0	25.0
WI	0.0	10.7
WY	135.0	tbd
Canada		120.0 MW

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STATES WITH MAJOR WIND ACTIVITY



As of 6/20/94

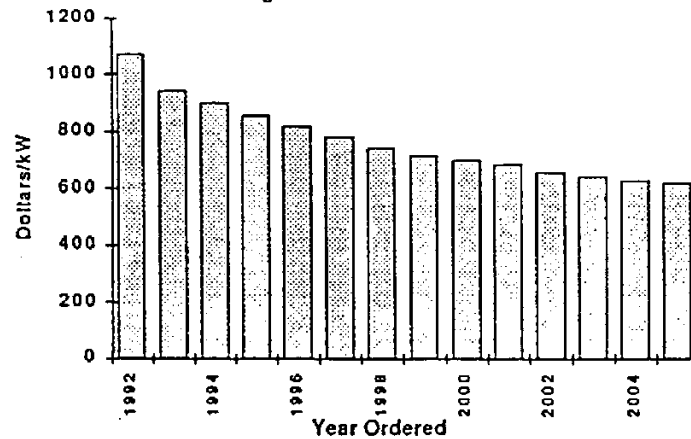
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Wind Power Firms in the U.S.

	<u>Turbines</u>	<u>Plants</u>
Atlantic Orient	X	
AWT	X	
Carter Wind Systems	X	
Cannon	X	X
Flowind	X	
Kenetech Windpower	X	X
New World Power		X
Northern Power Systems	X	
SeaWest		X
Wind Eagle	X	
Zond	X	X

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Wind Power Plants Projected Installed Cost – 50 MW Base Case Excluding Substation and Interconnection

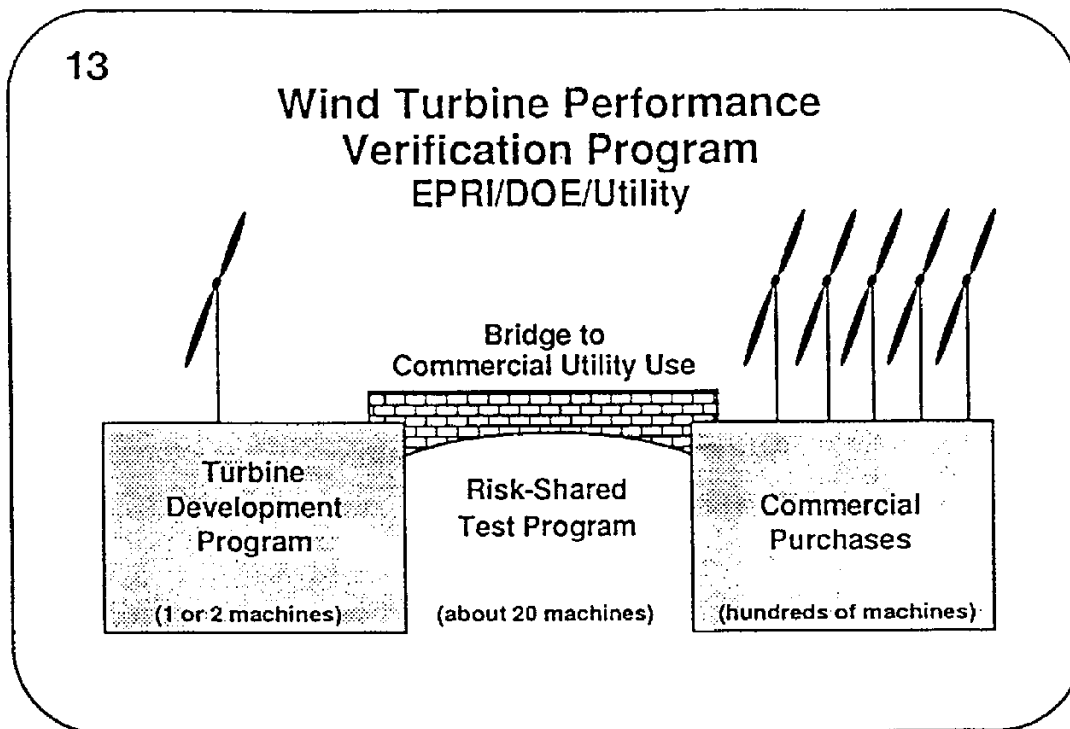


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Utility-EPRI-DOE Wind Turbine Verification Program

OBJECTIVES

- Expand direct utility experience with wind power
- Evaluate state-of-the-art wind turbines
- Provide a bridge to commercial purchases



- 14
- ### Turbine Verification Program
-
- ROUND I
- Central & South West Services
- 6 MW, Ft. Davis area
 - Turbine Procurement RFP, May 94
 - Operational early 1995
- Green Mountain Power
- 6-8 MW, south central Vermont
 - Looking for partners, R&D project
 - Starting Forest Service EIS for NEPA
 - Operational 1996

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Wind Power Expansion

ISSUES/BARRIERS

- Electricity competition/overcapacity
- Wind capital and operating costs
- Environmental impacts
- Nondispatchability/integration
- Transmission requirements
- Market sustainability

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National Wind Coordinating Committee

BROAD OBJECTIVES

- Provide a forum for . . .
 - Identifying issues and impacts
 - Promoting coordination
 - Pursuing societal benefits optimization
- Catalyze actions to . . .
 - Understand roles and value
 - Reduce barriers
 - Encourage prudent acceleration
 - Promote sustained markets

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National Wind Coordinating Committee

OBJECTIVE

The purpose of the National Wind Coordinating Committee (NWCC) is to ensure the responsible use of wind power in the United States. The Committee will identify issues that impact the use of wind power, establish dialogue among key stakeholders, and catalyze appropriate activities. The Committee's vision is a self-sustaining commercial market for wind power.

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National Wind Coordinating Committee

MEMBERSHIP REPRESENTATION

Utilities/utility trade organizations

Supplier industry/AWEA

Environmental community

Regulatory community

State energy offices

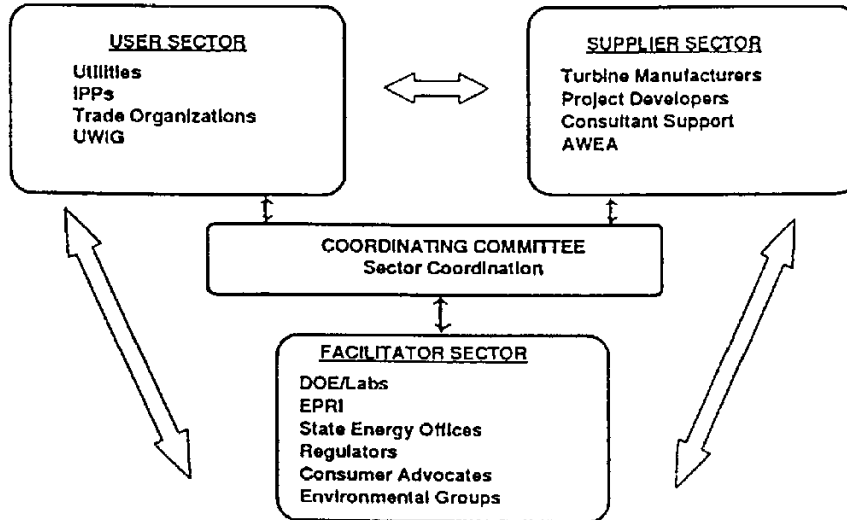
Consumer advocate community

DOE/DOI/EPRI

Facilitator: Resolve

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WIND POWER EXPANSION Organizations



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National Wind Coordinating Committee

INITIAL SUBCOMMITTEES

- Avian issues
- Transmission issues
- Resource assessment issues
- Regulatory opportunities
- Sustained development

construction and other changes during wind plant construction can have various ecological effects, including interrelated effects on habitat, on wildlife other than birds, and on prey available to birds. Some participants noted that all of these points should be dealt with, e.g. in the environmental assessment. It was agreed, however, that the focus during the present meeting should be on the avian fatality issue and directly related issues.

AVIAN MORTALITY QUESTIONS AT WIND PLANTS

Initial List of Avian Mortality Questions

Before the meeting, a lengthy list of questions concerning the issue of bird mortality at wind plants was compiled by the meeting organizers and circulated to all attendees. It was hoped that this list would help the attendees identify the range of issues to be discussed. It was recognized that no one question from this list fully defines "the bird problem at wind plants". Collectively, however, these questions go some way toward defining the problem.

The organizers hoped that the list might serve as a starting point from which to begin formulating a prioritized list of major research questions relevant to the issue of bird mortality at wind plants. It was recognized that the list probably does not include all relevant questions. Meeting participants were asked to suggest other important questions that should be added to the list.

Many of the avian mortality questions on the initial list were suggested by the organizers and their respective organizations. Others were questions that came up at meetings of the Kenetech Windpower Avian Task Force, either during Task Force deliberations or from the public in response to Task Force presentations. Still other questions were suggested to the organizers by prospective meeting attendees during informal discussions in the weeks preceding this meeting.

While compiling the list, the organizers gave some attention to the wording of the questions in order to clarify the issues. However, no serious attempt was made to refine the wording to any "optimal" form. Some related questions were combined, but other overlapping questions remain separate. The organizers listed the questions under six more-or-less self-explanatory categories:

- ▶ Structural Design of Wind Plants
- ▶ Bird Populations
- ▶ Wind Plant Siting in Relation to Habitat
- ▶ Experimental Design
- ▶ Management Approaches
- ▶ General Questions

Some questions could have been listed under more than one category, but for simplicity are listed only once. The organizers made no attempt to set priorities, and the sequence of categories and questions is largely arbitrary.

The following is the list of avian mortality questions as circulated before the meeting, with a few italicized explanatory notes concerning the origin of the questions or the discussion of those questions during the meeting. After initial discussion, meeting participants decided not to attempt a detailed revision of these questions, but rather to formulate a new and shorter list (see p. 27ff).

Structural Design of Wind Plants

[This category deals with questions concerning the design, spacing and spatial layout of turbines, turbine support structures, and ancillary equipment.]

What aspects of a wind plant and turbine design result in vulnerability?

Is it possible that some parts or a part of the turbine (tower, support structure wires, blades, or the nacelle) are more responsible for mortality than other parts?

If yes, can the structural parts be (1) designed to reduce mortality? (2) redesigned or retrofitted?

Is this a species-specific issue?

Are wind turbines being used for birds to perch upon?

Is this a problem? If yes, can turbines be designed to prevent perching?

Is there a relationship between spacing and/or height of the towers in relation to kills?

Are the electrical pole lines and/or substations contributing to mortality if designed to the latest avian design specifications?

[The relevance of this question was recognized. However, meeting participants agreed that this question is largely separate from the question of mortality attributable to wind turbines per se. Therefore, most participants preferred not to deal with this question at the present meeting.]

Is there any difference between *[the effects of]* upwind and downwind machines on birds?

Bird Populations

This category of questions is centered on **population effects**; critical points include the following:

- ▶ how is population being defined?
- ▶ what exactly is a population effect?
- ▶ what segment(s) of the population are being killed, and how does this impact the population near- and long-term?
- ▶ should population analysis be an integral part of all studies?
- ▶ does direct mortality resulting from collision result in net increase in mortality in the region? (i.e., is compensatory mortality operating?)
- ▶ what is the impact *[of turbine-related mortality on dispersal of birds]* to other populations?

Could mortality caused by wind turbines ever be reduced to zero by mitigation?

[Attendees agreed that this is impractical, because sooner or later birds collide with any tall object.]

Wind Plant Siting in Relation to Habitat

What habitat features are being modified by wind farm development that might be attracting birds (e.g. ground disturbance that enhances squirrel habitat; creation of man-made perches)?

Are there opportunities for win-win situations, e.g. by using wind farms as a means to prevent alternate land uses that are more damaging for birds, e.g. housing developments?

Are there locations or situations where passerines would be impacted? *[or other types of birds such as waterfowl, shorebirds, etc.; raptors may not be the birds most seriously affected in some parts of the country.]*

Experimental Design

[This category is recognized as a "catch-all" that overlaps other categories. It includes questions relating to fundamental research principles, the generality of results from specific studies, temporal and seasonal effects, and the need to aim for rigorous science so as to obtain results that will be widely accepted by all stakeholders.]

What data are needed and how can we gather these data?

How long is it going to take to get answers about the biology of the avian/wind-facility interactions? At what levels of funding?

What is the priority of species we should be studying?

How can we use site-specific research to validate or refine available tools-procedures-databases?

How can success be measured?

How can we ensure that any studies we define and describe will be accepted for their scientific content?

How and under what circumstances are birds being killed (perching, stooping); when are birds being killed (diurnal/nocturnal migration or otherwise); what birds are being killed (resident vs. migrant); are there geographic differences?

What use do studies in one area have for siting of facilities in other areas?

Is information (e.g. inventories, counts, databases) available that can be correlated to site-specific assessments of avian impacts? How can site experimental design relate to collection of this kind of information?

What existing tools or procedures can be used to improve inventories at sites where there is interest in development of a wind plant?

Should radar or other quick surveys be done at study sites?

How relevant are data on collisions of birds with other structures, such as transmission lines, radio towers, etc.?

What are the most appropriate procedures for assessing the potential impacts of proposed wind developments on bird populations, and for comparing the potential impacts of different alternatives?

What role does experimentation and/or adaptive resource management have in the development/design of future plants? That is, rather than deciding "all or nothing" for a facility, what about developing an experiment that allows production while refining understanding of the problem and/or mitigative measures?

What is the applicability of using surrogate species to the species in question (e.g. pigeons for raptors, hawks for eagles)?

What is the applicability of using passerines as surrogate species?

Do migration paths shift over time? How long do you have to take measurements to determine width of path? What species/region/topographic variations exist in path width and consistency?

Are there any man-made devices available that would deter birds from coming near wind turbines?

Management Approaches

[This category applies mainly to the management of existing wind power facilities, although there are implications for new facilities as well.]

If no population impacts are seen, is mitigation necessary for the kills that do take place?

What can be done with existing plants if they are causing high levels of mortality?

Are kills of birds at wind farms "worse" than mortality from other man made-structures of the same size?

Are kills of birds at wind farms "worse" than mortality that would occur in the same area if there were no development?

Is direct mitigation a useful or legally legitimate approach, i.e. enhance habitat, increase populations in other areas to compensate for mortality by collisions?

General Questions

[These questions, although considered no less important, did not fit easily into any of the previous categories.]

Can projects continue under development without probable irreparable damage to critical avian populations?

Can "safe" wind production zones be identified *a priori*, i.e. must topographically enhanced sites such as ridges and bluffs be avoided?

Would it be helpful to identify high wind resource areas and areas where birds are "funnelled" or locate in high concentrations?

If a national need for electricity is a given, should wind facilities be examined in the context of likely or probable alternatives, such as avian mortality associated with coal or natural gas plants (upstream plant and downstream effects)?

Toward a Prioritized List of Research Questions

Meeting participants held a lengthy and wide-ranging discussion of the procedures by which they might identify a smaller number of key questions that could, in turn, provide guidance for the design of high-priority research.

Recurring Themes in Discussion

1. How can we ***define high and low priority***? It was suggested that this question is itself a potential research question. This question will have to be addressed at some point even if it cannot be answered now. It is important to identify such issues even if they cannot be resolved at this time.
2. It is often difficult or impossible to separate ***technical*** from ***policy*** questions. Many of the questions raised above have direct or indirect policy implications. In many situations such as this, stakeholders identify problems, and technical specialists then decide how to address the problems through research or other technical measures. In the present situation, although there has been much discussion of the bird mortality issue prior to this meeting, no broadly-constituted group of stakeholders has yet identified a consensus position on the key

components of the problem. The National Wind Coordinating Committee, and particularly its Avian Subcommittee (see p. 10), may ultimately fill this role. However, that group is still in its early stages, as described in Appendix 2A. In the meantime, wind power developments are being planned and constructed, and avian-wind power research is being planned and conducted in various parts of the country. Many attendees felt that, in this situation, it was appropriate for a technically-oriented group to do its best to address research needs at this stage, and to submit its recommendations to the NWCC and other interested parties as the basis for a continuing round of discussion and refinement.

3. There is a ***need for good scientific work*** that is not unduly constrained by the policy agendas of various stakeholders. Some attendees indicated approval of an approach whereby policymakers would identify a few key questions, and then would allow research to proceed without micro-management by stakeholders.
4. Many participants believed that, in the above context, it is desirable for a technical group to attempt to set policy matters aside, insofar as possible, and to focus on research priorities, research design, and other technical issues. Others believed strongly that technical and policy issues are so intertwined that research priorities cannot be defined adequately in isolation from further consideration of the policy context. In practice, the attendees focused most discussion on technical issues, and attempted to rephrase some policy-related matters in more technical terms. However, policy-related matters including questions about wind power economics, legal issues, risk-analysis and other issues going beyond purely technical issues arose periodically throughout the meeting.
5. The best ***sequence for discussion*** of research questions and existing information on birds at wind plants was discussed. Some attendees considered it better to defer discussion of research priorities until after research conducted to date had been summarized (p. 33ff). Others felt it best to raise some of the questions early in the meeting to serve as a basis for discussion of the research-to-date presentations. In the end, the attendees made some progress toward narrowing the list of key research questions prior to the detailed discussion of research-to-date, and further discussed the key research questions later in the meeting (p. 72ff).
6. Many meeting attendees believed that the main research focus should be on the existence, severity and mitigation of wind plant effects on avian ***populations***. Notwithstanding this, there appeared to be broad agreement that efforts should also be made to reduce ***individual fatalities*** of birds even if these deaths have few or no effects on the bird populations. However, different attendees placed varying degrees of emphasis on the importance of research to find ways of reducing individual fatalities. The meeting recognized that, from a legal perspective, any mortality of protected birds is sometimes deemed to be unacceptable, whether or not it has population consequences.

7. Some attendees felt that an initial focus for research should be "**whether there is a bird problem**" at wind plants. Others felt strongly that the existence of a bird problem is self-evident given the scientific, legal, political and ethical concerns that have been raised. One industry and utility perspective is that, as a result of presently threatened regulatory and legal actions, some existing wind plant operations may be curtailed and some new wind plants may be delayed or prohibited. From that perspective, the regulatory and legal threat constitutes "the bird problem". In that regard, the bird problem is real and self evident regardless of the consequences to birds.
8. Attendees' views on the importance of addressing whether or not there is "a bird problem" were related in part to their views on the relative importance of population effects vs. individual fatalities. Attendees who emphasized population approaches also tended to emphasize the need to conduct research to investigate whether there is "a bird problem", i.e. an effect on bird populations. Some attendees who expressed strong concerns about individual fatalities independent of population effects felt that the existence of a bird problem was self evident.
9. A related view is that there exists a "bird problem" until we can be reasonably sure that there will be no significant population impacts from a mature wind industry. In evaluating potential impacts on bird populations, it is important to consider the likely effects of the number of wind turbines that wind industry proponents foresee being operational in coming decades. For example, 100,000 turbines might cause significant problems for bird populations even if 10,000 turbines do not.
10. These approaches, which are not mutually exclusive, suggest **two research goals**: (1) Determine effects of wind turbine mortality on bird populations. (2) Identify methods to lower and/or mitigate wind turbine mortality.
11. Pre- and especially post-construction assessments of birds at U.S. wind plants have been restricted to a rather **small number of situations**. Almost all U.S. data on impacts of operating wind turbines on birds concern effects on birds in California, where raptors have been the main recognized casualties. Other types of birds, including waterfowl and night-migrating passerines, could be a larger concern in other parts of the U.S. where wind plants are now being planned. The extent and nature of the bird problem are not yet well defined for the U.S. as a whole.
12. Some attendees noted that, in assessing the magnitude of the bird mortality problem, it would be useful to have **comparative figures on avian mortality** attributable to other methods of electrical generation—traditional and renewable. Some data on avian mortality and habitat-mediated effects are obtained for certain other types of generating facilities. However, there is presently no coordinated program to obtain these data, and research and monitoring methods

are not standardized. Attendees accepted the view that this information would be valuable, but that it is beyond the scope of this meeting to develop a research program concerning the impacts of other methods of power generation. It was also noted that the occurrence of some bird mortality at other types of generation facilities does not necessarily mean that mortality at wind power facilities is acceptable.

Condensed Lists of Major Research Areas

The 14-Point List.—After discussion of the above themes, meeting attendees compiled a list of 14 research areas that were considered important. These items were presented in no specific order, and are numbered below strictly for reference purposes. These item numbers do not imply any priority sequence:

1. What are the population effects of avian mortality, including long-range cumulative effects?
2. Assess avian mortality attributable to wind turbines: population effect? if not, how many individuals?
3. Identify ways to reduce or mitigate mortality.
4. Develop capability to predict avian mortality at new sites.
5. Develop methods to reduce mortality, whether or not that mortality leads to population consequences.
6. Assess the overall ecological significance of avian mortality: what are the ecosystem effects?
7. Determine whether wind plant mortality is additive or compensatory. (Additive mortality refers to deaths that would not occur in the same time frame in the absence of the phenomenon of interest, here a wind plant. Compensatory mortality refers to deaths that would have occurred for another reason if the wind plant had not been present.)
8. Estimate the decrease, if any, in the average annual survival rates of species of interest.
9. Of the available turbine designs and layouts, what configurations result in minimum mortality?
10. What are the most appropriate research design protocols?

11. What factors cause avian mortality at wind turbines (what aspects of siting? turbine design? environmental conditions?)
12. What win-win situations exist under which wind park developments may lead to net improvement in conditions for birds and other biota.
13. What are the "indirect" effects of wind plant development on avian populations, including disturbance and habitat-modification issues?
14. What role can the lay person fill in monitoring and assessment of wind plant effects.

Seven-Point "Distilled" List.—A subgroup of the attendees reviewed the above list of 14 points and concluded that they could be reduced to seven main research topics by combining related items. These seven points, again not in any logical or priority sequence, were as follows:

1. What are the population effects of avian mortality at wind plants, including cumulative effects?
 - ▶ Determine whether wind plant mortality is additive or compensatory (see definitions above, p. 30)
 - ▶ Estimate the decrease, if any, in the average annual survival rates of species of interest
2. Determine avian mortality, including consideration of appropriate and comparable tools, methods, and techniques.
3. Identify ways to prevent or mitigate mortality or enhance avian viability:
 - ▶ Develop ability to predict impacts
 - ▶ Develop methods to reduce unnecessary mortality
4. What causes avian mortality from wind turbines or wind plants?
 - ▶ bird behavior
 - ▶ turbine design
 - ▶ wind plant design
 - ▶ location of wind plant
5. Assess overall direct effects and indirect ecological effects of avian mortality at wind plants.
6. What are the indirect effects of wind development on avian populations, i.e. disturbance and habitat modification effects?
7. Agreement on research design protocols, including how to involve lay people in monitoring and assessment of wind plant effects.

There was considerable discussion as to whether items 1 and 2 should be combined into a single point: "Determine avian mortality". It was noted that items 1 and 2 overlap, and that there are difficulties in any population-level assessment. However, many attendees believed that items 1 and 2 refer to different concepts—population vs. individual effects—and should be kept separate.

Five-Point "Sequenced" List.—Some attendees recommended that the seven point list be further condensed and reorganized. In this case, the numerical sequence was deliberately chosen to represent a progression that, to some attendees, seemed logical. Again, however, the sequence does not represent any consensus on priority:

1. Assess mortality attributable to wind turbines at existing sites (including control data from "no turbine" sites).
2. Predict mortality at planned wind power sites, based in part on (1).
3. Predict population consequences.
4. Identify ways to reduce bird kills at wind plants.
5. Set values for off-site mitigation.

Some attendees preferred this five-point formulation and others preferred the preceding seven-point list. Some felt that the sequence of approaches identified in the five-point list is logical. Others were uncomfortable with this sequence on the grounds that, in their view, it might imply that construction of additional wind plants is a foregone conclusion.

There was general agreement that the above lists of potential research areas, whichever version one prefers, provide a good indication of the research topics that the meeting attendees collectively considered important. The majority of attendees believed that it would be premature, at this stage of the meeting, to attempt to set priorities among these potential research areas. It was agreed that the best approach would be to move on to a review of previous and ongoing research on bird-wind power interactions, and then to a discussion of research design principles applicable to this area. It was agreed to give further consideration to research priorities later in the meeting (see p. 72).

AVIAN MORTALITY AT WIND PLANTS: PAST AND ONGOING RESEARCH

This section of the meeting consisted of six presentations, with discussion of those presentations. (1) S.A. Gauthreaux, Jr., summarized studies in the United States, excluding some ongoing work that is described in the next two presentations. (2) T.J. Cade summarized work organized by the Kenetech Avian Task Force (p. 36). (3) R.W. Thresher summarized work presently being funded (or soon to be funded) by the U.S. Federal Wind Energy Program (p. 39). (4) S. Byrne summarized utility experience in designing and conducting research on the bird-power line interaction problem in the U.S.A., and lessons that this may provide for research on bird-wind power interactions (p. 41). (5) J.E. Winkelman summarized work on bird-wind power issues in Europe, emphasizing the extensive studies done in the Netherlands (p. 43; see also p. 110, 121). (6) R. Martí of the Sociedad Española de Ornitología summarized ongoing research on bird-wind plant interactions in southern Spain (p. 48).

The following five subsections are based on the extended abstracts for the five prepared reviews, augmented by points made during the oral presentations and subsequent discussion. The sixth subsection summarizes the presentation of R. Martí.

The History of Wind-Related Avian Research in the U.S.A.

by

Sidney A. Gauthreaux, Jr., Clemson University³

This presentation summarized the major studies already completed, and mentioned the main ongoing pre-construction studies. Ongoing work organized under the aegis of Kenetech Windpower and the Federal Wind Energy Program is not described here, but is summarized in the next two presentations (p. 36, 39). Points raised in the discussion of this presentation have been incorporated into the relevant subsections rather than at the end.

ERDA/NASA 100 kW Experimental Wind Turbine, Ohio

Studies of the potential impact of wind turbines on birds in the U.S.A. began in the middle 1970s when the potential for environmental effects from the development of electrical generating capacity using wind energy was assessed at the ERDA/NASA 100 kW Experimental Wind Turbine at NASA's Lewis Research Center Plum Brook Station near Sandusky, Ohio (Rogers et al. 1977). The avian component of this study concentrated on assessing the potential for nocturnal migrant collisions with a wind turbine, because this was the only impact considered significant enough to warrant field studies. (It was assumed that birds

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would see and avoid the turbine in the daytime.) Observation methods for nighttime migratory movements included (a) making vertical ceilometer beam observations with 10x50 binoculars and an image intensifier scope (5x), and (b) monitoring migration over the general area using ARSR-2 radar units. Daytime studies included grounded migrant surveys and searches for dead and wounded birds at the base of the wind turbine generator and the meteorological tower. During four migration seasons only two birds were found dead at the meteorological tower and one bird at the wind turbine generator. It was concluded that the wind turbine was not proven to be a high risk to birds, including nocturnal migrants.

Boeing/PG&E MOD-2 Wind Turbine, California

Approximately five years later, bird movements and collision mortality were studied as part of Pacific Gas and Electric Company's performance monitoring program for a 350 ft Boeing MOD-2 wind turbine and associated meteorological tower located on the western edge of the Suisun Marsh just south of Cordelia, Solano County, California (Byrne 1983, 1985). Both raptor and waterfowl movements were monitored prior to construction. Nocturnal migration over the site was monitored during the fall of 1982 and the spring of 1983 using a portable ceilometer and image intensifier system. Dead bird searches were conducted five days a week during nocturnal migration monitoring and once a week thereafter. Weather data were gathered to examine relationships between migration intensity and weather conditions. Findings indicated relatively low rates of waterfowl movements and nocturnal songbird migration over the wind turbine site. Raptor activity in the area was moderate to high. Migration rates were considerable lower than those recorded in the eastern United States. During the year of mortality monitoring (1 Sep 1982—31 Aug 1993), seven dead birds were found: one was observed to have collided with the rotor (an American Kestrel), four more were thought to have collided with the wind turbine, and two were thought to have collided with guy lines or the meteorological tower. The mortality adjusted for scavenger removal and detectability suggests an actual mortality during the study as high as 54 birds.

California Energy Commission Studies

In 1989 the California Energy Commission Report, "Avian mortality at large wind energy facilities in California: Identification of a problem" was released (CEC 1989). The report reviewed existing data on bird injuries and mortality caused by wind turbines in 1984-1988. Nearly all incidents involved raptors, including 108 individuals of seven species (72 collisions and 36 electrocutions). Raptors are protected by both California and federal laws. These collisions were in the Altamont and Tehachapi areas. Most of the reported mortality was during winter, not during migration.

This report stimulated a two-year study conducted by BioSystems Analysis, Inc., to evaluate the extent and significance of the impact of wind turbines on birds, to identify the causes and factors contributing to bird injuries and deaths, and to recommend mitigation measures (Orloff and Flannery 1992). The study areas included an established wind turbine area at Altamont Pass, Calif., and another still under development in Solano County, Calif. Observations and dead bird searches were conducted for six seasons. Of 183 dead birds

found, 119 (65%) were raptors and only 19 carcasses were fresh. Most dead raptors were Red-tailed Hawks (36%), followed by American Kestrels (13%) and Golden Eagles (11%). Fifty-five percent of the mortality was attributed to collisions with turbines, 11% to collisions with wires, 8% to electrocutions, and 26% unknown. During the study no birds were observed flying into wind turbines. The investigators concluded that, of the potential factors contributing to mortality, the following were most important: end-row turbines, turbines within 500 m of a canyon, the elevation of a turbine, and a lattice type turbine tower. The statistical robustness of these conclusions has been the subject of much subsequent discussion.

A follow-up study, also by BioSystems Analysis, Inc., is presently underway. This will include further mortality searches in the Altamont, and additional analysis of the existing Altamont mortality data in relation to turbine characteristics.

Ongoing Pre-Construction Surveys

Currently, several studies are underway or planned to assess the potential impact of wind farm development on bird injury and mortality. Nearly all of these studies involve pre-construction monitoring of bird movements, including local movements of resident species and migration traffic rates of transient species. These studies are being done in the vicinity of potential wind farm developments in order to identify the species that have the greatest risks of negative impact. Many of the studies are using direct visual observations during the day and image intensification and radar observations at night to quantify the amount of movement, height of flight, and flight behavior of local and migratory species. These studies are underway in the Kibby Range of Maine, eastern Lake Ontario/Tug Hill region of New York, and the Fort Davis area of the Trans-Pecos of Texas. Similar studies are planned for the Searsburg and Readsboro areas of Vermont, eastern Oregon, and the Norris Hill Wind Resource Area of Montana.

The opportunity to acquire valuable pre-construction data is great, but to date the methodologies applied in different studies have not been standardized. If this were done, meaningful comparisons of data would be possible. Likewise, if post-construction studies use standardized methods of monitoring bird movements and measuring mortality, a reliable data base can be accumulated in a relatively short period of time on a continental scale. These data will be very useful in determining the geographical variability in avian mortality and/or species and numbers of birds that may be at risk.

