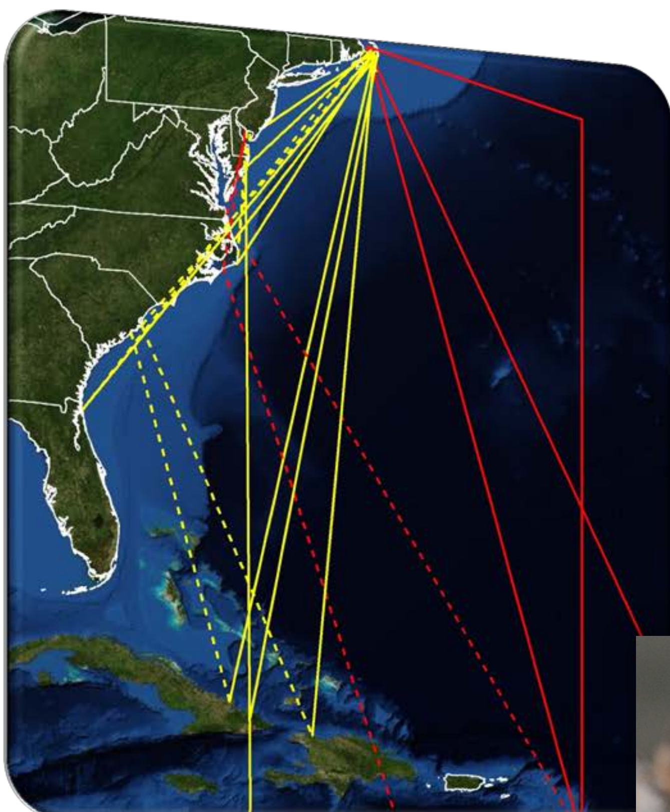
OCS Study
BOEMRE 2011-048

New Insights and New Tools Regarding Risk to Roseate Terns, Piping Plovers, and Red Knots from Wind Facility Operations on the Atlantic Outer Continental Shelf

Final Report



U.S. Department of the Interior
Bureau of Ocean Energy Management,
Regulation and Enforcement

OCS Study
BOEMRE 048-2011

New Insights and New Tools Regarding Risk to Roseate Terns, Piping Plovers, and Red Knots from Wind Facility Operations on the Atlantic Outer Continental Shelf

Final Report

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ABOUT THE COVER

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Burger, J., C. Gordon, L. Niles, J. Newman, G. Forcey, and L. Vlietstra. 2011. Risk evaluation for federally listed (roseate tern, piping plover) or candidate (red knot) bird species in offshore waters: A first step for managing the potential impacts of wind facility development on the Atlantic Outer Continental Shelf. Renewable Energy 36:338–351.

Section 3.2—First results using light level geolocators to track red knots in the Western Hemisphere show rapid and long intercontinental flights and new details of migration pathways (used with permission of Wader Study Group Bulletin):

Niles, L.J., J. Burger, R.R. Porter, A.D. Dey, C.D.T. Minton, P.M. Gonzalez, A.J. Baker, J.W. Fox, and C. Gordon. 2010. First results using light level geolocators to track red knots in the Western Hemisphere show rapid and long intercontinental flights and new details of migration pathways. Wader Study Group Bull. 117(2):123–130.

Preface and Acknowledgments

This report details the objectives, structure, scope, results, and conclusions of the U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) contract #M08PC20060, titled "Potential for interactions between endangered and candidate bird species with wind facility operations on the Atlantic Outer Continental Shelf." This project was awarded by BOEMRE (then Minerals Management Service) to Normandeau Associates, Inc. (then Pandion Systems, Inc.) on 25 Sep 2008 with an expected period of performance of 3 yrs from the award date. The objectives of this study, as stated in the contract, were as follows:

(1) To evaluate the potential for the three endangered, threatened, and candidate species of interest (Roseate Tern, Piping Plover, Red Knot) to be impacted by wind facilities located on the Outer Continental Shelf (OCS)
(2) To determine the best methods to evaluate locations of future wind facilities to minimize risks to the(se) species

Reflective of this twofold objective, Normandeau's approach to this project had two primary thrusts: Risk assessment and methodological innovation. These two ideas are fundamental to this project's nature and structure and comprise one dimension of this project's organization.

The concept of ecological risk assessment (USEPA 1998)[1] has broad ecological application, including in the arena of assessing wildlife risk from wind facility development. This was a central organizing idea of Normandeau's approach to this project and permeates this report. For example, Section 1 is a synthesis of the "problem formulation" stage of the risk assessment, and Section 2 is presented as a preliminary risk assessment with conceptual models and analysis of effects, exposure, and risk characterization. The various subsections of Section 3 contain original research designed to advance knowledge frontiers with respect to the significant risk effects and exposure questions that were identified during the problem formulation stage, and Section 4 presents a final risk characterization, synthesizing the contributions of the original research conducted under this project toward generating new insights into the potential risk of adverse ecological impact to the three focal species of this project from offshore wind facility operations on the AOCS.

The methodological innovation component of this project was somewhat separate from the risk assessment component, although it is related in that it stems from the project's second objective and addresses the need for ecological study methodologies that can be applied toward future risk assessments in order to help evaluate locations of future wind facilities on the AOCS based on ecological risk criteria for the focal species. This methodological innovation component of the project was addressed exclusively in one, and partly in another, of this project's three pilot studies (pilot study structure explained below) as follows: the development of a new statistical model for evaluating the risk of flying birds colliding with offshore wind turbines is presented in Section 3.6 with application to Roseate Terns in Buzzards Bay, Massachusetts; the initial

[1] U.S. Environmental Protection Agency (USEPA). 1998. Guidelines for ecological risk assessment. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, D.C. EPA/630/R095/002F.

development and testing of a self-powered, remote operating acoustic/thermographic bird detector (Acoustic Thermographic Offshore Monitoring [ATOM] system) was supported by another of this project's pilot studies and is presented in Section 3.7.

Another dimension of this project's organization is created by the somewhat complex and multifaceted structure of the two separate contracts and three pilot studies that comprised the project's backbone. These elements are listed below and their relationship to the project's task structure, to each of the five original research and technology development initiatives, two synthesis sections, two midterm meetings, and to the project team and objectives is briefly outlined in the remainder of this section.

Contractual and Task Structure: This project was conducted under two distinct contracts. The first (CLIN 0001) provided an overarching structure for the entire project. It specified nine tasks, encompassing all of the elements of the study except for the pilot studies that were listed as Task 6 (see below). The pilot studies were funded separately under contract CLIN 0002.

Contractual and task structure of the project

Task or Pilot Study	CLIN 0001	CLIN 0002
Period of Performance	10/2008–9/2011	5/2009–8/2010
Task 1: Establish a Scientific Review Group	X	
Task 2: Post Award Meeting and Mid-Term Meetings	X	
Task 3: Collect and Evaluate Existing Data	X	
Task 4: Evaluate Methodologies for Determining Risk	X	
Task 5: Propose Pilot Study(ies) to Test Methodologies	X	
Task 6: Conduct Initial Pilot Study or Studies		X
Pilot study 1: Developing and Testing an Offshore Remote Bird Monitoring Device That Combines Acoustic and Thermal Image Detection		X
Pilot study 2: Using Tracking Devices to Map Out Where and When the Focal Species Intersect the AOCS		X
Pilot study 3: Wind Turbine Exposure Analysis (Risk/Exposure Modeling)		X
Task 7: Data Synthesis	X	
Task 8: Report Preparation	X	
Task 9: Cooperation and Coordination	X	

Project Meetings: Three meetings were held over the course of the project to create opportunities for interactive discussions and exchange of ideas at several critical phases of the project. Summaries and/or agendas from these meetings are included as Appendices A through C and details of each are provided below.

Basic descriptions of the three project meetings*

Meeting Feature	Kickoff Meeting	1st Midterm Meeting	2nd Midterm Meeting
Date	29 Oct 2008	5–6 Feb 2009	4–6 Nov 2010
Location	MMS Headquarters, Herndon, VA	Paramount Plaza Hotel, Gainesville, FL	Paramount Plaza Hotel, Gainesville, FL
Principal Meeting Objectives	Launch project. Clarify project roles, objectives, tasks, and procedures.	Synthesize existing knowledge. Conceive pilot studies.	Interpret/discuss original project results.
Attendees			
Mary Boatman	X		
Christian Newman	X	X	X
Caleb Gordon	X	X	X
James Newman	X	X	X
Greg Forcey	X	X	X
Joanna Burger	X	X	X
Lawrence Niles	X	X	X
Lucy Vlietstra	X	X	X
Edward Zillioux	X	X	X
William Warren-Hicks	X	X	X
Richard Podolsky	X		
Andrew Farnsworth	X	X	
David Mizrahi	X		
Marshall Iliff	X		
Allan O’Connell	X		
Andrew Gilbert	(via phone and web)		
Scott Johnston	(via phone and web)		
James Woehr		X	X
Chris Ribe		X	X
Alexis Teran		X	X
Steve Kelling		X	
Mark Desholm		X	X
Ian Baldwin			X
Michael Rasser			X
Michal Amaral			X
Susi Von Oettingen			(via teleconference)
Annette Scherer			X
Maria Tur			X
Caleb Spiegel			X
Don MacArthur			X
Erica MacArthur			X
Jennifer Seavey			X
Ron Rohrbaugh			X
John Carter			X

*See *Project Team* below for institutional affiliations and roles. In-person attendance is indicated, unless otherwise specified.

Pilot Studies: The initial contract specified that the contractor would conduct one or more pilot studies intended to evaluate risk to the three focal species or to evaluate methodologies that could be applied to risk assessments. A broad range of methodological, scientific, and analytical approaches was encouraged. The pilot study or studies were to be proposed by the contractor as part of the project (Task 5) with input from BOEMRE, the project's Scientific Review Group (SRG; see below), and other federal agency experts to help shape the direction of the pilot study(ies). The selected pilot study or studies were then to be contracted separately according to the resulting proposal and executed by the contractor as Task 6 of the project. The pilot studies were conceived, designed, and resourced as the central core of the original, project-supported research and/or technology development initiatives intended to accomplish the project's objectives.

Three pilot studies were conceived and selected for proposal development during the project's first midterm meeting in Feb 2009. This set of pilot studies was selected on the basis of its potential to make maximum possible progress toward the project's two objectives, both by addressing priority research questions as identified in the problem formulation stage of the risk assessment and also with respect to methodological advancements toward better evaluation of risk to the project's three focal species. The selected pilot study ideas were subsequently written up and submitted as a proposal to BOEMRE on 18 Mar 2009, with input from BOEMRE, the SRG, and the project's advisors and liaisons. This proposal was funded by BOEMRE as project contract CLIN 0002 and then executed by the project team between May 2009 and Aug 2010. The original pilot study proposal is included in this report as Appendix D. After the pilot studies were completed, the results of each were analyzed and written up in draft reports by the lead investigators and distributed to the project's investigators, managers, liaisons, SRG, and advisors during fall 2010 to solicit written comments to direct revisions of these reports. These draft reports were then discussed by the project team at the project's second midterm meeting on 4–6 Nov 2010, in Gainesville, Florida (see above). During this meeting, a separate technical session was held to discuss each of the reports that resulted from each of the pilot studies (four sessions to cover three pilot studies). Each of these technical sessions consisted of an oral/PowerPoint presentation of the study by the lead investigators followed by discussion from the project team. All meeting participants filled out comment sheets on each of the pilot studies immediately following each of these technical sessions. These comment sheets were subsequently compiled and provided to the lead authors of each pilot study along with all of the written commentary on the draft pilot study reports in order to direct the revisions of these reports. The revised reports are contained within this report in the sections indicated below, which also present other basic information about each of the pilot studies.

Basic nature, structure, and project team for the project's three pilot studies

Feature	Pilot Study #1	Pilot Study #2	Pilot Study #3
Title	Developing and Testing an Offshore Remote Bird Monitoring Device that Combines Acoustic and Thermal Image Detection	Using Tracking Devices to Map Out Where and When the Focal Species Intersect the AOCS	Wind Turbine Exposure Analysis (Risk/Exposure Modeling)
Objective(s)	Develop an improved methodology for risk assessments of focal species from wind development on AOCS	Characterize geographic scale exposure pattern of Red Knots to potential wind facilities on AOCS	Characterize wind turbine behavioral avoidance and collision susceptibility of Roseate Terns and surrogate species
Methodology(ies)	Technology development	Capture Red Knots, attach light sensitive geolocators, recapture tracked Red Knots to retrieve data	Behavioral observations and mortality studies of Roseate Terns and other birds at a coastal wind turbine, mathematical modeling of collision risk based on empirical observations
Location(s) of work	Gainesville, FL; Cape Cod, MA	Quebec, MA, NJ, FL, South America	Buzzards Bay, MA
Taxonomic scope	Broad. All vocalizing birds, all warm-blooded flying animals	Red Knots	Roseate Terns, Common Terns, other birds occurring at Massachusetts Maritime Academy wind turbine
Principal investigators or technology developers	Chris Ribe, Caleb Gordon, Christian Newman, Ian Baldwin	Larry Niles, Joanna Burger, Caleb Gordon	Lucy Vlietstra, William Warren-Hicks, Caleb Gordon, James Newman, Mark Patrick, Richard Podolsky
Report sections containing detailed results writeup	Section 3.7	Section 3.2 (published as Niles et al. 2010; reproduced with permission) Section 3.3	Section 3.5 Section 3.6

Geospatial Analysis: One of the important issues identified during the problem formulation stage of the risk assessment was a need to better understand the focal species' macroscale exposure patterns to potential offshore wind facility development on the AOCS. Macroscale exposure was defined by the project team as geographic occurrence in a given area at a given time (Burger et al. 2011), which is a necessary, though not sufficient, criterion for exposure of a species to wind turbine collision risk in that area at that time. The project team identified this issue as one that could be addressed, at least in part, by analyzing existing spatiotemporal records of the three focal species within the AOCS region. The project team acknowledged that while existing spatiotemporal records were very sparse for the offshore environment of the AOCS itself, records are much more comprehensive for the coastal regions that border the AOCS, and the team identified several sets of hypotheses and research questions about AOCS macroscale exposure that could potentially be indirectly inferred from coastal geospatial evidence. In order to address these specific questions, as well as the broader issue of delineating what is known about these species' patterns of AOCS macroscale exposure, we conducted a quantitative, GIS-based analysis of all existing geospatial information on the three focal species. This analysis was conducted under the auspices of project Task 3 "collect and evaluate existing data" and is presented in Section 3.4 of this report. The data on which it is based was compiled from various original sources within the Avian Knowledge Network (AKN), as described in Section 3.4. This compilation was done with the assistance of the Cornell Laboratory of Ornithology (CLO), who created and maintains the AKN, and who also identified, acquired, and entered additional project-relevant existing datasets for use in this analysis, also described in Section 3.4 of this report. A database containing the data used in this analysis is included as an accompaniment to this report.

The geospatial analysis results writeup, commentary by the project team, presentation and discussion at the project's second midterm meeting, and subsequent revision for the final report proceeded in exactly the same manner and along the same timetable as the pilot study reports (see previous subsection).

Original Research Syntheses: This report also contains two original syntheses of scientific information pertinent to the risk assessment objective of this study (Objective #1). The first is a synthesis of all existing information in published and unpublished technical literature as of spring 2009. This synthesis was written up in the format of a preliminary ecological risk assessment and is presented in Section 2 of this report. It is reproduced herein with permission from the copyright holder as it has been published in *Renewable Energy* (Burger et al. 2011).

The second original synthesis section of this report, presented as Section 4, focuses on the new advances in knowledge gained through the original research initiatives of this study. It is not written in classical risk assessment format, although it roughly corresponds to an updated risk characterization section from the preliminary risk assessment (Section 2) based on the new information generated by this study. This section also incorporates new technical information from sources outside the project that have become available subsequent to the preliminary risk assessment.

Project Team, Roles, and Contributions: We acknowledge the contributions of many individuals to this project. These individuals are listed below, along with the institutional affiliation and project role of each. Certain project constituencies are described in further detail below.

Project personnel with institutional affiliation and project role

Person	Institution	Project Role
Debra Bridge	BOEMRE	Contracting Officer (through Apr 2010)
Lisa Algarin	BOEMRE	Contracting Officer (since Apr 2010)
Mary Boatman	BOEMRE	Contracting Officer's Representative (through Oct 2009)
James Woehr	BOEMRE	Contracting Officer's Representative (since Oct 2009)
Michael Rasser	BOEMRE	Project liaison
David Bigger	BOEMRE	Project liaison
Tre Glenn	BOEMRE	Project liaison
Kimberley Skrupky	BOEMRE	Project liaison
Sally Valdes	BOEMRE	Project liaison

Person	Institution	Project Role
Brian Hooker	BOEMRE	Project liaison
Jill Lewandowski	BOEMRE	Project liaison
Christian Newman	Normandeau Associates	Project Director
Caleb Gordon	Normandeau Associates	Project Manager, lead investigator
James Newman	Normandeau Associates	Ornithologist, risk assessment director, co-principal investigator
Greg Forcey	Normandeau Associates	Ornithologist, geospatial analyst, co-principal investigator
Ian Baldwin	Normandeau Associates	Technology development manager
Chris Ribe	Normandeau Associates	Technology designer/engineer
James Ribe	Normandeau Associates	Technology assistant
Jenny Carter	Normandeau Associates	Project administrator, editing
Alexis Teran	Normandeau Associates	Project coordinator
Karen Hill	Normandeau Associates	Editing
Patti Casey	Normandeau Associates	Editing
Julia Willmott	Normandeau Associates	Editing, report coordination
Akela Ribe	Akela Ribe Productions	Film review, editing
John Carter	Rhinosys, Inc.	Software development
Don MacArthur	Innovative Automation Technologies, LLC	Technology testing
Erica MacArthur	Innovative Automation Technologies, LLC	Technology testing
John Cox	Independent Consultant	Technology development manager
Kenneth Rosenberg	Cornell Laboratory of Ornithology	Project advisor
Andrew Farnsworth	Cornell Laboratory of Ornithology	Project advisor
Steve Kelling	Cornell Laboratory of Ornithology	Project advisor
Ron Rohrbaugh	Cornell Laboratory of Ornithology	Project advisor
Michael Harvey	Cornell Laboratory of Ornithology	Field ornithologist, system testing
Marshall Iliff	Cornell Laboratory of Ornithology	Avian Knowledge Network data acquisition and processing
Allan O'Connell	U.S. Geological Survey	Project liaison
Andrew Gilbert	U.S. Geological Survey	Project liaison
Michael Amaral	U.S. Fish and Wildlife Service	Project liaison
Susi Von Oettingen	U.S. Fish and Wildlife Service	Project liaison
Annette Scherer	U.S. Fish and Wildlife Service	Project liaison
Anne Hecht	U.S. Fish and Wildlife Service	Project liaison
Maria Tur	U.S. Fish and Wildlife Service	Project liaison
Scott Johnston	U.S. Fish and Wildlife Service	Project liaison
Caleb Spiegel	U.S. Fish and Wildlife Service	Project liaison
Richard Podolsky	Independent Consultant	Scientific Review Group
Eric Smith	Virginia Technical University	Scientific Review Group
David Mizrahi	New Jersey Audubon Society	Scientific Review Group

Person	Institution	Project Role
Mark Desholm	Danish National Environmental Research Institute	Project advisor
Tony Fox	Danish National Environmental Research Institute	Project advisor
Edward Zillioux	Environmental Bioindicators Foundation	QA/QC manager, Project advisor
William Warren-Hicks	EcoStat, Inc.	Co-principal investigator
Lucy Vlietstra	U.S. Coast Guard Academy	Co-principal investigator
Lawrence Niles	Conserve Wildlife Foundation	Co-principal investigator
Joanna Burger	Rutgers University	Co-principal investigator
Jennifer Seavey	University of Florida	Project advisor
Mark Patrick	Massachusetts Maritime Academy	Co-principal investigator
Evan Dalton	Massachusetts Maritime Academy	Ornithology field technician

Some of the roles of project personnel, as listed above, are self-explanatory. The specific nature of certain other project roles and constituencies are detailed briefly below.

Principal Investigators contributed ideas toward the original research initiatives and/or original research syntheses supported by this project and made significant contributions toward the conception, execution, interpretation, and/or writeup of this research.

Project Advisors and Liaisons helped improve and/or refine the original research initiatives and/or syntheses supported by this project by participating in one or more project meetings or teleconferences to discuss revisions to the work in progress by providing written comments on drafted sections of the work in progress, or both.

Scientific Review Group members provided written comments to help improve drafts of the pilot study proposal as well as the write-ups of all of the original research, technology development, and synthesis components of this project.

Additional Acknowledgements: In addition to the people and institutions whose contributions to this project are acknowledged above, the project wishes to acknowledge several additional individuals and institutions that made valuable contributions to this project, as follows:

- The staff of all subcontractors' institutions for administrative and technical support
- The volunteer network of Red Knot observers who contributed to the Red Knot geolocator pilot study effort
- Additional sources of funding and scientific support that were synergized and combined with the Red Knot geolocator pilot study effort of this project
- The sources of data and funding support for the AKN
- The Massachusetts Maritime Academy (MMA) for use of their coastal wind facility for initial field testing of the acoustic/thermographic bird detector

- Additional volunteers and assistants who contributed to the Massachusetts Maritime Academy pilot study fieldwork
- Additional funding sources and scientific contributions to previous studies of tern behavior at the MMA wind turbine that were synergized and combined with project-supported research
- Previous research and development of Normandeau Associates' (formerly Pandion Systems) Remote Bat Acoustic Technology (ReBAT™) ultrasonic bat detection system

Summary

We conducted a 3-yr study intended to (1) evaluate the potential for Roseate Tern, Piping Plover, and Red Knot to be impacted by wind facilities located on the Atlantic Outer Continental Shelf (AOCS) and (2) to determine the best methods to evaluate locations of future wind facilities to minimize risks to these species. These species were selected because they are currently or potentially protected under the U.S. Endangered Species Act (ESA) as follows: Roseate Tern (*Sterna dougallii,* endangered North Atlantic breeding population); Piping Plover (*Charadrius melodus,* threatened Atlantic coastal breeding population); Red Knot (*Calidris canutus,* candidate for ESA listing), and because they have been identified as the set of ESA-listed or candidate bird species with the highest potential for experiencing adverse impacts as a result of offshore wind energy development on the AOCS.

Difficulty in acquiring the data needed to adequately assess risk to Roseate Terns and Piping Plovers was a significant challenge for the Cape Wind Project, America's first proposed offshore wind energy facility. This difficulty resulted both from a lack of understanding of these species' biology in the offshore environment as it relates to potential risk from offshore wind and also from a lack of available study methodologies to gain the data necessary to address this risk issue. The current project was undertaken to provide new insights into the risk of potential adverse ecological impacts to these three focal bird species from AOCS offshore wind development and also to develop new tools to be able to better characterize such risk in the future. Such new knowledge and new tools are intended to streamline offshore wind leasing and permitting on the AOCS by solving a key challenge faced by the Cape Wind Project and, in so doing, provide an essential part of the foundation for addressing ecological risk issues associated with all other current and future proposed offshore wind facilities located in federally regulated waters of the AOCS.

We used ecological risk assessment as a framework to focus this study on the highest priority efforts that could advance the project objectives. This resulted in a multifaceted approach, consisting of the following distinct elements:

- We characterized risk to the three focal species from AOCS wind facility development based on synthesis of technical literature, expert opinion, and all other preexisting information (preliminary risk assessment) as well as new insights gained through this project's original research initiatives (final risk characterization). Our analyses revealed that while certain important knowledge gaps persist, the overall risk of adverse impacts to all three species from AOCS wind energy development is low. In the case of Red Knot and Piping Plover, macroscale exposure is limited to a likely maximum of two AOCS crossings per individual per year; hence, there can be little exposure to collision risk. Macroscale exposure is somewhat higher for Roseate Tern, as some exposure occurs during breeding and postbreeding staging periods of the year in addition to migration. However, pre-existing and new information on meso- and microscale exposure factors for Roseate Terns suggest that both of these types of exposure are low for this species.

- We developed and conducted initial tests of an acoustic/thermographic monitoring device intended for remote, unmanned, long-term continual deployment on a fixed platform in

the marine environment that is capable of providing species-specific data on the occurrence of the focal species within rotor swept altitudes at proposed AOCS wind facility locations. Our initial deployment and testing of this device demonstrated its effectiveness at recording thermal images of the focal species in a marine environment and at obtaining acoustic recordings capable of rendering the desired species-specific information for Roseate Terns. Target recognition and flight height calculation algorithms from thermal image data were also developed and tested, and successful performance was demonstrated.

- We conducted a field study of bird fatality patterns at a coastal wind turbine in Massachusetts, located within 12 km of a Roseate Tern breeding colony, including experiments to correct for searcher efficiency and carcass removal by scavengers. One season of carcass searching, with associated searcher efficiency and carcass scavenging experiments, combined with two previous years of carcass searching data at the MMA's coastal wind turbine in Buzzards Bay, Massachusetts, yielded a total of four avian carcasses and estimates of 1.8–3.3 avian fatalities per year at this turbine. None of the observed fatalities were of the focal species, though the small sample size limited our ability to make any conclusions about the collision susceptibility of these species.

- We developed a new statistical model of bird collision risk at offshore wind facilities that incorporates behavioral avoidance. We applied this model to the case of Roseate Tern risk at offshore wind facilities on the AOCS, using empirical observations of Roseate Terns in the vicinity of a wind turbine, and in the marine environment of Buzzards Bay, Massachusetts. The model's structure is based on the model developed by Hatch and Brault (2007)[2] and applied to model collision risk of Roseate Terns and Piping Plovers at the proposed Cape Wind Energy Facility. Our model includes a novel mechanism for incorporating behavioral avoidance at three spatial scales, as well as increased sophistication in statistical distributions of input variables and associated model output variation. Our application of this model to Roseate Terns produced collision mortality predictions comparable to those included in the Cape Wind Biological Opinion on risk to Roseate Tern and Piping Plover. The general nature of this model makes it potentially applicable to any bird species that may be exposed to risk of collisions with offshore wind facility turbine rotors.

- We conducted a region-wide, population-level, GIS-based analysis of all available geospatial distributional data for the three focal species in the marine and coastal portions of the AOCS region, including an evaluation of hypothesized AOCS-crossing migration pathways in Piping Plover and Red Knot. This was based on data pre-existing within, and also added through the course of the project to, the Avian Knowledge Network (AKN), which includes extensive coastal land-based observations of these species. Our analysis confirmed the pelagic migration tendency of Roseate Tern, but provided little additional insight into the three focal species' spatiotemporal patterns of occurrence in the offshore environment of the AOCS. Our analyses of coastal data suggested that both Red Knots

[2] Hatch, J.J. and S. Brault. 2007. Collision mortalities at Horseshoe Shoal of bird species of special concern. Report no. 5.3.2-1 Cape Wind Associates.

and Piping Plovers may have general tendencies to cross the AOCS on long-distance single flights, rather than hugging the coastline with a series of shorter distance flights, though it is almost certain that some individual birds exhibit tendencies toward the latter. This finding suggests that Red Knots and Piping Plovers are both likely to experience macroscale exposure to AOCS wind facilities during migration, though this exposure is likely to be restricted to two episodes per year per individual. The specific regions of the AOCS in which this macroscale exposure occurs are not well known, though for Red Knot it may be concentrated south of Cape Cod in fall and south of Delaware Bay-North Carolina in spring. Actual exposure to AOCS wind turbine collision risk remains uncertain for both species, as migratory flight altitudes and behavioral avoidance tendencies during migratory flights are unknown.

- We identified the specific migration routes taken by 11 individual Red Knots based on data from light-sensitive geolocators placed on the legs of birds captured at Atlantic Coast migration stopover sites and then recaptured at the same sites 1 yr later. These data revealed that macroscale exposure of this species to AOCS wind turbine collision risk may occur virtually anywhere within the region, though there is some evidence to corroborate the seasonal geographic patterns suggested by the geospatial analysis (south of Massachusetts in fall; south of Delaware Bay-North Carolina in spring).

Our findings suggest the following conclusions:

- Overall risk of significant adverse impacts from collision with wind turbine rotors on the AOCS is likely to be low, though some degree of exposure is likely to occur for all three focal species in this region.

- It is difficult to reach very robust conclusions regarding the risk of significant adverse impacts from collision with wind turbine rotors in the AOCS region for all three focal species because of limited available information. Key unknowns for all three focal species include (1) behavioral responses to offshore wind turbines, (2) specific locations of AOCS-crossing migration paths, and (3) migratory flight altitudes.

- The acoustic/thermographic monitoring device whose prototype was developed during this study will be able to fill in the most important of these knowledge gaps for specific proposed wind facility locations on the AOCS by providing species-specific, day/night, long-term continual occurrence and flight altitude data from fixed platforms located at the proposed sites.

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Abbreviations and Acronyms

AKN	Avian Knowledge Network
ANOVA	Analysis of Variance
AOCS	Atlantic Outer Continental Shelf
ATOM	Acoustic Thermographic Offshore Monitoring
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
CLO	Cornell Laboratory of Ornithology
CM	Collision Mortality
EEZ	Exclusive Economic Zone
ERA	Ecological Risk Assessment
ESA	Endangered Species Act
GA	Geospatial Analysis
HRA	Health Risk Assessment
ISS	International Shorebird Survey
MMA	Massachusetts Maritime Academy
MMS	Minerals Management Service
NRC	National Research Council
NRDA	Natural Resource Damage Assessment
pdf	Probability Density Function
PIPL	Piping Plover
PSA	Primary Search Area
QA/QC	Quality Assurance and Control
ReBAT™	Remote Bat Acoustic Technology
REKN	Red Knot
RFP	Request for Proposals
ROST	Roseate Tern
RSA	Rotor Swept Area
RSZ	Rotor Swept Zone
SAMP	Special Area Management Plan
SRG	Scientific Review Group
USFWS	U.S. Fish and Wildlife Service

1 Introduction

1.1 Study Background, Objectives, and Basic Approach

This project is composed of two basic elements, both relating to the core issue of characterizing the risks to Roseate Terns, Piping Plovers, and Red Knots from the development of offshore wind energy facilities on the U.S. Atlantic Outer Continental Shelf (AOCS). The AOCS is defined as the region beginning three nautical miles offshore of the coast and ending at the border of the U.S. Exclusive Economic Zone (EEZ) on the AOCS with a focus on the areas that are potentially developable for offshore wind with current technology (e.g., out as far as the 30-m isobath). The first element is ecological risk assessment and the second element is methodological innovation. We introduce our approach to this study in this section by describing the relationship of these two core study elements to the general underlying risk issue as well as the specific objectives they were intended to address.

The original request for proposals (RFP) issued by the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE; then Mineral Management Service [MMS]) for this project stated that "This study will provide an initial evaluation of the potential for endangered, threatened, and candidate bird species to interact with offshore wind facilities located along the Atlantic Coast…." It also stated that "The key question to be addressed by this study is whether these bird species are at risk from offshore wind facility development." These statements were the basis for Normandeau Associates' (then Pandion Systems) risk assessment approach to this project.

Furthermore, the RFP stated that "The determination of risk can be evaluated either through physical observations or through predictive models or a combination." This statement underscores the importance of both physical data and predictive models for addressing this risk assessment problem.

A final statement from the RFP also contains important implications for this project: "Equally important is the ability to demonstrate that these birds are not at risk based on a lack of observations (i.e., they are not observed in an area where development would occur as demonstrated by proven technology) or through predictive models." In essence, this statement addresses the fundamental problem of attaining positive evidence of physical absence. If one or more of the species in question does not regularly occur in the region of interest, how can that be definitively demonstrated, if at all? This issue points to the importance of methodological innovation for producing the data needed to fill essential risk assessment data gaps.

These ideas were then crystallized into two specific study objectives defined in the original Master Service Agreement (#M08PC20060) as follows:

(1) to evaluate the potential for the three endangered, threatened, and candidate species of interest to be impacted by wind facilities located on the Outer Continental Shelf (OCS); and

(2) to determine the best methods to evaluate locations of future wind facilities to minimize risks to the species.

Normandeau's two-pronged approach to this project reflects these two study objectives. We approached the first objective as a risk assessment problem. The foundation and first steps of this risk assessment element of our approach are described in the remainder of this introduction and in Section 2 of this report, which presents a preliminary risk assessment based on information gathered and synthesized prior to the original research initiatives of this project. Various original research efforts to address priority risk questions as identified in the problem formulation are presented in Section 3. A risk characterization incorporating the original findings of project-generated research is presented in Section 4 of this report.

The second objective is separate from the risk assessment, though it is related in that it is an essential step for conducting future risk assessments. It is a methodological objective, and it stipulates that the desired methods for characterizing risk must be able to inform siting decisions by providing the necessary information on risks to these species from AOCS wind energy development. The methodological element of this project was manifest in two of the project's pilot studies—reported in Section 3 of this report—as follows: one technology development initiative is described in Section 3.7, and one modeling initiative is described in Section 3.6.

1.2 Risk Assessment Phase 1: Problem Formulation

In the concept of formal Ecological Risk Assessment, risk is defined as the probability of an adverse effect occurring, and the first step in the process of assessing risk is called " problem formulation" (NRC 1986, 1993). Problem formulation involves developing working hypotheses on how and why stressors (e.g., the wind turbines) might increase the probability that one or more receptors or endpoints (e.g., Red Knots, Roseate Terns, Piping Plovers) are exposed to one or more ecological effects (e.g., collision mortality, habitat displacement, behavioral avoidance, etc.). The goal of problem formulation is to define the ecological relationships that need to be evaluated and plan how to evaluate them. Problem formulation lays the foundation for the entire risk assessment.

The endpoints are defined based on values considered important by society. Problem formulation also involves selecting the exposure and effects measurements and defining the spatial and temporal extent of the analysis.

Products of problem formulation include the following:

- Delineation of conceptual models of the exposure/effects relationships
- Identification and prioritization of the key questions that need to be addressed in order to characterize risk
- Identification of the data that need to be collected to answer the key questions
- Identification of the methods that can most effectively produce the needed data

Building upon the preliminary research conducted by the Normandeau team, as well as the collective expertise of the entire project team, the problem formulation took initial shape during the project kickoff meeting held on 29 Oct 2008 in Herndon, Virginia. Following this meeting, additional input was provided by all of the principal investigators (especially Lucy Vlietstra, Joanna Burger, and Larry Niles), who were asked to provide species-specific information on Roseate Tern, Piping Plover, and Red Knot, respectively, based on their areas of specific expertise. The Normandeau team combined this information with additional information from technical literature, government documents associated with the environmental review and approval of the Cape Wind Project, and input from U.S. Fish and Wildlife Service (USFWS) personnel, which included the recovery team leaders for the focal species. The synthesis of this pre-existing information during the problem formulation phase of this project is presented in the preliminary risk assessment section of this report (Section 2).

