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September 20-22, 1995

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National Wind Coordinating Committee

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ABSTRACT

National Avian - Wind Power Planning Meeting II was organized by the Avian Subcommittee of the National Wind Coordinating Committee. Government regulators, scientists and other stakeholders met in Palm Springs, Calif., on 20-22 September 1995 to share ideas about research that could be helpful in predicting and reducing bird mortality from wind turbines. This meeting was the second in a series. The purposes of this meeting were to

- provide information on avian/wind power interactions that will help meet the needs of regulators, researchers, and other stakeholders concerned with responsible development and permitting of wind plants;
- create dialogue among regulators, researchers and other stakeholders to help all parties understand the role that research can play in responsible development and permitting of wind plants, and allow researchers to understand the relevance of their research to the process; and
- propose research projects and the appropriate sponsorship.

The meeting began with oral presentations and discussions of nine White Papers on the theory and methods for studying and understanding impacts. These were organized into three groups:

- Stakeholder Questions, Interests and Concerns;
- Fundamental Methodologies (study design, "metrics", models); and
- Observation Protocols (surveys, migration monitoring, mortality searches).

The Proceedings includes the written version of each of the nine White Papers, plus a summary of the oral discussion associated with each paper.

The second part of the meeting consisted of four working group sessions:

- Site evaluation and pre-permit research and planning;
- Operational monitoring;
- Modeling and forecasting, including population dynamics models; and
- Avian behavior and mortality reduction.

The Proceedings includes a summary of the discussions on these topics, including each working group's recommendations for future research or associated activities.

A final plenary session drew together the main recommendations. These included the following topics, as described in the "Next Steps" section of the Proceedings:

- Development of a framework or conceptual model of the principal causes of avian mortality at wind plants;
- Further definition of the most appropriate "metrics" (variables); and
- Further develop the research protocols, data collection guidelines, and statistical analysis techniques appropriate for this field.

Mechanisms for implementing these main recommendations were suggested. In addition, there were other recommendations regarding a process for future updates to the framework and protocols, formation of a Technical Review Committee, further evaluation of radar and other methods to document bird movements, and development of procedures to assess cumulative effects.

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INTRODUCTION

Government regulators, scientists and other stakeholders met in September 1995 to share ideas about research that could be helpful in predicting and reducing avian mortality resulting from wind turbines. This meeting was the second that the Avian Subcommittee of the National Wind Coordinating Committee (NWCC) has hosted in the Subcommittee's attempt to address and build consensus on issues of public policy, scientific research, and stakeholder/public involvement related to avian/wind power interactions. The Proceedings of the first meeting[1] are available, while the supply lasts, from RESOLVE; they are also available from the National Technical Information Service, Springfield, VA.

The purpose of the present meeting was to

- provide information on avian/wind power interactions that will help meet the needs of regulators, researchers, and other stakeholders concerned with responsible development and permitting of wind plants;
- create dialogue among regulators, researchers and other stakeholders to help all parties understand the role that research can play in responsible development and permitting of wind plants, and allow researchers to understand the relevance of their research to the process; and
- propose research projects and the appropriate sponsorship.

By design, fewer people were invited to this meeting than to the meeting held during July 1994; this change was intended to enhance individual participation. Attendees are listed in Table 1. Appendix 1 provides their full mailing addresses, telephone and facsimile numbers, and (when available) e-mail addresses.

Organizers made a special attempt to foster dialogue between regulators and scientists. Regulators involved in planning the workshop were seeking reliable methods for assessing potential harm to birds. They were looking to avian scientists and statisticians

- to help refine the research questions that need to be answered in light of what was already known, and
- to help construct feasible short- and long-term research goals.

The Avian Subcommittee attempted to include a full range of perspectives at the meeting. In developing the list of invitees, subcommittee members identified specific people who could represent different regions and different areas of expertise. They also asked RESOLVE to interview a variety of people, the majority of whom would not attend the meeting, about their research interests. RESOLVE drafted the interview results into a White Paper and discussed the findings during the meeting's first session.

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[1] *Proceedings of National Avian - Wind Power Planning Meeting*, Denver, Colorado, 20-21 July 1994. DE95-004090. RESOLVE Inc., Washington, DC, and LGL Ltd., King City, Ont. 145 p. Available from RESOLVE, 2828 Pennsylvania Ave NW, Suite 402, Washington, DC 20007 (phone 202-944-2300, fax 202-338-1264).

Table 1. List of Attendees, National Avian - Wind Power Planning Meeting II. See Appendix 1 for addresses, telephone and facsimile numbers, and e-mail addresses.

Attendee	Affiliation
Anderson, Dick	California Energy Commission
Arnold, Abby	RESOLVE
Azeka, Mike	SeaWest Energy Corp.
Bain, Don	Oregon Dep. Energy
Behr, Chris	RESOLVE
Beyea, Jan	National Audubon Society
Bortner, Brad	USFWS, Portland
Colson, Ed	Consultant
Cooper, Brian	ABR Inc.
Curry, Dick	Kenetech Windpower
Davis, Earl	EPRI
Davis, Holly	NREL
DeMeo, Ed	EPRI
Eames, Michelle	USFWS, Washington
Gauthreaux, Sid	Clemson University
George, Walt	BLM
Gray, Tom	AWEA
Hunt, Grainger	Univ. of Calif. Santa Cruz—PBRC
Jamison, Van	Montana Natural Resources Dep.
Johanson, Carl	Montana State Univ.
Kendall, Bill	USFWS, Laurel, MD
Kerlinger, Paul	Consultant
Loose, Ron	Wind Energy Prog., DoE/HQ
Mayer, Larry	Good Samaritan Regional Medical Cent.
McIsaac, Hugh	Raptor Res. Cent., Boise State Univ.
Morrison, Mike	University of Arizona
Orloff, Sue	Ibis Environmental Services
Penning, Bill	Minnesota DNR
Pollock, Ken	North Carolina State University
Richardson, John	LGL Ltd. (for EPRI)
Shenk, Tanya	Colorado State University
Strickland, Dale	Western EcoSystems Technology Inc.
Thresher, Bob	NREL
Ugoretz, Steve	Wisconsin DNR
Wilson, Kenneth	Colorado State University

In addition, the National Renewable Energy Laboratory and/or the meeting organizers asked eight additional individuals or groups to prepare White Papers on various relevant methodological topics. Most of the draft White Papers were circulated to prospective meeting attendees in advance of the meeting, and the White Paper authors were invited to summarize those eight topics during the meeting.

Although organizers did not expect to reach consensus on a research agenda at this meeting, they hoped that participants could agree on common definitions of the problems, and that they would discuss suggestions for next steps. Full consensus requires a longer process that involves identifying research questions about avian/wind power interactions, debating studies that should be conducted, and deciding on available and feasible approaches and methodologies for conducting studies. Nonetheless, this meeting, the one before it (see footnote [1]), and the ongoing research have helped to raise the level of technical discussions. As a result, the thinking of most people at the table has coalesced regarding the next steps that should be taken in gathering information needed to reduce avian mortality at wind plants.

Agenda

The meeting was structured in two parts. The first day and a half consisted of technical presentations and discussion on the theory and methods for understanding avian impacts. The authors of the nine White Papers mentioned above summarized their topics. Following each presentation there was an opportunity for open discussion of that topic. The information exchanged during these sessions provided ground work for the second part of the meeting, when participants divided into working groups to discuss research priorities and proposals within four general topic areas. The detailed agenda can be found in Appendix 2.

The second part of the meeting consisted of two concurrent working group sessions followed by another pair of concurrent workgroup sessions. Thus, each participant attended two sequential workgroup sessions. Members of each workgroup drafted a set of research questions and proposed research methodologies or activities that address these questions. The workgroups focused on the following areas:

1. ***Site evaluation and pre-permit research and planning:*** What types of avian research ought to be conducted before deciding whether a site should be developed? What methodologies ought to be used?
2. ***Operational monitoring:*** Once a site is developed, what types of research can help estimate and predict the number of birds killed by wind turbines? What methodologies ought to be used?
3. ***Modeling and forecasting, including population dynamics models:*** What research studies will help model or forecast where wind energy developments may conflict with priority species or with large numbers of species or individuals? Are population models helpful? What models ought to be developed and used?
4. ***Avian behavior and mortality reduction:*** What research should be conducted to better understand why birds are killed and whether and what technology can mitigate this impact?

Proceedings Outline

This Proceedings volume summarizes the technical presentations and associated discussions, the working group discussions, and the meeting's conclusions regarding the next steps that should be taken. The Appendices list the Meeting Participants and Meeting Agenda.

The largest part of the Proceedings consists of the nine White Papers. Each White Paper is followed by a summary of the discussions that occurred during and/or after the oral presentation of the White Paper. The White Papers are organized into three groups:

A. ***Stakeholder Questions, Interests and Concerns***

1. Stakeholder Views on Research Questions Regarding Avian - Wind Power Interactions, by *Abby Arnold and Christopher Behr*

B. ***Fundamental Methodologies***

2. Assessing Avian - Wind Power Interactions: Sampling, Study Design and Statistical Issues, by *Kenneth H. Pollock*
3. The Use of Epidemiological Measures to Estimate the Effects of Adverse Factors and Preventive Interventions, by *Lawrence S. Mayer*
4. Population Models: Their Use and Misuse, by *Kenneth Wilson*
5. A Model to Estimate the Annual Rate of Golden Eagle Population Change at the Altamont Pass Wind Resource Area, by *Tanya M. Shenk, Alan B. Franklin* and Kenneth Wilson

C. ***Observation Protocols***

6. Use of Radar for Wind Power-Related Avian Research, by *Brian A. Cooper*
7. Avian Risk Assessment Methodology, by *Richard L. Anderson, Judith Tom, Natasha Neumann, Jennifer Noone* and *David Maul*
8. Suggested Practices for Monitoring Bird Populations, Movements and Mortality in Wind Resource Areas, by *Sidney A. Gauthreaux, Jr.*
9. Protocols for Evaluation of Existing Wind Developments and Determination of Bird Mortality, by *Michael L. Morrison* and *Holly Davis*

Following the nine White Papers and their associated discussions, the Proceedings summarizes the discussions and conclusions of the four working groups. The final section lists the "Next Steps" identified as priorities during the concluding plenary session.

The overall intention is to provide a record of the technical presentations, discussions, and recommendations for those in attendance and for others interested in some or all of the topics discussed. The discussion summaries were prepared by Chris Behr of RESOLVE and W. John Richardson of LGL Ltd., and the Proceedings were edited by W.J. Richardson.

STAKEHOLDER QUESTIONS, INTERESTS AND CONCERNS

During the summer of 1995, before the second Avian - Wind Power Planning Meeting, RESOLVE interviewed 18 people to identify remaining questions about bird - wind power interactions that might be resolved through research. Based on those interviews, RESOLVE prepared a White Paper entitled *Views on Research Questions Regarding Avian - Wind Power Interactions*. This document was circulated to meeting participants in advance of the meeting. Abby Arnold of RESOLVE summarized the main points during the meeting. The following is the text of the White Paper, plus a summary of the discussion that followed Ms. Arnold's presentation.

Stakeholder Views on Research Questions Regarding Avian - Wind Power Interactions

by

Abby Arnold and Christopher Behr, RESOLVE[2]

1. Introduction and Background

In preparation for the September 1995 workshop, RESOLVE interviewed representatives from state and local permitting agencies, environmental advocates, and the wind industry. The individuals to be interviewed were selected by the Avian Subcommittee, and are identified in Attachment A. Interviewees were asked to identify remaining questions that they had about avian/wind power interactions, emphasizing questions that may be resolved through research. Each person commented on his or her ▸ involvement with avian/wind power issues, ▸ perspectives on issues, and ▸ ideas about questions that would benefit from research. Emphasis was placed on research that would reduce uncertainties about specific avian interactions at proposed or existing wind power developments.

Although the parties interviewed expressed a range of opinions about wind development, all raised common questions and research priorities. Most interviewees expressed support for wind power as long as there was low or no impact on birds. The primary differences among parties were their perspectives on how many data are needed on potential avian impacts before one can predict the actual mortality rate at a particular site. Environmentalists who were interviewed generally wanted more site-specific information, collected over a longer period, while others seemed more satisfied with the research that is presently being conducted to predict impacts.

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[2] RESOLVE, 2828 Pennsylvania Ave NW, Suite 402, Washington, DC 20007. *Internet:* Arnold% Resolve@mcimail.com

Interestingly, almost all parties expressed interest in receiving better guidance on conducting pre-construction site evaluations and post-construction monitoring, with more emphasis on the former. Some interviewees suggested that more effort should be directed at investigating why birds are injured by turbines and what technological improvements could mitigate these effects. Others called for better avian population and behavior models that predict where and when avian mortality levels threaten the integrity of the species.

2. Interview Process

Avian Subcommittee members who were organizing the second Avian - Wind Power Planning Meeting directed RESOLVE to contact nearly 20 individuals about avian/wind power interactions. Contact was made through an initial letter followed by telephone calls to schedule interviews. Interviews were conducted from July 28 to August 7, 1995.

Interviewees consisted of technical and policy representatives from wind energy industries and associations, five state or local Audubon Society chapters, a renewable energy advocate organization, and national, state and county government planning officials involved with permitting wind developments. All interviewees were currently involved with evaluating wind power impacts on birds. Collectively these parties have been involved with proposed or constructed wind power developments in California, Maine, Minnesota, Oregon, Vermont, Virginia, Washington, West Virginia, Wisconsin, and Wyoming.

3. Research Questions

The interviews revealed that all parties independently faced similar difficulties in answering two distinct yet linked questions:

A. How to evaluate a proposed wind development site for risk to bird species?

B. How to ensure that the research adequately analyzes a site for its potential impact on avian species?

In answering these questions, interviewees identified four major categories of research proposals that would help them in their work. The categories are research on (1) site evaluation protocols, (2) population modeling, (3) monitoring protocols, and (4) bird behavior and mitigation strategies. Note that, throughout this section, research questions are *not* presented in any priority order.

3.1 General Questions in Wind Development Siting.—Wind power developers pointed out that evaluating sites as potential energy sources combines studies on geophysical, geographic and climatic conditions with assessments of risk to birds and their habitats. Wind developers want to develop sites with a low impact on natural resources, especially birds. It is in the developer's own interest to examine impacts on natural resources, given the demands of the permitting process and public concerns about avian mortality.

Other interviewed parties agreed that background information on the habitat requirements, population dynamics, and potential mortalities of relevant species are critical infor-

mation needs. *However*, the interviewees did not agree on how much information was enough, how long sites should be studied, and the appropriate methodology to gather accurate information. Some parties assumed that the "experts" knew, while others were skeptical that any one "best" approach could be defined at present, and felt that comparative studies conducted over a longer time would reveal the best approaches.

Each party interviewed wants to understand the potential impacts of wind development and make decisions accordingly, yet many are frustrated by the lack of guidelines for conducting this kind of evaluation. In several states, interviewees stated that environmental impact assessment guidelines for examining wildlife impacts are inadequate for birds that travel over large areas. However, an interviewee in California suggested that, even though specific procedures for studying avian impacts have not been drafted in legislation, "unwritten" standardized procedures are currently in use by county permitting officials and industry representatives.

Another concern expressed during the interviews was whether research conducted at one site was applicable to other sites. Parties disagreed about the types and amounts of information that is transferable from one site to another. In particular, although numerous studies in the Altamont area have contributed to the collective understanding of injuries to raptors, interviewees from the mid-west and east coast were uncertain about applying this research to their specific circumstances. Sites in their regions have different species and geographical features than those at Altamont, and they were unsure how to compare their research with that at Altamont or how to evaluate whether enough had been done at specific sites proposed for development. Moreover, raptor research at Altamont provided no guidance on evaluating the risks to passerines in other areas. Some interviewees noted that wind park and technological designs have improved because of research at Altamont, and that these improvements should be generally applicable.

3.2 Site Evaluation Research Protocols.—The parties consistently called for nationally recognized research standards that incorporate state-of-the-art methods for site evaluation. Most interviewees agreed that such protocols, supported by environmentalists, industry, and selected representatives of relevant federal and state permitting authorities, would improve the ability of all parties to analyze wind development proposals critically. A protocol could include a list of research topics to consider and methods for addressing uncertainties. A protocol could be revised to incorporate new research developments. The protocol could also include suggestions for adjusting some of the variables to be measured in order to accommodate site-specific considerations.

Interviewees suggested that the following questions should be incorporated into a set of protocols that could be applied to different stages of wind power development:

- How to estimate species diversity, including the species present and their age and sex composition?
- Which species should be studied specifically?
- How to estimate the local and regional populations of potentially impacted species?

- What is the local and regional significance, for each species, of the habitats present in the proposed development area?
- How geographically large should the study area be?
- How long should studies be conducted?
- What are the implications of assumptions made about unknowns?
- How does the potential impact from wind development compare to impacts associated with other sources of energy?

Several interviewees suggested that these questions be formalized into an avian risk assessment structure. One interviewee described how data may be used in the development of a generalized risk assessment model that is based on resource selection functions (e.g. probability of use as a function of distance to an active nest, distance to active territory center, wind characteristics, topography, etc.). The generalized model could be based on the collection of utilization data for the same species in several areas. For individual species, the model would combine nesting data and expert opinion to refine site ranking in future site selection processes. Broad application of the general model would depend on the performance of the model throughout the range of the species and across habitats. For example, the model may only transfer from one site to another in its simplest form, using a small number of variables such as utilization versus distance to an active nest, topography, and wind characteristics.

3.3 Research on Population Dynamics of Priority Species.—In addition to site-specific research guidelines, other interviewees, especially the advocates on behalf of birds, stressed the need for more information on the population dynamics of priority species such as raptors and neotropical migratory species. Priority species were defined as bird species with special value to other species and to people, plus species with populations that are at risk or at potential risk if additional losses were incurred. These interviewees believed that population models for priority species should include estimated population size and distribution by age, sex and breeding status, and should cover all regionally significant points in the flyway.

The interviewees who wanted more research into population modeling felt that it was necessary to determine a critical threshold for mortality in priority species. Results from modeling would be useful in evaluating the direct impact from a proposed turbine site and its cumulative impact on species through their area of migration. Interviewees stated that these models will help all parties understand whether there is a significant effect on the population if the turbine kill rate increases from 1% to 2%, for example. Also, such a model may help better understand whether impacts are additive or compensatory.[3] Some interviewees stated that impacts on birds are difficult to analyze statistically because there are

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[3] ***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.

few actual deaths within a wind plant per species or in total. Models would, therefore, aid in determining if there would ever be significant cumulative impacts on bird species if the number of turbines increased.

3.4 Site Monitoring Protocols.—Site-evaluation includes estimating the potential impact on avian populations. Many interviewees suggested the need to develop better data on avian mortality. Interviewees said that nationally recognized monitoring protocols would help local planners, developers and environmental advocates evaluate proposed sites and currently operating wind plants. Suggestions for standardized protocols for mortality monitoring included

- data collection methods (including carcass searches, scavenging rate trials, and observer efficiency),
- mortality analysis (cause of death),
- ancillary and environmental variables (e.g. turbine type, location of turbine within turbine string, distance to active nest, distance to active territory center, wind characteristics, and topography),
- control site selection and evaluation, and
- how to apply findings from one site to another.

Some interviewees mentioned that, whatever protocols are developed, they should be flexible to allow for the best allocation of research efforts and funds. For example, it may be clear that some sites require extensive monitoring whereas others appear to have virtually no potential avian impacts.

3.5 Avian Behavior, Mortality Modeling and Technological Mitigation.—Planners, wind power developers, and advocates for both birds and renewable energy all mentioned that a better understanding of avian/wind power interactions and the cause of mortality would help focus technological efforts to reduce avian mortality.

One component of bird behavior mentioned frequently was migration. Some interviewees expressed dissatisfaction with their current knowledge of bird migration. These parties wanted migratory path research conducted for relevant species and geographical areas. Other individuals noted that significant amounts of information on the migration routes, patterns of flight, seasonal patterns and nesting areas already exist, and suggested that effort should be focused on collecting, evaluating and disseminating this information. Some suggested that lessons may be learned by examining research on bird behavior with respect to other structures such as power lines.

Other research areas mentioned by interviewees focused on developing surrogate or proxy measures for understanding the cause of bird mortality. Because deaths occur infrequently in existing U.S. wind developments, it is difficult to evaluate the statistical relationships between risk and variables such as turbine type, turbine location, etc., and thus to understand when birds are most likely to be killed. One interviewee suggested that

a measure of risk based on avian behavior, acting as a surrogate variable for mortality, would help in predicting avian impacts if the data could be modeled analytically. This surrogate variable should be based on observations that are, in comparison with mortality data, more easily and more commonly collected, e.g. how birds adjust flight patterns and nesting strategies with respect to wind developments and various types of structures.

Several interviewees wanted more information on how to adjust on-site and off-site mitigation strategies for particular species and areas of concern based on avian behavioral research. Several people had questions about the locations of turbines with respect to recognizable avian habitats such as wetlands. Others wanted to know more about design features such as audio or visual deterrents such as blade painting. Interviewees also wanted better comparisons of the impacts of lattice-tower and tubular-tower turbines on bird species, including designs that inhibit perching. Several people strongly suggested that research should examine whether turbines with slower blade rotation speeds reduce avian injuries.

4. Additional Comments

4.1 Consultation Models.—Almost all interviewees specifically mentioned that they were in favor of furthering wind development, but only in the most appropriate places. However, the fear of setting a precedent at the wrong site was mentioned several times by planners and environmentalists. Many advocates for birds have been dissatisfied with the pattern of siting wind development in the past and would like to have a more open process for evaluating alternatives. Others have suggested that the competitive nature of wind development creates constraints to disclosing proprietary research. These concerns are indicative of problems in communication between industry representatives and environmental advocates. When told of processes for including the public in siting decisions being developed in California and Minnesota, parties asked for more information.

4.2 National Repository of Avian/Wind Power Research.—Many people suggested the need to establish a public, national repository for studies on birds, wind power, and their interactions. Interviewees suggested that a central source of information would "level the playing field" and help all parties agree on what is known and what needs to be known on a site-specific basis. Several people mentioned a concern about managing the repository and suggested that the data should be catalogued in a standard format for quality control and quality assurance, and managed independent of vested interests. Data on migration patterns, resident species and potential wind energy sources could be incorporated together in a GIS system to identify areas of low impact and high energy yield. Data from Christmas Bird Counts and NEXRAD radar were discussed as largely untapped resources that might be included in the repository. Interviewees also wanted to incorporate findings on bird collision mortality from the U.S. and abroad. A report by Colson and Associates, *Avian Interactions with Wind Energy Facilities: A Summary*, was mentioned as a starting point for collecting these data. There should be a regular process for updating this information.

5. Conclusions

During the year since the first National Avian - Wind Power Planning Meeting, held in July 1994, communication has improved among those interested in bird - wind power interactions. However, more discussion will be needed among the interested parties to better understand one another's questions and then to develop means to answer the questions. The second National Avian - Wind Power Planning Meeting in September 1995 offers an opportunity for those who have been immersed in these issues to sit back and reflect on the suggestions about research priorities offered by the various parties with their many differing but overlapping perspectives.

Attachment A: Interviewee List

Don Arnosti
National Audubon Society
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Discussion

This section summarizes the discussion that followed Ms. Arnold's oral summary of the preceding White Paper. As the first opportunity for meeting participants to share their perspectives, this discussion session was quite fruitful. A number of important issues were raised that participants returned to over the next 2½ days. Some of the comments reiterated and supported the paper's summary and a few others introduced further complexities that will arise in development of policy. In some respects, this was an important opportunity for regulators to express some fundamental concerns about the current state of knowledge and what will be expected of them in permitting a wind power facility.

Several of the comments discussed the complexity of the permitting process. One person mentioned that regulators should be involved earlier in the design phase. After significant resources have been invested in site evaluation and design, industry representatives may expect to receive a permit and regulators may find it difficult to require additional abatement measures or to deny a permit.

One way in which regulators could be involved earlier is through participation in the design of the site evaluation process. One regulator suggested that the process for evaluating a single site should be consistent with the processes at other existing and *potential* sites

within a larger wind resource area. To do this, research should be expanded from the single wind development site to provide data for assessing comparative and cumulative impacts over a broader wind resource area. Regulators would be instrumental in overseeing this process by ensuring that consistent and comparable data were collected.

The question, "Who would pay for non-site-specific studies", remained open. One person commented that requiring the first applicant for a permit in a given area to cover the costs of the broad survey would be a disincentive to the first developer. To reduce this problem, one participant suggested that government should contribute to the cost of area-wide studies of comparative and cumulative impacts, and that individual wind developers pay a research fee that would help defray these costs.

Discussion proceeded from this suggestion to the feasibility of comparative and cumulative assessments. The main difficulty would be comparing studies conducted by different people, in different areas, at different times. On this topic meeting participants echoed the suggestion from the White Paper: develop a standard, but flexible, set of guidelines for evaluating a site. Participants stated the need for common definitions on the type and scope of studies; research processes that can produce statistically consistent data; and procedures for transforming data to keep them comparable when research procedures are modified.

Another issue that participants raised was the importance of forming a central repository for studies and data. This suggestion reemphasizes comments summarized in the White Paper. One person thought that the repository would help clarify a lot of the misinformation that exists when a site is evaluated. It would also be a source that all people can look to in order to answer some basic questions about potential avian impacts. The repository would be the first step in consolidating the best professional judgment on research and analytical methods. As some people pointed out, in this era when many stakeholders are looking to the courts to resolve differences, scientific expertise is being raised to a new level of importance, and standards for admissibility of expert opinion and evidence are increasing.

FUNDAMENTAL METHODOLOGIES

This section of the meeting consisted of four presentations on fundamental methodological approaches relevant in evaluating the effects of wind power developments on birds, along with discussion of those presentations:

(1) Dr. Kenneth H. Pollock described basic sampling, study design and statistical issues that arise when assessing avian - wind power interactions. He pointed out the key assumptions that must be made when applying traditional experimental design and hypothesis testing, and some difficulties that often arise when attempting to apply traditional designs to environmental field studies. He introduced two alternative approaches: the BACI (Before-After-Control-Impact) approach and modeling.

(2) Dr. Lawrence S. Mayer described the use of epidemiological concepts, terminology and measures to assess the effects of wind developments and associated mitigative measures (p. 26). He emphasized the care that needs to be taken in defining terms and in choosing the dependent or outcome variable, which is usually a rate.

(3) Dr. Kenneth Wilson introduced the uses (and misuses) of population models (p. 40). He summarized the nature and uses of models, the selection and validation of models, and the importance of sensitivity analysis.

(4) Tanya Shenk described, as an example of a population model, the then-current version of a model being developed for the Golden Eagle population in the Altamont Wind Resource Area (p. 47). She summarized the hypotheses that the model is being developed to test, the structure of the model, and the assumptions that must be made. This model is being developed in parallel with a radiotelemetry field study of the Altamont population of Golden Eagles. Ms. Shenk outlined the two-way links between the modeling work and the field study.

In each case, a White Paper on the topic was prepared. Most of these documents were circulated in draft form in advance of the meeting. The following four sections consist of updated versions of these White Papers, in each case followed by a summary of the discussion that followed the oral presentation.

Assessing Avian - Wind Power Interactions: Sampling, Study Design and Statistical Issues

by

Kenneth H. Pollock, North Carolina State University[4]

Abstract

Interactions between birds and wind power facilities are complex to measure and assess but they have importance to all parties involved in setting policy. In this paper I present a discussion of sampling, study design and other statistical issues. The paper is written from the viewpoint of a scientist trained as a statistician with a strong biological background and a deep interest in modeling.

I begin by discussing the various sampling methods used to sample avian populations and how they relate to sampling theory. I emphasize methods involving counts and methods that involve capture and resighting (usually by radio-tagging).

The heart of the paper is a discussion of traditional experimental design, which depends on three principles. These are use of controls; randomization of "treatments" to experimental units; and replication of experimental units within treatments. This leads to a discussion of testing to compare treatments and the importance of the test having high power. Power depends critically on the number of replicates and the inherent variation in the experimental units. With the stage set, I then discuss the difficulties of assessing an environmental impact, such as that of a wind power facility. Often there is a lack of good control sites, no randomization is feasible, and replication is inadequate due to scale and cost considerations.

Given the difficulties with traditional experimental design, I discuss alternative approaches considered in the literature. These include the so called BACI design (Before, After, Control Impact), which assumes that it is possible to replicate experimental units on both control and impacted units both before and after the impact, even though it is not possible to randomize. I then briefly mention the more radical alternative of using mechanistic models in attempting to assess impact; this is not always popular with traditional statisticians. Modeling is considered in more detail in other papers in this conference.

The next part of the paper discusses several types of studies related to avian - wind power interactions. These include avian risk reduction studies, avian - wind farm interaction studies, sampling and modeling to assess population impacts, and preliminary population modeling exercises to aid in the design of all field studies. I emphasize the importance

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of funding and implementing more examples of each type of study so that we can get to understand their properties in more detail.

I conclude with a discussion and summary of the important issues raised. I emphasize key immediate and longer term decisions that need to be made. I also emphasize the need for good coordination to avoid wasting resources, and the need for future research.

1. Introduction

A statistician may be involved in avian - wind power interaction studies at various levels. First, he or she may be involved in deciding how to measure variables of interest on one area or plot. This involves traditional sampling approaches to count or capture-resight methods. A second and more difficult type of involvement concerns assessment of environmental impact at a larger scale involving multiple plots or areas. Traditional experimental design has weaknesses that lead to alternatives like BACI designs or modeling (Fig. 1).

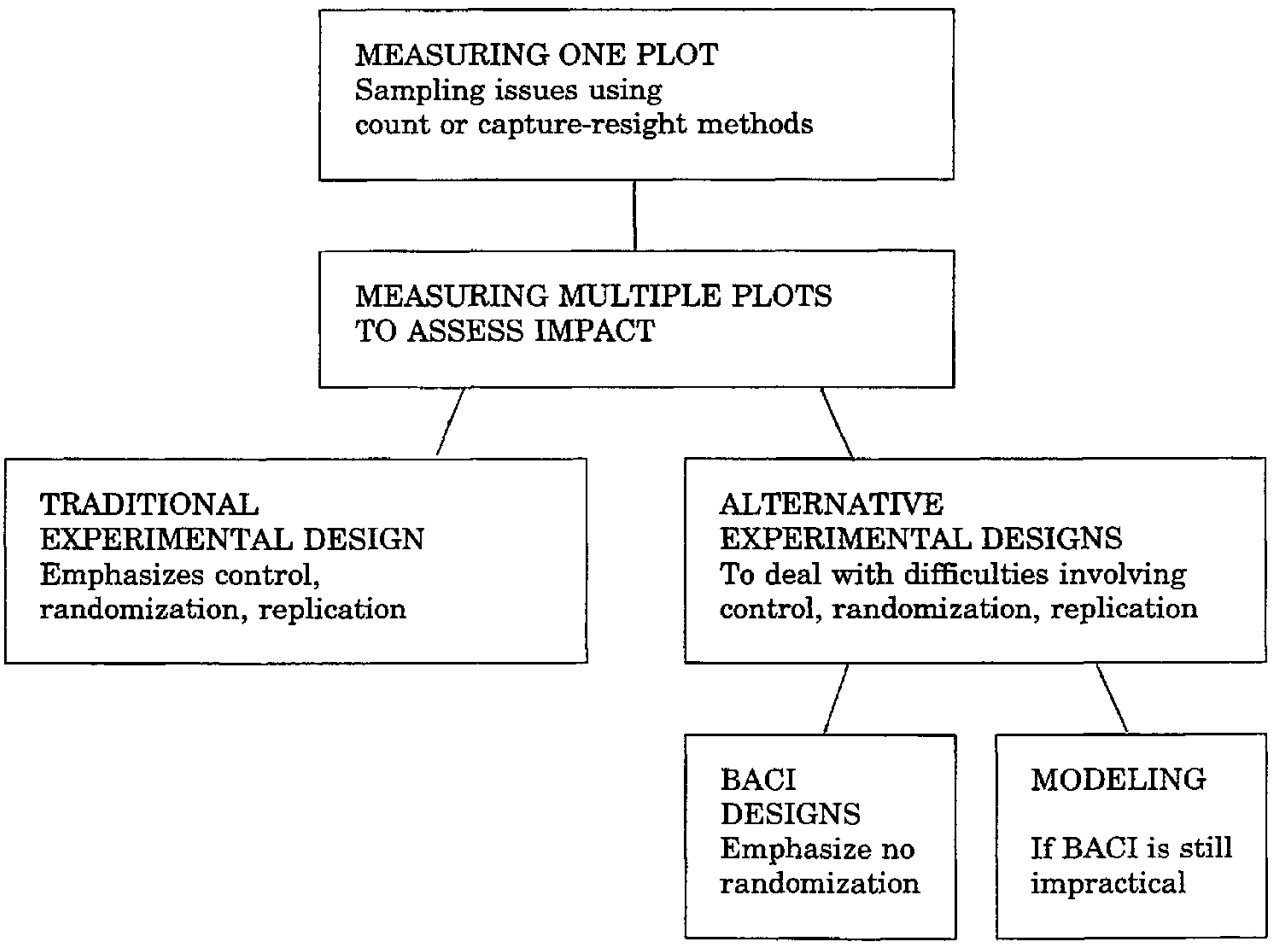

FIGURE 1. How statistical issues affect measurements of avian populations on one plot and assessment of impacts through measurements on multiple plots. The emphasis is on alternatives to traditional comparative experimental designs, which are not very practical here.

Section 2 of this paper discusses sampling issues on one area or plot. Section 3 presents traditional experimental design concepts. Section 4 presents alternative designs that may be relevant to our work. These include BACI designs and modeling approaches. Section 5 presents some possible study designs for avian - wind interactions. Section 6 summarizes the most important recommendations.

2. Sampling Avian Populations

2.1 Finite Population Sampling Theory.—At the smallest scale, a scientist may want to measure certain variables related to avian - wind power interactions on a particular area of land. It might be an area around one turbine, around a string of turbines, or perhaps around a whole wind farm of similar turbines. In all these cases it will be necessary to measure variables using statistical sampling of a finite population (Cochran 1978; Thompson 1992) because it is often not possible to take a census of the whole area.

As an example, let us consider measuring raptor use of an area with a group of wind turbines for one year. In this case a multi stage design might be used (Thompson 1992, Chapter 13). It is necessary to sample some of the days in the year at random. Therefore, the days are what we refer to as primary sampling units. Within each day sampled it also might be necessary to have observers make counts at various randomly-selected times through the day so the observers do not have to count all day. These points in time would be referred to as secondary sampling units. The methods used here are very similar to instantaneous counts used in angler surveys (Pollock et al. 1994).

Whatever the sampling design used, the usual questions about precision of estimators are present. The obvious way to increase precision is to take a larger sample. However, there may be more cost-effective ways to increase precision via stratification and use of auxiliary variables in ratio or regression estimators (Thompson 1992).

Next we consider briefly methods of sampling birds either by counts or by capture and relocate (typically using radio-tagging).

2.2 Count Methods.—The easiest method of sampling *dead* or *live* birds is by carrying out counts in defined areas. When the area of interest is a long narrow strip, or is large enough to contain one or more of these strips, transect methods may be used. In other cases point counts may be used. Often counts of all the birds in an area can be made by searching the area systematically. Important assumptions usually made are that all birds are seen and that no birds are counted twice. The realism of these assumptions depends on the practical aspects of the problem (live or dead birds, species of bird, etc.). A rather statistical treatment is given by Seber (1982). The first chapter of the book by Buckland et al. (1993) on distance sampling is relevant. However, when dealing with large birds like raptors, which are easily sighted, we often will not need the sophistication of the Buckland et al. approach, which takes account of varying detection probability vs. distances of observers from birds.

2.3 Capture-Resight Methods.—In some cases the area to be studied may be large and may include a valued population of birds that inhabits a wind farm (e.g. Golden Eagles in the Altamont Pass, California). One method of estimating survival of these birds is to capture and mark the birds and then resight (or relocate) them. In many cases, the only practical way to do this relocation is with radio tagging (White and Garrott 1990). Important papers on survival analysis for radio-tagging studies are Heisey and Fuller (1985), Pollock et al. (1989a,b, 1995), and Bunck et al. (1995).

3. Traditional Experimental Design

3.1 Fundamentals.—First, it is important that a statistician or biometrician should be involved in all aspects of ecological field studies. Following Hurlbert (1984) I suggest that the important aspects are

(a) Specifying the objectives: This involves deciding on hypotheses to be tested, the variables to be measured, the treatments to be compared, the resources available, and so on.

(b) Study design: This involves the structure of the treatments, controls, replication, randomization and blocking if appropriate. (These terms are defined below.)

(c) Study execution: This involves actually implementing the study design in the field.

(d) Statistical analysis: This might involve formal tests or just graphs, tables etc. depending on the study.

(e) Interpretation of results: Are the statistical procedures used valid? Has too much been made of the results in an attempt to make the study seem more important than it actually is? Statistical ideas will be crucial to valid interpretation of the results of any study.

The following definitions are critical in developing experimental design concepts:

Treatment: A set of experimental conditions of special interest to the scientist. Usually there is a need to compare two or more treatments, or a treatment vs. an untreated "control" or reference situation.

Experimental unit: This is the experimental material to which the treatments are applied. An example might be an experiment comparing two types of wind turbine on avian mortality. The two types of wind turbine would be the two treatments and the experimental units could be areas of land where strings of turbines of each type were constructed.

Moore and McCabe (1993), and many other statistics books going back to Fisher (1935) in his classic *Design of Experiments*, consider the following principles crucial to a comparative experiment. These principles could be said to define the traditional experimental design paradigm.

(A) Control: The scientist tries to control (standardize) as many variables as possible except for those associated with the different treatment conditions that are to be compared.

(B) Randomization: The scientist randomly allocates treatments to experimental units so that variables not controlled are allocated equally over units (at least on average).

(C) Replication: Each treatment is allocated to multiple experimental units so that unexplained or inherent variation can be quantified. Information about the amount of inherent variability is needed for valid statistical testing procedures.

(D) Blocking: To increase precision for a fixed number of replicates, the scientist may randomly allocate treatments within homogeneous blocks of experimental units if such blocks can be identified in the real experiment at hand. Blocking is important but not essential, unlike principles (*A*, *B*, *C*). I emphasize that the blocking factors chosen should be independent of the treatments being tested (i.e. no interaction between treatment and block effects). Alternatively, it may be possible to improve precision by analysis of covariance (Steel and Torrie 1980, p. 401) if auxiliary variables are available. An auxiliary variable is one whose relationship to the dependent variable can be defined by a regression model.

3.2 Hypothesis Testing.—For illustration let us consider a simple experiment with two treatments, each replicated n times in a completely random design. The treatments may be two types of wind turbine and each experimental unit may be a string of 10 wind turbines of one type. The variable measured could be number of dead raptors/year.

The classic test for use on this problem is the two sample t-test (Steel and Torrie (1980, p. 96), which is based on a normality assumption, or the corresponding two sample rank sum test, the Mann-Whitney U-test (Steel and Torrie 1980, p. 542). The null hypothesis being tested is that the population mean responses of the two treatments, as estimated by the mean number of dead raptors/year per 10-turbine string, *are* equal. The alternative hypothesis is that the population mean responses *are not* equal.

The power of the test is the probability that the test will reject the null hypothesis when it is false. Ideally, the power should rapidly approach one as the population means for the two treatments become more and more different. For a fixed difference between the two population means, the power obviously can be increased by increasing the number of replicates (here, the number of 10-turbine strings being monitored per treatment). An alternative way to increase the power might be to use an alternative paired t-test, or its nonparametric equivalent, if homogeneous pairs or blocks of experimental units can be found (Steel and Torrie 1980, p. 102). Randomization, unlike replication and blocking, does not directly affect the power of the test, but randomization is fundamental to ensuring the validity of the test.