Industry Research: Kenetech Windpower

by

Tom J. Cade, Chairman

Kenetech Avian Research Task Force⁴

With growing concern that wind power plants present certain hazards to birds and cause some injuries and fatalities, in 1992 Kenetech Windpower assembled a group of outside experts to review information about avian collisions at the Altamont and Solano wind farms, where strong concerns exist about accidents involving raptors. This group is called the Kenetech Avian Research Task Force. It consists of five academic scientists with interests in raptor ecology and behavior, aerodynamics of avian flight, flight behavior and orientation, migration, and avian sensory physiology. The functions of the Task Force are to recommend and oversee specific areas of research needed to understand the interactions between birds and wind turbines, and to use the information (a) to help design ways to reduce the frequency of bird collisions, and (b) to assess the biological significance of wind farm-related fatalities. While trying to maintain the scientific rigor of these studies, the Task Force is aware that its recommendations for research have to be implemented within a socio-political arena in which the wind power industry is under regulatory constraint to "solve the problem" of individual bird fatalities, regardless of "whether raptor populations are significantly affected by turbine-related mortality".

Research Initiated

The Task Force feels that it is important to acquire precise quantitative data in sufficient quantities to allow reliable assessments and conclusions. After reviewing the existing reports on avian activities and fatalities in the Altamont and Solano plants, the Task Force was impressed by the fact that, although systematic searching turned up numbers of dead birds on the ground over the course of a year, the rate of accidents per turbine was so low that direct human observations of collisions were impractical for determining how and why birds get into trouble.

One approach to this problem has been to focus on controlled flights of homing pigeons in and amongst the turbines as a way to obtain quantifiable data on the behavior of birds during close encounters with wind turbines. Pigeons are not raptors, but the Task Force believes that much can be learned about general bird/turbine interactions from careful tests with pigeons. Pigeons released near strings of turbines during the daytime clearly recognize the turbines and, when necessary, adjust their flight to avoid them. Of about 2,270 study flights near turbines to date, three pigeons have collided with the turbines.

Another approach has been the development of automatic, machine-recording systems such as video monitoring. However, review of tapes is very time consuming, and the resolu-

⁴ The Peregrine Fund, Inc., 5666 W. Flying Hawk Lane, Boise, ID 83709

tion of standard video systems is a limiting factor. "Smart-camera" equipment that records only when a bird is detected may prove valuable, but its usefulness in this application is unproven.

Because visual observation and even standard video-recording do not provide an accurate location of a flying bird relative to other objects in three-dimensional space, considerable effort has been directed to the development of a tracking system that will automatically and accurately record the position of a flying bird as it moves through space near turbines. Such a system would allow researchers to measure and understand avoidance behavior or failure to avoid under a variety of conditions, and to demonstrate behavioral changes associated with modifications of turbines. A system employing two simultaneously recording video cameras has been field-tested and shows promise for yielding the needed information.

In order to modify turbines in ways to make them more avoidable by birds, it is necessary to know how birds perceive their world. In particular, we need to know their visual and auditory capabilities. To that end, the Task Force recommended a program of research, now under way at Boise State University, on the visual and acoustic capacities of raptors. American Kestrels and Red-tailed Hawks are being trained for use in these tests. Study to date on vision indicates that contrast, color, and rotation are the three most important variables influencing a raptor's detection of turbine blades.

Contrast between the blades and their background is most important. Thus, an effective warning pattern should maximize pattern contrast against environmental background, especially since birds, including raptors, have poorer ability than humans to resolve spatial frequencies at low contrast. It is hoped to begin field tests this year.

Early observations in the Altamont indicated that raptors perch on turbine towers and even on the blades when they are not rotating. Recent study shows that this behavior is more common than previously supposed, and that there may be a tendency for raptors to perch more often on end-of-row turbines, where fatalities are also indicated to be higher (Orloff and Flannery 1992). The possibility of a significant association between perching and collisions requires detailed investigations, which are under way.

It is desirable, from the standpoint of public perception and ethical considerations, to reduce bird collisions as much as practicable, not to mention the legal requirements to do so. However, the Task Force takes the view that some level of mortality associated with wind plant operations is acceptable, so long as it does not influence the long-term population viability of any species negatively. How fatalities at wind plants fit into the overall balance between natality and mortality of avian populations is the main biological question that needs to be addressed.

In the Altamont region, the Golden Eagle is the species of first concern. Numbers in the area are unusually high, and some are killed by collisions with wind turbines. The Task Force recommended in 1993 that a long-term study of eagle population dynamics be carried out in the region to determine the impact, if any, of eagle fatalities in the wind farms on the

associated breeding population of Golden Eagles. A one-year pilot study by the Santa Cruz Predatory Bird Research Group has been funded by NREL and Kenetech to obtain first estimates of relevant population parameters and to test study methods and identify needed resources for a multi-year project. Since January 1994, 31 adult and immature eagles have been trapped in the Altamont and equipped with radio-transmitters, and 25 nestling eagles from the surrounding Diablo Mountains have also been radio-tagged. Thirty-one active nests and 50 resident pairs have been located in the Diablo Mountain/Altamont region.

Recommended General Approach

After reviewing avian-wind power problems for two years, the Kenetech Avian Task Force feels strongly that adequate management of bird collisions at the wind plants must be approached at four levels. (1) Initial plans for siting wind farms must take into consideration the entire annual cycle and pattern of avian use of the proposed area. If the area proves to be one of high use and dense concentration for birds, then alternative sites should be sought. (2) The size and physical configuration of the wind plant, spacing of turbines, position of turbine rows, etc., need to be evaluated with respect to the kinds of birds and their activities in the area. (3) The structure of turbines and turbine towers should be designed to reduce collisions by reducing perching opportunities to a minimum. In addition, turbine blades should be patterned to maximize their visibility to birds under as wide a range of conditions as possible; exactly how to accomplish this remains to be worked out. (4) Where unpreventable fatalities may continue to occur, off-site mitigation can be helpful. For example, if Golden Eagles foraging in the Altamont continue to contribute to an increase to population-wide mortality, off-site mitigation to insure the long-term integrity of eagle nesting territories in the Diablo Mountains could do more to perpetuate population viability of eagles in the region than spending millions of dollars in efforts to eliminate all eagle fatalities on the wind farms.

Discussion

Homing Pigeon Releases.—Individual pigeons are released repeatedly, and presumably gain experience with wind turbines over time. It was noted that the relevance of the pigeon experiments has been the subject of much discussion.

Raptor Behavior and Mortality in Wind Plants.—Is there information on whether soaring birds take advantage of local updrafts caused by the turbines themselves? Answer: No, and it would be difficult to distinguish micrometeorological effects of turbines from those of the often-hilly terrain on which the turbines are situated.

What is the distribution of mortality relative to lattice vs. tubular towers? There have been suggestions that death rates of raptors in the Altamont are higher at turbines with lattice towers. However, interpretation is confounded by various factors, including the non-random distribution of turbine and tower types in relation to topography. The CEC report notes that causal links could not be isolated (Orloff and Flannery 1992, p. 3-80ff, 4-8 and 4-13). They note (p. 4-13) that "Any causal agent must be statistically associated with

mortality, but the association of a variable with mortality does not necessarily imply causation. We do not imply that any of the variables we found to be associated with mortality were actually causing bird deaths." Some meeting attendees commented that observations such as this should be treated as hypotheses that could be investigated by controlled tests.

Are birds found dead in the wind plant being autopsied to determine cause of death, and the possible contribution of debilitating factors such as lead poisoning? To some degree, but there are complications associated with the treatment of bird bodies as evidence for potential prosecutions. This is an example of a situation in which policy/legal questions have direct effects on research.

Golden Eagle Population Study.—What are the objectives? See following presentation (p. 40). One important objective is to determine whether the eagles killed in the wind plant are breeding birds, and whether the mortality is affecting recruitment into the breeding population.

No "control" Golden Eagle population is being studied as part of the present pilot study, but Golden Eagles have been studied elsewhere.

The Pacheco Pass area south of the Altamont has topography similar to that of the Altamont, and only a few wind turbines. No systematic study of birds has been done in that potential "control" area, but it seems similarly suitable for eagles.

Approach.—Regarding the suggestion that off-site mitigation could be more effective than costly efforts to eliminate all eagle fatalities on the wind farms, it was noted that this concept is not unanimously accepted from either an ethical or a legal perspective. Likewise, the view that some individual bird deaths are acceptable (legally or otherwise), provided that bird populations are unaffected, is controversial.

U.S. Federal Wind Energy Program Avian Research Projects

by

Robert W. Thresher, NREL⁵

The two-year study by BioSystems Analysis Inc. to examine the impact of wind turbines on birds in the Altamont Pass and Solano County wind resource areas has focused attention on avian mortality related to wind turbines. The BioSystems study concluded that there was significant Golden Eagle mortality due to collisions with wind turbines. However, the impact on the population of Golden Eagles normally using the Altamont Wind Resource Area was not addressed. NREL identified a population study of the Golden Eagles using

⁵ National Renewable Energy Laboratory, 1617 Cole Blvd, Golden, CO 80401

this wind resource area as fundamental to understanding the significance of the observed deaths.

A pilot study of the Golden Eagles in the Altamont Pass wind resource areas, and particularly on their population dynamics, has been initiated, as noted in the preceding presentation (p. 37). The University of California at Santa Cruz is carrying out this pilot study. The pilot study will develop methods to obtain preliminary estimates for the following population data:

1. Determine first estimates of the population of Golden Eagles using the Altamont Wind Resource Area.
2. Develop an estimate of the transient Golden Eagle using the area.
3. Identify what attracts Golden Eagles to the wind plants and what activities increase the risk of collision.
4. Estimate the yearly mortality rates caused by wind turbines and the impact on the overall population.

The primary focus of this study is to provide estimates for population data. In addition, the pilot study is to develop a comprehensive plan for surveying the Golden Eagle population in Altamont. The plan will recommend experimental methods and procedures, and provide a schedule and budget that will be based on the experience and data from the pilot study. The pilot study is to be completed in December 1994. In this way, proposed follow-on study plans can be based on real data and field experience, and the benefits of a more comprehensive study can be judged more accurately.

NREL regularly runs a solicitation to encourage university participation in the Federal Wind Energy Program. This past spring an avian research category was included in this solicitation as a high priority research topic. Boise State University's proposed research on avian perching and related mortality has been selected for negotiation of a research subcontract. The Statement of Work for this effort has not been completed at this time. The proposal outlined a series of experiments designed to determine the influence of perching on raptor mortality and to test anti-perching devices to determine their effectiveness. The research effort is planned for three years beginning this fall, but the "perching hypothesis" will be tested first and follow-on efforts adjusted accordingly. The wind industry partner for this proposed effort is Kenetech Windpower, and field experiments will take place in Altamont Pass.

The Utility Wind Turbine Verification Program sponsored by DOE and EPRI (p. 10) provides cost sharing for the deployment of small 6 MW wind power plants using the latest technology. Under this program, pre-construction environmental impact studies are being carried out to assess the potential impact on birds. In addition, several other high potential wind farm development areas are planning pre-construction avian monitoring studies, and the Federal Wind Program is considering support of these efforts.

Lessons from Utility Structure Environmental Impacts

by
Sheila Byrne, PG&E⁶

The first published account of birds colliding with overhead wires dates from the 1870s, shortly after the first telegraph wires were stretched across the prairies (Avery et al. 1980). Incidents were reported sporadically through the next century. Reports and studies of bird collisions with powerlines have greatly increased, starting with the early 1970s and the passage of the National Environmental Policy Act and the Endangered Species Act. Other impacts of utility structures on birds have similarly been documented. Birds collide with tall stacks and cooling towers. They are electrocuted on distribution and transmission lines, and rights-of-way modify their habitats. Birds, in turn, impact utility operations. They perch and nest on utility structures, shorting lines and fouling insulators and substations. Electrocutions often result in outages, and can cause fires.

These problems have been examined extensively for nearly 25 years. Several national meetings have been held on bird/utility issues. The most recent was in December 1993, in Miami, sponsored by the Electric Power Research Institute and the Avian Powerline Interaction Committee (APLIC) (EPRI 1993).

The paper is based on utility experience in two areas: biological and procedural. Particular biological lessons may or may not be applicable to wind turbine developments. However, I think that the procedural lessons are all applicable.

Biological Generalizations

- ▶ If you put it in the air, sooner or later a bird will fly into it.
- ▶ Collision vulnerability varies with species, age, sex, habitat use, weather, human disturbance, and especially location. Raptors and gulls seem less vulnerable than some other types of birds to collisions with power lines.
- ▶ Not all dead birds found under a line were killed by colliding with it, and it is often difficult or impossible to determine the specific cause of death.
- ▶ Although some problems can be solved solely by better engineering, knowledge of bird behavior is critical to finding quick and cost-effective solutions. For example,
 - ▶ During the 1970s, observations of a trained eagle landing on a test pole were helpful in identifying how to reduce the electrocution problem.
 - ▶ It is important to examine prospective warning devices from the bird's perspective, e.g. observing from a helicopter rather than from the ground.
- ▶ The significance of mortality depends upon the population affected.

⁶ Pacific Gas and Electric Company, 3400 Crow Canyon Rd., San Ramon, CA 94583

Procedural Generalizations

- ▶ It is difficult to get good estimates of collision mortality. It is easier to do a "worst case analysis" whose errors and unsupported assumptions will be copied in all subsequent studies. Reasonable correction factors for scavenger removal and search bias can now be obtained. Estimates of the percentage of birds crippled or lost in inaccessible habitats are difficult to obtain, and easy to misuse.
- ▶ Always do necropsies.
- ▶ Developing solutions to impacts requires good scientific studies, which are time consuming and expensive. These studies are not easily accommodated in the permitting process, even though the lack of these studies results in even more delay and expense to projects.
- ▶ The perceived significance of mortality depends upon many non-biological factors.

Avian Powerline Interaction Committee (APLIC)

Utilities have responded to the problems inherent in developing solutions to utility structure impacts on birds by forming a cooperative study group, the Avian Powerline Interaction Committee. APLIC has recently

- ▶ tested powerline marking devices, and
- ▶ developed a manual for studying and mitigating collisions with powerlines,

and is

- ▶ revising the manual on preventing raptor electrocutions.

APLIC's recommendations are widely accepted by utilities and agencies. In the author's view, the following factors have contributed to APLIC's success:

- ▶ it is a truly cooperative effort, involving not only agencies and utilities but also environmental groups and academic scientists,
- ▶ dedicated agency and utility biologists have nurtured it, often through periods of limited funding, and
- ▶ it has kept a limited focus, restricting its attention primarily to collisions and electrocutions.

Discussion

Other attendees who have been involved in APLIC reiterated the preceding comments on factors that have contributed to APLIC's success, and suggested several additional points:

- ▶ APLIC has been very successful in developing methods to reduce avian mortality due to electrocutions and to some degree to powerline collisions.
- ▶ APLIC has sponsored conferences to disseminate these results.
- ▶ It has been recognized that one can reduce but not totally eliminate bird deaths caused by powerlines. Through openness and cooperation, stakeholders have accepted this as a worthwhile objective.

- ▶ APLIC provides interested parties with information about the available options for dealing with bird collision issues; decisions as to how to use this information are left to the responsible groups.
- ▶ The use of standardized study methodologies is important to allow meaningful comparisons of results from different studies.

Bird/Wind Turbine Investigations in Europe

by

*J.E. Winkelman, The Netherlands*⁷

This presentation gave an overview of research carried out in Europe, with special emphasis on the results of the two most detailed studies. (1) Oosterbierum wind park, Netherlands, with 18 middle-sized (300 kW) turbines in cluster formation on 55 ha of arable land close to the Wadden Sea (Winkelman 1992a-d). (2) Urk wind park, Netherlands, with 25 middle-sized (300 kW) turbines in line formation along a 3-km dike bordering lake IJsselmeer, a major wintering area for ducks (Winkelman 1989). Most results of other European studies are consistent with those from these two areas. The main exception is the recent work in southern Spain (p. 48), where bird mortality (mainly of raptors) has been more evident than in the Netherlands.

A more detailed version of this presentation, including Tables and a Bibliography of European bird-wind power research, appears as Appendix 2B (p. 110). English-language summaries of the Winkelman (1989, 1992a-d) reports on the Urk and Oosterbierum studies appear in Appendix 2C (p. 121).

In Europe discussions about the possible impact of wind energy on birds started in the late seventies, when the first national wind energy strategies were formulated and the first (mostly small sized, solitary) wind turbines were erected. This was followed by a huge number of speculative articles in newspapers, magazines and popular scientific journals, nearly all of them focusing on the possible collision risks for birds. The first research results became available in Sweden, Denmark and The Netherlands in 1983 and 1984, again followed by many articles and reports on possible effects, pre-construction studies, progress reports, and overview studies.

To date, 14 studies have been finalized in Europe, covering 108 different sites with one or more wind turbines. These studies were in southern Sweden (2 studies, 2 sites), Denmark (3,18), northern Germany (1,10), Netherlands (6,85), and United Kingdom (2,3). Research is now underway or will start soon in the south of Spain, The Netherlands, and Denmark.

⁷ DLO-Institute for Forestry and Nature Research, POB 23, NL-6700 AA Wageningen, The Netherlands. *Present address:* BirdLife/Vogelbescherming Nederland, Driebergseweg 16-C, NL-3708 JB Zeist, The Netherlands.

Most studies include small, solitary turbines (<100-150 kW). Wind parks, and especially middle-sized (250-500 kW) and large (MW) turbines, are less studied. Three general topics have been studied:

1. Collisions with rotor, tower, power lines;
2. Disturbance (usually without much habitat modification):
Loss of habitat for breeding, feeding, migration;
3. Behavioral Changes:
Flight behavior when approaching wind turbines.

Bird Collisions

Studies on bird collisions were mostly carried out by searches for dead birds. The proportion of birds colliding in relation to the total numbers passing the wind turbines was studied at 13 sites. Estimates of the total numbers of bird victims could only be made in three studies (3 sites), as the other studies did not take into account the search efficiency, predation pressure, number of days with searches, causes of death of the corpses found, and/or total areas searched. These factors may all have strong effects on total estimates. It was proven that, even with careful searching, the proportion of the bird bodies found could be low, especially for small birds in high vegetation.

At the 108 European study sites, a total of 303 dead birds were found, of which at least 124 (41%) were proven collision victims. In the Dutch Oosterbierum wind park, only 27% of all birds found were killed by collision. It is noteworthy that there were no nights with large kills, that very few collision victims were found near small wind turbines, and that almost all victims were of common species. Virtually none of the victims were scarce or rare species. Estimated average numbers of collision victims in the Oosterbierum and Urk wind parks, in birds per turbine/day, varied between 0.04 (Urk, autumn) and 0.09 (Oosterbierum, spring), depending on season and site. These figures were based on regular searches.

Based on nocturnal observations with a thermal image intensifier in the Oosterbierum wind park in autumn 1988, an estimated 170 birds collided with turbines during seven consecutive nights, or 0.051 dead birds/h/100 m front. This was equivalent to 2.5% of all birds passing at rotor height (20-50 m). In both the Oosterbierum and Urk studies, most bird victims were found after nights with both poor flight conditions and visibility. Mean numbers per kilometer of wind park are comparable to the numbers of birds killed by traffic per km of highway, and comparable to or somewhat lower than the numbers of victims per km of power line in risky situations. Total numbers likely to be killed per 1,000 MW of wind power capacity are low relative to other human-related causes of death.

In the Oosterbierum wind park, only a few birds were seen very close to a rotor during daylight. Of these, one (14%) was hit and killed. During the night, 20% of all birds crossing a rotor were killed. It was noteworthy that not all observed collisions were fatal, and that some "collisions" were caused by the wake behind the rotor. In the latter cases, birds that

did not contact the rotor were sometimes swept down by the wake, and injured or killed as a result.

Disturbance and Habitat Loss

Several studies evaluated the effects of disturbance and habitat loss on numbers of birds present. Five of these studies concerned loss of habitat for breeding birds (mainly waders). Three studies concerned resting birds (several larger bird species), three concerned daytime migrants and two concerned nocturnal migrants—largely songbirds.

Habitat loss/disturbance effects were demonstrated at distances up to 250-500 m from the nearest turbines.⁸ The reduction in the numbers present in the disturbed zones ranged up to 95%. Some bird species were far more vulnerable than others, and vulnerability depended on site, season, tide, and whether or not the wind park was in operation. Breeding waders seemed less vulnerable than some other birds. However, those results may have been confounded by the high site fidelity and long life spans of waders, coupled with the fact that the studies were carried out for only one or a few breeding seasons. *From a European nature conservation point of view, disturbance/habitat loss effects associated with wind plants are thought to be of much more importance than direct bird mortality due to collisions.* However, the ongoing study in Spain (see p. 48) may be an exception to this generalization.

Flight Behavior

Changes in flight behavior during migration were examined during seven studies of day-time migration involving 28 wind turbine sites, and during three studies of nocturnal migration at three sites. Aspects studied included numbers and types of reactions. These were mostly within 100 m of the nearest turbine during diurnal migration, and within 20 m of a rotor during nocturnal migration. Changes in flight paths were also studied. During diurnal migration these changes mostly occurred within 300-500 m.

During daylight, proportionally fewer of the migrating birds reacted when the turbines were not operating than when turbines were operating (2% vs. 11-18%). The frequency of reactions with turbines operating depending on the distance between the turbines, with reactions being more frequent when the turbines were 150 m apart than when they were 300 m apart. During the day-time, most reactions were calm and gradual, mainly consisting of horizontal shifts. Only a minority of the approaching birds needed more than one passing attempt before crossing the wind park.

⁸ Habitat loss/disturbance effects were shown by generalized linear regression analyses relative to distance from windplant, and by analysis of variance of bird counts on a control site and a wind-park before and after it was constructed. The latter approach, including both spatial and temporal controls, met the requirements of a BACI design (Before-After Control-Impact). The BACI design has been considered optimal for field studies of environmental impact (Green 1979).

In the Oosterbierum wind park only a very few birds were seen within 20 m of a rotor during daylight. Nocturnal migrants were more commonly seen within 20 m of the rotors. During the night, reactions of 47 birds within 20 m of a rotor were observed by means of a thermal image intensifier. Of these, 43% approached without hesitation. The proportion of the birds that reacted depending on the wind direction. Birds flying with headwinds were more likely to react, perhaps because they encounter the rotor wake before reaching the operating rotor. During the daytime, 15% of the closely-approaching birds altered their flight paths calmly to avoid crossing the rotor, whilst at night 36% did so. The other birds all crossed or tried to cross between the rotor blades. While doing so, most of them either flapped their wings powerfully or fluttered.

Discussion

Migration Behavior and Collisions.—In Dr. Winkelman's opinion, direct collision mortality with wind turbines does not now constitute a significant biological problem for bird populations in most of Europe; Spain may be an exception. This conclusion was discussed at some length. It is not established whether this conclusion applies to wind plant situations in the United States, or that it would apply after larger scale wind development in either continent. Also, it was noted that bird deaths may be a legal, ethical or political problem whether or not they are significant in the context of bird population dynamics.

What will be the impact on birds of offshore wind plant developments planned for Europe? Initially, offshore wind plants will be near the shore. However, there are proposals for wind plants up to at least 10 km offshore, e.g. between Denmark and Sweden. Nothing specific is known about their effects on birds. Also, little is known about the effects of coastal wind plants on nocturnal migrants flying low along coastlines. (But see Buurma and van Gasteren 1989.)

Were field observers aware of the hypotheses being tested when they were categorizing behavioral reactions to the turbines? Yes, it was not possible to do this in a "blind" manner. In the Netherlands, it has proven to be very important to use observers who are highly experienced in visual observation of migration. Also, it should be noted that some key observations were based on videotape, where there is a permanent record of the event. The birds thrown to the ground by the turbine wake were documented on videotape.

Why is the kill rate so much higher in the Netherlands, e.g. 0.05 birds/turbine/night during migration, than in the Altamont? What are the implications of proposed wind developments in other parts of the United States with different species and numbers of birds, and with concentrated migration corridors? The amount of nocturnal migration at low altitude is probably considerably higher near the Netherlands coast than in the Altamont. During nights of high-density nocturnal migration, on the order of 4,000 birds/night pass over the Oosterbierum wind park at low altitudes (0-50 m above ground). Some parts of North America are also known to have higher rates of nocturnal migration than have been documented in California. However, in most areas little is known about the proportions of the nocturnal migrants that are at altitudes low enough to encounter wind turbines. In any

case, the Altamont, with a very high density of Golden Eagles and other raptors, is not comparable to areas of Europe and North America with fewer raptors but concentrated nocturnal migration. Many participants believed that the types and numbers of birds that would collide with turbines in some parts of North America will differ widely from those documented in the Altamont.

In the U.S.A., collisions are so infrequent at any given turbine that it is impractical to observe them directly. In Europe, are collisions common enough to allow direct study? Even with the higher collision rate in the Netherlands, collisions are infrequent events. They can be observed directly, but these observations are very labor intensive. It took one year to analyze the thermal imaging recordings obtained on 17 nights. Automated techniques for video review were investigated in the Netherlands several years ago. At that time there did not seem to be any practical automated method for automated video review. New technology for video surveillance might now allow automated detection of birds. However, meeting participants were not aware of any case where this has been implemented for birds in a field situation.

What is the present state of knowledge about the effects of lighting on collision rates at night? Large numbers of nocturnal migrants occasionally collide with tall structures that are continuously lit, e.g. by floodlights, by interior lighting visible through windows, or by steady or slowly-flashing red lights. On these rare occasions with much mortality, there is usually fog or drizzle. On these nights, migrants are attracted to the lights; many individuals circle or hover near the lights. Many fewer nocturnal migrants collide with structures illuminated by flashing white strobe lights.

Disturbance and Habitat Loss.—What attributes of wind parks in the Netherlands cause reductions in bird densities in habitats near those wind parks? This is not known. Noise and movement are possibilities. However, the same disturbance effect has been noted at a noisy and a quieter wind park, suggesting that turbine noise may not be the main factor.

Why do disturbance effects extend several hundred meters from a wind park, when the literature suggests that, for birds, maximum disturbance distances around other "public access areas" are more typically about 50 m? This is not known. Because of the relatively large radius of effect in Europe, questions have been raised as to whether it is better

- ▶ to have a few large wind parks rather than a large number of small ones, and
- ▶ for turbines to be in line or cluster formation.

Was there any possibility that the disturbance effect was partly an artefact of observer bias? No, the effect was real. The same types of counts were done at varying distances from the turbines, on control as well as wind park areas, and before construction as well as during wind plant operations. The same observers were involved in all of this work.

Bird/Wind Turbine Investigations in Southern Spain

by
*Ramón Martí, Spain*⁹

Ramón Martí noted that he was presenting preliminary results based on the first few months of an ongoing study. This work is being conducted by Luis Barrios and Enrique Aguilar, from Sociedad Española de Ornitología (SEO/BirdLife Spain) under contract with the Agencia de Medio Ambiente de Andalucía (Andalusian Environmental Agency).

Wind development in Spain is now concentrated at Tarifa, at the southern tip of Spain near Gibraltar (Fig. 1). The average wind speed at Tarifa is 6.5-7.5 m/s, which is not as high as at some other locations in Spain. However, the Tarifa area is attractive for wind power development because useable winds blow on over 95% of the days of the year.

Tarifa, the Spanish edge of the Strait of Gibraltar area, forms one of the two main "bottle-necks" for concentrated bird migration in the Mediterranean basin. The other is the Bosphorus Strait around the eastern Mediterranean, between the Balkans and Turkey. A third route, less important compared with the other two, is across the Messina Strait, Italy (Fig. 2). Large numbers of migratory birds, including a high proportion of the soaring raptors and storks that nest in Western Europe and winter in Africa, migrate through the Tarifa/Gibraltar area. Finlayson (1992) provides a recent general review of bird movements and populations in the area. About 20 species of soaring birds totalling at least 300,000 individuals migrate through the area in autumn. The Honey Buzzard, Black Kite and White Stork are especially common, along with large numbers of non-soaring birds.

Because of the importance of this area for migratory birds, the area has been given international recognition as an "Important Bird Area" by the ICBP (International Council for Bird Preservation), now called BirdLife International. It has also been declared a "Special Protection Area" under European Union Directive 79/409 on conservation of wild birds. Furthermore, because of the migratory birds and other natural values, it has also been declared a Natural Park by the Andalusian Government.

The main migration axis for soaring birds in the Tarifa area during fall migration, when there are many more birds than during spring migration, is NNW-SSE under the dominant easterly-wind conditions (Fig. 3). Several wind parks have been established within the area traversed by soaring birds on migration. Many of the turbine strings are aligned roughly parallel to the main NNW-SSE migration direction, but some strings cross that axis at an angle (Fig. 3). Large numbers (hundreds or thousands) of soaring birds sometimes land and roost on flat ground or promontories in the Tarifa area, including some locations with existing or proposed wind turbines, while waiting for weather conditions good for crossing the sea.

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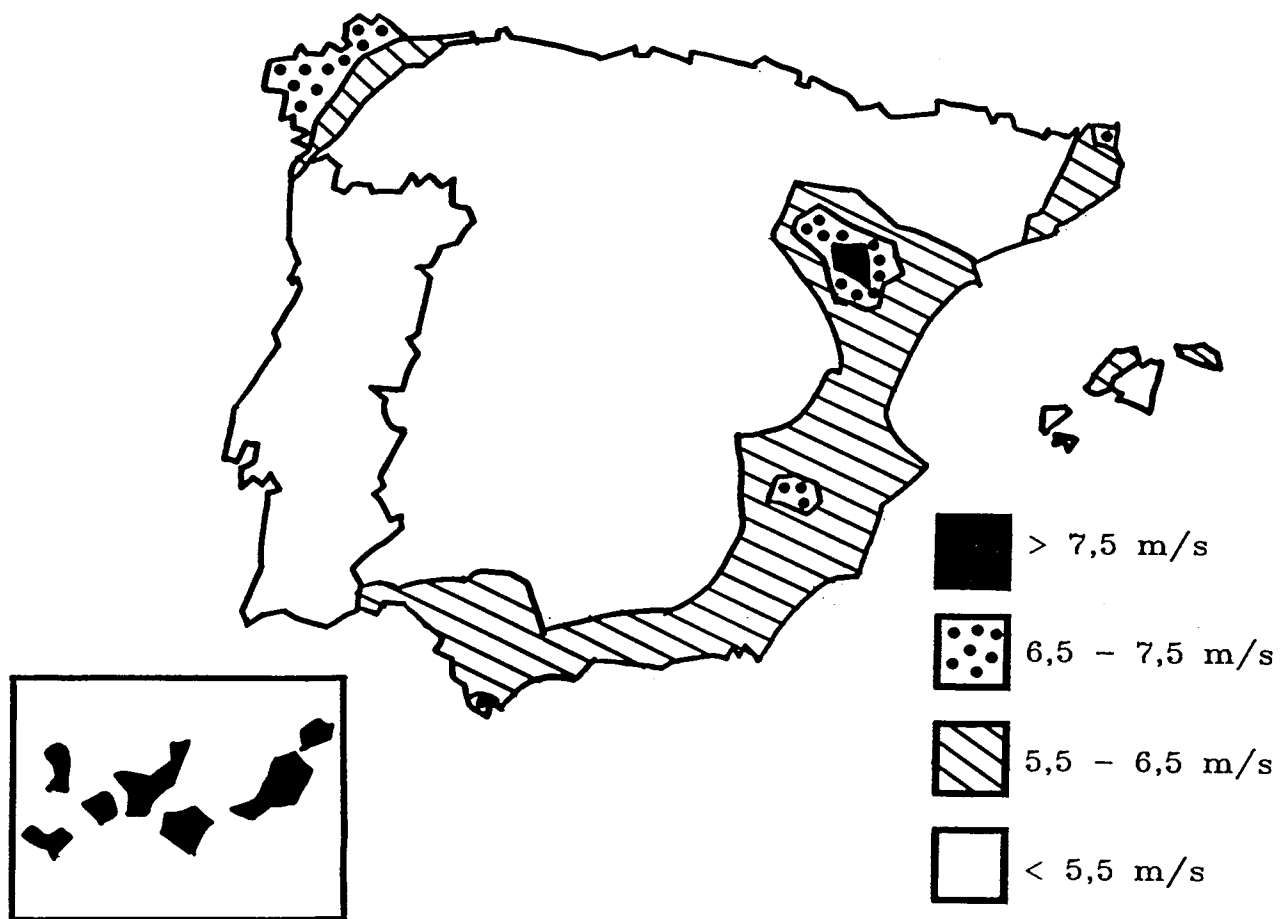


Figure 1. Wind resource potential in different parts of Spain.