One idea that emerged from the problem formulation was that a single stressor (wind turbines) and a single associated effect (mortality or serious injury caused by collisions with wind turbines) were identified as the most important risk issue for the focal species associated with AOCS offshore wind facility development. Other possible stressors, including boat traffic and turbine platforms, and other possible adverse effects, including habitat displacement, were also considered but were generally deemed to be unlikely to pose significant risk to the three focal species (see Section 2). The exposure of the focal species to risk of direct collisions with offshore wind turbines on the AOCS therefore became the primary thrust of the risk assessment.

One core idea that emerged from the problem formulation with respect to this risk issue was a scale-based classification of different types of collision exposure based on the different spatial scales of the biological phenomena that drive wind turbine collision risk. Three distinct scales of exposure were defined (see below). It was noted that these scales of exposure are nested. For exposure to occur at a given level, it must occur at all of the higher levels (i.e., microscale exposure can only occur if macro- and mesoscale exposure occur). The three scales of exposure were defined as follows (see also Burger et al. 2011; report Section 2):

- **Macroscale exposure** occurs if individuals of the species occur within the geographic region of interest, in this case on the AOCS ≥3 miles from shore. Macroscale exposure is therefore governed by biogeography as well as geographic-scale patterns of habitat use, in this case pelagic vs. near-shore vs. coastal.

- **Mesoscale exposure** occurs if individuals of the species are exposed at the macroscale level *and* if they fly within the Rotor Swept Zone (RSZ) of wind turbines such as would be installed on the AOCS (roughly 20–130 m above sea level). Mesoscale exposure is therefore governed by flight altitude.

- **Microscale exposure** occurs if individuals of the species are exposed at the macro- and mesoscale levels *and* if they fly within the Rotor Swept Area (RSA) of wind turbines. A species with a high degree of exposure at the mesoscale (it flies at rotor height) would have a high degree of microscale exposure if behavioral and morphological constraints render it highly susceptible to collisions with wind turbine rotors, but it would have low microscale exposure if it has a high capacity for avoiding the turbines. Microscale exposure is therefore governed by behavioral avoidance factors such as visual acuity, visibility conditions, maneuverability, and behavioral patterns.

Another principal step in the problem formulation was the identification and prioritization of scientific knowledge gaps and corresponding research questions that could fill those gaps based on risk assessment criteria. Prior to and during the first project midterm meeting, the members of the project team generated a list of these knowledge gaps and research questions. These were classified into three priority tiers (1 is highest and 3 is lowest) during the midterm meeting using the following criteria:

- Is the question important to answer in order to satisfy the risk assessment objective of this study (Objective #1)?
- Does the question represent a significant gap in current knowledge (i.e., answer is largely or wholly unknown)?

This was done separately for each of the three focal species of this project, and information on the type of data needed to address the question was added. The results are presented below in Table 1–1, Table 1–2, and Table 1–3. This information was then used to develop specific pilot study ideas specifically designed to gather the data necessary to address the prioritized research questions.

Table 1–1

Prioritized pilot study questions for Roseate Tern (ROST).

Question	Current State of Knowledge	Importance for Study Objectives	Data Needed to Answer the Question	Priority Level (initials of person)
Where and when do migrating ROST intersect the AOCS affected by weather?	Poor to moderate	High	Geospatial observations	1 (LV, JB, MD)
What numbers of ROST feed in the AOCS and how far out will they feed during the breeding season (affected by weather, forage farther out in bad weather)?	Moderate to good	High	Geospatial observations	3 (LN, LV)
In what spatiotemporal pattern do ROST encounter the AOCS during movements either to or from postbreeding and oceanic staging areas?	Moderate to poor	High	Geospatial observations	1
What are the movement patterns of nonbreeding adults during breeding season and migration?	Poor	Moderate	Behavioral/ demographic tracking studies	2
Do the flight trajectories of migrating ROST intersect the RSZ of wind turbines?	Poor	High	Flight heights	1
Do the flight trajectories of foraging ROST intersect the RSZ of wind turbines?	Very good	High	Flight heights	3

Table 1–1. Prioritized pilot study questions for Roseate Tern (ROST) (continued).

Question	Current State of Knowledge	Importance for Study Objectives	Data Needed to Answer the Question	Priority Level (initials of person)
Do the flight trajectories of ROST intersect the RSZ of wind turbines as they commute between breeding areas, feeding areas, and staging areas?	Moderate	High	Flight heights	2 (LN, LV)
How is the height of migratory flight trajectories affected by weather conditions (spring vs. fall weather patterns)?	Moderate to poor	High	Flight heights	1
When ROST flight trajectories do occur within the RSZ, can they avoid the RSA of offshore wind turbines through behavioral avoidance? If so, to what degree and under what conditions?	Poor to moderate (some avoidance at MMA turbine, but it's on land)	High	Behavioral observations at (offshore) wind turbines	2 (LV) 1 (but unrealistic to do before turbines are in place offshore)
Will the presence of offshore wind turbines or boat/helicopter traffic associated with maintenance activities from wind facility operations cause ROST to avoid feeding areas or migratory routes?	Poor	Low	Behavioral avoidance observations at offshore wind turbines; before/after observations	2
Will the structures associated with offshore wind facilities attract ROST, either because of lights, "artificial reef" effect, or perch availability for either courtship flights or resting spots, and will this occur to a greater degree in adverse weather?	Poor to moderate (oil platforms, Denmark, Germany, turbines-cormorants, gulls, passerines)	High	Behavioral observations at offshore wind facilities	1
Would the presence and operation of offshore wind turbines on the AOCS impact the viability of the North Atlantic population of ROST?	Poor to moderate (Cape Wind prediction of 4–5 birds killed per year based on many assumptions)	Moderate-high	Demographic studies; calculation of collision mortality rates with offshore turbines	2

Table 1–1. Prioritized pilot study questions for Roseate Tern (ROST) (continued).

Question	Current State of Knowledge	Importance for Study Objectives	Data Needed to Answer the Question	Priority Level (initials of person)
Would the various phenomena associated with ROST exposure to, and effects from, offshore wind turbines on the AOCS exhibit scale dependency? Would there be any nonlinearities such that certain (high) buildup scenarios might generate effects not predicted by impact levels observed under other (low) buildup scenarios?	Poor	High	Spatially explicit modeling studies	1

Note: Priority 1 = *most important*. Priority 3 = *least important*.

Table 1–2

Prioritized pilot study questions for Piping Plover (PIPL).

Question	Current State of Knowledge	Importance for Study Objectives	Data Needed to Answer the Question	Priority Level (initials of person)
Do migrants venture greater than 3 mi offshore into AOCS areas? If so, when, in what number, and where?	Poor	High	Geospatial observations	1 (JB)
Assuming that migration is primarily coastal, do peninsulas and large bays along the coast create "shortcuts" where normally coastal migrants regularly cross federally regulated waters rather than taking circuitous routes along the coast (e.g., across Delaware Bay, southbound from Monomoy Island)? If so, where are the shortcuts? Is their use affected by weather?	Poor (but we strongly suspect that shortcuts do exist)	High	Geospatial observations	1 (JB)
If PIPL do venture over federally regulated waters during migration, does their flight trajectory cross the RSZ?	Poor	High if applicable	Flight height	1 (JB)
If PIPL do venture over federally regulated waters during migration and their flight trajectory does intersect the RSZ, do/can they avoid the RSA of the turbines, and is avoidance behavior affected by weather/visibility?	Poor	High if applicable	Behavioral observations at (offshore) wind turbines	3 (JB)
Is the construction of offshore wind facilities on the AOCS or boat and helicopter traffic associated with their operation and maintenance likely to cause breeding or migratory habitat disruption or alteration of migratory route?	Low to moderate	Low	Behavioral observations; before/after studies of habitat use; migratory route	2 (JB)

Table 1–2. Prioritized pilot study questions for Piping Plover (PIPL) (continued).

Question	Current State of Knowledge	Importance for Study Objectives	Data Needed to Answer the Question	Priority Level (initials of person)
Would the presence and operation of offshore wind turbines on the AOCS impact the viability of the North Atlantic population of PIPL?	Poor to moderate (Cape Wind prediction of 0.5 birds killed per year based on many assumptions.)	Moderate to high	Demographic studies; calculation of collision mortality rates with offshore turbines	2
Would the various phenomena associated with PIPL exposure to and effects from offshore wind turbines on the AOCS exhibit scale dependency? Would there be any nonlinearities such that certain (high) buildup scenarios might generate effects not predicted by impact levels observed under other (low) buildup scenarios?	Poor	High	Spatially explicit modeling studies	1

Note: Priority 1 = *most important*. Priority 3 = *least important*.

Table 1–3

Prioritized pilot study questions for Red Knot (REKN).

Question	Current State of Knowledge	Importance for Study Objectives	Data Needed to Answer the Question	Priority Level (initials of person)
Do short-distance migrant populations of REKN follow coastal migratory routes?	Poor	High	Geospatial observations	1
If short-distance migrant populations do hug the coast, do they regularly cross federally regulated waters in topographically defined “shortcuts” (see under PIPL)? If so, where are the shortcuts? Is crossing affected by visibility/weather?	Moderate (We know that they can fly across Delaware Bay, but we don’t know where, or if, there are other shortcuts.)	High if applicable	Geospatial observations	2
Where and when do long-distance migrant REKN cross the AOCS on migratory flights?	Moderate	High	Geospatial observations	1
Do the flight trajectories of REKN intersect the RSZ of wind turbines at distances ≥3 mi from shore during ascent/descent to/from migratory flights, and is this affected by weather?	Poor (predict that ascent and descent are likely to be different)	High	Flight height	1
Are the cruising altitudes of migratory flights of REKN ever within RSZ height? (This includes weather-related variability and “shortcut” flights of short-distance migrants.)	Poor to moderate	High	Flight height	1
Do REKN commuting flights between roosting and feeding sites within a migratory stopover ever bring them ≥3 mi from shore?	Poor to moderate (unlikely)	High	Geospatial and behavioral observations	3 (LN, JB)
If so, do REKN fly within the RSZ during such flights?	Poor	High (unlikely to be applicable)	Flight height	3 (JB, LN)

Table 1–3. Prioritized pilot study questions for Red Knot (REKN) (continued).

Question	Current State of Knowledge	Importance for Study Objectives	Data Needed to Answer the Question	Priority Level (initials of person)
If REKN flight trajectories ever intersect the RSZ of turbines located ≥3 mi from shore, how well can they avoid the RSA of the turbines (including effect of variable light/visibility conditions)?	Poor	High (if applicable)	Behavioral observations at (offshore) wind turbines	2
Would the installation of offshore wind turbines ≥3 mi from the coast on the AOCS, or the boat/helicopter traffic associated with their operation/ maintenance, disrupt the migratory routes or behavior of REKN?	Poor to moderate	Moderate	Behavioral and habitat-use studies; migratory route tracking; before and after studies	3
Would the presence and operation of offshore wind turbines on the AOCS impact the viability of the North American populations of REKN?	Poor	Moderate to high	Demographic studies; calculation of collision mortality rates with offshore turbines	2
Would the various phenomena associated with REKN exposure to, and effects from, offshore wind turbines on the AOCS exhibit scale dependency? Would there be any nonlinearities such that certain (high) buildup scenarios might generate effects not predicted by impact levels observed under other (low) buildup scenarios?	Poor	High	Spatially explicit modeling studies	1

2 Risk Evaluation for Federally Listed (Roseate Tern, Piping Plover) or Candidate (Red Knot) Bird Species in Offshore Waters: A First Step for Managing the Potential Impacts of Wind Facility Development on the Atlantic Outer Continental Shelf[3]

2.1 Abstract

With a worldwide increase in attention toward developing a reliance on renewable energy, there is a need to evaluate the effects of these facilities (solar, wind, hydropower) on ecosystems. We conducted a hazard and risk evaluation for three species of birds that are listed, or candidates for listing, as federally threatened or endangered in the U.S. and that might occur offshore on the AOCS where wind power facilities could be developed. Our objectives were to (1) provide conceptual models for exposure for each species, and (2) examine potential exposure and hazards of Roseate Tern (*Sterna dougallii*) and Piping Plover (*Charadrius melodus*), both federally endangered in the U.S. and Red Knot (*Calidris canutus rufa*, candidate species) in the AOCS. We used a weight-of-evidence approach to evaluate information from a review of technical literature. We developed conceptual models to examine the relative vulnerability of each species as a function of life stage and cycle (breeding, staging, migratory, wintering). These methods are useful for conducting environmental assessments in when empirical data are insufficient for a full risk assessment. We determined that (1) Roseate Terns are likely to be exposed to risk during the migratory and breeding season when they occur in the AOCS as well as while staging. (2) Piping Plovers are not likely to be at risk during the breeding season, but may be at risk during spring or fall migrations. Risk to this species is likely to be low to turbines located far from land as this species migrates mainly along the coast. (3) Red Knots are potentially exposed to some risk during migration, especially long-distance migrants whose migratory routes take them over the AOCS. More information is required on exact spatiotemporal migration routes, flight altitudes (especially during ascent and descent), and behavioral avoidance of turbines by birds to ascertain their risk.

2.2 Introduction

Public policy makers, managers, scientists, and the public have long been aware that it is essential to assess risk to both human and ecological health from contamination, habitat degradation, and other stressors. Ecological evaluation is essential for siting new facilities, evaluating current ecosystems, making decisions about remediation and restoration, and conducting Natural

[3] Burger, J., C. Gordon, L. Niles, J. Newman, G. Forcey, and L. Vlietstra. 2011. Risk evaluation for federally listed (roseate tern, piping plover) or candidate (red knot) bird species in offshore waters: A first step for managing the potential impacts of wind facility development on the Atlantic Outer Continental Shelf. Renewable Energy 36:338–351. (Used with permission by Elsevier.)

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Resource Damage Assessment (NRDA). It also forms the basis for many management practices (Burger 2008), such as determining status and trends of biological, physical, or chemical/radiological conditions; conducting environmental impact assessments; performing remedial actions should mitigation fail; managing ecosystems and wildlife; and assessing the efficacy of remediation, restoration, and long-term stewardship. Intact, functioning ecosystems provide the goods and services that healthy human populations require, including clean air and water, food and fiber, medicines, other products, protection from storms and inclement weather, recreational opportunities, aesthetic pleasures, cultural and religious experiences, and existence values, among others (Bridgen 2005; Burger et al. 2008; Harper and Harris 2008; Harris 2000; Harris and Harper 2000; Stumpff 2006; Zender et al. 2004).

Maintaining healthy ecosystems, and the organisms within them, is a daunting task given the literally hundreds or thousands of species in any ecosystem. This complexity has necessitated the development of bioindicators of ecosystem health (Burger 2007; Burger 2008), ranging from algae to birds (Becker 2003) and mammals (Tataruch and Kierdorf 2003). To develop an effective bioindicator, one requires a sufficient science base from which to evaluate the health status, abnormalities of biological significance, and long-term changes in health status and reproductive success. In place of a lengthy bioindicator selection process that involves examining characteristics of a wide range of potential species (Burger et al. 2008), managers often select endangered or threatened species, or those of special concern, as bioindicators. This has the advantage of selecting species that have already been deemed important by the public, managers, and regulators and are clearly at risk from a range of stressors. While sufficient information on population levels and viability were required to list species as threatened or endangered, information on exposure to specific stressors needed for a full ecological risk assessment may not be available. However, for many species, behavior and ecological information is available to examine potential exposure to a given hazard, such as a commercial wind power facility, and such information can be used in the hazard and exposure assessment phase of risk assessment.

In this paper we examine the hazards from offshore wind development on the AOCS to three species of coastal water birds: Roseate Tern (*Sterna dougallii*), Piping Plover (*Charadrius melodus*), and Red Knot (*Calidris canutus rufa).* Roseate Terns and Piping Plovers are both federally endangered in the U.S., although the Atlantic population of Piping Plover is federally threatened. Red Knot is a candidate species for listing as a federally threatened or endangered species. Our analysis is restricted to waters at least three nautical miles (5.5. km) from shore, which is the federally regulated region for which the MMS has jurisdiction over commercial energy leases by the 2005 Energy Policy Act. The results of this analysis are also likely to be applicable to much of the state-regulated coastal and near-shore waters in the AOCS region, though risks may be somewhat different closer to the coast, particularly in the immediate vicinity of the coast and nesting areas.

Roseate Terns breed in a few colonies in the northeastern U.S., Piping Plovers breed all along the Atlantic Coast, and Red Knot stops at bays along the Atlantic Coast during its spring and fall migrations (Gochfeld et al. 1998; Haig 1992; Harrington 2001; Niles et al. 2008). Thus all three species could be vulnerable to mortality, and/or other adverse impacts from offshore wind facilities on the AOCS, although the extent of this risk has not been determined. We were particularly interested in developing conceptual models for potential exposure of these birds to offshore wind turbines and relating their behavior and ecology to characteristics of offshore wind facilities that could prove hazardous for flying birds. Both the conceptual models and the approaches to gathering qualitative data relevant to the hazards posed by wind facilities can be adapted to other species and to other environmental problems. As the world turns increasingly toward renewable energy sources, the potential risks of renewable energy development to various ecological receptors, including birds, will require new approaches that can both predict potential harm and be used to identify key research needs to reduce the risk to eco-receptors before and during operations.

State and federal agencies are faced with making decisions about whether to allow companies to develop offshore wind facilities (see for example USFWS 2008b). While many individual studies and databases describe avian use of terrestrial habitats (e.g., the AKN), few studies examine offshore habitat use by birds, and none provide the detailed information needed to perform a complete risk assessment of the potential impacts of offshore wind facilities on birds in the AOCS region. Bird mortalities around terrestrial wind facilities have received considerable attention in the U.S. and elsewhere, but much less attention has been devoted to offshore facilities, probably because no such facilities yet exist in Atlantic coastal waters. Additional adverse impacts to birds such as habitat displacement or behavioral disruption are also possible as a result of the construction, operation, and decommissioning of offshore wind facilities. In this case offshore does not include coastal facilities, but refers to those that are more than 3 nautical miles offshore. Many difficulties occurred in the early days of terrestrial wind facility development, when information on bird migration and ecology was not sufficiently taken into account when siting facilities. This paper provides a model for beginning the discussion about risks posed to birds by offshore wind facilities. We examine the hazards and exposure of three species of birds to offshore wind facilities at an early stage in the development of this energy resource, prior to the construction of any offshore wind facilities in the U.S.

2.3 Background

2.3.1 Environmental Evaluation and Risk Assessment

Foresters, ecologists, conservationists, and managers have been evaluating ecological health for centuries, and farmers for much longer. Healthy ecosystems are essential to providing the necessary goods and services for human communities. Ecological evaluations range from qualitative statements about the state of a habitat to a formal process, such as ecological risk assessment (ERA) (Beyer et al. 1996; Suter et al. 2000; Suter et al. 2003). Less formal approaches are often taken where sufficient data are not available for each of the required steps of ERA, the problem being examined does not require a formal process, or a more complex series of problems need to be integrated (e.g., chemical contamination in areas with physical disruption, avian mortality from tall buildings, migration patterns and human disturbance). Evaluations can be retrospective, forward-looking, or focused only on present conditions (Bartell et al. 1992; NRC 1993; Suter 1993, 1997, 2001; Suter et al. 2005).

At the same time that conservationists, ecologists, and others were searching for consistency among evaluations or assessments, human health assessors were searching for uniform assessment methods. The lack of consistency among evaluation or assessment methods led to confusion on the part of managers, regulators, decision makers, and the public, which created a need for a formal risk assessment paradigm that could be applied uniformly to scenarios involving risk to both humans and the environment.

In 1983, the National Research Council (NRC) formalized the human health risk assessment paradigm (HRA) to include four parts: hazard identification, dose-response assessment, exposure assessment, and risk characterization (NRC 1993). Hazard identification is defining the agent (or condition) that has the potential to cause harm. Dose-response usually involves laboratory tests with animals that indicate how the response varies with the exposed dose. Exposure assessment is determining the pathways (source, fate, and transport) and routes (of uptake) of exposure, both to humans themselves, and to target organs; it is identifying the pathway from source to receptor. Risk characterization is integrating the hazards, dose-response curves, and exposure data to describe or characterize the risk to given receptors (for HRA = humans). Shortly thereafter, the NRC formal risk assessment paradigm for humans was modified and adapted for ecological risk assessment (Burger 1997; NRC 1986, 1993; Sorensen et al. 2004; Suter 2001), and modified to fit the needs of individual agencies, such as the U.S. Environmental Protection Agency (Norton et al. 1992). While the process varies among agencies, the overall steps are similar: problem definition or formulation, which includes hazard identification, assessment of potential effects (and dose-response curves where possible), exposure assessment, and risk characterization (melding exposure with assessment of effects).

While a full, ecological risk assessment is ideal, there are many situations in which one cannot be performed, such as when sufficient data are not available. Nonetheless, in most situations, several steps can be performed to provide the best available information to target key research needs and to act responsibly using a weight-of-evidence approach (Linkov et al. 2009). The information gathered can then be used for making decisions about managing lands or offshore exclusion zones, restoring endangered species or those of special concern, planning forest harvesting, controlling water levels, remediation (level and extent of cleanup required, as well as its timing), restoration (re-establishing functioning ecosystems), and establishing public policies.

2.3.2 Potential Risk from Offshore Wind Farms

Initially, terrestrial commercial wind energy facilities, such as the Altamont Pass Wind Energy Center in Alameda County, California, were sited without regard to the risks wind turbines posed to birds, bats and other species (Smallwood and Thelander 2008; Smallwood and Neher 2009; Smallwood et al. 2009). More recently, permits for siting terrestrial commercial wind energy facilities have required risk evaluations of the potential hazards to wildlife. For the past two decades, considerable research has been directed at understanding the risks to wildlife from wind facilities (before, during, and after construction), and to the behavior of birds that puts them at risk (Hoover and Morrison 2005). While most attention was initially devoted to birds, more recently additional attention has been given to bats (Arnett et al. 2008; Baerwald et al. 2009; Durr and Bach 2004; Kunze et al. 2007). Many facilities now have regular monitoring programs to detect avian mortality (see for example ACCDA 2008; James 2009). Leaving aside the issue of the relative mortality at wind farms compared to fossil-fuel and nuclear facilities (NAS 2009; NYSERDA 2009), the issue of avian mortality at wind facilities remains a significant ecological impact concern, including at offshore wind facilities.

Effects of terrestrial wind energy facilities on birds have recently been reviewed by Kuvlesky et al. (2007) and the National Academy of Sciences (2007). Much less is known about the effects of offshore wind facilities on birds (Fox et al. 2006). Monitoring wildlife mortality at offshore wind energy facilities is more difficult than it is on land, as there are no carcasses lying on the ground, and thus the effects to birds are more difficult to examine (Exo et al. 2003; Landmark Practice 2009). The risk to wildlife depends upon the attractiveness of the habitat (and geography), behavior and ecology of species, habitat and spatial use, and the ability of wildlife to perceive and avoid wind turbines at close range. Our intent for this paper was to focus on the risk of adverse impacts to U.S. federally listed or candidate species in the AOCS region, as this region has been identified as having high offshore wind development potential, and these species receive a high level of legal protection, hence, there is a greater need for the evaluation of risk to them.

2.4 Methods

2.4.1 Study Region and Species

Regions of interest for this assessment are the AOCS with water no deeper than 100 m, from 3-nautical miles (5.5 km) offshore outward. Offshore regions available for wind energy development under MMS purview extends to the edge of the EEZ, approximately 200 km offshore. However, development would likely be limited, at least at first, to offshore regions closest to the 3-nautical–mile boundary as the cost of transferring energy to onshore processing stations and regular facility maintenance may limit development in regions farther away. This region is of interest because it is where commercial wind facility development could potentially occur in the near-term, with existing commercial marine wind power technology. This region is attractive for offshore wind energy development because of consistent, strong winds located in close proximity to major U.S. electricity load (usage) centers, particularly in the northern- and mid-Atlantic portions of the AOCS (Clarke et al. 2009).

Roseate Terns are small terns that nest in very few colonies in the northeastern U.S., although other colonies exist in tropical regions. About 80 % of the northeast population of less than 5,000 pairs breeds in two colonies: Great Gull Island in New York and Bird Island in Massachusetts (Gochfeld et al. 1998). They feed by plunge-diving for fish in bays, estuaries, and coastal waters, sometimes relying on predatory fish to force prey fish to the surface (Safina 1990a, 1990b; Safina and Burger 1985, 1988). Longevity ranges up to 26 yrs, but most live shorter lives (Gochfeld et al. 1998).

Piping Plovers nest solitarily on sandy beaches, often in association with Least Terns (*Sterna antillarum*), where they are adversely impacted by human disturbance, competition from humans, and increased predation because of human commensals (foxes, raccoons) and pets (cats, dogs) (Burger 1994). Piping Plovers also utilize sandy beaches and mudflats for foraging. Longevity ranges us to 11 yrs, but average may be 5 yrs (Elliott-Smith and Haig 2004).

Red Knots breed in the Canadian Arctic, but during migration they stop at only a few bays and estuaries along the Atlantic Coast, most notably along Delaware Bay, where in the spring they feed on the eggs of horseshoe crabs (*Limulus polyphemus*). In addition to the threat of decreasing food supplies (Niles et al. 2008, 2009), competition with gulls and predators, and human activities pose a problem (Burger et al. 2004). Red Knots are an indicator for the overall health of the migrant shorebirds in Delaware Bay (Clark et al. 1993). Red Knots can live up to 25 yrs, but very few live more than 7 yrs (Niles et al. 2009).

2.4.2 Methods

We used a weight-of-evidence approach (Linkov et al. 2009) to (1) evaluate the hazards that the three target avian species might face from offshore wind facility development on the AOCS, (2) examine information from the literature that relates potential hazards of offshore wind facilities and exposure to the target species, (3) use our collective experience with the target species to construct conceptual models of potential exposure and tables of relevant exposure and effects information, and finally, (4) evaluate whether each species is likely to be impacted. A weight-of-evidence approach uses all available information to examine the question, even though the types of qualitative and quantitative data available (and questions addressed) may vary from one paper to another. The authors have considerable research experience with all three species and with risk assessment. For all three species, there is little quantitative information on the natural causes of mortality to the overall population each year (Everaert and Stienen 2007; Gochfeld et al. 1998; Harrington 2001; Niles et al. 2009).

2.5 Results

2.5.1 Levels of Exposure

We identified three general levels of exposure for the three species: macroscale, mesoscale, and microscale.

Macroscale exposure is defined as the occurrence of the species within the geographical region of interest. In this case, the region is the zone equal to or greater than 3 nautical miles from shore within the AOCS. Avian exposure within this region is thus a function of both whether the species occurs in this geographical region and more specifically, whether the avian species actually occurs greater than three miles from shore within this region.

Mesoscale exposure relates to whether the species flies at rotor swept altitudes within the rotor swept zone (RSZ) (i.e., the altitudinal span of the wind turbine blades), and hence, within the hazard zone of wind turbines. Mesoscale exposure is governed by flight height.

Microscale exposure is a function of whether the species occurs within the RSA. That is, whether the species is likely to fly within the circles swept by the wind turbine blades. A species with a high degree of exposure at the mesoscale (i.e., it flies at rotor swept height) might have low exposure at the microscale if it is able to avoid the turbines. Behavioral avoidance may be a function of visual acuity, visibility conditions, maneuverability, and behavioral patterns.

2.5.2 Conceptual Models of Exposure

An important phase of evaluating the potential risk to birds from physical stressors such as wind farms, chemical stressors, or other stressors is to construct conceptual models that indicate the assessment endpoints, vulnerable life stages, and potential parameters of the stressor that might interact with the species of concern. While there are some general factors, such as age (adult, subadult, juvenile), there are also a number of periods and activities that result in vulnerability (migration, staging, foraging). We used these, as well as the features of wind facilities that might prove hazardous, to construct conceptual models for each of the three focal species.

Because of the different habitat use and life histories of the three species, we developed three different conceptual models (Figure 2–1 through Figure 2–3). The applicability of these models is restricted to the AOCS region of interest, as defined above. Staging populations refers to times (or locations) where a species concentrates prior to migration.

On each conceptual model, we indicate the likelihood of there being a risk to the populations or individuals of each species. These evaluations are based on the information reported below.

2.5.3 Exposure/Effects Assessment for Each Species

Based on the literature and our personal research with each species, exposure information for the three scales of exposure is presented for Roseate Tern (Table 2–1), Piping Plover (Table 2–2) and Red Knot (Table 2–3). Potential effects information at the individual and population level is presented for Roseate Tern (Table 2–4), Piping Plover (Table 2–5) and Red Knot (Table 2–6). Significantly more information was available for Roseate Terns than for the other species because of long, continuous concerted research efforts focused on this species at all of the major northeast colonies and because variety of detailed studies of this species was gathered in association with the Cape Wind offshore energy facility proposed for Nantucket Sound, Massachusetts. Even so, there is little quantitative data on offshore movements of all three species, of mortality from wind facilities from elsewhere in the world, and on potential risk.

Taken together, this information leads to the following conclusions about exposure (Table 2–7): (1) Direct collision mortality is the primary adverse impact from AOCS offshore wind facility development that has a significant likelihood to adversely affect any of the focal species, (2) Roseate Terns have high potential exposure to collision risk at the macroscale, low exposure during foraging flights, and the level of mesoscale exposure for migratory flight heights is poorly known. There are few data to evaluate their potential for microscale exposure, (3) Piping Plover have low potential exposure to collision risk during migration at the macroscale, which results in low exposure at the other two scales, and (4) Red Knots have high potential exposure to collision risk for long-distance migrants and low exposure for short distance migrants at the macroscale, moderate exposure at the mesoscale since they may descend to (or ascend from) migratory stopovers at critical/vulnerable heights, and there is little information about exposure at the microscale.

Exposure information from Table 2–1 through Table 2–3, combined with information on the potential effects in Table 2–4 through Table 2–6 leads to the conclusion that Roseate Terns could be at risk of collision mortality both during the migratory season and the breeding seasons, while Piping Plovers and Red Knots are only potentially exposed to this risk during their spring and fall migrations in the northeast (Table 2–8).

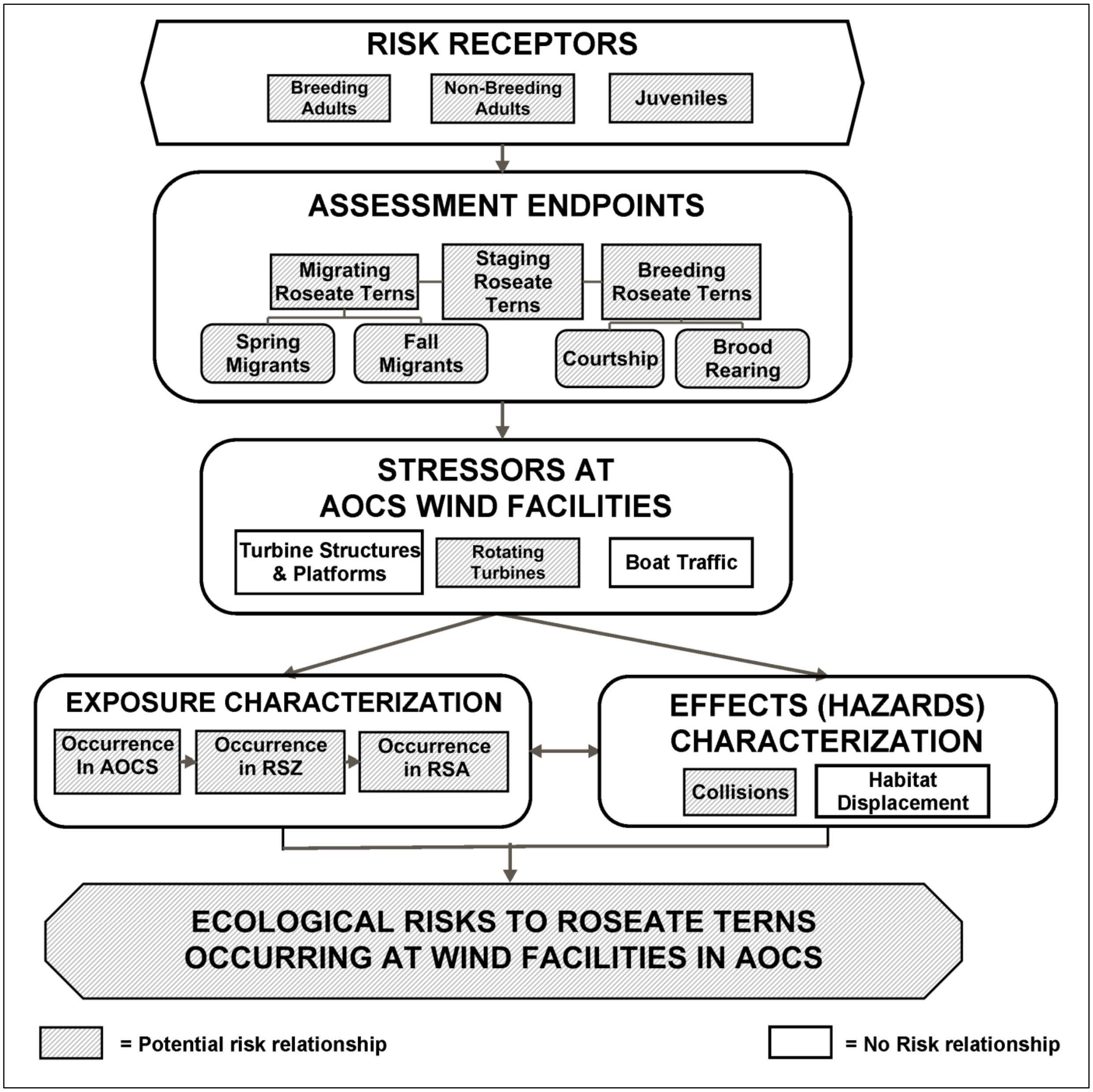

Figure 2–1. Conceptual model for risk evaluation of Roseate Terns for effects from wind facilities. Shaded areas indicate potential for risk to each species.