3.3 Difficulties.—The three fundamental components of traditional designs—randomization, controls, and replication—all can be difficult to satisfy in field studies of environmental impact:

Lack of randomization: A fundamental problem with applying traditional experimental designs to studies of avian - wind power interactions is the impossibility of randomizing in most cases. Locations of wind power facilities are fixed by economics and politics, not randomization. It may sometimes be possible to randomize the type of turbine allocated to a particular area of land within a wind farm. However, even that may be problematical if

the wind farm with the various types of turbines is in operation before the experiment begins.

Lack of controls: Because of the large scale of many wind farm developments, it is often very difficult to find reasonable control areas for comparison with the treated (wind farm) area. In addition, the cost of monitoring the large areas may be prohibitive even if control areas can be found. Also, when designing a study of a wind farm already in operation, it may be difficult or impossible to determine whether, before the wind plant was constructed, that site was similar to a suggested "control" site.

Lack of replication: It is usually impossible to replicate wind farms. They are unique! Even when two or more wind farms are present in one region, their environmental situations will inevitably differ. It may be possible on rare occasions to replicate control areas but the cost is usually prohibitive. During studies on a smaller scale, where the objective might be to compare types of turbines, replication can be achieved for each treatment.

Hurlbert (1984) has discussed in detail examples of what he calls pseudo replication during ecological field studies. The widespread practice of using inappropriate or pseudo replication is related to the difficulties in obtaining true replicates due to cost and practicality.

4. Alternative Study Designs for Environmental Impact Assessment

4.1 Before-After-Control-Impact Type Designs (BACI).—Stewart-Oaten and Murdoch (1986) popularized the Before-After-Control-Impact Design of Green (1979). This design attempts to get around the problems of traditional experimental designs and especially the lack of randomization. The idea is that, by comparing control and impact sides before and after the impact, it should be possible to separate the impact effects from temporal changes. The rationale of BACI designs in the context of avian - wind power interactions was discussed in PNAWPPM (1995, p. 65-69).

Extensions of this concept have been described by Underwood (1994) and others. Underwood (1994) recommends multiple control sites. However, the scale of his examples is much smaller than here. His examples often involve sampling invertebrates in marine intertidal zones affected by sewage projects. There are severe logistical and cost complications in applying these principles in the present context, where both the temporal and the spatial scales are much larger. Eberhardt and Thomas (1991) also discuss the design of environmental field studies. They recommend that a wide variety of approaches be considered for different problems. They also recommend that modeling approaches be considered.

4.2 Modeling Impacts.—Formidable difficulties arise when attempting to apply traditional experimental designs, with their reliance on randomization and replication of different treatment conditions. Logistical and other difficulties also are common when using the BACI-type extensions. I am, therefore, reluctantly drawn to conclude that study design

and research on avian - wind power interactions will often have to rely on modeling of the impacts. The scale of the problems encountered necessitates radical methods.

I have been involved in an advisory team of scientists designing a detailed population study of Golden Eagles effected by the Altamont wind energy facilities in central California. The objective of the study is to assess the impact of the wind development on the population of eagles in the area. Is the population likely to decrease because of the wind development? After considering traditional experimental designs and their BACI modifications, we concluded that the only feasible approach to the Altamont Golden Eagle study was to use a stage structured population model (Caswell 1989; Shenk et al., these Proceedings, p. 47). The inputs to the population model are survival and reproductive rates estimated by sampling the population. We recommended use of radio tagging methods to estimate the survival rates and use of nest searches to estimate reproductive rate.

It is important to acknowledge, however, that use of models in environmental impact studies is not without serious drawbacks. Inferences made will necessarily be weaker than from traditional experiments and will depend heavily on the validity of model assumptions. Part of the study design should involve validation of model assumptions where possible.

5. Some Possible Avian - Wind Power Interaction Study Designs

In this article I have attempted to show the complexity of studies to assess avian - wind power interactions. Here I present a tentative list of possible studies that might be useful, based on ideas from the NREL Avian Research Brainstorming Group. The studies are very varied and range from small scale to large scale.

5.1 Avian Risk Reduction Studies.—The objective here is to test methods of treating wind turbines to reduce the risk of killing birds. Some possible treatments might be painted blades, tower configuration, perch guards, decoys, and other warning devices. The experimental unit would be the area around a turbine or group of turbines in a wind farm. The variables to be measured would be avian utilization and mortality.

As the experimental unit is on a fairly small scale, replication should be possible. Also, randomization of treatments to experimental units should be possible if the study is planned into some new or expanded wind farm developments. Therefore, this study fits into the framework of a traditional experimental design.

5.2 Avian - Wind Farm Interaction Studies (BACI).—The objective here is to measure the effects of wind farms on avian species in the area. For the wind farm area and a reference (or control) area before and after construction, a comparison of important variables (such as utilization, mortality, species composition, etc.) is made

These are very complex and expensive studies to carry out. They can be viewed as being generally of the BACI type. However, it may be difficult to have any replication of

control sides, and replication of the wind farm area is usually impossible. Randomization is also not practical.

5.3 Assessing Population Impact by Sampling and Modeling.—Following from Section 5.2, there may be difficulties in implementing before and after assessment and also in finding reference sites. Therefore, if one wants to study an important population in detail, there may be a need to combine modeling with sampling, with the latter being used to estimate parameters in the model.

An example of this is already being implemented in the Golden Eagle Population Study in the Altamont Region in central California (see also Section 4.2). We considered a stage structured population model (Caswell 1989). We recommended sampling using radio tagging to estimate survival rates, and using ground nest searches to estimate reproduction rate.

These studies are weaker than traditional experiments. However, they are often the only possible way of assessing population impacts.

5.4 Preliminary Population Modeling Exercises.—In some cases preliminary population modeling with parameter estimates from the literature may be used to help plan field research. This approach could be very helpful and cost effective, in that field studies would be more likely to be attempted only when they were necessary, and would be more likely to measure the critical parameters.

6. Recommendations

(a) Clarify when Standard Experiments, BACI extensions and models are best used in assessments of avian - wind power interactions.

(b) Develop detailed protocols for different types of study designs.

(c) Fund and implement at least one study with each type of design so we can learn more about the usefulness of various approaches.

(d) Assess the results of studies to enable better decisions about the need for and design of further research.

(e) Use models as planning exercises to help improve the design of future research.

(f) Continue to include statisticians and modelers in research teams.

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I would like to thank all the members of NREL Altamont Golden Eagle Study Review Team and the NREL Avian Research Brainstorming Group for their assistance. Most of the ideas in this paper came from discussions with these individuals. Of course, responsibility for any deficiencies in this paper is entirely my own. I also thank W. John Richardson for editing the manuscript.

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Discussion

Sampling Avian Populations.—Several questions and comments were raised concerning problems associated with *repeated counts* of the same birds. Many statistical procedures assume that each observational unit is represented in the dataset only once. Violations of this assumption are common. Dr. Pollock noted that this was not a serious problem in the Golden Eagle study because it was based on individually tagged animals. Other commenters noted that the repeated-counting issue ▸ can be a significant concern in studies of habitat use, where there may be repeated counts in a given area, and that ▸ the severity of the problem depends on the parameter being measured and the way in which it is measured.

Traditional Experimental Design.—Questions were raised regarding what might be useful as a *blocking factor.* ▸ Dr. Pollock noted that habitat or topography could be appropriate for blocking. For example, one block of experimental units (e.g. turbine strings) might be on north facing slopes and another block on south facing slopes. ▸ A commenter noted that one should not block experimental units based on some aspect of habitat that could change differentially among experimental units during the study. ▸ Dr. Pollock indicated that, with blocking, the blocking factor must not interact with the treatment factor(s); if it does, then the blocking factor is really a treatment as well, and should be handled as such.

Analysis of covariance vs. blocking: Dr. Pollock was asked whether analysis of covariance is useful as an alternative to blocking when homogeneous blocks are not present. He said yes, but cautioned that this method is based on assumptions about linear models. Dr. Pollock indicated that the clearest distinction between the two approaches is that ▸ blocking is appropriate when discrete and homogeneous groups of experimental units can be identified, whereas ▸ the covariance approach assumes that there is a regression relationship between a continuously-distributed predictor (auxiliary) variable and the main variable of interest.

Hypothesis testing: A commenter noted that null and alternate hypotheses should be defined in advance, not after inspecting the data. Dr. Pollock agreed; traditional experimental design requires predefined hypotheses, and traditional statistical tests are not valid if the same data are used to identify hypotheses and then to "test" them.

Another question was whether traditional hypothesis testing can be applied to the following common type of question: whether the impact from Phase I of a development exceeds a threshold level that has been identified as being too severe to allow continuation with Phase II. The answer is yes, based on discussion after the meeting. For example, the null hypothesis could be, "Post-development mortality will not exceed pre-development mortality by more than x", where x is some pre-defined "threshold of concern". In most hypothesis testing x is 0, but x can be non-zero.

Alternative Study Designs: BACI.—Some commenters noted that problems can arise when the bird populations at nearby treatment and control (or reference) sites are not

independent. One participant recommended that sites should be spaced far enough apart so that birds using one study site would be unlikely to also use another study site.

The desirability of more than one reference site, as emphasized by Underwood, was mentioned. However, the costs and logistics of multiple reference sites are likely to be difficult to accommodate, especially when development of a given wind resource area is just beginning. One participant suggested that government might pay for initial studies, and then charge future developers a portion of the already-incurred cost. Government would assume a risk; it would recover its initial costs only if the area were later developed.

There was some discussion of the possibility that a site initially selected as a control/reference site might later be selected for development. If there were only one such site, responsibility could fall on the regulatory system to ensure that the control/reference site remains as such. However, if more than one of these sites was selected and studied from before the start of development of a given region, it might be acceptable, within the BACI context, for some (not all) of the initial reference sites to be developed later. However, there was further mention of the logistical and economic constraints on this approach, given the recognized difficulties in obtaining an adequately-long set of pre-development data from even one or two sites.

Dr. Pollock noted that Underwood has made strong methodological recommendations based on invertebrate sampling near sewage outfalls. However, these approaches are very difficult to apply to larger-scale issues such as those associated with avian - wind power interactions.

Alternative Study Designs: Modeling.—One participant noted that the limitations of traditional and BACI designs do not necessarily mean that one should abandon field studies entirely in favor of modeling. He mentioned that, even without randomization or adequate replication, well-designed field efforts (e.g., matched-pair comparisons) can be useful, at least on a weight-of-evidence basis even if not as a basis for formal hypothesis testing.

Dr. Pollock agreed that modeling and fieldwork are complementary and should be done in a coordinated and iterative manner. It is also important to use existing ("old") or additional ("new") data when attempting to validate or confirm a model. It was pointed out that all models are simplifications of reality. For this reason, some consider it more appropriate to refer to a model as "confirmed" than as "validated". However, a model cannot be "confirmed" solely by demonstrating consistency with data used in developing the model.

One participant stated that there may be insufficient incentive to follow through with model validation/confirmation. For the modeler, the benefits accruing when a model is confirmed may be too small to offset the risk of negative consequences should the model be demonstrated to be wrong. However, if the modeler is part of a research team, this should not be a serious concern. Methods should be sought to encourage a productive interplay between modeling, fieldwork, and other forms of model confirmation.

The Use of Epidemiological Measures to Estimate the Effects of Adverse Factors and Preventive Interventions

by

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Outline

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- Measuring the Frequency of Disease, Injury or Death
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- Testing the Effect of External Factors on Avian Mortality
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1. Introduction

Epidemiological studies conducted by researchers in medicine and public health may appear, at first blush, to be empirically based, statistically analyzed, experimental and observational studies of the frequency of disease, injury or death. They do indeed fit this description but they have additional defining characteristics. Epidemiological studies are defined by their role in the testing of hypotheses regarding the mechanism of disease, injury or death. An epidemiological study is a statistical study that focuses on testing a hypothesis that arises from the consideration of a disease process and must be designed in a manner that sheds light on that process. A study which characterizes the relative frequency of people with different color eyes and tests the hypothesis that the different colors occur with equal probability is not an epidemiological study unless eye color is being tested as a risk factor or outcome variable in a disease process.

Epidemiology studies are probably unique among statistical studies in the degree of attention given to choosing the dependent variable or outcome variable, as it is usually labeled in epidemiology. In epidemiology, the outcome variable is almost always a rate related to the frequency of disease, injury or death. The outcome variable adopted should be

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the variable that the experimenter considers most likely to shed light on the hypothesis about the mechanism of disease, injury or death.

In epidemiology, the choice of the outcome variable (frequency of disease, injury or death) depends heavily on the mechanism hypothesized for the transmission of disease or the cause of injury or death.

Once a measure of the frequency of disease is chosen, a measure of effect must be chosen. This measure is used to summarize the difference between two populations (or among several populations). After the measure of the frequency of disease, the measure of effect is the next most critical choice in designing, running and interpreting an epidemiological study. For example in looking at the effects of radiation on workers at a nuclear plant, we might use the risk of death from cancer as the measure of the frequency of death. To compare nuclear workers to workers in another plant in the same community we might use the risk ratio, the measure of effect.

Once the measure of the rate of disease/injury/death and a measure of effect are selected, the data collection, whether experimental or observational, can be structured. The design of an epidemiological study must provide a test of the difference between two or more populations with regard to the chosen measure of effect applied to the chosen measure of the frequency of disease.

In this paper I discuss the problem of measuring ▸ the rate of bird mortality for Wind Resource Areas and ▸ the effect of the wind resource development on the risk of death for members of a particular species of bird. I comment on the problems of designing data collection efforts that estimate and test the effects of the wind resource development or preventive interventions on the rate of mortality. I close with a discussion and some comments on the implications of epidemiology for the study of avian mortality.

2. Measuring the Frequency of Disease, Injury or Death

Epidemiological studies are central to the study of the welfare of human populations. They are statistical studies that analyze the frequency of disease, injury or death (usually abbreviated as the frequency of disease) in order to make statistical inferences about the process underlying the disease, the etiology of the disease, or the causal path involved in the occurrence of the disease (Lilienfeld and Lilienfeld 1980; Kleinbaum et al. 1982; Rothman 1986; Hennekens and Buring 1987; Kahn and Sempos 1989).

Statistically, the purposes of epidemiologic studies are to characterize the frequency of disease, injury or death for a population and to test the impact of potentially adverse exposures or preventive interventions on the frequency. The guiding principles are description and hypothesis testing.

The starting point for any epidemiological study is to quantify the frequency of disease. The simplest measure of disease frequency is the count of newly affected individuals or the

count of all affected individuals. But count data by themselves have limited value in epidemiological studies. To investigate the distribution and determinants of the frequency of disease, the raw measures must be expressed as relative measures or ratios. Such expressions are called standardizations or rates; I prefer the latter term. Results expressed as rates allow comparison of two or more populations with regard to the frequency of disease. The differences among rates for these populations are the basis for epidemiological inferences about the process that underlies the disease.

Care is required in defining a rate suitable for use as a measure of disease frequency. Consider a simple hypothetical example. Suppose City A has 100 new cases of Tuberculosis while city B has 50. The statement, "City A has twice the frequency of Tuberculosis as City B" is true but may not be important as a scientific statement because it fails to control for the population sizes of the cities. Suppose City A has 100,000 residents and City B has 25,000. The ratio of the number of new cases to the population size, which is referred to as the incidence or incidence rate of the disease, is a standardized measure of disease frequency. The incidence for City A is 0.001 and for City B it is 0.002. Thus, while City A has more new cases, after controlling for the size of the city, City B has twice the incidence of Tuberculosis.

Suppose we learn that the count for City A is for two years and the count for City B is for one year. To compare the two cities we might adjust for both the size of city and the length of the reporting period. The annual incidence rate for City A is 0.0005 and for City B it is 0.002. Controlling for city size and reporting time, City B has four times the annual incidence rate of Tuberculosis.

These comparisons, while better than the comparison of the raw counts, are only sound if the standardization is appropriate on theoretical grounds. The standardization is only appropriate if it gives insights into the transmission, cause, or course of Tuberculosis.

This type of measure of disease frequency, a rate defined by the size of the population or by the person-years covered, is the most commonly used in epidemiology. It works well for chronic disease morbidity or mortality but may not work well for injury or death.

Suppose we knew that only a small fraction of the population of each city was at risk for contracting Tuberculosis and then only while doing certain activities. We might want to standardize the comparison of disease frequency by using rates standardized by the person-hours of exposure at these activities. We might hypothesize that this standardization or rate would give us more insight into the disease process. This type of standardization is not feasible with most chronic diseases but does point out the importance of considering that **a rate is only as good as its denominator**. A good epidemiological study considers the denominator of the rate of disease as closely as it considers the numerator.

Turning to the problem of defining rates for studies of mortality, suppose we want to compare two types of aircraft, the Boeing 747 and the Beaver 36, a 19 passenger prop-driven

commuter aircraft, in terms of risk of death. We could count the deaths that have occurred in a given year in each type of aircraft. Suppose that 1000 people died in Boeing 747 accidents and 500 died in Beaver 36 accidents. (Note: All such numbers are artificial.) We could state that the 747 has twice the frequency of deaths of the Beaver 36, but the statement would have little meaning because we have not standardized the counts. We could standardize the death counts in a variety of ways. The denominator might be the number of aircraft of each type; the number of passengers flown by each type of aircraft in a given year; or the number of passenger miles flown by each type in a given year. We might also standardize by the difficulty of the types of flights undertaken by each type of aircraft.

The best choice for the denominator depends on the purpose of the study. If the study is designed to test hypotheses about the relative safety of traveling on different types of equipment, then the natural denominator might be the number of passengers carried or the number of passenger miles. If it is to analyze the risk for pilots then it might be reasonable to standardize by the number of flights. If it is to estimate the actuarial risk of piloting the aircraft then it might reasonable to standardize by the hours of flight. In any case the appropriate standardization is obtained from theoretical analysis of the process of death under consideration.

Suppose the Boeing 747 fleet carried 10,000,000 passengers in a year while the Beaver 36 carried 100,000 passengers. Then the annual mortality rate for the Boeing 747 is 1000/10,000,000 or 1 death per 10,000 passengers or 0.0001 while the annual mortality rate for the Beaver 36 is 500/100,000 or 5 deaths per 1000 passengers or 0.005. Using the rate of death per passenger, the mortality rate is 50 times greater on the Beaver 36.

But suppose the Boeing 747 fleet covered 10,000,000,000 passenger miles in the year while the Beaver 36 fleet covered 10,000,000 passenger miles. On a passenger mile basis, the mortality rate for the 747 would be 1000/10,000,000,000 or 1 death per 10,000,000 passenger miles or 0.0000001, while for the Beaver 36 it would be 500/10,000,000 or 500 deaths per 10,000,000 passenger miles or 0.00005. Based on the rate of death per passenger mile, the mortality rate is 500 times greater on the Beaver 36.

The choice between these two measures is a matter of debate. Both are widely used in epidemiology. But in some epidemiological contexts other types of disease frequency seem more natural than either of these measures.

For example, suppose the purpose of the study of death per aircraft is to focus on the major risk to the aircraft and its passengers, the risk of take-off and landing. In order to compare the Boeing 747 to the Beaver 36, the rate of death per take-off (or landing) could be used. Suppose the 747 fleet makes 20,000 take-offs per year and the Beaver 36 fleet makes 40,000 take-offs per year (it often carries no passengers on take-off). Then the mortality rate for the Boeing 747 is 1000/20,000 or 1 death per 20 take-offs or 0.0001 while the mortality rate for the Beaver 36 is 500/40,000 or 1 death per 80 take-offs or 0.00005. Using deaths per take-off, the mortality rate is four times greater on the Boeing 747.

Note that the mortality rate for the Beaver 36 is 500 or 50 or 0.25 times the mortality rate for the Boeing 747 depending on the standardization of the frequency of disease. The issue of which type of aircraft is safer can only be answered relative to a selected measure of mortality rate, which in turn depends on the hypothesis under study.

The effect of standardization is that it makes two or more populations comparable except for the hypothesis under study. We never believe the two populations are identical but we try to ensure that they are similar enough, given the standardization, to allow unbiased assessment of the hypothesis under consideration.

Clearly standardization has limits. For example, the safest way to travel, per passenger mile, is by elevator. However, no type of standardization provides a reasonable basis for comparison of the safety of elevators and the safety of aircraft. The underlying processes are simply too dissimilar.

The best measure is the one that comes closest to the causal process while still being feasible. For example, in comparing the adverse health impacts of drinking water in two cities, we could measure the rate of disease associated with drinking water and then divide it by the number of residents in each city, or divide it by the number of children in the city if the disease predominantly affects children, or by the total number of glasses of water drunk by children in a year. **The choice of the best denominator for the mortality rate is a scientific choice, not a statistical choice. Statistically, no one choice is preferable to another. The choice arises from the preliminary understanding of the process of disease, injury or death, an understanding that must be developed before definitive statistical research can be done.**

Turning to the occupational setting, additional issues of standardization arise (Checkoway et al. 1989). Work-related injuries and accidental deaths are difficult frequencies to standardize. Consider Plant A in which workers cut hardwood boards with a potentially dangerous machine, a large circular saw. Suppose that there were 10 significant accidents (serious cuts or amputations) in a given year and that the 100 workers in the plant work 20,000 days in the year. The injury rate is 1 per 10 workers or 1 per 2000 days worked.

Suppose Plant B has 100 workers who also worked 20,000 days cutting hardwood boards with the same type of circular saw with an additional safety shield attached. Suppose they had 20 accidents for a rate of 2 per 10 workers or 2 per 2000 days worked. By either measure Plant B has twice the injury rate of Plant A. The safety shield does not appear to protect the workers from serious injury.

But before we conclude that the safety shield fails we might want to isolate the actual risk behavior, cutting the boards. Suppose we learn that in Plant A the average worker cuts 500 boards a day but that in Plant B the average worker, in part because of the added margin of safety from the shield, cuts 2000 boards a day. Then the rate of significant accidents per board cut in Plant A is twice the risk in Plant B.

The chosen measure of the rate of serious accidents dramatically affects the comparison the two plants. Which plant is safer? It depends on how you measure the rate of injury.

In most epidemiological studies the choice of the measurement of disease frequency has a stronger impact on the analysis then does the difference between the populations being studied. In other words, the treatment effect usually is small compared to the variability that would arise from allowing alternative measures of disease frequency.

3. Applying these Measures to Avian Mortality

Suppose we want to estimate the frequency of death for Platinum Eagles in a given Wind Resource Area. And suppose we can count the number of deaths of Platinum Eagles in the area in the year. One standardized measure of the frequency of death is the number of deaths divided by the total number of birds that live in the area. Suppose there are 100 deaths and 1000 birds. Then the mortality rate can be expressed as 100/1000 or 1 death per 10 birds or 0.1.

Suppose we decide to compare the Wind Resource area to another area, the Control Area. Suppose the Control Area has about the same size and terrain as the Wind Resource Area and supports the same number of Platinum Eagles. Suppose this area has 50 deaths and thus a mortality rate of 50/1000 or 1 death per 20 birds or 0.05. For this measure of the frequency of death, the Wind Resource has twice the mortality per Platinum Eagle. But is the comparison appropriate? It depends on the purpose of the study.

Suppose the Wind Resource Area has a better prey base for Platinum Eagles than does the Control Area, and consequently has a higher utilization intensity than the Control Area. Suppose that, on the average, an eagle entering the Wind Resource area spends eight hours per day, but that, on average, an eagle entering the Control Area spends only two hours per day. Then the Control Area has twice the rate of mortality per eagle hour as does the Wind Resource Area. The Wind Resource Area has a higher frequency of death but a lower mortality rate per bird hour of usage. In this example, an apparent contradiction is explained by the fact that the development of the Wind Resource Area changes the utilization intensity.

4. Testing the Effect of External Factors on Avian Mortality

The measure of disease frequency, once chosen, is used to describe the distribution of disease in the population. Epidemiology focuses attention on description of the distribution of disease because this distribution may give insight into the cause or transmission of the disease. For example, the fact that Tuberculosis rates are highest among HIV patients, the homeless, Hispanic Americans, detention officers, and health care workers may give insight into the cause of the recent sharp increase in the incidence rate of Tuberculosis.

The second use of the measure of disease frequency is in a designed experiment or observational study that tests the effect of a potentially adverse exposure or a preventive or therapeutic intervention on the rate of disease or injury or death. For this use a second type of measure, the **measure of effect**, is used in conjunction with the measure of disease frequency. The **measure of effect** indicates the impact of an external factor on the measure of disease frequency. These external factors are usually potentially adverse exposures, such as exposure to a contagious disease or exposure to a toxin; or an intervention (preventive or therapeutic), such as a vaccine to prevent childhood disease or a medication to reduce the impact of hepatitis C on the liver.

In the case of avian mortality the external factor could be the presence of wind turbines, which could be considered a potentially adverse exposure; or the removal of all perches from the turbines, which could be considered a preventive intervention.

The ideal situation for testing the effect of an external factor is to find or construct two populations that are comparable on all key parameters except that one population, the exposed, is influenced by the external factor of interest. The other population, the control, is known not to be influenced by the external factor. Often the experimental population serves as its own control. We compare the population before and after an intervention as if they were two different populations. This is a powerful design provided the potential confounding variables do not change over time. We compare the two populations with regard to the chosen measure of the frequency of death. If they differ significantly we conclude that the external factor contributes to the death of the species.

Suppose we consider the wind turbines as a potentially adverse exposure and want to the test the hypothesis that they contribute to the death of Platinum Eagles. Suppose we can locate a Wind Resource Area, called Area A, that supports a population of Platinum Eagles, and a similar area, Area B, that resembles Area A on several critical parameters and supports a similar population of Platinum Eagles.

As a measure of the frequency of death, the rates given above—the number of deaths per bird per year or the number of deaths per bird per hour of utilization per year—can be used. Or, by analogy to the example of two plants that cut boards, if the behavior at issue is crossing the planes of the blades, then we could measure the rate of death per crossing of these planes.

Ideally, we might record every bird flight in Area A that cuts through the plane of an operating turbine blade and every flight in Area B that cuts through an equivalent plane. We might choose to measure the frequency of death in terms of "deaths per bird passing through these critical planes". This rate is a third measure of the frequency of death and is an alternative to the two given above.

Suppose that 100 Platinum Eagles die passing through the critical plane in Area A and that 1 Platinum Eagle dies during equivalent flights in Area B. Furthermore, suppose that Area A has 10,000 critical passings but that Area B has 20,000 critical passings. The

mortality rate for Area A is 100 out of 10,000 or 1 death per 100 critical bird passings or 0.01 and the mortality rate for area B is 1 out of 2000 or 5 deaths per 10,000 or 0.0005.

Regardless of the measure of the frequency of death chosen, a measure of the size of effect must be chosen if the two populations are to be compared. The choice of the measure of effect is independent of the choice of the measure of the frequency of death.

The oldest measure of effect is the **risk difference**, which is the difference in mortality rates. Using the mortality rate defined by the number of deaths per passing through the critical planes, the risk difference is 1 out of a hundred minus 5 out of a 10,000 which is 95 out of 10,000. The risk of death while passing through the planes of the blades is increased by 95 out of 10,000. This difference could be tested for statistical significance.

If the difference is significantly greater than zero, we conclude that the presence of the turbines increases the risk of death per passing through a critical plane, and thus within the Wind Resource Area generally. The next task is to hypothesize a mechanism of death, blunt trauma perhaps, and design an experiment to test the mechanism.

A more common measure of effect is the **risk ratio** or the **relative risk**, which is the ratio of the mortality rates, 0.01 divided by 0.0005 or 20. The relative risk of death is 20 times higher if a randomly chosen bird on a randomly chosen critical passing is in the Wind Resource Area vs. the Control Area.

For diagnostic purposes, the relative risk has proved useful. It focuses on the relative increased risk, which is valuable in determining the diagnosis or cause of death for an individual patient. It allows the clinician to update his or her degree of suspicion of a certain diagnosis or cause of death.

5. Attributable Risks and Prevented Fractions

In public health we are concerned with the implications of disease, injury or death for an entire population, not just the individual at risk. Thus we use different measures of effect.

For public health purposes a measure of effect that has proved very useful is the **attributable risk**. It combines the relative risk with the likelihood that a given individual is exposed to the external factor. It is the proportional increase in the risk of disease, injury or death assignable, or attributable to the external factor.

Let $P(D)$, $P(D \mid E)$ and $P(D \mid \bar{E})$ be the probabilities of death for the entire population, the probability of death for the exposed population, and the probability of death for the unexposed population, respectively. For exposure E, the **attributable risk** is

$$AR(E) = [\, P(D) - P(D \mid \bar{E}) \,] / \; P(D)$$

For example, suppose that, for a Platinum Eagle living in the general vicinity of the Wind Resource Area, the probability of flying through the plane of the blades during the year is 1 out of 10 or 0.1. The probability that a randomly chosen Platinum Eagle dies is 0.1 x 0.01 + 0.9 x 0.0005 = 0.01045. The probability that a Platinum Eagle in the control area dies crossing the theoretical blade plane without the presence of blades is 0.0005. The attributable risk is (0.01045 - 0.0005) / 0.01045 = 0.95. About 95 percent of the risk of dying while crossing the blade plane is attributable to the presence of the turbine. This large percentage makes sense as it is rather unlikely that the bird would die while crossing the critical plane if there are no blades present.

It could be argued that it is this large attributable risk that gives conservationists, regulators and the public concern, even if the number of bird deaths is relatively small.

Note that the relative risk treats doubling the count as doubling the risk regardless of the size of the risk. The attributable risk tends to down-play small risks because they are less critical for the health of the population.

Turning to testing a preventive, or therapeutic, intervention, the same issues arise. The risk difference can be used to compare two populations, as can the risk ratio. Suppose we removed the perches from one-tenth of the turbines in a Wind Resource Area and decided to use deaths per bird as a measure of mortality. Suppose that 1000 Platinum Eagles live in the Wind Resource area and 200 of them live in the area where the perches were removed. Suppose that 100 Platinum Eagles die in a year and that 10 of them died in the area of the turbines without perches.

The mortality rate for the birds living around the turbines with perches is 90 out of 800 or about 1 out of 10 or 0.1. The mortality rate for the birds living around turbines without perches is 10 out of 200 or 0.05. The risk difference is 0.05 and the risk ratio is two. Removing the perches appears to reduce the risk of death by cutting a small risk in half.

For a second measure of effect, the attributable risk can be adapted for the case of a preventive intervention by defining the preventable fraction as the proportion of the cases that would be removed if all individuals got the preventive intervention (in our avian example, if all perches were removed).

The **preventable fraction** is defined by considering the preventive intervention as removing the adverse exposure (in the avian example, perches) and then calculating the attributable risk. For intervention I, the **preventable fraction** is

$$PLF(I) = [\ P(D) - P(D \mid I)\ ] / P(D)$$

where P(D) and P(D | I) are the probability of disease/injury/death and that probability given the intervention.

For the Platinum Eagles in the Wind Resource Area the mortality rate for the population is 100 out of 1000 or 1 out of 10 or 0.1. For those living in the area without perches the mortality rate is 10 out of 200 or 0.05. The preventable fraction is 0.05 / 0.1 = 0.5. About 50 percent of the risk would be removed if all perches were removed.

A third measure of effect is the **prevented fraction**, which is the actual reduction in mortality that has occurred from the preventive intervention as implemented. For intervention I, the **prevented fraction** is

$$PF(I) = [\, P(D \mid \bar{I}) - P(D) \,] / \; P(D \mid \bar{I})$$

where P(D) and $P(D \mid \bar{I})$ are, respectively, the probability of disease/injury/death in the population and the probability of disease in the absence of the intervention.

For the Platinum Eagles in the Wind Resource Area, the mortality rate for the population is 100 out of 1000 or 1 out of 10 or 0.1 and for those living in the area with perches it is 90 out of 800 or 0.1125. The prevented fraction is 0.0125 / 0.1125 = 0.11. About 11 percent of the risk of death has been removed by removing 10 percent of the perches.

These three measures of effect, the attributable risk, the preventable fraction and the prevented fraction, remove emphasis from the risk to individual and place emphasis on the risk to the population.

6. Estimating Mortality From Data

Ideally the contribution of the wind turbines to mortality of Platinum Eagles might be assessed by comparing the Wind Resource Area and a similar Control Area in terms of the risk of death to a Platinum Eagle flying through the plane of the blades. In practical terms several problems arise in trying to make this comparison.

We cannot match the Wind Resource Area and a Control Area as regards all potential confounders. Confounders are differences between the areas that, if not controlled, reduce the validity of comparisons of the mortality rates. In practice, we match the areas on the most critical confounders, statistically control for other major confounders by using methods such as blocking, stratification or analysis of covariance. We assign the lesser confounders to the statistical error term.

Once we match the Wind Resource Area and a Control Area, the second problem is to choose a measure of the **mortality rate**. It is practically impossible to record each time a Platinum Eagle crosses the plane of a turbine blade. There is no simple technology available for making this measurement. The cost would be prohibitive. So we have two courses. We can revert to defining the mortality rate as the number of deaths divided by the population size. Or we can try to choose a surrogate variable for the number of crossings of the planes of the blades. A surrogate variable is defined as a variable that can replace the outcome variable in a statistical study without significant loss in the validity or power of the study.

For example, polyps in the colon are often used as a surrogate for colon cancer in studies of preventive interventions such as a high fibre diet. One possible surrogate in the eagle/wind power study would be number of hours of utilization of the two areas by the Platinum Eagles. The mortality rate would be the number of deaths per hour of utilization.

Utilization is a rough indicator of the level of at-risk behavior. If we adopt a measure of utilization, we are implicitly assuming that the higher the utilization the higher the level of at-risk behavior.

Suppose the measure of mortality used is the number of deaths per unit of utilization. One anomalous result may arise. The risk to the birds as measured by mortality rate may be lowered by wind resource development while the frequency of death actually increases. For example, suppose the development of the Wind Resource Area increases the food supply or the number of premium perches for the eagles. Suppose these changes quadruple the utilization rate of the Area and double the frequency of death. The mortality rate would be halved even though the raw number of deaths is doubled. This calculation helps clarify the distinction between the frequency of death and the mortality.

Once a mortality rate is chosen, a **measure of effect** must be chosen. This measure could be the risk ratio, as used in most clinical trials, or one of the public health measures such as the attributable risk.

The use of the attributable risk implies that the importance of the risk is going to be weighted by the absolute size of the risk. The risk ratio ignores the absolute size of the risk. Whether the absolute size of the risk should be embraced or ignored should be a matter of debate among experts on avian behavior and wind resource development. Again, the choice between the measures of effect may shape the results of the entire epidemiological study.

Having chosen two or more areas to compare, a mortality rate that measures the frequency of death, and a measure of effect, we must design the experiment or data collection effort.

The most obvious **experimental design** is to compare two areas, the Wind Resource Area and a Control Area, that are virtually identical in all major confounding variables except for the presence of the wind resource development. This design is covered in any standard text on statistical methods.

A second common design is the standard single population *before-and-after design*. In this design the mortality rate is measured before and after an adverse affect is implemented. The Resource Area observed before the development of the wind resource is used as the Control Area. The effect of wind power development on the mortality of Platinum Eagles for the Wind Resource Area could be assessed by measuring the mortality rate before developing the area and then measured after development. The measure of effect would be used to calculate the effect of the presence of the turbines on mortality. In order to be valid study several key assumptions must be made. Most importantly, the before-and-after comparison

assumes that the study area is the same, aside from the presence of the wind development, during the before and after periods. This design can be confounded (biased) by failure to control for changes in external factors such as weather, prey bases, availability of water, or natural fluctuations in the underlying population. The study may be invalid if one year has a drought and the next has record rainfall.

Two additional designs, which are rather unique to epidemiology, are worth mentioning. In the *case-controlled design*, cases of death are sampled and then the population membership for each case is determined. Case-controlled designs are excellent for studies of mortality when the risk of death is small.

For a case-controlled study, dead Platinum Eagles might be sampled at random from two areas, the Wind Resource Area (Area A) and the Control Area (Area B). In addition, the number of Platinum Eagles living in each area would be estimated. The natural measure of disease/injury/death frequency for the case-controlled study is the odds of death (the probability of dying divided by the probability of surviving) and the natural measure of effect is the odds ratio (the odds for Area A divided by the odds for Area B). With human populations, case-controlled studies are the most practical way of testing hypotheses about the mechanism of death when death is rare. This may be a good design for assessing avian mortality.

Finally, *proportional mortality* studies might be helpful. Suppose that the sampling mechanism used to sample deaths from the Wind Resource Area and Control Area are almost identical but that both are quite incomplete. Suppose that necropsies could be used to determine the cause of death for each bird, with the pathologist being unaware of the area in which each bird died ("blind"). Better yet, the pathologist could be unaware of the entire nature of the study. We could examine the necropsies and classify each bird by cause of death, creating a distribution of death by cause. If the Wind Resource Area causes a large number of deaths by turbine strikes, then the Wind Resource Area should have a larger proportion of deaths from blunt trauma. Testing the equality of the death-by-cause distributions in the two areas would give statistical insight into the hypothesis that the turbines, via blunt trauma, are responsible for a significant proportion of the deaths.

7. Comments and Discussion

In designing a study of the impact of a potentially adverse exposure or a preventive intervention on the risk of disease, injury or death, the first task is to isolate the hypothesis of mechanism that is being tested. The second task is to choose a measure of disease frequency that best isolates the hypothesis being tested. The two components of this choice are to choose a disease count to use as a numerator and a base count to use as a denominator. The third task is to choose a measure of effect that uses the measure of disease frequency and isolates the hypothesis of interest. The fourth task is to design a study that compares two or more groups using the measure of effect applied to the measure of disease frequency chosen.

The logic is sequential and nested. Each choice depends on the choice made before.

In the case of avian mortality the first task is to isolate the process and hypothesis of interest. No single study can isolate both the impact of the development of the Wind Resource on the Platinum Eagle population and the physical risk of a turbine to an individual eagle traversing the plane of a turbine. The second task is to decide whether the hypothesis is most easily examined by the mortality rate as defined as death per bird, death per bird year, death per hour in the wind resource area, death per mile of flight, death per crossing of the planes of the turbines, or death per other suitable denominator. The third task is decide whether the relative risk, the attributable risk or another measure of effect should be used in comparing populations of Platinum Eagles living in different areas. The fourth task is to design a study that isolates the effect, controls for potential confounding factors, and allows a test of the critical hypothesis.

For example our hypothesis might be that wind resource development increases the utilization of the Area and therefore increases the frequency of death but does so in such a way that the death per unit of utilization is not increased. We might design a before and after study to test whether the development increases the utilization rate and use a case-control study or proportional mortality study to estimate the risk of death from various causes including blunt trauma from the turbines.

If we see that the rate of utilization is increased by development and that the risk of death is also increased then we might ask if we can design and test preventive interventions that would reduce the death count without significantly reducing the utilization rate.

A final comment: If the underlying hypothesis is that there is an epidemic of death occurring in the Wind Resource area then the problem is epidemiological regardless of the fact that the deaths are non-human. Epidemiology is often applied to the study of disease among animals, but usually in an effort to learn about the disease among people. The study of AIDS related viruses in primates is a good example. The use of epidemiology to study the mortality of animal species is very exciting. Applying the principles of epidemiology may lead to a more clearly defined data collection effort where the relationships among the data, the hypothesis, the measure of disease frequency, the measure of effect, the disease process, and alternative policies are isolated before any analysis is attempted.