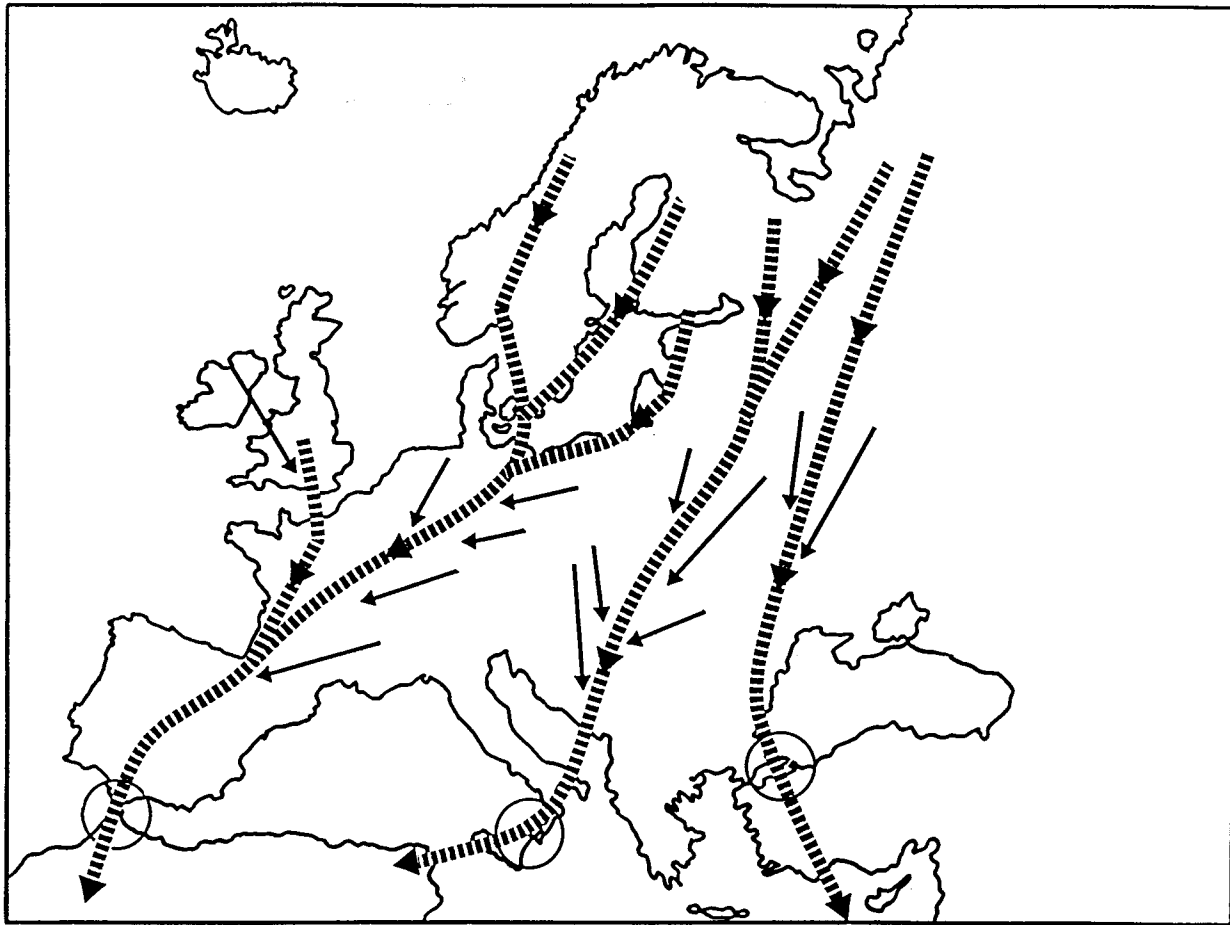


Figure 2. Main autumn migration corridors across and around the Mediterranean Sea for birds departing from Europe.

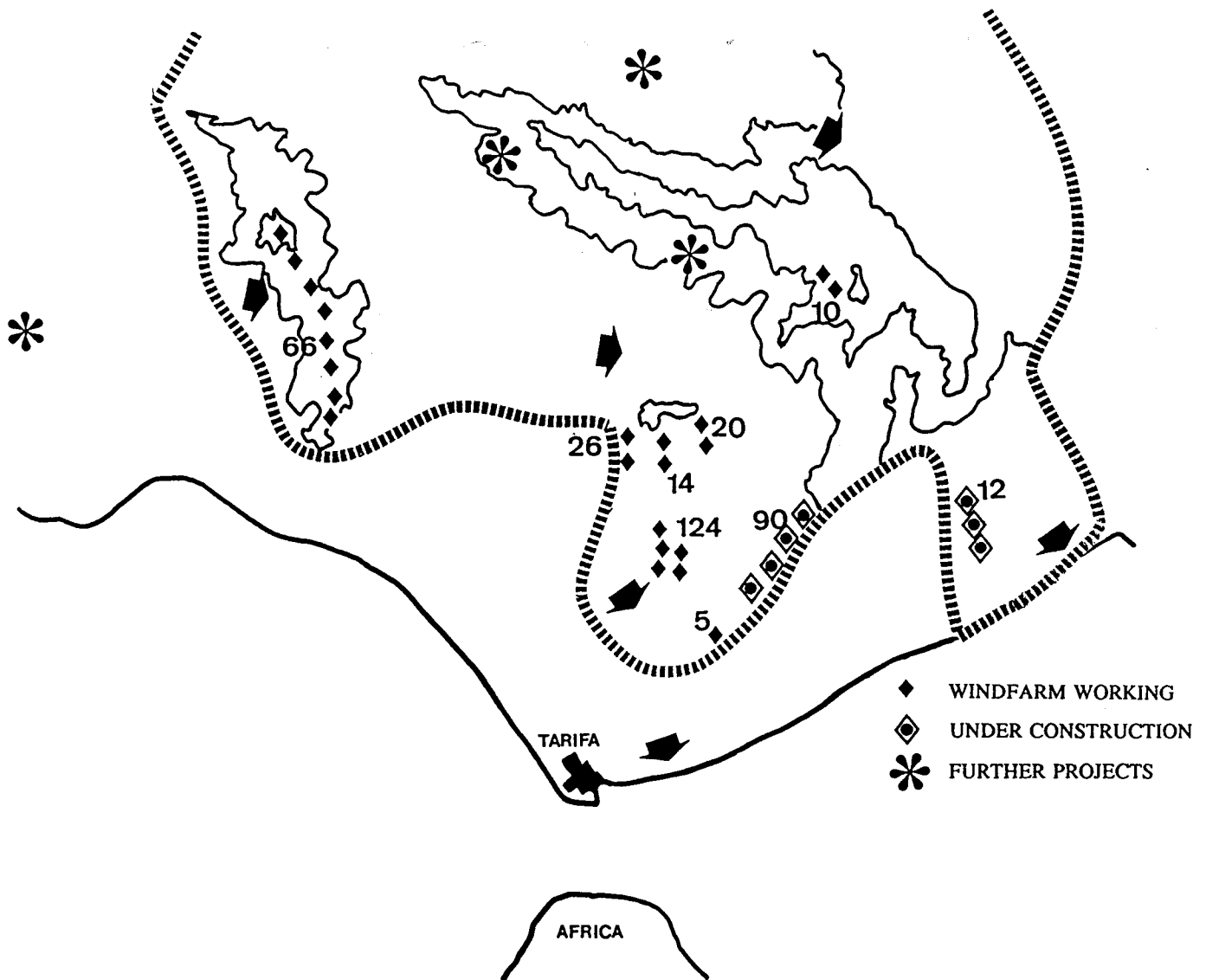


Figure 3. Tarifa area of southern Spain, showing main autumn migration corridor of soaring birds (arrows) with the prevailing easterly winds, in relation to the positions and orientations of strings of wind turbines. Numbers refer to the number of wind turbines in various areas.

The SEO/BirdLife study now underway includes searches for dead birds near the turbines plus direct observations of the behaviour of soaring birds nearby. During the first few months of study, a number of birds killed by collisions with turbine blades have been found. These have raised concern at SEO/BirdLife Spain. The casualties include 14 protected species, but the majority were Griffon Vultures¹⁰. They are large and relatively unmanoeuvrable birds that depend on slope-winds and thermals. This study, and another one on wind resources, will provide the basis for further rational development of wind energy in Tarifa area, if appropriate.

No studies of nocturnal migration in relation to wind power development are being done in the Tarifa area. In general, the region near the Strait of Gibraltar is known to be an important corridor for nocturnal migration of passerines and other species travelling between Western Europe and Africa, based on radar and (to a lesser degree) moon-watch studies in past years. This nocturnal migration, and the daytime migration of non-soaring species, occurs on a broader front than does the daytime migration of soaring raptors and storks.

¹⁰ A report on the results of this study is expected to be completed soon for the Agencia de Medio Ambiente de Andalucía (Andalusian Environmental Agency). Detailed results had not been released when these Proceedings were finalized.

DESIGNS FOR AVIAN-WIND POWER RESEARCH

This part of the meeting included

- ▶ an initial presentation by S.A. Gauthreaux on standardized assessment and monitoring protocols;
- ▶ follow-up discussion by meeting attendees, e.g. on the degree of standardization that is desirable and on approaches during bird mortality searches;
- ▶ a presentation by T.D. Nudds on a conceptual framework for avian-wind power research, including the Adaptive Resource Management approach and how one might consider integrating diverse types of studies;
- ▶ follow-up discussion by meeting attendees.

Standardized Assessment and Monitoring Protocols

by

Sidney A. Gauthreaux, Jr., Clemson University¹¹

Monitoring studies of birds in relation to wind power development can involve

- ▶ preliminary site selection surveys;
- ▶ pre-construction surveys of bird populations, movements and mortality at specific proposed sites;
- ▶ post-construction monitoring of bird populations, movements and mortality at operating sites;
- ▶ special monitoring studies related to development of mitigation methods; and
- ▶ monitoring of decommissioned wind plant sites.

The techniques that can be employed to study avian-wind turbine interactions are strongly dependent on the questions that must be answered. If questions are related to environmental impact studies where pre-construction monitoring of bird movement may be required, then the techniques used are very different than those that might be used to study the influence of tower designs on avian mortality at wind turbine sites.

In this presentation, I concentrate on techniques that can (and should) be employed to monitor bird movements within a few hundred feet of the ground during the day and at night, and to assess bird injury and mortality during pre- and post-construction studies. Some of the same methods could be used during preliminary site surveys or to monitor decommissioned sites, if and when that becomes necessary.

In general, the objectives of pre- and post-construction monitoring studies are to gather data that can be used to assess the impact of wind plant development on avian populations.

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Pre-construction data are needed

- ▶ to predict the impact of a proposed wind plant, and
- ▶ as a baseline for measuring impact if the wind plant is later constructed and monitored.

It is important to ensure that data for the pre- and post-construction periods at a given wind plant are comparable, and that data collected at different sites can also be compared. To this end, there is a need for agreement on units of measurement. When questions in different areas are similar, standardized methodologies are recommended to allow meaningful across-study comparisons. The experience of the APLIC avian-power line interaction group (p. 41) has demonstrated the importance of standardized study methodologies.

Preliminary Site Selection Surveys

Existing information on types of birds (e.g. raptors), their densities in potential project areas, and their flight patterns should be used in helping to select the locations of potential wind turbine projects. Existing information that should be taken into account would include occurrence of

- ▶ Endangered/Threatened species;
- ▶ Candidate species;
- ▶ Species of Special Interest/Concern;
- ▶ Neotropical migrants, some of which are declining in numbers and most of which are predominantly nocturnal migrants;
- ▶ Migratory species, which are protected under Migratory Bird Treaty Act.

It will be important to take account of the types of habitats present in the area when predicting the occurrence and numbers of various types of birds.

If these types of general information about birds and habitats are not available for the area of interest, then some monitoring of bird populations and movements at potential wind turbine sites may be needed so site selection can be made with reference to potential bird collision problems. It is important to use generic methods so data from different studies can be compared. Methods will vary somewhat depending on circumstances (e.g. different topographies, different types of birds) so some flexibility in methodological detail is required.

Pre- and Post-Construction Surveys

Bird Populations.—There are existing standard methods for conducting studies of bird populations in various circumstances. For example, one can use

- ▶ Breeding Bird Censuses (BBC) to determine species present and number of territories per 40 hectares; and
- ▶ Winter Bird Population Studies (WBPS) to determine species present and average numbers per visit per 40 ha.

Methods similar to the WBPS can be used to quantify numbers of migrants at migration stopover sites.

There is a very large literature on methods for bird census work. Much of this is summarized in Ralph and Scott (eds., 1981) and Bibby et al. (1992).

Bird Movements.—Again, it is essential that standardized methodologies be developed and implemented for studies of bird movements at planned and existing wind turbine sites. There is a need to document low-altitude movements, migratory and local, and to distinguish birds that are at risk because of their low flight altitudes from those flying higher and not at risk. The protocols should address the following topics:

- ▶ Observer skills, which vary widely;
- ▶ Observation periods: daytime and nighttime; seasonal;
- ▶ Data requirements: data sheet design can be flexible provided the key variables are recorded in a manner that can be compared with other studies;
- ▶ Altitude of flights; flight directions;
- ▶ Observation techniques: direct and indirect visual, closed circuit television, image intensification, forward looking infrared (FLIR), marine surveillance radar (preferably 10-25 kW peak power), fixed beam radar. It is important to use these techniques in a way that quantifies the low-altitude bird movements that are potentially at risk of collision.

Searches for Dead and Injured Birds.—To assess the rate of collisions with wind turbines, meteorological towers and power distribution lines, searches for dead and injured birds should be made before and after periods of monitoring flight activity. It is essential that collision rates be expressed in terms of the percentage of birds passing through the "envelope of risk", as determined by the previously-mentioned methods for quantifying low-altitude bird movements. There is a potential for birds to collide with meteorological towers that are used, prior to wind turbine construction, to assess wind resources in planned project areas. Searches for dead and injured birds should be done near these towers as part of any pre-construction assessment. Once turbines have been placed at a site, searches should be conducted in a way that will allow determination of the cause of the collision whenever feasible.

The following issues should be addressed when designing a search program:

- ▶ Search area;
- ▶ Timing and frequency of searches—ideally both early morning and late afternoon, to partition mortality between day and night. (If there is significant mortality, this information would be needed to design effective mitigation measures.)
- ▶ Data records for collision victims, including position relative to nearby structures, associated weather;
- ▶ Biases in injured and dead bird searches: search bias, removal bias, habitat bias, and crippling bias, on a species- and site-specific basis. (These data are difficult to acquire but necessary when quantifying mortality.)

- ▶ Necropsies to determine cause of death;
- ▶ Estimating total collisions and collision rates; what is the denominator in rate calculations?

Conclusions

If pre- and post-construction studies use standardized methods of monitoring bird movements and measuring mortality, a reliable data base can be accumulated in a relatively short period of time on a continental scale. These data will be very useful in determining the species of birds that are at risk in different geographical areas as well as the severity of the problem in different geographical regions. Once this information is acquired, specific research initiatives can be developed to eliminate or greatly reduce the risk of avian mortality at wind turbine sites.

Discussion

How Important is Standardization?—Attendees agreed that there was a need for rigorous and defensible survey methods that would provide reliable estimates of bird populations, movements, and expected or actual mortality. However, there was no clear consensus on the degree of standardization of field survey methods that would be best to achieve this objective. In particular, several attendees questioned whether strict standardization is really necessary or appropriate, provided that the methods used are well-defined and repeatable.

Some attendees suggested that emphasis should be placed on use of consistent methodologies within a given study area, so as to facilitate pre- vs. post-construction comparisons. Although there was no disagreement with the need for consistent methods within a given area, other attendees noted that it should not be assumed that a wind plant would be approved or built wherever a pre-construction study is done. They noted that it is also important to obtain consistent data allowing comparisons of different proposed sites, and that across-study standardization would facilitate those comparisons.

Points raised by some meeting participants in favor of standardized methods included the following:

- ▶ bird-wind power research is a relatively new discipline; it is not too late to attempt to establish consensus on a common set of standard methods;
- ▶ after a set of standard methods is defined, funding agencies might make it a prerequisite that projects incorporate those methods;
- ▶ some investigators would welcome the availability of a recommended or required set of research guidelines;
- ▶ in the absence of standardized methods, comparisons between sites are subject to criticism and may be discounted;
- ▶ standardized methods allow some comparisons of results from different studies even if it has not been possible to fully correct for detection biases and other methodological limitations. Although it is important to quantify the precision and biases of

monitoring methods, practical experience has shown that many studies with limited resources are unable to fully evaluate their methods, notwithstanding the recognized desirability of doing so. These limitations often can be reduced by using standardized field methods;

- ▶ attendees who had been involved in the APLIC avian-powerline interaction committee (p. 41) emphasized that it had been APLIC's experience that lack of standardization was a serious problem, and that one of APLIC's main accomplishments had been to highlight the need for standardized survey methods.

Some alternative points were raised by attendees who considered total standardization impractical, unnecessary, and in some cases undesirable:

- ▶ there have been many attempts to require and enforce standardization in various research fields, e.g. wildlife habitat assessment. It has proven to be virtually impossible to get scientists to agree on the most appropriate methods;
- ▶ standardized methods may not be appropriate because site-specific differences in types of birds present, environmental conditions, and other factors may result in legitimate requirements for different research techniques during different studies;
- ▶ standardized methods are not essential provided that the methods used provide reliable known-precision data on the required parameters;
- ▶ detection and counting biases vary depending on habitat, species, observer, etc., so systematic evaluations of biases are required whether or not standardized methods are used.

In summary, meeting attendees agreed that monitoring methods need to be designed to provide reliable and defensible data that can be compared among studies. Attendees were not able to reach consensus on the degree of standardization of methods that would be optimal to achieve this objective. Further consideration is needed.

Methods for Monitoring Populations and Movements.—It was suggested that, besides determining total numbers of birds in large areas (e.g. by techniques like Breeding Bird Censuses and Winter Bird Population Studies), it is also important to determine the specific distribution of birds in and near proposed or existing wind plants. The latter data are needed for analyses of disturbance/habitat modification effects of the type documented in the Netherlands (see p. 45, 114). These data need to be collected before as well as after construction, to allow proper comparisons (temporal control). Also, they should be collected in an adequate number of nearby control areas before as well as after construction of the wind plant, to help determine whether pre- to post-construction changes were truly attributable to the wind plant and not to some other factor that changed over time (BACI or "Green sequence" design, see Green 1979; Underwood 1992).

When monitoring bird movements, either migratory or local, several attendees re-emphasized that it is important to apply methods that quantify bird movements at low altitude, e.g. below 50 m. Methods that provide counts of all passing birds, regardless of altitude or horizontal distance, are not very useful. The horizontal as well as the vertical

distance within which birds are counted needs to be restricted in order to obtain reliable and useable data on the Migration Traffic Rate or MTR.¹² Combinations of observation techniques are usually necessary to obtain comprehensive and reliable bird movement data by day and night on a species-specific basis, e.g. radar plus direct visual methods by day; radar plus image-intensifier or thermal imaging (FLIR) methods at night.

Monitoring of Collisions With Surrogate Tall Structures.—Wind power developers often prefer to site wind plants near existing transmission lines. Do existing studies of bird-powerline interactions provide a sufficient database for use in lieu of preliminary site-selection surveys or pre-construction surveys? No, because bird-powerline interactions have been studied for only a low percentage of powerlines, and because most of the existing studies were not done with adequate, well-defined, and standardized methodology.

During pre-construction surveys, would it be useful to monitor mortality at existing tall structures such as TV transmission towers? Mortality at structures whose heights greatly exceed those of turbines would not provide realistic information about the types and numbers of birds that might collide with a future wind plant. However, some attendees felt that it could be useful, during pre-construction surveys, to monitor bird collisions with meteorological towers or other structures similar in height to planned wind turbines.

To this end, would it be useful to set up many meteorological towers or "dummy" turbines during the pre-construction phase and to monitor collision rates? Perhaps the structures should include turbine towers with and without blades. Some attendees thought that this type of study could be useful, but noted that the required effort and cost would be substantial.

The objectives of any study that erected different types of structures and compared bird collision rates would presumably be more specialized than those of a "standard" pre-construction survey. This type of study might determine the relative contributions of various turbine attributes to the bird collision risk—an objective different from the objectives of a standard pre-construction survey. It was pointed out that the objectives, need and priority for any study of this type should be clearly defined in advance.

During one of the Netherlands studies, there was a 1½-year period when turbine towers without rotors were present and bird collisions were monitored. There were very few collisions with these towers, or with turbines whose blades were stationary. Based on this, plus experience concerning the rarity of bird collisions with various types of utility poles, some attendees felt that there was little to be gained by studying bird collisions with stationary towers. Others felt that further work along these lines would be needed as part of any study to determine which attributes of turbines contribute to bird mortality. How-

¹² Migration Traffic Rate is usually expressed in birds per kilometer of front per hour, where the "front" is a line perpendicular to the direction of travel. In this application, MTR should be restricted further to birds/km/h below some appropriate altitude, e.g. 50 m.

ever, this type of study would have different objectives than a standard pre-construction monitoring study.

Control Data on Bird Mortality.—There was some discussion of the value of bird mortality searches during pre-construction monitoring and at control sites during post-construction monitoring. Some attendees suggested that mortality searches in the absence of turbines were too unproductive to be worthwhile, and that mortality attributable to the turbines could be identified by necropsies of birds found in wind plants. Other attendees felt strongly that, for a proper evaluation of the number of dead birds found near turbines, it is essential to have comparable data on the number of dead birds that would be present in the same area and/or a nearby comparable area in the absence of turbines. The latter attendees noted that it is often impossible to be certain of the cause of death of when bird remains are found in a wind plant. The remains have often been moved and/or partially consumed by predators.

Conceptual Framework: Adaptive Resource Management and the Integration of Diverse Studies

by
*Thomas D. Nudds*¹³

This presentation began with some reminders about the scientific method, including the fact that it produces no absolute and final answers: Current knowledge is always an imperfect model of whatever is the truth. One of the major values of the scientific method is that it provides a way to get from a situation of having unconnected observations to a situation in which one has organized knowledge. At present, the avian-wind power field seems to be largely at the stage of having a few observations and many opinions, but little organized knowledge. Observations and opinions can serve as the basis for formulating hypotheses, but these are not final answers in themselves. Instead, they need to be tested by properly-designed scientific investigations.

Adaptive Resource Management (ARM)

Traditionally, most scientific experiments are done at least partly in isolation from the "real-world" situation that is of ultimate interest. However, many hypotheses about environmental phenomena are not easily addressed on a sub-scale, controlled, laboratory basis. These hypotheses are usually difficult to test by traditional methods because a "real-world" experiment would have to occur on a large scale and over a long period, and would have complex logistics, high costs, and few or no opportunities for replication.

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Management actions in the "real world" must often be taken even in the absence of organized scientific knowledge about the phenomena being manipulated. These "real-world" actions often have some of the characteristics of a large-scale experiment even when they were not designed as such. They may also be on scales larger than would be practical for most individual experimenters. With proper design, management actions can be implemented as experiments whose outcomes can be used to improve both future management actions and scientific knowledge of the underlying phenomena. "Proper design" will normally involve a testable hypothesis, systematic measurements, controls, and replication.

Adaptive Resource Management (ARM) is an iterative approach in which policies are treated as hypotheses and management actions are implemented as experiments (Walters 1986; Walters and Holling 1990). In general, there is a parallelism between the policy/management paradigm and the hypothesis/experimentation paradigm (Fig. 4). This allows policies to be tested through management actions implemented as experiments. Based upon the outcome of such an experiment, policies may be changed or refined and further tested by another stage of management action implemented as an experiment.

"In the broadest sense, ARM is done whenever the dual goals of achieving management objectives and gaining reliable knowledge are accomplished simultaneously. With ARM, we acknowledge the uncertainty about biology that underpins our prescriptions for management, so the prescriptions are treated as predictions that should be verified or refuted. If refuted, knowledge gained in the process provides new and better prescriptions. This adaptive process mandates articulation of underlying assumptions and implementation of management by designs that allow predictions to be tested with adequate statistical power. Thus, ARM treats every management action as a potential learning opportunity that can feed back more reliable information in a process of continuous quality improvement." (Lancia et al. 1993)

It is proposed that many questions about bird-wind power interactions could best be addressed in an ARM context. For example, collisions with wind turbines, at least in the Altamont area, are too rare to allow meaningful study in small-scale experiments. However, when wind plants are built, it should be possible to use this as an opportunity to conduct larger scale experiments. For example, by installing and monitoring two types of wind turbines in a "split-plot" arrangement in an area where there had also been pre-construction monitoring of birds, bird behavior and mortality at the two turbine types could be compared. If the same two designs were also installed in a similar arrangement in at least one other wind plant, the design could be replicated. Other aspects of turbine design or spacing could also be tested at the same or other wind plants. These experiments would be done while wind energy was being produced, thus recouping some of the costs of the experiments. The results could be used to refine the design of future expansions or new wind plants.

This approach would involve some costs and complications over and above the basic cost of establishing and operating a wind plant. There would be a need for detailed bird studies before and after construction. There might also be some extra costs or inefficiencies associated with use of different turbine designs or layouts in different parts of the wind plant. For optimum results, coordinated designs should be implemented at two or more wind

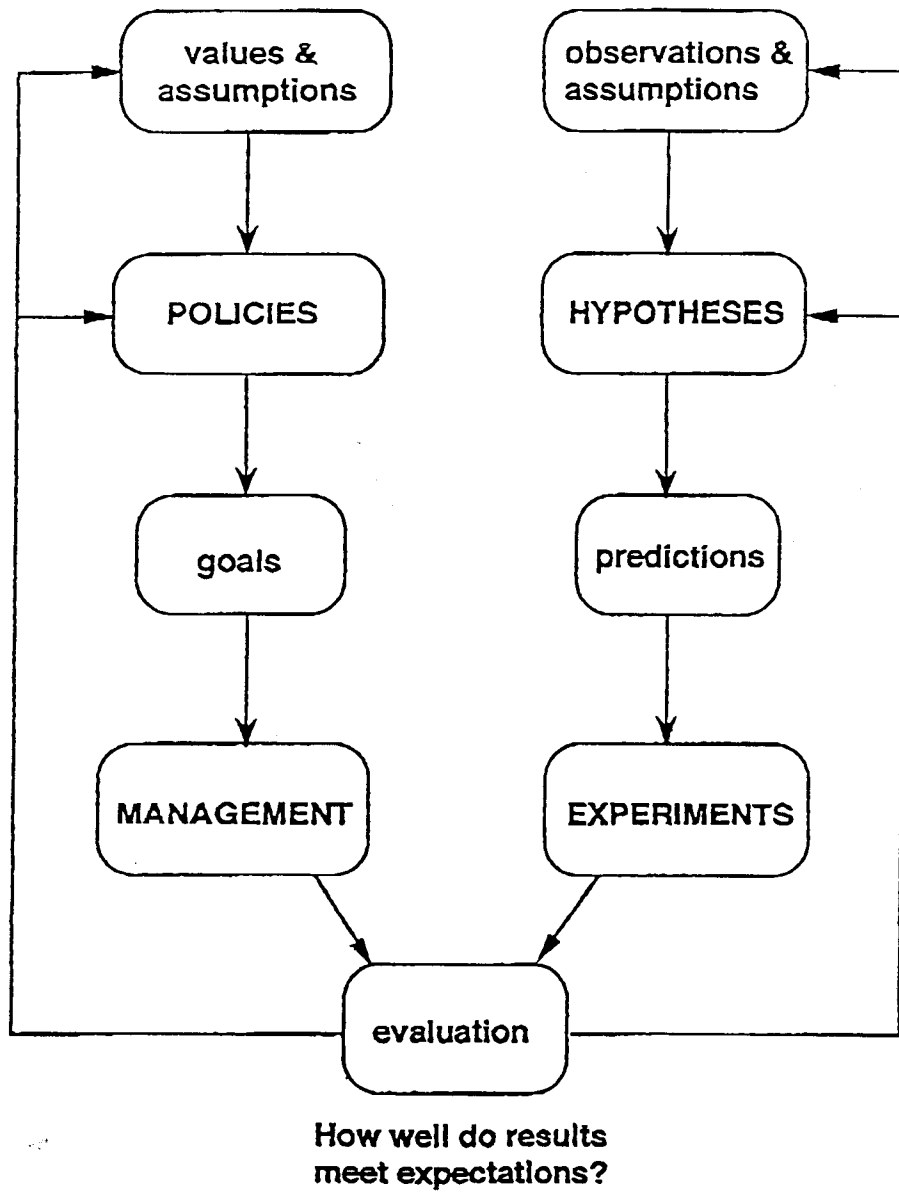


Figure 4. Adaptive Resource Management: Policy as hypothesis, management by experiment.

plants, to achieve experimental replication. However, the incremental costs of this ARM approach are expected to be low when compared with the cost to obtain equally reliable scientific results in some other manner. Because the best possible business decisions can only be made with the best possible knowledge about how to avoid costly mistakes, over the long term ARM should, in principle, result in net savings, despite the initial costs of the ARM approach. In this context, good science is good business.

Integration of Diverse Studies

Some of the main sources or axes of variation that must be recognized when designing and conducting studies of bird-wind plant interactions are as follows:

Affected entity: individual vs. population
 Type of bird and life history,
 r vs. *k* selected species, e.g. passerine vs. raptor
 Spatial scale: broad vs. local
 Seasonal pattern: migratory vs. resident

In designing any bird-wind plant study, including its temporal and spatial scale and the variables to be measured, it is necessary to consider each of these sources of variation. Whether or not wind plant effects are observed may be conditional on any of these factors.

In order to determine the direct and indirect effects of wind development on birds, two main classes of studies are needed: (1) siting studies and (2) existing site studies.

(1) Siting Studies.—The main objective of siting studies is problem avoidance, through development of an ability to predict the effects of future wind plants on birds, and avoidance of sites where serious bird-wind plant problems are predicted. Ideally, one would want to identify locations that have good wind resources and few birds that would be at risk.