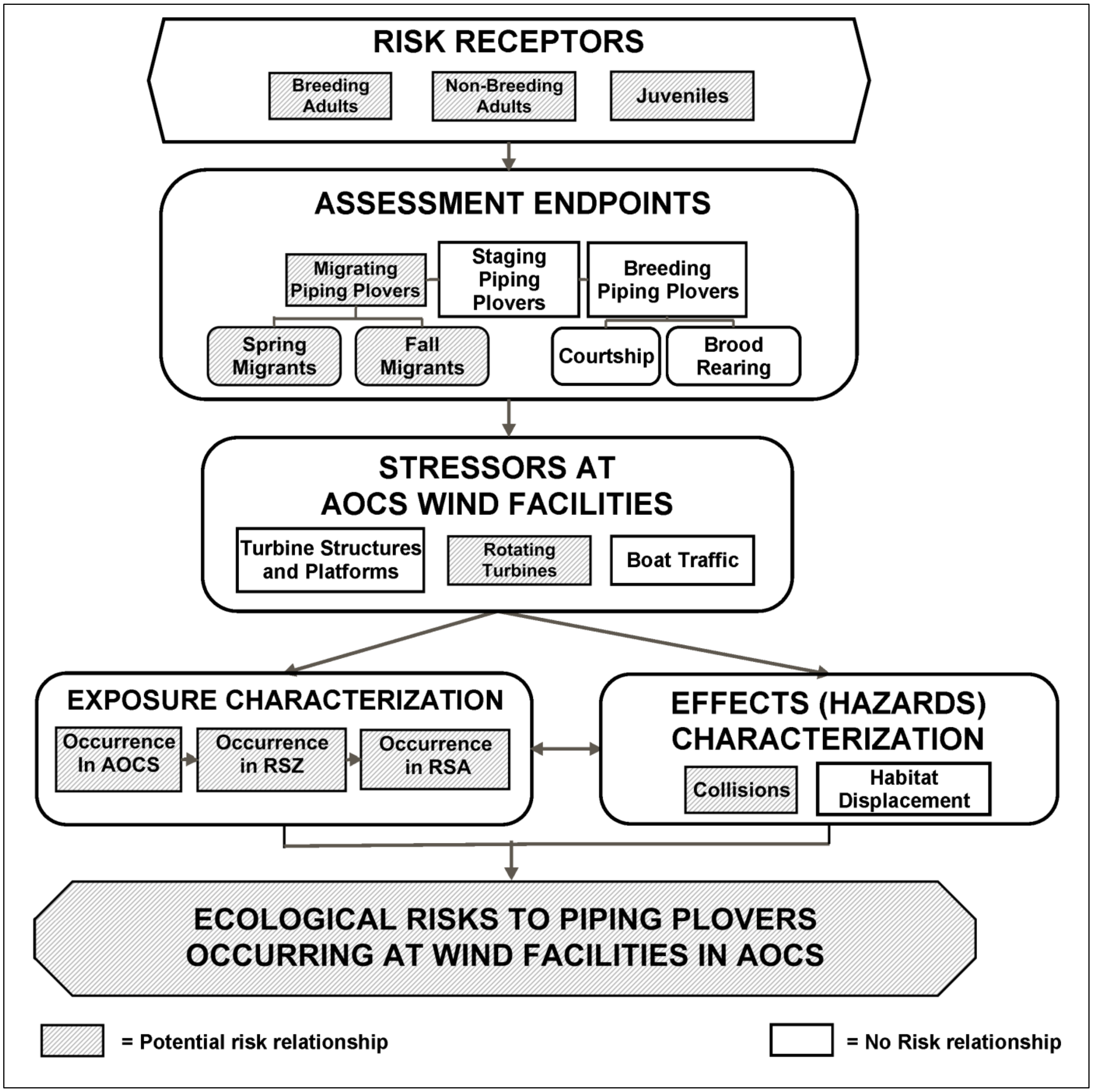

Figure 2–2. Conceptual model for risk evaluation of Piping Plover for effects from wind facilities.

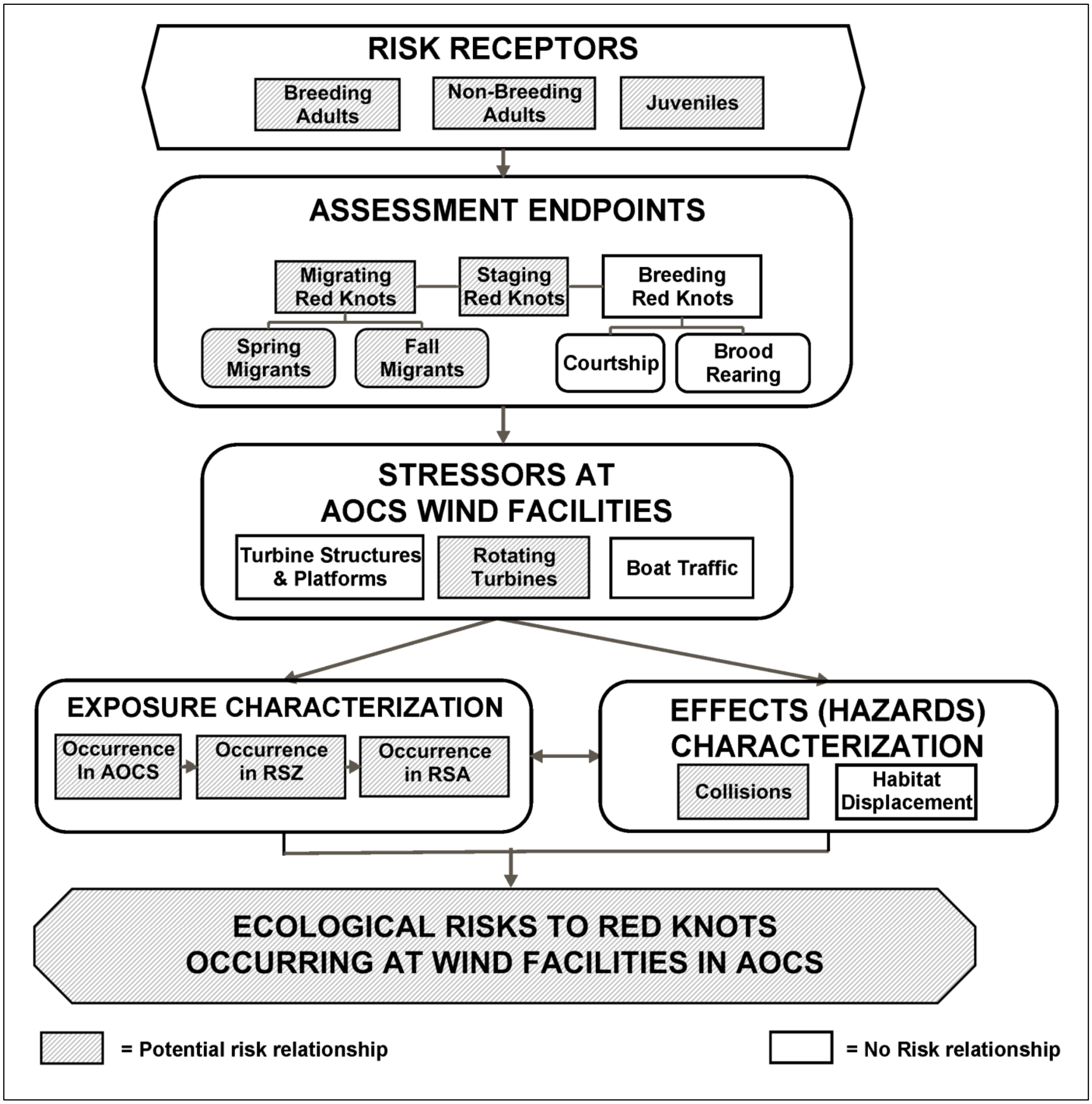

Figure 2–3. Conceptual model for risk evaluation of Red Knot for effects from wind facilities.

Table 2–1

Risk exposure summary for Roseate Tern based on the literature and our research experience.*

Exposure Relationships		Evidence/Discussion
Macroscale exposure (occurrence ≥3 mi from shore in AOCS region)	Breeding season	Breeding grounds are islands or sand spits close to shore. Only two main breeding colonies in northeast U.S. (80% breed in Bird Island in Massachusetts and Great Gull Island in New York) (Gochfeld et al. 1998). After remaining constant for two decades (at about 4,300 pairs), numbers of the northeast population have declined by nearly 1,000 pairs (Roseate Tern recovery team, unpub data, 2006). Little is known about pre-breeding adults, or failed breeders, during the nesting season. Some colonies have disappeared in the last 20 years (Cedar Beach, New York). A study employing radio telemetry (Rock et al. 2007) found that most Roseate Terns foraged within 7 km of the nesting islands (sometimes as far as 24 km). In Buzzards Bay, Massachusetts, some Roseate Terns regularly forage 11 km from the Bird Island or Ram Island colonies (Vlietstra 2008). However, just because Roseate Terns will travel several miles from the colony to forage does not mean that they head directly offshore. On the contrary, they seem to remain in relative shallow water, close to land (L. Vlietstra, pers. comm.). Roseate Terns in Buzzards Bay may travel up to 30 km from the colony to feed, but they usually remain close to shore during this time (Heinemann 1992). Shealer and Burger (1995, for tropical populations) and Hatch, as cited in Gochfeld et al. (1998, Buzzards Bay), also indicate that most fish are caught within 8 km (usually less) of the colony. When Common Terns are present, Roseate Terns may shift to clear, deeper water offshore (Gochfeld et al. 1998), or they may continue to feed with Common Terns (Safina and Burger 1985). When predatory fish fail to come inshore, terns may be forced offshore (up to 25 km) to feed over predatory fish (J. Burger, pers. comm.). Roseate Terns regularly forage up to 10 km from the colony, but regularly fly up to 22 km from colony during nesting season foraging forays over water (Duffy 1986). ESS et al. (2004) suggested that Roseate Terns may go as far as 48 km from nesting colony on feeding-commute flights.
	Postbreeding staging	After chicks are reared (early Aug), Roseate Terns leave the vicinity of nesting colonies and congregate in certain spots, such as near Chatham on the east end of Cape Cod (Perkins et al. 2004; Sadoti et al. 2005b; Vlietstra 2007) where nearly the entire northeastern population may stage (Trull et al. 1999). The staging population may range up to 7,000 birds in one place (Veit and Petersen 1993).

Table 2–1. Risk exposure summary for Roseate Tern based on the literature and our research experience (continued).

Exposure Relationships		Evidence/Discussion
		Another post-breeding staging spot is near Stratton Island-Saco Bay, Maine, where 5–10% of the northeastern breeding population may congregate from about Aug 7 to Aug 23, including color-banded birds from eight different nesting colonies from New York to Maine (Shealer and Burger 1995). These colonies include Great Gull Island in New York, and Bird Island in Massachusetts. Common and Roseate Terns flying near Chatham, Massachusetts, staging grounds were most abundant close to shore, near Monomoy Island. Some (many fewer) occurred as far as 16 km offshore (Perkins et al. 2004). Roseate Terns staging in Maine primarily forage between 0.2 and 2 km offshore (Shealer 1996). Some exposure to the AOCS may occur during flights from breeding grounds to post-breeding staging areas.
	Migration	With wintering grounds in Brazil (Hays et al. 1997, 1999), it is safe to assume that Roseate Terns breeding in the northeast migrate through the AOCS at some point. Nisbet (1984) reports Roseate Terns banded in New England collected well offshore, 60–500 km from land, during the month of Sep. These birds would have moved through the AOCS. Nisbet also reports anecdotal sightings of other banded Roseate Terns observed “at sea” and not “close to shore,” leading him to suggest that Roseate Terns migrate “directly across” the North Atlantic from their breeding grounds in New England to wintering grounds in the West Indies. Nisbet’s (pers. comm.) recent studies with light-sensitive geolocators suggest the existence of oceanic staging areas far offshore, and stop-and-start migratory movement patterns that may help delineate the occurrence of Roseate Terns in the AOCS during migration. Roseate Tern migratory routes are not well-known in either spring or fall but are presumably well offshore or pelagic, as there are few coastal records during migration (ESS et al. 2004). There is a scattering of offshore records of presumably migrating Roseate Terns reported for trips that go out to the continental shelf, by pelagic bird tour leaders (J. Burger, unpub. data). Britton and Brown (1974) observed Roseate Terns wintering off the coast of East Africa feeding in association with predatory fish at locations 6–10 km out to sea. If wintering birds feed regularly offshore, migrating birds might do so as well. Gochfeld et al. (1998) indicate that northeastern Roseate Terns migrate “offshore.” Roseate Terns are reportedly “regular at-sea” off N. Carolina late Aug to late Sep, but peak in early Sep” (D. Lee as cited in Gochfeld et al. 1998). Reported as definitely pelagic by C. Mostello (Mass. Div. Fish and Wildlife, pers. comm.).
		Safina (1990a), Heinemann (1992), Shealer (1996), and Gochfeld et al. (1998), indicate that migrating Roseate Terns sometimes feed in association with predatory fish that force smaller fish to the surface, so it is possible that terns feed opportunistically over deeper water during migration. This result was corroborated by Safina and Burger (1988).
	Subadults	Banding data suggest that Roseate Terns spend their first 2 years on the wintering grounds (Spendelow et al. 2002), but this is based on no censusing off the northeast coast.

Table 2–1. Risk exposure summary for Roseate Tern based on the literature and our research experience (continued).

Exposure Relationships		Evidence/Discussion
	Nonbreeding adults	Spendelow et al. (1995) suggest that Roseate Terns have been seen moving between Massachusetts, Connecticut, and New York following nesting failure. Radio-tracking of Little Terns (*Sterna albifrons*) showed that foraging ranges vastly increase among failed breeders (Perrow et al. 2006). In this study, failed breeders had foraging ranges of 52 km^2, whereas successful breeders had foraging ranges of less than 6.3 km^2. Foraging movements of adult nonbreeding Roseate Terns, or failed breeders, are unknown (J. Burger, pers. comm.).
Mesoscale exposure (flight height within RSZ=20–120 m asl)	Foraging flights	The average height from which Roseate Terns plunge dive for fish is 4.4 m above the water's surface (Duffy 1986), and foraging flights rarely, if ever, exceed 12 m in height (ESS et al. 2004; Mostello 2007). USFWS (2008b) suggested that Roseate Terns are unlikely to travel through the RSZ for the proposed Cape Wind turbines, given the low flight altitude and low abundance of Roseate Terns relative to Common Terns. Gochfield et al. (1998) indicated that foraging Roseate Terns hover and dive from altitudes of 1–6 m. Perkins et al. (2004) found that during the breeding period, most (90%) Common and Roseate Terns flew at altitudes below 70 ft (21 m). At an experimental wind tower at the Massachusetts Maritime Academy in Buzzards Bay, Massachusetts, Vlietstra (2008) observed that terns identified as either Common or Roseate Terns regularly flew at heights equaling the RSZ (26.5–73.5 m) of the wind turbine, especially when the rotor was still. Most terns, however, flew below the RSZ. The few terns identified as Roseate Terns usually flew at altitudes (range 9–21 m) below the RSZ when they flew over land, but it was not unusual to see Roseate Terns flying at higher altitudes (up to 50 m) over the water (L. Vlietstra, pers. comm.). Perkins et al. (2003) recorded most terns (Common and Roseate) seen in Nantucket Sound (<10 mi offshore) flying at altitudes of <100 ft (30 m). While actively feeding over Horseshoe Shoal, terns flew at lower altitudes, 5–50 ft (12–15 m), which would likely be below the RSZ. Heinemann (1992) found that during the breeding season, most Roseate Terns performed "shoal feeding," in which terns foraged in water less than 3m deep.
		In Nantucket Sound, most terns (Common and Roseate) flew below the RSZ of turbines in the proposed Cape Wind Project, but some flew at altitudes on par with the RSZ (Sadoti et al. 2005a, 2005b).
		Feeding groups of Common and Roseate Terns often form an "inverted cone," with a small number of birds down low at striking height (presumably at 2–5 m above the water's surface; see above), and a large number of birds flying higher above them (Duffy 1986).
	Migratory flights	Perkins et al. (2003) reported Common and Roseate Terns flying at approx. 400–500 ft (122–152 m) on the same day as cormorants apparently migrating at similar altitudes, suggesting that terns may have been embarking upon migration.
		European studies of migrating tern flight height (but no Roseate Terns) have shown that wind direction exerts a strong influence on tern flight behavior, with birds staying very low, at wave top height, in a headwind, and higher, but still usually below RSZ, in a tailwind (always below 25 m in one study and 1.3% of birds above 50 m in another study) (ESS et al. 2004).

Table 2–1. Risk exposure summary for Roseate Tern based on the literature and our research experience (continued).

Exposure Relationships		Evidence/Discussion
	Courtship flights	Roseate Tern display flights (at nesting colonies, but sometimes at other areas in springtime) may take them as high as 100 m (ESS et al. 2004). Fear of Roseate Tern courtship flights taking place on structures associated with the Cape Wind facility is a major reason for installing bird-deterrent devices (USFWS 2008b).
Microscale exposure (behavioral avoidance of wind turbines, avoidance of RSA)	Behavioral avoidance	Common Terns avoided rotating blades of an experimental, coastal wind turbine in Massachusetts (Vlietstra 2007). Even so, some terns still passed through the RSA when the blades were rotating. Sample size was very low for Roseate Tern (n = 1), because few flew nearby. European studies of Common Terns indicate a high degree of wind turbine avoidance except when turbines are ≤30m from the nesting colony (Everaert and Stienen 2007). The effect of fog or high winds, however, is unknown. Common Terns were found more likely to collide with power lines when carrying food intended for chicks (Henderson et al. 1996), suggesting they may be less likely to avoid wind turbines while carrying food. Likewise, Vlietstra (2007) found more Common Terns, many of which carried fish, flying in close proximity to the MMA wind turbine during the chick-rearing period than during other phases of the breeding period.
	Visibility	Vlietstra (2008) found little evidence that fog reducing visibility to 100 m affected tern passage rates through wind turbine airspace, although her analysis contained few data, and observations of tern passage rates were impossible when visibility was very poor, so flight behavior in these conditions could not be evaluated. She searched the ground for carcasses after periods of heavy fog and did not find any tern carcasses during the 2-year study.

*In this and other tables, the 3 mi (=4.8. km) limit is used because it is the waters that are controlled federally in the U.S.

Table 2–2

Risk exposure information for Piping Plover based on the literature and personal research and observations.

Exposure Relationships		Evidence/Discussion
Macroscale exposure (occurrence ≥3 mi from shore in AOCS region)	Unlikely, with the possible exception of "shortcuts," where normally coasthugging migrating Piping Plover skip across various large bays/inlets rather than taking long, circuitous, strictly coastal routes around them (e.g., Delaware Bay, Long Island Sound)	Breeding population along the East Coast of North America is stable to increasing and is currently about 1,500 nesting pairs (http://www.fws.gov/northeast/pipingplover/). However, populations in New Jersey have remained stable for nearly 20 years. Published accounts state that Piping Plovers migrate along a narrow margin of coast (Elliott-Smith and Haig 2004; Haig 1992), but this is based on scant evidence and is largely speculative. The USFWS Atlantic Piping Plover recovery plan (2009b) states that during spring and fall migration they are, "believed to follow a narrow strip along the Atlantic Coast." Piping Plover has been seen in Bermuda (USFWS 2008b), so it is possible that this species can migrate or be blown out to sea. Pelagic bird tour datasets that represent broad and long-term coverage of the northern and central AOCS, and which do contain observations of several species of shorebirds, have never produced a record of a Piping Plover ≥3 miles from shore (M. Iliff, J. Burger, F. Lesser, P. Guris, B. Patteson, pers. comm.). An in-depth survey of the Atlantic Coast revealed that the highest coastal winter population (n = 105) occurred in Georgia, but a large proportion of the Atlantic population probably winters outside the U.S. There was some overwintering in North (n = 50) and South Carolina (n = 43), but none from Virginia northward (Nicholls and Baldassarre 1990). Feeding grounds are strictly land-based, either along the intertidal, on high tide wrack lines, or in inner pools and wet areas along the shore, during both the migration and breeding season (Burger 1991, 1994; Elliott-Smith and Haig 2004; Haig 1992; USFWS 2009b).
Mesoscale exposure (flight height within RSZ=20–120 m asl)	Unknown. Seems low, except possibly in "shortcuts," where Piping Plover may migrate across large bays (see above).	Nonmigratory flight height is normally below RSZ, except for courtship flights, which are land-based (USFWS 2008b). Migratory flight height unknown (A. Hecht, pers. comm.) (USFWS 2008b). Even if migratory flight height is normally above RSZ, low cloud ceiling conditions could bring them lower, into the RSZ.
Microscale exposure (behavioral avoidance of wind tur-bines, avoid-ance of RSA)	Unknown. Seems generally low, with possible exceptions.	Visual acuity and maneuverability known to be good, including night vision, but no actual interactions with wind turbines observed (A. Hecht, pers. comm.; USFWS 2008b). Ability to avoid turbines, even if normally good, could be reduced in poor visibility conditions.

Table 2–3

Risk exposure information for Red Knot based on literature and personal research and observations.

Exposure Relationships		Evidence/Discussion
Macroscale exposure (occurrence ≥3mi from shore in AOCS region)	Yes, for long-distance migrants. For short-distance migrants, same as Piping Plover (see Table 2–2, coasthugger "shortcuts"). Migration periods are the only significant times of potential exposure for Red Knots in the AOCS.	The Atlantic flyway population of Red Knot is currently 27,000 to 30,000 (L. Niles, pers. comm.), but in the early 1990s it was over 90,000 (Niles et al. 2008). Peak numbers in Delaware Bay in 2010 were only 15,000. Both short-distance and long-distance migrants use the mid-north Atlantic Coast of the U.S. as a migratory stopover region. Short-distance migrants winter in Florida and other southeastern states, while long-distance migrants winter in South America. The normal fall migratory period is Jul–Oct (Harrington 2001). Very small numbers (< few hundred) of individuals remain until Dec, but leave when it freezes in mid winter (L. Niles, pers. comm.). The species does not breed in the region. Red Knot feeding activity is strictly land-based (Harrington 2001; Niles et al. 2009). The risk is highest in known major stopover areas (Delaware Bay and Virginia coastal islands [thousands of migrants]), and in inlets, small coastal river mouths, throughout the area from Virginia to Long Island. Smaller numbers (less than 2,000) migrate through northeast Florida, Georgia barrier islands, north to Cape Cod. The most serious risk comes when northbound long-distance migrants make landfall, and we have almost no information on these movements. Southbound flights might not present a problem because long-distance migrants probably are far offshore (L. Niles, pers. comm.). Red Knots also move south along the Atlantic Coast in fall migration, involving short offshore jumps (based on sightings), suggesting potential movement in the AOCS (Niles et al. 2009).

Table 2–3. Risk exposure information for Red Knot based on literature and personal research and observations (continued).

Exposure Relationships		Evidence/Discussion
Mesoscale exposure (flight height within RSZ=20–120 m asl)	Possible; restricted to several distinct situations: Migratory flight cruising (low risk) especially of long-distance migrants, but also possibly short-distance migrants within “shortcuts” (see above). Migratory flight ascent/ descent (low to moderate risk) especially of long-distance migrants, but also possibly short-distance migrants within “shortcuts” (see above). Tidal commuting flights (intra-stopover) (low risk). Probably do not extend ≥6 km from shore.	Cruising altitude of both long-distance and short-distance populations during migratory flights is normally between 1,000–3,000 m (C. Minton, pers. comm.). They might enter the RSZ in periods of bad weather or high winds (L. Niles, pers. comm.) or during short coastal flights during migration (Niles et al. 2009). They might enter the RSZ when they are approaching stopover or wintering sites (L. Niles, pers. comm.). Tidal commuting flights may not normally take them ≥ 5 km from shore, but they have been observed flying at RSZ height over land, on such flights commuting between the bay and ocean sides of southern New Jersey (L. Niles, pers. comm.). Exceptions include inclement weather that might force migrants to fly into large bays or offshore at lower altitudes, that might put them at risk, when leaving stopover sites (J. Burger and L. Niles, unpub. data).
Microscale exposure (behavioral avoidance of wind turbines, avoidance of RSA)	Unknown. Seems generally low, with possible exceptions.	Visual acuity and maneuverability known to be good, but no actual interactions with wind turbines observed (L. Niles, pers. comm.). Ability to avoid turbines, even if normally good, could be reduced in poor visibility, high winds, and inclement weather. Red Knots avoid mist nets during the day and even on moonlit nights, but they get caught in new or quarter moon nights. It may also be harder for them to see and avoid moving blades than stationary nets on dark nights. Avoidance will be more difficult for Red Knots when they must make decisions about landing, particularly after long migratory flights (J. Burger and L. Niles, pers. comm.), but ascent is thought to be direct (Harrington 2001).

Table 2–4

Potential risk effects for Roseate Tern based on the literature and personal research and observations.

Type of Effect	Qualifier	Likelihood of Experiencing Effect	Supporting Basis for Exposure Conclusions
Fatal collisions with wind turbines	Individual effects	Poorly known. Depends upon placement and on whether Common Terns are effective surrogates.	Common Terns (and other tern species) are killed by wind turbines placed at the Zeebrugge wind facility adjacent to a tern breeding colony in Belgium, showing that it is possible for wind turbines to cause tern mortality (Everaert and Stienen 2007). Despite the location of the Zeebrugge turbines in a line between the nesting colony and the principal tern feeding areas, tern mortality at this site was highly concentrated at a few turbines located within 30m of the colony (Everaert and Stienen 2007). No Roseate Tern mortality has been documented, nor high likelihood of collision risk suspected at the three North American wind facilities located near Roseate Tern colonies (USFWS 2008b). At one of these sites, the single coastal turbine located at the Massachusetts Maritime Academy, Common (n = 226) and Roseate (n = 1) Terns regularly flew close (within 50 m) to the turbine with no tern fatalities observed over a 2-year period (Vlietstra 2007). However, the placement of the turbine was not in a regular path for the Roseate Terns. The final analysis of Roseate Tern collision risk for the Cape Wind Project estimated that the wind facility (130 turbines) was likely to kill 4–5 Roseate Terns per year (USFWS 2008b).
	Population effects	Low	After reviewing data from three existing wind turbines on the Atlantic Coast, USFWS (2008b) concluded that the Cape Wind facility is unlikely to impact the north-west Atlantic population of Roseate Tern, even though this project would be the largest offshore wind project in the world, and it would be located directly between major breeding colonies and postbreeding staging areas, and 31 km from one of the most important breeding colonies for this species (Bird Island).

Table 2–4. Potential risk effects for Roseate Tern based on the literature and personal research and observations (continued).

Type of Effect	Qualifier	Likelihood of Experiencing Effect	Supporting Basis for Exposure Conclusions
Loss or modification of habitat	Loss of feeding grounds - actual loss of habitat	Low	Heinemann (1992) found that during the breeding season, most Roseate Terns performed “shoal feeding,” in which terns foraged in water less than 3 m deep, hence turbines placed ≥3 miles from shore in the AOCS would not impact the primary feeding grounds of breeding Roseate Terns. Perkins et al. (2003) found that, in Common and Roseate Terns, a greater proportion of those occurring within 1.6–3.2 km of shore in Nantucket Sound were engaged in foraging activity than terns occurring 3.2 to 16 km offshore. The USFWS (2008b) concluded that Horseshoe Shoal, the proposed location for the wind turbines of the Cape Wind Project, which consists of a relatively shallow area in Nantucket Sound, did not represent a primary feeding location for Common and Roseate Terns during the staging period and would have an “insignificant” habitat displacement effect upon them. If terns do feed far offshore during migration, then wind turbines may interfere with migration activity and/or tern survivorship. Such foraging locations and patterns are largely, if not wholly, unknown (L. Vlietstra, pers. comm.).
	Blockage of commuting routes between nesting and feeding areas	Low. Locality-dependent	Little information exists. Could be significant under large build-out scenarios, or with linear turbine arrays.
	Creation of new feeding habitat	Low to moderate	Offshore structures, such as offshore drilling platforms, are known to be colonized by a variety of marine plants and sessile animals that attract fish and other planktonic/nektonic marine life. This could possibly include small fish that would be utilized by Roseate Terns, possibly attracting them to feed in the vicinity of offshore wind facilities, particularly if bluefish were also attracted to the structures (Safina 1990b; Safina and Burger 1985, 1988).

Table 2–4. Potential risk effects for Roseate Tern based on the literature and personal research and observations (continued).

Type of Effect	Qualifier	Likelihood of Experiencing Effect	Supporting Basis for Exposure Conclusions
			Roseate Terns can habituate to the presence of human activity, and this might allow them to forage around wind farms rather than avoiding the entire region of a wind farm (Burger et al. 1993). Exo et al. (2003) described birds likely to be deterred by wind farms. Terns were not among those likely to be deterred. One study conducted in Denmark indicates that terns and gulls preferred a particular offshore region once wind turbines had been constructed, but the proximate cause of the attraction (e.g., increased boat traffic, changes in food availability, wind turbines themselves) was not identified (Drewitt and Langston 2006; Petersen et al. 2004).
	Altered migration routes	Unknown, but seems unlikely	After reviewing data from several sources, USFWS (2008b) concluded that no evidence exists to suggest that Roseate Tern migratory flight would be altered in response to safety lighting currently used on wind turbines associated with the Cape Wind Project. Even if Roseate Terns fly around wind facilities, it would be difficult to build out at a level that would require them to alter their migratory routes significantly.
Disruption by boat traffic		Low	Roseate Tern colonies are located within areas of heavy boat traffic, and they are not generally disrupted by it. The increase in boat traffic from the Cape Wind Project was projected to be minimal and to have negligible effect (USFWS 2008b).

Table 2–5

Potential risk effects for Piping Plover based on technical literature and personal research experience.

Type of Effect	Qualifiers	Conclusions	Supporting Basis for Exposure Conclusions
Fatal collisions with wind turbines	Individual effects	Unlikely	Very unlikely to occur in AOCS; see discussion above. The USFWS (2008b) estimated that the total annual Piping Plover mortality from the Cape Wind Project (130 turbines) was not likely to exceed 0.5 individuals per year.
	Population effects	Unlikely	Based on the above, the USFWS (2008b) anticipates no significant impact of the Cape Wind Project on the Atlantic population of Piping Plover.
Loss or modification of habitat	Loss of feeding grounds - actual loss of habitat	No	Feeding habitat is strictly coastal.
	Barrier to normal nonmigratory movement	No	Nonmigratory movements are strictly on or near coast.
	Altered migration routes	Possible; seems unlikely	No information available. If oceanic migratory “shortcuts” exist (see above), large wind facilities located within them could possibly disrupt migratory movements, particularly if they were oriented in linear arrays perpendicular to the direction of Piping Plover migratory movement.
Disruption from boat traffic		Possible, though unlikely	The only way Piping Plovers might regularly be affected by boat traffic is by boat traffic that leaves the beach or inlets if the boats come too close to them while they are feeding in the intertidal (Burger 1991).

Table 2–6

Potential risk effects for Red Knot based on the literature and personal research and observations.

Type of Effect	Qualifiers	Conclusions	Supporting Basis for Exposure Conclusions
Fatal collisions with wind turbines	Individual effects	Unlikely	This is difficult to say, as there are few coastal turbines in the U.S., and there is very little information available on shorebird collision mortality at these wind facilities. In Europe, a limited number of studies have suggested that shorebird casualty rates are low at coastal wind turbines near major stopover and wintering habitat (Dirksen et al. 1998; Lowther 2000; Landmark Practice 2009). There is likely to be small impact depending on the number of turbines and the likelihood of operation in periods of poor visibility and inclement weather, but this also depends on the amount of movement within the AOCS (L. Niles and J. Burger, unpub. data).
	Population effects	No information, but if they occur, they could have population effects	The population of Red Knots is relatively small for a species migrating such large distances, so even small impact could accumulate to population level (Niles et al. 2008, 2009). At present, the most important threats to the Red Knot are the overharvest of horseshoe crabs on the Delaware Bay, disturbance in winter areas, and oil spills in a few key sites (L. Niles, J. Burger, pers. comm.). If turbines were placed near inlets important to northbound birds, the mouth of the Delaware Bay, or in key migratory or wintering areas, turbines could also become another serious potential threat, particularly during ascent and descent (L. Niles, pers. comm.).
Loss or modification of habitat	Loss of feeding grounds - actual loss of habitat	No	Feeding habitat is strictly land-based (Harrington 2001; Niles et al. 2009).
	Deterring species from feeding grounds - effective loss of habitat	Unlikely	The activity of people working on facilities and the power lines and structures themselves would be relatively new in most of the places where offshore power is considered. These accessory structures could have a significant impact (L. Niles, pers. comm.).

Table 2–6. Potential risk effects for Red Knot based on the literature and personal research and observations (continued).

Type of Effect	Qualifiers	Conclusions	Supporting Basis for Exposure Conclusions
	Altered migration routes	Unlikely	Build-out scenario sufficient to significantly alter migratory routes over ocean seems unlikely, except if large wind facilities were located in mouths of bays near stopover locations, or in "shortcuts" used by coasthugging short-distance migrants, especially if turbines were arranged in linear arrays perpendicular to the direction of migratory movement. Information on altered routes due to weather affecting pathways (especially during ascent or descent) is lacking.
Disruption from boat traffic		No	There is already considerable boat traffic in the areas of concern, and there is no known impact (L. Niles, pers. comm.), unless boats come close to shore (Burger et al. 2004).

Table 2–7

Comparison of exposure for the three focal species at different exposure scales.

Species, Scale	Macro Exposure to Turbines in AOCS	Stage of Exposure	Certainty of Macroscale Exposure
Roseate Tern Macro-	Yes, observed >3 mi (4.8 km) off shore.	Migration, breeding	High, though exact migratory routes and oceanic staging patterns not well known.
Meso-	Low during foraging flights (almost entirely below 12m); moderate during commuting flights with tailwinds. Migratory flight height poorly known.	Migration, breeding	High for nonmigratory flight height; low for migratory flight height.
Micro-	Probably low. Limited observations of Roseate Terns at MMA suggest good avoidance ability. Congeners demonstrate high avoidance rate except ≤30m from nesting colony.	Migration, breeding	Low to moderate. Very few observations of Roseate Terns.
Piping Plover Macro-	Generally unlikely, except for possibility of regular ocean crossings in certain spots based on coastal topography (e.g., south of Monomoy Island).	Migration	Low. No records of birds over ocean.
Meso-	Low, poorly known.	Migration	Low. No data on migratory flight height.
Micro-	Probably low.	Migration	Low. Entirely speculative, based on good Piping Plover night vision, maneuverability, and low shorebird casualty rates at coastal wind facilities.
Red Knot Macro-	Yes, for long-distance migrant populations, especially in spring. In fall, long-distance migrants are probably farther offshore. Short-distance migrants may follow coasthugging pattern of Piping Plover. All populations may stay ≤6 km from shore on tidal/commuting flights.	Migration	High for long-distance migrants; low for short-distance migrants. Precise locations of crossing AOCS poorly known.
Meso-	Moderate for springtime long-distance migrants on migratory flights (but greater during ascent and descent). Migratory cruising height probably above RSZ. Possible peak exposure during migratory flight ascent/descent.	Migration	Low. Migratory cruising height poorly known. Pattern of ascent/descent over ocean to/from migratory flights unknown.
Micro-	Probably low.	Migration	Higher degree of uncertainty; exact locations, abundances, and flight height not known.