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Discussion

There were several questions and comments about the most appropriate basis for standardization. One attendee suggested that "birds/turbine·year" is questionable because large and small turbines may not be comparable. It was noted that the best measure will depend on ▸ identifying the behavior that places the birds at risk, and ▸ the hypothesis being tested. Several attendees suggested that researchers report results using a variety of potentially relevant measures, not just one of them. This could facilitate across-study comparisons and use of the data to address additional questions.

There was some discussion of the possibility of using "per kilowatt-hour", or some related measure, as a basis of standardization. One reason for doing so is that it would allow comparisons of risk across widely varying technologies for power generation.

Population Models: Their Use and Misuse

by

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In this paper, I will briefly cover some of the potential uses and abuses of population models. I will begin by defining models as they will be discussed here, with a discussion of their connection to reality. This is followed by a discussion of the types of population models used in ecology and a general approach to modeling. Finally, I will address how population models can be used and abused, focusing on assumptions, bias, precision, model selection, validation, and sensitivity.

1. What Is A Model?

"Model" is defined in Webster's dictionary as "a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs" (Woolf 1975). Population models are, at best, approximations or abstractions of reality, and, thus by definition, all models are *wrong*. In science we continually strive to understand the truth about our surroundings. Yet, despite this effort, truth is unobtainable. The philosophy of science, and the experimental methods that scientists use are well studied (*cf.* Goldstein and Goldstein 1978; Manly 1992). One notion of this philosophy is that theory and practice play an important part in the learning that can be achieved (Box 1976). There is a feedback loop between facts (which come from reality or truth) gathered from nature and deductions made from testing hypotheses based on theories about these facts. But there is always some lack of fit of these facts to new theories and this leads to the induction of new hypotheses and testing, and the iteration continues. Theories are often represented as models, and, as such, models are often represented by mathematical formulations. The lack of fit of a model to "reality" is important in furthering our learning about the systems in question. The extent to which a model assists us in understanding "reality" is one measure of a model's worth.

2. Use of Models

All population models are used to make predictions. Caswell (1976) categorizes models into two classes based on their purposes:

(a) "models that are constructed primarily to provide accurate prediction of the behavior of a system, and

(b) models that, as scientific theories, are attempts to gain insight into how the system operates."

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An example of (a) might be the prediction of the population size of steelhead, *Salmo gairdneri*, within the Columbia river basin in the Pacific Northwest. A simple population model such as the logistic growth model (see below) could prove useful in meeting this objective. This type of information might be used by a state natural resource agency to establish fishing regulations. The information gained might be useful, but it would provide little understanding of the processes that determine the population at the next time step.

A more theoretical approach, (b) in Caswell's delineation, would include a model that attempts to explain why the population grows the way it does. For example, we may hypothesize that the population at some time in the future depends not only on the population dynamics, but also on genetic variability, environmental conditions, and interspecific interactions. The testing of hypotheses involving these factors might ultimately lead to a clearer understanding of the "why" behind population growth, persistence, or extinction. For example, the steelhead population model might be modified to incorporate genetic variability and interspecific competition. And further, we may wish to couple the model directly to a global climate change model in order to investigate potential effects on steelhead populations if global warming occurs.

Levins (1968) has argued that it is impossible to simultaneously maximize generality, realism, and precision in a model. Hence, it is critical to understand that very general theoretical models will probably be useless for specific predictions (e.g., the population size of steelhead next year). It would be nice if the reverse were true, i.e., that coupling simple models together accurately predicts general properties, but this too is rarely the case. Often, our learning from very complex models comes from investigating why the model fails to represent "reality", rather than from the model's ability to "track" a certain set of data.

In addition, many population models are more statistical in nature, with the objective to estimate some parameter of the population such as population size or survival rate based on a specific sampling method (*cf.* Seber 1982; Thompson 1992). The specific population parameters may then be used in more complex models, or the estimates may be compared, spatially or temporally, to those from other populations. For example, the effect of hydroelectric dams and spillways on the Columbia River on the survival of fish has been extensively studied by estimating survival rates from tagging studies involving capture and recapture of marked fish at downstream dams (Burnham et al. 1987).

Population models can be deterministic or stochastic. An example of a simple deterministic model is the classic logistic growth equation:

$$N_t = \frac{K}{1 + e^{a - rt}}$$

where N_t is the population at time t, r is the intrinsic rate of population growth (birth rate - death rate), K is the carrying capacity or maximum number of individuals the environment will support, and a is the constant of integration defining the position of the curve relative

to the origin. Despite its simple nature, this model is useful for predicting the future population size of laboratory animals, insect populations, and humans.

Once the initial parameters are entered into this deterministic equation, the outcome is always the same. This is an unrealistic result, because the exact size of the population at time t is uncertain. We know that birth and death rates vary from season to season and year to year depending on a variety of factors such as food, weather, the ability to find mates, etc.

By assuming that r arises from a stochastic process, we can create a stochastic model in which the population is not completely predictable at the next time step. For example, we might assume that the parameter r follows a normal distribution with a certain mean and variance, and let the population at the next time step vary accordingly. The model has now become more complex and arguably more realistic, but it still is not "truth". A further modification to the above model might include the addition of stochasticity to K, the carrying capacity, because the carrying capacity also may vary seasonally. The result is a more general and complex model. An important question then becomes, "Which model is appropriate?" The answer depends on the objectives behind creation of the model.

3. General Approach

Let us focus for a moment on a general approach to modeling some aspect of a population. One approach is to first choose a sufficiently general model such that any of the processes that might be considered can be included (Burnham et al. 1987:54). If our objective was to estimate the annual size of the steelhead population, we might argue that a general model should include birth, death, immigration, and emigration rates. In addition, we might argue that the rates should be allowed to vary by time and location. The specific model selected will be a special case of this general model—one that "best" fits the data associated with the specific experiment. In essence, we have just specified some of the assumptions that are necessary for our general model. More specific (simpler) models can be represented by tightening the assumptions of the general model. For example, a simpler model might assume that the rates do not vary by time and location. Recognition of these assumptions is critical to any modeling process.

A major abuse in modeling is the failure to state and understand the assumptions inherent in the model. Further, once the data are collected, there should be some attempt to evaluate these assumptions before the model is used. Failure to understand and consider model robustness (ability of models to perform when one or more model assumptions have failed) can lead to poor inference and unreliable results.

4. Model Selection

How is the "appropriate" model selected? The topic of model selection has been well covered (*cf.* Linhart and Zucchini 1986; Burnham and Anderson 1992). There are two undesirable extremes when selecting the correct model, namely choosing too simple a model

(i.e., a model with too few parameters) and choosing too general a model (i.e., one with too many parameters). This tradeoff between under fitting and over fitting the model is known as the Principle of Parsimony (McCullagh and Nelder 1989), and can be viewed as a tradeoff between model bias and sampling variance. For example, as the number of parameters increases, bias decreases but sampling variance increases. The goal, then, is to find the optimal model that has biological meaning for the data at hand.

Before computers, the exercise of model selection was often independent of the data, and model selection was left up to the researcher (Burnham and Anderson 1992). More traditional thought put model selection in an hypothesis testing framework, where we might ask whether there is a significant difference in fit when the steelhead population model excludes versus includes time variation in the rates. Types of tests used include likelihood ratio tests (Mood et al. 1974:409). This method has limitations in that one model must be nested within another. For example, likelihood ratio tests can be used with multiple regression to choose a model with two parameters versus one parameter.

An alternative approach is to view model selection as an optimization problem over the set of candidate models from the general to the specific. The Akaike Information Criterion (AIC) can be used. This approach incorporates the idea of parsimony and uses information about model bias, along with a penalty for the number of parameters, to choose the appropriate model (Burnham and Anderson 1992; Anderson and Burnham 1994).

5. Model Validation

Regardless of the type of model constructed or how the model is used, some time should be spent on model validation. Oreskes et al. (1994) have argued that both model validation and model verification are impossible in natural systems. They argue that, at best, a model can be confirmed by demonstrating agreement between observations and predictions. Verification, which has often been used synonymously with validation, is the assertion of truth. Because we can never ascertain when reality has been obtained, they argue that this term is inappropriate. Validation, they argue, "denotes the establishment of legitimacy". Again, because we cannot ascertain reality, models can be internally valid, but they may not represent truth. There is never any certainty about reality; therefore, at best, we can confirm or reject model predictions. Still, the term "validation" is commonly used when discussing models.

Validation is quite different for a predictive model than for a theoretical model (Caswell 1976). In a predictive model, "truth" is not the main question; rather, validation involves determining when and where the model is a good predictor (Caswell 1976). In a theoretical model, the focus is on inference about truth (although that is unknowable), and validation should center on attempts to invalidate the theory (Caswell 1976).

6. Sensitivity Analysis

A complex model with many parameters will require a large number of data in order to estimate the numerous parameters with some degree of precision. Sensitivity analysis of a model can be thought of as "the intensity of response to error or change" for a given parameter (Innis 1979). A sensitivity analysis involves a systematic search for the model parameters to which the model is most sensitive. Sensitivity analysis may focus on changes to the parameters or the initial conditions. For example, a sensitivity analysis of our steelhead population model would allow us to determine which parameter(s)—birth, death, immigration, or emigration—are most sensitive to change over a specified range, and this result could be used to help design our field sampling effort. Because the cost of experiments is an important consideration, an initial sensitivity analysis can be useful in maximizing the benefit to cost ratio before gathering data for parameter estimation.

7. Conclusions

There is no one unique model for a specific situation. Even if two researchers start with the same data and population parameters as outlined in the steelhead model, their resulting models can take quite different forms. For example, one individual might incorporate the rates into the model assuming linear relationships, while the other might assume nonlinear relationships. In fact, alternative models can be useful for validating and corroborating a model (Caswell 1976). If the same general outcomes are achieved from different models using the same data, then there will be greater confidence about the results. Ultimately, this still does not demonstrate that both models are "realistic" and, no matter what type of model is used, we must remember that development of population models is an iterative process with the goal of understanding our surroundings.

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Discussion

Use of Models.—One participant pointed out another tradeoff between simple and complex models: With a simple model, many people can understand it but it is likely to be unrealistic. A more complex model may be more realistic, but few people can understand or use it. It may be desirable to use both approaches.

Another commenter mentioned a category of models known as "resource selection models". These are designed to predict the probability of use of resources such as habitat or food types based on empirical data. Dr. Wilson noted that this type of model is described in the book *Resource selection by animals* (Manly et al. 1993).

General Approach.—One participant noted that models should be hypothesis-driven; they should shed light on a specific scientific hypothesis. He suggested that it is critical to obtain the empirical data needed to characterize key model parameters, and that it is not useful to develop models if the key data must be simulated.

However, another participant indicated that there are unknown or little-known components in any complex model. He explained that Monte Carlo approaches applied to inadequately-known model components can be useful, e.g. in assessing sensitivity and planning research. Also, he suggested that, when there are many unknowns, a Bayesian approach sometimes can achieve useful predictions despite the uncertainties about individual parameters. Analogies to the Central Limit Theorem were mentioned.

Model Selection.—One attendee noted that the AIC (Akaike) approach requires fitting a general model and then working backward, eliminating parameters that seem unnecessary. In the regression context, the corresponding "backward elimination" method is rarely used nowadays. The commenter suggested that it is better to start with a simple model, evaluating which additional terms are useful, as contrasted with the AIC approach requiring a complex model as a starting point.

In expressing concern about complex models, one participant suggested that, with a complex model, ▸ some parameters and some of the algorithms linking parameters are sure to be unknown, ▸ there will be many interactions among parameters, and ▸ validation will be very difficult. Another participant noted that this was another reason for developing both simple and complex models for the same issue; if they do not give similar results, there is reason to be sceptical of both.

Model Validation.—There was discussion of the fact that a model cannot be "validated" based on the same data as were used in developing the model. One approach is to split the dataset, build the model using one portion of the data, and evaluate the model with the other portion. Another approach is to develop the model based on existing data, use the model to make predictions, collect new data, and then evaluate the model based on those data. This approach may take considerable time, but has the advantage that data collection can be designed to collect the specific data needed to test the model.

An attendee asked whether there is a danger in trying to apply static models to animals that learn and habituate. Dr. Wilson replied that model development is iterative; models should be modified and adapted to take account of processes like learning and habituation.

A Model to Estimate the Annual Rate of Golden Eagle Population Change at the Altamont Pass Wind Resource Area

by

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1. Introduction

Golden Eagle (*Aquila chrysaetos*) deaths caused by wind turbines in the Altamont Pass Wind Resource Area (APWRA), Mt. Diablo Range, California, have been well documented (Hunt 1994). The impact of these wind turbine fatalities on the APWRA Golden Eagle population has not, however, been determined. Determining a population effect and establishing a direct causal relationship to the APWRA would require estimates of demographic parameters in the APWRA and an appropriate control area both before and after construction of the wind turbines (see Eberhardt and Thomas 1991). Unfortunately, no pre-construction data were collected and no control area was established. However, the concern over a potentially detrimental population impact from the APWRA is still relevant.

In general, impacts on populations can be either positive or negative. Annual rates of population change (λ) can be measured to assess such impacts. An annual rate of population change that is positive, i.e. population size increasing, suggests a positive impact. A rate of change that is negative, i.e. population size decreasing, suggests a negative impact. Therefore, if we could estimate the annual rate of population change for the Golden Eagle population in the area surrounding the APWRA, some inference could be made to the effect of the APWRA on the Golden Eagle population. If the population size is stationary or increasing, we would infer that the defined Golden Eagle population is viable despite the presence of the APWRA. If the annual rate of population change is negative, we would be unable to ascribe cause and effect; the population might be declining either because of APWRA or for other reasons. However, if the annual rate of population change were found to be decreasing, there would be reason to initiate a series of more penetrating studies.

To estimate the annual rate of population change, we developed a 3-staged population model for the defined Golden Eagle population around the APWRA. The objective of the model is

> to estimate the annual rate of population change (λ) and its standard error (se(λ)) to test whether the population is stationary, increasing, or decreasing.

The annual rate of population change (λ) is a useful metric in that it measures the direction as well as the magnitude of population change: $\lambda = 1$ indicates a stationary population; $\lambda < 1$ a declining population, and $\lambda > 1$ an increasing population. The magnitude of change is

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λ - 1. Therefore, we can frame our initial question in terms of null (H_0) and alternate (H_A) hypotheses to be tested:

H_0: $\lambda \geq 1$ (the population is stationary or increasing)

H_A: $\lambda < 1$ (the population is declining).

A key consideration is that model results apply only to conditions during the period of data collection, and not necessarily to the future behavior of the population. Therefore, the model does not attempt to predict the future but is used only to estimate the finite rate of population change (λ) within the period of study—a snapshot of the status of the population within a given time. Although this model was not the only way chosen to assess the effects of the APWRA, it does provide a key component in addressing those effects.

2. Model Structure

We chose a single-sex, stage-based model in the interest of parsimony (Burnham and Anderson 1992). This model represents a tradeoff between funding constraints and number of parameters that can be estimated precisely (i.e., with coefficients of variation <10%). As additional parameters are added to the model, $\hat{se}(\hat{\lambda})$ will increase because sampling variances in the model are essentially additive. This can be rectified by increasing the precision of each parameter, but to do so requires a larger sample size and, hence, increased project costs. In order to maintain high power for H_0: $\lambda \geq 1$ (i.e., a high probability of rejecting H_0 if it is false), we chose to estimate a smaller number of parameters with sufficient samples for adequate precision. By restricting the model to a single sex, the number of parameters to be estimated can be reduced by about 50%. Given this rationale for a single-sex model, a female-based model was selected because female fertility can be assessed more directly.

The model follows the life history characteristics of Golden Eagles in the APWRA as described by Hunt (1994). A fledged young has a certain probability of surviving to become a non-territorial "floater" the following year. The bird remains in this stage for an indeterminate period of time. Each year, it has a certain probability of surviving as a floater or of entering the territorial population if a vacancy occurs. If it becomes a territorial bird, it continues to survive each year with some probability and produces more fledged young at some rate, thus starting the cycle over again. This life cycle can be described in terms of a mathematical model, which in turn can be used to estimate annual rates of population change (McDonald and Caswell 1993).

To describe the life cycle of Golden Eagles at APWRA, we used a standard stage-based model with three stages and five annual loop transmissions (Fig. 1a; Caswell 1989). The three stages are defined as discrete classifications of individuals. The directional lines (Fig. 1a) connecting the stages represent transmission loops between the stages in the form of survival (P_i), reproduction (F_i), or transition probabilities (G_i). The model is based on a post-breeding survey and has a time step of 1 year (Noon and Sauer 1992). As stated previously, the model only incorporates a single sex. To modify the standard model to represent the Golden Eagle population in the Altamont Pass area, we first define the stages to represent

three discrete behavioral categories. Stage 1 contains female fledglings alive at time t. Stage 2 contains non-territorial females, which include both subadults (<4 years of age) and floaters (non-territorial adults) at time t. Stage 3 contains territorial females at time t. Fewer transmission loops are necessary to describe the defined population because two of the transition probabilities are assigned values of zero: (1) $P_1 = 0$ because fledglings cannot remain in this stage for longer than 1 year, and (2) $F_2 = 0$ because we assume non-territorial females do not breed. Therefore, a reduced model of three transmission loops adequately describes the Golden Eagle population model (Fig. 1b). For clarification of the reduced model, we substitute the theoretical nomenclature with the behavioral stages and parameter estimates to be used for each of the transition probabilities (Fig. 1c, Table 1). Transition from stage 1 to stage 2 (G_1) will be estimated as survival of female fledglings from year t to t+1 (s_F). P_2 will be estimated as non-territorial female survival (s_{NT}). G_2 will be estimated as the probability (α) of a non-territorial female becoming a territorial female. P_3 represents annual territorial female survival (s_T). Annual reproduction, F_3, is represented as the number of females fledged per surviving territorial female ($s_T b_T$).

TABLE 1. Parameter notation and description for a 3-staged population model developed for the defined Golden Eagle population around the Altamont Pass Wind Resource Area.

Parameter			
Caswell notation	Eagle Model notation	Estimate (Eagle model)	Definition
P_1			Theoretically the probability of a female fledgling in year t remaining a fledgling in year t+1 stage (impossible, therefore eliminated).
P_2	S_{NT}	$\hat{s}_{NT}$	Probability of a non-territorial female in year t surviving to year t+1.
P_3	S_T	$\hat{s}_T$	Probability of a territorial female in year t surviving to year t+1.
G_1	S_F	$\hat{s}_F$	Probability of a female fledgling in year t surviving to become a non-territorial female in year t+1.
G_2	α	$\hat{\alpha}$	Probability of a non-territorial female in year t surviving and transitioning to a territorial female in year t+1.
F_2			Theoretically, the mean number of female young fledged per non-territorial female. However, we assume this always = 0
F_3	$S_T b_T$	$\hat{s}_T \hat{b}_T$	Mean number of female young fledged per surviving territorial female.
λ	λ	$\hat{\lambda}$	Annual rate of population change.

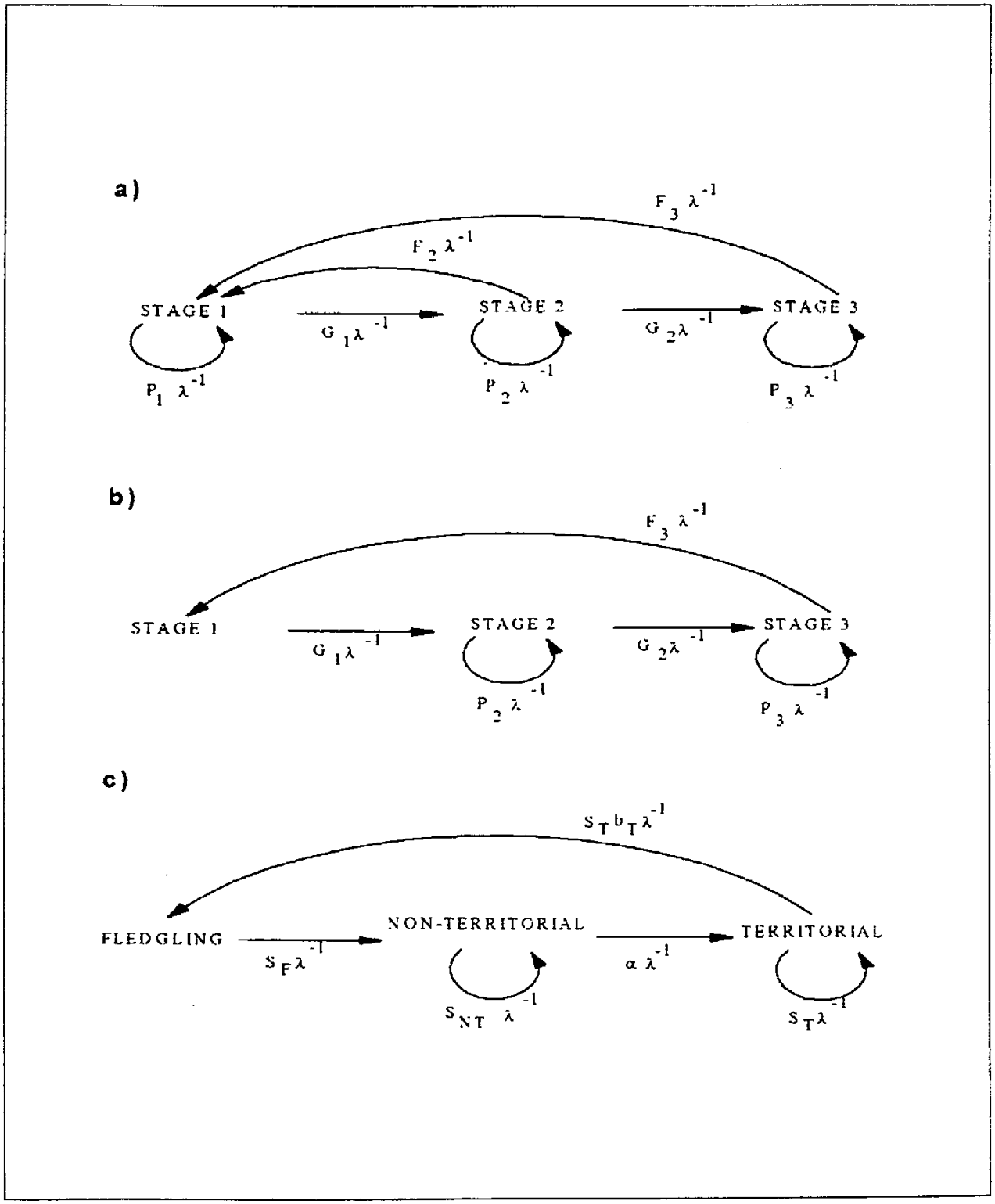

FIGURE 1. A graphical representation of (a) a general, theoretical, 3-staged population model, (b) the reduced Golden Eagle theoretical model, and (c) the parameter-based model for the defined Golden Eagle population around the Altamont Pass Wind Resource Area.

Matrix representations of the general theoretical model, the reduced Golden Eagle theoretical model, and the parameter-based Golden Eagle model are as follows:

$$\begin{bmatrix} P_1 & F_2 & F_3 \\ G_1 & P_2 & 0 \\ 0 & G_2 & P_3 \end{bmatrix} \Rightarrow \begin{bmatrix} 0 & 0 & F_3 \\ G_1 & P_2 & 0 \\ 0 & G_2 & P_3 \end{bmatrix} \Rightarrow \begin{bmatrix} 0 & 0 & \hat{s}_T\hat{b}_T \\ \hat{s}_F & \hat{s}_{NT} & 0 \\ 0 & \hat{\alpha} & \hat{s}_T \end{bmatrix} \tag{1}$$

respectively, where all parameters are defined in Table 1.

Substituting the Golden Eagle model parameters, the three loop transmissions, modified from Caswell (1989:102), are as follows:

$$\begin{aligned} L^{(1)} &= s_{NT}\ \lambda^{-1} \\ L^{(2)} &= s_T\ \lambda^{-1} \\ L^{(3)} &= s_F\ \alpha\ s_T\ b_T\ \lambda^{-3} \end{aligned} \tag{2}$$

where all parameters are defined in Table 1. The characteristic equation of the model is

$$1 = s_{NT}\ \lambda^{-1} + s_T\ \lambda^{-1} + s_F\ \alpha\ s_T\ b_T\ \lambda^{-3} - s_{NT}\ s_T\ \lambda^{-2} \tag{3}$$

which simplifies to

$$1 = \frac{s_F\ \alpha\ s_T\ b_T}{\lambda(\lambda - s_{NT})(\lambda - s_T)} \tag{4}$$

Estimates for s_F, s_{NT}, s_T, α, and b_T obtained from data collected in the field will be substituted into Eq. (4), the characteristic equation, to solve for λ. The standard error of λ will be estimated using the delta method, which incorporates the sampling variances for each of the parameter estimates (Oehlert 1992; Alverez-Buylla and Slatkin 1994). The estimate of λ and its standard error can then be used to test the null hypothesis

$$H_0 : \lambda \geq 1 \tag{5}$$

using a *Z*-test where Z ~ N(0,1).

3. Model Assumptions

All models rely on certain assumptions. The more general the model, the longer the list of assumptions that must be met for model inferences to be unbiased. Two sets of assumptions are associated with our model. First, three assumptions underlie our use of the basic matrix model (McDonald and Caswell 1993):

1. Individuals are classified into discrete, homogenous stages per period. The majority of individuals within the population must be classifiable as either fledglings, non-

territorial individuals, or territorial individuals, and no other class is important in describing population dynamics. Our model relies heavily on descriptions of the population from Hunt (1994), and we assume that our life history stages adequately describe the APWRA Golden Eagle population.

2. The vital rates (survival and fertility transitions from any given stage) are time-invariant processes. For our purposes, this is a reasonable assumption because we are only estimating the population rate of change over a 2-year period.

3. The vital rates are density-independent. Again, we believe this is a reasonable assumption because of the short time period over which we are estimating λ.

Second, there are additional assumptions that are specific to modeling the Golden Eagle population at APWRA. These include

1. Subadult and non-territorial females have the same survival rate. Subadult Golden Eagles are non-territorial and generally do not become territorial until they reach breeding maturity. However, adults can be non-territorial as well even though they are physically capable of breeding (Hunt 1994). These two classes of individuals were pooled into a single non-territorial class because of sample size considerations in estimating survival parameters. We felt that, in this case, age has less effect on survival than does population status (i.e. territorial versus nonterritorial).

2. Results apply to a limited (2 year) time frame. In this sense, the estimate of population change (λ) represents a parameter for this time period.

3. There is no effect of capture, handling or radios on female reproduction, survival, or transition from a non-territorial to a territorial state. This assumption applies primarily to the parameters being used in the model rather than the structure of the model itself. If the parameters used in the model are biased or imprecise, then the results from the model will also be biased and imprecise.

4. Estimates of Model Parameters

Estimation of parameters for inclusion in the model is key to the results of the model. The model and the parameters used in the model are interlinked in terms of bias and precision. The model to estimate the finite rate of population change was chosen based on which parameters could be estimated accurately and precisely in the field, where precision of the estimates depends on having sufficient sample sizes. For the purposes of our model, we are interested in both (a) a point estimate of each parameter and (b) its standard error as a measure of the precision of that point estimate.

Proposed methods for estimating survival within stages and transitions between stages rely heavily on radio-telemetry of individuals. The use of radiotelemetry allows estimation of these parameters using appropriate statistical models (Pollock et al. 1989; Bunck and

Pollock 1993). Estimation of fledgling rate is more problematic in that it requires determining whether territorial pairs nest and whether those nests are successful. To identify whether territorial pairs nest, individuals must be correctly determined to (a) hold a territory and (b) either have a nest or not (G. Hunt, pers. comm.). Once numbers of fledglings can be ascribed to each sampled pair of birds (including zeroes for nonbreeding territorial pairs), fledging rates can be estimated as arithmetic means with their standard errors.

5. Conclusions

The estimate of λ based on our model measures only changes in the defined Golden Eagle population related to birth and death rates. Immigration or emigration rates are not included in the model. Therefore, inferences from this model will only reflect whether the population within the defined limits around the Altamont Pass area can be sustained solely on birth and death processes. This model represents the first step in an iterative approach to estimating the effects of the APWRA on Golden Eagle populations. Additional steps may include more experimental approaches if the model indicates that the Golden Eagle population surrounding the APWRA is not self-sustaining, based on birth and death rates.

We recognize that use of this model is not an ideal approach. However, we believe that it is a good initial approach, given the constraints of time and funding and the fact that the Altamont wind development has been in place for a considerable length of time. However, we would not recommend this approach for proposed projects of a similar nature that have not yet been built. For these types of projects, a more classical experimental approach (see Eberhardt and Thomas 1991) would allow for causal inferences concerning effects of the project on the populations being considered.

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Discussion

Introduction.—Ms. Shenk indicated at the outset that model development is an iterative process. The modeling group believes that the present model is defensible in its present form but can be improved; they solicited suggestions for improvement.

Model Structure.—A participant asked how the "Altamont population" of Golden Eagles is defined. Ms. Shenk indicated that it is defined geographically; there are some "natural" boundaries, including urbanized areas and habitat boundaries that make this defensible. Although the intention is to consider only the resident eagles in the model, when an eagle is captured and radio-tagged it is not known whether it is a resident.

The modeling group initially considered distinguishing eight categories of eagles: four groups of females (fledglings, subadults, adult floaters, and adult territory holders) and the corresponding four groups of males. However, it was determined that it would not be possible to obtain adequate sample sizes for all of these groups, and in the end the model considers three groups ("stages"):

- The subadults and adult floaters were combined, but there is concern that their population parameters may not be the same.
- In developing the model, there also was much discussion about which sex to model if only a one sex could be considered. Females were chosen because their reproductive contribution is easier to measure.

One participant expressed concern about the decision to model only the female component of the population, given that

- both sexes must be present if the young are to be raised successfully, and
- males may be limiting (male raptors are smaller than females, and have higher mortality rates).

A participant asked whether it is important to focus on the "limiting" sex, or whether that issue is of mainly academic interest. Ms. Shenk responded that, if there is a limiting sex, that sex should be modeled. However, in practice, radio-tags have been placed on both male and female eagles in the Altamont area, given the high cost to catch eagles relative to the tag cost. Hence, data will be obtained for both sexes, and the issue of "which sex(es) to model" may be moot.

It was also indicated that, given overall funding limitations, there is a tradeoff between the funds that can be devoted to the Altamont Golden Eagle population study and other avian - wind power studies.

Concern was expressed that the population study and modeling effort might not be able to obtain a reasonably precise estimate of the annual rate of population change (λ). Ms. Shenk responded that a preliminary power analysis suggested that, to estimate λ with a 10% coefficient of variation, about 80 fledglings, 25 non-territorial birds, and 25 territory holders would need to be studied. Actual survival rate may be higher than was initially assumed, in which case the required sample sizes would be smaller. Dr. Hunt's view is that λ can be estimated with reasonable precision if the radio-tagged eagles of both sexes can be pooled, but otherwise not. Some attendees noted that pooling of sexes is not justified unless statistical analyses based on adequate sample sizes show no significant difference between sexes.

Model Assumptions.—An attendee expressed concern that the model assumes constant λ across all categories of eagles. He noted that, in the quite likely event that λ is not constant across categories of eagles, the power of the study and model to reject H_0 if it is false would be reduced (i.e., the required sample size would be much larger than has been estimated). He recommended that "stage-invariant λ" should be listed explicitly among the main model assumptions.

Another attendee felt that, notwithstanding those concerns, the field study should provide a good indication whether or not the Altamont Golden Eagle population is "healthy". In addition to an estimate of λ, the study will provide estimates of juvenile survivorship, abundance of "floaters", reproduction data, and data on the occurrence and circumstances of deaths. This information should provide a good indication of population status. If the population does not appear to be doing well, follow-up studies would be needed to evaluate the problem. Also, all of these data will be available for future refinements of the model. Ms. Shenk noted that the present study will itself provide information about the number of deaths of radio-tagged eagles that can be attributed to the Altamont wind facilities, and thus the effect of these deaths on λ.

A participant noted that, even if the field study and model indicate that the Altamont Golden Eagle population is doing well, the occurrence of any eagle deaths attributable to the wind facilities has legal ramifications. He also noted that the Altamont eagle population study was developed in part to be responsive to the concerns of regulatory and environmental groups, with the objective of evaluating the key questions that they had identified.

A question was raised about the complications created by immigration and emigration. Ms. Shenk noted that the present study and modeling effort cannot address that issue explicitly, but the study will provide information useful for designing a possible future study of dispersal. She mentioned that the determination of juvenile survival is strongly confounded by uncertainty about emigration rate.

Estimates of Model Parameters.—A participant suggested that, in attempting to address this and other uncertainties, data from other Golden Eagle populations should be taken into account. Ms. Shenk explained that some members of the modeling group strongly believe that the model should be driven by data from the Altamont area, and are not keen to use data from elsewhere. The questioner noted that data from elsewhere can be relevant in defining the biology of the species, and comparison of parameter values from other locations with those from the Altamont could provide a "reality check" for the present results.

Conclusions.—Another participant asked what would constitute a reasonable balance between study duration and confidence in results. Ms. Shenk indicated that a 2-year study is very short in relation to the lifespan of eagles and in relation to the range of variability in environmental conditions. Dr. Pollock mentioned that any attempt to study the effects of wind development on an eagle population using traditional or BACI approaches would require a much longer study. He said that, if a very long term study were possible, he would want to consider using a BACI approach in addition to modeling.

During the concluding discussion, one participant expressed the view that the resources being devoted to the Altamont eagle study were insufficient to provide definitive answers, but he agreed that—whatever the merits and problems of the present model—the field study would provide useful information on population status and guidance for follow-on work. Another participant mentioned that, in deciding how to allocate limited resources, a single study and issue such as the Altamont eagles should not be considered in isolation from other potentially valuable work, including risk-reduction and monitoring studies.

OBSERVATION PROTOCOLS

This section of the meeting consisted of four presentations dealing with suggested approaches for conducting field studies to predict or measure various effects of wind developments on birds, along with discussion of those presentations. Some approaches were discussed or recommended in more than one presentation. The recommended approaches were recognized as overlapping and not mutually exclusive. It was acknowledged that we are at an early stage in developing standard protocols for bird - wind turbine studies, and that all four of the suggested protocols contain useful elements.

(1) Brian A. Cooper described the use of small radars to study bird movements near potential or actual wind resource areas. He summarized the basic features of radars, the types of radars useful in bird studies, the use of small, mobile radars for avian - wind power studies, the limitations of radars, and the need for complementary visual observations (day and night). Also, he commented on standardization of radar methods and methodological improvements that would be desirable.

(2) Richard L. Anderson described a field survey approach developed and implemented by the California Energy Commission to document bird utilization and bird mortality simultaneously in and near California wind resource areas (p. 74). This avian risk assessment methodology is designed to determine the risk attributable to the WRA, based on Phase I surveys of bird populations and bird mortality at various distances from wind turbines and on focused follow-up Phase II and III studies as necessary. The methodology is designed and recommended for application in any area.

(3) Dr. Sidney A. Gauthreaux, Jr., summarized the guidelines that he has developed for monitoring pre- and post-construction populations, movements and mortality of birds in wind resource areas (p. 88). These guidelines take account of experience during studies of avian - power line interactions. They emphasize monitoring of bird movements through the zone of risk around actual wind turbines or proposed turbine locations, based on visual, night-vision device, and radar methods. These guidelines also include recommended procedures for dead bird searches.

(4) Dr. Michael L. Morrison and Holly Davis described suggested protocols for evaluating impacts of existing wind developments, including determination of bird mortality (p. 111). They discussed the development of two protocols: (a) the avian risk assessment protocol now being applied by the California Energy Commission [see *(2)*, above], and (b) a protocol to determine whether differences in turbine design or layout affect bird utilization and bird mortality.

A White Paper on each topic was prepared for distribution to meeting attendees. The following four sections consist of updated versions of these White Papers, in each case followed by a summary of the discussion that followed the oral presentation.

Use of Radar for Wind Power-Related Avian Research

by

Brian A. Cooper, ABR Inc.[8]

Radar has been an important tool in ornithological research for nearly five decades (Eastwood 1967). Radar was first used in wind power-related avian research during the mid-to-late 1970s in Ohio and California (Rogers et al. 1977; McCrary et al. 1984), but in the last five years it has been used widely for wind power-related studies of birds in North America and Europe (Pedersen and Poulsen 1991; Cooper and Ritchie 1994; Cooper et al. 1995a,b). Radar was used in these studies mainly because many species of birds (e.g., songbirds and ducks) migrate largely at night, when they are impossible to study with standard visual techniques. Radar also is useful during periods when fog or clouds restrict visibility during daytime, for observations over large areas that cannot be covered by a single visual observer, and to help visual observers detect and locate birds that otherwise would be missed (Kerlinger and Gauthreaux 1984, 1985; Cooper and Ritchie 1995). This is not to say that radar detects all birds in an area; it also is a sampling tool with its own biases and limitations. In fact, none of the sampling tools we have at our disposal today can detect all birds in an area at all times. Fortunately, radar and visual techniques complement one another well for avian studies relevant to wind power developments.

The purpose of this paper is to familiarize a general audience with the practical aspects of using radar for wind power-related avian studies, discussing both radar's benefits and its limitations. I will discuss briefly some principles and a history of radar, then will explain some of the benefits and limitations of some of the most commonly used types of radars, and next will describe in detail the marine radar laboratory we have used, including some practical aspects of its operation. The paper concludes with some ideas on how radar could be used for avian research during the pre- or post-construction phases of windfarm development, and lists some of the future needs for radar studies.

Radar and Bird Studies

Introduction to Radar.—Radar stands for RAdio Detection And Ranging. Pulses of electromagnetic radiation are transmitted many times per second. During the brief intervals between pulses, the radar receives the echoes that are reflected back from objects within the radar's beam (e.g., a bird, plane, ship, or hill). At any given time, the pulses are transmitted toward a particular range of directions and elevation angles, determined by the antenna design and orientation. Objects from which echoes are received are normally within that same range of directions and angles, so antenna orientation provides information on target position. The radio waves travel at the speed of light, so the time interval between transmission of a pulse and reception of an echo is directly related to the distance to the object.

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The maximum detection distance for a particular object depends on many factors, including the radar power output, radar wavelength, and size and composition of the object. Object size and composition determine its "radar cross-section" at the wavelength in question. For birds, maximum detection distance varies from a few hundred meters for single small birds studied by the smallest marine radars to over 150 km in the case of bird flocks studied by long-range surveillance or tracking radars.

Radar was developed during World War II. Some of the first radar operators saw what they called "angels" on their radar screens over areas that they knew were devoid of aircraft. Most of these "angels" turned out to be birds, and the field of radar ornithology was born. Many studies of migratory and local movements of birds have been conducted with radar since the 1950s; the general principles and the early work were reviewed by Eastwood (1967).

We have used radar for several different studies during the past nine years, including wind power-related studies of birds for the Niagara Mohawk Power Corporation in upstate New York and for Kenetech Windpower in Spain. I will focus on the use of marine radars, the type of radar that we use for bird studies, but first I will describe some of the other types of radar that have been used by ornithologists.

Common Types of Radar Used for Bird Studies.—Large weather radars (e.g., WSR-57, NEXRAD or WSR-88D) and air surveillance radars are excellent tools for studying patterns of bird migration over extensive areas (Eastwood 1967; Gauthreaux 1975; Richardson 1979; Able 1985; Buurma and Bruderer 1990; Buurma 1995). These types of radars could be useful for broad-area preliminary site selection surveys. However, they are not useful for collecting high-resolution data over small areas such as wind sites. Further, they are usually stationary and may not always be available near a particular wind site. Finally, some of these radars are equipped with devices that filter out and remove echoes of some birds (Richardson 1972). For these reasons, the following discussion will focus on smaller, mobile types of radar that could provide high-resolution data from a desired location.