A GIS (Geographic Information System) with good analytical capabilities would seem to provide a useful basis for integration and analysis of existing data on bird populations and movements, wind resources, topography, and other relevant environmental factors. The GIS should be used to its full analytical capability, not just as a mapping system. The types of bird information that are needed were discussed earlier by S. Gauthreaux (p. 53). One source of useful information that is becoming widely available is breeding bird atlas information. The databases from which these atlases are prepared generally contain more detailed information than appear in the published atlases.

Likely effects on birds if a wind plant is established at a proposed site should be predicted based on bird survey data obtained at the proposed site plus results from bird studies at existing wind plants elsewhere. These predictions can be used to help decide where to establish wind plants. The predicted effects should attempt to allow for cumulative effects of all aspects of the wind plant combined with other natural and human activities affecting the bird populations present.

It is important to realize that predicted levels of impact may or may not be correct. Knowledge of bird populations and factors that may affect them is imperfect, so predictions will inevitably be subject to some degree of uncertainty. Post-construction monitoring should be done to assess the accuracy of predictions. The results can then be used to refine future prediction abilities. This is a simple example of Adaptive Resource Management. A more elaborate variation of this ARM approach to wind plant siting would be to identify two similar sites, conduct pre-construction surveys of bird populations and movements on both, build a wind plant on one site, and continue to monitor birds on both sites during the post-construction period. This would provide data on wind plant effects with both spatial and temporal controls (see "Experimental Design", BACI design, p. 65). The phased or modular construction of wind plants may be conducive to the Adaptive Resource Management approach, including the BACI experimental design.

(2) Existing Site Studies.—Studies at existing sites can be designed to look at direct effects on mortality or at indirect effects involving disturbance, habitat change, or change in food availability. Studies of wind plant effects on birds in the Netherlands have suggested that disturbance/habitat loss effects may be a larger concern than direct collision mortality (p. 45, 114).

Direct effects studies could test for and measure changes in the average annual survival rate of birds occupying areas with and without wind plants. This would involve measuring population sizes and determining the death rate attributable to collisions with wind turbines. Improved methods for determining these parameters may need to be found through methodological research (p. 53ff). In determining mortality rates, careful consideration must be given to a definition of the "envelope of risk", and to the numbers of birds coming within that envelope. Some measure of the number of birds at risk will be needed as the denominator of the rate calculation.

As noted above, the results of these "existing site" studies and analyses should be used in making predictions of the impact of proposed sites on birds. The accuracy of these predictions could be tested when new wind plants are constructed.

Components of wind plants responsible for direct bird mortality can also be addressed through a two-step process: (a) existing-site studies, followed by (b) tests at new or expanded wind plants. This process can be used to identify and test collision mitigation measures:

- ▶ By measuring bird behavior and collision rates vs. turbine design, turbine layout, and environmental conditions, it should be possible to develop hypotheses (but not final answers) about the factors contributing to high vs. low collision risk.¹⁴

¹⁴ The virtual impossibility of isolating causal relationships based on uncontrolled correlational evidence is exemplified by the results of the available bird mortality surveys and analyses for the Altamont wind resource area (Orloff and Flannery 1992). That study identified situations with seemingly lower or higher death rates, but noted that specific causal relationships cannot be proven because of various potentially confounding factors.

- ▶ These hypotheses should then be tested in an ARM context when new or expanded wind plants are constructed. The approach should be to include two or more treatments (turbine types or layouts) in the new wind plant(s) in a carefully designed manner, and to compare bird behavior and mortality among these treatments.

There might be a temptation to simply predict, from an existing site study, which turbine design and layout is expected to cause the least risk to birds, and then to implement only that design in new wind plants. This approach is not recommended. It would provide no direct method to determine whether the prediction is correct. Instead, the new or expanded wind plant(s) should provide a direct experimental (ARM) contrast of the predicted "low-risk" design with other relevant designs.

Indirect effects studies concerning effects of disturbance, habitat change, and food availability are also recognized as potentially important, but were not addressed in detail as part of this presentation.

Generic Hypotheses to be Tested

Three generic null hypotheses were proposed for testing in an ARM context during studies at existing and proposed wind plants. The specific wording would need to be adapted to the individual sites, species, and situations under consideration. Two of these hypotheses apply to "Existing Site Studies" and one to "Siting Studies". The two hypotheses for existing sites are

- H₀: Population sizes, recruitment rates, survival rates, etc., are the same at sites with and without wind plants.

It is suggested that data on these parameters from North American wind plants are very meagre, and that it remains necessary to confirm that this null hypothesis can be rejected. The alternate hypothesis is that these parameters are *different* at sites with and without wind plants. That is, the test is two-sided: these parameters might be either lower or higher at wind plants.

- H₀: Mortality rates are the same at sites with and without mitigative measures.

In this case, the alternative hypothesis is that mortality rates are *lower* at sites with mitigative measures. That is, the test is one-sided.

The third hypothesis, for siting studies, might be

- H₀: Cumulative effects at new wind plants will not differ from those predicted.

Suppose, as a result of a siting study, a location is deemed appropriate for a wind facility on the grounds that it will have no, or minimal but accept-

able, effects on birds (e.g. some obvious habitat alteration that cannot be avoided if the decision is to build the plant). As a result of the siting study, it should be possible to predict the effects of plant construction. Continued monitoring will tell whether those predictions are borne out. If the changes are other than those predicted, this might initiate alternative actions at that "trigger point" (*cf.* p. 67).

Experimental Design

As noted previously, the best design for environmental impact studies in the field, where complete randomization is often logistically impossible, is some variant of the so-called BACI (Before-After-Control-Impact) or "Green's sequence" design (Green 1979). In the wind plant context, the pre- and post-construction phases are the Before-After dimension, and a wind plant site vs. nearby control site form the Impact-Control contrast. With the BACI design, data are collected in four situations:

	Control (No Wind Plant)	Impact (Wind Plant)	
Before (Pre)	✓	✓	(1)
After (Post)	✓	✓	

Data from "without wind plant" control site(s) are necessary to help determine whether any observed difference on the wind plant site between pre- and post-construction periods is attributable to the wind plant itself or to some other factor that changed over time.

In contrast, studies started at existing wind plants after the turbines are in operation lack both temporal and spatial controls:

	Control (No Wind Plant)	Impact (Wind Plant)	
Before (Pre)	-	-	(2)
After (Post)	-	✓	

These studies provide no direct basis for comparing mortality rates or other parameters with rates that might be expected in the absence of the wind plant.

A design that is notably better than (2) but not as good as (1) is the following:

	Control (No Wind Plant)	Impact (Wind Plant)	
Before (Pre)	-	-	(3)
After (Post)	✓	✓	

In this case, contemporaneous control data are collected off-site, but there are no pre-construction control data from either the wind plant or the off-site control location. The difficulty with this design is that, especially in field studies where exact controls are difficult to obtain, any difference that might be observed may result from unforeseen site-related differences other than those associated with the "treatment" (here, the wind plant).

A design that is often applied is the pre- vs. post-construction comparison without contemporaneous control:

	Control (No Wind Plant)	Impact (Wind Plant)	
Before (Pre)	-	✓	(4)
After (Post)	-	✓	

Although better than (2), this design provides no basis for judging whether any pre- vs. post-construction difference was attributable to the wind plant or to some other temporal effect, such as climate change or natural population cyclicity.

The BACI approach, design (1), is strongly recommended for environmental impact studies. Although the BACI design has limitations, it is much better than designs (2), (3) or (4). The limitations of the BACI design can be largely overcome if

- ▶ there are two or three control and two or three treatment sites rather than just one of each,
- ▶ there are replicate sampling locations within each site,
- ▶ time-series data are taken at each sampling location, and
- ▶ potentially confounding environmental variables are measured and treated as covariates.

Discussion

GIS Approach.—Regarding the GIS approach to wind plant siting, J. Winkelman noted that in the Netherlands a system was devised in consultation with the Nature Conservancy categorizing lands as

- ▶ Green—safe: few bird collisions expected,
- ▶ Orange—risky: wind plants can be built but research to evaluate effects on birds is needed,
- ▶ Red—hazardous to birds: no wind plants should be built.

As it turned out, all parts of the Netherlands that were ideal for wind development were categorized as red. However, this would not necessarily be expected in some other countries. The Netherlands is a special case because of its coastal location; the prevalence of low, wetland habitats; and the dense bird migrations occurring near the coast.

Behavioral Data.—The above presentation emphasized collecting data on population parameters. How important are behavioral data in this type of study? Some attendees suggested that questions about the importance of bird collisions are largely population questions, and that these questions are answered by data on population parameters such as population size, mortality, natality, immigration, and emigration. Others noted that data on behavior of birds near wind turbines is critical in order to determine such key factors as

- ▶ the numbers of birds passing through the "envelope of risk", which must be known in order to estimate the proportion of the birds at risk that actually collide.
- ▶ the situations in which birds are especially at risk, and
- ▶ the circumstances and ways in which birds react to wind turbines, which are relevant to the design of mitigation measures.

J. Winkelman noted that, in Europe, discovery of the fact that some small birds were killed when flung to the ground by turbine wakes was based on observations of flight behavior. She noted that behavioral observations during the daytime are relatively easy, whereas observations of behavior and collisions at night are difficult. Rather than conduct duplicative studies of easily-measured phenomena, it is important to identify the key data gaps, and concentrate research on those

It was suggested that specific questions about bird behavior near wind turbines should be identified at the start of research programs. Behavioral observations should be done in the manner necessary to test specific predictions.

Population Models, Uncertainty, and ARM.—Some meeting attendees felt that population models based on existing data, along with associated sensitivity analyses, could be valuable in identifying population parameters to which predictions of impact are most sensitive. If so, this could help focus research on key data gaps. Some others felt that available data on population processes and parameters of birds are generally too imprecise to allow development of preliminary models that would be very helpful in this regard. It was suggested that, if the state of knowledge about bird population dynamics is truly that imprecise, then it can be argued that further wind plant construction should be delayed until a reasonable predictive ability is available. However, some attendees were more optimistic that enough is known to allow development of useful conceptual models, conduct initial sensitivity analyses, and obtain some guidance as to the key data gaps.

Another viewpoint was that everyone would like to have a good predictive ability regarding avian population consequences of wind plant development, but models of proven efficacy will be time-consuming and costly to develop, and will require testing and refinement. Development of this predictive ability may be financially and logistically impractical unless it goes hand-in-hand with wind plant construction and operation. As a practical matter, wind plant construction is a gradual process, and development of U.S. wind resources to the extent hoped for by wind power proponents would take many decades (p. 11). At present, wind turbines are being installed in the U.S.A. at the rate of a few hundred megawatts per year at most. Many attendees felt that this gradual development, in conjunction with a well-planned and coordinated Adaptive Resource Management (ARM) approach on a national scale, would provide an opportunity to

- ▶ resolve uncertainties through careful study of the avian effects of initial developments, and to
- ▶ develop siting guidelines and mitigation measures where these are necessary,

and to do so without risk to bird populations.

It was noted that one of the central features of the ARM approach is that there are pre-planned alternatives and *trigger points*. Alternative actions that might be taken at a trigger point can include going ahead with development, adding mitigation measures, or ceasing development.

This raised the questions,

- ▶ What is the minimum size of wind plant that is economical?
- ▶ Is this size consistent with avian research needs?
- ▶ Would the avian mortality associated with this size of wind plant be tolerable?
- ▶ If avian mortality associated with a 'test wind plant' is unacceptably high, would it be practical to remove the wind plant?

It was agreed that at least some of these questions are relevant to an assessment of the practicality of the ARM approach, and that these issues need to be addressed. However, this was beyond the scope of the present meeting. It was noted, however, that the initial phase of most wind plant developments involves no more than 50-100 wind turbines. For many reasons unrelated to birds, there is typically an initial evaluation phase with that number of turbines before a final decision is taken to expand the wind plant. Even though the environmental assessment for a wind plant may address the potential effects of the projected final wind plant size, development may be curtailed at less than the originally-planned size.

Although wind power economics was not discussed in any detail, and was largely outside the meeting scope, it was noted that economic issues could have important implications for research design. It was suggested that it will be economically difficult for the "young" wind power industry to do studies to a higher standard than is followed in other competing power generation industries. Also, any phased development plan calling for removal of turbines in the event of unacceptable and unmitigable bird mortality would have significant economic implications. There may be no market for turbines removed from a decommissioned wind plant after several years of use.

BACI Design.—The BACI design can be applied to almost any type of question relating to bird-wind power interactions, e.g. mortality surveys, population studies, mitigation measure design, and disturbance/habitat modification effects. Much of the discussion of the BACI approach concerned its application to population and disturbance studies. However, it was pointed out that some other types of studies, e.g. mortality surveys and mitigation measure studies, may prove to be more common, and thus a more frequent application for the BACI approach. In designing studies of all types, there is a need to consider both the optimum experimental design, as discussed here, and the best field techniques for collecting the necessary standardized data, as discussed previously (p. 53).

One of the limitations of the basic BACI design is that it involves only one control and one "Impact" (here wind plant) site. No two sites are identical, and this can confound interpretation. The BACI design assumes that any temporal changes in the control and impact areas would be in parallel if the development (here wind plant) were not built. However, this parallelism may not exist if processes on the two sites differ. Conclusions based on unreplicated BACI designs are open to challenge because of uncertainty about the possibility that results were confounded by unrecognized differences between wind plant and control sites. To alleviate this problem, it is best if the BACI approach is expanded to include replication of sites. That is, there should be two or more control sites and two or more impact

sites (wind plants), on each of which there are corresponding pre- and post-operational studies.

Attendees knowledgeable about BACI and related experimental design issues agreed that replication is always desirable, but noted that even the basic BACI design without site replication is much superior to commonly-used unreplicated designs lacking temporal or spatial controls, e.g. designs (2), (3) or (4) on p. 65. Also, it was pointed out that the "lack of site replication" issue is not a serious problem in evaluating the effects of a given wind plant, only in assessing the generalizability of the conclusions to other sites.

DEFINING AN INTEGRATED PLAN FOR AVIAN-WIND POWER RESEARCH

This topic was taken up on the second and last afternoon of the meeting. First, Jan Beyea of the National Audubon Society gave a short introductory presentation suggesting some "Principles for a National Avian-Wind Power Research Plan". This was followed by a group discussion of the components of a National Research Plan. Various components that were suggested and discussed included

- ▶ policy and conceptual context,
- ▶ general research approach,
- ▶ site-selection and pre-construction studies,
- ▶ need for clear and appropriate definitions,
- ▶ important research categories,
- ▶ specific studies needed under each research category,
- ▶ key elements of any good scientific research project,
- ▶ guidelines for field surveys, and
- ▶ priorities associated with (a) categories of research and (b) suggested individual projects.

Principles for a National Avian-Wind Power Research Plan

by

*Jan Beyea, National Audubon Society*¹⁵

This presentation suggested some principles that could be useful in formulating a national plan. It is based on experience in dealing with

- ▶ economists,
- ▶ critical reviews of applied research on other topics,
- ▶ examples of successful research plans developed for other topics,
- ▶ general principles of the scientific method, and
- ▶ principles of negotiated conflict resolution.

Principles Related to Management

Cost Sharing: This is appropriate for the avian-wind power issue, given the diversity of stakeholders. Also, prior to the days of cost sharing, results from many research programs in energy were not adequately used. Research that can gain partial funding from many stakeholders is more likely to be relevant to the users of the research and to encourage active interest in its conduct and application.

¹⁵ National Audubon Society, 700 Broadway, New York, NY 10003

Portfolio of Projects: Not all stakeholders can be expected to support each individual research project. It is not reasonable to expect full advance agreement on priorities, research timing, and other research details. There should be a mechanism to allow different combinations of stakeholders to support different projects.

Adequate Management Support: A workable program will require a management structure sophisticated and large enough to assure that the research fits into a coordinated framework and is focused, adequately funded, delivered on time, and disseminated.

Clearly Stated Program Objectives: These are necessary to focus the research and provide a basis for evaluation of progress and success.

Measures of Success: Some measure of actual program performance is helpful for management in identifying the need for "mid-course corrections". Decision trees can be helpful; an example was circulated to meeting attendees before the meeting (Appendix 4).

Establishing a Research Climate

Competitive, Peer-Reviewed Research: In general, proposals tend to be better when proposals are competitive and peer-reviewed. The research also tends to be better-done when different groups try to measure the same or similar variables (possibly in different ways), and when the results are peer reviewed. Having competition in the field may at first sight seem duplicative, but the benefits of competition and replication outweigh the apparent redundancy.

Hypothesis-Based Research: Exploratory research is often valuable at an early stage of enquiry in any given field. However, once the issues are defined, hypothesis-based research improves efficiency and focus, and reduces the amount of money spent on unproductive data-gathering activities.

Who Should Sponsor or Conduct Various Kinds of Research?

Different types of research are best done by different types of groups, including environmental groups, industry, trade associations, and government. It is most appropriate for government or trade associations to sponsor and/or conduct research when single private firms do not have an incentive to do so. This generally occurs when private firms cannot capture the benefits of the research for themselves, e.g. when other companies can use the results without having paid for them.

Collaborative Research

Collaborative research is especially appropriate when research credibility is difficult to obtain. When research results have economic implications, stakeholders may question the results of research that was sponsored by stakeholders with different interests. This could

occur in the case of studies

- ▶ reviewing overlap between migration routes and wind resource areas, or
- ▶ assessing mitigation and enhancement options.

A collaborative approach toward sponsorship and management of controversial research is more likely to produce results that will be accepted by all concerned. When results are accepted, progress toward informed site selection, mitigation and enhancement can be made.

Toward a National Research Agenda

Following the above presentation, there was a wide ranging discussion of the components of a national research agenda. Many of these points had been discussed earlier in the meeting. Rather than repeat previously-discussed points, the following section refers to the relevant pages of these Proceedings.

Policy, Conceptual and Research Management Context

Some attendees believed that the first step in developing a national research framework must be to consider the policy, economic and legal situation that surrounds wind power development and the avian-wind power mortality question. They suggested that, without a broad policy-oriented conceptual plan, it is difficult to focus on specific research requirements.

Although there was considerable agreement with this, it was noted that decisions about research priorities and methods are being made on an ongoing basis because of the many wind power proposals now under active consideration in various parts of the U.S.A. Many attendees felt that it was appropriate for a technically-oriented group to do its best to address research needs at this stage, and to submit recommendations to interested stakeholders and potential funding agencies for further discussion and refinement. It was noted that questions and guidance formulated by the present technically-oriented group could be helpful in defining questions about wind power economics, policy, legalities, and risk analysis that might then be dealt with by a group with a broader representation and mandate.

There was general acceptance of the suggestion that a collaborative approach would be appropriate for management of a national research plan on avian-wind power issues. There was also general acceptance of the idea that the National Wind Coordinating Committee's Avian Subcommittee may, when formed, be appropriate for at least part of this role (see "Next Steps", p. 79). Some attendees suggested that the overall goal should be to devise a process, incorporating scientific research as a major element, that would allow the wind industry to develop without being stopped by the occurrence of an unacceptable number of bird deaths. In order to meet this goal, the program would need to assure that bird mortality at wind plants does not reach unacceptable levels.

General Research Approach

Many attendees felt that the general approach or framework for a national research agenda needed to be established before devoting much discussion to the merits of individual categories of research and specific proposed projects. It was agreed that, in general, scientific research was urgently needed to help resolve existing questions related to bird-wind power developments.

Many attendees were supportive of the *Adaptive Research Management (ARM)* concept, as outlined earlier in the meeting (p. 59ff). It was noted that there is increasing industry and utility interest in constructing new wind plants in various parts of the U.S.A. (p. 9). Some felt that the ARM approach provides a "golden opportunity" to conduct well-designed scientific experiments on high-priority research topics at the scale necessary to obtain meaningful results. However, it was noted that ARM would only be relevant if new or expanded wind plants are to be constructed. Several questions were raised relating to the phasing of wind plant development, and to the economics and politics of terminating a development if bird problems prove to be severe and unmitigable (p. 67). Notwithstanding the need to resolve these issues, meeting attendees agreed that well-designed avian-wind power research should be done in conjunction with new wind plant developments.

Some attendees recommended that *conceptual modeling* of bird population processes and potential wind plant effects be used as planning tool. This might help identify the key data gaps (p. 67). Other attendees expressed some doubt as to whether enough is known about bird population dynamics for this to be a useful approach in advance of specific population studies. The question warrants further consideration.

Some attendees felt that detailed studies of population dynamics could be important in specific circumstances, but that the first priority at most existing and proposed wind plants would be for *systematic monitoring* of bird numbers, movements, and mortality. These attendees tended to place high priority on the need for standardized survey methodologies (p. 53, 56).

The above approaches are not mutually exclusive. Any research program, whether site specific, regional or national, might well incorporate all of the above elements: conceptual models to help identify key data gaps, an ARM approach to the experimental testing of hypotheses, and use of standardized field methods.

There was some discussion as to whether comprehensive bird studies would need to be a part of every wind power development project:

- ▶ One view was that there are certain areas where impacts on birds can be predicted to be low, and that it is not cost-effective or necessary to conduct detailed studies there.
- ▶ Another view was that, in some situations, it may be sufficient to conduct brief "snapshot" surveys during each season.

- ▶ Others suggested that what is now needed is rigorous testing of defined hypotheses. Studies that are opportunistic, exploratory or short-term are unlikely to provide data of a quantity or quality sufficient for hypothesis tests with adequate statistical power. From a cost-effectiveness viewpoint, if studies are to be done at all, they should be done in a rigorous fashion with sample sizes adequate to provide meaningful results. Otherwise, the money that is spent is unlikely to provide useful or convincing results.

A related perspective is that wind power impacts on birds in other parts of the U.S.A. can be expected to be very different from those in California, where almost all U.S. studies to date have been done. Given this, there is a need to investigate the extent of "the bird problem", and the types of birds involved, in different parts of the country. Both pre- and post-construction studies would be important components of this work. Where problems are anticipated (based on pre-construction studies) or identified during post-construction monitoring, mitigation measures appropriate to those circumstances should then be developed. Attendees expressing this view suggested that it would be ineffective to expend scarce resources on development of mitigation measures for areas and species where they are not needed. However, it was noted that this approach might be assumed to imply that mortality of individual birds is not a serious concern in the absence of population effects. This assumption involves legal, ethical and other non-biological considerations, and attendees had varying views on this (p. 28).

Site-Selection and Pre-Construction Studies

It was agreed unanimously that, for the foreseeable future, there should be some form of pre-development bird survey at each proposed wind plant. Some attendees suggested that, for the foreseeable future, bird studies will inevitably be done in association with any newly proposed wind plant in the U.S.A., notwithstanding any technical arguments about the need (or lack of need) for bird studies in that area.

Attendees agreed that pre-development studies should be divided into two stages, as discussed earlier by S. Gauthreaux (p. 53):

- ▶ preliminary site-selection or "resource assessment" surveys of general areas under consideration for wind plant development, and
- ▶ more detailed pre-construction surveys of specific sites where wind plants are proposed.

Site-selection surveys can be based largely on previously-available literature and data, but would probably include some fieldwork. Preliminary estimates of potential bird mortality if a wind plant were constructed are desirable even at this early stage.

The more detailed pre-construction surveys should include several components. **(1)** They should determine the species present, their local population sizes, and their movement rates (migratory and local, day and night) through the potential envelope of risk.

Measurements or estimates of all of these parameters are needed through the year (a) to predict potential impacts on birds if a wind plant is built, and (b) as a baseline against which to measure actual impact if wind plant construction goes ahead. (2) Ideally, these parameters should be measured not only on the proposed wind plant site(s), but also on at least one nearby, similar site that can serve as an undeveloped control if the wind plant is built. This type of control area is necessary for a BACI (Before-After-Control-Impact) design, which is highly desirable (p. 65). (3) It would also be desirable to determine mortality rates under pre-construction conditions, but this is a difficult task. Meeting attendees were not unanimous as to whether dead-bird searches were useful or necessary during pre-construction surveys (p. 59). However, data on pre-existing mortality rates, if obtainable, would be valuable for baseline purposes.

Need for Clear and Appropriate Definitions

Terms such as survival and mortality have many different definitions, and are often used in a loose and ill-defined manner. Wildlife biologists and human epidemiologists may use these terms to mean quite different things. It is important to calculate these population parameters in a manner appropriate to the question at hand. Mortality is a rate, derived by dividing the number of birds that died by a denominator representing the spatial and temporal bounds of the birds under consideration and at risk. The choice of denominator is a critical factor in determining mortality rates, and the most appropriate measure will depend on the question being asked.

In the case of wind plant-related mortality, it is important to separate deaths attributable to the wind plant from other deaths that would have occurred with or without a wind plant. This requires necropsies to determine causes of death, and/or appropriate control data against which death rates in wind plants can be compared. Many wildlife population studies assume that all animals that disappear are dead, when in fact some may have dispersed (emigrated) from the area. In a bird-wind power study, deaths must be distinguished from dispersal, and deaths must be further partitioned into those attributable to the wind plant and those that are not.

The meeting did not reach a full understanding of the most appropriate measures of mortality for the purposes at hand. This issue deserves further consideration during development of guidelines for appropriate measurement protocols (p. 77).

Important Research Categories

During the second afternoon of the meeting, there was further discussion about the types of research needed, and how they should be categorized and prioritized. The important categories of research had also been discussed previously, during the first day, when a long list of possible questions was first narrowed to 14 points and then (depending on the attendees' individual preferences) to 7 or 5 points. These lists of research categories, and associated discussion, were summarized earlier (see p. 27ff).

Some attendees suggested that three main research questions need to be addressed:

1. Does the avian mortality caused by wind plants constitute a problem, from a population, ecological, or other perspective?
2. If mortality is a problem, how can the impact be reduced?
3. If mortality is a problem, how can future wind plants be sited or designed to reduce mortality?

Item (1) is carefully worded to avoid pre-judging whether deaths of individual birds would be deemed to constitute a problem if there were no population or ecological consequences. As discussed on p. 28 and elsewhere, there was a spectrum of opinion among meeting attendees about the degree of concern that should be attached to individual bird deaths without population consequences.

Item (2) is also carefully worded. Most obviously, it allows for the possibility that bird mortality might be alleviated through direct mitigation measures reducing mortality, e.g. turbine design features or bird deterrent measures. However, it also allows for the possibility that impact might be reduced through some indirect mitigation or habitat enhancement effort on the wind plant or elsewhere, if this is deemed appropriate and effective.

Some attendees felt that these three general categories did not explicitly cover all necessary research. For example, prior to initiating detailed studies of avian mortality (topic 1), it might be appropriate to conduct a preliminary assessment to determine which bird populations might be at risk, and then to focus attention on those.

Some attendees felt that the research categories identified in this 3-point list are undesirably broad. They preferred to work with the previously-developed 7 or 5 point categorization schemes, as listed on p. 31ff. It was agreed that, taken together, the various closely-related lists of 7, 5 or 3 research topics provide a good sense of the types of research needed.

Research Priorities

The attendees narrowed an initial list of many potential research questions first to a list of 14 questions and then to alternative lists of 7, 5 and 3 questions. Although there was no consensus as to which of the "short" lists of 3-7 questions was optimum, these lists were closely related. To that extent, priorities were identified. However, meeting attendees did not assign priorities to the various categories of research identified on those "short-lists" of 3-7 general research topics. All categories on the short-lists were identified as important.

Suggested Specific Research Projects.—Many meeting attendees submitted specific research suggestions during the meeting. Appendix 3 (p. 141ff) is a summary of these research questions, compiled by Michael Morrison. Many participants wanted to discuss these specific suggestions during the meeting. However, the majority felt that it would be impossible to reach consensus on the merits of specific research proposals in the absence of a more general framework, and that it was more urgent to work toward consensus on that

general framework. Therefore, the meeting did not undertake a group discussion of the specific research projects listed in Appendix 3.

Near-Term Contract Awards by DoE/NREL.—Some attendees felt that the attendees should attempt to formulate recommendations to DoE and NREL regarding the priority that should be given to various proposals that have been received by those agencies. Others did not consider this appropriate. In any event, these specific proposals were not described in any detail and were not discussed at the meeting. As noted earlier, the attendees did agree unanimously that, for the foreseeable future, there should be some form of pre-development bird survey at each proposed wind plant.

Key Elements of any Good Scientific Research

Attendees compiled the following list of key elements that should be part of any scientific research on avian-wind power issues:

- ▶ competitive proposals,
- ▶ peer review of proposals and results,
- ▶ clearly stated objective(s),
- ▶ statement of hypothesis(es),
- ▶ experimental design appropriate to test the hypothesis(es),
- ▶ measurement protocols that will produce consistent data, and
- ▶ specified measures of success.

Guidelines for Field Surveys

Some attendees pointed out that, as evident from the above list of key research elements, one should first define the key research questions and objectives, then determine the appropriate experimental design, and only then decide what should be measured and how the measurements should be obtained.

Others noted that systematic surveys of bird numbers, movements, and mortality will inevitably be essential components of most pre- and post-construction surveys, and will also be required for specific tests of mitigation measures. Given that studies of these types are already going on and that others are planned for the near future, there is much merit in addressing the issue of measurement protocols and standardization now.

There were differences of opinion as to the importance of standardized methods (p. 56). At the least, it is essential that consistent and systematic methods be used within a given study area, and that the results be comparable among regions whether or not the specific methods used to obtain those results are identical. For example, in conducting mortality searches, it is not essential that the same search radius be employed in all studies. However, all studies should report the search radius used and the specific distances from turbines at which the birds were found. With these data, among-study comparisons would

be possible even if search radii were unequal. Many attendees felt strongly that standardized methods are very desirable and would be welcomed by many researchers.

S.A. Gauthreaux, Jr., is presently preparing draft guidelines for standardized research protocols for bird-wind plant studies, under contract to the Electric Power Research Institute. These draft guidelines will take into account the experience gained by the Avian Powerline Interaction Committee (APLIC) group.

NEXT STEPS TO BE TAKEN

During this meeting, the participants reviewed much relevant background information from U.S. and European studies, identified and discussed many potentially relevant research areas, and identified many of the key elements of the research that should be done in those areas. They also outlined in some detail what should be done during pre-construction surveys of birds, including how those surveys can be done in a manner that will provide a good baseline for comparisons if the proposed wind plant is ultimately built. The Adaptive Resource Management approach (ARM) was suggested as an effective way to address important scientific questions through cooperative efforts among scientists, wind power developers, and regulators. Some important aspects of research design were discussed, including the desirability of both temporal and spatial controls (BACI design).

The present Proceedings provide a record of the background information, discussions and suggestions arising from the meeting. These Proceedings have been reviewed by the meeting organizers, Technical Presenters and Technical Participants to ensure that, insofar as possible, they provide a full and balanced account of the information and discussions.

It was proposed at the meeting that more specific recommendations for the conduct of baseline studies should be formulated, starting from the concepts discussed at this meeting and the work being done under contract to EPRI by S.A. Gauthreaux. A process for this effort is to be worked out, coordinated by RESOLVE Inc. This should include the identification of a process to develop consensus on variables to be measured, their definitions, methods for making the necessary field measurements, and the degree of standardization desirable.