Table 2–8

Summary of potential risk for the three focal species from AOCS offshore wind facility development.

Species	General Risk Summary
Roseate Tern	Yes, during migratory and breeding seasons, but flight height is normally below RSZ, reducing likelihood of risk. More information is needed on oceanic migration routes, migratory flight height, and behavioral avoidance of turbines.
Piping Plover	During migration only. Risk is likely to be low, but needs confirmation. Anecdotal observations, surveys, and other observations have produced no evidence of the occurrence of Piping Plovers ≥3 miles from shore to date. More information is needed on coastal migratory "shortcutting" over water, as well as migratory flight height and behavioral avoidance of turbines.
Red Knot	Possibly during migration, especially for long-distance migrant populations, and for short-distance migrants that move along the coast. Very little information exists on distance and height of ascent and descent, oceanic occurrence, migratory flight height, or behavioral avoidance of wind turbines.

2.6 Discussion

2.6.1 Role of Conceptual Models and Literature on Exposure Assessment

The construction of conceptual models for each species allowed us to begin to evaluate the similarities and the differences between the risks posed to the species of concern from AOCS offshore wind facility development. The first stage in building a conceptual model is to determine the assessment endpoints, the potential stressors, and potential effects, followed by an evaluation of the potential effects. Initially the generalized conceptual model developed contains no probabilities of adverse effects, but simply represents a concept of the resource being exposed and the time periods of potential exposure. For a full ecological risk assessment, quantitative values may be placed on each box (or parameter). However, in the absence of quantitative data, it is important to acknowledge the qualitative data that can be brought to bear on the problem.

For many species, particularly those in North America, there are extensive literature reports of ecology, behavior, and migration patterns of the species of interest. These have been summarized in the Birds of North America accounts (Gochfeld et al. 1998; Haig 1992; Harrington 2001). While such information cannot provide data for quantitative analyses, the data can be used to understand the likelihood that a particular species will occur coastally or in the AOCS (leading to an understanding of macroscale exposure). Other information on flight heights and foraging behavior can suggest the degree of potential overlap between wind turbines and their blades and the species in question (mesoscale, microscale exposure). Together, this information can be used to depict hazard/exposure/risk scenarios.

2.6.2 Interspecific Differences

There were clear differences in the exposure, and therefore the potential risk, of each species from AOCS offshore wind facility development. These differences derived directly from information on their life history, habitat use, stopover behavior, and migratory pathways. Even with imperfect information, it was possible to determine that the risk to the three species differed because of both their normal foraging behavior and foraging habitat choice, and their migratory behavior.

Of the three species, the case was most clear for Piping Plover because all information to date suggests that they breed and migrate primarily or exclusively along the coast. The occurrence of this species within the AOCS is likely to be extremely rare and limited (see Table 2–2 and Table 2–5). It cannot be concluded, however, that they never occur in AOCS region. Indeed, some individuals most certainly do, as indicated by a few records of this species from Bermuda (USFWS 2008b). It is unclear whether any individuals regularly migrate between the U.S. Atlantic Coast and Bermuda, or if these records indicate a few vagrant birds that had been blown off course. We suggest that the primary scenario in which Piping Plovers could potentially be exposed to macroscale risk is in very limited portions of the AOCS if the “shortcut hypothesis” is true. We suggest a shortcut hypothesis: coasthugging migrants will take shortcuts across major bays or inlets, rather than following much longer, more circuitous routes that strictly follow the coastline along their migratory route. Examples of such potential shortcut regions include the Delaware Bay, Chesapeake Bay, Long Island Sound, and others along the Atlantic Coast. The shortcut hypothesis remains to be tested for the focal species of this study. If coasthugging species such as Piping Plover and short-distance migrant Red Knots (see below) do traverse potentially developable offshore wind sites in the AOCS as they take migratory shortcuts across the water, then further studies of flight height and behavioral avoidance will be necessary to determine whether this macroscale risk exposure results in exposure to risk at either the meso- or microscales.

Available data for Roseate Tern suggest that they are exposed to macroscale risk during migration because they migrate pelagically. Given the location of their breeding colonies in the Northeast and their wintering grounds on the northeastern coast of South America, their migratory trajectory would take them through the AOCS (Gochfeld et al. 1998). Mesoscale risk during migration is impossible to assess, as migratory flight height is unknown. Roseate Terns may also be exposed to macroscale risk during the breeding season, when they may forage regularly in the offshore region of interest (see references in Table 2–1 and Table 2–4), and immediately following the breeding season, when they form large aggregations at a few, certain locations along the northeastern U.S. coast (e.g., southeastern Cape Cod, Massachusetts) during post-breeding staging (Perkins et al. 2003; Trull et al. 1999; Veit and Petersen 1993). During these periods, mesoscale exposure is low, as Roseate Terns generally fly below the RSZ during normal foraging and commuting flights (see references in Table 2–1 and Table 2–4). Microscale exposure is difficult to assess, as opportunities to study the behavior of this species in the vicinity of wind turbines has been extremely limited (Vlietstra 2007, 2008).

Of the three focal species, Red Knots are the least well-known in terms of their potential exposure to risk from AOCS offshore wind facility development. Given that they stage in northeastern Canada and U.S. down to Massachusetts, it is likely that they may traverse the AOCS during migration, but they may fly considerably higher than the RSZ. However, since Red Knots descend (and ascend) to these migratory heights, they may be vulnerable during these periods, making information on their behavior near these sites of heavy concentrations during the migratory stopover critical, especially offshore from Delaware Bay, for example.

A further risk consideration for Red Knot is the presence of both short- and long-distance migrant populations. Short-distance migrant populations of Red Knot spend the winter along the coast of the U.S., while long-distance migrants winter primarily in southern South America (Niles et al. 2008, 2009). The macroscale exposure possibilities for short-distance migrant Red Knot populations may be similar to those of Piping Plovers, as both are primarily coastal species. Hence, testing the “shortcut hypothesis” (see above) is critical for gaining an understanding of the macroscale exposure for short-distance migrant Red Knots. In contrast, long-distance migrant Red Knot populations must cross the AOCS at some point as they travel between North, and South America. Understanding macroscale risk exposure for these populations depends on elucidating their spatiotemporal patterns of migration, and ascent and descent behavior, over the AOCS region. Further studies of flight heights and behavioral avoidance are necessary to make any determinations about the levels of risk of Red Knots at the meso- or microscales.

Overall, the three species have different vulnerabilities based on their breeding, staging and migratory behavior. The lack of site-specific information on their occurrence and behavior in the AOCS makes it difficult to arrive at a definitive conclusion vis-a-vis risks to these species from offshore wind facility development, and illustrates the importance of studies directed at obtaining sufficient information to answer the key questions.

2.6.3 Management Implications and Research Needs

These three species seem appropriate for use as bioindicators because they are species of concern due to their status, they represent coastal species that might pass through the AOCS, and there is information on their behavior and ecology. However, we also suggest that other species that are more common should also be used to evaluate potential impacts for offshore wind facilities. Even common species can be at risk if a substantial part of the population is vulnerable either because of geography (during foraging or migration), or their flight behavior.

The above assessment suggests that (1) interspecific differences exist which must be taken into account when evaluating risk to federally listed or candidate bird species from offshore wind energy development on the AOCS, (2) the adequacy of data available to assess risk differs among the species, (3) the risk based on current knowledge varies among the three species. It also makes clear that key information is lacking. This information includes the degree and extent to which each species ventures into the AOCS, the height at which each species flies while foraging and/or migrating within the AOCS, and the extent to which they are capable of avoiding wind turbine blades if the birds are flying within rotor swept altitudes in the vicinity of offshore wind turbines on the AOCS. Further, model development that predicts potential effects of wind facilities on overall mortality in comparison to natural mortality is needed. While it is currently impossible to have perfect information to answer all of these questions for the whole AOCS region, it is possible to design research projects to examine the key questions. Information on migratory flight pathways of the two species most likely to occur in the AOCS (Roseate Tern, Red Knot) can be obtained by tracking methods, but at present satellite transmitters, which would provide information at the highest spatial resolution, are too heavy (4–5 g) to place on these two species. Light-sensitive data-loggers, which weigh approximately 1.2 g with attachments, are currently being used, but the spatial resolution may be limited (100–200 km error), which restricts the applicability for precisely defining migratory macroexposure zones within the AOCS. Refinements in technology for both satellite transmitters and geolocators are reducing the weight of the devices, and reducing errors in precision.

One outcome of this evaluation is the identification of the key research questions that need to be addressed for each species to characterize the risk of adverse impacts to these species from AOCS offshore wind facility development. The highest priority questions are the following:

- What is the likelihood that the species occurs within the AOCS?
- What is the extent and spatial distribution of the species occurrence within the AOCS?
- What proportion of the population enters the AOCS, and in what spatial pattern?
- At what heights do the birds fly when foraging, staging, and migrating (including ascent and descent) within the AOCS?
- What factors (e.g., fog, wind speed, and direction) affect the likelihood of these birds being exposed to risk?
- What is the trajectory of flights that might put any species at risk?
- Can these birds perceive and/or avoid the wind turbines if and when the birds are flying within rotor swept altitudes in the vicinity of offshore wind turbines on the AOCS, and under what conditions?

While the limited potential macroscale (Piping Plover, Red Knot) and mesoscale (Roseate Tern) exposure of these species suggests that the potential for adverse impacts to these species from AOCS offshore wind facility development is low, this conclusion must be regarded as preliminary and tentative, as much of the data necessary for a comprehensive and definitive risk characterization is lacking. Further research is necessary to determine precise migration routes, ascent and descent behavior, flight altitudes, and behavioral avoidance of wind turbines by Red Knots, Roseate Terns, and Piping Plovers, as well as any potential noncollision-related adverse impacts to these species, before the risk of adverse impacts to these species from offshore wind facility development in the AOCS can be fully determined. It is also essential to determine if there are specific zones in the AOCS where Roseate Terns or Red Knots may be most at risk, particularly near staging sites or migratory stopovers.

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3 Project-generated Original Research and Technology Reports

3.1 Overview

Five distinct research and/or technology development initiatives comprise the core activities of this project. In this section of the report, the specific objectives, methods, results, and findings of each of these initiatives is described in full detail, prefaced by an overview that briefly describes the nature of each and the relationship of each to the project's overarching objectives and organization. Four of these initiatives stemmed from the project's three pilot studies (project Task 6, contract CLIN 0002) and a fifth (the geospatial analysis) stemmed from Task 3 of the original contract (CLIN 0001).

The first of these initiatives, presented in Section 3.2, was a study of the migratory pathways of 11 individual Red Knots whose geographic position was tracked for up to 1 yr using light-sensitive geolocators. These geolocators were attached to birds captured at migratory stopover sites on the Atlantic Coast in 2009. Geospatial position was calculated using light and time data that were recorded by the attached devices and then downloaded when these birds were recaptured 1 yr later at the same stopover sites. This research effort was led by project co-principal investigators Joanna Burger and Larry Niles, who contributed their synergistically funded research efforts toward the advancement of this component of the project, in collaboration with the project's lead scientist, Caleb Gordon, and with input from the entire project team. This research was conducted under the auspices of one of the project's pilot studies, and it was directed toward the project's risk assessment objective, to evaluate risk to the focal species from offshore wind facility operations on the AOCS. More specifically, this research was directed toward one of the high priority risk questions identified by the project team during the problem formulation phase of the project: what are the patterns of macroscale exposure of Red Knots to offshore wind facility operations on the AOCS? This research initiative is presented in two parts. The first (Section 3.2) reports the movements of three individual Red Knots from the "long-distance" migratory population that were tracked between captures on the Delaware Bay shore of New Jersey in May 2009 and 2010. This report subsection has been published in the Wader Study Group Bulletin (Niles et al. 2010) and is reproduced here with permission. The second part (Section 3.3) reports the movements of eight individual Red Knots from the "short-distance" migratory population that were tracked between captures on Monomoy Island, Cape Cod, Massachusetts, in Aug 2009 and 2010.

The second research initiative of this project, presented in Section 3.4, was a continental-scale analysis of the spatiotemporal occurrence patterns of Red Knots, Piping Plovers, and Roseate Terns within the entire AOCS and surrounding coastal region deriving from pre-existing geospatial data. Data were compiled from the AKN with the collaboration of CLO personnel who maintain this database as a worldwide, publicly available compendium of geospatial data on birds intended to advance scientific research efforts. Existing datasets of taxonomic and geospatial relevance to this project's objectives were first identified and any that were not already contained within the AKN were sought by individually contacting the dataset owners to seek permission to include their data within this analysis. All of the resulting data were compiled and transferred to Normandeau Associates, who performed additional QA/QC steps on the data, and then designed and conducted an original, quantitative geospatial analysis of the data. This research effort was led by Normandeau ornithologists Greg Forcey and Caleb Gordon with input from Joanna Burger, Larry Niles, and other members of the project team. Unlike all of the other research and technology initiatives reported in this section, this effort was not conducted as one of the project's pilot studies but under the auspices of Task 3 of the original project contract CLIN 001: "collect and evaluate existing data." This research effort was targeted at the project's risk assessment objective and was focused more specifically on illuminating the focal species' patterns of macroscale exposure to offshore wind facilities located on the AOCS. Because of the relative scarcity of geospatial data for the focal species in the offshore environment, the brunt of this analysis was conducted on offshore-relevant components of macroscale exposure that could be indirectly inferred from the wealth of coastal geospatial data that exist for these three species.

The third research initiative of this project, presented in Section 3.5, was a study of collision-related mortality patterns at a coastal wind turbine located at the MMA in Buzzards Bay, Massachusetts, within 12 km of North America's largest Roseate Tern breeding colony. Bird mortality was examined using carcass searching corrected for methodological biases using searcher efficiency and carcass scavenging experiments. Further information on carcass scavenging at the site was obtained with automated game monitoring cameras. This effort was led by Lucy Vlietstra in collaboration with Caleb Gordon, William Warren-Hicks, James Newman, and Mark Patrick and with input from the entire project team. Dr. Vlietstra added carcass monitoring data from earlier studies that she and collaborators conducted at the same turbine in order to strengthen and add value to the project-generated research. This research was conducted under the auspices of one of the project's pilot studies and was targeted at the project's risk assessment objective. More specifically, the aim of this study was to address questions of meso- and microscale exposure of Roseate Terns and other syntopic birds to risk of wind turbine collisions. The latter include Common Terns, which are very abundant at the project site and are often regarded as an effective surrogate species for Roseate Tern, as the two are closely related (congeners) and possess very similar life histories, size, morphology, and behavior and are therefore likely to experience similar meso- and microscale exposure patterns and susceptibility to wind turbine collision risk.

The fourth research initiative of this project, presented in Section 3.6, was the development of a new collision risk model for birds at offshore wind facilities with application to Roseate Terns in Buzzards Bay, Massachusetts. This study used empirical observations of Roseate Tern flight heights in the offshore environment of Buzzards Bay, Massachusetts, as well as observed tern densities in nested airspace volumes around the coastal wind turbine at the MMA to develop a new mathematical model of bird collision risk at offshore wind facilities that includes a novel method for incorporating behavioral avoidance of turbines by birds. This report applies the model to examine Roseate Tern collision risk at offshore wind facilities in Massachusetts' waters, but the model's basic structure and machinery can be applied to examine any specific instance of bird-wind collision risk where the necessary model input data are available. This effort was led by William Warren-Hicks with collaborators Lucy Vlietstra, Caleb Gordon, and Richard Podolsky and was conducted under the auspices of one of the project's pilot studies. This initiative was directed at both the project's risk assessment objective and also its methodological objective. In terms of risk assessment, it was designed to gain new understanding of key meso- and microscale exposure phenomena in Roseate Terns and surrogate species. On the methodological front, it was intended to provide a new mathematical tool that can be applied to improve bird risk assessments at offshore wind facilities.

The fifth project-generated original initiative, presented in Section 3.7, was an effort to develop an initial design and prototype of a new monitoring technology capable of producing necessary data on the occurrence of the focal bird species at offshore wind facilities that were not attainable using other existing methodologies. The essential core elements of this device and the innovations in risk-assessment–relevant data gathering capacity attached to each element were conceived as follows:

- Acoustic monitoring for species-specific identification of birds
- Self-powered and remote operating for day/night, long-term data gathering on the AOCS
- Thermographic (infrared) monitoring for increased quantification, flight height calculation, and added value for post-construction monitoring

This concept was conceived and initially developed during the project's first midterm meeting during a break session attended by Caleb Gordon, Andrew Farnsworth, Mark Desholm, Chris Ribe, and Greg Forcey. Technical development, prototyping, and initial system testing and deployment were led by Chris Ribe with consultation and guidance from Caleb Gordon, Christian Newman, and Ian Baldwin and with technical contributions from a variety of Normandeau staff and subcontractors. Synergistic support of this initiative was provided by Normandeau (then Pandion Systems) through research and development work on its Remote Bat Acoustic Technology (ReBAT™) system for automated, self-powered, remote-operating ultrasonic bat monitoring. This initiative was targeted at the project's methodological objective. More specifically, it was designed to produce a monitoring device capable of gathering data (as described above) that would significantly improve the ability to assess risk to the focal and other bird species from offshore wind facilities on the AOCS. This project-generated effort has provided a foundation for an additional contract (#M10PC00101) awarded to Normandeau Associates in Sep 2010 by BOEMRE intended to develop a sea-worthy version of this device with expanded capabilities and deploy it for up to 3 yrs on a fixed platform on the AOCS to gather acoustic and thermographic data on birds and bats, thereby informing offshore wind wildlife risk-based policy, leasing, and siting decisions.

3.2 First Results Using Light Level Geolocators to Track Red Knots in the Western Hemisphere Show Rapid and Long Intercontinental Flights and New Details of Migration Pathways[4]

Geolocators affixed to Darvic leg flags were attached to the tibia of 47 Red Knots (*Calidris canutus rufa*) during the 2009 spring migratory stopover in Delaware Bay, New Jersey, U.S. We found no difference between the behavior of birds with and without geolocators in the weeks after release and saw a greater proportion of birds with geolocators than those with inscribed leg-flags a year after release. There were no significant differences in the resighting rate in Delaware Bay in the year of attachment or in places other than Delaware Bay during the ensuing twelve months. Three individuals were recaptured in May 2010 in Delaware Bay. All three birds flew to the Arctic, only one apparently bred, and all three wintered in South America. The longest roundtrip flight was 26,700 km, which included an 8,000 km, 6-day flight from Southern Brazil to the coast of North Carolina. All three wintered away from the main sites thought to be used by the subspecies. Two birds appeared to detour around weather systems. These results suggest that geolocators are likely to afford valuable new insights to our understanding of Red Knot migration strategies as well as their breeding and wintering locations, and underpin their conservation.

3.2.1 Introduction

Understanding the biology, constraints of migration, and the yearly movement patterns of birds is essential to conserving them, particularly in the case of long-distant migrant shorebirds that rely heavily on a limited number of stopover locations (Piersma and Baker 2000). For decades, biologists and conservationists have examined terrestrial habitat use, behavior, and the prey base of shorebirds (van de Kam et al. 2004). However, there is now a pressing need to understand the pattern and timing of movements as well as their spatial use of inshore and offshore migratory pathways that may intersect both coastal and offshore development, including oil drilling and wind facilities. Remarkably little information is available on the offshore movements of most birds, and of the potential risk they face during the migratory periods when they fly along coastal margins or cross oceans.

Band recoveries and sightings of color-marked shorebirds have been the main methods of determining their migration routes, stopover sites, breeding and wintering locations. Satellite transmitters used on larger shorebirds have encountered problems due to their weight (26 g) and method of attachment (Driscoll and Ueta 2002; Gill et al. 2005). These problems have been reduced with the use of lighter transmitters (<10 g, Watts et al. 2008) and surgical implantation (Gill et al. 2009). Light-level geolocators were originally designed for use on elephant seals (DeLong et al. 1992) and later the British Antarctic Survey developed 9-g geolocators for use on seabirds (Afanasyev 2004). Recent advances in their technology and miniaturization have made

[4] Niles, L.J., J. Burger, R.R. Porter, A.D. Dey, C.D.T. Minton, P.M. Gonzalez, A.J. Baker, J.W. Fox, and C. Gordon. 2010. First results using light level geolocators to track red knots in the Western Hemisphere show rapid and long intercontinental flights and new details of migration pathways. Wader Study Group Bull. 117(2):123–130. (Used with permission of Wader Study Group Bulletin.)

it possible to use them to track the movements of 50 g terrestrial birds (Stutchbury et al. 2009) and shorebirds (Conklin and Battley 2010; Minton et al. 2010). These instruments record time-stamped, periodic, ambient light-levels that can be used to determine the geographical location of birds (Stutchbury et al. 2009; Conklin and Battley 2010; Minton et al. 2010). Their advantage is that they can be used on the legs of medium-sized shorebirds; their main disadvantage is that the birds must be recaptured to access the data. Although geolocators record data for only about a year, the data are still retrievable for up to twenty years if birds are recaptured.

Red Knots (*Calidris canutus*) are one of the better studied migrants in the world, and a species where fundamental knowledge has often been put to good use in conservation cases (e.g., Baker et al. 2004; Piersma 2007; Buehler and Piersma 2008). In the Western Hemisphere, Red Knots of the subspecies *rufa* are of conservation concern because of a major population decline over the past 25 years (Baker et al. 2004; Morrison et al. 2004; Niles et al. 2008). It is therefore vital that conservation prescriptions are underpinned by a thorough knowledge of the birds' annual cycle, migration strategies and the sites they use. This is particularly important in the light of recent proposals for offshore drilling and the location of wind facilities on the outer continental shelf, where they might pose a danger to migrant shorebirds.

We present preliminary findings on the migratory pathways of three Red Knots fitted with geolocators in 2009 and recovered a year later in 2010. Our objectives were to determine (1) whether the technology would work with Red Knots, (2) to test whether knots would suffer any immediate or long-term detrimental effects from the geolocators, and (3) the annual movement patterns of Red Knots. We detail our method of geolocator attachment, immediate behavioral responses of birds fitted with geolocators, resighting data on those birds with and without geolocators (but banded and flagged in the same year), and on the movements of three instrumented Red Knots.

3.2.2 Methods

Overall Protocol

Our experimental design was to place light-level geolocators on Red Knots during their migratory stopover in Delaware Bay in May 2009, and recapture them on their return to Delaware Bay and at other locations during migration and on the wintering grounds. The geolocators (Mk 10 design supplied by the British Antarctic Survey, Cambridge, UK) weighed 1.7 g including attachment materials. As part of our overall protocol working with shorebirds in Delaware Bay, we captured 622 Red Knots in 2009; each was provided with a uniquely coded flag (Clark et al. 2005) and we placed geolocators on 47. We relied on a network of observers to report sightings of geolocators during migration, on the wintering grounds, and again in Delaware Bay the following year. The protocol for this research with Red Knots, including attaching geolocators to birds, was approved by the Rutgers University Animal Review Board.

Red Knots were captured with cannon nets, removed immediately from the net, and placed in holding cages shaded from the sun. Processing occurred shortly after, and birds were then released. Geolocators were fitted (see below) on 48 birds that weighed over 125 g (Figure 3–1). A sample of birds fitted with geolocators was observed in a 3 m x 5 m enclosure made of dark material for 1–2 hours after attachment of the geolocators, and behavioral data were recorded to ascertain any immediate effects. One bird seemed disturbed by the geolocator, as evidenced by continuous pecking at its leg, and this geolocator was removed. The bird walked and flew normally, and was later observed feeding with other Red Knots. Controls with flags (those without geolocators) were also observed. Behavior recorded included time spent walking, running, sitting, pecking at eggs on the sand, and pecking at their leg. An extensive network of volunteer observers searched for Red Knots with leg flags, and especially noted the behavior of birds with geolocators.

Geolocator Attachment

Although we used essentially the same method of attaching geolocators to leg bands as Minton et al. (2010), we made two changes: we clipped the terminal pins of the instrument to reduce the likelihood that they would cause injury to the bird by chaffing and we placed a spacer ring beneath the geolocator band to prevent rubbing against the tibio-tarsal joint. All geolocators were applied with the sensor on the side facing outward away from the body when the flag is rotated forward of the leg, which is the natural position during most activities (Figure 3–2).

3.2.3 Results

Geolocator Attachment

We examined whether birds were adversely affected immediately upon attachment of geolocators by observing them in pens for an hour before release and then observing them in the field before they left Delaware Bay in 2009. In the pens immediately following attachment, we could discern no behavioral differences between knots with geolocators and flags and those with flags but without geolocators. After deploying geolocators on 25 knots, efforts were made to observe all those birds in the field. It was then noticed that a few appeared to walk with a very slight limp. Further deployments were stopped to allow time to evaluate the issue. It was then found that some recently flagged birds without geolocators as well as some unmarked birds also appeared to walk with a slight limp. Later we observed two birds with geolocators that had previously appeared to limp that were no longer doing so. We therefore concluded that slight limping in a small minority of birds was probably a not uncommon but previously unnoticed short-term phenomenon; therefore, geolocators were deployed on a further 22 birds. Twenty-three of the 47 knots fitted with geolocators in May 2009 were resighted in Delaware Bay a year later when none were seen to walk with a limp.

Figure 3–1. Red Knot Y0Y with geolocator and lime flag, Delaware Bay, United States, May 2010 (photo: Jan van de Kam).

We also evaluated the effects of the geolocators by comparing resightings in 2009 and 2010 of knots with geolocators and individually inscribed leg flags with those fitted with leg flags alone. There were no differences between the proportion of resighted birds with and without geolocators either during the May 2009 Delaware Bay stopover or during the winter elsewhere in the flyway (Table 3–1). However, in 2010 a greater proportion of geolocator knots (23/47, 49%) were resighted in Delaware Bay than those with only leg flags (203/622, 33%; $X^2 = 5.19$, $P = 0.023$).

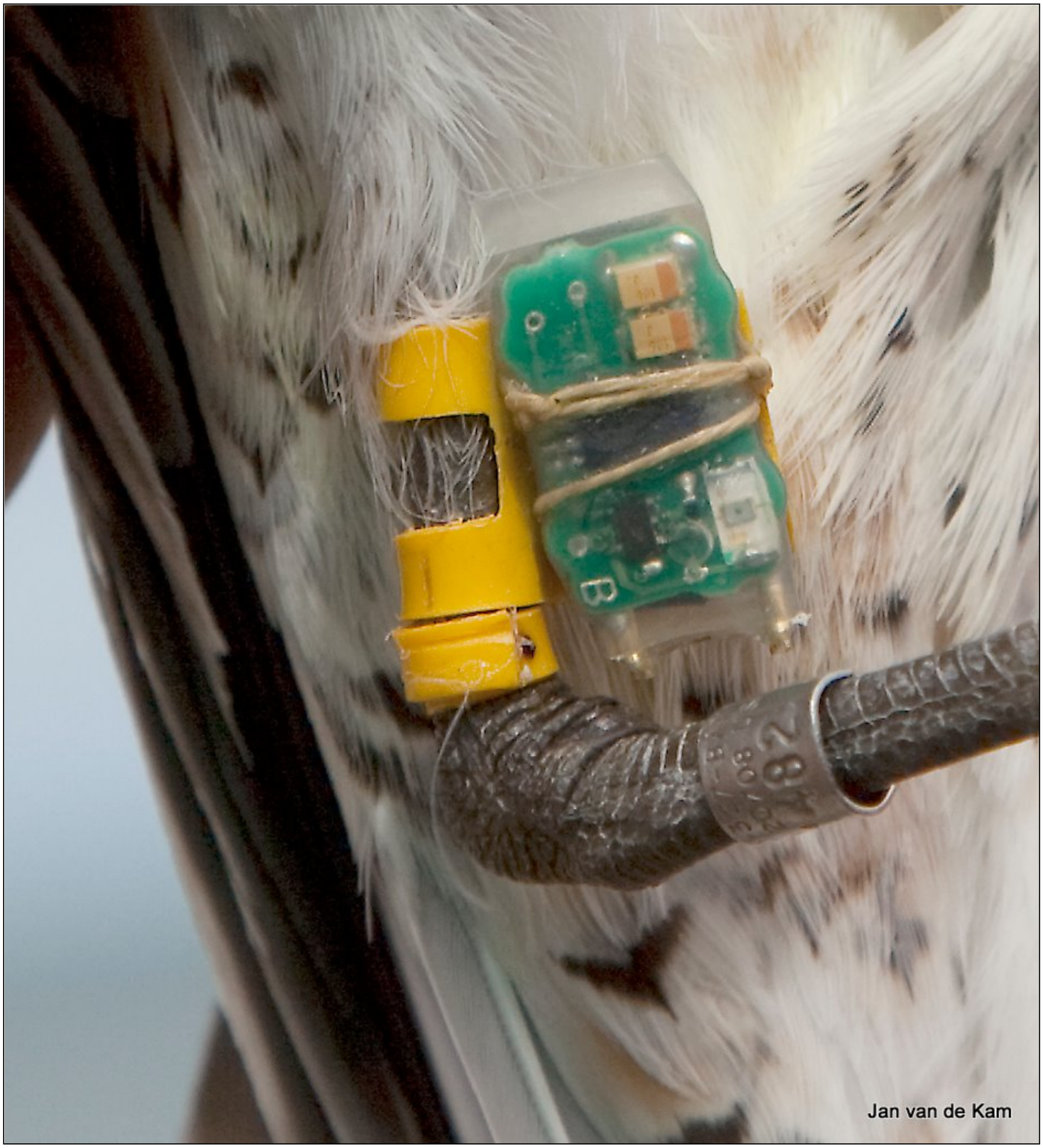

Figure 3–2. Close up of geolocator fitted to the tibia of a Red Knot in San Antonio Oeste, Argentina, 2009 (photo: Jan van de Kam).

Table 3–1

Numbers of Red Knots with individually inscribed leg flags that were marked in May 2009 and later resighted with and without geolocators on the New Jersey side of Delaware Bay and elsewhere during May 2009 to May 2010.

	Geolocators and leg flags	Leg flags only	X^2 (p)
Number of birds marked	47	622	
Resighted May 2009 in Delaware Bay	29 (62%)	342 (55%)	0.80 (ns)
Resighted elsewhere May 2009 to May 2010	4 (9%)	46 (7%)	0.06 (ns)
Resighted in Delaware Bay in 2010	23 (49%)	203 (33%)	5.19 (p = 0.023)

Of the 47 Red Knots fitted with geolocators in Delaware Bay in 2009, three were recaptured in May 2010. The Red Knot with flag code "Y0U" was first captured on 11 May 2009 weighing 121 g and recaptured on 12 May 2010 weighing 107g and recaptured again on 14 May 2010 at 128 g. The date on which this bird arrived on the Bay is unknown because the geolocator stopped working on 12 Feb 2010. The Red Knot with flag code "Y0Y" was first captured on 11 May 2009 weighing 121 g. In 2010, it arrived on the Bay on 20 May and was recaptured on 23 May 2010 weighing 158 g. The Red Knot with flag code "1VL" was originally captured on 26 May 2009 weighing 171 g. In 2010 it arrived on the Bay on 24 May and was recaptured on 25 May at 134 g. The geolocators were removed from all three birds shortly after recapture and new geolocators were attached. The legs of all three birds showed no abnormal wear or evidence of irritation suggesting that the geolocators had no adverse impact on leg morphology.

Geolocator Data

Geolocator data were processed using a fixed light threshold value and edited using BASTrak TransEdit software to reject false and noisy locations caused by shading. The output was then plotted on Google Earth maps which showed considerable noise around each site at which the birds stopped. These were then simplified to a single point representing the average location, but assuming in the case of stopover and wintering sites that it was on the coast (Figure 3–3, Figure 3–4, and Figure 3–5). In most cases when a bird was migrating, the series of locations was within the expected average error of ±150 km (according to the British Antarctic Survey) from the great circle route, and in these the great circle route and distance are shown in the maps. However, in respect of three flights (one relating to Y0U and two to 1VL) it was evident that the bird deviated far from the great circle. In these three cases, the routes shown by the geolocator output are presented in the maps along with both the great circle distance between the points of departure and arrival and our estimate of the actual distance flown.

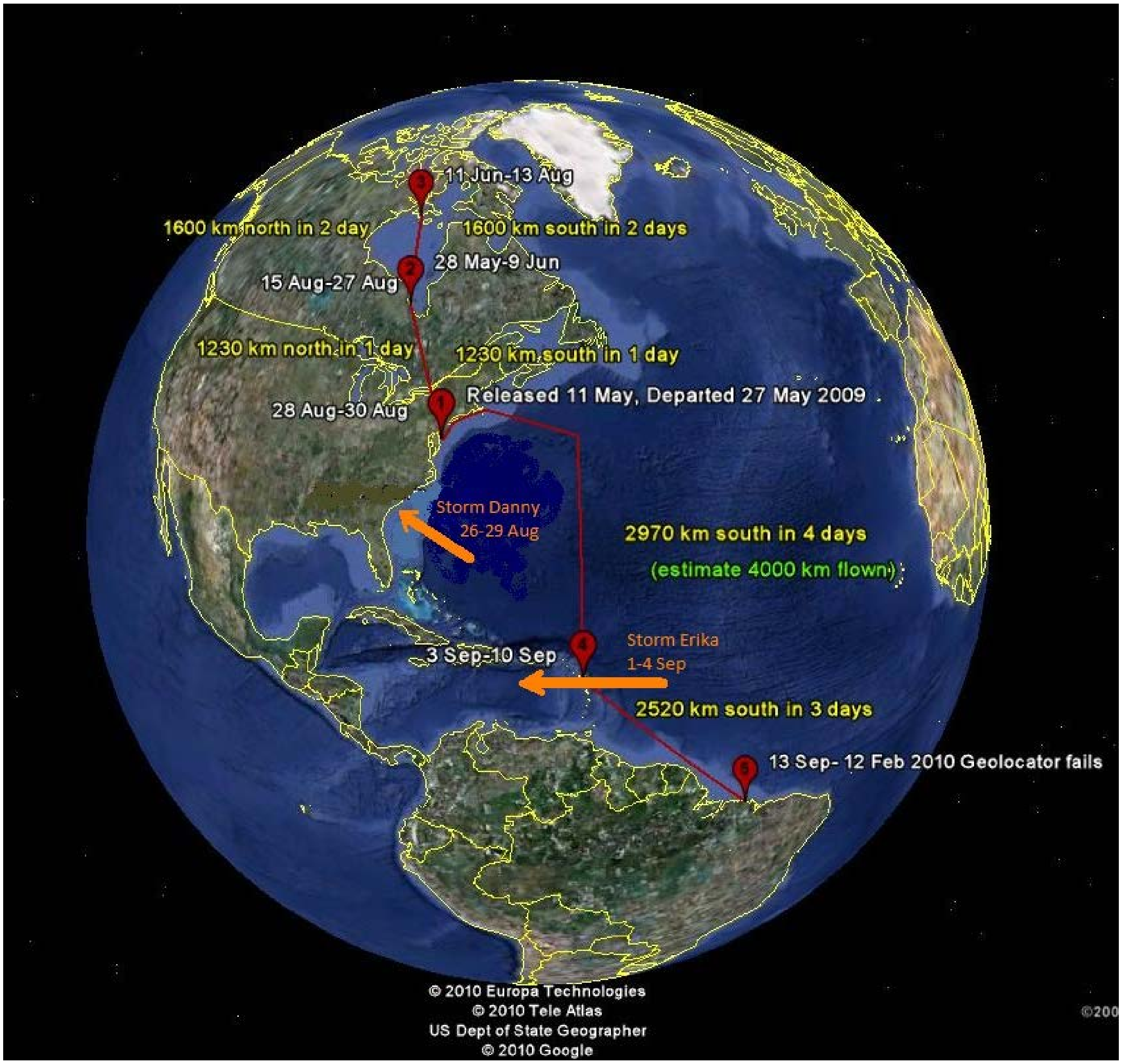

Figure 3–3. Geolocator output for Red Knot Y0U: periods when the bird remained in the same location are shown in white; the great circle distance of movements are shown in yellow; when the bird deviated far from the great circle route, the estimated distance flown is shown in green.