Tracking radars are designed to lock onto and follow targets such as aircraft or missiles, providing continuous data on their positions and movements in three dimensions. Small military surplus tracking radars can provide good information on the flight behavior of birds (including altitude, speed, and direction), provide some limited identification ability via wingbeat signature, and have MTI (Moving Target Indicator) circuitry to reduce ground clutter (echoes from the ground and other stationary objects). The disadvantages of these systems are that they do not provide a broad picture of migration over a site unless they are used in a surveillance mode (e.g. Bruderer et al. 1995), are not readily available, require fairly extensive training to operate, and are difficult and expensive to repair. Although a mobile military tracking radar may be the ultimate system for many ornithological studies, it probably would get only a "good" rating for most types of wind power-related avian research because of these limitations. For more details on the specifications, past use, and merits of tracking radar for ornithological studies, see Eastwood (1967), Blokpoel (1971), Bruderer and Steidinger (1972), Griffin (1973), Larkin et al. (1979), Richardson (1979), Ker-

linger (1980, 1982), Able (1982, 1985), Buurma and Bruderer (1990), and Bruderer et al. (1995).

Marine radar, which typically is used on boats for navigational purposes, is an excellent tool for many types of wind power-related avian research. The advantages of marine radar systems are that they are inexpensive, are available off-the-shelf, require little modification or maintenance, are dependable, have repair personnel readily available worldwide, are easy to operate, have very high resolution, and can be modified to collect altitude information (Williams et al. 1972; Korschgen et al. 1984; Williams 1984; Gauthreaux 1985a,b; Cooper et al. 1991). Largely because of these factors, almost all avian-wind power research based on radar has been done with marine radar systems (McCrary et al. 1984; Pedersen and Poulsen 1991; Cooper and Ritchie 1994; Cooper et al. 1995a, b); the exception was Rogers et al. (1977), who used long-range air surveillance radar. The disadvantages of marine radars as compared with tracking radars are that marine radar systems have more problems with ground clutter interference, have a very limited ability to identify birds to the family let alone the species level, and have shorter range than many of the tracking radar systems. Small marine radars (10 kW peak power) can detect small, individual songbirds to range 1 km and large, individual hawks (e.g., Red-tailed Hawk) up to 4 km (Cooper et al. 1991). With the Flycatcher tracking radar system, single thrushes can be detected to 7 km (Buurma and Bruderer 1990). I believe that the disadvantage of the more limited range of the marine radar is compensated for by its ease of operation, convenience, cost, simpler surveillance capability, and high resolution.

Components of a Mobile Marine Radar Laboratory

Radar Equipment.—Our mobile laboratory (Cooper et al. 1991) consists of two small marine radars mounted on a cab-over camper on a four-wheel-drive pick-up truck (Fig. 1). One of the radars (surveillance) is used to scan the entire area around the lab, gathering information on flight paths, movement rates, and ground speeds of flying birds. A second radar (vertical) has been modified to measure altitudes of flight. A description of a similar radar laboratory can be found in Gauthreaux (1985a,b). The lab can be powered by a generator or by deep-cycle batteries; when fully charged, four 6-V golf cart batteries can power the lab continuously for ~14 h.

Surveillance radar: The surveillance radar (Furuno Model FCR-1411, Furuno Electric Co., Nishinomiya, Japan) is a standard X-band marine radar transmitting at 9410 MHz (i.e., 3 cm wavelength) through a slotted wave guide 2 m long. The peak power output is 10 kW; however, Furuno now makes a similar model that operates at 25 kW. The radar can be operated at a variety of maximum range settings, from 0.5 km to 133 km. Pulse length can be set at 0.08, 0.6, or 1.0 ms, depending on the range setting used. At shorter pulse lengths, echo definition is improved (giving you more accurate information on target location and, hence, distance), whereas at longer pulse lengths echo strength is improved, increasing the probability of detecting a target. An echo is a picture of a target on the video display screen. A target that is of interest here consists of one or more birds flying so closely that the radar presents them as one echo on the display screen.

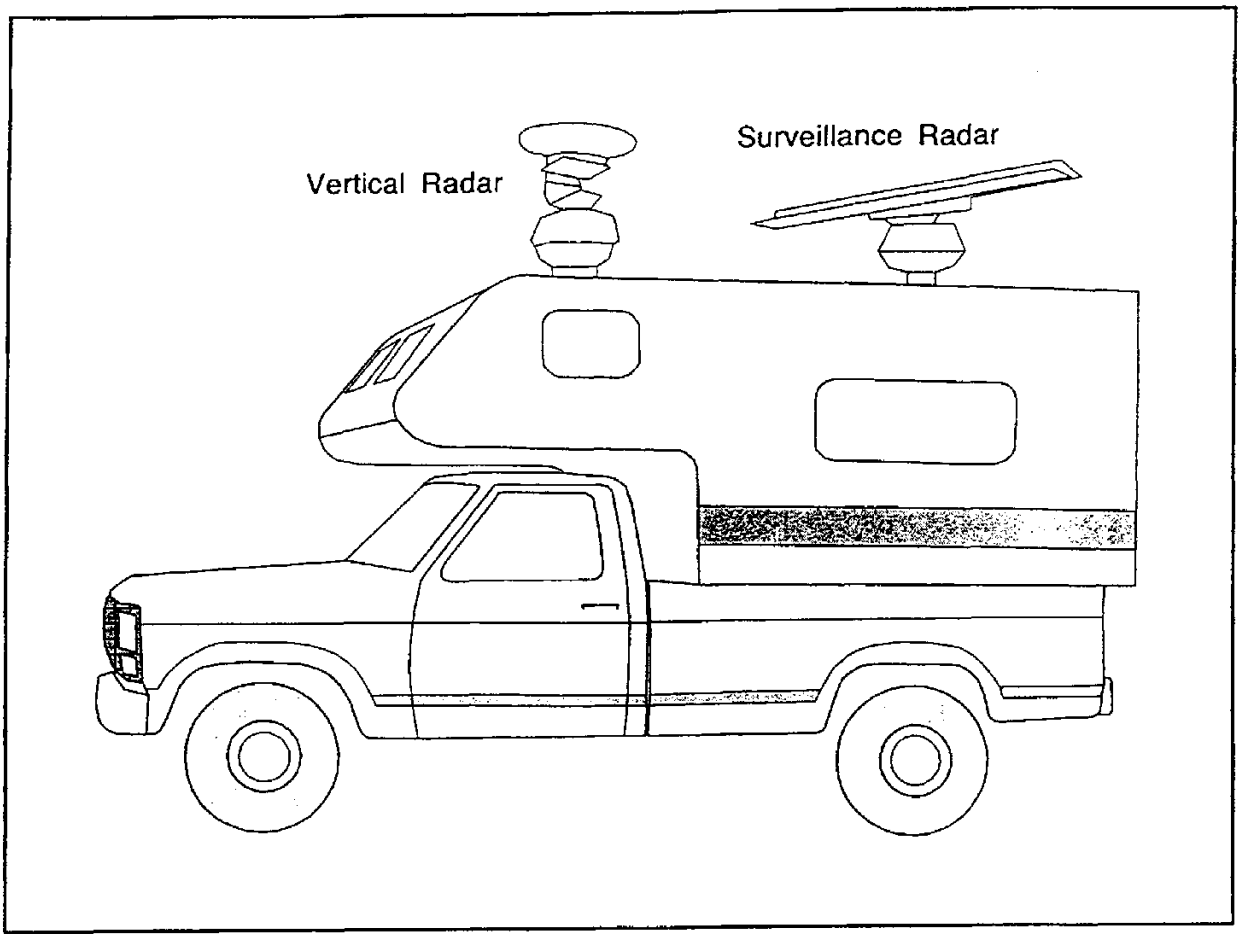

FIGURE 1. The mobile radar lab.

Our surveillance radar has a digital, color display with several scientifically useful features. These include color-coded echoes (to differentiate the strengths of return signals), on-screen plotting of the sequence of echoes obtained during different antenna revolutions (to depict flight paths), and True North correction for the display screen. A plotting function records the location of a target at selected time intervals (0.25, 0.5, 1, 3, or 6 min) (Fig. 2). Because these time intervals are fixed, ground speed is directly proportional to the distance between consecutive echoes and can be measured with a hand-held scale. In addition, an alarm function can be set to sound when echoes above a certain signal strength appear on the screen.

Vertical radar: The vertical radar (Furuno Model FR-8100) is a standard marine radar that was modified by replacing the slotted wave guide with a 0.6-m-diameter parabolic dish. This radar also transmits at 9410 MHz with a peak power output of 10 kW, can be operated at various maximum ranges from 0.5 to 89 km, and has a digital, eight-shade, monochrome display. Pulse length can be set at 0.08, 0.3, 0.6, or 1.0 ms, depending on the range setting used. A plotting function records the position (in this case, altitude) of a target, either continuously or at intervals of 0.5, 1, 3, or 6 min. An alarm function can be set to sound

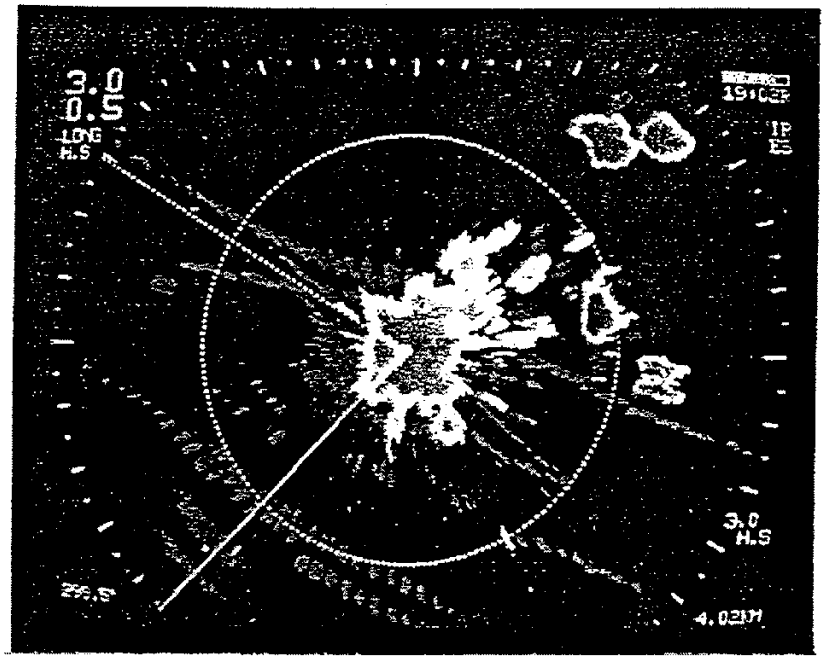

FIGURE 2. The surveillance radar display with plotted echoes of swans flying from southeast to northwest (note that the screen is oriented so that north is up). The large, irregular blotches are ground clutter. The adjustable, dashed ring has a radius of 4.02 km (noted in lower right corner of screen). The dashed, straight line (oriented at 299.5°, see lower left corner of screen) can be moved to determine flight direction (from Cooper et al. 1991).

when echoes above a certain signal strength appear on the screen. In addition, interference rejection circuitry allows simultaneous operation of both this and the surveillance radar. Because of the vertical orientation of its beam, the vertical radar cannot detect birds flying below an altitude of approximately 25 m above ground level. In contrast, the surveillance radar can (depending on terrain, antenna angle, range, etc.) detect some birds that are only ~1 m above ground level, but cannot detect birds within a horizontal distance of ~25 m.

The vertical radar is mounted on a hinged assembly that allows one to swing the antenna from the vertical position useful for counting birds directly above the laboratory and measuring their flight altitudes to a horizontal position useful for sampling birds crossing a nearly-horizontal line. Excessive scattering of radar energy from the antenna can be prevented by installing a tight-fitting collar of aluminum flashing ~100 cm high around the antenna (Gauthreaux 1985a; Cooper et al. 1991; Beerwinkle et al. 1993).

In a partially modified vertical radar system, the radar display screen shows only a thin, illuminated line that does not move. As birds pass through the radar beam, the targets appear along this line as bright spots; these are easily missed. We modified this system further by moving the antenna motor plate ~10 mm off-center, disengaging the gears

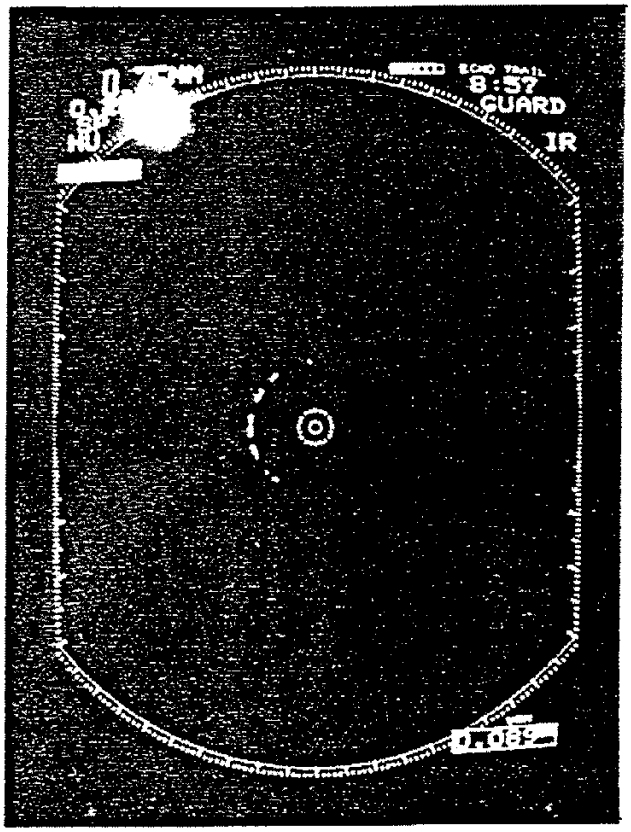

FIGURE 3. The vertical radar display with plotted echo (the broken arc) of a Great Blue Heron flying at 324 m above ground level. Note that the adjustable, dashed ring (here set at 89 m, see lower right part of screen) can be used to measure flight altitude (from Cooper et al. 1991).

between the motor and antenna, and allowing the motor to turn while the parabolic dish remained stationary. With this additional modification, targets form large areas or circles that are not easily missed on the display screen (Fig. 3).

A customized data downloading system has been developed for a vertical radar system used to study insect migration (Beerwinkle et al. 1993). We currently are determining if "off-the-shelf" software can be modified to download the vertical radar information automatically into a database.

Equipment for Nocturnal Visual Observations.—Visual observations are an essential complement to any radar study. During the day, observations can be made with binoculars and telescopes. At night, night-vision scopes or Forward-Looking InfraRed (FLIR) devices are more useful. The range of the night-vision scope is positively correlated with the amount of incident light present (e.g., from streetlights, cars, the moon). The performance of this scope can be enhanced dramatically by using a spotlight equipped with an infrared filter as an external source of light. The filter renders the light invisible to the human eye

and presumably to birds, thus avoiding effects on the birds' behavior while enhancing the images in the eyepiece of the night-vision scope. Using a 5X night-vision scope (second generation) and a 1.25 million candlepower spotlight equipped with an infrared filter, one can detect small songbirds to ~150 m and gull-sized birds to ~400 m. With enough incident light, gull-sized birds can be detected to ~1000 m.

Forward-looking infrared (thermal imaging) devices like FLIR model 2000A (FLIR Inc., Portland, OR) do not require any incident light to work and can detect gull-sized birds to ~800 m. Other FLIR units designed for long-range use can detect birds considerably farther away, but have a narrow field of view (Liechti et al. 1995). Unfortunately, the larger FLIR scopes are not as portable as a night-vision scope, and FLIR scopes are very expensive (~$100,000 US) compared to night-vision scopes (~$4000 to $8000 for 2nd or 3rd generation equipment, respectively).

Limitations of a Marine Radar System

The major limitations of a marine radar system, common to many of the other types of radar as well, are (1) the actual number of birds represented by each target is unknown; (2) identification to the family or species level usually is not possible; (3) insects and bats sometimes make echoes that can be confused with slow-flying birds; (4) ground clutter can obscure large parts of the screen; and (5) birds cannot be detected during periods with moderate-heavy precipitation. An additional limitation of the vertical (but not surveillance) radar system is that, when it is in the vertical mode, birds cannot be detected below an altitude of 25 m. Fortunately, several techniques are available to minimize or mitigate the effects of these limitations.

Number of Birds.—A flock of birds usually appears as one echo on the radar screen. That is why most radar studies report movement rates as targets/h rather than as birds/h. For many types of research, this index of movement can be used without problems, but there are occasions when one wants information on actual numbers of birds crossing a site. The best way to estimate the actual number of birds from radar data is to obtain concurrent visual information on mean flock size. The number of targets can be multiplied by the mean flock size to obtain an estimate of the actual number of birds. The concurrent visual information can be collected with standard optical equipment during the day, but at night it is necessary to use night-vision (image intensification) devices or FLIR scopes. Because all radar and visual methods are sampling techniques, and as such are likely to miss at least a few birds, a further correction for missed flocks may be desirable based on double counting methods.

Species Identification.—Another reason that radar ornithologists often report their data in terms of "targets" rather than "ducks" or "geese", for instance, is that the identity of most echoes is unknown. With the marine radar system, it often is possible to separate targets into "songbirds", "raptors", "shorebirds", and "waterfowl", based on flight speed, target strength, target size, and flight behavior. In areas where a particular species has unique flight characteristics, it is possible to identify targets to species. For example,

Marbled Murrelets were identified to the species level on radar with an accuracy >95% at inland nesting locations in northern California (Hamer et al. 1995). These results were verified with auditory and visual observations. This type of confirmation is needed for any studies using marine radar that wish to report species-specific information.

A promising new auditory technique for obtaining information on species identification of nocturnal migrants is being developed (B. Evans, Cornell Laboratory of Ornithology, pers. comm.). This technique uses special microphones to record the call notes of nocturnal migrants. (Most landbirds, except for tanagers, vireos, and flycatchers, emit call notes at least occasionally when they are migrating at night.) The calls are then analyzed by ear or with spectrographic analysis. The Cornell Bioacoustics Research Program is developing software that could be used in the future to automatically detect and classify warbler and sparrow calls. During fall 1994, we used this auditory technique concurrently with radar observations in upstate New York and obtained a strong correlation between the number of birds detected by the two methods. Because acoustic monitoring allows one to determine the species of many calling birds, this technique might have potential for monitoring the abundance of vocalizing species during their night migrations. In any case, it certainly is a very useful complement to the radar technique because of the ability to identify many night-migrating birds to the species level.

Insects and Bats.—Large, fast-flying insects sometimes can be confused with birds on X-band marine surveillance radars, but it often is possible to identify and disregard insect targets based on flight speed and target strength. These criteria are not valid for bats, which often are indistinguishable from birds on radar, except when the bats are foraging. Again, visual sampling is recommended to assess the extent of this potential problem. There may be periods when the problem (especially with insects) is severe enough that radar sampling should be discontinued until conditions improve. Insects and bats are more problematic for the vertical radar because, on that system, one does not receive information on flight speed or behavior, only altitude. In fact, a vertical radar system nearly identical to the one I describe has been used by entomologists to study insect migration (Beerwinkle et al. 1993). The extent of insect and bat activity can be assessed by making vertical, visual observations. A nice system for making concurrent visual and vertical radar observations is described in Gauthreaux (1985a). Alternatively, the level of insect activity can sometimes be assessed with a surveillance radar operating concurrently. Observations should be discontinued if large insects (e.g., large moths, beetles) are abundant above the minimum range of the vertical radar (25 m). For additional information on the separation of bird and insect targets, refer to Larkin (1991) and Vaughn (1985).

Another possible solution to the insect problem would be to use S-band marine radar instead of X-band radar. S-band radars transmit at a lower frequency (2000-4000 MHz) and have a longer wavelength (~10 cm) than do X-band radars (~9000 MHz and 3 cm). When target size is much smaller than the wavelength, radar cross-section diminishes very rapidly with decreasing ratio of target circumference to wavelength (Skolnik 1980). Thus, most insects produce far less echo on S-band (10 cm) than on X-band (3 cm) radars. S-band radars probably also do not detect small songbirds as well as do X-band radars, which is a problem

if songbirds are of interest. Almost all bird studies to date that have used small marine radars have used X-band radars. However, S-band and even L-band (~23 cm) radars of other higher-powered types have been widely used to study bird movements (Eastwood 1967; Richardson 1979).

Ground Clutter.—Whenever energy is reflected from the ground, surrounding vegetation, and other objects that surround the radar unit, a ground clutter echo appears on the display screen. This can obscure bird targets. Ground clutter can be caused by, for example, stubble as low as 0.5 m high in a newly harvested agricultural field. Ground clutter can be minimized in some cases by elevating the forward edge of the antenna and by using a ground clutter reduction screen (described in Cooper et al. 1991). Ground clutter also can be reduced by selecting radar sites that are surrounded closely by trees, buildings, or low hills, or sites in a low depression, such as a shallow quarry or pit. These objects act as a radar fence that shields the radar from low-lying objects farther away from the lab and produces only a small amount of ground clutter in the center of the display screen. For further discussion of radar fences, see Eastwood (1967), Williams et al. (1972), Skolnik (1980) and Williams (1984).

More expensive radars usually have Moving Target Indicator (MTI) circuitry to reduce ground clutter. Although MTI is often extremely useful in bird studies, there are complications: it does not fully suppress echo from moving vegetation, and it has complex effects on the echoes from moving birds as well. For instance, slow-moving bird echoes, or echoes moving perpendicular to the radar beam, may be suppressed by MTI. Further, birds flying over areas with heavy ground clutter echoes are less likely to be detected even though MTI eliminates the ground clutter (Richardson 1972; Buurma and Bruderer 1990).

Effects of Weather.—Rainy or snowy conditions make radar observations of birds difficult to impossible, because the attenuation required to remove the echoes of the precipitation also removes most or all bird echoes. For X-band radars, there is no solution to this problem beyond designing sampling sessions to be short enough (15 to 30 min in length) so that some sessions could fit between periods of precipitation. S-band marine radar probably could detect birds (or at least larger flocks) in very light precipitation, but field verification is needed to confirm this. L-band radars are less sensitive to precipitation, and birds flying in light precipitation are often detectable with such radars (W.J. Richardson, LGL Ltd., pers. comm.).

Quantification of Low Flight Altitudes with Vertical Radar.—Despite radar modifications and improvements, data on the heights of birds flying at night below the lowest level sampled by the vertical radar (25 m) remain difficult to collect. The hinged assembly on which the vertical radar antenna is mounted makes it possible to sample lower elevations over water bodies or smooth, snow-covered fields by orienting the antenna horizontally. Over any other surface, however, ground-clutter echoes from vegetation or an uneven ground surface obscures the display screen. To my knowledge, a marine radar system that samples flight altitudes below 25 m over anything but water or a snow-covered field has not been developed (Korschgen et al. 1984; Gauthreaux 1985a,b; Cooper et al. 1991). Until such a system is devised, direct visual observation with night-vision or FLIR

scopes, concurrent with vertical radar observations, probably is the best way to obtain altitude data for the lowest 25 m of airspace.

Standards for Equipment, Settings, and Methods

Equipment.—A marine radar system used to monitor birds should be X-band (3-cm wavelength), transmit with 10 to 25 kW of peak power, and have plotting and alarm functions. A color display monitor is an excellent feature to reduce observer fatigue (especially on surveillance radar), but monochrome displays are easier to videotape and are less expensive than are color monitors. The cost of one of these radars, including the modifications for the vertical or surveillance radars, would range from ~$8000 to ~$15,000 (US), excluding installation.

Night-vision equipment should be second- or third-generation equipment. Goggles can be used for very short distances, but scopes usually are more versatile for data collection. Forward-looking infrared scopes would be useful for bird observations, but the cost may be prohibitive. Image quality through good FLIR units is excellent, but the view through many of the smaller, less expensive infrared scopes is too grainy and small to be of much use for anything except observations within ~25 m.

Equipment Settings.—Once a radar is properly tuned, the gain must be set near the level where a light speckling appears on the screen. The STC (Sensitivity Time Control) should always be in the "off" position. The FTC (Fast Time Constant) should be "off" if possible, but can be applied sparingly to reduce some light clutter on the screen. Range should be set at 0.75-1.5 n.mi. on the vertical radar. On the surveillance radar, range should be set at 0.75-1.5 n.mi. to observe small-bodied species (e.g., songbirds) and at ≤3.0 n.mi. to observe large species. Some helpful advice on using marine radar for bird observations can be found in Williams (1984).

The importance of training in the use of radar for bird study cannot be stressed enough. It is relatively simple to learn how to operate the radar, but it takes training and extensive experience to learn how to adjust the radar properly under a variety of conditions and to learn how to interpret targets. Radar data gathered by untrained or insufficiently trained personnel are suspect and may be inadequate.

Radar Placement.—One of the most important and difficult-to-learn aspects of using surveillance radar is selection of sampling location. The site one chooses has important implications for data quality and comparability among sites. Basically, one needs to choose a site where ground clutter and shadow zones (e.g., areas behind hills or other objects that shield bird targets from radar) do not obscure or exclude important portions of the study area. Within a particular area, it usually is possible to find a particular site from which observations can be made, especially if "radar fences" are used. One additional technique that could allow greater flexibility in siting would be to mount the radar on a small crane that could be elevated to a desired height. This technique would be particularly useful in flat, heavily wooded areas.

Methods for Data Collection.—Data collection techniques for radar are discussed in Gauthreaux (1985a, this volume) and will not be extensively discussed here. One of the most important aspects of data collection, however, is to collect data in discrete sampling periods no longer than 30 min in length, at a standard range. By collecting data this way, one can standardize movement rates to targets/h/km, which allows comparison among studies. Further, time and weather data should always be collected, as these variables can be strongly correlated with movement rates and flight behavior. A sampling design for a visual and radar study to quantify bird movements and flight altitudes at proposed or existing windfarms can be found in Cooper et al. (1995a).

Applications of Radar for Wind Power-Related Avian Research

Pre-construction Studies.—*Siting:* Locating windfarms in areas with few low-flying birds probably is the best solution for minimizing bird fatalities. Within an area of interest, radar and visual sampling should occur at a number of sites; the resulting data will provide a comprehensive, around-the-clock look at where "windows of movement" exist and will identify areas with heavy concentrations of low-flying birds. Radar also can be used on a microscale level to identify particular spots within a small area that have concentrations of low-flying birds. Both macroscale and microscale information would be useful in planning facility siting to minimize the potential for bird collisions or in reducing the concerns for collisions (either because all birds are high-flying or because few birds use an area).

Once specific sites are identified for structures such as wind turbines, radar can be deployed to measure the number and altitudes of birds passing through these specific corridors of air. This assessment may help identify critical (i.e., maximal) heights and locations for structures.

Identifying Periods of Risk: It may happen that an area is devoid of significant numbers of low-flying birds most of the time, but that there are certain seasons and/or weather conditions when significant numbers of birds do fly low enough to be at risk. Bird migration often is a pulsed phenomenon, and there are huge differences in both numbers of birds and their flight altitudes, depending on weather conditions, time of day, time of year, location, and the species under consideration. Radar and visual studies could be used to develop procedures to predict critical periods of high risk. Once the wind plant is operational, wind turbines could be shut down during periods when large numbers of low-flying birds are expected to pass through a windfarm, or plant operators could be alerted to watch for birds during those periods and shut down turbines if a large number of birds are at risk.

Post-construction Studies.—*Monitoring impacts:* Radar and visual studies can be used to assess post-construction changes in avian use or behavior over an area (day or night). Combined with ground searches, this type of study can help to establish mortality rates, estimate total flight and collision rates, and identify specific areas of concern at existing sites. If mortality occurred, one could determine if it occurred in proportion to bird use, or identify other factors that were involved.

Assessing effectiveness of collision reduction techniques: To assess the success of collision reduction techniques properly, it is necessary to know the number and altitude of birds flying over the area, in addition to number of collision victims. Radar and night-vision equipment can be used to monitor and measure the success of these techniques during periods of peak night-time use, under low light conditions, or when visual observations cannot cover a large enough area.

Real-time warning system to reduce bird collisions: Visual and radar monitoring could provide information so that schedules for wind power generation could be adjusted to adapt to periods when large numbers of low-flying birds are passing through a windfarm, either during the day or at night. Kenetech Windpower has supported studies to determine the feasibility of this technique at a wind plant in Spain. An automated radar system would be ideal for such a task, if it could be set up with an alarm to alert wind plant operators when high-risk conditions were occurring. In related applications, marine radars have been used to detect the approach of waterfowl to contaminated ponds and to trigger bird scaring devices at those times (Denver Knight Piésold 1992; C. Johansen, Brigham Young Univ., pers. comm.). Also, software has been added to a few large military radar systems in order to monitor numbers of birds aloft; this information is used to help reduce the risk of collisions between aircraft and birds (Buurma and Bruderer 1990; Buurma 1995).

Future Needs

If radar becomes a standard technique for wind power-related avian research, it probably will be used by more than the small number of researchers who currently are familiar with it. To ensure quality of data, standardization of equipment, training, and data collection techniques would become even more critical than they are now. Efforts are being made to develop standards for equipment and data collection (S.A. Gauthreaux, Jr., Clemson University, pers. comm.) but no progress has been made in development of training protocols.

S-band marine radars need to be field tested to determine how well they work for detection of small birds, for reduction of insect echoes, and for monitoring birds during precipitation. The S-band marine radar may prove to be better than X-band radar in locations with many large insects or frequent precipitation, especially if the birds of interest are large-bodied species.

Efforts should be continued to develop and field test inexpensive, easy-to-use software that can automatically download radar information into a database. Such a system would streamline data collection and would decrease study costs. Similarly, an effort should be made to stay abreast of developments in the fields of radar, thermal imaging, night-vision, and computer technology, which promise additional benefits for wind power-related avian research.

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Discussion

Types of Radars.—An attendee asked whether already-existing airport radars could be used for broad-area surveillance, e.g. during site-selection studies. Other attendees noted that airport surveillance radars (ASR) routinely detect birds, as do most other types of radar. Airport and other air surveillance radars have been widely used for bird studies for many years. However, as previously noted, ASR resolution is lower than that of short-range marine radars, and ASRs usually are not mobile. At most ASR sites, the bird information normally is not recorded or used in any way, variable radar settings may strongly affect bird detectability, and security restrictions often limit access.

Limitations and Calibration.—An attendee asked whether detection biases of marine radars had been studied by attempting to radar track birds that were radio-tagged. This has not been done, but could be a useful approach.

Another question concerned the possible use of an active acoustic sounder, as used by meteorologists, to detect birds aloft. It was noted that such sounders have been used to monitor micrometeorological phenomena relevant to bird flight while radar was used to monitor migrating birds. However, acoustic sounders are not known to be useful in monitoring birds themselves.

There was discussion of the fact that marine radar beams, as normally applied, are wide in the vertical dimension. As a result, when used in a surveillance mode, marine radars do not provide information on flight altitude.

One user of marine radar noted that, in one study, only 1 of 2000 birds seen passing through a radar beam was missed by the radar, and that radar detected many birds not seen visually. Another user of marine radar mentioned that, in a different study, radar detected three bird targets for each one seen visually, and that it would be inefficient *not* to use radar.

In response to the question, "Would two experts in the use of radar get the same results from a radar study of bird movements", it was stated that they would get very similar results if they used the same equipment at the same site. Although the choice of radar settings is somewhat subjective, experienced radar users select similar settings. One

radar user suggested that there is less individual-to-individual variation in bird detections when using radar than when observing visually.

Future Needs.—Several attendees noted that radar and visual studies of bird movements are complementary, and should be done in coordinated fashion. One commenter suggested that assessments of radar limitations and biases usually are done on an *ad hoc* basis, and need to be more systematic than has been the case in most radar studies.

One attendee commented on the need for automated procedures for digitizing, summarizing and archiving radar data on bird movements. He indicated that he is developing such a capability for a marine radar system.

Avian Risk Assessment Methodology

by

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Overview of Project

This project will establish and test an innovative avian risk assessment methodology involving wind energy development. Phase I studies are focused on the key question of determining if a developed and operating Wind Resource Area (WRA) results in an increased risk of bird mortality. While this approach may not entirely exclude the need for additional studies, it should allow researchers to focus quickly on key areas for further inquiry and uncover potential relationships that could be verified through follow up studies.

This methodology will determine the relative abundances of birds in the WRA and their utilization of the area, and will sample for bird mortality. From these data the study will determine indices of bird risk and attributable risk due to the WRA. The methodology lends itself to the comparison of multiple sites from around the nation.

Although this approach is not entirely new, its application to bird/wind energy studies is ground breaking and should yield results valuable to many WRAs throughout the U.S. It is possible to conduct such a project only in California because of the extensive wind development there. The results from this study should be available in time to help guide the planned development of WRAs elsewhere in the U.S.

Because WRAs are not all alike, research at one or a few locations should not be used to characterize the issues at all WRAs. The limited number of areas already studied may not be representative for California or for the United States as a whole, and may give an undeserved negative impression of the impacts of wind energy developments on birds. The California Energy Commission considers it important that credible, comprehensive avian mortality monitoring studies be conducted in Tehachapi Pass WRA and San Gorgonio Pass WRA (Fig. 1).

The study is being conducted as a result of the combined interest of local, state and federal agencies, the wind industry, environmental organizations, landowners, and utilities. There is agreement among these parties that comprehensive, credible studies are needed to provide a broader base of data and reports from a larger and more representative selection of WRAs. Therefore, an extensive review process has been undertaken to ensure that all stakeholders have had opportunities to review the methods and to recommend modifications.

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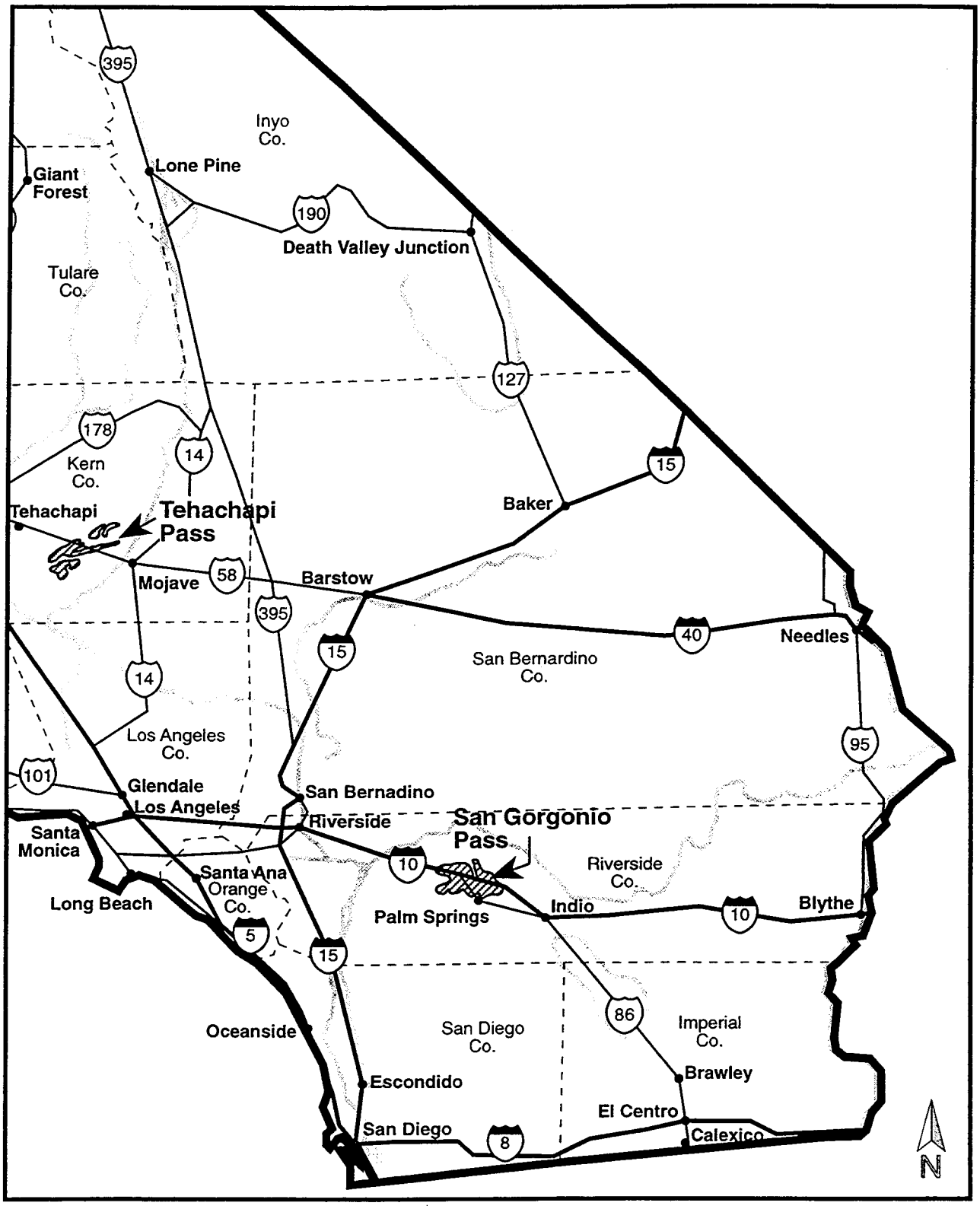

FIGURE 1. Developed Wind Resource Areas of southern California.

Phase I of this specific project is not designed to determine the absolute number of birds dying in the WRA nor the absolute net difference in mortality levels between the WRA and an undeveloped comparison area. Such numbers, in isolation, are of little value without also knowing the larger context of avian activity in the area and the "natural" mortality levels. We assume that all birds die eventually but we are interested in knowing if an operating wind plant in the WRA causes an increase in mortality. We believe it is prudent to start with a research design that can identify the *relative risk* caused by an existing and operating wind plant. The results of this type of research can be used as both a screen to determine if further research is warranted and as a guide for more focused research.

Methodology Development

An extensive effort to develop methodologies acceptable to all stakeholders has been undertaken. The "Measurements/Concepts" technical discussion found below is a consensus approach developed by several biostatisticians and field methodology experts representing federal, state, utility, and environmental organizations. (See the chapter by M. Morrison and H. Davis in these Proceedings [p. 111*ff*] for further discussion of the development of this methodology.) The methodology described here was current as of mid-1995; it will receive additional review as the project continues. A very desirable aspect of this project and its methodology is our willingness to be adaptive and to modify the proposed methodology in order to meet reasonable consensus standards. During the anticipated several years of research at Tehachapi Pass and San Gorgonio Pass WRAs, additional methodologies will be developed in a similar consensus manner to resolve more focused problems (Phases II and III). This approach will result in credible, comprehensive, objective studies providing standard methods that can be considered for application during subsequent studies elsewhere.

A. Key Questions.—The goal of the project is to determine if an operating wind plant results in an increased risk of bird mortality compared to the surrounding non-developed area. The key questions are as follows:

1. What influence does the operation of a wind plant have upon birds?
2. Does the wind plant operation influence the level of bird activity, called "utilization rate", compared to that of nearby undeveloped areas?
3. Does the wind plant operation influence the rate of bird mortality, called "mortality rate", compared to that of nearby undeveloped areas?
4. When comparing the utilization rates and bird mortality rates in the operating wind plant and surrounding undeveloped areas, is there any change in the risk to birds that is attributable to the operating wind plant?
5. Does utilization rate, mortality rate, or attributable risk vary depending on the type of technology (e.g., different wind turbine types, infield powerlines, transformers, etc.), the environmental conditions, or the species of bird?