The future of the present technical working group and of its recommendations was also discussed, emphasizing its relationship to the National Wind Coordinating Committee's soon-to-be formed Avian Subcommittee. That subcommittee is expected to include representatives of a wide variety of stakeholders (see Appendix 2A, p. 100), and will have a policy as well as a technical role. A few of the participants in the present meeting are expected to be members of the Avian Subcommittee. It is suggested that some other participants in the present meeting who are interested in and qualified for continuing involvement in this area could become a technical advisory group to the Avian Subcommittee. In this manner, the activities of present group and of the NWCC Avian Subcommittee could be merged onto a single track. Finalization of such an approach must await formal creation of the Avian Subcommittee. However, in anticipation that some such mechanism will be created, it was agreed that any of the present meeting participants *not* interested in providing technical assistance on an as-needed basis would advise the meeting Facilitator.

Other topics that might be taken up by such a technical group for further consideration and consensus building are the following:

- ▶ Mitigation/enhancement opportunities,
- ▶ Population level effects, modeling, etc.,
- ▶ Experimental design approaches, and
- ▶ Peer review of proposals and results.

MEETING SUMMARY

This Meeting Summary is a synopsis of the main points discussed. The majority of reviewers of the draft Proceedings considered that a summary was necessary and helpful. However, some reviewers were concerned that readers would not obtain a full understanding of the nature of the discussions from a summary. Readers are encouraged to review and reference the full text.

The overall goal of the meeting, as set out in the invitation, was to define a research program that addresses wind power-related avian mortality issues. This research program should investigate both individual site impacts and national cumulative impacts. To reach this goal, the meeting should (1) identify and prioritize key issues with respect to bird-wind turbine interactions, (2) define a research agenda to resolve scientific and technical issues, while (3) insuring transferability of results, (4) avoid duplication and inadequate science, and (5) build consensus on approaches to the research needed to address the issues."

At the start of the meeting, a more specific list of meeting objectives was agreed upon by meeting participants:

- ▶ to help all parties understand the principal interests and concerns of one another;
- ▶ to identify and where possible prioritize the key scientific and technical questions regarding avian-wind interactions at wind power plants;
- ▶ to define and where possible prioritize research projects to address the questions identified;
- ▶ to identify research study requirements (e.g. time frame, resources and challenges associated with particular research proposals);
- ▶ if there is time, to develop consensus on a national research plan and establish priorities where possible; and
- ▶ define possible next steps.

For the purposes of this meeting, consensus was taken to mean that "all participants at the table can live with a decision being considered".

Wind Technology Overview

1. Electricity generation from wind power is becoming a commercial reality in many parts of the United States, expanding across the country from the established base in California. In California, installed capacity is about 1,600 MW, with an additional 500-1,000 MW under discussion. In the U.S. outside California, about 50 MW has been installed, about 250 MW is at the permitting or construction stages, and at least 500 MW of further capacity has been proposed.
2. At present, about 15,000 wind turbines are installed in the U.S.A. To reach 10,000 MW of capacity ~~would~~ require about 16,000 new turbines of present design. If the

upper limit on the economically exploitable wind resource in the U.S.A. is 100,000-200,000 MW, an upper limit of about 200,000 to 400,000 wind turbines would be needed, assuming no further increase in average power per turbine. However, power generated per turbine has increased ten-fold in the past decade. Also, expansion to this level would require many decades.

3. The U.S. wind turbine supplier industry is expanding, in part because of technical and financial support from the EPRI/DoE/NREL/Utility wind turbine development and testing programs. These programs provide risk-shared funding to conduct operational tests of about 20 turbines of a given type.
4. Continued expansion of wind power in the U.S. will require successful resolution of a number of key issues, including concerns about collisions between wind turbines and birds.
5. Resolution of these issues will require careful, reasoned discussion and teamwork among the major sectors of society that will be affected by the growth and use of wind power. The National Wind Coordinating Committee (NWCC) has been formed to provide a forum for discussion and resolution of such issues.
6. Some meeting participants noted that plans for rapid expansion of the wind power industry provide a unique opportunity to do carefully planned tests of wind plant effects on birds, including well-controlled pre- vs. post-construction comparisons. This might be done in an Adaptive Resource Management framework.

Avian Mortality Questions at Wind Power Plants

1. Meeting participants reviewed and discussed a lengthy list of questions about bird-wind plant issues that had been compiled in advance of the meeting. It was agreed that many of these questions were related, and that essentially all of them could be taken into account by a much shorter list of general questions about bird-wind plant issues. The initial list was condensed first to a 14-point list of questions (p. 30), then to a 7-point "distilled" list (Table 3A) and then to a 5-point "sequenced" list (Table 3B).
2. Some attendees preferred the five-point formulation and others preferred the seven-point list. There was insufficient time during the meeting to reach consensus on a single list. However, there was general agreement that the 5-, 7- and 14-point lists of potential research areas, whichever one prefers, provide a good indication of the research topics that the meeting attendees collectively considered important.

Table 3. Condensed lists of major research areas.

A. Seven-Point "Distilled" List, not in any logical or priority sequence:

1. What are the population effects of avian mortality at wind plants, including cumulative effects?
 - ▶ Determine whether wind plant mortality is additive or compensatory (see definitions above, p. 30)
 - ▶ Estimate the decrease, if any, in the average annual survival rates of species of interest
 2. Determine avian mortality, including consideration of appropriate and comparable tools, methods, and techniques.
 3. Identify ways to prevent or mitigate mortality or enhance avian viability:
 - ▶ Develop ability to predict impacts
 - ▶ Develop methods to reduce unnecessary mortality
 4. What causes avian mortality from wind turbines or wind plants?
 - ▶ bird behavior
 - ▶ turbine design
 - ▶ wind plant design
 - ▶ location of wind plant
 5. Assess overall direct effects and indirect ecological effects of avian mortality at wind plants.
 6. What are the indirect effects of wind development on avian populations, i.e. disturbance and habitat modification effects?
 7. Agreement on research design protocols, including how to involve lay people in monitoring and assessment of wind plant effects.
-

B. Five-Point "Sequenced" List:

1. Assess mortality attributable to wind turbines at existing sites (including control data from "no turbine" sites).
 2. Predict mortality at planned wind power sites, based in part on (1).
 3. Predict population consequences.
 4. Identify ways to reduce bird kills at wind plants.
 5. Set values for off-site mitigation.
-

Relevant Past and Ongoing Research

The History of Wind-Related Avian Research in the U.S.A.

1. The first study of the potential impact of wind turbines on birds in the U.S.A. involved a mid-1970s study of the ERDA/NASA 100 kW Experimental Wind Turbine in Ohio. The wind turbine was not proven to be a high risk to nocturnal migrants or other birds.
2. Bird movements and collision mortality were studied for one year as part of the performance monitoring program for the large Boeing/PG&E MOD-2 Wind Turbine in Solano County, California. One American Kestrel was seen to fly into the turbine, and seven dead birds were found although not all of these necessarily collided with the turbine. Actual mortality, allowing for scavenging and detectability biases, might have been as high as 54 birds.
3. A survey and review by the California Energy Commission (CEC) of reported bird mortality at California wind plants in 1984-88 found evidence of bird mortality, mostly of raptors. A follow-on 2-year study conducted in the Altamont Wind Resource Area by BioSystems Analysis Inc. found 183 dead birds, of which 119 were raptors (mainly Red-tailed Hawks, American Kestrels and Golden Eagles). Fifty-five percent of the mortality was attributed to collisions with turbines, but no birds were directly observed flying into turbines.
4. Several studies are underway or planned to assess the potential impact of wind farm development on bird injury and mortality. Nearly all of these studies involve pre-construction monitoring of bird movements. These studies are in Maine, New York and Texas, and similar studies are planned for Vermont, Oregon, and Montana. The opportunity to acquire valuable pre-construction data is great, but to date the methodologies applied in different studies have not been standardized.

Industry Research: Kenetech Windpower

1. The Kenetech Avian Research Task Force feels that it is important to acquire precise quantitative data in sufficient quantities to allow reliable assessments and conclusions. The rate of accidents per turbine is very low, so direct human observations of collisions are impractical for determining how and why birds collide with turbines.
2. Studies initiated to date by Kenetech include controlled flights of homing pigeons near turbines to obtain quantifiable data on general bird/turbine interactions, development of automatic machine-recording systems such as video monitoring, development of a tracking system to provide precise 3-dimensional data on bird movements near turbines, studies on the visual and acoustic capacities of raptors, a study of perching behavior by raptors on turbines, and a population study of Golden Eagles in the Altamont area, as monitored via radio-telemetry.

3. The Kenetech Avian Task Force feels that adequate management of bird collisions at wind plants must take account of (1) initial siting, (2) size and layout of the wind plant, (3) design of turbines and towers, and (4) the possibility of off-site mitigation.

U.S. Federal Wind Energy Program Avian Research Projects

1. The population study of Golden Eagles in the Altamont region, mentioned above, has been initiated as a one-year pilot study with federal support.
2. Avian research was identified as a high priority in a 1994 request to universities for proposals to the Federal Wind Energy Program. A raptor perching study likely will be funded.
3. The cost-shared Utility Wind Turbine Verification Program mentioned above includes federal support.

Lessons from Utility Structure Environmental Impacts

1. Based on almost 25 years of studies of bird collisions with powerlines and other utility structures, various biological generalizations can be formulated: ▶ Sooner or later, birds collide with any tall structure. ▶ Collision vulnerability varies with species, age, sex, habitat, weather, human disturbance, and location. ▶ Not all dead birds found near a tall structure were killed by colliding with it; cause of death can be difficult to determine. ▶ Knowledge of bird behavior is critical to finding quick and cost-effective solutions. ▶ The significance of mortality depends on the population affected.
2. Procedural generalizations based on utility experience include the following: ▶ It is difficult to get good estimates of collision mortality. ▶ Necropsies of dead birds are needed. ▶ Good scientific studies are needed in order to develop solutions; these studies are time consuming and expensive. ▶ The perceived significance of mortality depends on many non-biological factors.
3. The Avian Powerline Interaction Committee (APLIC) has been successful because it has been a broadly-based cooperative effort with a narrow and specific focus, nurtured through periods of limited funding by dedicated agency and utility personnel. Other important factors have been that APLIC has ▶ emphasized achievable objectives (reduction but not total elimination of bird deaths), ▶ developed information about options for dealing with bird collision issues, but left decisions as to how to apply this information to other groups, and ▶ emphasized standardized study methodologies.

Bird/Wind Turbine Investigations in Europe

1. Studies of bird-wind plant interactions in Europe have dealt with collision frequency, disturbance/habitat loss effects, and avian flight behavior.

2. **Bird collision studies** in Europe have found that determination of search bias is essential. Even with careful searching, the proportion of the bird bodies found can be low, especially for small birds in high vegetation.
3. Estimated average mortality in two Dutch wind parks was 0.04-0.09 birds per turbine per day. These are very high figures relative to values reported for California. Most bird victims were found after nights with both poor flight conditions and visibility.
4. Mean mortality per kilometer of wind park is similar to that per km of highway, and comparable to or somewhat lower than that per km of power line in risky situations. Total numbers killed per 1,000 MW of wind power capacity are low relative to other human-related causes of death.
5. Why is the kill rate so much higher in the Netherlands than in the Altamont? The Altamont, with a high density of Golden Eagles and other raptors, is not comparable to areas of Europe and North America with fewer raptors but concentrated nocturnal migration. The types and numbers of birds that would collide with turbines in some parts of North America may differ widely from those documented in the Altamont.
6. Even with the higher collision rate in the Netherlands, collisions are infrequent events. They can be observed directly, but this is very labor intensive.
7. **Habitat loss/disturbance effects** were demonstrated in the Netherlands up to 250-500 m from the nearest turbines. Numbers there were reduced by up to 95%, depending on species, site, season, tide, and whether the wind park was in operation. In Europe, disturbance/habitat loss effects are thought to be much more important than direct collision mortality. However, Spain may be an exception.
8. **Flight behavior** near Dutch wind turbines differed between day and night. By day, most reactions of migrating birds to turbines were calm and gradual. Few birds needed more than one passing attempt before crossing the wind park. Reaction frequency was higher when turbines were 150 m apart and/or operating than when 300 m apart and/or inoperative. Few birds were seen within 20 m of a rotor during daylight.
9. Nocturnal migrants were more commonly seen within 20 m of the rotors, especially with headwinds. By day, 15% of the closely-approaching birds altered their flight paths calmly to avoid crossing the rotor, whilst at night 36% did so. The other birds all crossed or tried to cross between the rotor blades. While doing so, most of them either flapped their wings powerfully or fluttered.

Bird/Wind Turbine Investigations in Southern Spain

1. There is an ongoing study of bird mortality and behavior in the Tarifa area of southern Spain—one of the three main routes of concentrated migration of soaring raptors and storks en route between Europe and Africa. Also, large numbers of soaring birds

sometimes land in the area while waiting for weather conditions good for crossing the sea. The international significance of the Tarifa area for migratory birds has been recognized in several ways.

2. Several wind parks have been established within the area traversed by soaring birds on migration. Most turbine strings are aligned roughly parallel to the main migration direction, but a few strings cross that axis.
3. Preliminary results show that, during the first few months of study, a number of birds were killed by collisions with turbine blades. These included 14 protected species. The majority were Griffon Vultures. This mortality has raised concern in Spain.

Designs for Avian-Wind Power Research

Standardized Assessment and Monitoring Protocols

1. Monitoring studies of birds in relation to wind power development can involve ▶ preliminary site selection surveys; ▶ pre-construction surveys at specific proposed sites; ▶ post-construction monitoring; ▶ development of mitigation methods; and ▶ monitoring of decommissioned wind plants.
2. The objectives of pre- and post-construction monitoring are to gather data that can be used to assess the impact of wind plant development on avian populations. Pre-construction data are needed ▶ to predict the impact of a proposed wind plant, and ▶ as a baseline for measuring impact.
3. There is a need for agreed units of measurement and, where practical, standardized methods. Meeting participants agreed that data need to be comparable within and among studies, but had varying opinions about the importance and practicality of requiring the use of the same specific survey methods in different areas.
4. Preliminary site selection surveys should use existing information on bird species, densities, habitat dependencies, and flight patterns in potential project areas to help select the locations of potential wind turbine projects. If general information about birds and habitats is not available, some monitoring of bird populations and movements at potential wind turbine sites may be needed.
5. Pre- and post-construction surveys should include surveys of bird populations, movements, and mortality. Ideally, surveys should be done on both the wind plant site and otherwise-similar comparison sites both before and after the wind plant is constructed. This BACI (Before-After-Control-Impact) design, provides both temporal and spatial control data. Both types of control data are needed to determine whether apparent differences are truly attributable to a wind plant.

6. *Population surveys* should be based on existing standard methods.
7. *Bird movement studies* should use standardized methodologies to document low-altitude movements, migratory and local, and to distinguish birds that are at risk because of their low flight altitudes from those flying higher and not at risk.
8. *Searches for dead and injured birds* should quantify mortality related to wind turbines, meteorological towers, and powerlines. Collision rates should be expressed in terms of the percentage of birds passing through the "envelope of risk". Methodological aspects requiring careful attention include area, timing and frequency of searches; data to be recorded; quantification of biases; provision for necropsies to determine cause of death; and methods for estimating total collisions and collision rates.
9. Attendees had varying views about the importance of mortality searches during the pre-construction phase, or in a nearby comparison area during the post-construction phase. In many areas, few dead or injured birds are found in the absence of turbines. However, some attendees felt strongly that it is essential to collect these data.

Conceptual Framework: Adaptive Resource Management and Integration of Diverse Studies

1. *The Adaptive Resource Management Approach:* "Real world" management actions must often be taken in the absence of organized scientific knowledge. These actions often have some of the characteristics of a large-scale experiment. Adaptive Resource Management (ARM) is an iterative approach in which policies are treated as hypotheses and management actions as experiments. Based upon the outcome of such experiments, policies may be changed or refined and further tested by another stage of management action implemented as an experiment.
2. Many questions about bird-wind power interactions might best be addressed in an ARM context while wind energy was being produced, thus recouping some of the costs. The results could be used to refine the design of future expansions or new wind plants or, if necessary, to cancel a planned expansion or new development.
3. This approach would involve some costs and complications over and above the basic cost of establishing and operating a wind plant. However, the incremental costs are expected to be low when compared with the cost to obtain equally reliable scientific results in some other manner.
4. *Integration of Diverse Studies:* To determine the direct and indirect effects of wind development on birds, two main classes of studies are needed: (1) siting studies, and (2) existing site studies.
5. The main objective of siting studies is problem avoidance, through development of an ability to predict effects of future wind plants on birds, and avoidance of sites where

serious bird-wind plant problems are predicted. A GIS (Geographic Information System) with good analytical abilities would provide a useful basis for integration and analysis of data.

6. Post-construction monitoring should be done to assess the accuracy of predictions. The results can then be used to refine future prediction abilities—a simple example of Adaptive Resource Management. A more elaborate variation would be to identify two similar sites, conduct pre-construction surveys on both, build a wind plant on one site, and then monitor birds on both sites (BACI design).
7. Existing site studies can be designed to look at direct effects on mortality or at indirect effects involving disturbance, habitat change, or change in food availability. Results should be used to predict the impact of proposed sites on birds. The accuracy of these predictions could be tested when new wind plants are constructed.
8. Components of wind plants responsible for direct bird mortality could also be addressed by a two-step process: (a) existing-site studies, followed by (b) tests at new or expanded wind plants. Step (b) is necessary to determine whether predictions are correct.
9. *Generic Hypotheses to be Tested:* Three generic null hypotheses amenable to testing in an ARM context during studies at existing and proposed wind plants were proposed. The specific wording would need to be adapted to the individual circumstances. The first two hypotheses apply to existing sites and the third to siting studies:
 - H₀: Population sizes, recruitment rates, survival rates, etc., are the same at sites with and without wind plants.
 - H₀: Mortality rates are the same at sites with and without mitigative measures.
 - H₀: Cumulative effects at new wind plants will not differ from those predicted.
10. Data on bird behavior near wind turbines can also be necessary. Specific questions about behavior near turbines should be identified at the start of research programs. Behavioral observations should be done as necessary to test specific predictions.
11. *Experimental Design:* The best design for environmental impact studies in the field is some variant of the BACI (Before-After-Control-Impact) design. This design has limitations, but is much better than designs lacking pre-construction and/or contemporaneous control data. The limitations of BACI designs are known and can be largely overcome.
12. *Population Models, Uncertainty, and ARM:* The value of population models and associated sensitivity analyses in focussing research on key data gaps was discussed. Opinions varied as to the value of this approach, given the imperfect knowledge about bird population dynamics.

13. Many attendees felt that gradual wind power development, in conjunction with Adaptive Resource Management (ARM) on a national scale, could resolve uncertainties, develop siting guidelines and mitigation measures where necessary, and do so without risk to bird populations. The ARM approach incorporates pre-planned alternatives and trigger points. Alternative actions that might be taken at a trigger point can include going ahead with development, adding mitigation measures, or ceasing development.
14. This raised several questions: ▶ What is the minimum economical size of a wind plant? ▶ Is this size consistent with avian research needs? ▶ Would the avian mortality associated with this size of wind plant be tolerable? ▶ If not, would it practical to remove the wind plant? Answers to these questions were beyond the scope of the meeting, but they relate to the scientific and economic practicality of the ARM approach and need to be addressed.

Defining an Integrated Plan for Avian-Wind Power Research

Principles for a National Avian-Wind Power Research Plan

1. *Management Principles:* An effective national plan should provide for ▶ cost sharing by various stakeholders, ▶ different combinations of stakeholders to support different projects, ▶ adequate management support, ▶ clearly stated program objectives, and ▶ a system to measure the degree of success.
2. *Establishing a Research Climate:* This might best be done through adoption of a competitive, peer-reviewed approach for proposals; replication of key work by different groups; peer-review of results; and emphasis on hypothesis-based research.
3. *Who Should Sponsor or Conduct Various Kinds of Research?* Government or trade associations should sponsor and/or conduct research when single firms have no incentive to do so, e.g. when other firms can use the results without having paid for them.
4. *Collaborative Research:* When research is controversial, a collaborative approach toward sponsorship and management is more likely to produce results that will be accepted and used by all concerned.

Toward a National Research Agenda

1. Questions and guidance from this technical group may help define questions, e.g. on wind power economics, policy and legalities, that require attention by a group with broader representation and mandate.
2. There was general acceptance that a collaborative approach would be appropriate for management of a national research plan on avian-wind power issues, and that the

National Wind Coordinating Committee's Avian Subcommittee may, when formed, be appropriate for at least part of this role.

3. The overall goal might be to devise a process, incorporating scientific research as a major element, that would allow the wind industry to develop without being stopped by the occurrence of an unacceptable number of bird deaths.
4. It was agreed that, in general, scientific research is urgently needed to help resolve existing questions related to bird-wind power developments.
5. Many attendees supported the *Adaptive Research Management (ARM)* concept. The ARM approach, combined with planned wind power development, may provide a "golden opportunity" to conduct well-designed scientific experiments on high-priority research topics at the scale necessary to obtain meaningful results. However, questions were raised relating to the phasing of wind plant development, and to the economics and politics of terminating a development if bird problems prove to be severe and unmitigable. Nonetheless, attendees agreed that well-designed avian-wind power research should be done in conjunction with new wind plant developments.
6. The merits of *conceptual modeling* of bird population processes and potential wind plant effects require further discussion if a consensus is to be reached.
7. Some attendees felt that detailed studies of *population dynamics* could be important in specific circumstances, but that the first priority at most existing and proposed wind plants would be *systematic monitoring* of bird numbers, movements, and mortality. These attendees tended to emphasize the need for standardized survey methodologies.
8. Approaches (5)-(7) are not mutually exclusive. Research might incorporate conceptual models to help identify key data gaps, an ARM approach to the experimental testing of hypotheses, and use of standardized field methods.
9. Wind power impacts on birds in other parts of the U.S.A. can be expected to be very different from those in California, where almost all U.S. studies to date have been done. Thus, there is a need to investigate the extent and nature of "the bird problem" in different parts of the country.
10. It was agreed unanimously that, for the foreseeable future, there should be some form of pre-development bird survey at each proposed wind plant. Pre-development studies should be divided into (a) preliminary site-selection surveys, and (b) more detailed pre-construction surveys of specific sites as summarized on p. 74.
11. When calculating survival and mortality rates, the choice of denominator is critical, and the most appropriate denominator depends on the question being asked. Deaths must be distinguished from dispersal, and must be further partitioned into those that

are and are not attributable to the wind plant. The most appropriate measures of mortality for present purposes deserve further consideration.

12. During a further discussion about the types of research needed, some attendees suggested that three main research questions need to be addressed: ▶ Does the avian mortality caused by wind plants constitute a problem, from a population, ecological, or other perspective? ▶ If mortality is a problem, how can the impact be reduced? ▶ If mortality is a problem, how can future wind plants be sited to reduce mortality?
13. Other attendees felt that these three research categories are undesirably broad or incomplete, and preferred the previously-developed 7 or 5 point categorization schemes (p. 31ff). It was agreed that, taken together, the closely-related lists of 7, 5 or 3 research topics provide a good sense of the types of research needed.
14. Attendees did not assign priorities to the categories of research identified on those "short-lists" of 3-7 general research topics. All categories on these lists are important.
15. Many attendees submitted specific research suggestions (Appendix 3, p. 141ff). There was much interest in this list. However, in the absence of a more general research framework, the majority of attendees preferred to work toward consensus on that framework rather than discuss the specific research projects listed in Appendix 3.
16. The following key elements should be part of any scientific research on avian-wind power issues: ▶ competitive proposals, ▶ peer review of proposals and results, ▶ clearly stated objective(s), ▶ statement of hypotheses, ▶ experimental design appropriate to test the hypotheses, ▶ measurement protocols that will produce consistent data, and ▶ specified measures of success.
17. There were different opinions about the importance of standardized methods (p. 56). At the least, consistent and systematic methods should be used within a given study area, and the results must be comparable among regions whether or not the methods used are identical. Many attendees felt that standardized methods are very desirable and would be welcomed by many researchers.

Next Steps to be Taken

1. More specific recommendations for baseline studies should be formulated, starting from concepts discussed at this meeting and work being done under contract to EPRI by S.A. Gauthreaux. A process for this effort is to be worked out, coordinated by RESOLVE Inc.
2. A few participants in this meeting are expected to be members of the National Wind Coordinating Committee's soon-to-be-formed Avian Subcommittee. Some other participants in this meeting could become a technical advisory group to the Avian Subcommit-

tee. In this way the activities of present group and of the NWCC Avian Subcommittee could be merged onto a single track.

3. Other topics that might be taken up by such a technical group for further consideration and consensus building include ▶ mitigation/enhancement opportunities, ▶ population level effects, modeling, etc., ▶ experimental design approaches, and ▶ peer review of proposals and results.

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Appendix 2. Detailed Presentations and Background Material

Appendix 2A. National Wind Coordinating Committee, by *E.A. DeMeo*, EPRI

I have the privilege of reporting on a coordinating effort that's germinating within the wind community and that involves a number of very dedicated and thoughtful people from many sectors within that community.*

This effort has led to the formation of a new group known as the National Wind Coordinating Committee. This group's primary aim is to provide a forum for multi-stakeholder teamwork to optimize the societal benefits of wind power technology. I'll begin by outlining the broad objectives of the group as it is evolving, then I'll review the background behind the Committee's formation. I'll then focus in more specifically on the Committee itself, and I'll close with my own perspective as to where I think things are going with respect to the Committee.

This report is based on remarks presented at the American Wind Energy Association's WINDPOWER '94 Conference, as outlined in the charts that follow the text.

Broad Objectives

The Committee hopes to provide a forum for identifying key issues associated with wind power. A primary aim is to promote a coordinated approach in addressing these issues, guided by a desire to optimize the societal benefits of wind power. To the extent possible, the group hopes to catalyze productive actions within organizations

*The following organizations have participated in formative meetings of the National Wind Coordinating Committee. Most have joined the Committee, and the remainder are actively considering membership. American Public Power Association, American Wind Energy Association, Arizona Corporation Commission, Edison Electric Institute, Electric Power Research Institute, Green Mountain Power Corporation, Iowa Department of Natural Resources, Izaak Walton League, Minnesota Attorney General's Office, Montana Department of Natural Resources, Montana Power Company, Montana Public Service Commission, National Association of State Utility Consumer Advocates, National Audubon Society, National Rural Electric Cooperative Association, Northern States Power Company, PacificCorp, Texas Public Utility Commission, Union of Concerned Scientists, U.S. Department of Energy, U.S. Fish and Wildlife Service, Worldwatch Institute

that already exist. Some of these actions will promote an improved understanding of the roles wind may play in the energy arena, and of the value that it will have in those various roles. Other actions will reduce the barriers that are standing in the way of further use of wind. The group aims to encourage the acceleration of this technology, but in a prudent way based on solid logic that recognizes needs, opportunities and constraints. The overall aim is to enable a sustained market situation so that wind can advance and make its way on its own feet, driven primarily by natural market forces.

Background

The current situation, which has become familiar to all in the community, is that commercial activity in wind power is expanding at a rapid rate. Decisions valued at hundreds of millions of dollars are being made in the commercial marketplace, and many hundreds of megawatts have already been installed. Because of this, wind is unique amongst the emerging renewable technologies in that it can begin to show substantial environmental benefits now. That fact, coupled with the emergence of the Clinton Administration's Climate Change Action Plan, caused a number of us who are involved in the community to ask some probing questions. The first question we asked is: With all the activity already underway in wind, is this enough? Should we just let normal market forces run their course? Conversely, would an acceleration program, carefully put together, make sense? If it did, how could we ensure that such a program would not interfere with the very significant commercial activities that are already in progress in the wind community? However, regardless of what one might think about acceleration, everybody felt that all these activities could benefit from better coordination.

In asking questions about acceleration or coordination and how these might be done better, a group of us put together a few basic guiding principles. First, whatever we do let's develop a minimum of new organizational structure. Let's instead try to work within what already exists, recognizing that there is already a great deal of activity and that a number of organizations are already involved. In addition, we wanted to seek maximum leverage for any funds that might become available for acceleration activity. In other words, we should not apply funds to a project that is already proceeding well on its own through normal market forces. Instead, we should direct those funds toward activities that might not happen without them or might happen sooner with them.

With a view toward working within existing organizations, we first attempted to identify those organizations currently involved. In our view, there are three sectors within the wind community: users, suppliers, and then a number of other organizations that we classified as facilitators (Chart 7). These last are entities that can help bring the suppliers and the marketplace together. Conversely, they can get in the way if they don't have good information. In the supplier sector, AWEA serves as a focal

point. In the user sector, which involves utilities and independent power producers, there is also a group that could serve as a focal point: the Utility Wind Interest Group.

Utility Wind Interest Group (UWIG) Expansion

UWIG has played a communication and outreach role over the past few years, including the production and dissemination of a number of topical brochures. The Group's been around for about five years now, and has attempted, with some success, to understand the wind power story and communicate it to other utilities. Right now UWIG is expanding its role. Its rationale in doing so is that it intends to become a very solid forum for utility issues discussion, and to evolve into a voice for utilities. It intends to focus in this new expanded role not only on information and outreach, but on a number of the other important issues such as wind resource assessment, and electrical interface and environmental issues. In general, the UWIG members have recognized that acceleration of wind is very nearly a certainty, since so many forces are at work within the public and political sectors that are pushing in this direction. The recent legislative direction announced in Minnesota is but one example. The feeling of the UWIG members is that it's much better to be involved in defining the acceleration process than to just let it happen and then have to deal with the result. So the UWIG is expanding. It is in the process of incorporating itself so that it can actually manage a number of activities involving utilities, and involving cost-share funding from the government, from EPRI, from utilities, and from others. And UWIG also wants to play a strong role in representing the utilities in this National Wind Coordinating Committee.

Coordinating Committee Formation

The National Wind Coordinating Committee's origins date back to last October, when AWEA announced plans toward a collaborative activity. Over the ensuing months, a number of meetings took place to bring more representatives into that discussion, including people from the utility trade organizations like EEI and APPA, ourselves at EPRI, and the Department of Energy. These have culminated in two meetings of this Coordinating Committee, which are discussed below in more detail. Through all those meetings it became very clear that a number of issues need attention if wind power use is to expand. First, there is growing competition within the electricity business. There is no question that cost is key. Any new technology such as wind is going to have to compete favorably on a cost basis. Then there are environmental issues, and the issue of intermittency and its implications for utility system integration. Transmission requirements will also be very important in many situations where good winds are far away from load centers. And then of course there's the issue of market sustainability. The situation right now is that some very substantial orders have been placed. But in order to launch a business and build a wind industry, a continuing succession of new purchases is needed -- not just a few to get things started.

It became clear that these issues are all encompassing, and that they require discussion in a very broad forum. There are many stakeholders from different sectors who have important input and will be affected by the outcome. That is really what is behind the formation of this Coordinating Committee. Its relationship to the three sectors discussed is shown on Chart 13, and its aim is to provide better communication and better coordination of present and future activities related to wind power. Representation on the Committee includes members from all sectors of the community -- the users, the suppliers, the environmental interests, consumer interests, regulators, as well as from government agencies and EPRI. We have brought on board a very capable, effective facilitator firm by the name of Resolve to assemble the Committee and coordinate its activities.