Location key:
1. Delaware Bay, United States
2. James Bay, Canada
3. Southampton Island, Canada
4. Lesser Antilles
5. Maranhão–Pará border region, Brazil

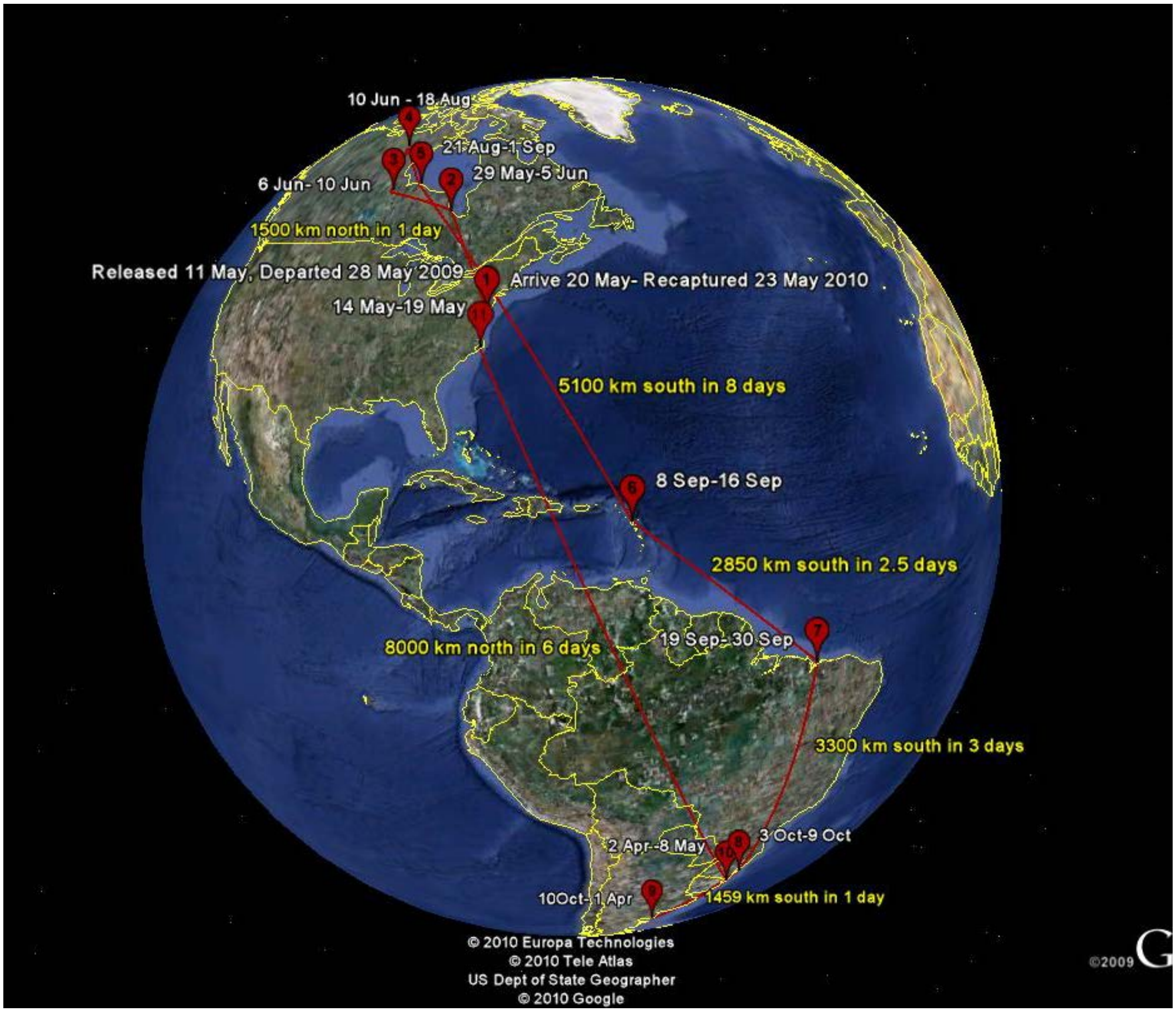

Figure 3–4. Geolocator output for Red Knot Y0Y: periods when the bird remained in the same location are shown in white; the great circle distances of movements are shown in yellow.

Location key:

1. Delaware Bay, United States
2. James Bay, Canada
3. Western Hudson Bay, Canada
4. Baker Lake, Canada
5. Churchill, Canada
6. Lesser Antilles
7. Maranhão, Brazil
8. Lagoa do Peixe, Brazil
9. San Antonio Oeste, Argentina
10. Uruguay–Brazil border
11. Ocracoke, North Carolina, United States

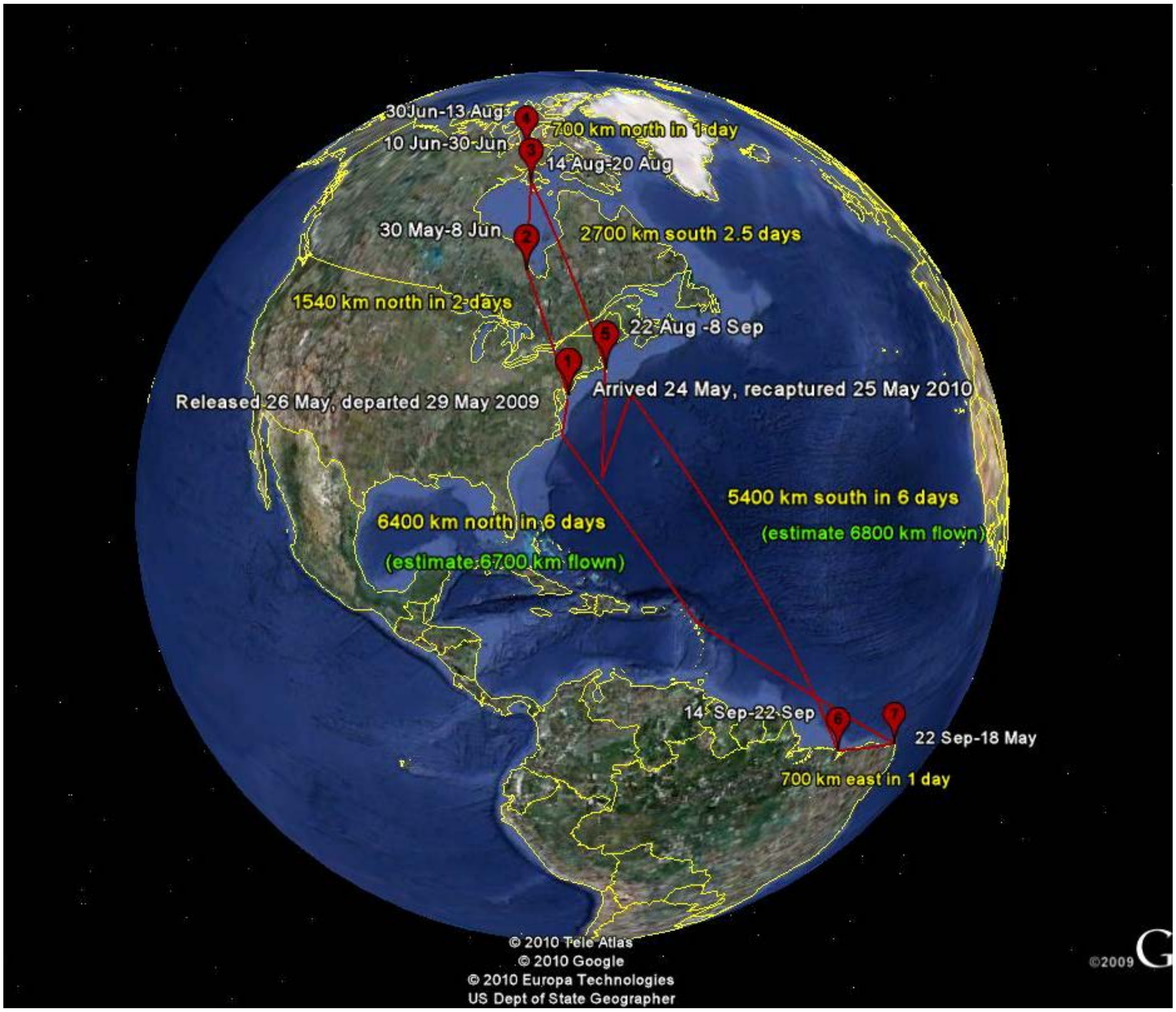

Figure 3–5. Geolocator output for Red Knot 1VL: periods when the bird remained in the same location are shown in white; the great circle distances of movements are shown in yellow; when the bird deviated far from the great circle route, the estimated distance flown is shown in green.

Location key:

1. Delaware Bay, United States
2. James Bay, Canada
3. Southampton Island, Canada
4. Pelly Bay (Kugaaruk), Canada
5. Cape Cod, United States
6. Maranhão, Brazil
7. Rio Grande do Norte, Brazil

The geolocator output for each bird is summarized as follows and in the maps (Figure 3–3, Figure 3–4, and Figure 3–5).

Y0U: After geolocator attachment on 11 May 2009, Red Knot Y0U stayed in Delaware Bay until 27 May, and then flew in one day to James Bay, Ontario, where it stopped for 12 days (Figure 3–3). After flying a further two days it arrived at Southampton Island, Nunavut, Canada, on 11 Jun, where it stayed for 63 days, presumably to nest. Y0U left Southampton Island on 13 Aug and flew in one day to James Bay, staying for 12 days. On 27 Aug, it flew to the Atlantic Coast of New Jersey, U.S., in 1 day (possibly Stone Harbor, a known Red Knot stopover site) and stayed for two days. After leaving New Jersey, it flew north along the U.S. East Coast to Cape Cod where it flew east out into the Atlantic, then south to arrive in the Lesser Antilles on 3 Sep. On 10 Sep, the bird flew for three days to the north coast of Brazil close to the border between the states of Maranhão and Pará, where it wintered. The geolocator on Y0U recorded location for 152 days before failing from saltwater intrusion, but it flew back to Delaware Bay where it was recaptured on14 May 2010.

Y0Y: The Red Knot with inscribed flag Y0Y departed Delaware Bay on 28 May 2009 and flew for one day to James Bay, Ontario, where it stayed for 7 days (Figure 3–4). On 6 Jun 2009, it flew to an inland area ~300 km southwest of Churchill, Manitoba, on Hudson Bay and stopped for 4 days. Y0Y then wandered across an area east of Victoria Island, south of King William Island, west of Southampton Island, and north of Baker Lake for 69 days, apparently not nesting because of its continuing movement. On 20 Aug, it left this area and stopped for 11 days just south of Churchill on Hudson Bay. Y0Y left Hudson Bay on 1 Sep and, like Y0U, flew to the Lesser Antilles, crossing Cape Cod, Massachusetts, in a nonstop, 8-day flight of 5,100 km. After 7 days in the Lesser Antilles, it flew to the eastern coast of the state of Maranhão, Brazil, arriving on 19 Sep and staying for 11 days. On 30 Sep, it left Maranhão, flew for 3 days, and stopped around the southern end of Lagoa dos Patos, Rio Grande do Sul, S Brazil, for 6 days. On 9 Oct, Y0Y moved to its wintering site probably on the shores near the mouth of the Río Negro estuary in northern Patagonia, Argentina, arriving on 10 Oct. It stayed in approximately the same area for 173 days, though it was observed at San Antonio Oeste, 100 km west, on 13 Mar 2010 by PMG and AJB. It left the area on 1 Apr 2010; flew for just 1 day to the shore close to the border between Uruguay and Brazil. It was seen by Joaquin Aldabe and Pablo Rocca on 10 Apr 2010 at Barra del Chui in Uruguay, and on 11 and 12 Apr on the Brazilian side of Barra del Chui. Y0Y remained around the Uruguay-Brazil border for 36 days. On 8 May, Y0Y flew 8,000 km in 6 days to the U.S. East Coast, stopping for 6 days at Ocracoke, North Carolina; then it flew in one day to Delaware Bay, arriving on 20 May.

1VL: The Red Knot with inscribed flag 1VL left Delaware Bay on 29 May and stopped in James Bay, Ontario, where it stayed for 9 days; on 8 Jun it flew on to Southampton Island, arriving on 10 Jun (Figure 3–5). On 30 Jun it moved to an area NNW of Southampton Island, centered near Pelly Bay, Nunavut, north of the Arctic Circle, where the lack of nighttime signals made location uncertain. It arrived again on Southampton Island on 14 Aug, stayed for 6 days; then it flew 3 days to Cape Cod, Massachusetts, where it stayed for 18 days. On 8 Sep, 1VL made a direct flight of 6 days and 5,400 km to an area 80 km northwest of Sao Luis, Maranhão, Brazil. On the way, it apparently encountered a weather system that caused it to detour nearly 1,000 km to the northeast. It stayed in Maranhão for 7 days, left on 22 Sep, and flew 1 day to winter in an area just north of Natal, Rio Grande do Norte, Brazil, close to the northeasternmost point of South

America, where it stayed for 8 months. It left Brazil on 18 May 2010, flying 6 days and 6,700 km, crossing the Lesser Antilles and the Virginia coastal islands, and arriving in Delaware Bay on 24 May. 1VL was recaptured the next day at 134 g, 1 day short of a year after it was first caught.

Flight Range

For each flight, we measured the great circle distance between departure and arrival sites and these data are presented on the maps (Figure 3–3, Figure 3–4, and Figure 3–5) in yellow. However, we emphasize that these represent the absolute minimum distances flown, if the birds deviated from the great circle route at all (which is very likely) the distances flown will be greater. In those cases in which the geolocator output makes it clear that the route flown was substantially different from the great circle, we have added our estimate of the actual distance flown to the maps (in pale green).

Y0Y, which wintered in Argentina, flew the longest aggregate distance, based on the great circle route between each stop, of 26,700 km and also made the longest single flight of 8,000 km. 1VL, which wintered in NE Brazil, flew an aggregate of 21,150 km on migration including two flights when it clearly deviated from the great circle. Y0U was recorded as having travelled about 12,200 km before its geolocator failed when it was on its wintering grounds in N Brazil. If it is assumed that it flew direct from there to Delaware Bay, it would have covered about 17,500 km in the year.

3.2.4 Discussion

Hitherto, everything we have discovered about the migration of Red Knots in the Western Hemisphere, including the location of their wintering, stopover and breeding sites has been based on direct observations of birds, and the absence of birds. These data are inextricably bound to our choice of survey location and their value is hampered by our inability to make observations simultaneously everywhere in the flyway. Thus they provide us with only a limited understanding. But now, with their ability to track birds throughout their annual cycle, it seems that geolocators are poised to greatly improve our comprehension of shorebird migration. However, until the impact of these instruments on the birds has been fully evaluated, the interpretation of results should always take account of the possibility that they were influenced by the method.

Our results substantiate some of what we already knew or suspected about Red Knots in the West Atlantic Flyway, but also reveal new aspects that had not been expected.

Effect of Geolocators on Red Knots

The geolocators mounted on Darvic flags did not appear to have any effect on the behavior, survival or leg morphology of Red Knots in this study. The devices weigh only 1.7 g (1.3% of the birds' average fat-free mass [Atkinson et al. 2007]), but as with most location devices, the method of attachment presents the greater problem. In a similar project on Ruddy Turnstones *Arenaria interpres* in Australia, eight birds were fitted with geolocators and four recaptured after round-trips of up to 27,000 km to the Arctic and back (Minton et al. 2010), which also suggests that geolocators attached to flags are virtually no impediment to medium-size shorebirds. The fact that proportionately more knots with geolocators were resighted in May 2010, compared with knots with only flags appears to be evidence that geolocators have little or no effect on annual survival, but this should be treated with caution because there are clear reasons for this result that do not relate to survival. The high resighting rate of geolocator birds probably arises partly because a bird with a geolocator is more conspicuous to an observer and partly because an effort was being made to find birds with geolocators for recapture. Therefore if a geolocator bird was seen, an observer would persist in following it until the flag could be read, but flagged birds without geolocators might be ignored if they proved too difficult to observe. In principle the high resighting rate could arise because the geolocator birds had a longer residence time in Delaware Bay, but we have no reason to believe that this is the case.

A potential impact of geolocators that we have not been able evaluate is that they could cause damage to eggs during incubation. We are aware of current breeding-ground based studies of Red Knots, Dunlins (*Calidris alpine*) and Hudsonian Godwits (*Limosa haemastica*) using geolocators, so whether this is a matter of concern should soon become clear.

Migration Routes

All three birds wintered in South America, providing us with the first direct evidence of the pathways Red Knots take between their arctic breeding grounds and South America. Three is a small sample from which to generalize, but there was some commonality among the birds in the routes they took that might be applicable to a substantial proportion of the knot population.

First, all three departed from Delaware Bay heading inland in a NNW direction, which is consistent with all observed departures of knots from the Bay (Harrington and Flowers 1996, authors' unpublished observations). They then flew to James Bay and on to Southampton Island and other breeding areas.

Second, flying south after the breeding season, they all either stopped at, or crossed, the U.S. mid-Atlantic Coast, and all stopped on or crossed the Lesser Antilles before reaching Brazil.

Y0U wintered on the north coast of Brazil on the border between Maranhão and Pará, 1VL made landfall in Maranhão but then wintered about 1,100 km to the east, while Y0Y stopped in Maranhão for 12 days before moving on to winter in Argentina. Only Y0Y went to southern South America and flew overland going both south and north. Its northbound path took it across the Pantanal region of Brazil, where 10 knots were seen in Sep 1989 (Niles et al. 2008 citing CEMAVE unpublished data). Therefore, although the evidence is sparse, it would seem quite likely that the Red Knots that winter in Patagonia can traverse the Brazilian interior in both spring and fall.

Stopovers and Wintering Sites

After leaving Delaware Bay, all three birds stopped at James Bay before moving on to the Arctic. This is surprising because James Bay was not thought to be a major spring stopover though large numbers have been seen over-flying the area, presumably en route between Delaware Bay and the breeding grounds (Niles et al. 2008). James Bay is only 1,500 km from Delaware Bay, which is a relatively short distance for the birds that leave Delaware Bay heavily laden with fuel. We do not think it likely that the three birds stopped in James Bay because they were hampered by the geolocators as they all made much longer nonstop flights later in the year. Probably the number of knots stopping in James Bay in 2009 was greater than usual because of a large area of persistent low temperatures and spring snow that forced the birds to delay their flight to the breeding areas (Paul Smith, pers. comm.). Therefore, although James Bay may not be a key stopover under normal spring conditions, in 2009 and in similar years it may support a substantial proportion of the population.

Two birds, Y0U and Y0Y, stopped in the Lesser Antilles arriving on 3 and 8 Sep respectively. The geolocator locations suggest that both were in the area of Guadeloupe, Martinique, and Barbados. However, so far as we know there are no previous observations of substantial numbers of knots stopping in this area, though small numbers occur during both north and south migration (Anthony Levesque, pers. comm.; Holland and Williams 1978; Steadman et al. 1997). Two tropical storms were active in the region at the time (Erika 1–3 Sep and Fred, 7–12 Sep), so it may be that the birds stopped in the Lesser Antilles on account of the weather conditions.

Y0Y stopped at the southern end of Lagoa dos Patos, Rio Grande do Sul, Brazil, on its southbound flight but in an area about 250 km to the south on the Brazil-Uruguay border for 36 days on its way north. This is at the southern end of the Rio Grande do Sul coast where in the 1980s researchers concluded that Red Knots move in short flights during Apr from south to north while feeding on the clam *Donax haleyanus* and the mole crab *Emerita brasiliensis* (Harrington et al. 1986; Vooren and Chiaradia 1990) coincident with the late summer peak of abundance of juveniles of these species (Gianuca 1983). Thus the fact that Y0Y stayed in the same area around the Brazil-Uruguay border from which it launched on an 8,000 km flight suggests that the local food supply is currently good enough to support major refueling for Red Knots, but was passed through continuously by the larger population that existed in the 1980s.

The main *rufa* wintering sites are thought to be the southeast U.S. Coast (mainly Florida), the coast of Maranhão, N Brazil, between São Luís and Baía de Turiaçu and Isla Grande, Tierra del Fuego (Niles et al. 2008). However, all of the geolocator birds wintered elsewhere. This is not particularly surprising because counts of knots stopping over on the U.S. East Coast are sometimes greater than numbers estimated to be wintering in the main sites (A.D. Dey, unpublished information). Nevertheless this result highlights the need for more extensive surveys before we can claim to have a thorough knowledge of the winter distribution of *rufa*.

Nonstop Flight Range

South American wintering knots have long been thought to make very long nonstop flights during their northbound migration. In May 1984, for example, individually marked knots were last seen at Lagoa do Peixe, S Brazil, and first seen in Delaware Bay 13 days apart, a great circle distance of 8,170 km (Harrington and Flowers 1996). At the time it was thought that the birds might have stopped en route; and there would have been time to do so because total flying time was estimated at about 6 days. However, subsequent discovery that long-distance migrants ingest much of their digestive apparatus before departure, and this has to re-grow before they can feed efficiently again (Piersma and Gill 1998) means that a refueling stop would be unlikely. Two similar instances of probable long nonstop flights occurred in 2010 when one individually marked knot was last seen at San Antonio Oeste, Argentina, and next seen in NE Florida 9 days later, a great circle distance of 8,050 km (PMG and P. Leary), while another was last seen at San Antonio Oeste and next seen in Delaware Bay 11 days later, a great circle distance of 8,900 km (PMG and AJB). The 8,000 km flight of Y0Y from the Brazil-Uruguay border to North Carolina provides the final proof that such long flights do indeed take place.

Although Y0Y and probably the other birds mentioned above flew from at least southern Brazil to the U.S. without stopping on the north coast of South America, count data and band resightings show that many other Patagonia-wintering knots do make a stopover there (Morrison and Harrington 1992; Antas and Nascimento 1996; Wilson et al. 1998; Rodrigues 2000; Piersma et al. 2005; González et al. 2006). We do not know why some knots overfly the north coast while others stop, but it would seem to be an analogous situation to that of the *canutus* knots that winter on Banc d'Arguin, W Africa, and fly direct to the Wadden Sea in NW Europe if the weather is favorable, but stop in W France if they encounter adverse wind conditions (Leyrer et al. 2009). Although there are several reasons why migrant shorebirds may choose to stop in one place and not in another (van de Kam et al. 2004), a reason why at least some knots may avoid stopping on the north coast of South America is the prevalence of ectoparasites in that area (D'Amico et al. 2008).

In a review of the northward migration of Red Knots worldwide, Piersma et al. (2005) assumed that all Patagonian *rufa* stop on the north coast of Brazil and that their longest nonstop flight is the 5,200 km from there to Delaware Bay. Among other knot subspecies, the longest flight they describe is that of *canutus*, some of which fly 6,900 km from South Africa to Mauritania. Possibly therefore those *rufa* that winter in southern South America and fly from at least S. Brazil to the U.S. make the longest nonstop flights of any population of Red Knots worldwide, but that remains to be confirmed.

1VL arrived in Delaware Bay on 24 May having just flown 6,700 km from NE Brazil. It was caught the next day at what seems, in the circumstances, the relatively high mass of 134 g, just above the average fat-free mass of *rufa* knots (Atkinson et al. 2007). It is unlikely that it had gained significant mass between arrival and capture in view of its need to re-grow its digestive apparatus (Piersma and Gill 1998). Though many low mass knots are caught in Delaware Bay at the beginning of the stopover, it is normally impossible to know how long the birds have been present. Therefore more observations like this will give a useful insight into actual arrival mass.

Influence of Adverse Weather

Adverse weather probably influenced the track of two birds, IVL and Y0U. When Y0U departed from New Jersey on southward migration, it first flew north to Cape Cod, then east out into the Atlantic, and ultimately south to the Lesser Antilles (Figure 3–3). The initial northward flight may have been a response to strong southerly winds during the dying phase of tropical storm Danny and the landfall on the Lesser Antilles may have been caused by storm Erika which was traversing that area at the time (Figure 3–3). We estimate the distance flown by Y0U to be around 4,000 km compared with the great circle distance between departure and arrival sites of 2,970 km. Similarly 1VL made a detour over the sea during its southward migration from Cape Cod to Brazil, probably in response to strong adverse winds recorded by weather buoys in the area at the time (www.buoyweather.com), flying at least 6,800 km as opposed to the great circle distance of 5,400 km. That two of the three birds encountered stormy weather in the early hurricane season in the Atlantic is not surprising, but the birds' responses to such weather events was not previously known. The extra flying represents substantial additional energy expenditure, which on some occasions might lead to mortality.

Risk of Collision with Wind Turbines

One focus of this work was to assess the potential risk to Red Knots of wind turbines that may be sited 3–20 mi (5–32 km) off the U.S. Atlantic Coast. BOEMRE has identified three primary questions that need to be addressed to characterize the risk to knots from offshore wind development on the AOCS: (1) do knots fly within the 3–20 mi area? (2) do they fly 40–150 m above sea level, the span of turbine rotors? and (3) can they avoid the rotors if they do fly within this zone? Geolocator data can only answer the first of these questions, but there are concerns over the low resolution of the locations. Currently, the resolution for their geolocators is estimated by the British Antarctic Survey at around 150 km, but this is greatly affected by local factors, especially shading and weather. Minton et al. (2010) found errors as high as 250–300 km when comparing several known resightings to geolocator derived locations. However, both newer software and further interpretation of locations, based partly on weather information and repeated locations in the same place, can narrow this error in geospatial position calculation. Nevertheless, with current analytical techniques, resolution was sufficient for the three birds to indicate that the area of the AOCS from North Carolina to Cape Cod, Massachusetts, and particularly the vicinity of Delaware Bay may be critical for migrant Red Knots.

Future Research Directions

In addition to the 47 geolocators attached to Red Knots in Delaware Bay discussed in this paper, we have since deployed a further 200 on Red Knots trapped between May 2009 and May 2010 on the Mingan Archipelago, Canada, the Atlantic Coast of New Jersey and Massachusetts, the Gulf Coast of Florida and Texas and at San Antonio Oeste, Argentina. We plan to continue efforts to recapture the knots already carrying geolocators and, subject to sufficient funding, intend to attach more geolocators to enable us to build up a comprehensive understanding of the birds' migration strategies, wintering and breeding locations. Such data will underpin conservation prescriptions for this vulnerable population and help assess the implications of coastal developments, including the placement of offshore wind facilities and drilling operations.

3.2.5 Acknowledgments

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3.3 Preliminary Analysis of Red Knot Macroexposure to AOCS Wind Facilities from the Migratory Paths of Eight Red Knots Tracked Over One Year with Light-sensitive Geolocators

3.3.1 Summary

The migratory pathways of eight Red Knots tracked for 1 yr with light-sensitive geolocators were analyzed to shed new light on the macroscale exposure of Red Knots to AOCS wind facilities. This was identified as a high priority question identified by the project team because Red Knots are of conservation concern and have the potential to be at risk from wind turbines on the AOCS as they are presumed to traverse the AOCS during their migratory flights. In previous work, we described the migratory pathways of three Red Knots fitted with geolocators when they were at a spring stopover on Delaware Bay and then recaptured on Delaware Bay the following spring (Section 3.2; Niles et al. 2010). In this report, we describe the migratory pathways of eight Red Knots, all from the short-distance migrant population, fitted with geolocators in Massachusetts and recaptured in Massachusetts 1 yr later. All eight birds went to the Arctic during the breeding season. Our initial theory was that the birds that migrated through Massachusetts went to Florida to overwinter and probably flew over the ocean from Massachusetts to Florida. However, we found that the pattern of movement for the eight birds was variable as follows: (1) the birds did not generally make one long flight from Massachusetts to Florida, (2) they did not generally remain in Florida, and (3) several birds spent considerable time along the Atlantic Coast in areas other than Delaware Bay and Virginia (the known migration stopover places). Some made short-distance hops, likely along the shore or into the AOCS region, and others crossed the area and flew over deeper water. With only 11 tracked birds captured at only two locations and limited geospatial precision of the geolocator data, our ability to generalize about exposure to offshore wind turbines is still severely limited. Nonetheless, the movement patterns of these birds suggest several preliminary conclusions with respect to this risk issue: (1) exposure for both long-distance and short-distance migratory populations of Red Knots is most

likely during 0–4 distinct episodes per bird per year when birds may engage in long migratory flight segments. This is possibly the only time when Red Knots are exposed to offshore (defined as >3 mi from shore) wind turbine collision risk, as Red Knots are likely to restrict their activity to coastal areas during other portions of their wintering and stopover periods, when they may be exposed to coastal or near-shore wind turbines, but are unlikely to be exposed to turbines located on the AOCS greater than 3 mi from shore. (2) The observed patterns of migratory paths, stop-over sites, and wintering areas in both long-distance and short-distance migratory populations of Red Knots suggests that potential exposure of Red Knots to wind turbines on the AOCS is rare, though fairly widely dispersed across the region.

We note that the macroscale exposure patterns presented and discussed in this chapter are a necessary, though not sufficient, condition for Red Knots to be at risk of collision with wind turbines on the AOCS. If Red Knots fly at altitudes either above or below the RSZ of wind turbines or if they exhibit a high capacity for behavioral avoidance of turbines, risk may be low even in cases where macroscale exposure occurs.

3.3.2 Introduction

Understanding migratory pathways, including both short-distance and long-distance flights, and stopover behavior of Red Knots is important for evaluating the risk to this species from offshore wind facility development on the AOCS. Knowledge about migratory pathways can only be gained with the use of satellite transmitters (currently too heavy for Red Knots) or geolocators. Geolocators that record light information can be affixed to the legs of birds and when recaptured this information can be downloaded, allowing calculation of their migratory route, as well as regional movements, from the sunset-sunrise times associated with particular latitudes and longitudes. Although the data provided by geolocators are less precise than those derived from satellite transmitters, the data provide information on spheres of activity (for references, see Niles et al. 2010).

Red Knots (*Calidris canutus rufa*) have one of the longest migratory routes of any shorebird; some individuals fly from their breeding grounds in the Arctic to the southern tip of South America and back (about 30,000 km). Each May and early Jun, Red Knots and other northbound shorebirds generally stop over at Delaware Bay (bordered by New Jersey and Delaware) to feed on the eggs of spawning horseshoe crabs (*Limulus polyphemus*). In less than 2 wks along Delaware Bay, Red Knots regain body reserves for their final flight to their Arctic breeding grounds, and the body reserves gained in Delaware Bay are critical for both the migratory flight and breeding in the Arctic. Yet Red Knots also stop at other locations along the Atlantic Coast to forage during spring and fall migration, and some of these places are also critical for migration. Because of the rapid decline of Red Knots over the last 20 yrs, it is important to understand the movement patterns and migratory behavior of Red Knots in order to accurately evaluate the potential macroscale exposure of Red Knots to offshore wind turbine facilities on the AOCS.

This report analyzes only the macroscale exposure of Red Knots to AOCS offshore wind facilities. Macroscale exposure is defined by Burger et al. (2011) as “the occurrence of the species within the geographical region of interest.” This is a necessary, though not sufficient, condition for Red Knots to be at risk of collision with AOCS wind facilities. Additional questions that must be addressed in order to evaluate the level of actual risk to Red Knots from AOCS wind facilities include the following: At what altitude do migratory flights occur? How quickly do migrating Red Knots ascend from or descend to migratory stopovers? To what extent do Red Knots avoid flying through wind facilities or avoid flying through the RSAs of wind turbines if they do fly through a wind facility? The answers to these questions remain largely unknown.

In Section 3.2 of this report (also published as Niles et al. 2010), we discussed the migratory pathways of three Red Knots that were fitted with geolocators while at a stopover on Delaware Bay in May 2009 and subsequently captured on Delaware Bay the following May. We found that all three flew to the Arctic during breeding season and all wintered in South America. Two of the birds appeared to make detours around inclement weather systems. This behavior has implications for the importance of understanding not only the pathways, but the factors that alter these pathways. The risk to migrating Red Knots is not only a function of the normal pathways, but of the pathways they may be forced to follow due to unusual or unexpected storms or weather patterns.

In this section, we report on information gleaned from eight Red Knots that were fitted with geolocators while in Massachusetts on their southbound journey and were subsequently caught in Massachusetts about 1 yr later. These are all known to be birds from the short-distance migratory population of Red Knots, as they were all observed molting their flight feathers during fall migratory stopover, whereas long-distance migrants are known to engage in pre-basic molt only after reaching their South American wintering grounds (Harrington 2001). We note that this report contains preliminary findings on these eight birds and will be subject to further analysis. Our objective was to increase the number of known migratory pathways to form a clearer picture of the movements along the Atlantic Coast that will provide useful information about the possible risk to Red Knots from wind facilities on the AOCS. We also present summary information and discussion of Red Knot AOCS wind turbine macroscale exposure based on combined consideration of these eight birds with the three birds from the long-distance migrant population that were also tracked with light-sensitive geolocators and presented in an earlier report.