B. Measurements/Concepts.—Several of the key measurements to be taken during the study need to be defined carefully:

1. Bird Utilization Rate

   "Bird utilization rate" of the developed WRA and nearby non-developed areas will be documented. The bird utilization rate is the number of birds detected utilizing the area during 5 and 10 minute variable point counts. The 5 and 10 minute variable point counts will be compared for effectiveness. The variable point counts must be conducted during standard time periods and (in California) during all seasons for comparison purposes. Because of the noise of turbines and wind in general, sound (bird calls) will not be used to detect birds utilizing the area. Observers are directed to ignore bird calls. Some observers may choose to wear ear plugs. The observer slowly turns around to monitor a full 360° (normal search pattern). If a bird sound is heard, the observer continues the 360° scan and only records the bird if it is seen during the observer's normal search pattern. This will insure that turbine noise will not bias the counts and calculated utilization rates from undeveloped comparison areas vs. developed WRAs. Utilization rates can be calculated for individual species, taxonomic groups and all birds combined, and for various natural communities, seasons, distances from the nearest turbine, etc. Bird activities will also be documented including flying, perching, soaring, hunting, foraging, height above ground, and behavior close to WRA structures. Both the height above ground and the horizontal distance to each bird will be estimated.

2. Bird Mortality

   The number of dead birds or bird parts found at each search site (a 100 meter diameter/50 m radius circle centered on each variable point count site) will be documented. Dead birds or bird parts of any age will be counted. Dead birds and bird parts will not be collected because, under the chosen sampling design (randomized sampling with replacement), a given area may be sampled more than once. The number of dead birds or bird parts documented per search site will be called "bird mortality". Ancillary information is collected to facilitate later analyses, including estimated time since death, cause of death, type of injury, distance to nearest turbine, and distance to nearest structure.

3. Bird Risk

   Bird risk relates the birds found dead in the area to those utilizing the area. Bird mortality will be used as the numerator and the bird utilization rate as the denominator to develop an index of "bird risk". Bird risk establishes a relationship between bird use and bird death; it does not represent absolute numbers of dead birds. If absolute numbers of dead birds and bird use increase commensurately, the bird risk will not change. Bird risk can be used to define and compare risk at varying distances from developed WRA facilities for species, taxonomic groups and all birds combined, and for various natural communities, seasons, and turbine

designs. Bird risk can be used for comparisons with other WRAs and other types of facilities such as highways, power-lines, and transmitter towers.

4. Attributable Risk

   The differences in bird risk will be used to discuss "attributable risk". This is the risk that may be attributable to a specific location or situation, such as risk to the birds associated with the developed WRA vs. non-developed nearby comparison areas or other comparisons. Locations and situations for which risk differs substantially would be candidates for more focused studies.

5. Scavenging Rate

   Scavenging activity can be quantified and calculated as a rate comparing a developed WRA with non-developed nearby comparison areas or other WRAs. In Phase I of this study, scavenging levels that differ between comparison areas will affect or bias the ability to detect and relate relative numbers of dead birds. If not detected, significant differences in scavenging rate would result in misleading bird risk. In Phase I of this study, if scavenging rates are equal in different parts of the same WRA or in different WRAs, then scavenging rate will have no effect when comparing bird mortality, bird risk, and attributable risk.

6. Observer Bias

   Differences between observers' abilities to perceive and record bird utilization parameters and find dead birds or bird parts need to be determined in order to minimize and account for this potential bias.

C. Sampling Design.—The sampling design for Phase I studies has been defined and tested. Some possible Phase II and III studies have been identified but their specific sampling designs have not yet been defined.

Phase I Studies

- Starting points were selected at random within strata representing all natural communities within the developed WRA and non-developed comparison areas. From each starting point, a randomly selected angle determines the transect direction along which variable point counts and dead bird searches are conducted (Fig. 2). Five and ten minute variable point counts to determine bird utilization rates (species, numbers, and behavior) are conducted every 300 meters along the transects. Bird vocalizations are not used; detection will be by sight. Other acceptable methods can be used, such as transects or permanent point count sites.
- A minimum of 250 points will be sampled each season, and a minimum of 1000 each year. The results of the 5 and 10 minute variable point counts will be analyzed to determine whether the 10 minute variable point counts provide significantly more

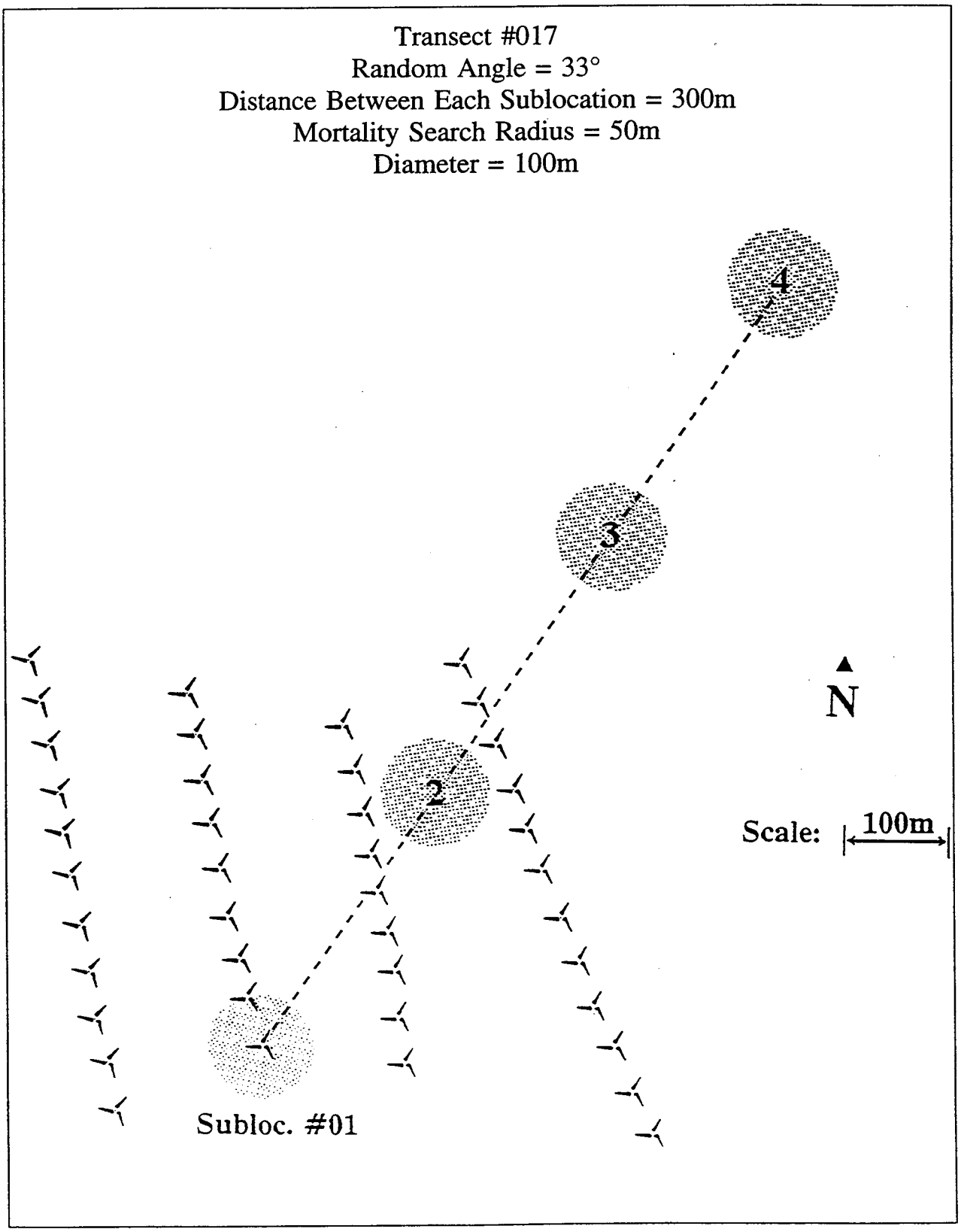

FIGURE 2. Avian risk assessment methodology, California Energy Commission (Sept. 1995).

information. Variable point counts will be conducted during standardized hours. All-day bird activity counts will be conducted seasonally in order to determine if and when there are significant hour-to-hour differences in activity and detectability. From these data correction factors will be developed, as needed, for different activity levels during different times of day.

- Phase I studies will be conducted at least until all four seasons have been sampled. The anticipated Phase I study length will be one to two years.
- Dead bird and bird part searches will be conducted at each variable point count location within a circle 100 meters in diameter (Fig. 2). The field researchers will conduct a complete search of the area. Detection distances will vary by season, natural community, and condition of vegetation. Dead birds and bird parts will not be collected but will be left in place, for the reason previously noted. Time since death and cause of death will be estimated for each dead bird.
- Scavenging studies will be conducted at randomly-selected points at varying distances from turbines. These points will be established as permanent scavenging study points. A minimum of three general distances (1 km, 500 m, near turbine) will be tested. Large and small dead birds will be marked, placed, documented, and monitored daily for 10 days. The rate and extent at which these dead birds are scavenged will be documented. If scavenging rate differences are detected, they are assumed to be due to scavenger numbers and activity, and/or differing scavenger species—not to study design or conduct. If significant differences in scavenging rates exist, an adjustment factor will be developed to equilibrate the sites. Replicate scavenging studies will be conducted seasonally.
- Observer bias factors will be determined. Dead bird detection bias will be determined by placing a known number of small and large dead native birds in a dead bird search area unknown to the observers. The birds will be placed just before the searches and removed immediately following the last search each day to avoid the possibility of scavenging. Dead bird detection bias factors will be based on number of dead birds detected in an area in proportion to number of dead birds there.
- Sampling is being conducted first in Tehachapi Pass WRA at four major wind company sites: Cannon Energy Corporation, FloWind Corporation, SeaWest of Tehachapi Inc., and Zond Systems Inc. These locations include the major turbine designs and the major natural communities found in the area. These companies' turbines constitute approximately 75 percent of the 5500 turbines in the Tehachapi Pass WRA. Sampling is anticipated to start in San Gorgonio Pass WRA during late 1996.

Phase II and Phase III Studies

Results of Phase I studies will identify and focus the Phase II studies and the Phase III studies (as needed). The following potential studies would start with a planning workshop of invited experts to assist in creating an acceptable study design and methodology for each study. These methods would be reviewed by all stakeholders.

- Over-sampling areas - If there are areas where dead birds are found more frequently, over-sampling could be conducted. This would concentrate study on specific areas in order to obtain sufficient data to determine mortality factors.
- Other facility monitoring - Other facilities such as power poles and meteorological towers could be sampled using an appropriate sampling design to determine their contribution to overall bird deaths.
- Perching Documentation - This study would focus on all birds perched on turbines. Perching will be documented using sampling designs appropriate to detect perching preferences by species, turbine structure type, and other facility type (i.e. power pole). The correlations of these data with mortality rate and utilization rate information can then be determined.
- Prey Availability - Relative prey levels in the various natural communities within the developed WRA and nearby non-developed areas will be determined for correlation with bird utilization rate and mortality rate.
- Nocturnal bird utilization rates may be determined using night vision equipment and/or radar as necessary and possible. Intensive studies of nocturnal bird utilization are desirable and, if funding allows, will be conducted for resident and migrating birds active at night. At this time, radar or other nocturnal work is beyond the funding scope of this study.

Results and Discussion

This study was started in May 1995, with field level modifications to data sheets and methods occurring through July 1995. Data discussed below are from only two months of field work and are for discussion purposes only. Data from only 186 variable point counts (including both bird utilization counts and dead bird searches at the same locations) have been summarized. This includes detections of 352 individual birds of 24 species. The mortality data represent the total mortalities detected (n = 13). Figure 3 illustrates the types of data collected and the information that can be obtained using this "Avian Risk Assessment Methodology". No real results are available at this time, and the data analyzed are a small sample that may not be representative of the final study results. Readers are requested not to reproduce or use these graphs without this or a similar warning discussion.

With the above cautions in mind, the following discussion describes how the Bird Utilization Rates, Bird Mortality, and Bird Risk were calculated.

Utilization Rates.—Three utilization rates were calculated for illustration:

 # Birds / Point Count: This is the total number of birds observed divided by the total number of point counts conducted. The results are average birds observed per point count:

Formula: Total number of birds/total point counts

Early Results: 352 birds/186 point counts = 1.89 birds/point count

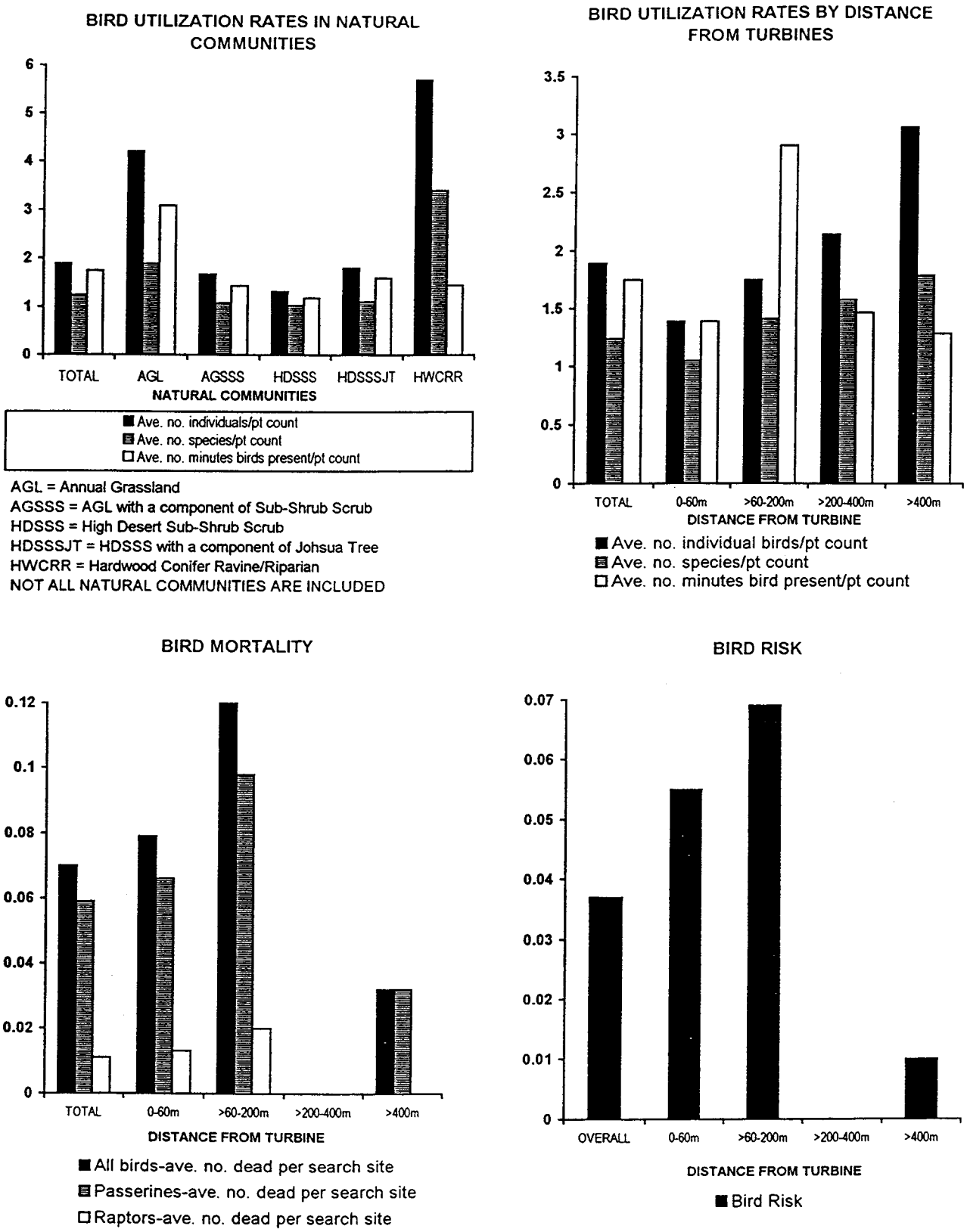

FIGURE 3. Types of data that can be collected with Avian Risk Assessment Methodology (based on small and possibly non-representative sample).

Average # Species / Point Count: One variation of the utilization rate calculated and illustrated on Figure 3 is the average number of species observed per point count. This rate provides species diversity information for the study area:

Formula: Σ (number of bird species in each count)/(total point counts)

Early Results: 230 bird species/186 point counts = 1.24 bird species/point count

Utilization Duration: This is the number of minutes each bird was observed during a five minute point count. If observed briefly, the minimum duration is recorded as one minute even though the bird may have passed out of sight within seconds. This measure provides an index of the amount of time birds spend in an area, which may have value in project siting or in understanding project effects:

Formula: Total # of birds/total # of minutes observed

Early Results: 352 birds/617 minutes observed = 1.75 minutes/bird

Figure 3 illustrates additional ways to analyze the data on bird utilization and utilization duration, e.g. by natural communities or by varying distances from wind turbines. A partial list of potentially useful comparisons of bird utilization rates would be by

- distance from turbines or other structures,
- season,
- time of day,
- bird species,
- natural community,
- defined area (company site, section of land),
- topography or topographical position,
- climatic conditions, including
    - temperature,
    - wind conditions and/or direction,
    - weather (i.e., rain, snow, cloud cover),
- turbine type or structure type (i.e., powerlines, highways, towers, etc.), and
- combinations of the above

The utilization rate information has great potential to provide valuable information in both pre-construction/pre-permitting applications and post-operational applications.

Bird Mortality.—Bird mortality is the number of dead birds and bird parts found per search site:

Formula: Total # of dead birds/total search sites

Early Results: 13 dead birds/186 search sites = 0.07 dead birds/search site

Other comparisons can be made for different species, natural communities, distances from turbines, structure types, etc. Most comparisons that can be done based on utilization

rates can also be done for Bird Mortality. This measure can be used to estimate dead birds/ square kilometer for subareas or for the whole study area, but caution must be used.

Bird Risk.—Bird Risk establishes a relationship between bird utilization and bird death. Bird Risk can be used to compare differences between various locations and situations. If Bird Risk is high or increases in certain situations, these situations would be focal areas for more concentrated studies:

Formula: Bird Mortality/Bird Utilization Rate = Bird Risk

Early Results: $\frac{\text{0.07 dead birds/search site}}{\text{1.89 birds detected/point count}} = 0.037$

Bird Risk can be calculated for any of the specific situations listed above for utilization rates. Bird Risk must be considered in the perspective of the local situation. An increased Bird Risk may or may not be of concern, depending upon the species and numbers of individuals involved. These are determinations that must be made based upon local knowledge and by the appropriate authorities and stakeholders.

Conclusions

We are in the early stages of testing the "Avian Risk Assessment Methodology". However, it appears that it has a great potential to provide the types of data and information that will be valuable in decision making and impact assessment. This methodology can be used throughout the nation in regards to wind energy development and other types of activities (powerlines, towers, highways, etc.) during pre-permitting and post-operational monitoring. This methodology lends itself to the Before-After Control-Impact (BACI) sampling design, and will work well for comparisons between WRA areas. In some situations, the results will require calibration by additional studies in order to give perspective to the observed rates (Bird Utilization Rate, Bird Mortality, and Bird Risk). If this methodology is applied consistently in different areas, within a few years the rate relationships can provide a national standard for decision making. The methodology is also well designed to provide data that can assist in developing forecasting (predictive) models.

Overall, this methodology shows great promise. It deserves an adequate testing period with sufficient time for data collection and data analysis. This will determine the utility and value of the methodology and its phased approach to the avian/wind energy issue.

Acknowledgements

The dedicated efforts of Dr. Michael Morrison, Dr. Larry Mayer, and Dr. Sheila Byrne are gratefully acknowledged. Without their wisdom, insight, and knowledge this methodology would not have been developed. These persons deserve the credit for this methodology. Any short-comings are because the investigators failed to fully develop their concepts, direction, and advice. We also thank Cannon Energy Corp., FloWind Corp., SeaWest of Tehachapi Inc., and Zond Systems Inc. for their cooperation and support.

Discussion

This presentation evoked much discussion among the meeting attendees, mainly on the following topics:

Most Appropriate "Control" or "Reference" Sites.—An attendee noted that wind plants are sited in the windiest parts of Wind Resource Areas, and individual turbines are sited in the windiest locations within a given wind plant. Does this cause bias in sampling birds? Mr. Anderson noted that, with the proposed methodology, sampling locations are randomized relative to turbine locations. Bird utilization, mortality, and related variables can be examined in relation to distance from turbines.

Are Repeat Sightings a Problem?—In this study, birds that are seen from more than one sampling point are counted each time. Sampling points are 300 m apart. Attendees noted that, with this spacing, repeated sightings are unlikely in forest or for small birds in open country, but may be common for large raptors. Mr. Anderson indicated that successive point counts are about 1½ hours apart, mainly because of the time required for the dead bird search at each point. He suggested that, if the methodology is applied consistently in different studies, results should be comparable. Repeated sightings would be most likely to cause complications if statistical methods treating each point as independent were applied.

Should Point Counts be "Bounded"?—Point counts can include all birds detected at any distance, or can be limited to some maximum distance ("bounded"). In this study, bird counts to determine utilization rate are not bounded, but the distance to each bird is estimated. It was noted that

- use of a fixed distance can cause complications if birds close to the point tend to avoid the observer,
- the most appropriate fixed distance would depend on the habitat and type of bird, and use of a fixed distance reduces sample size,
- unbounded point counts are commonly used in other studies, and
- with unbounded counts, analyses of detection distances can be used to evaluate sightability (see Laake et al. 1993, *DISTANCE user's guide*, Colorado Coop. Fish & Wildl. Unit, Col. State Univ., Fort Collins).

Fixed Radius During Mortality Searches.—Some attendees asked whether, in estimating Bird Risk, it was appropriate to relate dead birds found within a fixed radius (numerator) to a utilization rate based on unbounded point counts (denominator). It was suggested that this is not a problem because the resulting ratio is recognized to be an index, not an absolute estimate. However, the same method would need to be used in all studies being compared. It was agreed that complications could arise if sightability during point counts differs among the various situations being compared. If so, the sighting distance data could be used to truncate the utilization data to the same radius as used for dead bird searches, but then the problems associated with "bounded" counts (see above) would be of concern.

Rationale for Leaving Dead Birds in Place.—Mr. Anderson explained that, during dead bird searches, carcasses are left in place because some locations may be re-sampled later. During Phase I, obvious injuries are noted, but necropsy is not feasible when the dead bird is left in place. The priority during the Phase I study is to determine whether mortality varies from place to place, not to determine the causes of specific deaths. Attendees discussed the advantages and disadvantages of this approach, and the complications that may arise because of requirements to report dead birds to the Fish & Wildlife Service. If Phase I shows that dead birds are common enough to be a concern, it may be a high priority to collect dead birds for necropsy during a follow-up Phase II study.

Rationale for Various Measures.—There was considerable discussion about the merits of some proposed measures and analysis approaches, e.g.

- whether Bird Risk is a useful index when the numerator (dead birds found within fixed radius) and denominator (birds seen in unbounded area) are in different units and in areas of different sizes; and
- whether the categories used in preliminary analyses (e.g., the "Distance from Turbine" categories in Fig. 3) are the best choices.

It was noted that the analysis procedures are still being developed, and that comments such as these are being sought in order to improve the analysis approach.

Objectives and Relevance of the Phase I Study.—Several attendees made suggestions about additional types of data that might be desirable, including

- necropsies of dead birds to better define causes of death,
- focused dead-bird searches near turbines,
- determination of bird "passage rates" by day and by night, and
- use of surrogate variables for utilization, deaths, or both, if surrogates that are meaningful and easier to measure can be identified and measured.

It was pointed out that the goal of the Phase I study is "to determine if an operating wind plant results in an increased risk of bird mortality compared to the surrounding non-developed area". Determining the specific reasons for any differences is beyond the scope of Phase I. There would be complications and costs in implementing any of the extra tasks suggested above. However, Phase I is expected to identify the topics on which subsequent effort should be focused.

A key feature of the Phase I methodology is that it provides data on bird utilization and bird deaths in the same areas at approximately the same times. This approach may reduce the necessary study duration and level of effort because it allows one to calculate risk rates that take account of unavoidable fluctuations in bird utilization.

It was also noted that the Phase I study will provide data on the extent of inherent variability in utilization, bird deaths, etc. With this information, statistical power analyses can be done

- to document the effectiveness of the Phase I study in detecting differences in utilization, mortality, and risk between different situations, and
- to estimate the sample sizes necessary to achieve a specified level of precision during future related studies.

The inherent variability in biological systems cannot be avoided, but uncertainty in conclusions can be reduced by selecting an appropriate study design and sample size. The Phase I study should provide data useful in evaluating the effectiveness of Phase I and proposed follow-up Phase II studies in addressing questions of interest to decisionmakers and other stakeholders.

Suggested Practices for Monitoring Bird Populations, Movements and Mortality in Wind Resource Areas

by

Sidney A. Gauthreaux, Jr., Clemson University[10]

Introduction

This paper emphasizes the needs for minimum standards in formulating study designs for measuring low-altitude bird movements, and conducting dead and injured bird searches within wind resource areas and at specific wind development sites during pre- and post-construction periods. If future studies use standardized protocols, comparisons between data sets will be facilitated, prediction of regional impacts of wind resource development on birds will be possible, and all will be accomplished in a more timely manner.

In order to accurately assess the environmental impact of a wind farm project, pre-construction studies are indispensable. The function of a pre-construction study is to document baseline conditions that can be used to predict (1) changes in the distribution and abundance of avian populations on and near the wind farm, and (2) collisions with wind turbine blades, towers, guy wires, and transmission lines in the project area. These baseline data are also essential for the quantification of the actual impact after development (Jones 1986).

Population Assessment Studies

Sampling Design and Statistical Analysis.—Once the utility or developer decides to conduct a pre-construction assessment of bird populations and movements, a sampling design must be chosen. Green (1979) provided a useful guide to sampling designs and statistical analyses for environmental studies. The design and associated statistical analyses can be set in a "spatial-by-temporal" framework that generates options (Green 1979). He suggests that an optimal impact study design must meet four prerequisites:

- the study must begin before the impact occurs, so before-impact baseline data can be collected to provide a temporal control for post-impact data,
- the type of impact and time and place of occurrence must be known so a sampling design appropriate for the relevant tests of hypotheses can be devised,
- it must be possible to measure all relevant biological and environmental variables in association with the individual samples, and
- an area that will not receive the impact must be available as a spatial control.

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The first and last prerequisites dictate that controls in both space and time are necessary. The prerequisites also define a design with at least one time of sampling before impact and at least one after impact, at least two locations differing in degree of impact, and coordinated measurements of environmental and biological variables. The optimal impact study design is referred to as an "areas-by-times factorial design", and the appropriate statistical analysis of the data is an analysis of variance (ANOVA) procedure, with or without covariates.

Study Site Selection.—For a pre-construction study, specific study sites must be selected within and adjacent to the proposed wind farm site. These sites should be located at the same sites where wind resource data are being gathered. During the pre-construction bird study, the meteorological towers installed to measure wind resources can be used as references to estimate the heights of bird flights over the sites in the absence of wind turbines. Dead bird searches can also be made around these towers to assess mortality from the towers and guy wires. In the selection of study sites it is important to remember that two sites, at the very least, should be studied. One or (ideally) more of the sites will serve as control sites once construction activities begin. The control and treatment (wind turbine) sites should be matched as much as possible with regard to physiognomy (the topography and other geophysical characteristics of a land form and its vegetation) and landscape structure (e.g., species composition and species abundance in relation to the sizes, shapes, numbers, types, and configurations of habitats [Turner 1989]). Each study site should be mapped with respect to topographic features and habitats.

Most past and current bird studies at wind turbine sites have not used control areas, so pre- to post-construction changes cannot be attributed positively to construction and operation of the wind farm. At existing wind farms it is possible to establish control areas so future population fluctuations of birds can be compared between treatment and nontreatment sites. However, in the absence of corresponding pre-construction data, this will provide no information about pre-construction vs. post-construction differences in bird populations or habitat use. The optimal design requires pre- and post-construction surveys of both the wind farm and the spatial control site(s).

Recommended Monitoring Techniques.—It is important to use a technique for monitoring bird populations that will provide sufficient information for assessing the impact of the wind development on the avian resource. A monitoring program should provide information on (1) estimated population sizes and trends for various species of birds, (2) estimated demographic parameters for at least some of the populations, and (3) habitat data to link population size and demographic parameters to habitat characteristics. Because of the lack of information on the species at risk at wind farm developments, all species should be monitored. However, emphasis may have to be placed on particular species (e.g., endangered or threatened species) or groups of special concern (e.g., raptors). Many monitoring techniques are available, but the techniques differ depending on the bird species that require monitoring. Several techniques have been used to estimate populations of non-game birds (shorebirds, raptors, songbirds), and these techniques have been treated by several authors and assembled into volumes dealing with survey designs and statistical methods for

estimating avian populations (Ralph and Scott 1981; Sauer and Droege 1990; Bibby et al. 1992).

Despite the number and diversity of techniques available for monitoring populations of different species groups, point counts like those used in the Breeding Bird Survey (BBS) can gather data on all species of birds seen and heard during each census stop. The BBS uses 3 minute census stops, although other durations are used in some point count studies (Ralph et al. 1995). BBS counts, known as extensive point counts, are done at a series of points, placed a minimum of 250 m apart, largely on roads or trails over an entire region (Ralph et al. 1993). The procedure for making these point counts can be found in Ralph et al. (1993). It is important to include a brief description of the habitat for each point count (e.g., vegetation types, major layers with some information on heights and densities). This includes information on elevation, slope, aspect of slope [compass direction the observer faces when looking down hill], and presence or absence of water within 50 m of plot center). Additional details can be found in Ralph et al. (1993, 1995). The final paper in Ralph et al. (1995) consists of recommended standards for point counts, as developed during a workshop on point count methodology.

If manpower and financial resources permit, Breeding Bird Censuses (BBC) at study sites are very desirable for gathering data on the number of breeding pairs of birds per unit area. The BBC procedures have been developed primarily for songbirds and not for raptors and other large, sparsely-distributed species. The spot-mapped counts of the BBC determine the mean density of territories for each species per 40 hectares. The plots may range in size from 10 to 20 hectares for passerines, grided in 50 m squares, or they may be larger and grided in 100 m squares. The former is typical for woodland and brush areas while the latter is suggested for open terrain (e.g., grasslands). BBCs should be in relatively homogeneous habitat. It is desirable to have paired plots in different habitats in the windplant and control areas. All birds seen or heard are "mapped" on grided data sheets during a walk-through. A minimum of eight visits (one per morning) and one or two late afternoon or evening visits is recommended. A morning walk-through should begin about sunrise and continue for approximately three to four hours. The data are summarized for each species, and the mean number of territories per 40 hectares is calculated. Additional information on conducting a Breeding Bird Census can be found in Ryder (1986) and in *Audubon Field Notes*, 24:723-726 (1970).

For plot studies during the nonbreeding season, the format recommended for Winter Bird-Population Studies should be followed. Most plots range in size from 6 to 20 hectares (14.8 to 49.4 acres) and the plots are visited 6 to 10 times in midwinter. The totals for each species are averaged and the results are expressed in terms of birds per square kilometer and birds per 40.5 hectares (100 acres). Kolb (1965) provides additional details for conducting Winter Bird-Population Studies.

Statistical procedures for estimating avian population trends can be found in Sauer and Droege (1990). An analysis of variance procedure can be used to compare wind farm and control areas. Additional statistical recommendations can be found in Green (1979).

Monitoring Low-altitude Bird Movements

Comprehensive data on the number of low-altitude flights through the zone of potential collision are necessary if one is to calculate meaningful estimates of the numbers of birds at risk from collisions. The study methods that follow are generic and represent a synthesis of methods used in studies of low-altitude movements of birds over diverse landscapes, in different seasons, and during the day and at night. Methods for conducting assessment studies will vary somewhat depending on circumstances (e.g., different turbine designs and arrangements, different topographies, and different types of birds). Consequently some flexibility in methodological detail is required, but the fundamental design of an assessment study should be as standardized as possible.

Three types of observations should be made during pre- and post-construction monitoring studies of bird flights in a project area: (1) corridor observations, (2) circular scans, and (3) surveillance radar.

Schedule of Observations.—Initially full day and partial day visual observations extending from one-half hour before sunrise to one-half hour after sunset should be made for each study area. The frequency and duration of watches will depend on whether they are corridor or circular scan observations (see below). Other observation times should be scheduled so that flight counts are made during inclement weather and during darkness. (A few resident species may be active at night, and much migration occurs at night.) Twilight observations are feasible if observers position themselves so that birds are silhouetted against the horizon, and observations with 7 x 50 binoculars are also possible on nights with bright moonlight (Lee and Meyer 1977). However, image intensifiers and forward looking infrared devices are recommended for twilight and nighttime observations. Once the temporal patterns of daily movements have been worked out, visual sampling can be concentrated in periods of greatest activity.

Visual Corridor Observations.—Visual observation (often aided with binoculars or spotting scopes) is the most common type of monitoring in studies of low-flying birds, because no other method enables the observer(s) to identify readily and to count accurately the birds in a flight. Knowledge of the kinds and total numbers of birds and when and where they cross through the proposed or existing wind farm is essential for the times when dead bird counts are conducted. Data from these observations provide a basis for interpreting mortality levels obtained from dead bird counts and provide information on the effects of various turbine designs and placements on bird flight behavior under different environmental conditions. Many studies have used periodic and systematic observations of bird flights across an area or near existing man-made objects such as a string of wind turbines, broadcast towers and transmission lines, e.g., Rogers et al. (1977), Avery et al. (1977), McCrary et al. (1981, 1983), Gauthreaux (1985), Hugie et al. (1992). These studies have used fundamentally similar visual observation techniques. Based on the information in those studies, the following procedures are recommended during visual observations of bird flights at planned and existing wind resource development sites.

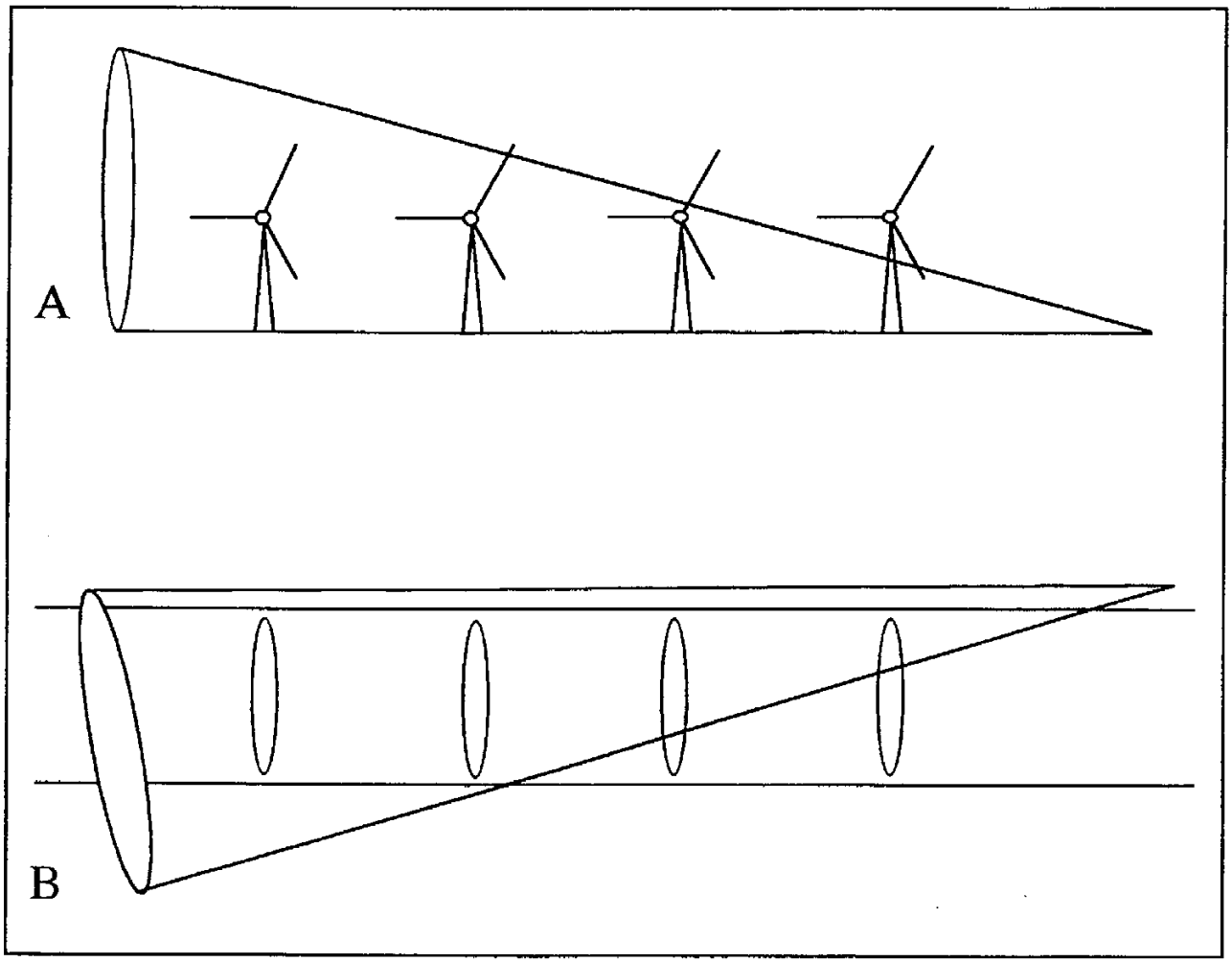

FIGURE 1. Cones of observation at a string of wind turbines. ***(A)*** The vertical sampling area increases as a function of distance. This area should be calculated in order to determine accurately the number of bird crossings per area sampled. ***(B)*** If the observer is positioned off the line of turbines, then distance to bird can be determined more accurately. Marine surveillance radar can also be used to determine distance to bird.

All observations of bird flights through a corridor where wind turbines will be or are located should last 30 minutes. An observer should be positioned slightly off the corridor line so that the distance to the birds crossing the corridor can be determined. Observers should station themselves so that their presence will not affect the flight behavior of the birds in the area and so that the observation point allows a view of the greatest linear distance for which birds can be readily observed (Fig. 1).

Observers should endeavor to record each bird crossing the corridor of observation. This can be accomplished by scanning the corridor with binoculars or by directing a telescope down the corridor and watching continuously. The optical equipment used to make observations

should also be noted on the data sheet, e.g., 7 x 50 binoculars, 20 x 60 telescope. Ten power binoculars are ideal for identifying birds at a distance and provide good depth of field. Spotting scopes (20x, 30x) are useful for observing birds at greater distances, but have a limited depth and breadth of field, and have less maneuverability because they must be mounted on a tripod to steady the image. Binoculars having objective lenses with diameters in mm greater than 5 times the magnification power (e.g., 7 x 50) provide bright images and are excellent for twilight observations. The cone of observation for each optical device should be determined because this information will be useful in calculating the sampling area and rates of passage (Fig. 1). Observers should use blinds or vehicles as observation stations. When large expanses of water are involved, observations can be made from an anchored boat. Single observers should use a tape recorder so that monitoring can be continuous when flights are frequent and contain many birds. Data can be transcribed from tape to data sheets after observation periods end. If two observers are involved, they can be separated with one person at each end of a string of turbines and can communicate via two-way radio. One observer should record all of the data. The observers can alternate assignments between watches. Two observers can also be positioned side-by-side with one observer monitoring movements within a few hundred meters of the station and the other observer monitoring movements at greater distances (Gauthreaux 1991). Each observer should be trained to record data the same way and checked and evaluated by the project leader on a regular basis. The maximum distance that can be monitored without loss of information will depend on visibility conditions (heat distortion, haze) and is about a mile (1.6 km) in warm, high humidity conditions and is greater in cool, dry conditions.