Status

The Coordinating Committee officially formed at its most recent meeting, which took place at the end of April. That's no small decision for most of the members, as I'll discuss below. The group is evolving. Its mission, its objectives, and its groundrules will be developed over the coming months. The membership is developing; and the key issues to address, the activities to conduct, these as well are evolving. Also the scope of activity is evolving. Is the group going to simply make recommendations? Is it going to go further and try to influence other organizations to act in accordance with these recommendations? Or is it going to take another step and structure itself so that it can actually conduct some of the activities it recommends? The scope is not yet clear; however, the feeling is that the Committee will gravitate toward the second option; that is, influencing other organizations. This again is in the spirit of not creating any more new organizations than is absolutely needed.

Five initial subcommittees have been formed. These will address avian issues, transmission issues, resource assessment, and regulatory opportunities. The fifth subcommittee will deal with sustained development of the wind industry toward rational goals for the next 10 to 20 years.

Perspective

I'll close with my own perspective on the Coordinating Committee. It has held two meetings and very substantial progress has been made in those meetings. This is particularly noteworthy in light of the great deal of activity already underway in wind. Many significant issues are already on the table. Tens of millions of dollars are involved. Significant environmental issues have been raised. In some cases strong positions have been formed, lines in the sand have been drawn; so it's a major decision for participants to change their mode of operation, come to the table and attempt collaborative resolution. A decision to become a member of this Coordinating

Committee is a very significant one from the standpoint of all the sectors involved. Wind is not like most of the other emerging renewables, for which multi-million-dollar decisions associated with installation, deployment, and purchase are still five or ten years off. Wind is happening now. So the people who have traditionally operated in an adversarial role have a very serious decision to make when they consider activity to address key issues in a collaborative fashion. That is where we're all headed with this Committee. What is most significant is that all of the people who have been involved so far want to continue this activity. They are seeing its potential value, and want to add to that value.

My own feeling is that this Committee is well on its way toward a substantial contribution in managing the process of wind power expansion over the next 10 to 20 years in such a way that society realizes optimal benefits from this sustainable, environmentally responsible technology.

All of us on the Committee encourage each member of the wind community to plug into the Committee's activities through a member from your sector. We look forward to working with all of you.

National Wind Coordinating Committee

A forum for multi-stakeholder teamwork to optimize the societal benefits of wind power

Edgar DeMeo
Electric Power Research Institute

Wind Power '94 Conference May 10, 1994

1

Outline

- Broad Objectives
- Background
- Organizational Involvement
- Coordination Committee
 - Formation
 - Issues/Barriers
 - Status
 - Perspective

2

National Wind Coordinating Committee

BROAD OBJECTIVES

Provide a forum for . . .

- Identifying issues and impacts
- Promoting coordination
- Pursuing societal benefits optimization

Catalyze actions to . . .

- Understand roles and value
- Reduce barriers
- Encourage prudent acceleration
- Promote sustained markets

3

Current Situation

- Wind at threshold of significant utility-scale use nationally
- Substantial utility deployment activity underway and planned
- Hardware available
 - one major domestic supplier
 - several strong players overseas
 - several players emerging in U.S.
- Wind can begin to show measurable environmental benefits

4

Key Issues

- Is enough wind deployment activity already underway or planned?
- Would an acceleration program be beneficial?
- If so, how can we avoid interference with efforts already in progress?
- Would better coordination of wind activities be beneficial?

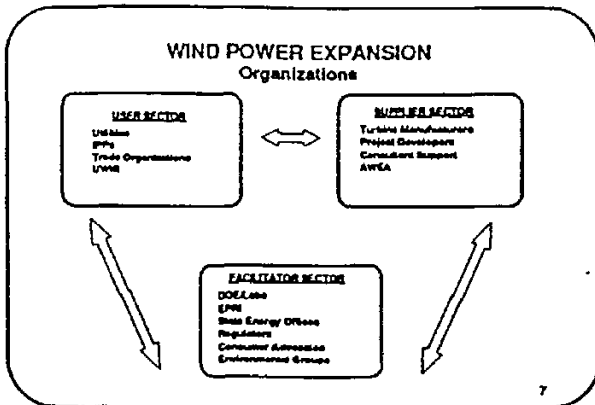
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Wind Deployment Coordination/Acceleration

GUIDING PRINCIPLES

- Develop a minimum of new organizational infrastructure
- Make maximum use of existing organizations, programs, and relationships
- Seek maximum leverage for funds that become available

6



Utility Wind Interest Group (UWIG)

Formed by utilities mid 1989 with DOE and EPRI support
 Current membership: 13 utilities
 Mission: Expedite appropriate integration of wind power for utility applications
 Strategy: Understand and communicate status and issues
 - experience exchange
 - wind industry interactions
 - brochures and seminars
 Seven brochures published; several in process

8

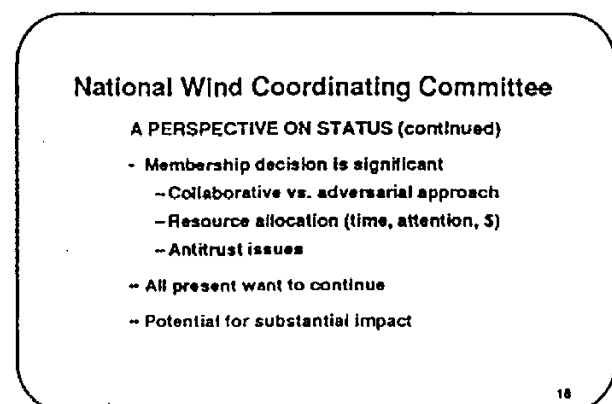
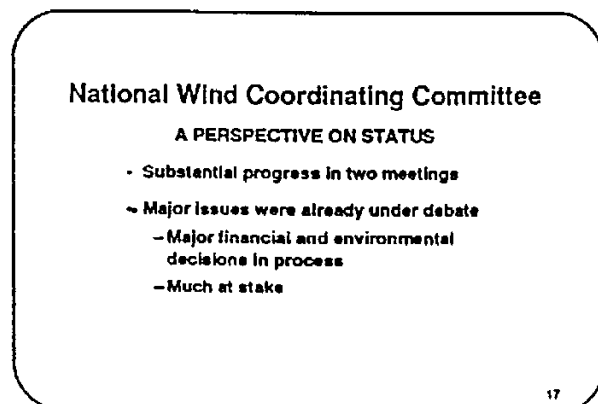
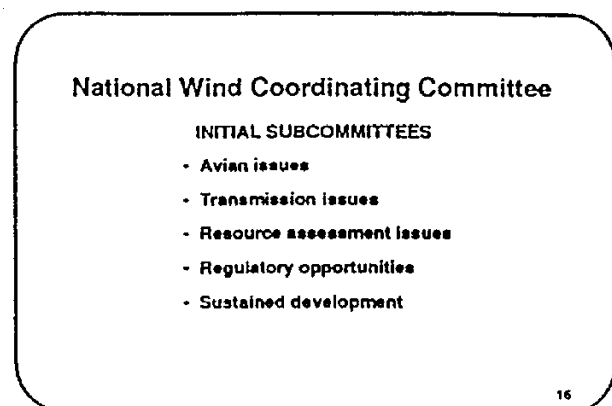
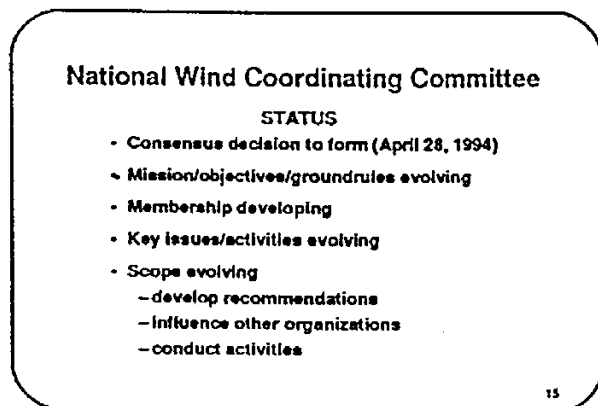
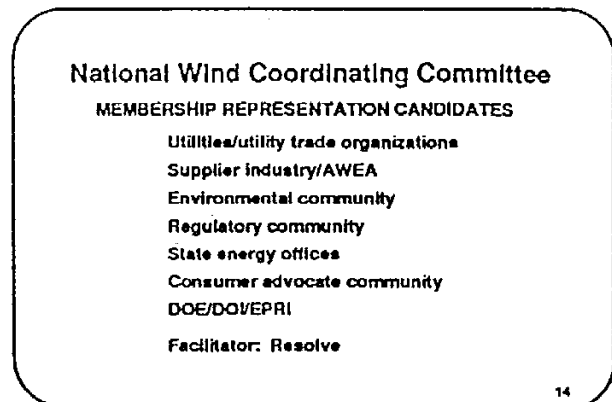
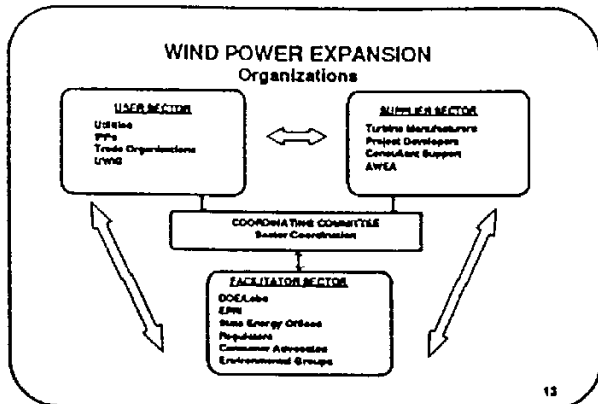
- UWIG Expansion Rationale**
- Forum for utility issues discussion
 - Focus for key wind activities
 - resource assessment
 - environmental issues
 - integration issues
 - status assessment
 - outreach
 - Accelerated use of wind nearly certain
 - help define the acceleration process
- 9

National Wind Coordinating Committee
 Formative Activities

10

- Toward a Collaborative Approach**
- | | |
|-------------------|--|
| October 1993 | Preliminary AWEA announcement
Early strategy discussion |
| November 1993 | Strategy/brainstorm session (APPA, AWEA, DOE, EEI, EPRI) |
| December 1993 | Utility-sector meeting
Environmental-sector meeting |
| Jan-Feb 1994 | Meetings to plan UWIG expansion and Coordinating Committee formation |
| March 3-4, 1994 | National Wind Coordinating Committee formation meetings |
| April 27-28, 1994 | formation meetings |
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- Wind Power Expansion**
- ISSUES/BARRIERS**
- Electricity competition/overcapacity
 - Wind capital and operating costs
 - Environmental impacts
 - Nondispatchability/integration
 - Transmission requirements
 - Market sustainability
- 12



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This paper gives an overview of research carried out in Europe, with special emphasis on the results of the two most detailed studies. (1) Oosterbierum wind park, Netherlands, with 18 middle-sized (300 kW) turbines in cluster formation on 55ha of arable land (Fig. A1) close to the Wadden Sea (Winkelman 1992a-d). (2) Urk wind park, Netherlands, with 25 middle-sized (300 kW) turbines in line formation along a 3-km dike bordering lake IJsselmeer, a major wintering area for ducks (Winkelman 1989). Most results of other European studies are consistent with those from these two areas. The main exception is the recent work in southern Spain, where bird mortality (mainly of raptors) has been more evident than in the Netherlands.

In Europe discussions about the possible impact of wind energy on birds started in the late seventies, when the first national wind energy strategies were formulated and the first (mostly small sized, solitary) wind turbines were erected. This was followed by a huge number of speculative articles in newspapers, magazines and popular scientific journals, nearly all of them focusing on the possible collision risks for birds. The first research results became available in Sweden, Denmark and The Netherlands in 1983 and 1984, again followed by many articles and reports on possible effects, pre-construction studies, progress reports, and overview studies.

To date, 14 studies have been finalized in Europe, covering 108 different sites with one or more wind turbines. These studies were in southern Sweden (2 studies, 2 sites), Denmark (3,18), northern Germany (1,10), Netherlands (6,85), and United Kingdom (2,3) (Attachment 1). Research is now underway or will start soon in the south of Spain, The Netherlands, and Denmark (Attachment 2).

Most studies include small, solitary turbines (<100-150 kW). Wind parks, and especially middle-sized (250-500 kW) and large (MW) turbines, are less studied (Table 1). Three general topics have been studied (Table 2).

Table 1. Configurations and wind turbine size in the finalized studies in Europe (N=14 studies, 108 different sites). At some sites more than one configuration or turbine size appears.

CONFIGURATION	SIZE OF WIND TURBINES			TOTAL
	SMALL	MIDDLE	LARGE	
Wind Park	20	6	1	27
Solitary Turbine	81	3	5	89
TOTAL	101	9	6	116

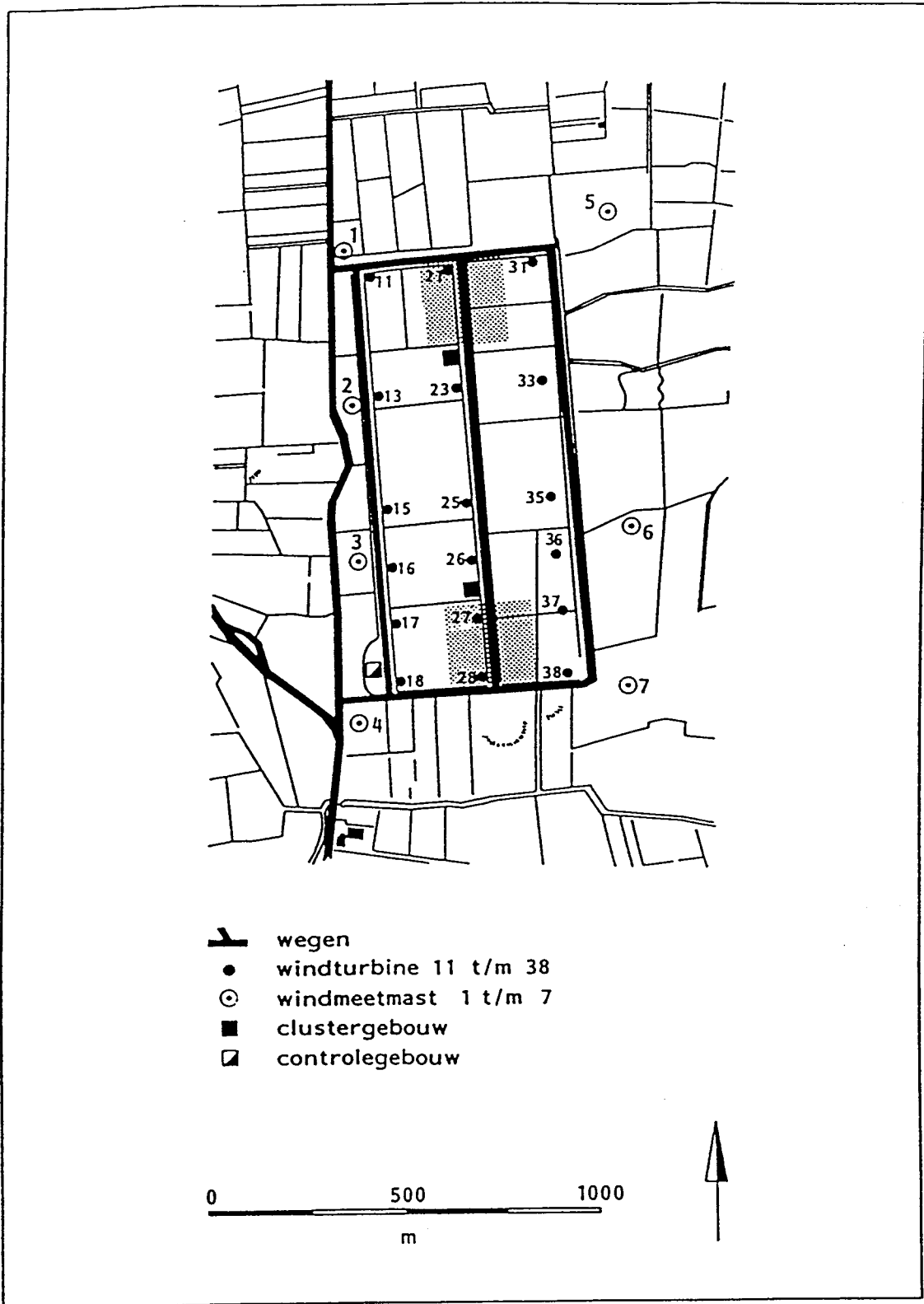


Figure A1. Configuration of the Oosterbierum wind park, The Netherlands. Wegen = roads; windturbine = wind turbine; windmeetmast = meteorological tower; clustergebouw = cluster building; controlegebouw = control building.

Table 2. Topics studied during bird/wind turbine studies in Europe.

IMPACT ON BIRDS: DIRECT AND INDIRECT EFFECTS:

1. Collisions with rotor, tower, power lines
2. Disturbance (usually without much habitat modification):
Loss or fragmentation of habitat for breeding, feeding, migration
3. Behavioral Changes
Flight behavior when approaching wind turbines

Bird Collisions.—Studies on bird collisions were mostly carried out by searches for dead birds (Table 3). The proportion of birds colliding in relation to the total numbers passing the wind turbines was studied at 13 sites. Estimates of the total numbers of bird victims could only be made in three studies (3 sites), as the other studies did not take into account the search efficiency, predation pressure, number of days with searches, causes of death of the corpses found, and/or total areas searched. These factors may all have strong effects on total estimates. It was proven that, even with careful searching, the proportion of the bird bodies found could be low (Table 4), especially for small birds in high vegetation.

Table 3. Methods used to study (potential) numbers of bird collision victims in Europe. **N:** number of sites (number of studies). Total numbers of sites and studies were 108 and 14, respectively. **Tests:** study included tests of search efficiency and scavenging as well. **Total estimates:** estimated total number of bird victims, taking into account number of dead birds found and killed by collision, number of days with searches, total area searched for dead birds, and/or search efficiency, and scavenging. **Relation to migration:** numbers found dead related to numbers of birds (closely) passing the wind turbines.

STUDY METHODS	SIZE OF TURBINES			N
	SMALL	MIDDLE	LARGE	
Searches for dead birds	93	3	5	101 (14)
Searches + tests	-	6	1	7 (7)
Total estimates	-	3	-	3 (3)
Relation to day-time migration	6	5	1	12 (12)
Relation to nocturnal migration	-	1	-	1 (1)

Table 4. Search efficiency for small songbirds (up to the size of Starling, *Sturnus vulgaris*) by careful searching (2 ha/hour) in two different wind parks with middle-sized wind turbines in The Netherlands (Oosterbierum: Winkelman 1992a; Urk: Winkelman 1989).

SITE	AVERAGE (%)	RANGE (%)	N
Oosterbierum 1987+1988	45	30-55	56
Urk 1988	73	60-83	22

At the 108 European study sites, a total of 303 dead birds were found, of which at least 124 (41%) were proven collision victims. In the Dutch Oosterbierum wind park, only 27% of all birds found were killed by collision (Table 5). It is noteworthy that there were no nights with large kills, that very few collision victims were found near small wind turbines, and that almost all victims were of common species. Virtually none of the victims were scarce or rare species. The estimated average numbers of collision victims in the Oosterbierum and Urk wind parks, in birds per turbine/day, varied between 0.04 (Urk, autumn) and 0.09 (Oosterbierum, spring), depending on season and site. These figures were based on regular searches (Table 6).

Table 5. Causes of death of 63 birds found dead during searches in the wind park near Oosterbierum, Netherlands (18 middle-sized wind turbines) (Winkelman 1992a). Certainly collided and other causes: proved by autopsy. Very probably collided: birds obviously wounded by collision, but no proof by autopsy. Probably collided: fresh remnants, bird killed by either collision or predation. Unknown: found whole or partial corpse in advanced state of decomposition.

CAUSES OF DEATH	%
Certainly collided	21
Very probably collided	6
Probably collided	25
Unknown	35
Other causes	13
TOTAL	100

Table 6. Estimated, average (minimum - maximum; based on 95% confidence limits) numbers of collision victims per turbine per day in two wind parks with middle-sized wind turbines in The Netherlands during autumn and spring (Oosterbierum: Winkelman 1992a; Urk: Winkelman 1989). Factors taken into account: number of birds killed by collision with the wind turbines (not all dead birds found were collision victims, see Table 5), search efficiency, scavenger pressure, number of days with searches, and total area searched for dead birds.

SITE	SPRING	
	AUTUMN	SPRING
Oosterbierum	0.06 (0.04-0.13)	0.09 (0.09-0.29)
Urk	0.04 (0.03-0.14)	0.05 (0.04-0.93)

Based on nocturnal observations with a thermal image intensifier in the Oosterbierum wind park in autumn 1988, an estimated 170 birds collided with turbines during seven consecutive nights, corresponding to 0.051 dead birds/h/100 m front. This was equivalent to 2.5% of all birds passing at rotor height (20-50 m), and with 1.2% of all birds passing at wind turbine height (0-50 m). In both the Oosterbierum and Urk studies, most bird victims were found after nights with both poor flight conditions and visibility. Mean numbers per kilometer of wind park are comparable to the numbers of birds killed by traffic per km of highway, and comparable to or somewhat lower than the numbers of victims per km of power line in risky situations. Total numbers likely to be killed per 1,000 MW of wind power capacity are low relative to other human-related causes of death (Table 7).

Table 7. Comparison of some estimates of annual total human-related bird-mortality in the Netherlands. The estimate for wind power is based on present initiatives of the Dutch government, which aim for 1,000 MW in the year 2000.

CAUSES OF DEATH	NO. BIRD VICTIMS
Road kills	2 - 8,000,000
Power lines	1 - 2,000,000
Hunting	650,000
1,000 MW wind power	21 - 46,000

In the Oosterbierum wind park, only a few birds were seen very close to a rotor during daylight. Of these, one (14%) was hit and killed. During the night, 20% of all birds crossing a rotor were killed. It was noteworthy that not all observed collisions were fatal, and that some "collisions" were caused by the wake behind the rotor (Table 8). In the latter cases, birds that did not contact the rotor were sometimes swept down by the wake, and injured or killed as a result.

Table 8. Summary of observed collisions of birds with a rotor, or of birds swept down by the wake behind a rotor, in the Dutch Oosterbierum wind park during the night (N=14), and fate (killed vs. recovered). Total number of observations: 51 (Winkelman 1992b).

COLLISION	KILLED		RECOVERED		TOTAL	
	N	(%)	N	(%)	N	(%)
With rotor blade	5	(10)	0		5	(10)
With wake	3	(6)	3	(6)	6	(12)
Unknown	2	(4)	1	(2)	3	(6)
TOTAL	10	(20)	4	(8)	14	(28)

Disturbance and Habitat Loss.—Several studies evaluated the effects of disturbance and habitat loss on numbers of birds present. Five of these studies concerned loss of habitat

for breeding birds (mainly waders). Three studies concerned resting birds (several larger bird species), three concerned daytime migrants and two concerned nocturnal migrants—largely songbirds (Table 9).

Table 9. Number of wind farm sites in Europe at which habitat loss/disturbance effects were studied, in relation to wind turbine size and category of birds. (Parenthetical values show number of studies.)

CATEGORY OF BIRDS	SIZE OF WIND TURBINES			TOTAL	
	SMALL	MIDDLE	LARGE		
Breeding birds	10	8	6	24	(5)
Staging birds	11	6	3	20	(3)
Day-time migration	10	8	4	22	(3)
Nocturnal migration	-	1	1	2	(2)
Breeding success	-	-	1	1	(1)

Habitat loss/disturbance effects were demonstrated at distances up to 250-500 m from the nearest turbines.¹ The reduction in the numbers present in the disturbed zones ranged up to 95%. Some bird species were far more vulnerable than others, and vulnerability depended on site, season, tide, and whether or not the wind park was in operation (Table 10, 11). Breeding waders seemed less vulnerable than some other birds. However, those results may have been confounded by the high site fidelity and long life spans of waders, coupled with the fact that the studies were carried out for only one or a few breeding seasons. *From a European nature conservation point of view, disturbance / habitat loss effects associated with wind plants are thought to be of much more importance than direct bird mortality due to collisions.* However, the ongoing study in Spain may be an exception to this generalization.

Flight Behavior.—Changes in flight behavior during migration were examined during seven studies of day-time migration involving 28 wind turbine sites, and during three studies of nocturnal migration at three sites (Table 12). Aspects studied included numbers and types of reactions. These were mostly within 100 m of the nearest turbine during diurnal migration, and within 20 m of a rotor during nocturnal migration. Changes in flight paths were also studied. During diurnal migration these changes mostly occurred within 300-500 m.

¹ Habitat loss/disturbance effects were shown by generalized linear regression analyses relative to distance from windplant, and by analysis of variance of bird counts on a control site and a wind-park before and after it was constructed. The latter approach, including both spatial and temporal controls, met the requirements of a BACI design (Before-After Control-Impact). The BACI design has been considered optimal for field studies of environmental impact (Green, R.H. 1979. *Sampling design and statistical methods for environmental biologists*. Wiley-Interscience, New York. 257 p.).

Table 10. Maximum disturbance distances, and percentage reductions within disturbed zones, based on two disturbance studies. *: data from Pedersen & Poulsen 1991 (1 MW turbine; Denmark); other data from Winkelman 1992b,d (Oosterbierum wind park; 18 middle sized turbines on 500 ha, Netherlands).

CATEGORY OF BIRDS	DISTURBANCE	
	DISTANCE (m)	REDUCTION (%)
Breeding	0 (-200*)	(?*)
Staging	100-250 (500)	≤ 95
Day-time migration	0-150	≤ 82
Nocturnal migration	+	+
Breeding success	(+*)	(6*)

Table 11. Maximum disturbance distances (m) caused by the Dutch Oosterbierum and Urk wind parks in autumn and/or winter/spring (Winkelman 1992d, 1989). Data are for wind parks in full operation. ?: not studied. Maximum distance studied: Oosterbierum 2,000 m from wind park; Urk 500 m from row of wind turbines.

SPECIES	OOSTERBIERUM		URK
	AUTUMN	WINTER/SPRING	WINTER/SPRING
<i>Anas platyrhynchos</i>	100-250	0	250
<i>Aythya fuligula</i>	?	250	100
<i>Fulica atra</i>	?	250	100
<i>Haematopus ostralegus</i>	?	100	?
<i>Pluvialis apricaria</i>	100	100	?
<i>Vanellus vanellus</i>	100	0	?
<i>Numenius arquata</i>	500	100-250	?
<i>Larus canus</i>	250-500	0	0
<i>Larus argentatus</i>	500	0	?
Corvidae	0	0	?

During daylight, proportionally fewer of the migrating birds reacted when the turbines were not operating than when turbines were operating (2% vs. 11-18%). The frequency of reactions with turbines operating depending on the distance between the turbines, with reactions being more frequent when the turbines were 150 m apart than when they were 300 m apart (Table 13). During the day-time, most reactions were calm and gradual, mainly consisting of horizontal shifts. Only a minority of the approaching birds needed more than one passing attempt before crossing the wind park (Table 13).

In the Oosterbierum wind park only a very few birds were seen within 20 m of a rotor during daylight. Nocturnal migrants were more commonly seen within 20 m of the rotors. During the night, reactions of 47 birds within 20 m of a rotor were observed by means of a thermal image intensifier. Of these, 43% approached without hesitation. The proportion of

the birds that reacted depending on the wind direction (Table 14). Birds flying with headwinds were more likely to react, perhaps because they encounter the rotor wake before reaching the operating rotor. During the daytime, 15% of the closely-approaching birds altered their flight paths calmly to avoid crossing the rotor, whilst at night 36% did so. The other birds all crossed or tried to cross between the rotor blades. While doing so, most of them either flapped their wings powerfully or fluttered.

Table 12. Number of European sites (and in parentheses number of studies) where flight behavior of birds approaching wind turbines has been studied, for different wind turbine sizes and types of bird migration. Variables recorded included changes in flight paths, numbers and/or reaction types.

	SIZE OF WIND TURBINES			TOTAL
	SMALL	MIDDLE	LARGE	
Day-time migration	18	7	3	28 (7)
Nocturnal migration	1	1	1	3 (3)

Table 13. Changes in flight behavior for day-time migration in the Dutch Oosterbierum wind park (Winkelman 1992c). *: accelerated wing beat, fluttering flights, alteration of the angle of the body. **: most common were (1) circling of a wind turbine after which the wind park was entered, (2) temporary flight path parallel to the outer row of wind turbines after which the wind park was entered, (3) circling the whole wind park system without entering the wind park, and (4) turning back without entering the wind park system. N-TOTAL: total number of observations.

FLIGHT BEHAVIOR	%	N-TOTAL
Numbers of reactions within 100 m of turbine		
non-operative park	2	6,913
operative, distance between turbines 300 m	11	3,214
operative, distance between turbines 150 m	18	3,541
Type of reaction within 100 m of turbine		
2-5 passing attempts	13	2,203
panic reactions*	25	2,203
Change in flight path within 300 m of wind park		
horizontal shifts**	30	1,130
vertical shifts	6	1,130

Table 14. Proportion of nocturnal migrants that reacted when approaching within 20 m of an operating rotor in the Oosterbierum wind park with head and tail winds (Winkelman 1992b). Birds flying with headwinds encounter the rotor wake before reaching the rotor.

WIND DIRECTION	%	N-TOTAL
Head Winds	87	23
Tail Winds	29	24
TOTAL	57	47

Attachment 1. Finalized Studies on Wind Power and Birds in Europe

- (1) Berkhuizen, J.C. 1987. Vogelschade door windturbines niet aangetoond (in Dutch). *Duurzame Energie 2* (April): 43-45.
- (2) Böttger, M., T. Clemens, G. Grote, G. Hartmann, E. Hartwig, C. Lammen & E. Vauk-Hentzelt. 1990. Biologisch-ökologische Begleituntersuchungen zum Bau und Betrieb von Windkraftanlagen, Endbericht (in German). *NNA-Berichte 3* (Sonderheft): 1-124.
- (3) Karlsson, J. 1983. Fåglar och vindkraft (in Swedish). Teknisk rapport 1977-1982, Naemden for Energiproduktionsforskning, Stockholm.
- (4) ---- 1987. Fåglar och vindkraft. Kompletterande resultatredovisning (in Swedish). Internal report, University of Lund, Ecologihuset, Lund.
- (5) Meek, E.R. J.B. Ribbans, W.G. Christer, P.R. Davey & I. Higginson. 1992. The effects of aero-generators on a moorland bird population in the Orkney Islands, Scotland. Report, Royal Society for the Protection of Birds Scotland, Edinburgh / Scottish Hydro-Electric plc., Edinburgh.
- (6) ---- 1993. The effects of aero-generators on a moorland bird population in the Orkney Islands, Scotland. *Bird Study* 40: 140-143.
- (7) Møller, N.W. & E. Poulsen. 1984. Vindmøller og fugle (Danish, English summary). Report, Vildtbiologisk Station, Kalø.
- (8) Musters, C.J.M., G.J.V. van Zuylen & W.J. ter Keurs. 1991. Vogels en windmolens bij de Kreekraksluizen (in Dutch). Report, vakgroep Milieubiologie, Rijksuniversiteit, Leiden.
- (9) Ornis Consult. 1989. Konsekvenser for fuglelivet ved etableringen af mindre vindmøller (in Danish). Report, Ornis Consult, Copenhagen.
- (10) Pedersen M.B. & E. Poulsen. 1991. En 90m/2MW vindmølles indvirkning på fuglelivet. Fugles reaktioner på opførelsen og idriftsættelsen af Tjæreborgmøllen ved Danske Vadehav (Danish, English summary). *Danske Vildtundersøgelser, Hæfte 47, Danmarks Miljøundersøgelser, Afdeling for Flora- og Faunaøkologi, Kalø.*
- (11) Swelm, N. van. 1988. Vogels en de multi-windturbine op de Maasvlakte. Onderzoek naar slachtoffers, vogelbewegingen en vogelgedrag (in Dutch). Report, Stichting Ornithologisch

Station, Voorne, Oostvoorne/provincie Zuid-Holland, Dienst Welzijn, Economie en Bestuur, Dienst Ruimte en Groen, 's-Gravenhage.