3.3.3 Methods

Our overall protocol for the project was to capture Red Knots stopping over during the spring migration at Delaware Bay, New Jersey Coast, Massachusetts, Florida, and at other locations, and to fit them with data-loggers (also called geolocators) and colored leg flags for the overall objective of studying migration routes and the potential risk Red Knots face from wind facility development on the AOCS. We attached geolocators to the legs of Red Knots along with field readable leg flags and USFWS bands. To obtain the information from the geolocators, it was necessary to recapture the birds and remove the geolocators. Considerable time and technical expertise was required to decode the information on the geolocators once birds were caught, and recapturing birds was not easy.

The methods are described in detail in Niles et al. (2010) for Red Knots caught on Delaware Bay, and similar methods were used on the eight birds we describe in this section.

Unlike the Niles et al. (2010) paper, this analysis uses the wet/dry signal to partly interpret the results. The sensors on the geolocators record a wet/dry reading every 3 seconds, which results in about 200 readings per 10 min. A wet reading means that the geolocator was in the water (or splashed enough to get wet) during those readings. Once a bird is out of the water, it takes about

10 min for it to dry out (and thereafter a dry reading is recorded if the bird does not go back into the water). Thus high readings of wet/dry indicate the bird has been standing in the water frequently and may indicate that it is foraging (or roosting in shallow water). Wet episodes can be defined as segments where there is no dry segment (or zero readings) to disrupt the continuous time when wet readings have been recorded. These wet episodes are very important because they indicate that the bird was not flying, but was on the ground with its geolocator in water (allowing for the 10 min lag to dry out).

3.3.4 Results

Captures and Resightings

Birds with geolocators can be resighted as well as recaptured. The resighting data show that birds carrying a geolocator are healthy, forage in a manner similar to those without geolocators, and do not appear underweight. Further, they have been observed in all the places where observers are located and where large groups of Red Knots congregate, including northern Canada, Delaware Bay to Massachusetts, along the Atlantic Coast south of New Jersey to Florida, and in South America, including Tierra del Fuego.

A summary of geolocators placed on Red Knots is presented in Table 3–2.

Table 3–2

Summary of geolocators placed on Red Knots over the course of this study.

LOCATION	DEPLOYED IN Spring 2009	DEPLOYED IN Fall 2009	DEPLOYED IN Winter 2009	RECAPTURES[b]
Delaware Bay	47 [a]	0	0	3
Coastal NJ	0	10	0	1
Massachusetts	0	41	0	8
Florida	0	23	47	1[b]
Tierra del Fuego	0	0	0	0
Madelaine Is, Canada	0	8	0	0

[a] One additional geolocator was put on a Red Knot, but removed.
[b] There have been several sightings of the birds with geolocators, all healthy and walking and running well.

The capture rate for Red Knots with geolocators is far above what we would have expected for Massachusetts based on recapture rates at the other locations. Capture rates are influenced by weather conditions, flocking behavior, tidal conditions, and our ability to isolate Red Knots with geolocators in such a manner as to minimize any possible harm to them during trapping. Thus, we frequently set traps in areas with geolocator birds, but are unable to deploy the net because of environmental or flock conditions. Capturing eight geolocator birds from Massachusetts increases our knowledge of their movements, particularly for a group of Red Knots that are generally considered “short-distance” migrants.

Migratory Pathways

One of the most interesting aspects of the work with geolocators is that the migratory pathways provide in-depth spatiotemporal information for the birds, showing places Red Knots stopped, time spent in particular locations, and maximum distances traveled. In Figure 3–6, we present a preliminary map of the routes of the eight Red Knots captured in Massachusetts. As is clear from this map, the birds all migrated to the Arctic breeding grounds. However, although the Red Knots all stopped at coastal Massachusetts, their migratory pathways and behavior diverged at this point.

Figure 3–6 (the composite map of all eight tracks) shows very clearly that there are places where Red Knots spend considerable time (shown here as yellow). Although these data relate to only eight birds, they clearly show that the short-distance migrant population of Red Knots has a much more varied pattern of stopover and wintering locations than was previously believed (Harrington 2001; Niles et al. 2010).

Summary of Migratory and Stopover Behavior

As is clear from these tracks, we had only partial records for two of the birds, but records for the others are complete. The birds did not show one pattern, but all used the continental shelf area and made some relatively short flights from place to place. Although all birds flew to the Arctic during the summer, they did not go to the same place (see Figure 3–6), nor did any winter in the traditional Gulf Coast region in Florida (although one went to the Atlantic Coast of Florida) as we had initially thought (Table 3–3). From what we understand, the signals indicate that all birds were incubating while in the Arctic.

Figure 3–6. Migratory patterns of eight Red Knots from the short-distance migrant population captured in Massachusetts in 2010.

Table 3–3

Summary of movement patterns of eight Red Knots with geolocators captured in Massachusetts, fitted with geolocators in 2009, and returned to Massachusetts on southbound flight one year later.*

Bird Number	Wintering site (after leaving Monomoy, Mass. in 2009)	Longest flight in the U.S. Atlantic Coast region (km) (truncated in Florida)	Number of days in AOCS region on southward movement (for birds that stayed along U.S. East Coast, it includes southern trip, overwintering and Northern trip	Number of days in AOCS region in northward movement (only for birds that wintered outside U.S.	Locations other than Delaware Bay or Virginia
7CJ	Maryland	280 [1-2] (Monomoy to NJ Coast)	268 (wet signal every day)	n/a	Maryland, Long Island, New Jersey
010	North Carolina and South Carolina	850[3] (Monomoy to North Carolina)	290 (289 days of wet signal)	n/a	North and South Carolina
014	Cuba	Ca 1800[4] (Monomoy to Bahamas) 950[5,6], (Bahamas to South Carolina)	75 (wet signal along coast)	88	North and South Carolina, New Jersey
016	North Carolina	800[4] (Monomoy to North Carolina) 500[5] (North Carolina to NJ Coast)	264 (wet signal once it reached NC)	n/a	North Carolina, New Jersey
032	Cuba	1800[5] (Monomoy to over Florida on way to Cuba)	59 (wet signal while in U.S. Coast)	56 (wet signal)	Florida and South Carolina
038	Florida, Atlantic Coast	1700[5] (Monomoy to Florida, then back to Monomoy)	263 (wet signal)	n/a	Florida
042	Venezuela/Columbia	800[5] (Maryland to Columbia, only for U.S. portion)	80	The battery died before its northbound migration	Maryland

Table 3–3. Summary of movement patterns of eight Red Knots with geolocators captured in Massachusetts, fitted with geolocators in 2009, and returned to Massachusetts on southbound flight one year later (continued).

Bird Number	Wintering site (after leaving Monomoy, Mass. in 2009)	Longest flight in the U.S. Atlantic Coast region (km) (truncated in Florida)	Number of days in AOCS region on southward movement (for birds that stayed along U.S. East Coast, it includes southern trip, overwintering and Northern trip	Number of days in AOCS region in northward movement (only for birds that wintered outside U.S.	Locations other than Delaware Bay or Virginia
058	Haiti	1250 (Monomoy to Haiti, flight of 2300 km over water, in 3 days) 850 (South Carolina to Monomoy)	65	70	South Carolina

*All birds were in the Arctic for breeding season. AOCS = Atlantic Outer Continental Shelf. N/A indicates that the bird did not leave U.S. Coastal Areas, and thus no clear northbound period can be defined.
1. Calculated 7 hr at assumed 40 kph = 280 km.
2. Coastal hops: occasional wet signals, short distance hops.
3. Coastal Flight, no wet signals, likely direct between coastal points
4. Offshore, crossed Atlantic Continental Shelf only to/from deep water. Actual nonstop flight = 2426 km
5. Over the Atlantic Continental Shelf
6. Red Knot flew to mid Bahamas, then to Cuba

Red Knots spent a considerable amount of time at their fall migratory stopover site in Monomoy after deployment of the geolocators before beginning their southward migration7CJ (70 days), 010 (65 days), 014 (75 days), 016 (58 days), 032 (58 days), 038 (65 days), 042 (70 days), and 058 (64 days). The time they remained at this fall stopover site does not seem to relate to the distance they first flew when leaving Monomoy.

The importance of the wet readings is that they indicate that the bird was on the ground, generally not taking long-distance flights during that time. Thus, for most of these birds, there were wet reading episodes during most of the migration/overwintering periods (for 8–10 hrs/day), except when they were taking long-distance flights (Figure 3–7). Long-distance flights show no wet readings because the birds are in the air nonstop.

The wet/dry data provide an important complement to the purely geospatial data produced by the light-sensitive geolocators because they indicate behavioral activity patterns such as feeding/ foraging periods and nonstop flight periods. They can potentially be used to determine when the birds might have taken short flights of 50 or 60 km (determined from the time between wet signals), which may be significant for assessing AOCS wind turbine exposure, in combination with longer, nonstop flight intervals inferred from longer dry periods.

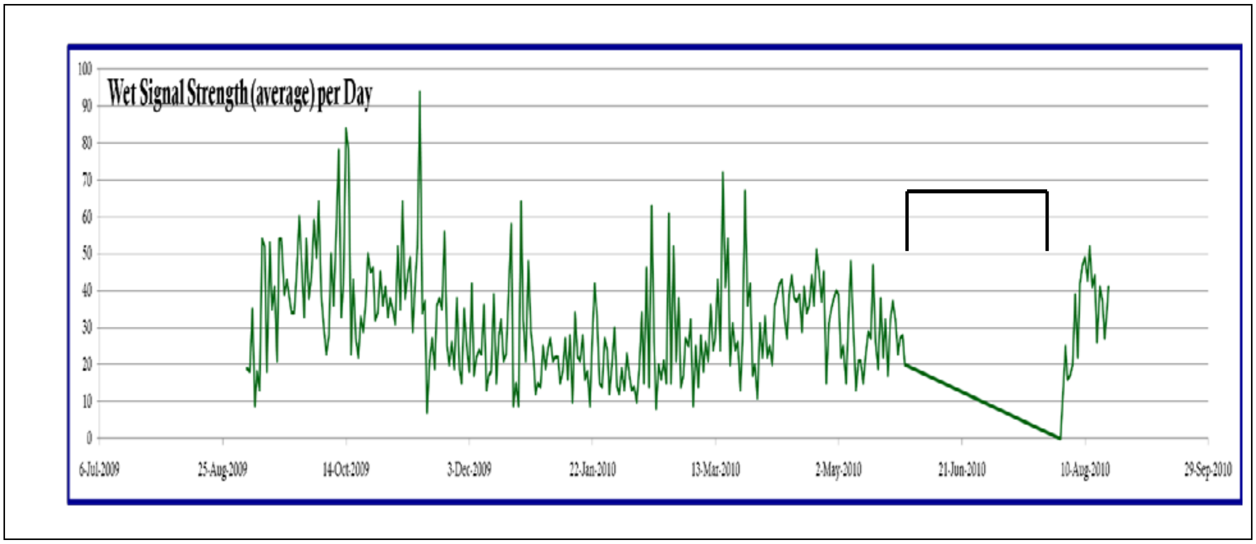

Figure 3–7. Summary of wet signal for one bird for a year. While the signal is variable, it clearly shows that the bird largely remained on land, except for the very low peaks in Nov (when it migrated south).

Migratory Flight Segments

In this section, we focus on the migratory flight segments taken by all 11 of the Red Knots tracked with light sensitive geolocators for this project. We define such segments as periods during which an individual bird moved at least 100 mi during less than 1 wk. In many cases, especially between locations on the U.S. Atlantic Coast, these flights lasted a single day. Longer flight segments, in particularly between the U.S. Atlantic Coast and South America or the Caribbean, lasted as long as 8 days. Such segments are especially important for consideration of AOCS wind turbine macroscale exposure in Red Knots because they are the times when exposure to offshore wind turbines (defined as turbines located at least 3 mi from shore) is most likely to occur in Red Knots. These segments were inferred and are represented in Table 3–4 and Figure 3–8 as the shortest possible lines between more precisely known stopping locations at either end. In some cases, we have limited evidence from the geolocators of nonlinear diversions taken during long, nonstop portions of these birds' migratory journeys, and these are also reported in Table 3–4 and Figure 3–8.

Table 3–4

Migratory flight segments of eleven Red Knots tracked during 2009–2010 with light sensitive geolocators as inferred from calculated position data.

		INITIAL CAPTURE INFORMATION		INFERRED AOCS CROSSING INFORMATION			RECAPTURE INFORMATION	
Bird Number	**Popu–lation**	**Location**	**Date**	**Departure Point**	**Arrival Point**	**Transit Dates**	**Location**	**Date**
YOU[1]	LD	Delaware Bay, NJ	May 2009	Cape Cod, MA	Lesser Antilles	30 Aug–3 Sep 2009	Delaware Bay, NJ	May 2010
YOY[2]	LD	Delaware Bay, NJ	May 2009	Cape Cod, MA	Lesser Antilles	1–9 Sep 2009	Delaware Bay, NJ	May 2010
				Brazil-Uruguay border	Ocracoke, NC	8–14 May 2010		
				Ocracoke, NC	Delaware Bay, NJ	20 May 2010	Delaware Bay, NJ	May 2010
1VL	LD	Delaware Bay, NJ	May 2009	Cape Cod, MA	80 km NW of Sao Luis, Maranhão, Brasil	8–14 Sep 2009		
				Lesser Antilles	Coastal VA	~20–22 May 2010		
				Virginia Coast	Delaware Bay, NJ	~22–24 May 2010		
7CJ	SD	Cape Cod, MA	Sep 2009	Cape Cod, MA	Brigantine, NJ	14 Nov 2009	Cape Cod, MA	Aug 2010
010	SD	Cape Cod, MA	Sep 2009	Cape Cod, MA	Outer Banks, NC	6–7 Nov 2009	Cape Cod, MA	Aug 2010
014	SD	Cape Cod, MA	Sep 2009	Cape Cod, MA	Cuba	16–18 Nov 2009	Cape Cod, MA	Aug 2010
				Cuba	Coastal SC	28–29 Mar 2010		
				Outer Banks, NC	Delaware Bay, NJ	5–6 May, 2010		
016	SD	Cape Cod, MA	Sep 2009	Cape Cod, MA	Outer Banks, NC	6–7 Nov 2009	Cape Cod, MA	Aug 2010
				Outer Banks, NC	Delaware Bay, NJ	15 May 2010		
032[3]	SD	Cape Cod, MA	Sep 2009	Cape Cod, MA	Cuba	29–31 Oct 2009	Cape Cod, MA	Aug 2010
038	SD	Cape Cod, MA	Sep 2009	Cape Cod, MA	Jacksonville, FL	6–8 Nov 2009	Cape Cod, MA	Aug 2010
				Jacksonville, FL	Cape Cod, MA	12–14 May, 2010		
042[4]	SD	Cape Cod, MA	Sep 2009	Cape Cod, MA	Coastal MD	11–13 Nov 2009	Cape Cod, MA	Aug 2010
				Coastal MD	Northern Colombia	21–23 Nov 2009		
058	SD	Cape Cod, MA	Sep 2009	Cape Cod, MA	Haiti	5–7 Nov 2009	Cape Cod, MA	Aug 2010
				Haiti	Coastal SC	21 Mar 2010[5]		
				Coastal SC	Cape Cod, MA	10–12 May 2010		

[1] Geolocator failed during winter, hence spring return flight track not recorded. Also, bird headed eastward before turning southward on southbound flight

[2] Southbound flight initiated in Hudson Bay, CA, but passed through Cape Cod, MA en route southward during nonstop flight

[3] Battery died 10 Apr 2010 near Cape Canaveral, FL

[4] Battery died 6 Dec 2010 in northern Colombia

[5] Some date uncertainty due possibly to shading of geolocator, presumed direct flight based on no intermediate locations

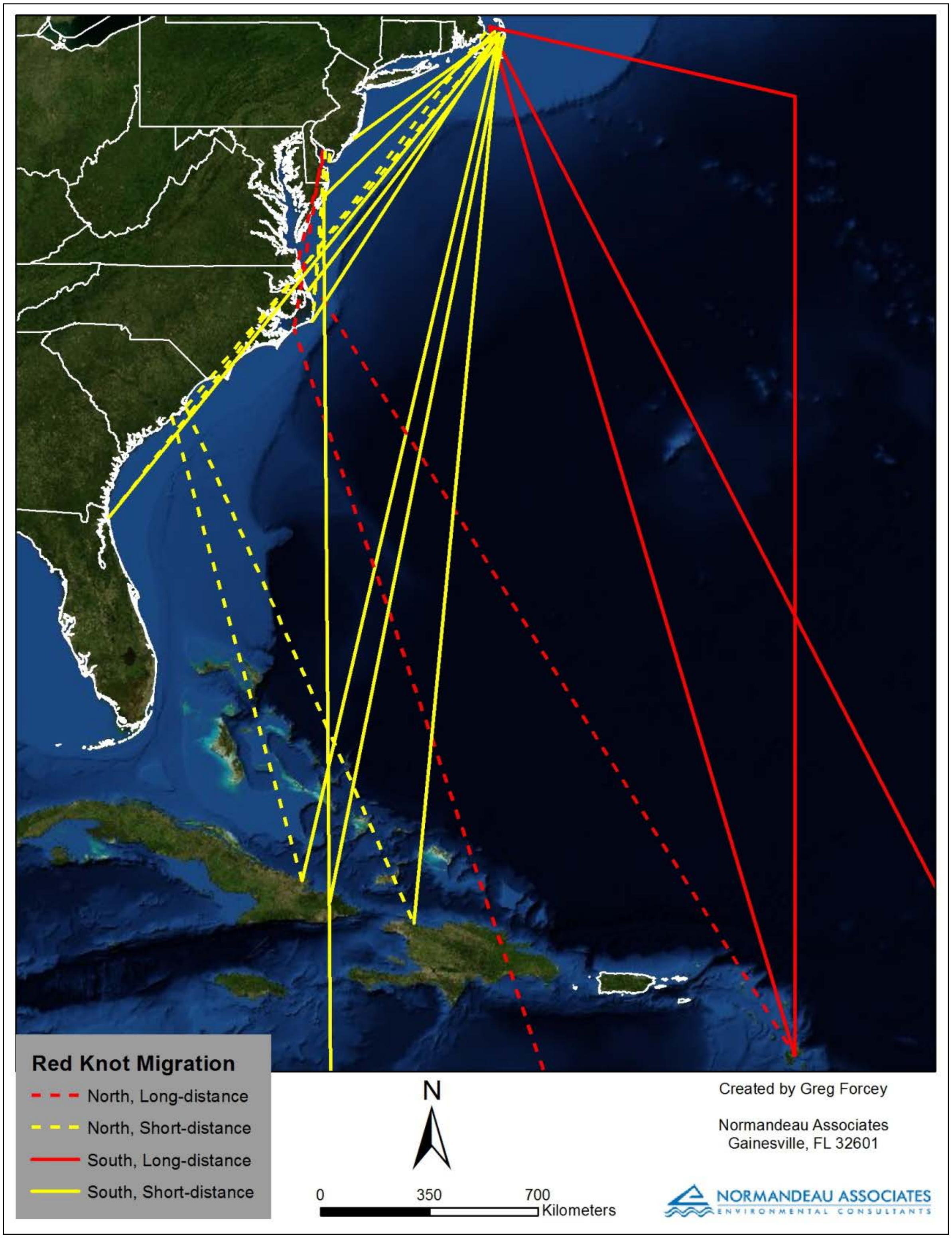

Figure 3–8. Visual representation of the migratory flight segments of eleven Red Knots tracked during 2009–2010 as inferred from light sensitive geolocator readings.

3.3.5 Discussion

Year-Round Itineraries of the Eight Birds

There are two major seasonal movements for the Red Knots captured initially at Monomoy and recaptured there 1 yr later: (1) the southward migration pattern to wintering grounds and (2) the northward migration pattern that leads to breeding grounds and back to Monomoy (the following years). The eight birds from the short-distance population of Red Knots captured in Massachusetts show a clear pattern in Canada: they all went to Port Nelson and then on up to their breeding grounds.

However, the birds showed a much less stereotyped migration and wintering pattern than we had predicted. Previous research had led us to believe that birds that migrated south through Massachusetts and New Jersey flew directly to Florida, where they overwintered. However, the birds did not simply go from the Arctic to Massachusetts and New Jersey and then to Florida to overwinter. This preliminary pattern clearly shows that there are a number of places along the coast where Red Knots from the short-distance migratory population are landing and over-wintering, including Maryland, North and South Carolina, Florida, Cuba, Haiti, and Venezuela/ Columbia. While a total of eight birds is still a small sample size, it indicates that the migratory patterns are variable and the wintering sites are variable.

The longest flight segments made by individuals in the short-distance population are also variable. Fewer of the birds made very long-distance flights (and only one bird flew more than 2000 km in one long flight [#014]). Many made shorter flights.

Macroscale Exposure of Red Knots to AOCS Wind Facilities During Migration

The primary exposure of Red Knots to wind facilities located at least 3 mi from shore is likely to be restricted to very long migratory flight segments for which AOCS-traversing paths can be confidently inferred. This conclusion derives from the evidence produced in this study and corroborated by the well-known tendency of Red Knots to feed and roost within coastal and near-shore environments during migratory stopover and wintering periods on the U.S. Atlantic Coast (Harrington 2001). Over the course of 1 yr, for the 11 individual birds we tracked with light-sensitive geolocators, we observed indirect evidence of as many as 24 AOCS-crossing flight segments (Table 3–4, including additional presumed flight segments after two batteries died, not listed on table). Some of these were shorter distance flight segments between points along the U.S. Atlantic Coast which may or may not have entailed birds' occurrence greater than 3 mi from shore (see below). While some degree of exposure can be inferred to occur, this level of exposure must be regarded as very low as AOCS-traversing flights account for a very small percentage of Red Knots' annual habitat occupancy or geographic occurrence. By contrast, the well-known cases in which birds have experienced relatively high levels of wind turbine collision risk entail individual birds being exposed to wind turbines more or less continually for long portions of the year, during which birds are exposed many times to collision risk, as each bird makes flights within rotor swept altitudes in the vicinity of wind turbines on a daily basis (e.g., Altamont Pass-Golden Eagles [Smallwood and Thelander 2008]; Smøla-White-tailed Eagles [Bevanger et al. 2009]).

In addition to the large, AOCS-traversing migratory flight segments as recorded in this study, it is also possible for Red Knots to experience additional exposure to wind turbines located 3 mi or more from shore on the U.S. Atlantic Coast during some short or intermediate segments of the migratory paths we recorded (e.g., between Cape Cod, Massachusetts, and New Jersey), for which it is impossible to determine from our data whether birds occurred greater than 3 mi from shore at any point or if they remained along or close to the coast the entire time. This limitation results primarily from the geospatial imprecision of geolocator data, which gives us a very limited ability to make inferences about potential exposure of Red Knots to coastal or near-shore wind facilities.

In comparison to wind facilities located far offshore, Red Knots are likely to experience a significantly higher degree of macroscale exposure to wind turbines located in coastal or near-shore environments because they spend significantly more time in such environments. This exposure may occur either during shorter-distance, coastal segments of migratory journeys, or during wintering and stopover periods during which Red Knots may encounter such turbines as they engage in daily movements associated with wintering or migratory stopover life phases. Regarding the latter possibility, the wet/dry patterns from our geolocator data show that, except for the long flights (which occurred over 1–3 days), the birds generally showed a wet pattern absence of 2 to 4 hrs (although it can be as high as 7 hrs). This means that they could be making short hops or flights (out over the water, over land, along the coast, or across open water from spit to spit), or they could be roosting on high dry ground. Assuming that they fly about 30–40 km/hr on short-distance flights, they could be traveling as far as 120 km or more in these dry periods, which could potentially take them far offshore within the AOCS. However, it is likely that they hug the coast or remain in near-shore regions during these movements as evidenced by personal observations of Red Knots flying distances of 44–51 km between foraging and roosting sites (e.g., Mispillion Harbor, Delaware, to Stone Harbor, New Jersey).

In interpreting our geolocator data, it is important to note that the geospatial precision of the flight segments is particularly low as latitude and longitude information is calculated from sunrise and sundown times; hence, it is done most accurately at points where individual birds remained in one place for at least an entire day. Even at such stopping points, the amount of geo-spatial imprecision ranges between 50 and 300 km depending on the latitude (higher latitudes render more precise readings) and other conditions, for example shading of the geolocators, which may diminish precision.

These conclusions are preliminary and are based on our initial analysis of the available data gleaned from eight geolocators placed on birds in Monomoy, Massachusetts. Further analysis of wet/dry episodes, weather patterns, and other refinements will improve the general migration tracks as well as the birds' behavior along the Atlantic Coast. The data by no means represent the whole population, but the observations provide many new insights into their migration and over-wintering. The data clearly demonstrate more variability in Red Knot migration and over-wintering behavior than we had assumed previously.

We note that the macroscale exposure patterns presented and discussed in this chapter are a necessary, though not sufficient, condition for Red Knots to be at risk of collision with wind turbines on the AOCS. Even during times and places where macroscale exposure is occurring, risk may be low if mesoscale (flight altitude) or microscale (behavioral avoidance/susceptibility) exposure factors are low (Burger et al. 2011). These factors remain poorly known for Red Knots, particularly in offshore environments (Burger et al. 2011).

3.3.6 Acknowledgments

This study received partial funding from Natural Land Trust of New Jersey, Rutgers University, and the Conserve Wildlife Foundation of New Jersey. We are grateful to the many people who helped us trap Red Knots each year. We especially thank Stephanie Koch and Kate Iaquinto of the Monomoy U.S. Fish and Wildlife Service Refuge, and Brian Harrington of the Manomet Center for Conservation for their help during this work.

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3.4 Geospatial Analysis of Macroscale Exposure of Roseate Tern, Red Knot, and Piping Plover to Offshore Wind Facilities on the Atlantic Outer Continental Shelf

3.4.1 Summary

In order to characterize macroscale exposure of Roseate Tern, Red Knot, and Piping Plover (collectively referred to as focal species) to offshore wind facilities on the AOCS, we conducted a comprehensive analysis of all available geospatial occurrence data for the focal species within the study region, including the portion of the Atlantic Coast of the U.S. that borders the AOCS. This analysis leveraged the pre-existing resources and structure of the AKN, a global repository of avian geospatial data created and maintained by CLO, to which we added nine project-relevant datasets through an intensive data acquisition effort that preceded the analysis. We conducted two separate analyses examining use of the AOCS by the focal species in our study: (1) a qualitative analysis of pelagic observation of the focal species examining distribution and

inferred migration routes, and (2) a quantitative analysis of coastal observations that we use to infer migratory paths of the focal species in the AOCS.

The extent of pelagic observations, defined as observations ascribed to locations ≥3 mi from the coast, was limited and did not permit quantitative analysis of pelagic spatiotemporal occurrence patterns at a region-wide scale. We performed a qualitative analysis of the existing available pelagic observations of the focal species and also reviewed additional published and unpublished technical studies in order to determine if it is possible to characterize risk or exposure of the focal species within the pelagic environment of the AOCS based on direct observations. This analysis produced anecdotal support for pelagic migratory behavior in Roseate Tern. The pelagic analysis did not provide any new insights regarding pelagic portions of the migratory paths of Red Knot or Piping Plover with the exception of anecdotal observations on islands, which suggest over-water crossings. Although available pelagic data—and pelagic avifaunal studies are extremely limited in this region—the scarcity of pelagic observations of the focal species in the AOCS suggests either that the species are extremely rare within this region, the species are not easily detected within this region using conventional methods, or both.

A more quantitative and in-depth analysis was performed on the extensive coastal data available for the focal species. While the applicability of coastal data toward the oceanic risk questions of interest in the current study is limited, it was nonetheless possible to address a limited set of project-relevant questions using coastal data, particularly relating to coastal vs. noncoastal migratory patterns in Red Knot and Piping Plover. These analyses were not possible for Roseate Tern, as the absence of coastal observations for this species during migration supports prior information suggesting that this species is primarily a pelagic migrant.

For the two focal shorebird species, we conducted region-wide, whole-population geospatial analyses and determined that while both species occur along the coast during migration seasons and exhibit at least some degree of coast-following pattern along their migratory routes, both also exhibit a significant tendency toward noncoastal portions of their migration. During such portions, these birds may fly over regions of the AOCS that are greater than 3 mi from shore, and they may also fly over inland areas far from the coast. Macroscale exposure of these birds to wind facilities is therefore broadly but thinly spread over terrestrial and offshore portions of the entire region, though it is concentrated in coastal regions where these birds spend the vast majority of their time.

Evidence for noncoastal portions of the migratory route of Red Knot comes primarily from the discontinuous and seasonally distinct coastal concentrations of Red Knot along the Atlantic Coast. This pattern suggests that the majority of individuals cross the AOCS somewhere south of the Delaware Bay region en route to arriving in Delaware Bay in spring, then fly over land between the U.S. Atlantic Coast and their breeding grounds in the central Canadian Arctic, and then cross the AOCS again during fall migration. Fall AOCS crossings are likely to be concentrated to the south of Cape Cod, Massachusetts, where the fall Atlantic Coast concentrations of Red Knot are highest. This conclusion is based on the observation of spatially discontinuous concentrations of Red Knot in different regions of the U.S. Atlantic Coast in spring (Delaware Bay) than in fall (Massachusetts). This pattern suggests that the bulk of the population of Red Knot may, indeed, be experiencing macroscale exposure to wind turbines on the AOCS, and that the geographic portion of the AOCS in which Red Knot are exposed may be different in spring (south of Delaware Bay) than in fall (south of Massachusetts) migration.

The primary evidence in support of noncoastal migration in the Atlantic Coast breeding population of Piping Plover is (1) the lack of increased maximum or mean flock sizes of Piping Plover in the Atlantic coastal portion of New Jersey during any time in spring or fall, as compared with their Jun (breeding only) distribution, and (2) the lack of increased observation frequencies of Piping Plover in Atlantic coastal New Jersey during any time in spring or fall, as compared with their Jun (breeding only) distribution. The former would be expected if birds were migrating coastally in concentrated flocks, and the latter would be expected if birds were migrating coastally as single birds or in smaller flocks. What these observations suggest is that rather than migrating coastally, the majority of the Atlantic Coast Piping Plover population is generally making nonstop, long-distance flights between their wintering and breeding grounds, which may or may not follow the contours of the coast. This pattern is well known to be the case for the inland-breeding populations of this species, but has not previously been suggested for the Atlantic Coast breeding population of Piping Plover. Several anecdotal observations of Piping Plover occurring at intermediate migratory stopover locations do exist both for inland and for Atlantic Coast populations, but these observations do not contradict the conclusion that nonstop, long-distance migratory flights may be the rule in all Piping Plover populations.

One implication of this pattern is that similar to Red Knot, some degree of macroscale exposure to wind turbines in pelagic, or offshore portions of the AOCS, as well as over inland areas, is likely to occur during migration, even if exposure is concentrated to some degree along the coast because of this species’ strong coastal affinity during wintering and breeding seasons. This conclusion is further corroborated by the observation that a significant portion of the Piping Plover population (as much as 10%, possibly more) winters in the Bahamas. This indicates that this species regularly makes large over-water migratory flights, entailing some macroscale exposure to wind turbines on the AOCS. The extent and pattern of exposure on the AOCS is not known and warrants further investigation with individual tracking devices. Further compounding the problem is the limited extent of banding and resighting studies to determine the specific wintering locations used by the Atlantic coastal breeding population of Piping Plover (USFWS 2009a). Based on existing evidence, the most plausible migratory path scenario for the Piping Plover that breed along the U.S. portions of the Atlantic Coast, based on the shortest distances between wintering areas and breeding areas, is that long-distance, nonstop migratory flights do occur both over coastal and offshore portions of the U.S. Atlantic Coast region, with some possibility of inland passage as well for Atlantic Coast breeders that may winter along the Gulf of Mexico Coast of Florida, and possibly other Gulf Coast states.

With regard to the risk assessment objectives of this project and the research priorities identified by the project team during the problem formulation stage, the geospatial analysis pertains only to the assessment of macroscale exposure (Burger et al. 2011), meaning that it only relates to broad patterns of geospatial distribution and abundance of the focal species within the AOCS region of interest. Macroscale exposure is a necessary condition in order for there to be any actual risk, (i.e., the species must occur there). However, even if macroscale exposure does occur, it does not automatically imply that the species is exposed to risk from wind facility development. In order to determine whether or not the species is at risk, mesoscale (flight altitude) and microscale (behavioral avoidance/susceptibility) exposure factors must also be assessed. As yet, these exposure factors are very poorly understood for all three focal species (Burger et al. 2011).

3.4.2 Project Background

Relationship to Project Objectives and Structure

The geospatial analysis (GA) was designed to address project objective 1: "to evaluate the potential for the three endangered, threatened, and candidate species of interest to be impacted by wind facilities located on the Outer Continental Shelf (OCS)." This was done by characterizing, to the extent possible using existing geospatial data, the tendency of the three focal species to occur over federally regulated waters within the AOCS during any part of their annual cycles. The GA was conducted as part of Task 3, "Collect and Evaluate Existing Data" of the original, nonpilot study component of the project, as defined in contract M08PC20060, CLIN 0001.

Relationship to Research Priorities Delineated During the Problem Formulation

The GA was designed to address key questions identified in the problem formulation with the caveat that it was possible to address the questions within the limitations of the available data in the AKN (Figure 3–9).

The final design of the GA consisted of two separate components:

1. *Pelagic analysis*: This consisted of a qualitative synthesis of existing pelagic data, defined as the region of the AOCS ≥3 mi from the coast, and literature on the spatiotemporal patterns of occurrence of the three focal species in the AOCS region.

2. *Coastal analysis*: This consisted of an analysis of the coastal bird sightings of Red Knot and Piping Plover along the Atlantic Coast bordering the AOCS study region using available land-based geospatial data on bird observations. Based on the timing, location, and abundance of birds along the coast, we inferred potential migratory pathways of birds during the spring and fall.

The first (pelagic) component of the GA was smaller and more qualitative than was the second (coastal) because of the very limited extent of geospatial information that exists on the occurrence of the three focal species within the marine environment of the AOCS. In contrast, there is a wealth of coastal geospatial data within this region that permitted a more in-depth and quantitative analysis, though the relevance of these data to the study objectives was limited to studying the migratory pathways of only two of the three focal species (Red Knot and Piping Plover) and to indirect inferences about the occurrence of these species within the pelagic region of interest, based on coastal occurrence records.