An example of a data sheet for bird movement observations can be found in Appendix 1. This data sheet can be used for three different types of observations: (1) corridor, (2) circular scan, and (3) marine surveillance radar. The information that should be encoded in each column of the data sheet can be found in Appendix Table 1. At the beginning of a watch (or the resumption of a disrupted watch) the observer(s) should fill out columns 1-12, 14-25, 45-46 and 47 when appropriate; the rest of the columns should be left blank. A check in column 12 indicates the start of a watch with a duration of 30 minutes. For each bird flight across the corridor a new line of data should be added to the data form. Most of the information added to the data sheet at the beginning of the watch will not change during the watch so there is no need to add this information for each bird crossing—simply draw lines to indicate that the information is unchanged. When a bird flight *crosses* the corridor, the pertinent information should be placed in columns 20-43. AOU numbers (columns 30-33) can be added at a later time if needed for data analysis. Corridor observations should last for 30 minutes, and at the end of a watch (or time out) the observer should indicate a stop time by checking column 13 and filling in columns 20-23. If no birds were observed, only the start time and finish time lines should appear on the data sheet.

The altitudes of birds passing through the corridor will have to be estimated. This is most difficult during pre-construction studies when turbines of known height are lacking. However, it is often possible to use meteorological towers or other objects of known height for reference. For more accurate altitudinal measurements a clinometer can be used to measure the elevation angle of the birds as they cross the corridor. Elevation angles and

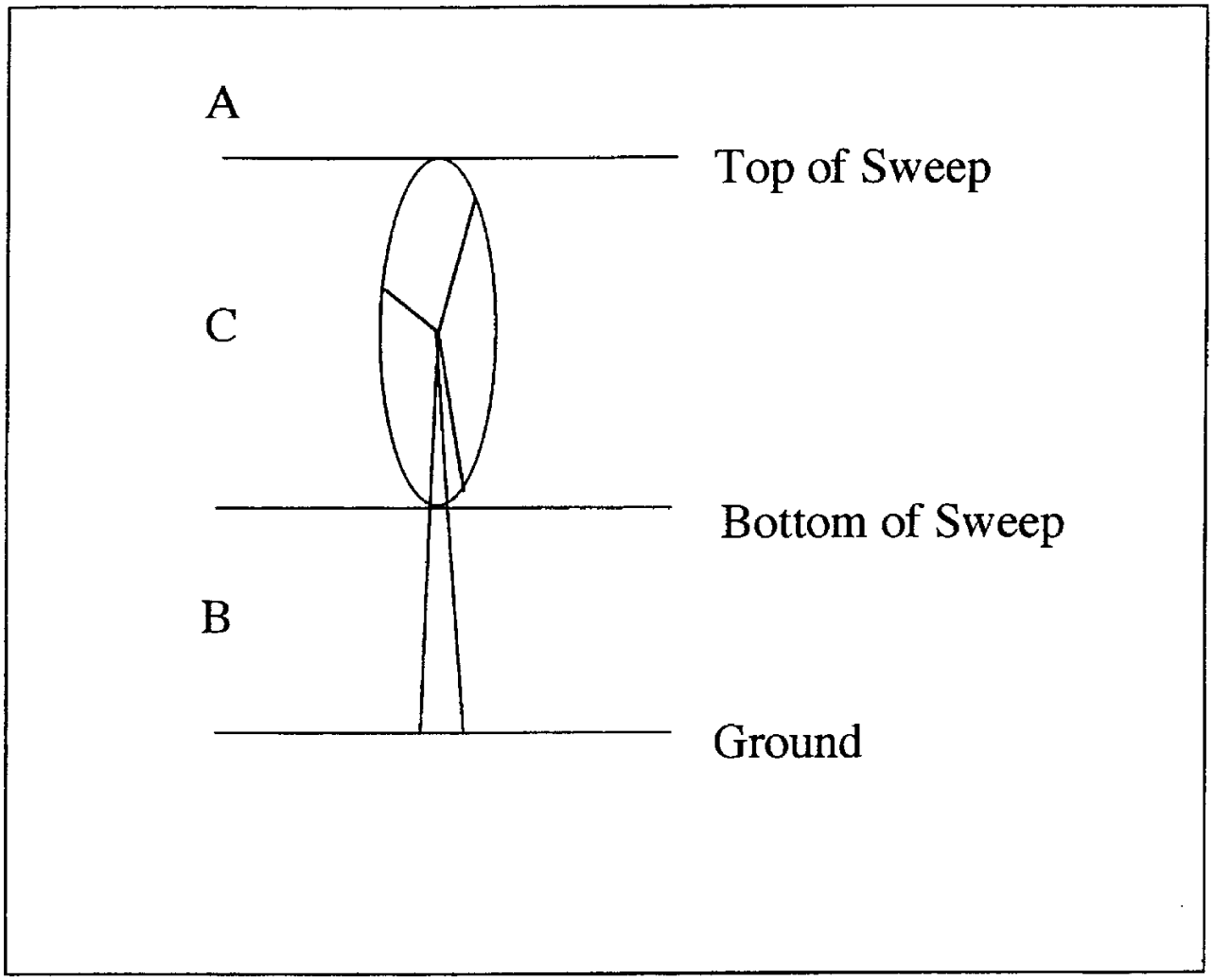

FIGURE 2. Altitudinal zones of bird flight relative to the wind turbine. **A**=above turbine. **C**=zone of potential turbine collision; also "zone of risk". **B**=below turbine, but in zone of potential collision with supporting tower and guylines.

exact or estimated distances from the observer are required to compute the altitude of flight. Marine surveillance radar can be used to measure exact distances (see below).

During post-construction bird studies, the flight altitudes of the birds can be coded with reference to the turbines (Fig. 2), but information on heights of flights (in meters) will be necessary for across-study comparisons. It is essential that the height categories in Figure 1 be measured in meters for the different turbine designs studied. Because of the differences in turbine designs and heights, details of the turbines such as configuration, size, rotational speed, tower design (lattice, solid, guy lines), and size of development (wind farm) should be noted for each observation location. This information should be the same for all observations at a particular study site.

Visual Circular Scans.—It is important to collect information on bird movements and activity in the general vicinity of the proposed or existing wind farm, not just along the corridor(s) where turbines will be placed or where string(s) already exist. Therefore, circular (360°) visual scans should be made. All circular scan observations should last for 8 minutes with 2 min devoted to scanning each of four sectors: NE, SE, SW, NW. The data form for corridor observations can be used for circular scans. At the beginning of a watch information should be added on the data sheet in columns 1-12, 14-25, 45-46 and possibly 47, and the remaining blanks left uncoded. The entry in column 12 will signify the beginning of the watch. The observer, using a compass, should start at N and slowly turn clockwise while scanning the sky up and down. When bird(s) are detected, the information in columns 20-44 should be recorded onto the datasheet or audiotape. At the very least the data should include information on species, number of birds (if a flock is observed), distance, and direction to bird(s). Altitudes of birds seen during this type of watch may be difficult to estimate, but if it is possible to indicate altitude above ground (column 40) this information could prove to be valuable. The addition of column 44 in the circular scan protocol (not used in corridor observations) permits coding the direction of the bird(s) from the observer:

Col. (44)	Direction to Bird(s):			
	1-N	(337.5-022.5°)	5-S	(157.5-202.5°)
	2-NE	(022.5-067.5°)	6-SW	(202.5-247.5°)
	3-E	(067.5-112.5°)	7-W	(247.5-292.5°)
	4-SE	(112.5-157.5°)	8-NW	(292.5-337.5°).

Marine Radar Observations.—Radar studies of bird movements are recommended during pre- and post-construction phases of wind farm development. They can rapidly provide information on low-altitude movements of birds in the project area. Moreover, radar surveillance is essential for monitoring low-altitude movements after dark during spring and fall migration. Small marine surveillance radars can provide useful information on the movements of birds within a range of a few kilometers, the units are relatively inexpensive, and they can be mounted on a small truck or van and powered by a small 500 W gasoline generator (e.g., Williams et al. 1972; Gauthreaux 1981, 1884, 1985; McCrary et al. 1981; Cooper et al. 1991). Small marine radars (10 kW peak power) can detect individual small birds (swallows) out to 1.2 km (0.75 mi.) and single larger birds (e.g., Ring-billed Gull, *Larus delawarensis*) out to 2.4 km (1.5 mi). Marine radars can detect birds crossing a corridor more readily than can observers with binoculars (Korschgen et al. 1984), and radar surveillance allows investigators to study nighttime, dusk, and dawn bird movements when visual observations are unreliable or impossible. Marine radar also operates well in fog when typical visual techniques are ineffective, but cannot detect birds in widespread rainfall.

Modern marine radars cost about $1,000 per kW of transmitter peak power; 10 kW marine radars cost about $10,000 US. They can be obtained with digital color displays that show echoes of differing reflectivities in different colors, and they have the capability of on screen plotting and an alarm function. On screen plotting allows the display of previous echo positions for a specified time period such that the tracks of the echoes are displayed on the radar screen. This facilitates gathering information on direction and speed of flight for each

bird target. The alarm function is of great benefit when the amount of movement is very low. This function sounds a beep when an echo enters a user-defined zone on the radar screen. The color display makes observing bird movements easier, but a monochrome display provides better resolution, is easier to video tape, and is less expensive. A marine radar for monitoring low-altitude flights of birds should have the following specifications:

- 3 cm (X-band) wavelength
- 10 to 25 kW transmitter power (peak power)
- 1.22 m (4 ft) antenna for 10 kW and 2.4 m (8 ft) antenna for 25 kW
- high resolution monochrome radar display
- echo trail to assess target's speed and direction
- audio-visual alert for targets in guard zone

On an X-band radar, a standard "slotted waveguide" antenna with a 1.22 m (4 ft) length has a nominal 25° vertical beamwidth and a 1.9° horizontal beamwidth. A 2.4 m (8 ft) antenna has 20° x 0.95° beamwidths.

The on screen plotting (echo trail) function displays echoes from targets detected during every antenna rotation within a 15 s, 30 s, or 1, 3 or 6 min period before screen refresh, or continuously. Thus it is possible to see the entire flight paths of birds as they pass through the area of radar surveillance. The radar display can be videotaped so that a single observer can make visual observations while the radar is simultaneously gathering information on bird movements in the area. Once the display has been photographed or briefly videotaped, the screen can be cleared for another cycle of on-screen plotting. The optimum interval will depend on the intensity of bird movement. The guard zone function will trigger an alarm when a target penetrates a perimeter delineated on the radar screen. These features, available on various "off the shelf" units, enhance the radar operator's ability to obtain information on movements of birds.

Special modifications to the antenna and development of a ground clutter reduction screen make bird detection near the radar easier (Cooper et al. 1991). A marine radar can be powered by a gasoline generator, by a series of fully charged deep-cycle marine batteries, or by 110/220 VAC, 50-60 Hz with a rectifier. Helpful instructions for using marine radars for monitoring bird movements can be found in Williams (1984).

For observations with a marine surveillance radar, the radar should be tuned correctly and all clutter suppression circuitry set in the off condition. The guard zone feature of the radar should cover areas without permanent ground echoes. If permanent echoes are within the guard zone, the alarm will sound every time the antenna rotates. Once the guard zone(s) are defined using the setup procedures, the range and azimuth settings of the guard zone(s) should be the same for every radar watch. The azimuth and range settings for the guard zone should be recorded in a notebook and photographed on the radar screen if possible. In most instances the range of the radar should be set to 0.75 nautical miles. The data sheet for corridor and circular scan visual observations can also be used for the radar data (see Appendix 1, including Appendix Tables 1 and 2).

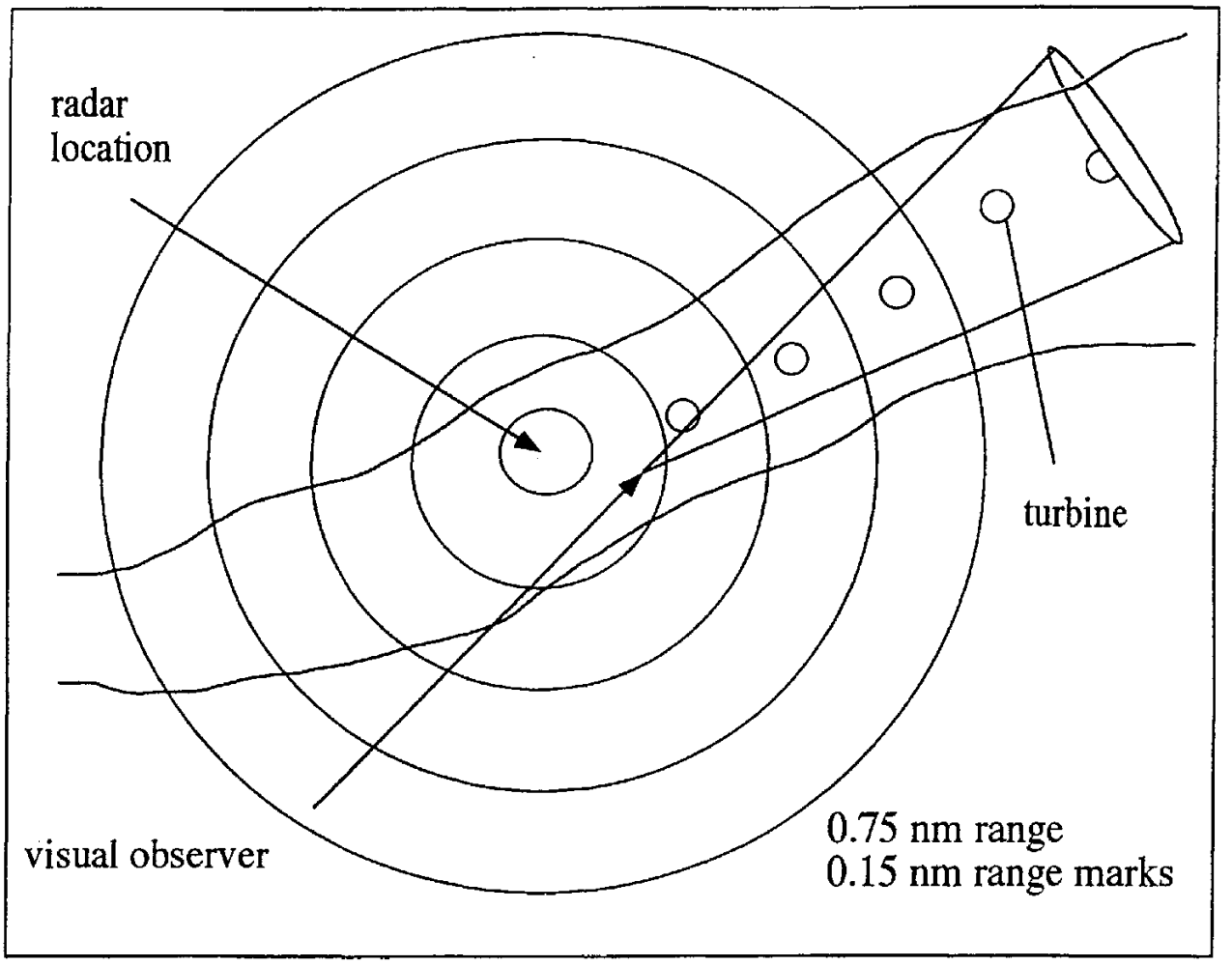

FIGURE 3. Radar and visual surveillance at a wind turbine site.

The positioning of a marine surveillance radar will determine the amount of ground clutter detected. Birds flying over ground clutter will not be visible on the radar screen, so it is important to position the radar unit in such a way as to minimize extensive ground return. Because wind turbines are often located on ridgelines, it is possible to monitor bird movements across the ridgelines by detecting them to either side of the ridge (Fig. 3). Birds moving across the screen will be easily detected as light echoes on a dark background. These echoes will "disappear" as they move over the ground clutter representing the ridge on the screen, and will reappear once they leave the area of ground clutter. Direct visual observations during daytime radar surveillance are strongly recommended. This is the only way to accurately identify the types of birds responsible for the echoes on radar.

Night Vision Device (NVD) Observations.—Because it is necessary to assess the amount of bird movement during twilight and after dark, some kind of night vision device (NVD) is required. Image intensifiers are readily available and the third generation devices offer increased resolution and sensitivity in very dark conditions. Technologically advanced forward-looking infrared (FLIR) devices have also been used for nocturnal observations of

birds. The high cost of FLIRs may make them less attractive for an assessment study, but their ability to detect birds in total darkness is of value. The availability and capabilities of FLIR units are increasing, and FLIR may become a method of choice in the future.

Image Intensifier Observations: Second and third generation image intensifiers can be used to observe low-altitude bird flights after dark. Although results are best when an observer is viewing directly through the scope, most night vision systems can be fitted with video, 16-mm movie, and 35-mm single-lens reflex cameras. Slow shutter speeds and the need for film development make the 16 mm and 35 mm cameras obsolete. The video camera/ image intensifier combination provides the best method for monitoring and documenting night movements of birds near the ground when the observer cannot monitor directly through the night vision scope. Observations are made directly from the high resolution video monitor and a record can be videotaped.

A NVD with a 135 mm or 300 mm lens is best for most observations. A NVD works best when birds can be seen as dark forms against a lighter background, but an infrared spotlight (200,000 candle power) can be used to illuminate birds and make them quite visible against a dark background without affecting their behavior (as can happen if a conventional spotlight is used). During observations, the NVD is placed in a fixed position at approximately a 15° angle to the corridor or string of turbines. The height band that can be sampled will be restricted by the narrow field of view, and will change as a function of distance. Near the observer only a very small altitudinal sample is possible, but at greater distances the range of heights that can be sampled increases. Because the field of view will vary depending on the type of NVD and the attached lens, one should measure the field of view at some known distance so the sampling space can be calculated. Observers should record the same types of data as are gathered during daylight observations.

Night vision devices must be used in an enclosed shelter during adverse weather such as rain, and in cold, wet weather the lens has a tendency to fog. A battery powered heating strip around the barrel of the scope will usually eliminate this problem. Some larger image intensifiers (e.g., VARO Model AN/TVS-5) weigh 3 kg (6.6 lb) and require a tripod, limiting mobility while viewing and the area sampled. The greatest drawback is that NVDs cannot be used in fog. Because NVDs are extremely sensitive to lights, a NVD should be placed such that marker lights will not be in the NVD's field of view. Additional details concerning image intensifier observations of nocturnal bird movements can be found in Gauthreaux (1985), McCrary et al. (1988), and Hartman et al. (1992).

Forward Looking Infra-red (FLIR) Devices: One of the most recent technological advances that may assist researchers in monitoring the movements of birds at night is thermal imaging. Unlike image intensifiers, which require some very low level of light to function, FLIR devices detect the thermal (infra-red) emissions of the targets and electro-optically generate detailed visual images on the screen of a video monitor. Because FLIRs can operate in the absence of any ambient light, they are ideally suited to monitoring bird movements at night, but the cost of a high quality thermal imaging unit ($75,000-$125,000 US) is considerably higher than the cost of a high quality image intensifier ($4,000-$10,000

US). Additional information about using FLIR devices to monitor bird movements at night can be found in Winkelman (1992, 1994), Cooper and Day (1992), and Liechti et al. (1995).

Dead Bird Searches

Search Area.—The search area around a wind turbine should be circular and the minimum radius determined by the height of the turbine. Taller turbines will require greater search radii. When the turbines are in a string, it may be most efficient to search a strip along both sides of the string and around the end turbines. Winkelman (1989) searched for dead birds within 60 m on both sides of a row of 25 mid-sized wind turbines (30 m tower height, rotor diameter 25 m). The distance between wind turbines was 125 m and the total length of the row of turbines was 3 km. In another study, Winkelman (1992a) searched for dead birds within 50 m around each of 18 wind turbines (tower height 35 m, rotor diameter 30 m). Most victims were found in the area behind the rotor or on the right front side of it. The search around each turbine took approximately 45 minutes.

Searches encompassing an area within 70 m (230 ft) from a turbine or meteorological tower should be sufficient for locating dead birds. A spiraling outward search path is most efficient, but a tight zigzag search pattern is also effective, particularly when turbines are in a string and less than 140 m apart. Depending on wind conditions, the height of the turbine, and the slope of the terrain (bigger radius if steep downslope), search areas may require enlargement. It would be useful if some post-construction studies were able to quantify the distribution of dead birds around turbines of different heights. When the positions of all dead birds are plotted one can assess if the area searched is adequate (see Hartman et al. 1992 for an example from a transmission line study). If the area is adequate, there will be very few or no dead birds near the outer edges of the areas searched.

At wind farms, searches along transmission lines should cover the entire right-of-way and the width of the search area should be chosen with reference to the height of the power line (James and Haak 1979; Ravel and Tombal 1991). The height of the line is, of course, dependent on the voltage of the line and local topography. Searchers should use a zigzag course in searching so the area is covered systematically. The following widths are suggested based on previous studies:

- out to 50 m (164 ft) from outer conductor on either side of a 500 kV transmission line
- out to 45 m (147.6 ft) for a 230 kV line
- out to 20 m (65.6 ft) for a 115 kV line.

Timing of Dead Bird Searches.—Although dead bird searches are time consuming, it is essential that searches be conducted daily, and if at all possible, twice daily—at first light in the morning and just before dark in the late afternoon (James and Haak 1979). In this way the collision victims can be categorized as colliding during the day or the night. In the Meyer (1978) study, searches were conducted daily and as early as possible, light permitting. This was done to minimize scavenger removal. Beaulaurier (1981) conducted searches before afternoon flight observations and again the next day after morning observations. This

schedule enabled the estimation of numbers of birds killed and injured at night, between observation periods. Winkelman (1992a) searched a wind park in the Netherlands once or twice a week in spring and on most week-days during autumn migration. Orloff and Flannery (1992) searched each sample site in their study for five weeks: twice a week in spring and once a week in five remaining seasons of their study. Although they found little evidence of scavenger removal, scavenging rates are known to be high in some areas, especially for small birds. Therefore, searches need to be done at more frequent intervals—ideally twice daily.

Data Records for Collision Victims.—A map showing the locations of all the turbines searched should be made. For each bird found the following information should be tabulated:

- nearest turbine identification number; bearing and distance from that turbine
- species
- sex
- age (adult or juvenile) if possible
- approximate time of death
- physical condition (including broken bones, lacerations, abrasions, blood, discolorations, gun shot wounds, decomposition, feeding damage by scavengers)
- probable cause of death
- necropsy (if possible)

In some studies all birds found were photographed and a waterproof tag with an identification number was attached to each bird's leg. A marker indicated the position of each dead bird that was left in place so that rates of scavenger damage and removal and of decomposition could be measured. Feather spots were recorded and listed separately from birds. When a dead bird is scavenged by a raptor or coyote, a rather tight cluster of feathers (feather spots) remains. For each feather spot the following information should be noted:

- date
- species or group
- location

Both dead birds and feather spots can be used in estimating the amount of collision mortality in relation to the number of flyovers. In certain cases, dead birds may be found without firm evidence of collision mortality; other factors may have been responsible for the mortality. In such instances some additional laboratory analysis (e.g., toxicological analysis) may be advised. Fluoroscopy has been used to detect lead pellets in dead birds and gizzards have been examined to see if they contained lead pellets (Anderson 1978). Because some mortality at wind farms is not related to collisions or electrocution, a necropsy may be necessary to determine the probable cause of death. A veterinarian specializing in birds can be consulted. A state or federal wildlife agent will know who to contact for this service.

A data form for dead bird searches is given in Appendix 1 (see also Appendix Table 3).

Biases in Dead and Injured Bird Searches.—Three biases cause underestimation of the number of dead birds: search bias, removal bias, and crippling bias. The objective is

to develop correction factors for biases, so that the number of actual collisions is not underestimated. In addition, some habitats (e.g. water) may be unsearchable, resulting in the need for a fourth correction factor for "habitat bias". In some wind turbine/bird mortality studies, efforts have been undertaken to measure these four biases (see Winkelman 1989, 1992a).

Search Bias: This bias represents the fact that not all dead birds present are detected during searches, given the effects of terrain, vegetation, and the searcher's ability and experience on detectability. To measure this bias an assistant should randomly place dead birds in the search area. The normal dead bird search procedure should then be followed by another investigator (the individual being evaluated). The percentage of "planted" birds not found determines the search bias:

$$SB = (TDBF/PBF) - TDBF,$$

where SB = search bias, TDBF = total dead birds and feather spots found in the search area during the study, excluding those found during the initial search, and PBF = proportion of planted birds found during the plant/recovery study. A separate estimate of dead birds for each species collected should be calculated, because the calculated search bias varies as a function of the conspicuousness of the bird and because scavenger removal and habitat biases often vary over time and location. In Winkelman's (1992a) study of 18 wind turbines, 18, 21 and 86 small birds were placed around the turbines and 39, 52 and 40 per cent were found in three different years. For large birds, 9 and 12 individuals were placed around turbines on the wind farm in two different years, and 89 and 75 per cent were recovered. This illustrates that correction factors for small and large birds must be calculated separately. The same is true for different habitats in the wind farm.

Removal Bias: This bias occurs when scavengers remove dead birds prior to a search. To measure removal bias, a number of dead birds is placed throughout the search area. Each day for a week, the condition of these birds should be monitored. Removal bias is the percentage of birds missing with no trace remaining and is expressed by the following formula:

$$RB = (TDBF + SB)/PNR - (TDBF + SB),$$

where RB = removal bias by scavengers and PNR = proportion of "planted" birds not removed by scavengers. Ravel and Tombal (1991) and others have noted that removal bias varies with the size of the birds such that smaller birds disappear more frequently and more quickly. This pattern was also noted by Brown and Drewien (1995). They found that crane carcasses sometimes remained for as much as a year after death and no crane carcasses were removed by scavengers during the removal studies. In contrast, passerines frequently disappeared overnight. Consequently the effects of size must be included in calculations of removal bias and must be considered when planning a removal bias study.

Habitat Bias: This bias occurs when some portions of a study area may not be searchable because of water or dense vegetation. Investigators can estimate the percentage of unsearchable habitat from on-ground surveys using the following formula:

HB = (TDBF + SB + RB)/PS - (TDBF + SB + RB),

where HB = habitat bias and PS = proportion of area that is searchable. Habitat bias estimates should not be used as a replacement for field work. Researchers should not extrapolate beyond the area sampled, because conditions could cause the rate of collision to differ in different habitats. Habitat bias estimates should be used only in very limited situations where unsearchable habitat is finely interspersed with searchable habitat and where the researchers can demonstrate that the numbers of dead birds occurring per unit area in searchable and unsearchable habitats are similar.

Crippling Bias: When some birds fall outside of the search area or fall in the search area, move out of the area, and subsequently die, they are missed by searchers. This miss factor is called crippling bias. Estimates need to be calculated for wind turbines of different designs. The adjustment for crippled birds can be calculated from the following formula:

CB = (TDBF+SB+RB+HB)/PBK - (TDBF+SB+RB+HB)

where CB = crippling bias; PBK = proportion of observed collisions falling within search area.

Crippling bias estimates are extremely difficult to obtain because of the effort required to witness an adequate sample of injury-causing collisions. Consequently, crippling bias is the least likely factor to be calculated in a study. However, the application of estimates from other studies may be inappropriate and may be very misleading. Once again, the size of the bird may make a significant difference because of flight dynamics considerations. Smaller birds might have a higher crippling bias than large birds. This possibility needs to be examined in future assessments of bird collisions with wind turbines and transmission lines. Winkelman (1992a) reported that 17 per cent of the 76 collision victims she found in a study of 18 wind turbines during six spring and four autumn periods were wounded but still alive.

Estimate of Total Collisions (ETC).—The estimate of total collisions (ETC) equals the total dead birds and feather spots found plus each of the estimates of the biases such that

ETC = TDBF + SB + RB + HB + CB.

Although this formula includes HB and CB, estimates of these biases should be included only if credible numbers have been calculated on-site. The shortcomings of estimating HB and CB have been addressed above.

Collision Rate Estimate (CRE).—An important statistic in studies of bird collisions with man-made structures such as wind turbines and transmission lines is the collision rate estimate—the percentage of birds that collide with the structure relative to the number that pass the structure in the zone of risk. This estimate should be calculated for different species groups (e.g., raptors, songbirds), and must be calculated using the estimated total collisions (ETC) and the estimated total flights (TF) for the study period, multiplied by 100 to convert to a percentage:

CRE = (ETC/TF) x 100.

The method of computation of total flights (TF) is very important because there is tremendous variance in the way these data are collected. In general, only crossings at altitudes where collisions seem possible should be included. Winkelman (1992b) has emphasized that only those birds attempting to cross through the rotor of a turbine are at risk. She noted that, during daylight, 14 birds were observed trying to cross through the rotors and one of these (7%) collided. During twilight and darkness, 51 birds tried to cross the rotors and 14 (28%) collided. Because there are no hard and fast rules for defining at-risk crossings, and definitions of the zone of probable collision may vary, it should be standard practice to compute collision rate estimates for birds crossing within a narrowly defined altitudinal band (at-risk crossing) as well as for birds crossing within the broadly defined altitudinal band (all crossings).

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Discussion

Appropriate Degree of Standardization.—Some attendees suggested that the most appropriate field sampling protocols will differ between projects depending on specific project objectives and local circumstances. They suggested that study objectives need to be defined before the list of variables to be recorded is determined. They further suggested that, for some studies, some of the variables on the suggested data sheets (see Appendix) will be unnecessary. Some attendees questioned whether one observer could record all the variables on the suggested data form, and suggested that investigators should be advised to focus on the variables actually needed in their particular studies.

Other attendees indicated that a considerable degree of standardization across studies is desirable to make the results from different locations and different investigators directly comparable. Dr. Gauthreaux indicated that all variables on the "Bird Movement Observation Form" (see Appendix) can be recorded by a single observer. However, some attendees recom-

mended that only a selected subset of priority variables should be recorded so the field observers can focus on gathering a large sample of precise data.

Dr. Gauthreaux indicated that his main concern was that any study include effective measurements of all key variables. He emphasized that data on numbers of birds flying through the wind farm are needed to interpret results from dead bird searches.

There was agreement that some refinement of any "standard" procedures will be necessary in each study. However, further discussion is needed concerning the most appropriate balance between standardization across projects vs. adaptation of procedures to individual objectives and circumstances.

Study Design.—There were several questions concerning the most appropriate temporal and spatial layout of sampling by the various methods described in the White Paper. What are the independent units of observation? Dr. Gauthreaux indicated that the units of observation are "birds seen per half-hour watch" during a corridor scan, and "birds seen per 5-min watch" during a circular scan. He suggested that there should be one scan of each type per hour. It should be recognized, however, that sequential scans 1 h apart might not be statistically independent of one another, at least for resident birds. The specific locations where the observation methods would be applied need to be determined taking local circumstances into account. It was agreed that these design issues need to be discussed in more detail during refinement of protocols.

Zone of Risk.—Several attendees commented about difficulties and complications in defining the potential "zone of risk" in which bird flights are counted. Questions included

- whether and how to include allowance for any "downwash" effect below the area swept by the rotor,
- how to count multiple crossings of the rotor plane, e.g. by a foraging raptor, and
- how to apply the "zone of risk" concept to situations involving multiple strings of turbines, or an array of turbines.

Dr. Gauthreaux recommended counting birds in altitudinal zones where birds are at risk either of colliding with turbine blades or of suffering downwash. When multiple crossings by a single bird are observed, the number of crossings should be noted. One can record the heights of bird movements with reference to the "zone of risk" notwithstanding the number of turbines creating the zone of risk.

Corrections for Bias in Dead Bird Searches.—Several attendees noted that different studies have used or are using different procedures, including different intervals between searches and native vs. non-native "planted" birds. Different investigators have given varying degrees of emphasis to the development of bias corrections. It was recognized that procedures for assessing search, removal and other biases need further discussion, and that a comprehensive assessment would be complex and require much effort.

Appendix: Codes and Explanations for Data Sheets

APPENDIX TABLE 1. Codes and explanations for visual observations data sheet.

Column Number	Description
(1)	**Location**—Use the same digit code (e.g., "1") to indicate the same observation segment.
(2)	**Type of Watch**—Corridor = 1; Circular Scan = 2; Radar Surveillance = 3.
(3)	**Wind Direction**: 1-N, 2-NE, 3-E, 4-SE, 5-S, 6-SW, 7-W, 8-NW
(4-5)	**Wind Speed**: mph (can get data from meteorological towers)
(6)	**Precipitation Type**: 1—none, 2—mist, 3—light drizzle, 4—light snow
(7)	**Visibility**: 1—<100 ft, 2—<500 ft, 3—<1000 ft, 4—<1/2 mile, 5—<1 mile, 6—<2 miles, 7—<5 miles, 8—<10 miles
(8)	**Cloud Cover**: (tenths) 0—clear to 1—overcast
(9-11)	**Temperature**: Celsius
(12)	**Start Watch**: check this column and add information to columns 14-23
(13)	**Stop Watch**: check this column and add information to columns 14-23
(14-15)	**Year**—last two digits only (e.g., 94)
(16-17)	**Month**—01 through 12
(18-19)	**Day**—01 through 30 or 31
(20-21)	**Hour**—00 through 24
(22-23)	**Minute**—00 through 59
(24)	**Time Zone**: (e.g., Eastern, Central, Pacific)
(25)	**Time Basis**: (e.g., Standard, Daylight Saving)
(26-29)	**Species Code**—use letter abbreviation codes derived from common name
(30-33)	**AOU Number**—use four digit AOU numbers
(34-36)	**Number**—the number of individuals in a flock
(37)	**Sex**: 1= male, 2=female, 3=unknown
(38)	**Age**: 1=adult, 2=immature, 3=young
(39)	**Flight Behavior**:
	1—straight; 2—curved; 3—zigzag; 4—hovering; 5—landed in corridor; 6—flew up from corridor; 7—circling; 8—; 9—
(40)	**Height of Flight**:
	1—0 ft and <30 ft (9 m); 2—30 ft and <137 ft (42 m); 3—137 ft and <200 ft (61 m); 4—200 ft and <400 ft (122 m); 5—400 ft and above
(41-42)	**Distance from Observer**:
	01—0 to 500 ft (152 m); 02—500 ft to 1k ft (305 m); 03—1k ft to 1.5k ft (457 m); 04—1.5k ft to 2k ft (610 m); 05—2k ft to 2.5 ft (762 m); 06—2.5k ft to 3k ft (914 m); 07—3k ft to 3.5k ft (1067 m); 08—3.5k ft to 4k ft (1219 m); 09—4k ft to 4.5k ft (1372 m); 10—4.5k ft to 5k ft (1524 m)
(43)	**Direction of Flight (towards)** : 1-N, 2-NE, 3-E, 4-SE, 5-S, 6-SW, 7-W, 8-NW
(44)	**Direction of Bird(s) from observer**:
	1-N (337.5-22.5°); 2-NE (22.5-67.5°); 3-E (67.5-112.5°); 4-SE (112.5-157.5°); 5-S (157.5-202.5°); 6-SW (202.5-247.5°); 7-W (247.5-292.5°); 8-NW (292.5-337.5°).
(45)	**Number of Observers**
(46)	**Observer Code**: apply individual codes (e.g., a, b) consistently throughout study
(47)	**Recorder Code**: same code letter as used above for observer code

Appendix (cont'd)

APPENDIX TABLE 2. Additional codes and explanations for radar observations.

Col. (41-42)	Distance to Echo:	
	1—0 to 0.1 nm (185 m)	6—0.5 to 0.6 nm (1111 m)
	2—0.1 to 0.2 nm (370 m)	7—0.6 to 0.7 nm (1296 m)
	3—0.2 to 0.3 nm (556 m)	8—0.7 to 0.8 nm (1482 m)
	4—0.3 to 0.4 nm (741 m)	9—0.8 to 0.9 nm (1667 m)
	5—0.4 to 0.5 nm (926 m)	10—0.9 to 1.0 nm (1852 m)
Col. (43)	Direction of Flight (towards):	
	1-N	5-S
	2-NE	6-SW
	3-E	7-W
	4-SE	8-NW
Col. (44)	Direction to Echo (from radar location):	
	1-N	5-S
	2-NE	6-SW
	3-E	7-W
	4-SE	8-NW

APPENDIX TABLE 3. Codes and explanations for dead bird searches.

Col. (2)	Type of Search: 1=wind turbine, 2=met tower, 3=power line
Col. (43)	Approximate Time of Death: 1=6-12 hrs, 2=12-24 hrs, 3=1-2 days, 4=1 week, 5=2 weeks, 6=several weeks
Col. (44)	Physical Condition: 1=broken bones, 2=lacerations, 3=abrasions, 4=bloody, 5=discolorations, 6=gun shot wounds, 7=decomposition, 8=scavenger damage
Col. (45)	Probable Cause of Death: 1=collision, 2=electrocution, 3=hunting, 4=predation, 5=unknown
Col. (46)	Necropsy: Y=yes, N=no
Col. (47)	Specimen Number: Whenever specimens are saved for future analysis.

Note: When a dead bird search is along a power line corridor, columns 36-39 are not used and columns 40-42 will indicate distance to power line in meters.

Appendix (cont'd) BIRD MOVEMENT OBSERVATION FORM

1	LOCATION
2	TYPE OF WATCH
3	WIND DIRECTION
4	WIND SPEED
5	
6	PRECIPITATION TYPE
7	VISIBILITY
8	CLOUD COVER
9	TEMPERATURE
10	
11	
12	START WATCH
13	STOP WATCH
14	YEAR
15	
16	MONTH
17	
18	DAY
19	
20	HOUR
21	
22	MINUTE
23	
24	TIME ZONE
25	TIME BASIS
26	SPECIES CODE
27	
28	
29	
30	AOU NUMBER
31	
32	
33	
34	NUMBER OF BIRDS
35	
36	
37	SEX
38	AGE
39	FLIGHT BEHAVIOR
40	HEIGHT OF FLIGHT
41	DISTANCE
42	
43	DIRECTION OF FLIGHT
44	DIRECTION TO BIRD(S)
45	OBSERVER NUMBER
46	OBSERVER CODE
47	RECORDER CODE
48	
49	
50	

Appendix (cont'd)

DEAD BIRD SEARCH FORM

1	LOCATION
2	TYPE OF SEARCH
3	WIND DIRECTION
4	WIND SPEED
5	
6	PRECIPITATION TYPE
7	VISIBILITY
8	CLOUD COVER
9	TEMPERATURE
10	
11	
12	START
13	STOP
14	YEAR
15	
16	MONTH
17	
18	DAY
19	
20	HOUR
21	
22	MINUTE
23	
24	TIME ZONE
25	TIME BASIS
26	SPECIES CODE
27	
28	
29	
30	AOU NUMBER
31	
32	
33	
34	SEX
35	AGE
36	NEAREST TURBINE ID #
37	BEARING TO TURBINE (°)
38	
39	
40	DISTANCE TO TURBINE (M)
41	
42	
43	APPROX TIME DEATH
44	PHYSICAL CONDITION
45	PROB CAUSE DEATH
46	NECROPSY
47	SPECIMEN NUMBER
48	
49	
50	

Protocols for Evaluation of Existing Wind Developments and Determination of Bird Mortality

by
Michael L. Morrison, University of Arizona[11]
Introduction by *Holly Davis*, National Renewable Energy Laboratory[12]

Introduction

With the increasing development of wind power in the United States, concern over the number of birds that might be killed by wind turbines has increased. To respond to the increasing concern and to address the many critical questions that still need answering, the National Renewable Energy Laboratory (NREL) is in the process of developing an avian-wind power research program. NREL is interested in the work that the Avian Subcommittee of the National Wind Coordinating Committee (NWCC) is doing to develop a research agenda and to understand all parties' needs and priorities. Because of the need to allocate NREL's 1995 dollars before the end of the 1995 fiscal year, NREL gathered together an *ad hoc* group of researchers versed in avian-wind interactions to develop a list of the most important research topics for future study. The group agreed on the need for two general types of studies: (1) pre/post construction surveys measuring utilization of the area by birds and their mortality both before and after a wind farm is constructed, and (2) studies to determine the effect of various treatments to turbines (such as painting blades or using perch guards) on avian mortality.