- (12) Winkelman, J.E. 1984. Bird impact by middle-sized wind turbines - on flight behaviour, victims, and disturbance (Dutch, English summary). RIN-report 84/7, Rijksinstituut voor Natuurbeheer, Arnhem.
- (13) ---- 1985a. Bird impact by middle-sized wind turbines - on flight behaviour, victims, and disturbance (Dutch, English summary). *Limosa* 58: 117-121.
- (14) ---- 1985b. Impact of medium-sized wind turbines on birds: a survey on flight behaviour, victims, and disturbance. *Neth. J. Agric. Sci.* 33: 75-78.
- (15) ---- 1988. Methodologische aspecten vogelonderzoek SEP-proefwindcentrale Oosterbierum (Fr.), deel 1: onderzoekopzet, nachtstudies en slachtofferonderzoek, voorjaar 1984 - herfst 1987 (in Dutch). RIN-report 88/46, Rijksinstituut voor Natuurbeheer, Arnhem.
- (16) ---- 1989. Birds and the wind park near Urk (NOP): bird collision victims and disturbance of wintering ducks, geese and swans (Dutch, English summary). RIN-report 89/15, Rijksinstituut voor Natuurbeheer, Arnhem.
- (17) ---- 1990. Impact of the wind park near Urk, Netherlands, on birds: bird collision victims and disturbance of wintering waterfowl. *Acta SS Congressus Internationalis Ornithologici*, Christchurch, New Zealand, Supplement, Programme and Abstracts: 402-403.
- (18) ---- 1992a. The impact of the SEP wind park near Oosterbierum (Fr.), The Netherlands, on birds, 1: collision victims (Dutch, English summary). RIN-report 92/2, DLO-Institute for Forestry and Nature Research, Arnhem.
- (19) ---- 1992b. The impact of the SEP wind park near Oosterbierum (Fr.), The Netherlands, on birds, 2: nocturnal collision risks (Dutch, English summary). RIN-report 92/3, DLO-Institute for Forestry and Nature Research, Arnhem.
- (20) ---- 1992c. The impact of the SEP wind park near Oosterbierum (Fr.), The Netherlands, on birds, 3: flight behaviour during daylight (Dutch, English summary). RIN-report 92/4, DLO-Institute for Forestry and Nature Research, Arnhem.
- (21) ---- 1992d. The impact of the SEP wind park near Oosterbierum (Fr.), The Netherlands, on birds, 4: disturbance (Dutch, English summary). RIN-report 92/5, DLO-Inst. for Forestry and Nature Research, Arnhem.
- (22) ---- 1992e. Methodologische aspecten vogelonderzoek Sep-proefwindcentrale Oosterbierum (Fr.), part 2 (1988-1991) (in Dutch). RIN-report 92/6. DLO-Inst. for Forestry and Nature Research, Arnhem.
- (23) ---- 1994. Thermal and passive imaging of nocturnal bird movements and behaviour near obstacles (in English). *J. Ornithol.* 135(3):505.

Addresses

- (1) CEA, Consultants on energy and the environment, P.O. Box 21421, NL-3001 AK Rotterdam, The Netherlands.

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- (2) Norddeutsche Naturschutzakademie, Hof Möhr, D-W-3043 Schneverdingen, Germany, and INUF des Vereins Jordsand, Haus der Natur, D-W-2070, Ahrensburg, Germany.
- (3, 4) Dept. of Animal Ecology, University of Lund, Ecology Building, S-22362, Lund, Sweden.
- (5, 6) RSPB Orkney Office, Smyrill, Stenness, Orkney KW16 3JX, Scotland, U.K.
- (7, 10) NERI, Wildlife Ecology, Kalø, Grenavej 12, DK-8410 Rønne, Denmark.
- (8) University/Milieubiologie, P.O. Box 9516, NL-2300 RA Leiden, Netherlands.
- (9) Vesterbrogade 140, DK-1620 Copenhagen V, Denmark.
- (11) c/o R. ter Horst, provincie Zuid-Holland, Dienst Ruimte en Groen, Koningskade 1, NL-2596 AA Den Haag, The Netherlands
- (12-23) c/o BirdLife/Vogelbescherming Nederland, Drieburgseweg 16-C, NL-3708 JB Zeist, The Netherlands

Reports 18-21 and 22 can still be ordered from DLO-Institute for Forestry and Nature Research, P.O. Box 23, NL-6700 AA Wageningen, Netherlands. Cost for full set of (18-21) including p&p is NLG 77.50; cost for (22) is NLG 18.50.

Useful overview of studies carried out in Europe

Crockford, N.J. 1992. A review of the possible impacts of wind farms on birds and other wildlife. JNCC Rep. 27, Joint Nature Conservation Committee, Peterborough, U.K. [Address: Joint Nature Conservation Committee, Monkstone House, City Road, Peterborough, PE1 1JY, U.K.]

Attachment 2. Ongoing Studies in Europe

- (1) **Spain, Tarifa:** bird collision victims (raptors, storks, gulls) in coastal wind farms (see also A. Luke. 1994. Bird deaths prompt rethink on wind farming in Spain. *Wind-power Monthly*, February 1994: 14-16) (field work to be finalized in autumn 1994).
Address: c/o SEO, Carretera de Humera No. 63-1, E-28224 Pozuelo de Alarcón (Madrid), Spain.
- (2) **Netherlands:** disturbance (mainly of ducks) by an off-shore wind park in lake IJsselmeer (pre-construction study more or less finalized; post-construction to be started after wind turbines have been erected).
Contact: Dr. A.L. Spaans, DLO-Inst. for Forestry and Nature Research, P.O. Box 23, NL-6700 AA Wageningen, Netherlands, and Sjoerd Dirksen, Bureau Waardenburg, P.O. Box 365, NL-4100 AJ Culemborg, Netherlands.
- (3) **Denmark:** impact of off-shore wind turbine park (10-12 wind turbines) on birds (pre-construction study finalized; study after construction planned for 1995, final report planned for 1997).
Contact: Ib Clausager, NERI, Grenåvej 12, Kalø, DK-8410 Rønne, Denmark.

Appendix 2C. English-Language Summaries of Reports on Bird-Wind Power Studies at the Urk and Oosterbierum Wind Parks, The Netherlands, by J.E. Winkelman

The following pages provide the English-language summaries of these five reports:

- Winkelman, J.E. 1989. [Birds and the wind park near Urk: collision victims and disturbance of ducks, geese, and swans]. RIN Rep. 89/15. Rijksinstituut voor Natuurbeheer, Arnhem, The Netherlands. Dutch, Engl. summ.
- Winkelman, J.E. 1992a. [The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 1: collisionvictims]. RIN Rep. 92/2. DLO-Instituut voor Bos- en Natuuronderzoek, Arnhem, The Netherlands. 71 p. plus Appendices. Dutch, Engl. summ.
- Winkelman, J.E. 1992b. [The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 2: nocturnal collision risks]. RIN Rep. 92/3. DLO-Instituut voor Bos- en Natuuronderzoek, Arnhem, The Netherlands. 120 p. plus Appendices. Dutch, Engl. summ.
- Winkelman, J.E. 1992c. [The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 3: flight behaviour during daylight]. RIN Rep. 92/4. DLO-Instituut voor Bos- en Natuuronderzoek, Arnhem, The Netherlands. 69 p. plus Appendices. Dutch, Engl. summ.
- Winkelman, J.E. 1992d. [The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 4: disturbance]. RIN Rep. 92/5. DLO-Instituut voor Bos- en Natuuronderzoek, Arnhem, The Netherlands. 106 p. plus Appendices. Dutch, Engl. summ.

Winkelman, J.E. 1989. [Birds and the wind park near Urk: collision victims and disturbance of ducks, geese, and swans]. RIN Rep. 89/15. Rijksinstituut voor Natuurbeheer, Arnhem, The Netherlands. Dutch, Engl. summ.

In the autumn of 1987 a wind park was erected along the landside of the dike bordering the Lake IJsselmeer north of Urk, Noordoostpolder, (fig. 1-3). The wind park consists of 25 middle-sized wind turbines (300 kW HAT, three rotor blades, tower height 30 m, rotor diameter 25 m), one meteorological tower and one control building. The distance between the wind turbines is 125 m, the total length of the wind park 3 km. The wind park was operating during daytime from 10 December 1987 onwards, and also during the night from February 1988 onwards.

In the periods from January to the middle of April 1987, from December 1987 to the beginning of May 1988 and from October 1988 to the middle of April 1989 the Research Institute for Nature Management (RIN), Arnhem, carried out a study on the possible impact of the wind park on birds. Aspects studied included (1) number of birds collided with the wind turbines (chapter 5 and 7), (2) disturbing effects to wintering waterfowl outside the dike (chapter 6 and 8) and (3) disturbing effects to swans and geese wintering in the area at the landside of the dike (chapter 6 and 9). For comparison data on numbers of swans and geese were also available from the period before 1987 (nearly weekly counts of swans from 1982/1983 onwards, one to three counts per month for geese from 1977/1978 onwards).

Numbers of birds collided Numbers of bird collisions were studied by searches for dead birds in the wind park and near surroundings (60 m on both sides of the row of wind turbines), in combination with autopsy, field studies on scavenger activities, and search efficiency. In winter and spring searches were made once or twice a week, in autumn on all days except weekends. Scavenger activity in autumn was determined by establishing the survival time of carcasses of day-old chickens and of wild birds in the wind park and at a control site along the same dike one km to the north (fig. 1). In winter only large birds were placed in the wind park area. Carcasses were placed independently from each other and *at random*, in the afternoon or early evening. In autumn checks were made three times on the first day after placement and twice on at least the next two days. In winter checks were made twice a week. Search efficiency was determined by hiding marked carcasses of birds for the people searching for bird victims.

During the study 63 dead birds were found (25 species) of which 13 were certainly killed as a result from collision with a wind turbine, four very probably so, and 16 possibly. Of 22 birds the cause of death was unknown and eight birds died from other causes (tab. 2, 3; app. 1-4). Although the birds were scattered all over the entire study area (fig. 7), most of them were found in the intensively searched parts of the wind park (fig. 8) and at sites where the vegetation was not too high and dense (fig. 9, 10; tab. 4, 5). In the wind park 10% of all small bird carcasses were removed after 7-8 hours, 25% after 17-20 hours, and 50% after 54-55 hours (tab. 6). For large birds the removal time was 17% within the first week. Of the hidden small carcasses 73% was found. For large carcasses search efficiency was 67% when roughly, and 100% when intensively searches were made.

The total number of collided birds was estimated by the formula $N_{\text{estimated}} = (N_a - N_b) / (P * Z * O * D * E)$, in which N_a = numbers of birds found, N_b = numbers of birds not collided, P = scavenger activity (numbers of birds not predated), Z = search efficiency (numbers of birds not overlooked), O = area looked for, D = numbers of days with searches, E = numbers of birds not leaving the study area (P , Z , O , D , and E : proportions of total). The values for P , Z , O and D in this study are given in appendix 6. For E the value is put at 1. Depending on the size of the birds, the correction factor in autumn amounts to 2.8-19.7 ($1 / (P * Z * O * D * E)$) (95%-confidence limits: 2.3-54.8), when almost daily searches were made. In winter and spring the correction factor amounts to 11.5-54 (8.2-228.9), when searches were made once or twice a week. The estimated number of victims (small and large birds separated) is given in table 8. On average, 0.5-1.2 bird collided per day in the entire wind park. For the entire period the estimated number of bird victims in the wind park on average is 150 to several hundreds of birds (tab. 9). In autumn two to three times more birds collided than in winter and spring. Mean numbers of estimated victims per turbine per day agree with those from the scarce literature (app. 7) and are less than those found near (unlighted) lighthouses in risky situations (lots of birds around), and the same or a little bit more than the numbers found near towers in areas with low risks (moderate or low bird life). Mean numbers per kilometre wind park per day are comparable to the numbers of birds killed by traffic per kilometre, and are mostly less than the numbers of victims per kilometre power line (appendix 8). There was no possibility to study the numbers of birds passing at night at wind turbine heights. So it is not known which proportion of passing birds really

collided with the wind turbines.

In autumn no certainly or very probably collided birds or possibly collided passerines were found after 13 nights with fine flight conditions and good visibility, five (0.63/night) were so after eight nights with fine flight conditions, but bad visibility, and five (1,00/night) after five nights with both bad flight conditions and bad visibility (tab. 7, app. 5).

Disturbance of wintering waterfowl on the Lake IJsselmeer The outside part of the dike and near-shore water between Urk and Rotterdamse Hoek was divided into 100 m plots along the dike and in seven distance zones (tab. 2). Birds were counted in every 100 m plot and distance zone, during good visibility and winds below 7-8 Beaufort. Counting data are given in figure 11, tables 10-12 and appendices 10-11. Important species groups were 'waterbirds' (all birds in appendix 10 minus birds of prey, gulls, waders, and passerines), and gulls. The nine most important species (93-99% of the total number) were Great-crested Grebe, Mallard, Pochard, Tufted Duck, Scaup, Goldeneye, Coot, Black-headed Gull, and Common Gull.

The disturbing effect of the wind park on these species (groups) was assessed by comparing data before and after the impact in a control area and in the impact area (BACI-model), using regression analysis and accumulated analysis of deviance following the model

$$E(n_{it}) = \exp \{ \mu + \alpha_i + \beta_t + \gamma * (i=2 \text{ and } t \geq t_0) \} \quad i=1,2; t=1 \dots n_t$$

In this model is n_{it} - the numbers of birds in site i and at time t , $\exp\{\mu\}$

the expected number of birds without impact, α_i the effect of site i (control site $i=1$, impact site $i=2$), β_t the effect of time t . γ figures only in the wind park area ($i=2$) when the wind park is operating. So the null hypothesis is $\gamma=0$. Following this model, the logarithm of the ratio of the expected numbers in both control and impact sites is:

$$\ln(E(n_{2t})/E(n_{1t})) = \alpha_2 - \alpha_1 + \gamma * (t \geq t_0).$$

For the log-ratio $\ln(n_{2t}/n_{1t})$ or $\log(n_{2t}/n_{1t})$ a constant value is expected for $t=t_0$, and another constant value from $t=t_0$ onwards. $\log((n_{2t}+1)/(n_{1t}+1))$ was plotted versus t , and an accumulated analysis of deviance was computed (app. 14). Also the interaction between season and site was studied (app. 15). The results of the BACI-model are given in table 13.

The winter before the impact (1986/1987) was very cold (tab. 15) with Lake IJsselmeer and inland waters totally frozen in the second half of January and in February. During these two months many birds left the study

area. To the contrary, the two winters after the wind park was erected, were rather mild, without ice or snow cover. It may therefore be questioned whether the bird data for these three winters may be compared. Therefore also the mean and estimated mean log-numbers of birds in the 100 m plots and distance zones in the wind park and the control area within the same season (wind park 30 plots, control area 75 plots, for all seven distance zones) were compared. It was supposed that before the wind park was erected the distribution of birds along the entire dike has been equal (not always true, see fig. 12). Differences were tested using the formula $E(n_{it}) = \exp(\mu + \ln(k_i) + \alpha_i + \beta_t)$, in which $\exp(\mu)$ = the expected number without any impact of the wind park, α_i = the effect of site i (wind park $i=2$, control site $i=1$), β_t = the effect of time t and k_i the numbers of counted 100 m plots along the dike in area i . Testing results are summarized in table 14 and appendices 16-18.

For some species significantly smaller numbers were found in some distance zones (tab. 13, 14) than in the control plots. Most negative effects were within 300 m distance of the wind park. Species most susceptible were Mallard, Pochard, Tufted Duck and Goldeneye, with numbers found mostly up to a factor 5 lower than expected (also factors >10 found). No or only little disturbing effects were found for Great-crested Grebe, Coot, Common Gull, and gulls as a species group. For Black-headed Gull and Scaup no to a slightly positive effect (more birds in the wind park area) was found. There was also a negative effect for passerines passing by over water.

Disturbance of wintering swans and geese bordering the wind park on the landside Three species of swans are wintering in the study area (Mute Swan, Bewick's Swan and Whooper Swan). The most important goose species are Bean Goose, White-fronted Goose and Barnacle Goose, totalling 99% of all geese. Swans were counted in 44 plots and geese in at least 12 plots near the wind park (fig. 1). Land use in plots 1-4 was noted in 1986/1987-1988/1989 (tab. 16). Counts are summarized in figures 13-16, tables 17-19, and appendices 19-21. For swans and geese in the plots along the dike (1-8, fig. 1) the distance to the dike (c.q. the wind park in plot 1 and 2) was also noted (swans 1987/1988-1988/1989; geese 1977/1978-1988/1989). The data showed that in cold, icy and snowy winters swans avoid the vicinity of the dike along Lake IJsselmeer. However, geese are more seen here, because of the availability of freshwater in ice-holes in the lake.

The disturbing effect of the wind park on these six species and two

species groups was assessed by using the BACI-model again, comparing data before and after the impact in the control area (swans: plot 3-44, geese: plots 3-5 and 13-19) and in the impact area (plot 1-2). It was not possible to divide the plots 1 and 2 into smaller parts, because in both the years before and after the impact only a few groups of swans and geese were seen in these plots. Because of irregular counts, very variable numbers in the different plots and small numbers in the impact area, also in years before the impact, counts were added for each month. For swans data from October-April were used, for geese data from December, January, and February only. Test results are given in appendices 22 and 23.

Because of high residual mean deviances in most species (app. 22, 23) an effect was only proved for Whooper Swan. For this species a significantly negative effect was found for 1988/1989, but there was no effect in 1987/1988. For the other two swan species and the geese the BACI-test shows that every season there were shifts in relative numbers in control and impact plots, so the effect of the wind park is fully trapped within this season.site interaction. For the swans as species groups there seems to be a small negative effect within the two impact plots, with a greater clustering in the middle of these plots than in the other plots along the dike. For geese the distribution over the plots along the dike does not prove any impact. Because of the very mild winters in the two years with wind turbines the effects found are not valid for cold winters.

Winkelman, J.E. 1992a. [The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 1: collision victims]. RIN Rep. 92/2. DLO-Instituut voor Bos- en Natuuronderzoek, Arnhem, The Netherlands. 71 p. plus Appendices. Dutch, Engl. summ.

In 1984-1991, the DLO Institute for Forestry and Nature Research (IBN-DLO), formerly the DLO Research Institute for Nature Management (RIN-DLO), Arnhem, conducted a field study on the impact of the experimental wind park near Oosterbierum, province of Friesland, northern part of The Netherlands, on birds. The wind park consists of 18 wind turbines (300 kW HAT, three rotor blades, tower height 35 m, rotor diameter 30 m), seven meteorological towers, and three cluster and control buildings, which are situated on 55 ha of arable land, 3-4 km inland of the Wadden Sea (Figs 1-4). Aspects studied included disturbance of breeding, resting or feeding, and migrating birds, behaviour of birds approaching the wind turbines during the day and night, and bird victims due to collision with the wind turbines and meteorological towers. The first meteorological towers were built in the winter of 1985, the first towers of the wind turbines appeared in the autumn of 1986, non-operational wind turbines were present from summer 1987 onwards. From autumn 1990 onwards the wind park was fully operative. The wind turbines were not illuminated during the night.

This report deals with the results of searches for dead birds collided with obstacles in the wind park in the spring of 1986-1991 and in the autumn of 1986-1988 and 1991. Numbers of bird collisions were studied by searches for dead birds in the wind park in combination with autopsy, field studies on scavenger activities and studies on search efficiency of the observers. Searches were made once or twice a week in spring, and on most week-days in autumn. Scavenger activity was determined in autumn by measuring the survival time of carcasses of day-old chickens and wild birds in the wind park. Carcasses were placed randomly and independently from each other in the field in the afternoon or early evening. Scavenger activity was particularly high for small birds, with in some periods up to 50% of the carcasses disappearing within the first 24 hours. Search efficiency was determined by distributing marked carcasses of birds in the wind park for the people that searched for dead birds. Of small carcasses 39-52% were found, of large carcasses 75-89%, depending on the year of study. Searching for dead birds appeared to be very time-consuming. Searching an area with a radius of 50 m around one wind turbine took about 45 minutes.

During the six spring and four autumn periods searches were made on 642 different days during which 2907 times an obstacle was searched for dead birds. During these days 76 birds were found (25 species), of which 36% were certainly or very probably killed as a result from a collision with a wind turbine, and 22% were possibly so. Of 34% the cause of death was unknown, and 7% died from other causes. Most collision victims were found in the autumn and spring season in which the wind park was fully operative. Of the 76 birds found 17% were wounded but still alive. There were no nights with large kills. Dead birds were found distributed over the entire wind park (Fig. 7), suggesting that in general numbers of bird victims are related to the number of wind turbines present. The figures indicate, however, that fewer birds probably collided with the middle row of wind turbines (Table 6), suggesting that in this respect a

cluster formation could be more favourable than a line formation. All birds that were certainly, very probably and possibly killed by a wind turbine were found in the area behind the rotor or on the right front side of it (Fig. 7) (position of rotor depending on the prevailing wind direction during the night before the search). Most victims were found after nights with both poor flight and sight conditions (strong (head) winds, mist, rain, dark nights), fewer after nights with both good flight and sight conditions (weak (tail) winds, clear nights with moonlight).

The total number of bird collision victims was estimated by the formula $N_{\text{estimated}} = (N_a - N_b) / P \cdot Z \cdot O \cdot D$, in which N_a = number of birds found, N_b = number of birds not collided, P = scavenger activity (proportion of birds not taken by a predator), Z = search efficiency (proportion of birds not overlooked), O = proportion of area looked for, D = proportion of days with searches. The values for P , Z , O , and D are given in Appendix 12, in which P relates to the time of the day on which most searches were done (Appendix 11). The total correction factors ($P \cdot Z \cdot O \cdot D$) for 1990 and 1991 are given in Table 8. The estimated number of collision victims for each period is given in Tables 9 and 10. For the period up to and including spring 1989 (wind park during building and non-operative situations) the total estimated number of bird victims in the wind park averaged to 100 (theoretical minimum and maximum based on the 95% confidence limits 74 and 298) certainly or very probably killed birds, and 120 (87-339) certainly, very probably or possibly killed birds. During the autumn of 1990, when the wind park was fully operative, on average 72 (42-153) birds were certainly or very probably killed, and 122 (84-284) were killed when possible collision victims are also included. For the spring of 1991, when the wind park was also fully operative, an average number of 110 (98-338) (146 (130-451) including possible collision victims) was calculated (Table 9b). The average numbers (with minimum and maximum based on 95% confidence limits) of bird collision victims per day per wind turbine and per kilometre wind park (perpendicular to the main direction of nocturnal migration) for each period are given in Table 10. The mean number of estimated victims per wind turbine per day agrees with the data from the scarce literature concerning bird collisions with wind turbines (Appendix 13). The Oosterbierum figures per wind turbine are lower than the numbers found near (unlighted) lighthouses and tall towers in risky situations (lots of birds around), and comparable to the numbers found near tall towers in areas with low risks. Mean numbers per kilometre wind park per day are comparable to the numbers of birds killed by traffic per kilometre highway. The numbers are comparable to or somewhat lower than the numbers of victims per kilometre power line in risky situations (Appendix 14).

A comparison of the estimated numbers of bird victims (excluding possible collisions) in the wind park when fully operative, with the numbers of birds passing the wind park during nocturnal and diurnal migration in autumn, those resting or feeding, and the numbers of breeding birds present in the area showed that on average less than 0.1% of the birds passing the wind park during the night collided with an obstacle in the wind park, and less than 0.01% did so when the diurnal migration is included. When all resting and feeding birds are also added less than 0.008% collided in autumn. In spring less than 0.06% of all breeding birds and all resting or feeding birds collided (Table 12). When the possible collisions are also included these figures are 0.2%, 0.02%, 0.01% and 0.1%, respectively.

Lighting of wind turbines is believed to be harmful rather than beneficial to the birds, particularly when weather and visibility are bad.

Winkelman, J.E. 1992b. [The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 2: nocturnal collision risks]. RIN Rep. 92/3. DLO-Instituut voor Bos- en Natuuronderzoek, Arnhem, The Netherlands. 120 p. plus Appendices. Dutch, Engl. summ.

In the spring of 1984, the DLO Institute for Forestry and Nature Research (IBN-DLO), formerly DLO-Research Institute for Nature Management (RIN-DLO), Arnhem, started a field study on the impact of the experimental wind park near Oosterbierum, province of Friesland, northern part of The Netherlands, on birds. The wind park consists of 18 wind turbines (300 kW HAT, three rotor blades, tower height 35 m, rotor diameter 30 m) and seven meteorological towers, situated on 55 ha of agricultural land, 3-4 km inland of the Wadden Sea. Aspects studied included daytime searches for bird victims due to collision with the wind turbines and meteorological towers (Winkelman 1990a, 1992a), disturbance of breeding, resting or feeding, and migrating birds, respectively (Winkelman 1990b, 1992c), and behaviour of birds approaching the wind turbines (Winkelman 1990c, 1992b).

Searching for dead birds during daytime does not provide answers to the questions of (1) how many birds pass the wind turbines at similar heights during the night before the search, and (2) the proportion of passing birds that have actually collided with the wind turbines. During 1985-1988, these questions were studied by using a search approach radar (to provide qualitative assessment of large-scale migration at heights above the wind park), two passive image intensifiers in combination with infrared spotlights (to provide quantification of bird movements near one wind turbine, with identification of bird species sometimes being possible), and a thermal image intensifier (species identification and quantification of numbers passing up to several hundred metres being possible as well as a description of the behaviour of birds approaching a rotor in operation). All images were recorded on film (radar) or videotape. Because cross references (passive image intensifiers) failed and such references were not possible with the thermal image intensifier, images were two-dimensional. Determination of flight heights was therefore only possible by calculation, using assumed air speeds of the species groups (own measurements and measurements taken from the literature) (chapter 3.6).

Migration pattern

During 16 nights and adjoining twilight periods simultaneous observations of migration through and above the wind park were made by radar, passive image intensifier and thermal image intensifier. Records from both a radar and thermal image intensifier were available for one night, records from a radar and passive image intensifier were available for four nights, while records from only passive image intensifier(s) were available for 20 nights.

The simultaneous observations showed that migration intensities at wind turbine height (0-50 m) and higher (50 to 300 or 1200 m) were not always related. At wind turbine height peaks in bird numbers occurred mainly during sunrise (resulting from flights from night roosts to feeding areas, end of nocturnal migration and start of daytime migration) and to a certain extent during sunset (resulting from flights to roosts and start of nocturnal migration). Relationships with low and high water were weak. Some low or moderate

migration was recorded at wind turbine height as well as at greater heights on the radar, especially during moderate winds from the west. During (tail) winds from the east, migration occurred mainly above wind turbine height. In this situation, (low) migration at wind turbine height was only recorded during strong large-scale autumn migration as indicated on the radar. Migration above wind turbine height (50 m, radar) often showed one peak before and one after midnight.

Bird movements were recorded in the wind park every night. Relatively strong migration was recorded in one out of seven nights in each of the two years (1986, 1988) we used a thermal image intensifier. During the 1986 'top night' (only a few wind turbine towers erected) 3132 groups or 4383 birds (24 groups or 33 birds/h/100 m) passed through the wind park at wind turbine height. During the 'top night' in 1988 (wind park complete and nine rotors in operation), 2543 groups (3705 birds) passed through (19 groups or 27 birds/h/100 m). During both nights 56% and 70% respectively passed at rotor height (21-50 m). At night few birds were recorded at 0-10 m above the ground, compared to numbers recorded at heights of 11-20 m, 21-50 m and 51-60 m. During twilight and daylight many more birds were recorded than at night, and most of these were at a height of 0-10 m. During the seven nights and adjacent twilight periods in 1988 in total 4324 groups (6793 birds) passed the wind park at rotor height, 7923 (13904) between 0 and 50 m, and 9376 (15330) between 0 and 60 m. This figures with an average of 13,7 birds/h/100 m front at heights between 0 and 60 m.

Flight behaviour

Flight behaviour near a rotor in operation could be studied at a distance of less than 20 m from the centre of the rotor (fig. 25). During daylight 92% of the birds approached the rotor without any hesitation (no difference between head and tail winds). During the night 43% approached without hesitation. With tail winds 29% approached with strongly fluttering flight, while with head winds 87% did so. During daytime 15% of the approaching birds altered their flight calmly to avoid crossing the rotor, while at night 36% did so. The other birds all crossed or tried to cross between the rotor blades, most of them doing so either flapping their wings powerfully or fluttering.

The video images do not provide an answer to the question as to whether birds also avoid the wind park at great distances by shifting their flight paths sideways or by shifting to higher altitudes. However, the distribution of birds in the air space between 0 and 100 m in and above the wind park shows that the shift to higher altitudes is rather unlikely, unless birds shift to altitudes above 100 m. Comparison of the number of birds approaching the rotors and those approaching the area in-between showed that about 25-30% of the former have shifted their flight paths sideways to avoid confrontation with the rotors when crossing the wind park.

Number of collisions

During daylight 14 birds were recorded trying to cross the rotor. One of these (7%) collided. During twilight and total darkness 51 birds were recorded trying to cross the rotor area, of which 14 (28%) collided. Collisions were not always mortal. In four cases the birds recovered after colliding and continued their flight (Table 17). Accidents were not always real collisions. In six of the 14

nocturnal accidents the birds were swept down through the wake behind the rotor. Three of these accidents were fatal, the other three birds recovered soon after the 'collisions'. All birds swept down did so after crossing the rotor blades with tail winds.

Five per cent of the birds that collided when approaching an operating rotor within a distance of 15 m to each side during night and twilight were killed. Small songbirds appeared particularly vulnerable. Of approaching songbirds, 75% of the small ones, 49% of the middle-sized ones, and 21% of the large ones showed a reaction to the rotor in operation during approach, and 25%, 15% and 3%, respectively, collided. Based on the number of birds passing through the wind park at rotor height, the number of wind turbines in operation, and the proportion of birds colliding, 68 birds (on average one bird out of every 64 groups or every 100 birds passing) were expected to be involved in a mortal collision with the wind park during the seven nights and adjoining twilight periods in 1988. This number is larger than the maximum of the 95% confidence interval calculated from the number of dead birds found in the wind park during the daily searches in that period, a proportion of birds disappearing through predation; birds are also missed through insufficiently searching (Winkelman 1990a, 1992a). If the entire wind park had been in operation during the seven nights and twilight periods in 1988, 170 birds would have collided (on average one bird out of every 25 groups or one bird out of every 40 (2.5%) birds migrating through the wind park at rotor height). This figures with an average of 0.051 dead birds/tv/100 m front at heights between 0 and 60 m. So for all birds approaching at night and adjacent twilight period and at heights between 0 and 60 m, 0.37% (0.06%/wind turbine) on average are believed to die due to collision (1.1% for all birds passing the wind park system).