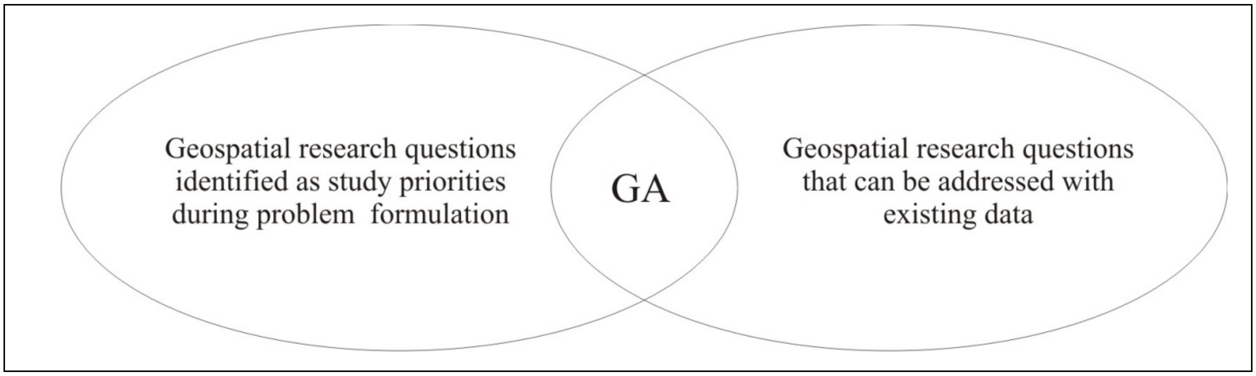

Figure 3–9. Conceptual diagram of Geospatial Analysis (GA) study design, as it relates to the research priorities for addressing the objectives of the study, and the limitations of existing available geospatial datasets.

The second (coastal) component of the GA focused on examining patterns of migratory abundance of the focal species along the Atlantic Coast bordering the AOCS region of interest in order to make indirect inferences about where the focal species' migratory routes may be pelagic within the AOCS region. This included testing the "shortcut hypothesis," which was identified during the problem formulation as a high priority research question for populations of the focal species that generally migrate along the coast. This latter qualification restricted the scope of this portion of the analysis to two of the focal species: Red Knot and Piping Plover. The shortcut hypothesis is not applicable to Roseate Tern because this species migrates pelagically. The pelagic migration tendency of Roseate Tern was confirmed by the GA based on the extreme scarcity of coastal records of this species, other than in areas where they are known to breed or to stage prior to fall migration.

It is important to note that the entire GA is relevant only for describing the focal species' broad, geospatial patterns of occurrence within the study region, or "macroscale exposure" to offshore wind development (Burger et al. 2011). Macroscale exposure is a necessary condition for there to be any risk to these species, but it does not necessarily imply actual risk. Phrased differently, if the species does not occur within the study region, it is not possible for it to be exposed to risk, whereas if the species does occur within the region, exposure to risk is possible, but not guaranteed. Whether or not macroscale exposure translates into actual risk depends on "meso-scale" exposure factors (flight within rotor swept altitudes) and "microscale" exposure factors (e.g., behavioral avoidance of turbines) (Burger et al. 2011).

3.4.3 Data Collection

The data analyzed in the GA consisted of all available geospatial data for the three focal species within the AOCS and adjacent coastal regions. These data were gathered and prepared for analysis through collaboration between Normandeau Associates (formerly Pandion Systems, Inc.) and the CLO's AKN. This collaboration was administratively and financially supported by the project as part of Task 3, CLIN 0001.

Data gathering entailed individual outreach and requests to all known agencies, researchers, and other owners of project-relevant datasets. It was undertaken from Oct 2008 through Jun 2009 and resulted in the addition of nine project-relevant datasets for the AKN (Table 3–5). Furthermore, the project supported quality assurance and control (QA/QC) processing of a 10th project-relevant dataset: the International Shorebird Survey (ISS) also included in Table 3–5. Data acquired from these efforts were used in conjunction with data that were already present in the AKN (eBird and ISS data, Table 3–5). All of these data were transferred to Normandeau Associates (formerly Pandion Systems) and imported into GIS for analysis during Nov and Dec 2009 (Table 3–5). Although much of the data in the AKN is publically available, access to several of the datasets used in this study is restricted. To use these data for this study, we sought and acquired permission from each dataset owner.

The AKN represents the best available source for existing geospatial data on the focal species in the AOCS region because it is spatiotemporally comprehensive and allows for study of the entire population of a species. This is in contrast to site-specific field studies that can only sample a small subset of the population.

In addition to the comprehensive nature of the AKN dataset, the metadata present is equally comprehensive. Metadata in the AKN includes information on the validity of observations (as determined by data review), whether the observation was part of a complete checklist (all species were recorded during a survey), and the level of effort expended for a survey. These metadata allow researchers to perform QA/QC on data before using it for a study. The extensive metadata available in the AKN allow researchers to refine the datasets for their own specific analysis and purpose. Normandeau Associates performed its own additional QA/QC process as defined below in the shortcut hypothesis testing section.

The comprehensive nature of the AKN and the ability to quantify sampling effort with AKN metadata allowed us to distinguish between biological gaps and sampling gaps in the spatio-temporal occurrence of the focal species along the Atlantic Coast. A biological gap is where sampling was performed but no birds were detected. A sampling gap is where birds were not detected because no surveys were conducted. This distinction is important because biological gaps indicate true negative data, which is a key prediction of the shortcut hypothesis (i.e., that true biological gaps in species' occurrence along the coast during migration are indicative of shortcuts taken over water).

Table 3–5

Available project-relevant datasets used in the project's geospatial analysis.*

Dataset	Description	Institution where dataset is maintained	Applicability to geospatial analysis
eBird	Birder sightings from around the hemisphere throughout the year. Each record includes a count, effort information, and information on whether all species are being reported. Data are vetted through the eBird Quality Control process.	Cornell Laboratory of Ornithology, National Audubon	Very good to excellent; hundreds or thousands of records of each
International Shorebird Survey	Periodic counts of shorebirds (Plover, sandpipers and allies), principally during northward and southward migration periods.	Manomet Center for Conservation Sciences	Very good to excellent; hundreds or thousands of records of both Piping Plover and Red Knot
Maryland sightings—REKN, PIPL, ROST (Bob Ringler's database); Collector/name within eBird is "MD Historical Data"	Complete historical record of published sightings from Maryland, including all known records of interest of target species	Private Database	Very good; majority of notable sightings for three target species from the state
Massachusetts sightings—REKN, PIPL, ROST (Bird Observer database); Collector/name within eBird is "Bird Observer Data"	Historical record of reported sightings from Massachusetts; coverage good for recent decades for all three species	Bird Observer	Very good; majority of notable sightings for three target species from the state
New Hampshire sightings—REKN, PIPL, ROST (New Hampshire Bird Records database)	Historical record of reported sightings from New Hampshire; coverage good for recent decades for all three species	New Hampshire Audubon/NH Bird Records	Very good; majority of notable sightings for three target species from the state
Programme Integre des Recherches sur les Oiseaux Pelagiques (PIROP)	At-sea transect surveys of seabirds. ECSAS is the more recent program; PIROP the older initiative.	Canadian Wildlife Service	Poor; mostly provides negative data (i.e., surveys of offshore waters that did not record the target species)
Manomet Offshore (Manomet Center for Conservation Science)	At-sea transect surveys of seabirds. CSAP is the more recent program; Manomet Offshore the older initiative.	Manomet Center for Conservation Science	Poor; mostly provides negative data (i.e., surveys of offshore waters that did not record the target species)

Table 3–5. Available project-relevant datasets used in the project's geospatial analysis (continued).

Dataset	Description	Institution where dataset is maintained	Applicability to geospatial analysis
Cetacean and Seabird Assessment Program (CSAP)	At-sea transect surveys of seabirds. CSAP is the more recent program; Manomet Offshore the older initiative.	Manomet Center for Conservation Science	Poor; mostly provides negative data (i.e., surveys of offshore waters that did not record the target species)
Avian Exposure to MMA Wind Turbine	Bird surveys along the southern end of the Cape Cod Canal. Birds were surveyed flying in the vicinity of a wind turbine on the MMA campus, and included a number of sightings of Common and Roseate Terns.	Massachusetts Maritime Academy	Fair; Roseate Tern recorded here with some regularity
Eastern Canadian Seabirds at Sea (ECSAS)	At-sea boat transect surveys of seabirds. ECSAS is the more recent program; PIROP the older initiative.	Canadian Wildlife Service	Poor; mostly provides negative data (i.e., surveys of offshore waters that did not record the target species)
Avalon Seawatch	Autumn counts of migrating seabirds and shorebirds in northern Cape May Co., NJ. Survey period runs 22 Sep to 22 Dec	New Jersey Audubon/Cape May Bird Observatory	Poor; a couple records of Piping Plover and ~8 of Red Knot; mostly negative data indicating that these species are not best detected from coastal seawatches starting 22 Sep

* eBird and International Shorebird Survey (ISS) data were already present within the AKN before the study began; other datasets were added as a result of the dataset acquisition effort undertaken as part of this project.

3.4.4 Pelagic Data Synthesis

<u>AKN Data Analysis</u>

Overview of Pelagic Data Extent and Limitations

Within pelagic waters (≥3 mi from shore) from Delaware to Massachusetts, there were 22,511 survey bouts from the AKN (Figure 3–10). This region was selected because it contains the majority of the pelagic and coastal observations in the AKN. Of those bouts, a total of 135 bouts recorded one or more of the three focal species. Within these bouts, 3,051 Roseate Terns, 425 Red Knot, and 38 Piping Plover were recorded (Figure 3–11). Our focal species were detected on 0.6% of pelagic surveys (observation bouts). Although the spatial extent of the pelagic observations in the AKN appears comprehensive when all years and months are summed (Figure 3–10), the spatiotemporal comprehensiveness is severely limited in several ways, constraining our ability to perform an extensive, detailed, quantitative analyses of geospatial patterns of the occurrence of the focal species in the marine environment.

First, the spatiotemporal distribution of sampling is highly clumped. Pelagic sampling effort is highly concentrated during spring and summer months. This is not too severe of a limitation for the purposes of this project, as the focal species are not expected to occur within the region during the winter, but it must be noted that the fall migratory period is underrepresented based on this temporal bias in the pelagic sampling effort. The pelagic sampling effort is similarly clumped in space. Although the spatial comprehensiveness appears fairly extensive when all years and months of observations are lumped (Figure 3–10), it must be noted that certain areas were sampled much more than others based on the different purposes of the different surveys (e.g., pelagic bird surveys seeking high diversity areas). Furthermore, the spatial comprehensiveness is eroded significantly when the data are subdivided by month; hence, these observations can result in positive observations of the focal species, but it is difficult to infer the absence of any of the focal species from most parts of the AOCS during most times of the year with any degree of certainty. The observations of the focal species were spatially limited to a very small number of sampling locations. While there were thousands of focal species birds recorded in the pelagic area, all of these observations were recorded from approximately 35 locations (Figure 3–11). Based on the limitations of the sampling just described, it is impossible to conclude that these birds were actually restricted to these locations within the AOCS.

Second, these counts must be regarded as having a high degree of spatial imprecision. Of the 135 pelagic counts in which one or more of the focal species were detected, 51 were long traveling counts or comprehensive boat transect surveys covering miles of ocean. These large traveling counts are represented by single points in the AKN dataset (e.g., all points shown in Figure 3–10 and Figure 3–11); thus, the spatial precision of these counts is low. This same imprecision applies to most of the pelagic observations in which the focal species were not observed.

Third, the quality of the pelagic AKN data on the focal species within the AOCS is also constrained by the inherent limitations of boat-based surveys. Boat surveys can only sample a limited transect area when traveling in the ocean. Typically boat surveys do not record birds more than 200 m on either side of the boat; it is visually difficult to detect birds beyond this range given boat movements and visibility limitations from the wake (Gould and Forsell 1989). Visual observations from boats, even by expert observers, are known to be an unreliable data gathering technique for Roseate Tern because visual discrimination of this species from other congeners (e.g., Arctic Tern, Common Tern) is extremely difficult. For example, boat-based surveys for risk assessment data gathering in Nantucket Sound, Massachusetts, for the Cape Wind Project resulted in a minority of terns being identified to the species level by both aerial and boat-based surveys (USFWS 2008b). Bias in boat-based avian survey data may also be introduced by the fact that some species of birds may be scared away by the presence of the boat, while others may be attracted. Some of the data were gathered on pelagic birdwatching tours, during which many tour operators provide food as bait to attract pelagic birds to the boat. Many pelagic bird species may be attracted from large distances on the open ocean. Observer visibility limitations also apply to birds flying at high altitudes as often occurs with migrating birds. Additionally boat surveys are almost exclusively conducted during the day and would therefore miss nocturnal migrants.

Red Knot

The pelagic records of Red Knot in the AKN are not extensive enough to make comprehensive statements about the distribution of potential exposure of this species to offshore wind turbines on the AOCS. There are 38 pelagic data points where Red Knot were observed (Figure 3–11). Some of them are listed from islands or coastal locations, so it is unclear whether or not they represent truly pelagic observations or, if so, how far from shore they truly took place. Nonetheless, they do contain at least a hint of support for the general pattern described in the coastal migration pattern analysis based on the coastal data. Twenty-five of the pelagic records of Red Knot come from the White and Seavey islands off the coast of New Hampshire. Of these, 18 occurred during fall migration and seven occurred during spring migration. The remaining 13 pelagic records of Red Knot come from off the coasts of Delaware Bay and southward to North Carolina. Ten of these were from spring migration. This spring-fall pattern supports the general pattern of Red Knot flying northward across the AOCS toward Delaware Bay in springtime and then crossing the AOCS farther north and east in fall, departing from Massachusetts. However, it is unclear whether this pattern may have resulted from sampling bias, as sampling effort within the database is not sufficiently comprehensive. In addition to these observations, there are three observations that recorded a total of 135,589 Red Knot from the ISS dataset listed as aerial surveys, and ascribed to offshore points over Delaware Bay, during spring of 1982. Little additional metadata are attached to these observations, but some of the locations are listed as coastal localities along the New Jersey side of Delaware Bay, so it is unclear whether or not these birds were truly observed offshore or, if so, how far from the coastline. These observations do support the well-known tendency of this species to form large aggregations in the Delaware Bay region during springtime (Harrington 2001).

Roseate Tern

Roseate Terns are believed to migrate pelagically in both spring and fall (Gochfield et al. 1998). This conclusion is based largely on the extreme scarcity of observations during their migration period at U.S. Atlantic coastal locations south of their known breeding areas during either migratory season (Nisbet 1984). Data from the AKN support this pelagic migratory pattern, though the comprehensiveness of sampling effort is not sufficient to permit a general statement about precisely when and where Roseate Terns generally travel through the AOCS during migration. There were 86 pelagic observations containing Roseate Terns in the AKN dataset, 13 of which are known to be truly pelagic, as noted in metadata. The offshore observations of Roseate Tern were distributed more or less evenly between the calendar dates of 26 Apr and 16 Sep and were widely dispersed throughout the region with many coming from islands or coastal areas near their breeding colonies.

Piping Plover

The AKN dataset contained 11 observations ascribed to offshore locations that contained Piping Plover (Figure 3–11). All of these occurred between Apr and Aug. Ten of them occurred between Massachusetts and New Hampshire, and a single observation was recorded off of Cape May, New Jersey. It is unclear whether any of these observations are truly pelagic, as many of them are ascribed to islands or coastal locations, and metadata are not sufficient to determine whether birds were truly recorded offshore and, if so, how far from shore. It is not possible to make a conclusive statement regarding potential exposure of Piping Plover to offshore wind turbines on the AOCS from existing available geospatial data in this region.

Conclusion

Pelagic geospatial data for Red Knot, Roseate Tern, and Piping Plover are very limited within the areas of the AOCS. Pelagic data on these three species provide mostly positive observations about where birds have been seen. While sampling effort data and the absence of birds in those areas provide some support of negative data, observing small shorebirds (or distinguishing among tern species) in flight over open water is difficult to do from a distance on a boat or plane. Furthermore, the general absence of nocturnal pelagic observations severely constrains our ability to infer the absence of the focal species within the region, and the two shorebirds are likely to occur within the region as nocturnal migrants. Nocturnal data gathering must be conducted, as well as further data gathering with conventional methods, in order to increase our understanding of the pelagic portions of the migration routes of Red Knot, Roseate Terns, and Piping Plover.

Review of Additional Information on Pelagic Occurrence of the Focal Species

The relative scarcity of the focal species within the AOCS is further supported by the recent offshore baseline ecological study conducted by the New Jersey Department of Environmental Protection, consisting of an extensive, 2-yr study of diurnal bird distribution and abundance in a 4,665 km^2 portion of the AOCS off the coast of New Jersey. This study did not result in a single detection of an individual of any of the three focal species (NJDEP 2010). There is not a single mention of any of the focal species in the entire final report for this study. Although this may be suggestive of the scarcity of the focal species in this portion of the AOCS, it is important to note that the ability to detect the three focal species is constrained by important methodological limitations employed by the NJDEP study. The spatially extensive sampling in this study was restricted to diurnal boat-based and, to a lesser extent, conventional aerial surveys. Such surveys would not detect nocturnal migrants, including most shorebirds (Harrington 2001) and probably Red Knot (Harrington 2001) and Piping Plover (Elliot-Smith and Haig 2004). It is unknown whether Roseate Terns migrate during daylight hours, nocturnally, or both (Gochfield et al. 1998). Nocturnal samples were gathered only at a single point and only by radar and thermo-graphic sensors. Such sensors cannot render species-specific information on birds. For these reasons, the NJDEP study is generally uninformative with respect to the focal species' exposure to wind facility development in the New Jersey portion of the AOCS.

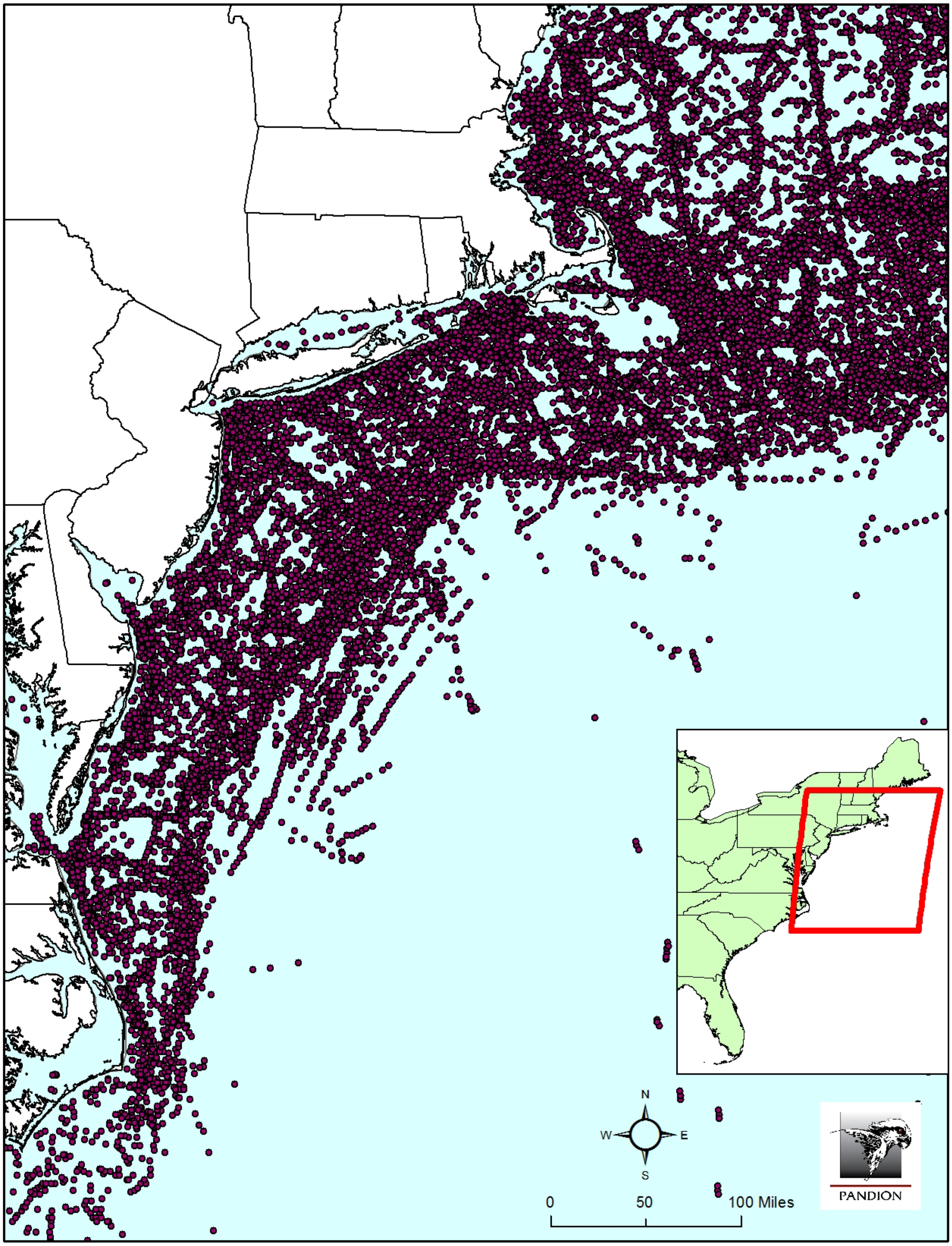

Figure 3–10. Distribution of all sampling points from the AKN in the pelagic areas in the AOCS.

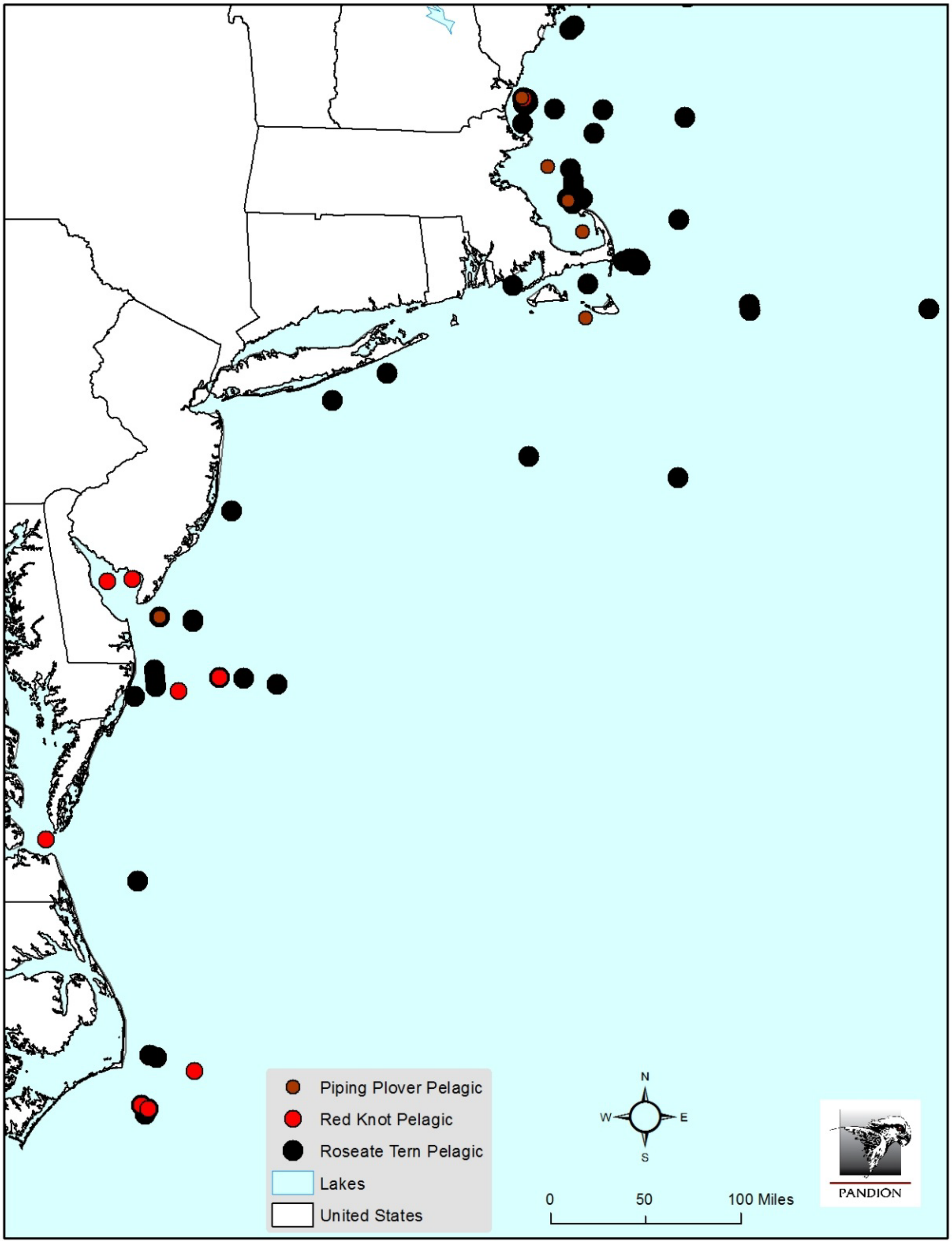

Figure 3–11. Distribution of pelagic observations of Roseate Tern, Piping Plover, and Red Knot in the AOCS from the AKN analysis.

Other pelagic data on Roseate Tern use of the AOCS includes a few banding and geolocator studies. Ian Nisbet placed light-sensitive geolocators on 10 Roseate Terns on Bird Island in Buzzards Bay, Massachusetts, in Jun 2007 (USFWS 2008a). Of the three birds that returned the following spring with geolocators, one geolocator failed completely, a second had failed earlier in the year in Mar, and a third contained complete year-round data. Geolocators provide limited data on latitudinal distribution of birds while at the equator, so most of the information available is on the birds' longitudinal distribution or their latitude within higher latitude areas. The two tracked Roseate Terns flew over the Atlantic Ocean in late summer, departing Cape Cod on 28 and 31 Aug, and arriving in Puerto Rico 2 to 3 days later, implying a relatively direct and speedy flight. The birds were subsequently tracked during the late fall, winter, and early spring at various coastal locations in Guyana and Brazil. Spring migration appeared to be a bit more gradual for the single tracked bird, which left South America on 30 Apr, spent 6 days traveling to the Dominican Republic, and then spent most of May moving in an irregular, stop-and-start pattern between the Dominican Republic and pelagic areas to the north and west (AOCS around Bermuda-Cape Hatteras, North Carolina), before arriving at the Bird Island Roseate Tern breeding colony again on 10 Jun, which is significantly later than the arrival time of most breeding individuals in this colony (USFWS 2008a).

In addition to recent geolocator studies, other incidental observations of Roseate Terns, either at South American wintering grounds or at pelagic points in between wintering areas and breeding grounds, provide further anecdotal evidence of pelagic Roseate Tern migration (Hays 1971; Nisbet 1984; Nisbet and Spendelow 1999). Of particular note are four pelagic recoveries of banded Roseate Terns from the Bird and Ram island colonies in Massachusetts. These recoveries were all during Sep and occurred between Bermuda and the Bahamas, leading Nisbet (1984) to conclude that Roseate Terns move southward fairly quickly during their pelagic fall migration, using the western portion of the Atlantic Ocean. Observations during spring migration are even fewer; hence, the timing and location of the Roseate Tern spring migratory route is even less well-known. Nisbet (1984) concluded that this migration takes place fairly rapidly in late Apr and early May on the basis of seven historical spring sight records of Roseate Terns along coastal South and North Carolina.

Like pelagic data in the AKN, existing pelagic data on our focal species from the literature was also scarce. This paucity of evidence limited our ability to make definitive conclusions on macroscale exposure of the three focal species to wind facility operations on the AOCS. Further data collection efforts are needed to shed new light on this essential risk issue.

3.4.5 Analysis of Coastal Migratory Patterns

Introduction

In order to assess the potential exposure of the focal species to risk from offshore wind facility operations on the AOCS, we tested two sets of hypotheses, as follows: (1) coastal migrants, shortcutter vs. coasthugger and (2) coastal vs. noncoastal. These hypotheses were addressed by analyzing geospatial bird occurrence data from the AKN. These hypotheses were selected because they both contain important implications for the potential exposure of the focal species to risk from offshore wind facility development in the pelagic region of interest, and yet they both can be tested using land-based datasets that comprise the only spatiotemporally comprehensive geospatial bird occurrence datasets that exist within the region. We acknowledge that only indirect inferences about potential noncoastal migration patterns are possible using onshore observations, and our conclusions should be viewed as preliminary based on this limitation.

The Shortcut vs. Coasthugger Hypotheses: Shortcutters vs. Coasthuggers

As discussed previously, the project team identified the “shortcut hypothesis” as a high priority research question for achieving the project’s objectives that could be addressed with existing available data. The shortcut hypothesis postulates that bird species or populations whose migratory routes generally follow the coast will sometimes take “shortcuts” across the water in areas where strictly following the coastline would result in a much longer and more circuitous migratory route. Among coastally migrating birds, the alternative to shortcutting is “coasthugging” behavior, in which birds strictly follow the coastline rather than flying shorter routes over open water (Figure 3–12) (Burger et al. 2011). Potential examples of where shortcuts might be taken on the U.S. Atlantic Coast include the mouths of the Chesapeake and Delaware bays, as well as island-hopping routes that incorporate migratory stopovers at Nantucket, Martha’s Vineyard, Block Island (Figure 3–13), and/or other islands that would take otherwise coast-following migratory birds over federally regulated waters. The shortcut hypothesis predicts that there should be gaps in migratory bird occurrence along the coastline, corresponding to the areas that the birds are not using during the segments when they are crossing over water. To illustrate this with an example, if coastal migrants are using the mouth of the Delaware Bay as a shortcut, they would be expected to be abundant along the coast of Maryland and Atlantic Delaware, then rare along the Delaware and New Jersey coastline in the interior of Delaware Bay, and then abundant again along the Atlantic Coast of New Jersey (Figure 3–13).

The shortcut hypothesis has important implications for the assessment of ecological risk from offshore wind development on the AOCS because it affects the probability and spatiotemporal pattern in which Red Knot and Piping Plover may be exposed to the risk of collision with offshore wind turbines within the federally regulated portion of the AOCS. If the shortcut hypothesis were confirmed for either or both species, it would suggest that there is at least potential exposure to such risk in certain parts of the AOCS at certain times of year. Examples of such potential exposure areas are illustrated with green ovals in Figure 3–13.

An alternative to the shortcut hypothesis is that coastally migrating populations of the focal species are “coasthuggers,” strictly hugging the coastlines as they move up and down the Atlantic Coast of the U.S. during their seasonal migrations. The coasthugger hypothesis predicts that there should be no gaps along the coastline in the occurrence of these birds during migration. For example, the abundance of these birds in coastal Delaware and New Jersey should be equal along the Atlantic Ocean and Delaware Bay coastlines during migration (Figure 3–12). If a coasthugging migratory pattern predominates, this would suggest that there is little or no potential exposure of these species to such risk within this region because their migratory paths do not regularly take them into pelagic environments.

The Coastal vs. Noncoastal Hypotheses: Coastal vs. Noncoastal Migrants

Both the shortcut hypothesis and its alternative, the coasthugger hypothesis, share the assumption that birds have a tendency to migrate along the coastline, whether very strictly as in the case of coasthuggers or by taking shortcuts. However, it is also possible that a significant portion of Piping Plover and/or Red Knot migration is noncoastal. Noncoastal components of migratory routes may occur over land or over pelagic environments, as illustrated in Figure 3–14. While the coastal habitat affinities of both Piping Plover and Red Knot are well-known, noncoastal migratory paths may be particularly likely to occur during long-distance, long-duration nonstop flights, as no stopover habitats are used en route. They may also be predicted to occur when the straight line distance between pre- and postmigratory destinations is much shorter than it would be if birds followed coastlines.

Noncoastal migration is known to occur in the inland populations of Piping Plover, which generally fly nonstop over land between wintering grounds along the Gulf Coast and breeding grounds in extensive sand dunes or playas in the Great Lakes and other interior portions of the continental U.S. (Haig 1986; Elliot-Smith and Haig 2004). This conclusion is based on the general scarcity of Piping Plover observations in stopover habitat along their migration routes (Elliott-Smith and Haig 2004; USFWS 2009a). By contrast, current literature suggests that the Atlantic population of Piping Plover migrates primarily along the coast during spring and fall migration (Elliot-Smith and Haig 2004; USFWS 2009a). This conclusion is logical, given that the straight line distance between some of the Piping Plover wintering areas (e.g., the Atlantic Coast of Florida) and their northeastern U.S. coastal breeding areas would entail a fairly straight trajectory, and as this species is almost always observed in coastal habitats. However, the evidence upon which this conclusion is based is purely anecdotal (e.g., Loegering 1992; Elliott-Smith and Haig 2004; Noel et al. 2007; USFWS 2009a), and there appears to be no evidence that can rule out the possibility that the Atlantic coastal breeding populations of Piping Plover might have a tendency to migrate between wintering and breeding areas in single, nonstop flights (either over land or water), as the interior-breeding populations are known to do. If such nonstop flights were, indeed, the rule for the Atlantic coastal breeding population, migratory routes may not necessarily be concentrated along the coast, but may be widely spread over terrestrial and pelagic environments along the Atlantic coastal portions of the U.S.

Red Knot are known to contain a significant noncoastal element to their migration because intercontinental ("long-distance") migratory populations are known to migrate long distances over water and over land as they travel seasonally between southern South America and the North American Arctic (Harrington 2001). However, some populations of Red Knot that occur along the U.S. Atlantic Coast are known to be short-distance migrants that overwinter in coastal areas of the southeastern U.S. While little is specifically known about the different migratory routes taken by these different populations of Red Knot, it is considered especially likely that the short-distance migratory populations migrate along the U.S. Atlantic Coast (Burger et al. 2011). Furthermore, it is also possible that the long-distance migratory populations of Red Knot engage in some coastal migratory segments within the broader itineraries of their intercontinental migratory routes. However, it is also possible that the migratory routes of these short-distance migrants also contain significant noncoastal elements. Identifying when and where these noncoastal portions of Red Knot migratory pathways occur is an essential step for determining where macro-scale exposure of Red Knot to wind turbines occurs in the AOCS region.

Figure 3–12. Theoretical flight path of a spring migrant exhibiting coasthugging behavior.