The two topics of research were brought before the Avian Subcommittee at its June 14, 1995, meeting in Jackson, Wyoming, to generate consensus among all participants regarding proceeding with Requests for Proposals (RFPs) on these topics. Agreement was reached at the meeting and NREL began developing a competitive solicitation. To ensure that the data gathered in these studies meet basic scientific standards and are transferable, NREL included the following two protocols as part of the RFP, and offerors were expected to follow the protocol if awarded a subcontract. These protocols were developed specifically for the RFP, but likely will have a much wider application.

Project Protocol I: Evaluation of Existing Wind Developments

The following protocol was initially developed at the request of the California Energy Commission (CEC) as part of their evaluation of the impacts of several existing wind resource

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areas (WRAs) on birds. Richard Anderson, CEC, has been involved with the continued development and field testing of this protocol (see p. 74*ff* of these Proceedings).

Objectives.—The protocol will determine the relative abundance and utilization rates of birds in an area, sample for bird mortality, and then determine the bird risk and attributable risk due to the WRA. This approach should allow researchers to focus quickly on key areas for further inquiry and uncover potential relationships that could be verified through follow-up studies, as warranted. The general goals of the protocol are

1. Establish a methodology for conducting avian mortality monitoring studies that will set standards for other such studies.
2. Determine if differing risk levels of avian mortality are attributable to the WRA, and if so, determine if they represent potentially significant problems for a population.
3. Develop research methods and conduct field research on increasingly focused problem areas, and develop recommendations that provide resolution of the problem(s) in order to facilitate siting of future developments.

Expected Research Outcomes.—The protocol is designed to determine the relative level of increased risk to birds that is directly attributable to the development and operation of the WRA. If the attributable risk is determined to be negative, zero, or only slightly increased, then the conclusion would be that the WRA does not pose a significant increased risk to birds relative to non-developed areas.

The protocol is not designed to determine the absolute number of birds dying in the WRA nor the absolute net difference between a WRA and one or more undeveloped comparison area(s). Such a number, in isolation from information about the impact on the actual population, is of little use in evaluating the impact of a WRA on birds. Thus, it is prudent to start with research that can identify the relative risk due to the project, and estimate if this risk is so large that it is likely to be having a negative impact on the population. If so, more intensive studies (e.g., population analysis of selected species) would then be warranted.

Thus, this protocol will allow a conclusion to be made regarding the relative risk that a WRA poses to birds. It also will allow formulation of hypotheses about inferred causal effects based upon any statistically significant correlations that are found.

Research Outline.—The *goal* is to determine if the development and operation of a Wind Resource Area (WRA) results in an increased risk of bird mortality.

Key Questions: The key question to be addressed is, "What influence does the development of the WRA have on birds?" More specifically,

a. Does the WRA development influence the level of bird activity, called utilization rate, compared to that of nearby undeveloped areas?
b. Does the WRA development influence the rate of bird mortality, called mortality rate, compared to that of nearby undeveloped areas?

c. When comparing the utilization and mortality rates in the WRA and undeveloped areas, is there any change in the risk to birds that is attributable to the WRA development?

d. Does attributable risk, utilization rate, or mortality rate vary by type of technology (e.g., different turbine types, infield power lines) or vegetation types available?

Definitions and Concepts: The following definitions and concepts are central to the proposed approach:

1. Bird utilization rate: The number of birds detected using the area during set periods of time. Rates can be developed for different species, vegetation types, locations within the WRA, and the like (if adequate sample sizes can be accumulated).
2. Fatalities: The number of dead birds found during sampling.
3. Bird mortality rate: The number of dead birds divided by utilization rate; this equates with bird risk in the WRA.
4. Attributable risk: The risk of death associated with a bird being in the WRA relative to the risk for a bird not in the WRA. This is derived by calculating mortality rate for both the WRA and undeveloped areas.

Sampling Design.—The protocol calls for an initial Phase I study based on a standardized protocol applicable in any WRA. This would be followed, if necessary, by Phase II or III studies focused on specific topics identified as important during earlier phases.

Phase I Studies: Studies to be done during Phase I should include the following:

1. Parallel transects traversing the WRA will be walked from randomly selected, strategic starting points, chosen to include all types of natural communities, developed WRAs, and non-developed comparison (non-WRA) areas. Transects should be 400-600 m apart, and are not placed to follow strings of turbines. The non-WRAs can be areas immediately surrounding the WRA, or areas similar in environmental conditions located nearby. Ideal locations for non-WRA sampling are nearby areas that are suitable for wind development, but have not as yet been developed as such.

2. Ten-minute point counts to determine bird utilization rates will be conducted every 400-600 m along each transect, with the first point randomly established within 300 m of the transect's starting point. The number of points established will be based on the size of the WRA. Data recorded will include species, number, behavior, distance from a turbine if in WRA, or distance from WRA if outside. Sampling can be conducted throughout the day during weather conditions favorable for observing birds. Points need only be sampled once per season, unless the WRA is so small that few total points have been established. In the latter situation, data collected at each point within a single season will be averaged.

3. Phase I sampling will be conducted until an adequate number of samples have been collected over at least four seasons. The anticipated Phase I study period is 1 year.

4. Dead bird searches will be conducted within a circle of 25-m radius around each point-count location. The field observers will start at the point-count location and walk a spiral path outward to 25-m radius, expanding outward so that a complete search of the area is made. The distance between successive coils of the spiral, and the time spent in each 25-m circle, will be based on the density of the vegetation.

5. Data should first be evaluated for adherence to parametric statistical assumptions (normality, equality of variances). Appropriate univariate or nonparametric tests should then be applied to test the hypothesis of no difference in utilization and mortality rates between WRA and non-WRA.

6. Scavenging studies should be conducted during each season to determine if scavenging differs between the WRA and non-WRA. Scavenging studies will be done at point-count sites at varying distances from turbines. A minimum of three general distances categories (near turbine, 500 m, 1 km) will be studied, with marked dead birds being placed and monitored at 10-30 point count sites per distance category. Replicates can be conducted within seasons as time allows. If significant differences in scavenging are found, a correction factor must be applied to the dead bird values.

7. Studies of observer bias will include replicate comparisons of each observer compared to other observers for both bird utilization and dead bird detection efforts.

Phase II and III Studies: The results of Phase I studies will determine if additional work is warranted, and if so, the nature and scope of the work.

1. Areas of high mortality: In areas where mortality rates are substantially higher than elsewhere, additional sampling will be warranted. This sampling is designed to obtain an adequate number of birds for necropsy so that causes and timing of death can be determined adequately.

2. Other structure sampling: Other structures such as power poles and meteorological towers will be sampled to determine their contribution to overall deaths. Specific sampling methods will be determined taking account of local structures and situations.

3. Behavioral documentation: Areas of high utilization and mortality determined during Phase I will be more intensively observed to evaluate the causes of bird use and mortality. Behavioral protocols will be developed according to the individual situation discovered. For example, turbines known to harbor perching birds can be observed according to the time of day, duration of perching activity, and entry and exit direction of the birds. Areas of known high utilization (e.g., for soaring, hunting) can be observed according to time of day, distance from turbine (vertical and horizontal), and outcome of hunting.

4. Prey abundance: Abundances of prey can be determined for areas found to harbor high concentrations of birds or high mortality rates during Phase I studies. Comparison data should be obtained for matched WRA and non-WRA areas of lower bird utilization and mortality. The specific methods used should conform to standard sampling techniques applicable for the species and environmental conditions present. In all cases, however, sampling should include an evaluation of the adequacy of the duration and intensity of trapping (e.g., number of trap nights; number and spacing of traps).

5. Nocturnal bird use: If Phase I studies show high mortality of nocturnally active birds (owls, nocturnally-migrating birds), then the use of night vision equipment or radar might be indicated.

Data Forms.—Data forms being used by the CEC in their ongoing studies in the Tehachapi Pass WRA are included in an Appendix, along with descriptions of the variables being recorded.

Project Protocol II: Determination of Bird Mortality

Problem Statement.—A central issue in wind power development is the mortality of birds within wind farms. Individuals from industry, the scientific community, conservationists, and regulators have postulated that mortality can be reduced by modifying towers to reduce perching, painting disruptive patterns on turbine blades, and other actions. However, the prevailing sentiment is that finding dead birds in wind farms is such a rare event that statistically valid analyses of the effectiveness of treatments designed to reduce mortality are not feasible. Thus, some have suggested that a reduction in bird use on and around towers, and/or marked changes in bird behavior there, would justify concluding that treatments have been effective. The weakness of this argument is that mortality is the issue, and changes in behavior could also cause increases in mortality even if use of turbines has declined. Further, without quantification of dead birds, no statements can be made regarding the influence of turbines on the abundance and dynamics of bird populations. If the risk per visit stays the same for a bird, then by that measure the mortality rate has not been reduced even if fewer birds visit. "Visit" must be carefully defined in all applications. For example, a visit might be defined as an approach within a certain distance (e.g., 100 m) of a turbine, or a bird simply entering a wind farm.

Thus, the goal of this protocol was to determine the best possible study design and testable hypotheses concerning the effect of treatments on bird mortality and/or use in wind farms or around individual turbines. Also of interest were protocols to test the effects of treatments on measurable variables potentially correlated with total mortalities and/or mortality rates. This protocol was developed with the assistance of Drs. Larry Mayer, Lyman McDonald, and Dale Strickland.

Issue Development.—If we test modifications to turbines or wind farms without considering both bird mortality and bird utilization, then the experiment is poorly designed; we will not know whether any decrease in deaths was due to decreased utilization, decreased

risk, or both. When we separate utilization from risk, it is clear that a modification reducing utilization of a wind farm could have a devastating effect on the population whether it decreases or increases the risk associated with flight in the wind farm. The farm could actually enhance a population, e.g., by enhancing food supply.

Population Effects: While data on population effects are ultimately desirable, they require an extremely intensive study that is beyond most budgets and may be unnecessary. Thus, we must design studies that address bird behavior and mortality in and around wind farms without directly studying population effects. Such "weight of evidence" results are, at a minimum, a good starting point to determine if one should even worry about more intensive studies. Such studies are of the "intermediate outcome" variety. They function in a stepwise fashion leading toward determination of the influence of a wind farm's impact on populations of birds.

Utilization: Measures of utilization can be based on many different parameters, including the number of birds, number of flights, number of landings, etc. The question is, do the changes on the wind farm effect the risk of death?

Definitions: Suppose we institute an intervention that can be viewed as a preventive intervention or as a factor that removes a risk. The following definitions are provided to help clarify the various types of risk:

a. Attributable risk: the maximum proportion of risk that would be removed if the risk factor (e.g., all perching) were removed.

b. Preventable fraction: the proportion of risk that would be removed if all birds got the preventive intervention (e.g., if we removed all perches).

Note that the attributable risk and preventable fraction are the same if we view a preventive intervention as the removal of a risk factor. The prevented fraction is quite different:

c. Prevented fraction: the actual reduction in mortality resulting from the preventive intervention as implemented (e.g., the proportion of risk actually prevented by removing certain perches).

These measures all assume that the risk factor does not interact with any other factor affecting mortality. For example, removing the perch is assumed not to increase risk of starvation.

Case Study Approach: Case studies have high utility in evaluating mortality. Here, one collects dead birds inside and outside a wind farm, and conducts blind analysis to determine the cause of death. Unfortunately, under most situations very few dead birds could be found outside the farm. However, all dead birds found in a study should be subjected to blind analyses because this information will assist with evaluation of observational data.

The case study approach suggests that epidemiological analysis can often be combined with clinical analysis to extend the inferential power of a study. Here the clinical analysis would be the necropsies of the birds. Suppose that we are successful at finding dead birds

inside a wind farm. If we look at *proportional mortality*—the proportion of the birds killed by blunt trauma, sharp trauma, poisoning, hunting, natural causes, etc.—then the proportions should differ significantly between the wind farm and the control area. It is assumed that the probability of finding a given dead bird is not affected by its cause of death.

Mortality Rates: The ideal denominator in epidemiology is the unit that represents a constant risk to the individual. In the bird/wind farm context, the unit might be miles of flight, hours spent in the farm, or years of life. If the denominator is the total population number then we are assuming that each bird bears the same risk by being alive. In human epidemiological studies, the total population size is usually used because we cannot estimate units of time or units of use. In avian studies, actual population density is extremely difficult to estimate. If the risk is caused by being in the area, then deaths per hour in the area is probably the best epidemiological measure in avian studies. This rate is then extrapolated to the population by estimating the utilization rate of the area for the entire population. Measuring utilization is difficult, however, and must be approached carefully.

Thus, we have two major ways to calculate mortality rate:

(1) = no. dead birds/no. birds in population, versus

(2) = no. dead birds/bird use.

Equation (1) is the ideal, but as discussed above, is usually impractical. Equation (2) is feasible, but results will vary widely depending upon the measure of bird use selected. In addition, for (2), the background (non-wind farm) mortality rate must also be determined for comparative purposes. Thus, equation (2) should be the center of further discussion.

Summary of Study Design:

1. Primary objective: measure bird use with different treatments (perching, flying, etc.).
2. Secondary objective: count number of dead birds with different treatments and estimate mortality rates by equation (2).
3. Analysis:
    a. Test for differences between treatments for primary objective (utilization); must achieve a reasonable level of statistical power.
    b. Test for differences between treatments for secondary objective (mortality rate); power will be poorer than for primary objective.

It is feasible to design treatment vs. control studies for inferences on measures of use. Determination of mortality (using eq. 2) is possible, but statistical power to conclude that treatment and control sites have different mortality rates will be low. For example, in a randomized pairs design, most pairs are expected to result in zero mortalities, with tied values and no mortalities on either member of a pair. The high frequency of zero values effectively reduces the sample size for most analyses.

Study Design.—*Experimental units:* There are two main options:

a. Wind-farm based study: In this design, a relatively large portion of the wind farm would serve as an experimental unit. For example, a group of 100 turbines would receive treatment (e.g., perch guards, painted blades), and a similar group of turbines would serve as a control. This basic approach could be applied both to existing farms and in planned farms. Unless preliminary studies are first conducted, an educated guess would be necessary to determine how many turbines to include in an experimental unit. Further, it will usually be difficult to replicate the pairs of experimental units. With a few pairs (1, 2, or 3), this design is most comparable to a series of observational studies even if treatments are randomly assigned to one member of the pair. With this design, however, extrapolation to the entire wind farm is relatively easy.

b. Small-plot based study: In this design, an individual turbine or a small group of turbines (e.g., a string) serves as the experimental unit. For example, pairs of turbine strings are selected and one string of each pair receives the treatment. This design has the advantage of being centered on discrete units that can be replicated and readily observed; it has more of the features of "classical" experimental design. However, extrapolation to the entire wind farm is relatively difficult.

The latter design is preferred because of the relative ease of gaining an adequate sample size. A relatively large number of pairs of units can be analyzed in the sense of a 'true' experiment. Extrapolation to the entire wind farm is possible in a limited sense if each pair consists of one unit that is randomly sampled and then matched with a second similar unit. The treatment is randomly applied to one member of each pair.

Design Considerations: Treatments and controls can be reversed after the initial experimental period. This would strengthen the test, and would be especially useful in the wind farm based study because of the likely small number of replicates.

Variable Selection: One primary variable will usually drive the study design; thus the initial sample size should be aimed at that variable. However, it is assumed that a reasonable sample size will also be gathered for the other, secondary variables. Sampling can be adjusted as data are collected (i.e., sequential analysis of sample size).

With the small, paired-unit design, 1-2 primary variables on use (e.g., passes through the blade plane, perch attempts) will likely be adequate. The minimum number of pairs to be sampled should be 12. However, a greater number of pairs would be desirable, at least initially. The sampling unit can be either individual turbines, or strings of turbines. It is expected that string length will range from 5 to 10 turbines, depending upon the size and configuration of the wind development; portions of longer strings can be subsampled.

Study Protocol.—The following study protocol concerns the small, paired-unit design, in which one turbine or a small group of turbines (e.g., a string) is the experimental unit.

Objective: To test the null hypothesis of no difference in primary variables and/or mortality rate following treatment.

Definitions: Utilization or use of turbines will be evaluated by measuring two primary variables: perching attempts, and number of passes by distance from the swept blade area. Mortality rate follows equation (2), above.

Secondary variables can include any measurements that do not interfere with the accurate recording of the primary variables.

Experimental Units: The basic sets of experimental units will be pairs (or larger blocks if there are 3 or more treatments) of turbine strings or turbine groups. Within each pair or block, turbines should have

- similar environmental conditions and/or
- similar breeding (nesting) densities for the species of interest, and
- (if possible) a similar history of mortalities.

The number of turbines/string will be based on the configuration of the wind farm. The researcher should attempt to sample a minimum of 12 pairs or blocks of strings. Treatments are randomly assigned to the members of each pair or block of experimental units.

Sampling Frequency: Sampling should be as frequent as possible initially; it can be scaled back after preliminary data are analyzed. It is recommended that each pair or block be sampled at least weekly. Sampling should be stratified by time so that adequate samples are taken both within and between days. If 12 pairs of strings are under observation, then a minimum of 4 observers would be necessary.

Stratification of sampling by major weather condition (i.e., high or low wind; clear or moderate to heavy fog) can be initiated if funds are available for the additional observers who would be necessary to take advantage of such conditions.

Variables: Two primary variables should be measured:

a. Number of passes: Record the number of passes by a bird by distance (at closest approach) from the swept blade area of the turbine. Multiple passes by the same bird (if identification known) should be recorded such that repeated observations of the bird can be identified in the data set. A bird flying onto, and then leaving, a turbine to perch is also recorded here. All birds flying by a turbine (regardless of distance) could be recorded. As a recording rule, assign the bird to the nearest turbine it passes in the string you are observing. An alternative sampling protocol would be to develop an activity budget for any bird approaching the string. Here, data (behavior, distance) would be taken at a fixed time interval (e.g., every 1 min).

b. Perching attempts: Record the number of times that a bird attempts to perch, or does perch, on a turbine. Also record the location of the perch, the perch type, the amount of time spent perching, and the apparent activity of the bird (e.g., preening,

scanning the ground, eating). As noted above, identify repeated perches or perching attempts by the same individual.

Dead Bird Surveys: An area within 100 m on either side of the turbine string will be searched for dead birds.

Data Analysis: Apply standard univariate analyses appropriate to the specific experimental design being used. Begin by evaluating equality of variances, normality, and other assumptions.

Discussion

An attendee enquired about the rationale for recommending a minimum of 12 pairs (or blocks) of turbine units. Dr. Morrison indicated that this recommendation was a general one based mainly on intuition and experience with other types of studies involving paired experimental units: 6 pairs rarely if ever provide enough information for meaningful statistical analysis, 12 pairs is generally a bare minimum, and 24 pairs usually provides good statistical power. Preliminary sampling (a pilot study) is needed in order to get a better sense of the required sample size.

Twelve pairs may be adequate to detect a difference in bird utilization, but not to study mortality. For mortality studies, more pairs likely will be needed because results from some pairs will be zero-zero ties.

The possibility of pooling results of similar tests at different wind plants was also discussed. It was suggested that results from different areas should not be simply pooled and treated as a single overall test, as many aspects of the two (or more) wind plants are likely to differ. However, if the same hypothesis is tested at two or more sites, results could be combined using the techniques of meta-analysis. These methods can derive a single overall hypothesis test from the combined results of separate studies.

Dr. Morrison noted that there are useful design and statistical approaches for studying rare events such as bird deaths at wind turbines [see, for example, R.H. Green and R.C. Young (1993), *Ecological Applications* 3(2):351-356]. This type of problem is not unique to the bird/wind turbine situation. Also, by obtaining similar types of observations in more than one study area, it may be possible to acquire sufficient data to draw at least a tentative conclusion based on the "weight of evidence".

Appendix: Data Forms and Variables

The following pages provide suggested data forms for point counts of bird utilization and for mortality/injury searches. Also attached are lists explaining the variables to be recorded on the two data forms.

POINT COUNT VARIABLES (CEC 5/22/95)

check1: First Quality Check: Mark this space when the original data on this sheet has been checked by someone other than the original observer.

comp: Entered Into Computer: Mark this space when the original data on this sheet has been entered into D-Base on the computer.

check2: Second Quality Check: Mark this space when the original data from this sheet has been entered into the computer, printed out, and checked by someone.

map: Mapped: Mark this space when this transect has been mapped out.

Date: month/day

Transect #: Transect Number:#001-?

Start Pt.: Starting Point of the transect.

Angle: Random angle taken from the starting point (magnetic bearing) through wind resource area.

OBS: Observer
- 1 = Dick Anderson
- 2 = Natasha Neumann
- 3 = Jennifer Noone
- 4 = Judy Tom

Company/Area:
- 100 = Zond
- 200 = Cannon
- 300 = Sea West
- 400 = FloWind

Precip: Precipitation. ie. 331 = hard rain all day.
- 100 = no information
- 200 = no precipitation
- 300 = rain - no other info.
  - 310 = sprinkle/mist
  - 320 = moderate
  - 330 = hard
- 400 = snow - no other info.
  - 410 = < 4"
  - 420 = ≥ 4" but ≤ 12"
  - 430 = > 12"

rain/snow duration:
- 001 = all day
- 004 = off and on all day
- 007 = rains and quits - include comments on hours.

Fog: 10 = no information
- 20 = no fog
- 30 = light
- 4 = dense (visibility < 100m)

fog duration:
- 01 = all day
- 04 = part of day
- 07 = most of day

Cloud: Cloud Cover.
- 10 = no information
- 20 = clear
- 30 = partly cloudy (>15% cloud cover) - no other info
- 40 = overcast - no other info.

partly cloudy/overcast duration:
- 01 = all day
- 02 = part of day
- 03 = most of day

Sloc: Sublocation: Each point along the transect where a bird count is taken. Assign a number (# 001-?) for each point. (m)= Distance from starting point in meters. Use ~ 300m intervals until within turbine area.

TDst: Turbine Distance: The distance(m) between the sublocation and the nearest turbine.(c)= code for distance.
- 1 = 0-20m
- 2 = 21-40m
- 3 = 41-60m
- 4 = 61-100m
- 5 = 101-200m
- 6 = 201-400m
- 7 = 401m-1km
- 8 = > 1km

Op.: Operating. Are turbines within 200m operating?
- 1 = yes
- 2 = no
- 3 = not applicable

Str.1ID: First Structure Identification: Description of the closest structure (ie. power pole/wind turbine)to the sublocation.(c)= Code for structure:
- 1 = lattice wind turbine
- 2 = tubular wind turbine
- 3 = vertical axis wind turbine
- 4 = distribution line associated with wind turbine machine.
- 5 = general distribution line
- 6 = telephone line
- 7 = large transmission line
- 8 = meteorological tower
- 9 = road - if no other structures within 200m.
- 10 = other human made structure - identify in space.
- 11 = none in sight
- 12 = substation

Str.1Dst: First Structure Distance: Distance between the closest structure and sublocation. (c) = code for distance.Use same codes for T.Dst.

Dens1: Density of first structure: Total number of structure 1 within 100m(1) and 200m(2) of sublocation.(c) = Code for density:
- 1 = 0 structure
- 2 = 1 structure
- c = # structures + 1

Str.2ID & Str.3ID: Secondary & Tertiary Structure Identification: Description of any secondary or tertiary structure in the area. Use same codes used for Str.1ID.

Str.2Dst & Str3.Dst: Distance between the secondary and tertiary structures and sublocation. Use same codes for TDst.

Dens2 & Dens3: Second and Tertiary Structure Density: Total number of secondary or tertiary structure within 100m(1) and 200m(2) of the sublocation. Use same codes used for Dens1.

NCom: Natural Community. Abbreviations in parenthesis. (c)= Code for natural community:
- 1 = Mohave Desert scrub and Joshua Tree woodland (MDJTW)
- 2 = high desert sub-shrub scrub (HDSSS)
- 3 = annual grassland with component of sub-shrub scrub (AGSSS)
- 4 = oak woodland (OW)
- 5 = chaparral (C)
- 6 = hard wood conifer ravine (HWCR)
- 7 = other - include description

(More on back of sheet)

Wd: Wind. Use (Beaufort scale + 1)x 10: (c) = code for wind.

10 = calm = 0-1mph
20 = light air = 1-3mph
30 = light breeze = 4-7mph
40 = gentle breeze = 8-12mp
50 = mod. breeze = 12-18mph
60 = fresh breeze = 19-24mph
70 = strong breeze = 25-31mp
80 = mod. gale = 32-38 mph
90 = fresh gale =39-46mph
100 = strong gale = 47-54mph
110 = whole gale = 55-63mph
120 = storm = 64-72mph
130 = 72+mph

Is the wind constant or gusty?
ie. 102 = a gusty strong gale; 10 = calm wind and no other info.
01 = constant
02 = gusty

Topog: Topography of the sublocation. Use same codes for topography of area which each bird is flying over.

10 = ridgetop
20 = midslope
30 = valley - no more information
31 = valley - ≤0.1 km wide
32 = valley - >0.1, <0.5 km wide
33 = valley - ≥0.5km
40 = unknown
50 = flat - open land

Incline: Incline of the sublocation. Use same codes for incline of area which each bird is flying over.

1 = steep (>30°)
2 = moderate (5°-30°)
3 = flat (>5°)
4 = unknown

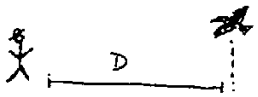
Tp: Temperature at each sublocation in °F.

Start: Time that count was started, recorded in military (24-hour) time.

Species: The 4-letter acronym for the bird species detected at the sublocation. See bird code

#: Number of a certain species at the sublocation which are doing a similar activity.

Dt: Distance of bird from the center of the sublocation as if bird was at ground level which it's flying above: Use same codes used for structure distance.



Ht: Height bird is seen from ground. Actual estimated height. Write comments that may help you to code as detailed as possible. Put general height information (100 series) in the first column. Put more specific codes regarding wind turbines/conductors in the second column.

100 general height - no info.
110 = <1m above ground
120 = 1-10m above ground
130 = 11-50m " "
140 = 51-100m " "
150 = 100+m " "
If bird flies near significant human-made obstructions excluding turbines and conductors, use:
001 = near other obstructions - describe in comments

200 in reference to turbines in area
210 = flying through blades - *also note in comments
220 = within 25% of blade length
230 = within 100% of blade length
240 = within blade height
Angle at which bird(s) are flying when near turbine(s): ie. 241 = bird(s) flying within blade height perpendicular to blades.
001 = parallel (0 - 45°)
002 = perpendicular (46 - 90°)

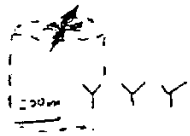
300 = in reference to conductors in area.
310 = flying through conductors - *also note in comments
320 = within 3m above/below conductors
330 = within conductor height

Behav.: Behavior: The first general behavior(s) of the bird(s) identified. Note or change code if sighnificant change in behavior occurs.

10 = other - specify in comments (ie.avoidance of blades, etc.)
20 = soaring
30 = flapping
40 = eating /foraging
50 = perching on ground
51 = " " on vegetation
52 = " " on lattice wind turbine
53 = " " on tubular wind turbine
54 = " " on power pole
55 = " " on conductor
56 = " " on other human-made structure - identify in comments
60 = gliding
70 = diving

WRA: Is bird flying within a cylinder with an ~200m radius that includes or borders a wind resource area?

1 = yes
2 = no
3 = unknown



Dur.: Duration: How long each bird or group of birds remain in the area.

| = 0-1 min. ; || = 1-2 min.; ||| = 2-3 min.

|||| = 3-4 min.; ||||| = 4-5 min.

(c) = code # (1-5) that corresponds with the number of tick marks.

Comments: Any comments not covered by codes. Also note if significant changes in weather occur. Note any bats flying in area whether or not during point count.

Dd.#: Number of dead/injured birds found within a 50m radius of the sublocation.(c)= Code for # of dead birds:

1 = 0 birds
2 = 1 bird
3 = 2 birds
c = # birds + 1

Any bird(s) hitting a structure within each of these 50m radii should also be recorded in the Mortality/Injury data sheet. If a bird is found or seen dead/injured outside of the 50m radius, note on the point count sheet, but it will not be included in the Mortality/Injury study. Include any feathers found in the mortality/injury data even if there is no certainty in the feather being part of a mortality.

Note: Preferably use meters for estimating distances. Otherwise, if using feet or yards, put (ft) or (yd) at top of each corresponding column.

POINT COUNT DATA SHEET 1995

check1:____ comp:____ check2:____ map:____

Date _____ Transect # ____ Start. Pt. _____ Angle _____ Obs _____ pg ___ of ___

Company _____ Precip. _____ Fog _____ Cloud _____

Sloc: #_____-(m)____ TDst:_____(c)___ Op:___(c)____ Str.1ID:_____#_____(c)___ Str.1Dst.:_____ (c)___ Dens1:(1)_____(2)_____(c)(1)____ (2)____

Str.2ID:_____#_____(c)___ Str.2Dst:_____(c)____ Dens2:(1)_____(2)_____(c)(1)____(2)____ Str.3ID:_____#_____(c)___ Str.3Dst:_____(c)____

Dens3:(1)____(2)____(c)(1)____(2)____ NCom:_____(c)____ Topog:_____(c)____ Incline:_____(c)_____ Tp:____ WdSp:_____(c)____ WdDir:(c)____

Start:

Species	#	Dt (m)	Ht (m)	Behav.	Topog.	Incline	WRA	Dur.	Dt	Ht	Beh.	Top.	Inc.	WRA	Dur.	Comments	Dd#:____(c)____

CODES

Sloc: #_____-(m)____ TDst:_____(c)___ Op:___(c)____ Str.1ID:_____#_____(c)___ Str.1Dst.:_____ (c)___ Dens1:(1)_____(2)_____(c)(1)____ (2)____

Str.2ID:_____#_____(c)___ Str.2Dst:_____(c)____ Dens2:(1)_____(2)_____(c)(1)____(2)____ Str.3ID:_____#_____(c)___ Str.3Dst:_____(c)____

Dens3:(1)____(2)____(c)(1)____(2)____ NCom:_____(c)____ Topog:_____(c)____ Incline:_____(c)_____ Tp:____ WdSp:_____(c)____ WdDir:(c)____

Start:

Species	#	Dt (m)	Ht (m)	Behav.	Topog.	Incline	WRA	Dur.	Dt	Ht	Beh.	Top.	Inc.	WRA	Dur.	Comments	Dd#:____(c)____

CODES

CEC 5/30/95

MORTALITY/INJURY STUDY 1995
Field Data Sheet with Variables

(CEC 5/30/95)

Check1___ Comp____
Check2___ Map____

CODE

_____ Rec.#: Record Number: sequential number starting with 001.(Will be assigned outside of field.)

_____ Date: Date bird discovered: month/day

_____ Trans#: Transect Number.

_____ Subloc.: Sublocation Number.

_____ Obs.: Observer:
1 = Dick Anderson
2 = Natasha Neumann
3 = Jennifer Noone
4 = Judy Tom

_____ Dd#: Dead Number: The total number of birds either dead, injured, or with unknown status(ie. one feather found only) found at that sublocation that day.

d = #bird(s) + 1

_____ Spp.: Species: the 4-letter acronym for the species of bird found dead.

_____ Age:
1 = unknown
2 = immature
3 = adult

_____ Sex:
1 = unknown
2 = female
3 = male

_____ Time: Estimated time since death:
1 = undetermined
2 = fresh kill - < 2 days old
3 = few days - maggots starting to appear
4 = 1 week - maggots over entire body
5 = 2 week - flesh at least half gone
6 = 1 month - no flesh left, just bones and feathers
7 = over 6 months - bones and feathers disassembled
8 = bird alive - not applicable
9 = status unknown - not applicable

_____ Cause: Cause of Death or Injury
1 = unknown
2 = collission with turbine
3 = collission with wire
4 = electrocution
5 = other - explain in comments
6 = not applicable

_____ Certain.: Degree of certainty for cause of death/injury.

1	2	3	4	5
low				high

6 = not applicable

_____ Cond.: Condition (also describe in detail in comments)
1 = dead
2 = alive
3 = unknown - not applicable

CODE

_____ Injur.: Injuries (For both dead and alive birds)
1 = no obvious signs
2 = wing sheared off
3 = head sheared off
4 = feet sheared off
5 = body sheared in half
6 = multiple dimemberment
7 = broken wing bone
8 = broken neck bone
9 = broken leg bone
10 = injury to wing
11 = injury to legs
12 = injury to eyes
13 = injury to body
14 = injury to head
15 = feather damage
16 = body and feathers intact
17 = feathers and body disassembled
18 = just feathers
19 = just bones
20 = just feathers and bones
23 = wing only
24 = electric burns on feet
25 = electric burns on wings
26 = internal injuries
27 = impact, then continued on
28 = stunned
29 = entangled in wires
30 = other - describe in comments
100 = unknown status - no indication of injury/mortality (ie. solitary feather(s) found.)

_____ Collected: Was the bird collected?
1 = collected
2 = not collected

_____ Mx.Dt.: Maximum Distance(m)at which bird could be observed:
1 = <0.5m
2 = 0.5m - 1m
3 = 1.1m - 5m
4 = 5.1m - 10m
5 = >10m

_____ Scav./Dec: Scavenged/Decomposed at time of discovery?
1 = unknown
2 = scavenged
3 = neither scavenged nor decomposed
4 = decomposed
5 = scavenged and decomposed

(MORE ON BACK)

CODE

COMMENTS:

_____ Str.1: Closest structure to dead/injured bird that could have caused mortality/injury.
1 = lattice wind turbine
2 = tubular wind turbine
3 = vertical axis wind turbine
4 = distribution line associated with wind turbine machine.
5 = general distribution line
6 = telephone line
7 = large transmission line
8 = meteorological tower
9 = road - hit by car
10 = other human-made structure - identify in comments
11 = none in sight
12 = mortality/injury not likely caused by structure - include comments
13 = unknown
14 = substation

_____ Str.2: If another type of structure is in close proximity and could have caused the mortality/injury - list second structure using Str.1 codes.

_____ Str.D1: Distance to closest structure. Use code:
1 = 0-20m
2 = 21-40m
3 = 41-60m
4 = 61-100m
5 = 101-200m
6 = 200- 400m
7 = 401-1km
8 = >1km

_____ Str.D2: Distance to second closest structure. Use code for Str.D2.

_____ Wind: Was the bird found generally upwind/downwind of structure #1:
1 = unknown
2 = upwind
3 = downwind

_____ Row: Was the closest structure an endrow turbine?
1 = not applicable
2 = yes
3 = no

MORTALITY/INJURY STUDY DATA SHEET 1995

Rec.#	Date	Trans#	Sloc.#	Obs.	Dd #.	Spp.	Age	Sex	Time	Cause	Certain	Cond.	Injur.	Coll.	Mx. Dt.	Scav.	Str.1.	Str.2	Str.D1	Str.D2	Wind	Row

Comments:

Comments:

Comments:

Comments:

Comments:

Comments:

Comments:

Comments:

CEC 5/22/95

WORKING GROUP SESSIONS

This section of the meeting consisted of four working group sessions, held two at a time such that each meeting attendee could participate in two of the four working groups. The working group topics were as follows:

(1) *Site evaluation and pre-permit research and planning:* What types of avian research ought to be conducted before deciding whether a site should be developed? What methodologies ought to be used?

(2) *Operational monitoring:* Once a site is developed, what types of research can help estimate and predict the number of birds killed by wind turbines? What methodologies ought to be used?

(3) *Modeling and forecasting, including population dynamics:* What research studies will help model or forecast where wind energy developments may conflict with priority species or with large numbers of species or individuals? Are population models helpful? What models ought to be developed and used?

(4) *Avian behavior and mortality reduction:* What research should be conducted to better understand why birds are killed and whether and what technology can mitigate this impact?

The results of Working Groups (1) and (2) follow immediately. Results from Working Groups (3) and (4) are summarized starting on pages 133 and 136.

The main recommendations from each Working Group were discussed at a concluding plenary session, and a short list of recommended "Next Steps" was compiled by the meeting as a whole. That list is given in the "Next Steps" section (p. 143), following the Working Group summaries.

Working Groups 1 and 2.
Site Evaluation and Monitoring

The assigned tasks for Working Groups (1) and (2), as listed above, were to identify the types of avian research needed during pre- and post-construction studies, respectively. Most of the same people participated in both working groups. They noted that topics (1) and (2) are closely related. One reason for this is that pre- and post-construction data need to be collected in consistent ways in order to facilitate comparisons and evaluation of impact. Therefore, the members of these two working groups decided to compile a combined set of conclusions and recommendations covering both topics. The combined working group consisted mainly of federal and state regulatory representatives, wind energy developers, and researchers. It was noted that environmental advocacy organizations were not represented in the group.

Regulators' Primary Questions

The working groups discussed the key questions about avian - wind power interactions that need to be answered in approving and siting a wind plant, monitoring its initial operations, and deciding whether future expansion would be acceptable. In addition, the regulators attending the meeting held a side-meeting to discuss these topics from their perspective (Appendix 3).

After considerable discussion, the following were identified as the regulators' primary questions:

- What is the net impact on individuals and populations? How many birds are predicted (pre-operational) or observed (during operations) to be killed, by species?
- Is project impact reasonably minimized?
- Is sufficient information available for decisionmaking?

Data Requirements

In discussing the general types of data that would be needed, several general principles were identified:

- *Consistency:* Data collected before and during operation of the wind plant need to be consistent and directly comparable in order to permit evaluation of impact.
- *Statistical Validity:* The study design, both before and during operation, must be appropriate for detecting and quantifying changes in the parameters of interest—bird populations and bird mortality.
- *BACI Design:* A BACI (Before-After Control-Impact) design is likely to be most appropriate. This approach can detect and quantify any changes on the wind plant from the before- to the during-operation phase, and can provide data helpful in assessing whether changes are attributable to the wind plant or to some other factor.
- *Risk:* The data need to be suitable for analyses of the risk posed by the wind plant to the species of concern. Different types of data may be needed in different areas depending on the species of main concern.

Standardization and Protocols

Many workgroup participants mentioned the need for standard observation protocols. This point was made during discussion of both site-selection issues and operational monitoring issues. It had also been discussed repeatedly during the preceding plenary sessions (see above). In addition, workgroup members knew that the interview process preceding the meeting, involving an even broader range of stakeholders, had identified a widespread desire for standard observation protocols (see the paper by A. Arnold and C. Behr in these Proceedings). Participating regulators discussed how standard protocols would help them make informed judgements about the adequacy of proposed, ongoing, and completed studies. In addition, standard protocols would facilitate comparisons among datasets

obtained at different times and places. This would be desirable both for long-term studies at one site and for regional comparisons involving different researchers working at different sites.

Several members mentioned the difficulties in developing statistically reliable sampling designs while keeping study costs to a practical level. A related point is the question, "Should all potentially relevant variables be measured in every study, to facilitate across-study comparisons, or should each study focus on the key variables at that particular site?" Some participants emphasized the value of collecting the maximum amount of standardized information to facilitate across-study comparisons and analyses that were not planned until after the study was initiated. Other participants cautioned that this approach can increase overall project cost and may reduce the effort that can be devoted to the most important issues at each specific site.