Illumination of the wind turbines to avoid collisions is not believed to be necessary, because birds seem to be quite good at spotting the wind turbines, even during conditions of moderate visibility at night. During poor visibility (foggy weather) the illumination may even attract birds, which may increase the risk of collision.

Winkelman, J.E. 1992c. [The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 3: flight behaviour during daylight]. RIN Rep. 92/4. DLO-Instituut voor Bos- en Natuuronderzoek, Arnhem, The Netherlands. 69 p. plus Appendices. Dutch, Engl. summ.

The impact of an experimental wind park on birds was studied by the DLO Institute for Forestry and Nature Research (IBN-DLO), formerly DLO Research Institute for Nature Management (RIN-DLO), Arnhem, between 1984 and 1991. The wind park is situated near Oosterbierum, province of Friesland, in the northern part of The Netherlands. The wind park consists of 18 wind turbines (300 kW HAT, three rotor blades, tower height 35 m, rotor diameter 30 m), seven meteorological towers, and three cluster and control buildings, which are situated on 55 ha of arable land, 3-4 km inland of the Wadden Sea (Figs 1-6). The wind turbines and the meteorological towers were not illuminated at night.

Aspects studied included bird victims due to collision with the wind turbines and meteorological towers (Winkelman 1992a), behaviour of birds approaching the wind turbines both during the day and night (this report, Winkelman 1992b), and disturbance to breeding, feeding/resting, and migrating birds (Winkelman 1992c). The first meteorological towers were built in the winter of 1985, the first wind turbine towers appeared in the autumn of 1986 and non-operational wind turbines have been present since the summer of 1987. The wind park has been fully operational since the autumn of 1990. This report deals with the flight behaviour of birds approaching the wind park system during daylight.

Study methods

The flight behaviour of birds approaching the wind park during daylight was studied in two different ways. For at least a fifth of the observations it was noted whether the birds passing within 100 m distance of a wind turbine showed a reaction or not. The passing distance to the nearest wind turbine was also estimated. This was recorded during regular counts of migrating birds in the northern and southern part of the wind park (see Fig. 2, Winkelman 1992c). A reaction was defined as each visible deviation from the 'normal' flight behaviour. The proportion of reactions was related to the wind park in or not in full operation, and to the distance between the wind turbines (northern and southern part of the wind park compared), species (group), flight height (noted in classes: 0-10, 11-20, 21-50 (rotor height), 51-100, 101-200, > 200 m), the passing distance, wind direction, and wind force.

Secondly the flight path of birds approaching the wind park from easterly directions during daylight (real autumn migration) and from southerly directions during late afternoon (flights of gulls to night roosts) was studied in detail. A bird or a group of birds was followed for at least 300 m, of which at least 200 m took place before the expected passing of one of the wind turbines along the eastern or southern row (numbers 31-38 and 18-38, respectively, see Fig. 2). Details noted were flight height (in classes: 0-10, 11-20, 21-50 (rotor height), 51-100, 101-200, > 200 m) and flight direction (16 compass directions),

both before and after passing, distance to the nearest wind turbine at which a reaction took place or started, nearest distance to a wind turbine during passing, and number of passing attempts. It was also noted whether a group split up, birds accelerated their wing beat or altered the angle of their body, and if so, when this occurred (before, during, or after passing). The flight path itself was plotted on a map. Recording of the flight paths over distances greater than 300 m by two observers using walkie-talkies failed, due to the presence of other obstacles in the landscape (farms and hedges 500-600 m to the east of the wind park, Fig. 1) affecting the flight paths, and difficulties which the observers had in picking up the same birds.

Differences in distances were tested by using the Mann-Whitney U-test (Siegel 1956, sample sizes both >5). All other differences were tested by using generalized regression analyses for multiplicative interactions (e.g. G-test of independence and STP-analysis, Sokal & Rohlf 1969). Differences were accepted as being significant when $P < 0,05$.

The proportion of reactions within 100 m distance of a wind turbine

Significantly more reactions (11-18%) were recorded with the wind park fully operational compared to the wind park not operational, when only during 2% of the observations the birds reacted (Table 1). This was true for most species (groups) (Table 2). When the wind park was fully operational, most species (groups) reacted more often when the distance between the wind turbines was small (southern part of the wind park) rather than large (northern part of the wind park). When the wind park was not operational, the distance between the wind turbines never affected the number of reactions (Table 3).

For most species (groups) flight height or/and passing distance could also be affected by both the wind park in or not in operation and the distance between the wind turbines (Tables 4, 5, Appendices 3, 4). When the distance between the wind turbines was large and the wind park was fully operational (situation 1) more birds flew at greater heights and at greater distances from the wind turbines than when the wind park was not in operation. On the contrary, when the distance between the wind turbines was small and the wind park was fully operational some of the birds flew at lower heights and nearly all birds flew at the same distances as when the wind park was not in operation. When the spatial relations to the rotor were taken into account (Fig. 7, Table 6), it was shown that in situation 1 all species (groups) except for the largest ones avoided the rotor itself and near vicinity compared to situations when the wind park was not in operation and the distance between the wind turbines was larger. When distances between the wind turbines were small the number of birds recorded in the different spatial areas around the rotor did not differ between the operational and non operational situation (exception: Black-headed Gull and Starling).

Reacting birds tended to pass close by the wind turbines, and tended to pass at rotor height more often than non reacting birds (Tables 7-9, Appendix 5). This was especially the case in the wind park in full operation. Reacting birds were also recorded more often in the rotor area and the spatial areas close to the rotor compared to non-reacting birds (Table 10, Appendix 6). It is remarkable that differences are mostly noted among relatively small birds (passeri-

nes, (small) waders, Black-headed Gulls), and not or only incidentally among large birds. Wind direction did not affect the number of reactions when the wind park was not in operation. In the fully operational wind park only Black-headed Gulls, Starlings and small songbirds showed significantly more reactions with head winds, as was the case for large birds with tail winds (Table 11).

The flight paths

In total 2203 flight paths of birds approaching the wind park were recorded during 151 hours of observation (Table 12). Of these 1153 observations concerned real autumn migration approaching the wind park in full operation from the east, and 283 concerned gulls approaching the wind park in full operation when flying northwards to night roosts. Due to lack of data it was not possible to distinguish between the northern and southern part of the wind park, or to study this aspect with the wind park not in operation.

The test results showed that a passing distance of less or more than 100 m of the nearest wind turbine did not affect the proportion of reactions (Table 13). Some species reacted more often at flight heights at rotor height (Table 14). Except for gulls during real migration, birds reacted less when approaching parallel to the row of wind turbines than when they approached the wind park at an angle (Table 15). Wind direction affected the number of reactions of some species (groups) (Table 16), but the direction of the effect was not unequivocal. Wind force only affected large birds and flights of gulls to night roosts (Table 17), with strong winds causing more reactions than moderate ones.

More than 75% of all reactions within 200-300 m of the nearest wind turbine took place within 100 m, with nearly 50% taking place within 51-100 m. Ducks reacted at the greatest distances, small songbirds at the smallest. Gulls flying to night roosts reacted at greater distances than gulls during real migration (Table 18). In total 84% of all reacting birds passed within 100 m of the nearest wind turbine, with ducks once more passing at the greatest and small songbirds passing at the smallest distances (Table 19). Of the large birds (ducks, gulls, other large birds) that reacted and passed at a distance of more than 100 m of the wind turbines, a significantly larger proportion was found not to enter the wind park system compared to those that reacted and passed within 100 m. No differences were found for small birds ((small) waders, Starling, small songbirds) (Table 21). It is unknown what proportion of reactions took place at a distance of more than 300 m of the wind turbines. Geese and swans have been shown to tend to react at greater distances from the wind park, at distances of up to 500-600 m.

Several reaction types and combinations were noted; and these could be separated into (1) gradual and calm reactions, carried out in about 75% of the cases (long) before passing the row of wind turbines, and (2) panic reactions, occurring just before or while passing the wind turbines. Shifts in the flight paths in the horizontal plane (including birds turning back) could always be characterised as to (1), while altering the angle of the body, accelerating the wing beat, several passing attempts, and turning over or backward could always be characterised as to (2) (see also Table 22). The splitting up of groups

and shifts of the flight paths in the vertical plane could be interpreted as either (1) or (2).

The most occurring reaction was a *shift in the flight path in the horizontal plane*, which occurred in all species groups at the same level (Table 23). The most noted shifts were (1) circling of the wind turbine after which the wind park was entered, (2) a temporary flight path parallel to the row of wind turbines after which the wind park was entered, (3) circling the whole wind park system without entering the wind park system, and (4) turning back without entering the wind park system. Most flight corrections in the horizontal plane concerned large angles (Table 25) and were permanent within the observation field in 75% of the cases. It is not known whether birds returned to the former flight directions after having left the wind park system. Turning back occurred in 12% of all observations. Turning back as well as other reactions in the horizontal plane were recorded more often with tail winds than with head or side winds, and mostly took place before passing (Table 26). The only exception was found for gulls flying to night roosts since these reacted more often after entering the wind park than those involved in real migration (Table 26).

Six percent of all observations recorded (14% of all reacting birds) showed a *shift in the flight path in the vertical plane* causing height loss, and 3% of the recorded shifts (7% of all reacting birds) caused a gain in height (Table 27). Losses as well as gains in height mostly occurred before (73%) or after (26%) passing, and the shifts were not affected by wind direction. Loss of height after passing in combination with tail winds mostly resulted in a downwards beat, presumably caused by the wake and air turbulence behind the rotor. Although it is commonly believed that birds will gain height to cross a wind park at heights above the wind turbines, this appeared only to be the case in 2% of all observations (Table 27).

Of all birds approaching the wind park 87% entered the system in *one passing attempt* (including all gradual flight corrections with angles less than 45 degrees). Of those making more than one attempt, 78% (74% for gulls flying to night roosts) passed during the second, 9% (20%) during the third, 8% (6%) during the fourth, and 4% (0%) during the fifth attempt. The wind direction affected the number of passing attempts, with more attempts being made with side and head winds than with tail winds. Ducks and gulls flying to night roosts showed more passing attempts when in groups (more than one bird) than when single (Table 29).

An *accelerated wing beat* (including fluttering flight) occurred in 14% of all observations (28% of all reacting birds), and mostly took place before or before, during and after passage (Table 30).

An *alteration of the angle of the body* occurred in 21% of all observations (45% of all reacting birds), with reacting ducks, large birds and small songbirds showing more often an alteration of the angle of the body than other species (groups). Gulls flying to night roosts showed more often an alteration of the angle of the body than gulls involved in real migration. Most alterations of the angle of the body took place before or before, during and after passage. Gulls flying to night roosts altered the angle of their body most during passage.

Forty-seven per cent of the observations (43% of all reacting birds) were of groups of birds (>1 bird). Thirty per cent of the gulls flying to the night roosts approached in groups (39% of all reacting birds). Eleven per cent of all approaching groups *split up* (26% of all reacting groups). In the case of gull flights to night roosts these figures were 22% and 39%, respectively. Splitting up mostly took place before passing. The wind direction did not affect the proportion of birds accelerating their wing beat, altering the angle of their body, or splitting up.

Fourteen of the observations were of birds flying *within reach of the operational rotor* (1.2% of all observations, 3.5% of all observations at rotor height). None of the birds were hit by the rotor but 13 showed a (panic) reaction. Six gulls flying to night roosts (2% of all observations and 4% of all observations at rotor height) came in reach of the rotor. None of them were hit by the rotor but all showed a (panic) reaction.

Eight per cent of all approaching birds or bird groups did not enter the wind park at all, and 3% left the wind park immediately after having passed the first row of wind turbines. This applied to 10% and 16% respectively, of gulls flying to their night roost. Large birds avoided the wind park more often than small birds (Table 33). When comparing these results with those of Winkelman 1992c (fewer migrating birds in the wind park after the impact than before when compared with a control area), it is very plausible that most birds only react at rather short distances (<200-300 m) from the wind park (6.6.2). A comparison of the observations recorded at rotor height with those recorded in the near vicinity of the rotor (6.6.1) showed that fewer birds than expected were recorded in the vicinity, indicating that birds tend to avoid the rotor.

Habituation of local birds (gulls flying to night roosts) was not expressed by a significant smaller proportion of reactions, but by a larger proportion of gradual and calm shifts of the flight path and a smaller proportion of accelerated wing beats compared to those shown during real autumn migration.

The scarce, and mostly anecdotal, observations taken from the literature tend to confirm those in this study.

The, from the birds point of view, less damaging configuration of wind parks is discussed in 7.1.2. As a result of this study and the results presented in Winkelman (1989, 1992a-1992c) it is believed that the preferred configuration of wind turbines is dependent on the bird life in the wind park and surroundings. To wintering and feeding birds, and maybe also to breeding birds, the best option is a (dense) cluster of wind turbines, to migrating birds this is either a line formation parallel to the main migration direction or an open cluster.

Winkelman, J.E. 1992d. [The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 4: disturbance]. RIN Rep. 92/5. DLO-Instituut voor Bos- en Natuuronderzoek, Arnhem, The Netherlands. 106 p. plus Appendices. Dutch, Engl. summ.

The impact of an experimental wind park on birds was studied by the DLO Institute for Forestry and Nature Research (IBN-DLO), formerly DLO Research Institute for Nature Management (RIN-DLO), Arnhem, during the period 1984-1991. The wind park is situated near Oosterbierum, province of Friesland, in the northern part of The Netherlands. The wind park consists of 18 wind turbines (300 kW HAT, three rotor blades, tower height 35 m, rotor diameter 30 m), seven meteorological towers, and three cluster and control buildings, which are situated on 55 ha of arable land, 3-4 km inland of the Wadden Sea (Figs 1-6). The wind turbines and the meteorological towers were not illuminated at night.

Aspects studied included the number of bird victims due to collision with the wind turbines and meteorological towers (Winkelman 1992a), the behaviour of birds approaching the wind turbines during the day and night (Winkelman 1992b, 1992c, 1992d), and the disturbance to breeding, feeding or resting, and migrating birds, respectively. The first meteorological towers were built in the winter of 1985, the first wind turbine towers appeared in the autumn of 1986, and non-operational wind turbines have been present since the summer of 1987. The wind park has been fully operational since the autumn of 1990. This report deals with the disturbance effects of the wind park on breeding, feeding or resting, and migrating birds, respectively.

General remarks

Four species of breeding meadow birds were mapped in an area of 955-1030 ha in the wind park and its vicinity (Fig. 7a) during the spring of 1984-1991. Feeding and resting birds were mapped in an area of 875 ha in and around the wind park (Fig. 8a) during 75 days in the autumn of 1984-1988 and that of 1990, and during 78 days in the winter and spring period of 1984/1985 through 1988/1989 and that of 1990/1991. The study area was divided into several distance zones during these censuses (Figs 7b, 8b, Appendices 15, 16). Migrating birds were counted at three different spots (Fig. 1) during early morning and late afternoon in the autumn of 1984-1987 and that of 1990 (Appendix 14). Counting data are given in Figure 9, Table 1 and Appendices 5-9 (breeding birds), Tables 2-5 and Appendices 10-13 (feeding and resting birds), Figure 10, Tables 6-7 and Appendix 14 (migrating birds). Except for the effects of different weather conditions in the seasons concerned (Appendix 3), a major problem met was the implementation of a land allocation programme in and surrounding the wind park, which took place simultaneously with our study. One of the results of this programme was a (temporary) increase in the area of arable land and a decrease in meadows, especially in the wind park and its vicinity (Appendix 4).

Breeding birds

Trends in the numbers of breeding pairs and the distribution patterns of nest locations in the study area were analysed using generalized linear regression analysis, following the model $E_{n_{ijk}} = O_{ijk} \cdot g_i \cdot t_j \cdot z_k \cdot t.z_{jk}$ (main model, including all years between 1984 and 1991), and $E_{n_{ijk}} = O_{ijk} \cdot g_i \cdot p_l \cdot z_k \cdot p.z_{lk}$ (derived model for period). In both models E_n is the (expected) number of breeding pairs, O the correction factor for the area of the different distance zones, g the effect of agricultural use, t the effect of time (year), z the effect of distance (zone), $t.z$ the interaction between time and distance effect (year.zone), p the period before, during and after construction of the wind park, and $p.z$ the interaction between period and distance (period.distance). The index i stands for agricultural use (arable land or meadows), j for time (year), k for the distance to the wind turbines (distance zones), and l for the period (1 = before construction, 2 = during construction (also including wind park not in operation), 3 = after construction, wind park in full operation). For each effect the basic model was compared with the model fitted to the concerning effect using approximate t-tests (for instance in the main model for the effect of agricultural use $E_{n_{ijk}} = O_{ijk} \cdot t_j \cdot z_k \cdot t.z_{jk}$ has been compared with $E_{n_{ijk}} = O_{ijk} \cdot g_i \cdot t_j \cdot z_k \cdot t.z_{jk}$). The differences between the logarithms of the means of each main effect (year or period and zone) were also compared by pairwise testing using approximate t-tests. The means were transformed according to $y = \ln(x)$, the variances to $\text{var}(y) = \text{var}(x) \cdot x^{-2}$, the covariances to $\text{cov}(y_1, y_2) = \text{cov}(x_1, x_2) / (x_1 \cdot x_2)$. In this case corrections were also made for differences in area and agricultural use.

The test results show that the wind park did not influence the breeding bird populations of Oystercatcher, Lapwing, Black-tailed Godwit and Redshank during the study period (Tables 8-10, Appendices 17, 18). But it must be said that negative effects on birds with a high breeding site fidelity and a long life span can usually only be proved after experiments lasting many years. Based on (not significant) trends showing a relatively smaller increase in the number of breeding pairs of the Oystercatcher in the wind park area itself and a relatively larger decrease in the number of the Lapwing in the wind park area and its surroundings, it has been recommended to continue this part of the study for several more years, to be sure about the lack of effects mentioned above. The results given in the scarce literature confirm the results of our study, although in one study a single large wind turbine (mostly not in operation) could have been affecting the number of breeding pairs in its surroundings. But up to now all available studies have dealt with a relatively (too) short study period. Data taken from the literature show that the noise emission from the wind park is probably too low to have been of any influence on the number of breeding pairs of meadow birds in the wind park and its vicinity.

Feeding and resting birds

The disturbance effect of the wind park on feeding and resting birds was assessed by comparing data before and after the impact in a control area and in the impact area (BACI-model). Regression analysis and an accumulated analysis of deviance was used according to the model $E(n_{it}) = \exp\{\mu + \alpha_i + \beta_t$

$+ \gamma \cdot (i = 2 \text{ and } t \geq t_0)$, with $i = 1, 2$, $t = 1 \dots n_t$, and $\alpha_1 = \beta_1 = \gamma_1 = 0$ and $\text{var}(n_{it}) = \sigma^2 \cdot E(n_{it})$. In this model n_{it} = the number of birds in site i and at time t , $\exp\{\mu\}$ the expected number of birds without impact, α_i the effect of site i (control site $i = 1$, impact site $i = 2$), β_t the effect of time t . γ figures only in the wind park area ($i = 2$) when the wind park is in operation (null hypothesis $\gamma = 0$). According to this model, the logarithm of the ratio of the expected numbers in control and impact sites is: $\ln\{E(n_{2t})/E(n_{1t})\} = \alpha_2 - \alpha_1 + \gamma \cdot (t \geq t_0)$. For the log-ratio $\ln(n_{2t}/n_{1t})$ or $\log(n_{2t}/n_{1t})$ a constant value is expected for $t = t_0$ and another constant value from $t = t_0$ onwards. $\log\{n_{2t} + 1\}/\{n_{1t} + 1\}$ was plotted versus t , and an accumulated analysis of deviance was computed. Because of the (temporary) increase in the area of arable land and the decrease in the area of meadows, the effect of agricultural use on the numbers of birds was also added to the model mentioned above. Corrections were made for differences in the area of the different zones.

The test results (Tables 11-13, Appendices 19-26) show significantly smaller numbers in the wind park area and its surroundings after the impact, the effect depending on species (group), season, tide (high or low water), and the wind park either being in or not in operation. The fully operational wind park was measured to have a disturbance effect up to a maximum of 500 m beyond the outer row of wind turbines, but was mostly limited to 100-250 m distance. For ten of the 13 species (groups) studied (Mallard, Tufted Duck, Coot, Oystercatcher, Golden Plover, Lapwing, Curlew, Common Gull, Herring Gull, doves) disturbance was proved in one or more situations. Neither the Black-headed Gull nor crows and the Starling were affected. Disturbance effects were proved for only seven of the 13 species (groups) studied (Tufted Duck, Coot, Golden Plover, Lapwing, Curlew, Herring Gull, doves) during the building phase and partly operational situations. This may prove that an operational wind park is more disturbing than a not operational one. The following birds were found in significantly smaller numbers in and around the wind park up to the distance given: ducks up to 250 m, waders up to 100 m (Curlew excepted), and gulls up to 250-500 m (Black-headed Gull excepted) (Table 14). The Curlew (up to 500 m distance) and the Golden Plover were sensitive in nearly every situation studied. The extent of the disturbance effect was often large. Decreases up to 60-95% were quite common, but decreases never reached 100%. In the literature (including those on the disturbance effects of wind turbines) the same species are often mentioned to be sensitive to disturbance. The same disturbance distances also are mentioned.

Migrating birds

Migrating birds often fly in groups during daytime. So the total numbers of birds during a count both reflect the numbers of groups and the mean group sizes. Therefore the disturbance effect of the wind park on migrating birds was studied for both the numbers of groups and the mean group sizes during a count. The effect was assessed by comparing data before and after the impact in a control area and in the impact area (BACI-model), using regression analysis and an accumulated analysis of deviance according to the model $E(m_{it}) = \exp\{\mu + \alpha_i + \beta_t + \gamma_1 \sin(\Theta_t) + \delta_1 \cos(\Theta_t) + \varepsilon_{it} > \tau\}$, with $\alpha_1 = \beta_1 = \gamma_1 = \delta_1 = \varepsilon_1 = 0$, and $\text{var}(m_{it}) = \sigma^2 \cdot E(m_{it})$ for the numbers of groups, and $E(n_{it}) = \exp$

$\{\mu + \alpha_i + \beta_t + \gamma_1 \sin(\Theta_t) + \delta_1 \cos(\Theta_t) + \epsilon_i I_{t>\tau}\}$, with $\alpha_1 = \beta_1 = \gamma_1 = \delta_1 = \epsilon_1 = 0$, and $\text{var}(n_{it}) = \sigma^2$. $E(n_{it})$ for the mean group size. In this model $E(n_{it})$ is the expected value for the number of observed groups, and $E(n_{it})$ for the mean group size; $\exp\{\mu\}$ is the expected number without impact, α_i is the term for the effect of the location i (1 = coast, 2 = northern part of the wind park, 3 = southern part of the wind park); β_t is the term for the effect of the period t (1 = without wind park, 2 = with wind park); γ_1 and δ_1 are location dependent coefficients for two mutual orthogonal components of the wind direction Θ_t in the period t . $\epsilon_i I_{t>\tau}$ is the term for the effect ϵ_i , related to the presence of the wind park on location 1 = 2 or 1 = 3, for counts t from the first count τ after construction of the wind park. $I_{t>\tau}$ is an indicator function with values 1 (if the condition is true) or 0. The wind direction was proved to affect the observed numbers of groups and mean group size in both the control and the impact spots (Tables 15-17, Appendices 27-32). Therefore the effect for wind direction was also added to the model. $\sin(\Theta)$ represents the wind direction effects perpendicular to the main direction of migration (side winds), $\cos(\Theta)$ represents the effect along the main direction of migration (tail and head winds). The main direction of migration in the study area is west-south-west, which is also the direction of the coast line and the east-west orientation of the wind park. The main questions solved with the model mentioned above were (1) does the wind park as a whole affect bird migration, and (2) does the distance between the wind turbines have any effect on bird migration (difference between the northern and southern part of the wind park, see Fig. 2). Therefore the model was limited by $\tau_2 = \tau_3$, $\delta_2 = \delta_3$, and $\epsilon_2 = \epsilon_3$.

The test results regularly show disturbance effects of the wind park on migrating birds after impact, depending on species (group), the wind park being in or not in operation, and the distance between the wind turbines (Tables 18-21, Appendices 33-38). The following species appeared to be very sensitive: Mallard, Common Snipe, Curlew and possibly also thrushes (independent of the distance between the wind turbines), and also pipits and the Starling when the distance between the wind turbines was small (i.e. in the southern part of the wind park, see Fig. 2). The following species appeared to be little sensitive: Lapwing, thrushes (including birds that were only heard calling) and possibly also the Skylark, wagtails and *Carduelis* spp. (independent of the distance between the wind turbines), and also pipits and the Starling when the distance between the wind turbines was large (i.e. in the northern part of the wind park, see Fig. 2). Finches and buntings appeared not to be sensitive. The disturbance effects could be expressed as (1) a decrease or an increase in the number of groups passing, and (2) a decrease or an increase of the mean group size during one count. Negative effects were expressed by the joining of groups during passage of the wind park or by the avoidance of the wind park. The joining of groups may lead to the same number of birds or to a decrease or increase in the number of birds. Avoidance always mean a decrease in the total number of birds migrating through the wind park area after impact. The extent of the effect in situations in which the wind park was not in operation could rise to a factor 1,6 (decrease with 36%), and with a wind park in full operation to a factor 3 (decrease with 67%).

Appendix 3. Suggested Research Projects

Participants were asked to submit questions that they thought were in particular need of study. Specifically, they were asked to list the general research question, briefly explain why the work was needed, provide an idea of how the study might be designed, and estimate the duration and anticipated cost of the study. Questionnaires were returned by 13 meeting participants; the number of suggestions ranged from 1-6 per person. Below is a list of the research questions asked, arbitrarily grouped into broad categories for ease of review; no priority is implied by the order given. Similar research suggestions were submitted by several participants; such generally redundant questions were not removed from the following list for the sake of completeness and to avoid misinterpretation by the meeting summarizers. Suggestions provided by the participants regarding study design, duration, and the like are not presented for the sake of brevity.

A. Standardization of Methods/Variable Selection

1. How can all pre-development and post-operational monitoring be made consistent and standardized?
2. What is needed to perform acceptable pre- and post-construction monitoring?
 - a. How does this vary according to project size?
3. What are the appropriate methods for siting evaluation?
4. What methodology should be used to estimate the mortality/injury threat posed by wind project accessory facilities (e.g., electrical towers)?
5. Develop standardized protocols for baseline studies to maximize comparability of results among studies.
6. Need to define research tools that can be used to conduct pre- and post-construction biological assessments.
7. Study protocols for conducting initial site surveys to identify high risk areas for bird collisions.

B. Mortality/Survival

1. How important is perching in causing avian mortality?
2. Population impacts of species of concern (e.g. Golden Eagles) for which modest numbers of birds are available.

3. What relative role do wind projects play as one source of threats among many threats within the larger habitat where the project is sited?
4. Need to identify the most probable causes of bird mortalities at wind power plants.
5. Are there differing mortality rates associated with different turbine configurations.
6. What are the characteristics of avian mortality of wind plants other than Altamont?
7. Are wind turbines causing detectable decreases in survival rates for species?
 - a. If so, what is the magnitude of the decrease?
8. What species are particularly susceptible to wind turbine mortality?

C. Development of Predictive Models

1. Do an assessment of migrating bird paths and flight height in comparison with wind resource.
2. Determine if overlaps exist between areas of concentrated bird migration and high wind resource areas.
3. Can "safe" wind production zones be found?
4. What habitat features are being modified by wind farm developments that might be attracting birds?
5. Can one predict the potential of bird-wind turbine collisions based on pre-construction assessments of bird flights in the vicinity of the planned sites?
6. Can preliminary screening assessments of bird use of potential wind power sites be effectively evaluated using landscape-scale data?
7. Can modelling the distribution of bird density be used to predict areas of potential conflict?
8. How do birds and turbines interact?
 - a. Can artificial situations be created (e.g., in larger hangars) to study bird-turbine interactions?
 - b. Determine use of latest radar equipment to study bird reactions to turbines in the wild.

D. Experimental Design (General)

1. What role does experimentation and/or adaptive resource management have in the development of future plants?
2. In conducting pre-construction baseline studies, what are the sources of risk in the results and their relative significance (i.e., what is the error/variance associated with current studies)?

E. Management

1. Need to develop cost effective mitigation procedures.
2. What are avian mortality statistics for non-wind related power generation facilities?
3. Can methods already developed for reducing bird collisions in other industries be applied immediately to the bird-wind development situation?
4. Is near real-time bird migration information needed to implement operational changes at wind farms?

F. Site-Specific Studies

1. What is currently happening in Pacheco Pass WRA California?
 - a. Mortality monitoring at existing sites
 - b. Pre-development monitoring at associated undeveloped sites with follow-up post-operation monitoring.
2. What levels of mortality are occurring in Tehachapi Pass WRA and San Gorgonio Pass WRA?
 - a. Under what conditions and situations?
3. Determine the proportion of migrant bird population passing through the proposed wind resource areas in Montana.
4. Are there different mortality rates associated with the 3 major areas of California wind development?

Appendix 4. Draft Decision Tree For Avian-Wind Power Issues

The following draft decision tree was circulated to meeting participants before the meeting. The workshop did not review the usefulness of this approach, but it is included here to provide a more complete record of the materials available at the meeting.

Does the Facility Already Exist?

Yes: 1.0

No: 2.0

1.0 Are there previous surveys of bird kills under presently existing conditions?

Yes: 1.1

No: Conduct bird surveys (Guideline 1A); then go to 1.1

1.1 Does the survey meet national guidelines?

Yes: Go to 1.1.1

No: Conduct bird surveys (Guideline 1A); then go to 1.1

1.1.1 Are kills evident (existing facilities) or expected (proposed facilities)?

Yes: Conduct cumulative impact assessment² (Guideline 2); then go to 1.1.2

No: End

1.1.2 Was the impact found to be significant?

Yes: Determine mitigation (Guideline 3); then go to 1.0

No: End

2.0 Do systematic surveys of temporal activities of birds exist for the site?

Yes: Go to 2.1

No: Conduct bird surveys (Guideline 1B); then go to 2.1

2.1 Does the survey meet national guidelines?

Yes: Go to 1.1.1

No: Conduct bird survey (Guideline 1B); then go to 2.1

² Includes impact assessment.

Guidelines³

Guideline 1.A (for existing sites):

- Population impact surveys
 - numerical impact
 - impact on reproduction
 - prediction of population model

Guideline 1.B (for proposed sites):

- Population impact surveys
 - numerical impact
 - impact on reproduction
 - prediction of population model

Guideline 2:

- Cumulative impact studies
 - numerical impact and source
 - impact of each source on reproduction
 - prediction of population model (sources of impact and segment of population impacted)

Guideline 3:

- Development of mitigation, to include some of the following:
 - modification of structural design
 - modification of tower replacement
 - modification of habitat
 - addition of bird warning/scaring devices
 - remove hazardous structures (for existing facilities)
 - cancellation of development (for proposed facilities)

³ Note: This assumes that national guidelines adopted by all interested parties do not exist; guidelines would need to be developed by consensus.

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