Pre-Construction Issues

The group noted that the pre-construction phase is generally divided into an initial site-screening and comparison phase, when a number of candidate sites may be examined in a preliminary way; and a follow-on site-evaluation phase involving more detailed assessment, often of only the single "preferred" site. Workgroup participants discussed the extent to which bird information should be sought and considered during the site-screening phase, and the types of studies needed during the site-evaluation phase.

Participants noted that site-selection and site-evaluation follow (or could follow) a sequence involving a gradual narrowing of focus combined with a gradual increase in the level of detailed investigation of relevant factors, including birds:

- identify wind resource areas in the region of interest;
- evaluate markets, accessibility, connectivity;
- review existing general data on wind, land use, and birds at candidate sites;
- identify key species;
- review habitats at potentially acceptable sites;
- identify a preferred site;
- implement specific studies to evaluate habitat quality, bird abundance and bird use (along with wind potential and other factors relevant to the wind developer); and
- focus on species of special concern; conduct specific studies as necessary.

Site-Screening Phase.—The group noted that bird issues should be considered early during the site-screening phase. The objective should be to identify areas with an optimum combination of wind potential, accessibility to markets, and minimal potential impacts on birds. By considering birds during the site-screening phase, it may be possible to reduce impacts on birds, reduce the need for costly mitigation, and reduce subsequent regulatory delays. Existing data or local knowledge of bird populations, movements, refuge locations, etc., can be used as an initial screen.

Some participants believed that limited field surveys are desirable at the site-selection stage to compare bird populations and movements at candidate sites. It was noted that in Minnesota, a radar study is planned to obtain comparative bird use information for various windy sites. Other participants said that, in their areas, the candidate areas were too numerous and large to allow meaningful field surveys of birds utilizing all candidate sites. Also, they noted the complications when a number of prospective wind developers are involved, and they raised questions about who could or would fund wide-ranging site comparisons.

Some attendees commented that, with or without any preliminary bird surveys, it can be useful to consider the habitats on the candidate sites in relation to general knowledge or specific models of habitat preferences for species of concern. Habitats are often less costly to survey than are bird populations. Remote sensing methods are often useful.

The types of information mentioned above as being potentially obtainable during the site-selection phase may provide an indication of *relative* risks to birds from alternative wind plant proposals. Even this limited information could be valuable in the site-selection process, and cost-effective to all concerned. However, general information of these types cannot be used for *quantitative* estimates of risk and impact.

Site-Evaluation Phase.—Participants agreed that more detailed and systematic bird studies are needed at this phase. There was general consensus that these studies should be designed to provide both

- the data needed for permit decisions and
- the baseline data that would be needed for comparison with post-operational data if the wind plant is constructed.

As noted earlier, pre- vs. post-operational comparisons are best done with a BACI study design (p. 128). Given the requirements of this design, it is important to obtain pre-construction data both from the preferred site and from one or more nearby sites that can serve as control or reference sites.

Several participants emphasized that, for a meaningful prediction of risk and to provide meaningful baseline data, an intensive avian study of at least one year's duration is required. Topics that require study or evaluation include

- the species and numbers of birds present,
- the expected changes if a wind plant is developed (including the expected incremental mortality),
- how those changes and additional deaths will affect the populations (especially of species listed as endangered or threatened), and
- the potential for mitigation.

With the possible exception of the need to estimate direct collision mortality, these requirements are not unique to wind power proposals. The same considerations apply in predicting impacts of many other human developments. Thus, there is a broad range of experience in how to conduct this type of work. However, given the emphasis on estimating poten-

tial collision mortality at a wind plant, we need more specific data on local and migratory movements than would be required to assess impacts of most other types of developments.

Participants noted that the level of concern will vary depending on the types and numbers of birds present in the preferred area. If it is obvious that few birds are present, and no listed ones, pre-development studies can probably be less detailed and lengthy than would otherwise be needed. However, if the wind plant is subsequently built, this approach may not provide sufficient baseline data for a conclusive demonstration of "no effect".

Operational Issues

The group identified the following as being among the key operational issues regarding the impacts of an operating wind plant:

- Has the wind development affected birds? If so, how? Are the species of concern at greater risk now? How much greater?
  - Is there a change in the abundances and variety of species?
  - Is there an impact on the local and regional habitat? If so, what kind of change? Positive or negative?
  - What is the best estimate of the number of birds killed by turbines?
- Do these measures differ statistically from corresponding pre-construction measures? Was the sampling adequate to detect a difference if it occurred?
- Does the actual impact match the impact predicted when the development was being planned? What are the discrepancies?
- If impacts are greater, less or otherwise different than predicted, what is the appropriate response, both in terms of regulatory action and research?
- Are imposed conditions effective in minimizing impacts? If not, what is the process for amending the operating conditions?
- How can monitoring results from one wind development be applied to subsequent developments?
- When a number of wind plants are being monitored, how can overlap in monitoring studies be minimized and efficiency maximized?

To help answer these questions, workgroup participants suggested that standard protocols should be established and adopted to improve consistency.

Most participants felt that the best way to estimate impacts was to apply the same research protocols for operational monitoring as for pre-construction studies. To make this possible, a Before-After-Control-Impact (BACI) design needs to be established at an early stage, when pre-construction studies are implemented. This means that both the prospective wind plant and appropriate control sites need to be studied before construction, with consistent follow-up studies on the same sites after construction.

When pre-construction studies are included in the monitoring design, they establish baseline data for longer-term monitoring and they allow rigorous testing of treatment effects

(impacts). When monitoring begins only in the post-construction period, impacts of wind developments can be assessed only by inference, not by rigorous statistical testing. Standardized data collection methods are desirable to allow researchers to combine data and analyses across time and also from different sites, thereby allowing stronger conclusions.

Recommendations

Methodological Guidebook.—The combined working group on pre- and post-operational monitoring identified, as its highest priority recommendation, the need for development of a guidebook on study designs, protocols, recommended "metrics", and related statistical issues. Suggested approaches included

- preparation of draft papers on these topics,
- review by technical experts and other stakeholders,
- a follow-up workshop to build consensus, and
- a series of regional workshops to discuss the application of the suggested methods in particular parts of the U.S.A.

There also needs to be

- a process for updating the recommendations based on experience.

In developing the recommended protocols, the first step would be to compare methods currently in use and determine where there are differences. In these cases, it will be important to build consensus about whether to recommend a single standard procedure. If so, the best features of all existing protocols should be taken into account. In other cases it may be appropriate to suggest two or more alternative approaches, or to allow certain deviations from a protocol's recommended practice. When alternative approaches are listed as being acceptable, the guidelines should indicate what additional steps are needed to ensure comparability of the data obtained via alternative procedures.

The "metrics" to be recommended as standards need further discussion. There will probably be at least three categories of metrics: utilization measures, mortality measures, and population measures. In addition, there will often be a need for measures of ancillary variables, such as habitat, weather, and prey base. Recommended measures should be as simple as feasible. There is a need to develop specific guidelines about metrics and sampling designs to avoid inefficiencies, missing data, and non-comparable results.

Other Methodological Recommendations.—Other methodological recommendations identified by the working groups included the following:

- Conduct studies to assess the effectiveness of techniques recommended in guidebook.
- Develop protocols for coordinated radar, visual and electro-optic observations of bird movements, taking advantage of the complementary strengths of these methods.
- Evaluate unbounded vs. fixed-distance point counts, and point counts vs. transect methods, for studying bird utilization of wind plants (pre- or post-construction).

Working Group 3. Modeling, Forecasting and Population Dynamics

Introduction

This Working Group was convened to discuss the following topics, and to make recommendations to the Avian Subcommittee:

> *What research studies will help model or forecast where wind energy developments may conflict with priority species or with large numbers of species or individuals? Are population models helpful? What models ought to be developed and used?*

In assessing the impact of turbines on resident and migratory bird species, regulators may want to use statistical models that incorporate site-specific information to predict the answers to key questions about potential impacts on birds. Models are useful because they predict potential impacts based on defined assumptions, functional relationships, and available data. Also, they can provide indications of the confidence that can be placed in the resulting predictions. Regulators can use this information to help evaluate permit applications and to assess whether permitted sites are in compliance with their permits.

The Working Group was composed primarily of scientists and regulators. It began by identifying some of the most important questions that are commonly posed by regulators, and then highlighted possible modeling efforts and discussed their statistical reliability. The group felt that the objective should be to develop models that help address questions important to regulators, and to do so with models that provide an adequate level of precision and confidence based on the minimum feasible number of parameters. The group distinguished between models that are primarily literature-based and those that are data-intensive.

Questions that Modeling Could Address

The workgroup focused on how models could help regulators answer their most important questions about past and potential avian impacts, including

- How many birds and which species will be killed by a proposed wind farm development?
- Are any of these species potentially critical species?
- Are there potential sites where less impact on avian species is expected?
- How many deaths from wind turbines could an avian population sustain?
- Are there technological improvements that could reduce the deaths and impacts?

The group discussed whether models exist that could answer these questions and, if not, whether model development was feasible.

It was recognized that, for each question, there is tension between what regulators need to know and what science can confidently predict. One problem, according to regulators, is

that the desired accuracy of mortality predictions may change subjectively depending on the species in question or on local politics.

Literature-Based vs. Data-Intensive Models

Several participants stressed the need to have adequate data to develop and test the validity of the models. Without data, they said, modeling efforts would be an inefficient use of resources. Other participants noted that literature-based models could be useful even when there are important data gaps, for example in identifying and ranking the data gaps, and in guiding research design. Preliminary models might also be useful for preliminary evaluations of the likely severity of the problem in locations where few or no data on bird-wind turbine interactions are presently available.

Data-Intensive Models.—Data-intensive models are based on scientifically collected data, often collected specifically for use in the model. Group members said that these models would be useful because they would predict a particular species' mortality attributable to a wind farm development. These models would introduce scientific rigor into the prediction of avian mortality and its potential impact on a population. In addition, members commented, the model predictions would be bracketed by a confidence region so that regulators could take into account the potential uncertainty in the model prediction.

Examples of data-intensive models that the group discussed were population dynamics models and flight behavior models. (a) Population models would be useful for determining a species' population integrity threshold. These models could be used to assess whether a wind development might have a population effect. (b) A flight behavior model could simulate bird flight and turbine air flow to better understand how different species avoid turbine-related injury, and how various potential turbine modifications might affect predicted mortality.

Workgroup members briefly discussed the advantages and disadvantages of different designs for data-intensive models. One person suggested that *equilibrium* models should be developed initially to establish the relationships among parameters. Simulations could then be run to allow researchers to test the sensitivity to various perturbations and random effects. Others argued that *disturbance* models better reflect natural variation and are currently favored by most researchers.

One working group member noted that the results from any model depend entirely on data and that, in the case of avian impacts, current data are insufficient to produce reliable models. From this viewpoint, the goal of data-intensive modeling efforts should be to determine what data to collect and then to collect those data, not to build a model that uses available data. In this light, the group discussed how data-intensive modeling may not answer the main questions in the short term. Potential first steps in modeling are *resource selection models* that anticipate avian mortality by identifying habitats that specific species are likely to utilize.

Literature-based Models.—The group discussed literature-based models as a way of starting to meet immediate information needs. These models would utilize information that already exists on bird distribution, habitat or resource selection, seasonal occurrence, migration, etc. These models could illustrate where impacts are most likely to occur and on what species, and could help determine the priorities that should be assigned to different data-collection efforts. Regulators and wind developers could use this information, along with wind resource data, to help direct baseline data collection. Also, regulators mentioned that these models would help identify the priority habitats for endangered species, and would assist in formulating appropriate recommendations to industry.

One participant noted that developing a model from these types of data involves combining several data sets, predicting outcomes, testing for accuracy, and making necessary adjustments. Some people might not view the model as "scientific", but it would help regulators around the country recognize and plan for potential conflicts. It could be helpful to organize the data via a GIS system.

Several members stated that population impacts may not need to be modeled explicitly if there is some procedure for temporary shutdown of turbine operations in circumstances with significant mortalities. They felt that much could be learned from hunting-control policies in states where regulators may limit the number of permits or may close hunting seasons if a single threatened species is killed. One group member said that upper limit "models" could be developed that represent the most conservative assessments of potential population impacts.

Recommendations

The group identified the following categories of models that could be helpful in this field:

- Preliminary models to identify key data gaps and guide data collection;
- Geographic/habitat selection models that predict, for priority species, the numbers of birds in different areas during various seasons, overlain onto maps of wind resource potential;
- Population dynamics models that predict the effects of specified mortality levels on the populations of priority species; and
- Flight behavior models that might help identify beneficial technical changes in wind plant or turbine design.

There is a general correspondence between these potential types of models and the previous list of key questions (p. 133).

Currently, data collected at proposed and operating sites around the country are not always comparable, and may be difficult to combine or compare. This workgroup suggested establishing data collection protocols to standardize data for future use in developing and testing models. Improvement of data collection protocols and continuing basic research at various sites will eventually yield better models.

Working Group 4. Avian Behavior and Mortality Reduction

Introduction

This Working Group was convened to discuss the following topic, and to make recommendations to the Avian Subcommittee:

> *What research should be conducted to better understand why birds are killed, and whether technology can mitigate this impact, and if so what technology?*

It is generally accepted that turbines can kill birds, but it is largely unknown ▸ why certain birds that approach turbines are killed whereas others survive, and ▸ how to lower the proportion killed. Scientists have many hypotheses about bird behavior near turbines, and regarding how visual and audio deterrents and siting plans could reduce mortality. However, as yet there has been little research to assess these effects statistically. One of the problems facing researchers is the infrequency of bird kills at turbines. This infrequency makes it quite difficult and costly to design a study that will collect sufficient data for a meaningful statistical analysis of the causes of fatalities, or of the comparative fatality rates with different turbine characteristics.

Interviews with stakeholders conducted by RESOLVE before the meeting (see paper by A. Arnold and C. Behr in these Proceedings) showed that stakeholders had three main types of questions in the area of avian behavior and mortality reduction:

- questions about bird movements (migratory and local) and their interactions with wind plants, including collision risk by night and day;
- questions about surrogate variables that might be studied to supplement difficult-to-conduct studies of mortality; and
- questions about how to mitigate, including
    - turbine locations vs. habitat, topography, etc.,
    - turbine design: tower design, perches, rotation rate, and
    - deterrent measures: audio, visual, other.

The Avian Subcommittee scheduled this workgroup to discuss what areas of research should be given priority. The group consisted of regulators, industry representatives and researchers. The group discussed macro-level issues, e.g. routes of migratory and local movements; how to site and design wind plants to reduce mortality. However, more time was spent on research needed to address micro-level questions, e.g. what types of avian behavior are related to turbines; how do birds learn to avoid turbines; how can turbines be designed to reduce mortality. The group discussed the types of data that are needed, and how surrogate variables that are easier to quantify than fatality rates might be used to better address micro-level impacts.

Even with the limited time, many ideas were offered and some priorities for future work were suggested. These areas included

- developing a basic framework for understanding the etiology of collisions, i.e. what are the relevant factors?
- understanding utilization of the zone of risk by resident and migratory species;
- researching whether resident and migratory birds adapt to turbines;
- examining the impact of different mitigation technologies on avian behavior near turbines;
- identifying applicable new technologies, e.g. through review and discussion with workers in related fields; and
- modeling mortality at wind resource areas using surrogate variables.

During the discussions, workgroup members suggested research ideas, feasibility, and potential gains and analytical costs. Several also raised the importance of being cognizant of potential differences among different species; research should reflect this. In addition, several members mentioned that, because collisions occur rarely, it will always be difficult to fully understand the reasons for collisions. In response to this problem, surrogate measures of avian utilization and behavior were discussed.

Framework for Understanding Avian Collisions

One of the major areas of discussion involved developing a preliminary model hypothesizing the factors that affect collision probability. While such a framework would initially rely on untested hypotheses, it could be reevaluated as data are analyzed and new research is conducted. This framework, based on the best available scientific judgment and information, would help all parties discuss and potentially agree on the most significant factors to research. The group suggested that the next steps in developing this framework would be to establish a group to draft a white paper on the topic, followed by a review process and possibly a workshop.

Some of the factors that would be considered in this framework include learning and adaptation, prey base near wind farms, species' behavior with regard to collision probability, migration routes, night activity, and weather effects on visibility and avian behavior. The framework could be useful in at least two ways: (1) It would help direct research design and data collection efforts at particular sites. (2) As additional research is conducted to evaluate the major assumptions built into the framework, the framework would evolve and become more realistic. Eventually, the framework could develop into a predictive model when the key assumptions are validated. It was noted that Dr. Vance Tucker of Duke University had begun developing a model of bird/wind turbine interactions that may be start in this direction.

One illustration of the value of such a framework in helping plan field research is as follows: If we expect that collisions would occur most frequently at night, then research should concentrate on utilization and abatement strategies for nocturnal species. Likewise, if migratory birds are held to be at the greatest risk, research should focus on their use of habitat near the wind resource area, emphasizing their behavior in close proximity to

turbines. Data collected during this research would be useful both on a site-specific basis and in improving the framework model for future applications.

Migratory Bird Utilization of Zone of Risk

The need to understand the specific impact for migratory birds was discussed. Some of the issues are different for migratory birds than for residents. An important hypothesis that remains untested is whether migratory birds are more or less likely be killed than are resident birds. Migrants may have briefer exposure to the wind plant, but are likely to be unfamiliar with it and with the risks. One member of the group asked whether wind resource areas affect migration routes by altering habitats that might be used by migrants.

Collisions of migrants with turbines are expected to be more common in some areas than in others. Experience in California is unlikely to be representative for some other parts of the U.S.A. In corridors heavily used by migrants, higher collision rates are possible, as shown in Europe (e.g., Winkelman 1995).

Several members noted that a starting point for anticipating impacts could be gained from existing data on migration routes. Airport or weather radars were also mentioned as a possible source of new information about general migration routes. Several participants questioned whether these data would be useful given the limitations of long-range radars (see the paper by B. Cooper in these Proceedings) and suggestions that migration routes can shift between years. However, the consensus was that broad-scale radar data from long-range radars could provide information on relative utilization of different migration routes, although not discriminating low from higher altitude migration. Once one or more specific sites of interest to wind developers are identified, higher resolution shorter-range techniques are available for site-specific studies of migration patterns (see the papers by B. Cooper and S. Gauthreaux in these Proceedings).

Several members discussed neotropical migrants. Since these species often migrate at night, their migrations are most readily studied by radar. However, radars cannot discriminate different species of nocturnal passerine migrants. It was also noted that estimating collision mortality of small birds can be difficult because the bodies are often scavenged quickly, as well as being more difficult to locate than bodies of larger species. As a surrogate for understanding the behavior of migrating neotropical migrants around turbines, members suggested examining the voluminous literature on their collisions with (or avoidance of) other tall structures such as television, radio, and water towers.

One member commented that it was important to distinguish between macro- and micro-level analysis. Macro-level analysis of migration examines siting issues and may use long-range radar and published studies as data. Micro-level analysis focuses on the causes of collisions and technological factors that could reduce the number of collisions. Different types of data are needed for these two levels of analysis, and researchers need to collect data of the type appropriate to the questions being asked.

Potential Adaptation of Resident Species to Turbines

Resident species would have more exposure to turbines than would migratory species. Although this increased exposure could lead to greater risk of collision, it could also provide an opportunity for resident birds to learn about turbine layout and dangers. Some members of the group questioned whether adaptation by resident birds confounds experimental design. Members hypothesized that observations of near-fatal encounters and of reactions to "unnatural" stimuli, as investigated through deterrent experiments, may yield important findings. Others mentioned that the effects of natural selection and adaptation (learning) on bird responses to wind plants and to specific turbines are largely unknown.

One suggested approach to measuring adaptive effects would be to reverse technological treatments part way through a study (initial control units become treated units; initial treatment units become controls). There were suggestions that results would probably be species-specific. Planned perching studies and Kenetech Windpower's experiments with pigeons may provide useful data. To examine the hypothesis that different species react differently to turbines, one participant suggested that a first step could be to examine "death lists" to begin to identify commonly- vs. rarely-struck taxa and behavioral guilds.

Effect of Different Mitigation Technologies on Behavior and Mortality

Participants suggested that the aforementioned "framework" could help identify and assign priorities to factors meriting tests or studies, and to research that could help answer the relevant questions. Elements that should be considered for inclusion on the priority list include turbine design (e.g., tower type, rotation rate, blade painting, and audio deterrents) and wind plant design (e.g. turbine layout, topography, prey base, and vegetation/habitat). The group noted that other types of bird deterrent measures should also be considered for efficacy testing, e.g. the possible use of strobe lights at wind resource areas to alert but not attract nighttime migrants.

Several group members expressed interest in having more meeting time to fully discuss specific recommendations for mitigation research. In general, it was noted that hypothesis tests would involve using data collected via survey methods and statistical designs proposed earlier in the workshop. These approaches would be used to examine the effects (on mortality, surrogate variables, or both) of changes in individual turbines and in overall wind plant design. Several participants also suggested that much could be learned from past experience in assessing collisions with other structures. Results from water towers may be of special relevance because they often have a similar height and outline as a turbine and its rotor plane.

Identifying Applicable New Technologies

Workgroup members felt that much could be learned from people designing and conducting studies in other related fields. Relevant work in other fields could include

- statistical methods useful in work on other kinds of rare events (not necessarily involving birds or collisions; e.g. Green and Young 1993);
- studies of bird collisions with other types of structures (reviewed by Weir 1976; Avery et al. 1980; EPRI 1993; Bevanger 1994; Hebert et al. 1995);
- deterrent measures used in attempts to keep birds away from other areas (airports, aircraft, crops, tailings ponds, oil spills, etc., as reviewed by Lucid and Slack 1980; DeFusco and Nagy 1983; Payson and Vance 1984; B.S.C.E. 1988; Knittle and Porter 1988; Marsh et al. 1991; Koski et al. 1993); and
- remote data recording and triggering devices useful in documenting rare events and/or triggering deterrent devices (Kenetech Windpower, NREL, and EPRI have cooperated in some preliminary work on these techniques).

It was suggested that a workshop bringing together appropriate technical "problem-solvers" from different fields might be the best approach to identify relevant technologies used in other fields.

Modeling Behavior and Mortality Using Surrogate Variables

A recurring discussion topic was the need to identify surrogate variables that are easier to study than mortality of birds at turbines. To be useful, a surrogate variable must be strongly correlated with the variable of interest (here mortality), and there must be a way to confirm that they are strongly correlated. The latter is difficult for the same reason that surrogate variables are desirable—because of the rarity of mortality. Variables that were mentioned as possible surrogate variables included occurrence and circumstances of perching on or near turbines, distance to active nests, measures of prey base, time spent within the zone of influence, and number of flights through or near the rotor plane by day or by night, by resident or by migratory birds.

Researchers need to know the circumstances that surround collisions and information on the collisions themselves. To collect baseline data, several participants suggested video systems. Ideally, these would be coupled with image analysis, audio, vibration, or other sensors ▸ to avoid recording during most periods of "no bird activity" and ▸ to provide more information on bird approaches to turbines and on collision events. The possibility of modeling the physics of bird flight and wind streams near turbines to better understand collisions was again mentioned. (This suggestion was also mentioned in Working Group 3, *cf.* p. 134, and during the "Framework" discussion by the present Working Group, *cf.* p. 137.)

One of the problems with identifying a surrogate variable for mortality is that, since collision deaths occur infrequently, it will not be easy to demonstrate that there is a reliable correlation. Demonstration of good correlation is important because variables that might initially seem to be closely associated with collision risk may involve various complications. It was noted that research to demonstrate the reliability of surrogate variables could be costly, with no guarantee that the variable being considered as a candidate surrogate would prove to be suitable.

Recommendations

The group recommended, as a first priority, the development of a framework or conceptual model to help understand the factors affecting the links between wind plant and turbine design, avian behavior, and collision risk. This framework would discuss the scientific opinions on possible factors and would identify the hypotheses deserving most immediate attention. To develop this framework, the group proposed that several people should draft a paper, distribute it, and then attempt to reach consensus. A follow-up workshop might be useful. The initial goal would be to develop a framework useful for focusing thinking and for planning data collection and research. As data are collected, the framework would be refined and would eventually evolve into a more specific model. The framework would help regulators identify the specific statistics that they should rely on, and the data that should be collected to evaluate a proposed site and a proposed wind plant design.

Another level of research would be to continue studying avian mortality at actual or proposed wind plants, and identifying and testing potential surrogate variables. This type of work is often done when evaluating a site for potential development or the mortality at a currently operating site. The group felt that the proposed framework could be useful in helping to design research on the effects of wind plant and turbine design on mortality and related surrogate variables. After the key variables are identified, this work could be implemented via procedures such as those discussed under "Protocol II" in the paper by M. Morrison and H. Davis (p. 115*ff*).

A third proposed activity would be to sponsor a workshop to bring together appropriate technical "problem-solvers" from different fields to discuss their experience in using technologies to overcome other related problems in research and data collection.

All three of these issues were raised in the final plenary as important areas for further research.

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MEETING SUMMARY AND NEXT STEPS TO BE TAKEN

Overview

This meeting was organized to foster productive, problem-solving discussions on how to better understand the impact of wind development on birds. The meeting commenced with a summary of interviews with a variety of people from around the country, in which many had expressed frustration about the lack of any specific guidance regarding how to assess the potential impacts of a proposed wind plant on birds. The remainder of the 2½-day meeting consisted of presentations and discussions about how to approach this problem.

Following the initial summary of interview results, the meeting was structured around four presentations on statistical design and modeling approaches, another four presentations on site assessment protocols and techniques, and two pairs of concurrent workgroup sessions. There was extensive discussion during or following most of the nine formal presentations as well as in the workgroups. The working groups were particularly effective in helping meeting participants focus on the questions that most needed answers. When participants reconvened at the end of the workgroup sessions, it was clear that they had independently and together identified similar questions and similar recommended approaches.

Major Recommendations from the Meeting

1. Framework/Conceptual Model

The first priority is to develop a conceptual model or framework of the principal causes of avian mortality at wind plants. The initial framework would include assumptions about the factors affecting collision mortality, such as day or night, weather and visibility, prey base and habitat characteristics, resident vs. migratory species, species susceptibility, etc. In formulating the initial framework, the critical tasks would include identifying the principal elements to be considered, and hypothesizing the nature of the linkages among those elements. The initial framework would incorporate many untested hypotheses, but it would represent the state-of-the-art and best professional judgment. The process of deriving this initial model would, in itself, be instructive in identifying key technical issues, assumptions, and data gaps.

The group proposed that several people should begin the process by writing a paper describing this initial framework and then distribute it for comments. Eventually, the group hoped that a consensus could be reached on the components and linkages of the initial framework. This framework would be refined as new data become available, and might ultimately evolve into a more quantitative model.

2. Metrics

Over the course of the meeting many people discussed the need to know how to assess a site and how to compare it with other sites. One key requirement, they said, was a common set of metrics, or statistics, that researchers could use to characterize the potential or existing impact from a wind development. For example, participants suggested the need to obtain various measures of utilization and mortality, and the need to derive ratios of the basic measures, e.g. mortality per unit utilization, or perhaps mortality per kilowatt hour generated. Participants suggested that, once the conceptual framework is established, a paper should be developed on the advantages and disadvantages of using various statistics to assess the principal impacts. Regulators, in particular, expressed interest in knowing the implications of relying on one statistic as opposed to another.

3. Data Collection Guidelines/Protocols

The third major recommendation concerned the need to further develop the research protocols and data collection guidelines discussed at the meeting. The guidelines should take account of the conceptual model (see 1, above) and should provide the needed metrics (see 2). The guidelines should discuss both general sampling design and specific data collection methods.

Several presenters at the meeting discussed their work in developing guidelines. Although there were few areas of major disagreement, the various proposed protocols emphasize different types of data. Thus, more work needs to be done to draw together the strong points of the various proposals and resolve differences. There is also a need to further address the extent to which data collection procedures should be adaptable to different circumstances, as opposed to rigidly standardized across all studies. When different procedures are adopted in different studies, procedures should be developed to ensure that the results can be compared and combined even though the data collection methods differed.

4. Statistical Analysis Techniques

Participants recommended that attention also be given to identifying and recommending appropriate statistical techniques for the kinds of questions, metrics and sampling techniques commonly encountered in this field. For example, statistical methods appropriate for ratios, rare events, and BACI designs are needed. Initial recommendations should be included with the protocols discussed in recommendation (3), above.

5. Updating the Framework and Protocols

Participants suggested that the preceding four recommended efforts should work together in an iterative process to adapt to new developments. The framework would help focus data collection efforts to address specific questions. The resulting new information would be analyzed by the recommended statistical methods to confirm or reject hypotheses about avian impacts. These results would be used to refine the framework. By this process,

the framework would gradually become more quantitative and potentially useful as a predictive tool. As experience is gained, desirable refinements in metrics, protocols, and analysis methods would also be identified.

Additional Recommendations

In addition to recommending the above primary agenda, participants suggested undertaking several other activities:

An *ongoing collaboration* between scientists and regulators was recommended by several participants.

A *Technical Review Committee*, including regulators, biologists and statisticians, was suggested. This group could provide peer review for studies at specific sites, and facilitate coordination among projects, including meta-analysis approaches when appropriate.

New technologies: The participants recommended seeking out relevant technologies or research methods not previously considered or used in this field. This could be done by arranging for White Paper(s) and/or a "Technology Workshop"; invite people with backgrounds in solving similar types of problems in other fields (e.g. aerospace engineers, physiologists, and bird scaring specialists).

Radar technologies and coordinated radar, visual, and electro-optic methods: There is a need to develop consistent and validated procedures and sampling strategies for migratory and local movements of birds. White Paper(s) and/or a workshop were suggested.

Cumulative effects: We need to develop an approach to measure cumulative effects in large wind resource areas over the long term, including consideration of data consistency and funding.

This meeting was also important for another reason: communication. In addition to wanting guidance on site assessments, many people interviewed by RESOLVE have been uncomfortable about the site evaluation process and associated communication links. This meeting improved links between researchers and scientists and helped them form common definitions of the problem. Through a series of dialogues between regulators and scientists, regulators' most important questions were articulated and scientists discussed feasible approaches to finding solutions. Many participants commented that relationships formed at the meeting may help to enhance collaborative working relationships among stakeholders.

APPENDICES

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Appendix 2. Meeting Agenda

AVIAN - WIND POWER PLANNING MEETING II

Sponsored by the Avian Subcommittee
of the National Wind Coordinating Committee

September 20, 21 and 22, 1995

Wednesday, September 20

8:30 - 9:15	**Introductions** * *Purpose of meeting* * *Product of meeting* * *Review agenda*	Bob Thresher & Abby Arnold, Facilitator
9:15 -10:15	**Stakeholder Questions, Interests and Concerns** * *Summary of the white paper* * *What are additional research areas in avian/wind interaction* * *What are our underlying concerns* * *Why are these questions essential to answer?*	Abby Arnold, Facilitator
10:15 - 10:30	Break	
10:30 - 12:30	**Available Methodologies** * *What state-of-the-art methods & tools can be applied to avian-wind power issues.*	
10:30 - 11:10	"Fundamentals": Introduction to session	Bob Thresher
11:10 - 11:50	Fundamentals design & statistical requirements	Ken Pollock
11:50 - 12:30	Questions and Comments	
12:30 - 1:30	Lunch (Catered)	
1:30 - 3:30	**Available Methodologies,** *continued*	
1:30 - 2:00	Def'ns of mortality & study designs for analysis	Larry Mayer
2:00 - 2:30	Questions and Comments	
2:30 - 3:30	Population Modeling	
	a. uses and misuses	Ken Wilson
	b. an example from Altamont	Tanya Shenk
3:30 - 3:45	Break	
3:45 - 4:30	Questions and Comments	
4:30 - 5:00	**Review of Day's progress and fine tune Day Two Agenda**	
5:00	Adjourn for the day	

Thursday, September 21

9:00 - 10:00 **Available Methodologies,** *continued*

9:00 - 9:10	*"Applications": Introduction to session*	Bob Thresher
9:10 - 9:35	a. Technology options: Use of radar	Brian Cooper
9:35 - 10:00	Questions and comments	

10:00 - 10:15 Break

10:15 - 12:00 Options for standardization

b. Avian Risk Assessment Methodology	Dick Anderson
c. Suggested Practices for Monitoring	Sid Gauthreaux
d. Draft NREL Protocols	Mike Morrison & Holly Davis

12:00 - 1:00 Lunch (Catered)

1:00 - 1:45 Options for standardization, *continued*

1:45 - 4:45 **Methodologies Applied to Questions** (*Work Groups)*

Issues for Each Group:

* *What research questions ought to be researched?*
* *What research methodologies are most appropriate to answer the questions?*

Work Groups:

1: Site evaluation and pre permit research and planning
2: Operational monitoring
3: Modeling and forecasting, including population dynamics
4: Avian behavior and mortality reduction

1:45 - 3:10 Session One: Work Groups 1 and 3

3:10 - 3:20 Break

3:20 - 4:45 Session Two: Work Groups 2 and 4

4:45 - 5:30 **Work Group (Brief) Report Out**

* *One member of each work group report out progress of discussion and identify goals for final meeting on Friday.*

5:30 Break for day

Friday, September 22

8:00 - 9:15 **Methodologies Applied to Questions** (*Working Groups continued)*

* *Continue discussions from Thursday and prepare talking points for Plenary*

8:00 - 8:35 Session One: Work Groups 1 and 3
8:40 - 9:15 Session Two: Work Groups 2 and 4

9:15 - 9:30 Break

9:30 - 12:00 **Work Group Reports and Synthesis** *(Discussion)*

12:00 - 1:30 **Develop Agreement On Recommendation to Avian Subcommittee**

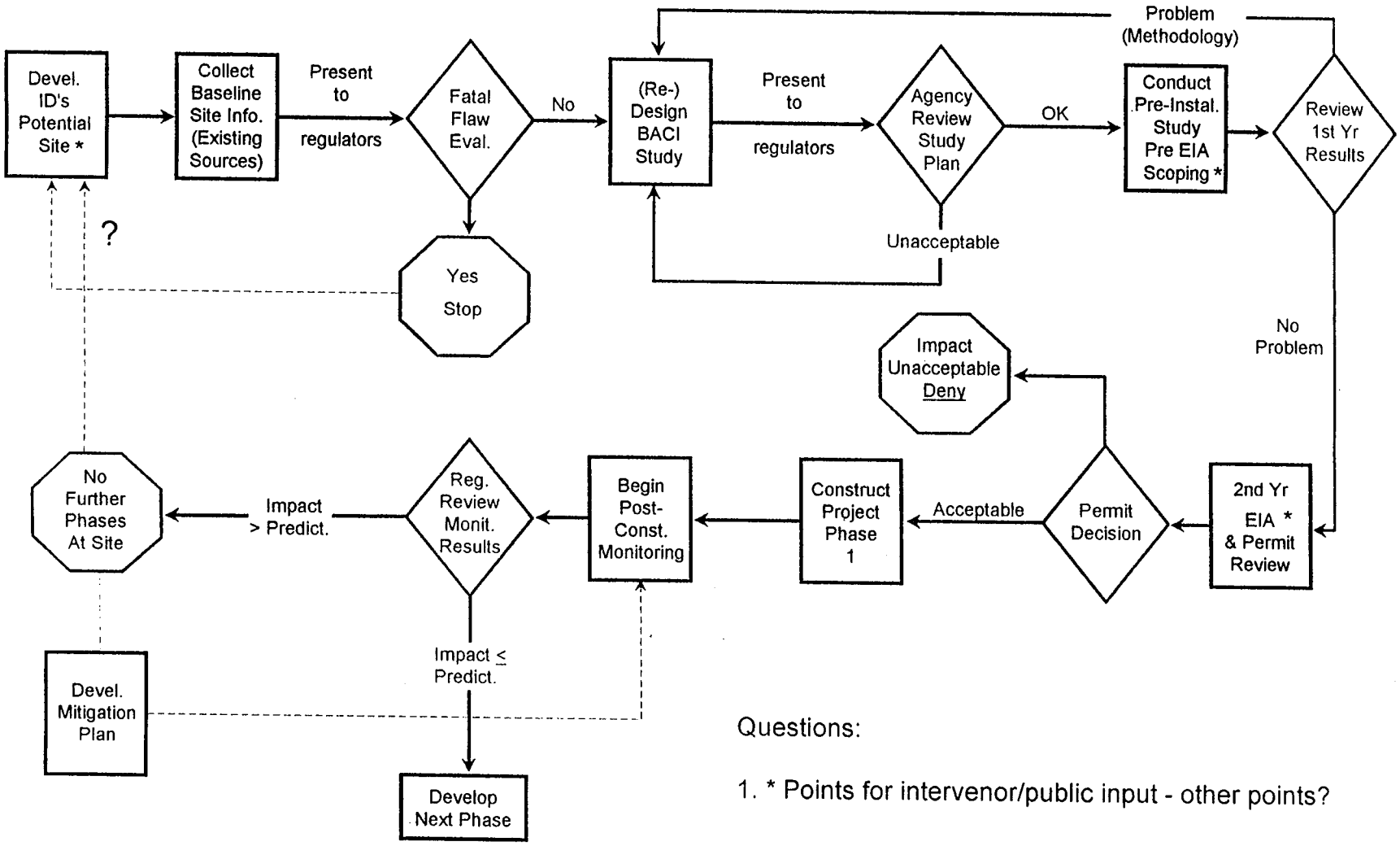
1:30 pm Adjourn

Appendix 3. Regulators' Key Points

Personnel representing regulatory agencies held a side-meeting during National Avian - Wind Power Planning Meeting II to discuss the main research needs from the regulatory perspective. They compiled the following list of key points, and brought these points to the attention of other meeting participants at various times during the plenary sessions and working group sessions.

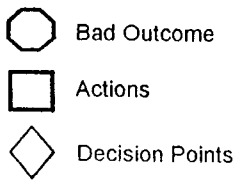
- Establish and maintain the researcher/regulatory interface.
- Define the link between models used and siting decisions.
- For law enforcement purposes it is important to know the size of the "take" and its significance. What level of effect would trigger action?
- Must identify critical questions to set priorities for studies. Input from regulators must be used to do this.
- Need to define the end state we want to be at in 4-5 years, with respect to avian impacts.
- Researchers need to communicate the effect of technical questions (methodology, etc.) on our ability to use data in the regulatory context.
- Need a larger database to provide more confidence in regulatory decisions.
- Regulators should define the questions and the research/technical group should propose methods and protocols to answer them. Both work to formulate hypotheses to test. Need to establish a feedback loop.
- The basic questions are still the number of birds killed, species affected, population effects, and significance of impacts.

The regulators also developed a flow chart illustrating their concept of the interactions among the planning, regulatory, and avian research components of a wind power development. This flow chart follows.



Questions:

1. * Points for intervenor/public input - other points?



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13. ABSTRACT *(Maximum 200 words)*

National Avian-Wind Power Planning Meeting II was organized by the Avian Subcommittee of the National Wind Coordinating Committee. Government regulators, scientists and other stakeholders met in Palm Springs, CA, on 20-22 September 1995 to share ideas about research that could be helpful in predicting and reducing bird mortality from wind turbines. This meeting was the second in a series. The purposes of this meeting were to: 1) provide information on avian/wind power interactions that will help meet the needs of regulators, researchers, and other stakeholders concerned with responsible development and permitting of wind plants; 2) create dialogue among regulators, researchers and other stakeholders to help all parties understand the role that research can play in responsible development and permitting of wind plants, and allow researchers to understand the relevance of their research to the process; and 3) propose research projects and the appropriate sponsorship.

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