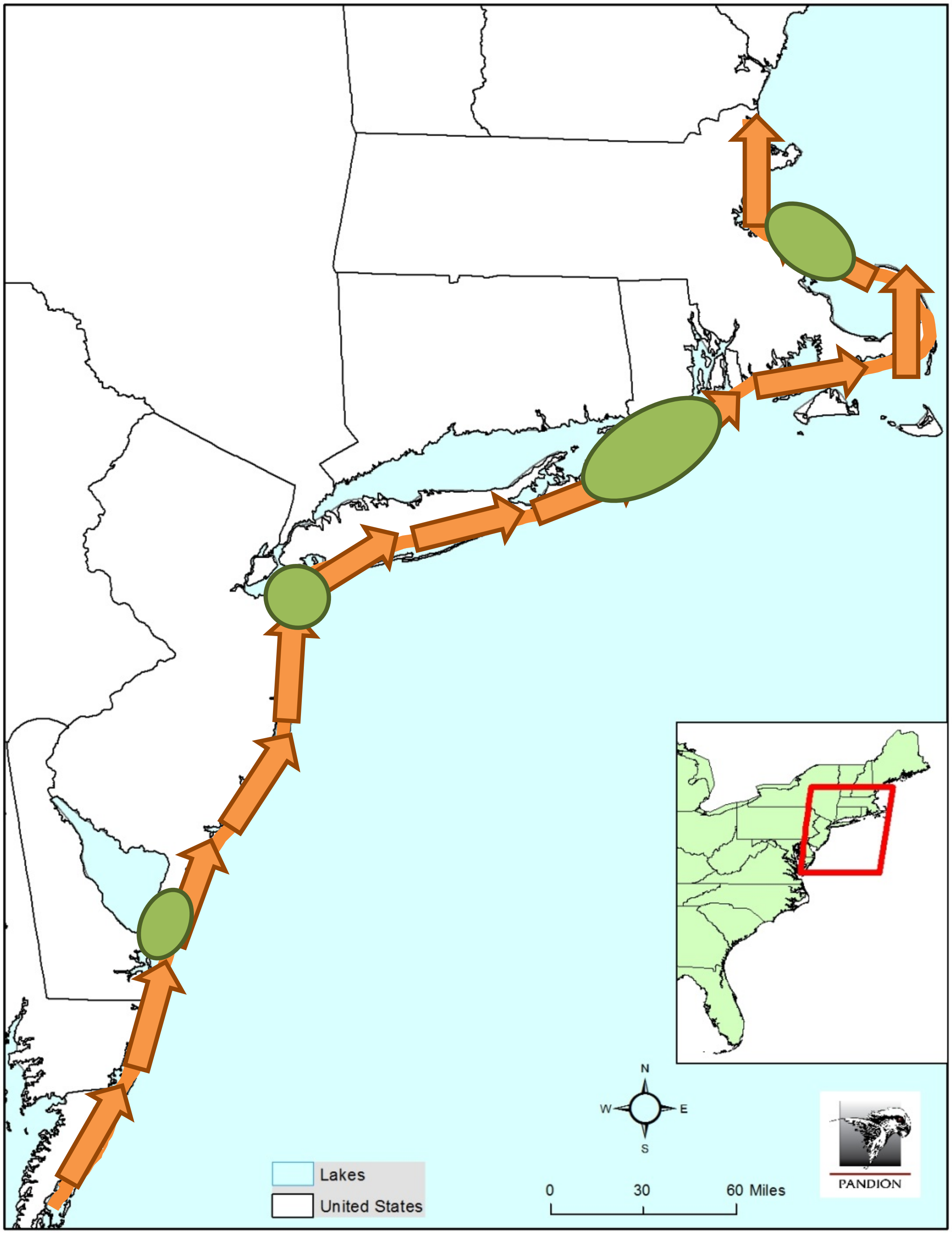

Figure 3–13. Theoretical path of a spring migrant exhibiting shortcut behavior. Shortcut behavior occurs when birds fly over bays and other areas of water instead of flying around them. The green ovals represent areas of potential exposure to offshore wind turbines.

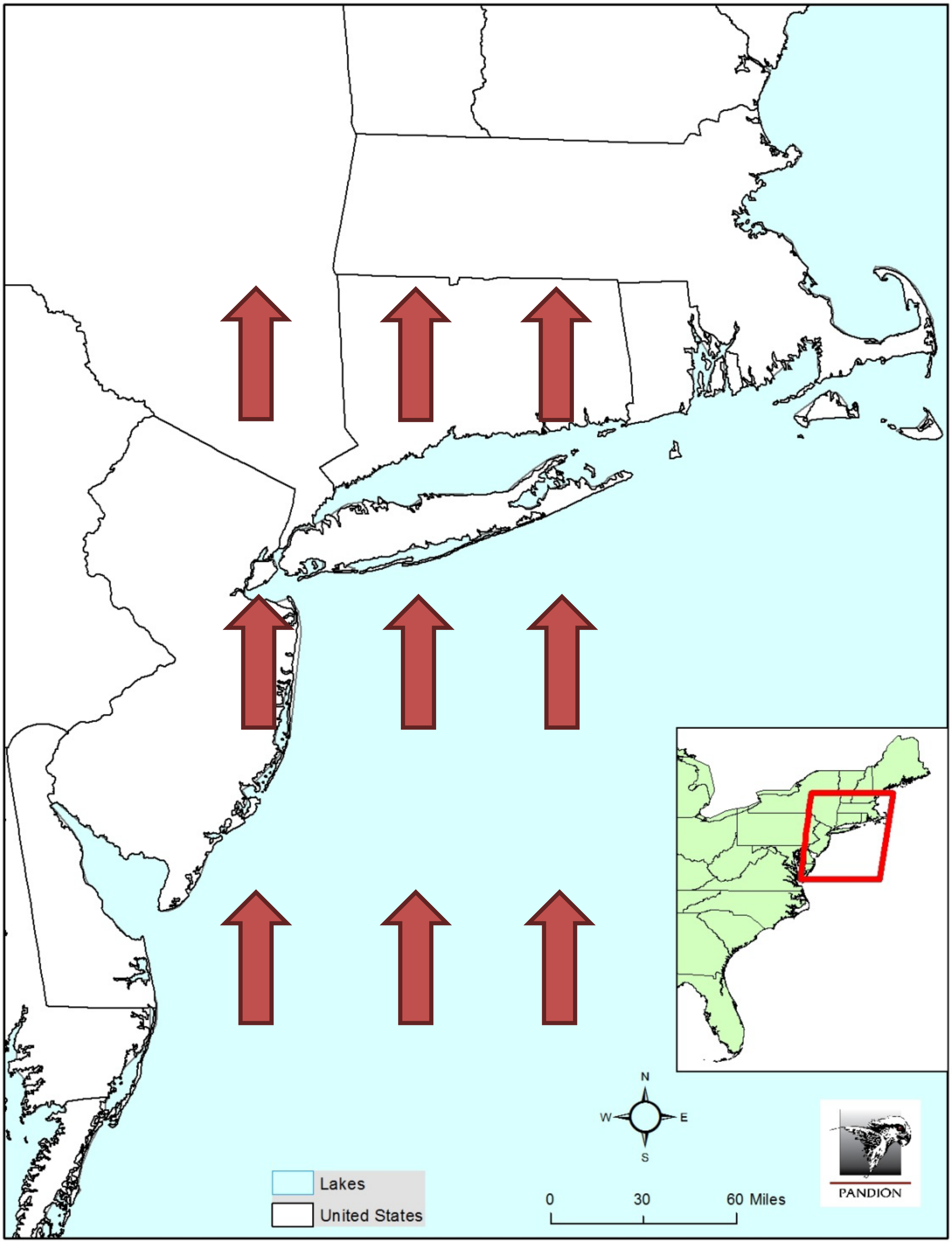

Figure 3–14. Theoretical noncoastal paths of spring migrant birds.

Because of the known noncoastal migratory pathways in long-distance migrant Red Knot and the uncertainty surrounding whether or not Atlantic Piping Plover and short-distance migrant Red Knot migrate coastally, we also examined the coastal hypothesis, which postulates that birds migrate generally along the coast, and its alternative, that the migratory routes of these birds are predominantly noncoastal.

The coastal hypothesis makes two specific predictions about the spatiotemporal pattern of migratory bird occurrence that can be tested using AKN data:

1. *Coastal concentration.* Coastally migrating birds should exhibit migratory concentrations along the coast, characterized by abundance levels that exceed those that occur during the breeding or wintering season. Such concentrations may occur in the form of small numbers of large migratory flocks or large numbers of small migratory flocks, pairs, or individuals. Furthermore, such spatial concentrations may be spread broadly across the migratory season or they may be concentrated during a short period of time. Yet whether the flocks are large or small and whether the migratory pulse is diffuse or highly concentrated in time, migratory concentrations should be observable using a dataset that is spatiotemporally comprehensive within the region. Figure 3–15 contains a graphical representation of this prediction.

2. *Spatial continuity*. Coastally migrating birds should exhibit spatially continuous patterns of migratory abundance along the coast when viewed across an entire migratory season. Small spatial gaps may occur, such as are predicted by the shortcut hypothesis, but if the migration is predominantly coastal, the entire coastal region over which they migrate should at one time receive a similar high concentration of migrant birds as they pass continuously along the coastline en route between their different seasonal destinations. Examples of such spatially continuous and discontinuous migratory concentration patterns are depicted in Figure 3–16.

Study Area

The study area for the migratory pattern analysis consisted of coastal areas bordering the AOCS between Delaware and Massachusetts. This area was chosen because it encompasses all of the coastal area within the study region that is well-sampled within the AKN. From Atlantic coastal Maryland southward along the Atlantic Coast, the density and consistency of coastal bird observations within the AKN drops off notably, limiting its value for comprehensive, population studies of migratory occurrence such as this. The region selected for study contains a large portion of the Red Knot migratory stopover region during spring and fall, as well as the majority of the breeding and migratory region of Piping Plover. This region also has multiple bays and inlets, which makes it suitable for testing both the shortcut hypothesis and the coastal hypothesis (Figure 3–17). Notable bays include Delaware Bay, Raritan Bay, Long Island Sound, Buzzards Bay, and Cape Cod Bay. Several islands also occur in the region and presence of the focal species in these locations is indicative of travel over water. These islands include Block Island, Martha’s Vineyard, and Nantucket.

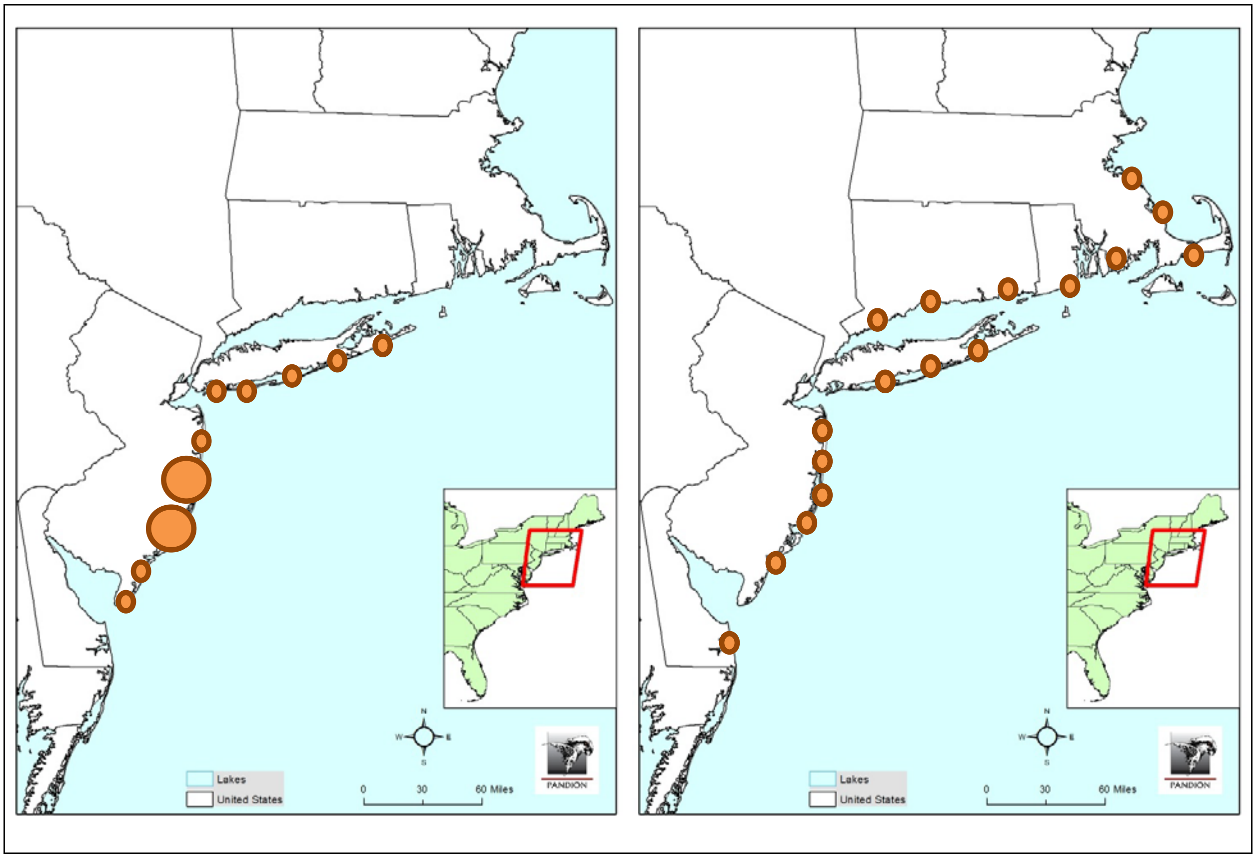

Figure 3–15. Theoretical migratory abundance patterns of coastally and noncoastally migrating birds. If a species' breeding distribution is reflected by the map at right, a coastal migrant should demonstrate a coastal concentration in excess of the locally breeding population along the coast during the migratory period as depicted in the map at left, whereas a noncoastal migrant would never show coastal concentrations in excess of those observed during the breeding season.

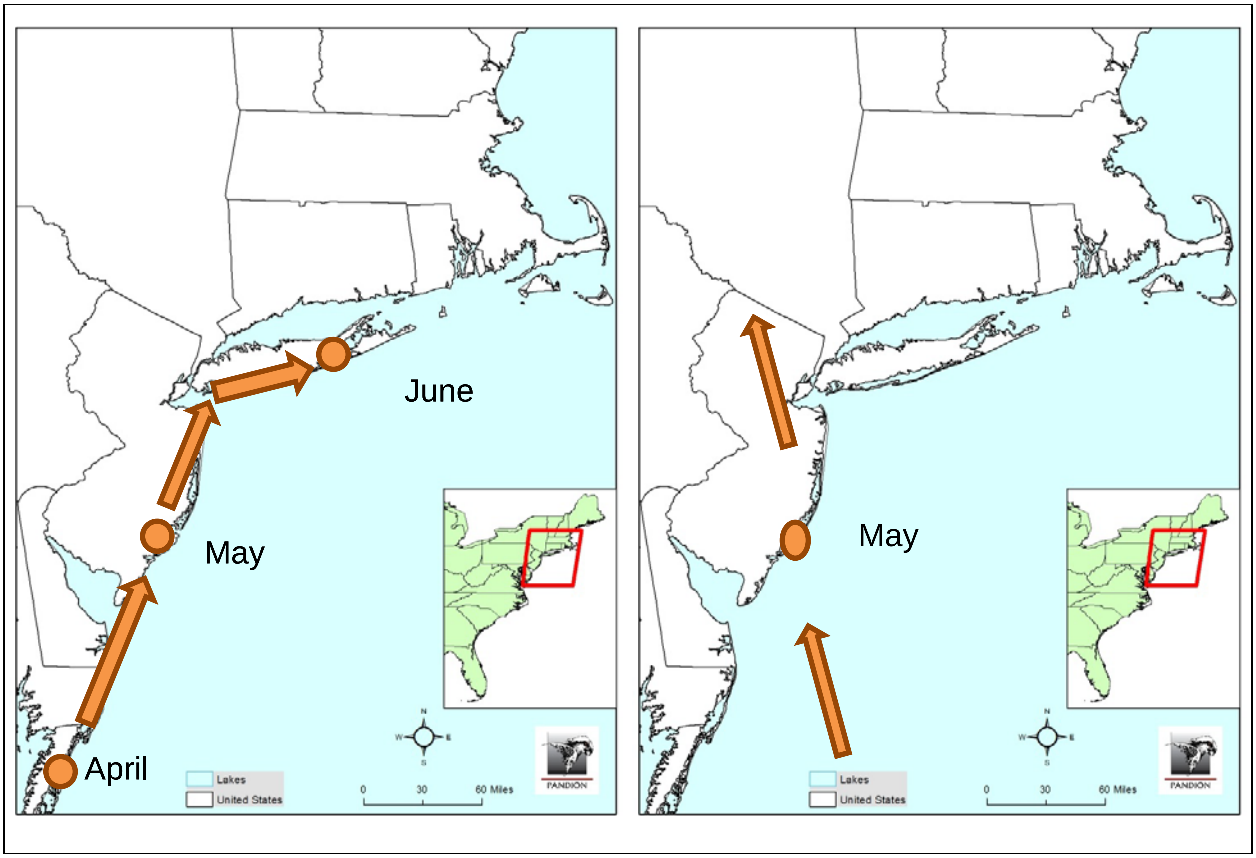

Figure 3–16. Theoretical distribution of spring coastal and noncoastal migrants. The coastal migrant (left) shows a spatially continuous pattern of coastal migratory concentration when the entire migratory season is summed, whereas the migratory concentration of the noncoastal migrant (right) is discontinuous in space. High migratory concentrations may be observed at a single stopover region along the coast, but are never observed to the north or south of that region, suggesting that they traveled over land and/or water on migration instead of along the coast.

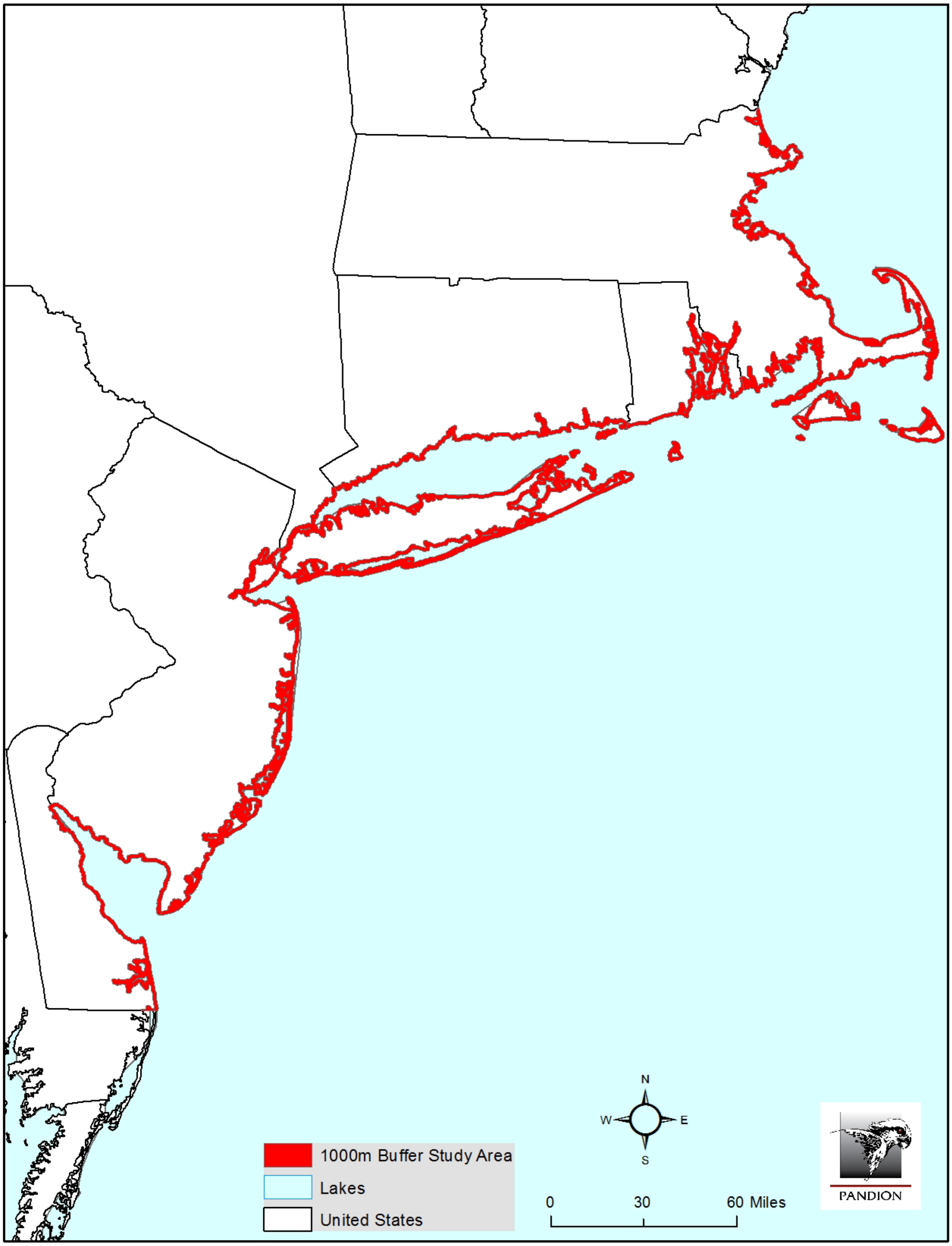

Figure 3–17. Study area for evaluating the migration patterns of Red Knot and Piping Plover.

Methods

We used coastal observations from multiple datasets in the AKN from Delaware to Massachusetts (Figure 3–17) to evaluate migratory patterns of Red Knot and Piping Plover in the AOCS. Pelagic observations were excluded from this analysis because there was not enough spatiotemporal coverage of sampling effort to comprehensively evaluate migration patterns over time and space. While these data come almost exclusively from land-based observations, the very large amount of data and the spatiotemporal comprehensiveness within the study region make the data suitable for quantitative evaluation of two sets of hypotheses regarding migratory routes that may incorporate parts of the AOCS.

Minimizing Biases within the AKN Dataset

The AKN consists of multiple datasets collected by a variety of scientists and both experienced and novice birders. Given the variation in data quality and collection methodology, it was necessary to perform a quality control process to remove observations that do not conform to standards that we defined at the beginning of the study. We performed a quality control procedure at multiple levels for the sampling event data (bouts) and bird abundance data. Within the 1-km buffer from the coast, we started with 83,407 surveys between the eBird and ISS datasets. This sample was reduced by performing specific database operations to remove data based on set criteria as described below and illustrated in Figure 3–18.

Remove Incomplete Checklists

The inference we desire to make is that the absence of observations of birds of our focal species in a given amount of sampling effort indicates that the species were truly not present. Therefore, we removed partial or incomplete observations from the dataset, notably “incomplete checklists” in the eBird dataset, as these observations would be registered as sampling effort in our analysis, but the focal species may have been left off of these observations even if it had been present. Using only complete checklists, plus observations from other data sources that are known to be comprehensive for our focal species, ensured that the only reason our focal species would not be recorded in an observation were if the observer did not observe that species at that place and time.

Remove Invalid Observations

CLO performs its own independent verification process on data submitted to the AKN. Observations are reviewed for credibility and whether the number of birds for each species fits within a defined range that is acceptable for a given time period and location. Every AKN observation is classified into one of four categories: (1) valid and reviewed, (2) valid but not reviewed, (3) not valid but reviewed, and (4) not valid and not reviewed. For our analyses, we removed observations that were not valid but reviewed and not valid and not reviewed. Observations that were classified as valid regardless of whether or not they were reviewed were included in our analyses.

Remove Long Traveling Counts and Large Exhaustive Areas Counts

Two of the count types present within the eBird database are traveling counts and exhaustive area counts. These types of counts involve collecting data over large areas. Although the surveys may cover large spatial extents, traveling counts and exhaustive area counts are still recorded as single points in the database. This problem is mitigated to a degree in the eBird database by attempting to ensure that the single point chosen for the observation is located near the center of the actual spatial extent surveyed; however, it is often unclear where certain birds were observed within the large areas covered by these types of surveys. To reduce spatial imprecision with the eBird point data, we excluded long traveling counts (>20 mi) and large exhaustive area counts (>3,000 ac).

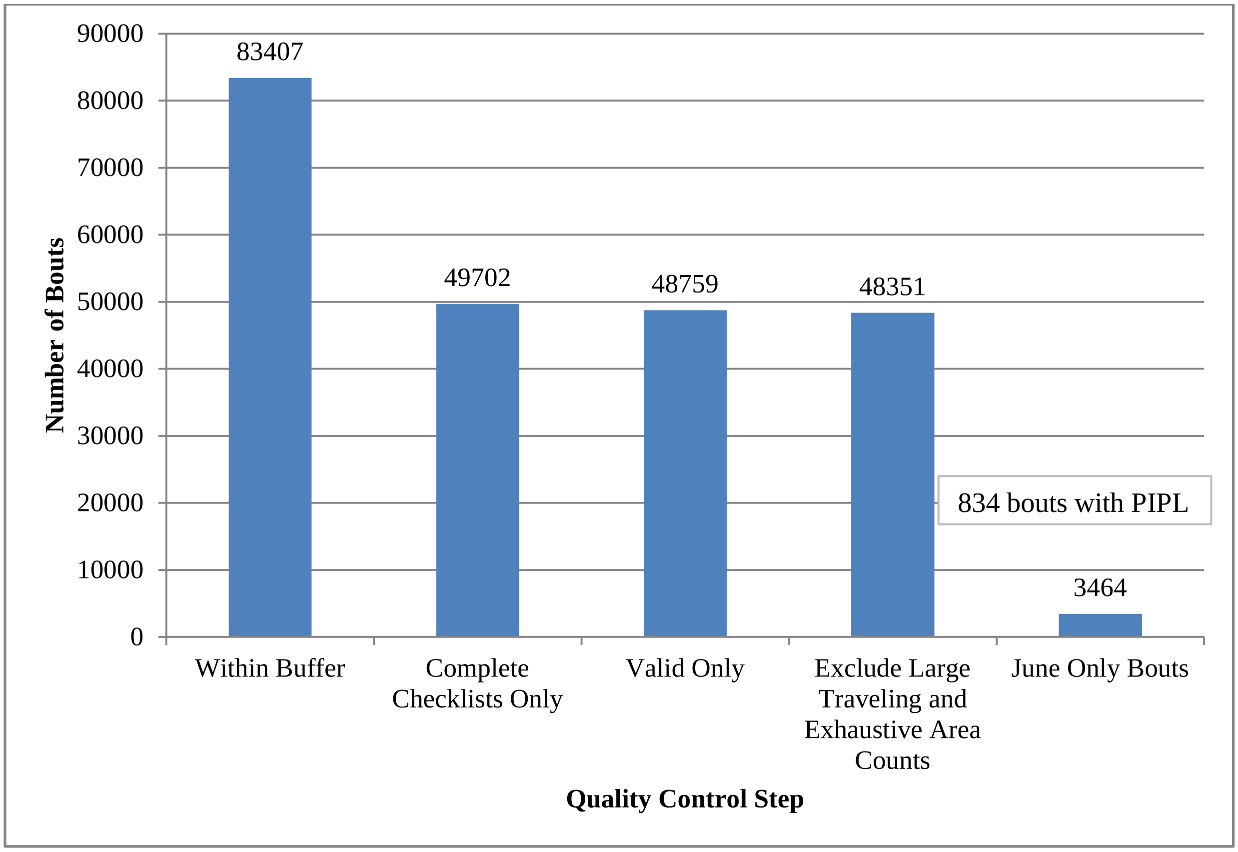

Figure 3–18. Example of AKN sample size reduction with quality control and biological refinement processes within the geographically defined study area, or "buffer," which corresponds to all areas within 1km of the coast from Massachusetts through Delaware. Numbers atop the bars indicate the total number of sampling bouts in the AKN dataset that remained after the listed filtering step was performed. The final bar on the right represents an example showing the number of bouts remaining when selecting only one month for study. The number of bouts containing Piping Plover (PIPL) in the study during that time is also shown.

Establishing Sampling Units

All data in the AKN occur as point data. We created sampling units so that the data could be more easily visualized and compared over space and time within defined areas as opposed to point locations. We created a 5-km vector grid across the coastal areas of the AOCS from Massachusetts to Delaware. The vector grid was created using xTools Pro and ArcGIS and clipped to a 1,000-m buffer in and out from the coast. Grid cells were constrained to 1,000 m from the coast because most Piping Plover and Red Knot habitat is not likely to occur outside this region (Figure 3–19). We also included the areas 1,000 m in and out from the coast to account for subtle differences between our GIS layer of coastal boundaries and the physical coastal boundary where birds were recorded. Within this sampling grid, there are 3,060 cells for which bird observations and sampling effort were quantified. Lumping observations within these grid cells in this way provides a means to translate point data into data within a defined area (sampling unit) so that it can be visualized and quantified.

Because sampling effort varies widely among regions and times, it was necessary to eliminate cells that had poor sampling effort. For all of our analyses, we only show cells that were sampled with ≥5 bouts during the time period of interest or that contain observations of at least one of the focal species. This eliminated undersampled cells from our analysis and increased our ability to discriminate between cells in which birds' absence was biologically meaningful (i.e., true negative data) and cells in which birds' absence is best explained by the scarcity or lack of sampling effort.

While most grid cells along the coast in our study region contain bird observations in our dataset, many cells have not been sampled. Sampling effort is further reduced if one separates observations into different seasons or months, as was done in this analysis. In order to render sufficient sample sizes for quantitative analysis, we combined observations temporally within migratory seasons for Red Knot and within months for Piping Plover. We also combined data across all years that data have been collected for both species. Though migratory routes may vary across seasons, we assumed they did not vary significantly across years, permitting us to increase sample sizes by lumping observations from multiple years. The sample size reductions manifest in insufficiently sampled grid cells for various time periods in various regions and are depicted in Table 3–6 and Figure 3–20.

Effort Corrected Sampling

Because effort varies widely across time and space within the AKN database, it is necessary to correct for sampling effort. We standardized abundance as a function of effort in order to remove the variance in observed bird abundances that comes from the variance in sampling effort across the region in time and space. This was done by dividing the number of birds observed in each sampling unit (grid cell) during a given time period by the number of survey sessions or "bouts" occurring in that grid cell during that time period. Final values within each sampling block represent the number of birds observed/number of sampling bouts; this is specific to each species and each timeframe within the analysis (i.e., month or season).

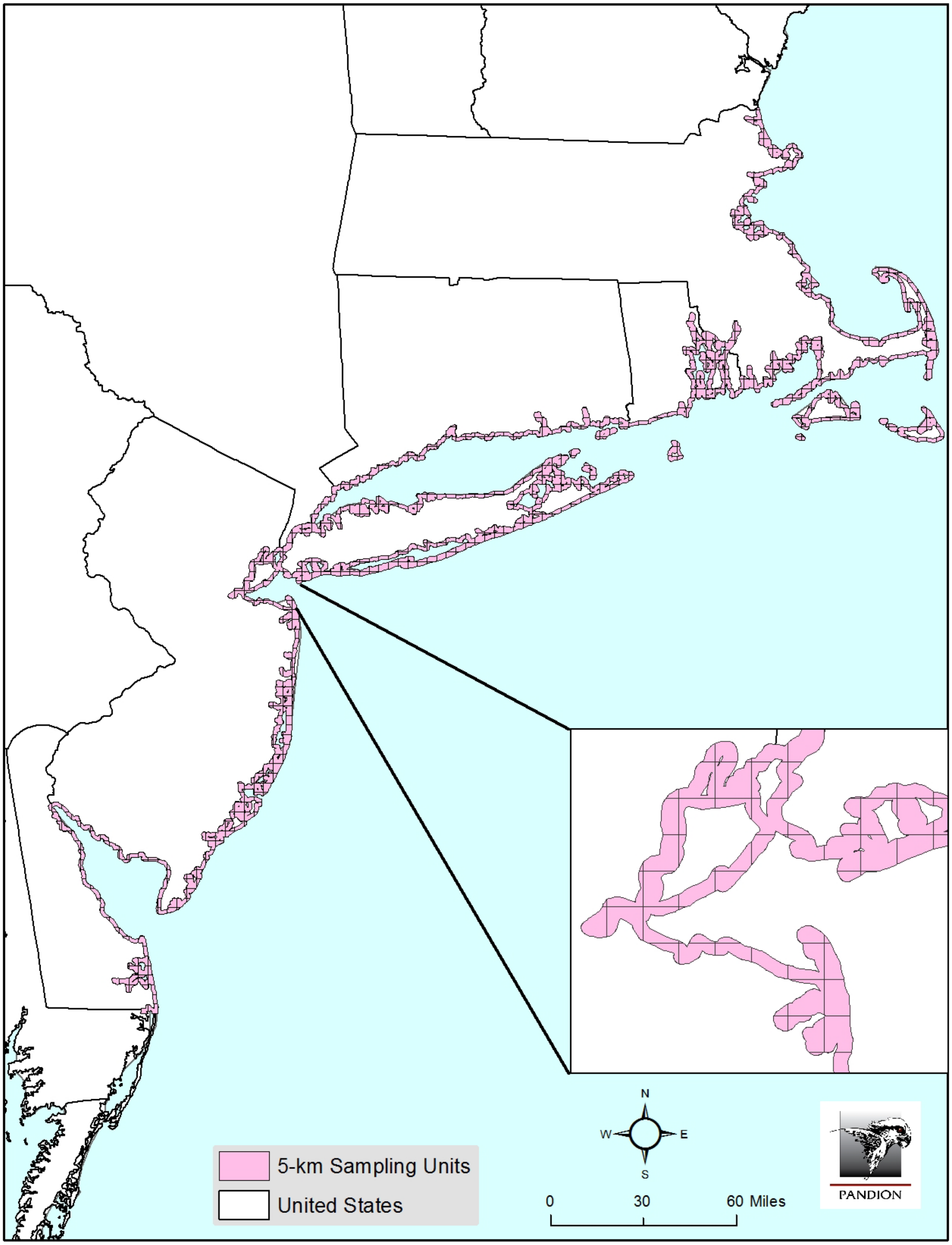

Figure 3–19. Five-km sampling grid for evaluating bird abundance along the coast of the AOCS. The enlarged areas of Raritan Bay show how the grid cells are arranged within the 1-km buffer in and out from the coast.

Table 3–6

Comprehensiveness of sampling effort reflected in the percent of coastal grid cells containing at least five valid observation bouts during different selected time periods.

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Red Knot Spring (Apr–Jun)	Red Knot Fall (Jul–Aug)	Week of 8–14 Sep
MA	18%	22%	25%	21%	24%	20%	19%	19%	32%	24%	11%
RI	7%	11%	5%	4%	9%	7%	4%	5%	12%	11%	1%
CT	26%	26%	27%	18%	19%	19%	25%	22%	41%	23%	7%
NY	22%	21%	24%	21%	18%	17%	15%	15%	34%	23%	4%
NJ	19%	15%	21%	12%	13%	9%	10%	12%	28%	16%	4%
DE	7%	14%	23%	19%	9%	11%	7%	9%	28%	14%	0%
MD	11%	8%	9%	5%	6%	6%	5%	5%	17%	11%	1%
VA	6%	6%	8%	3%	4%	3%	4%	4%	12%	6%	2%
NC	2%	2%	3%	4%	3%	3%	2%	2%	6%	5%	0%

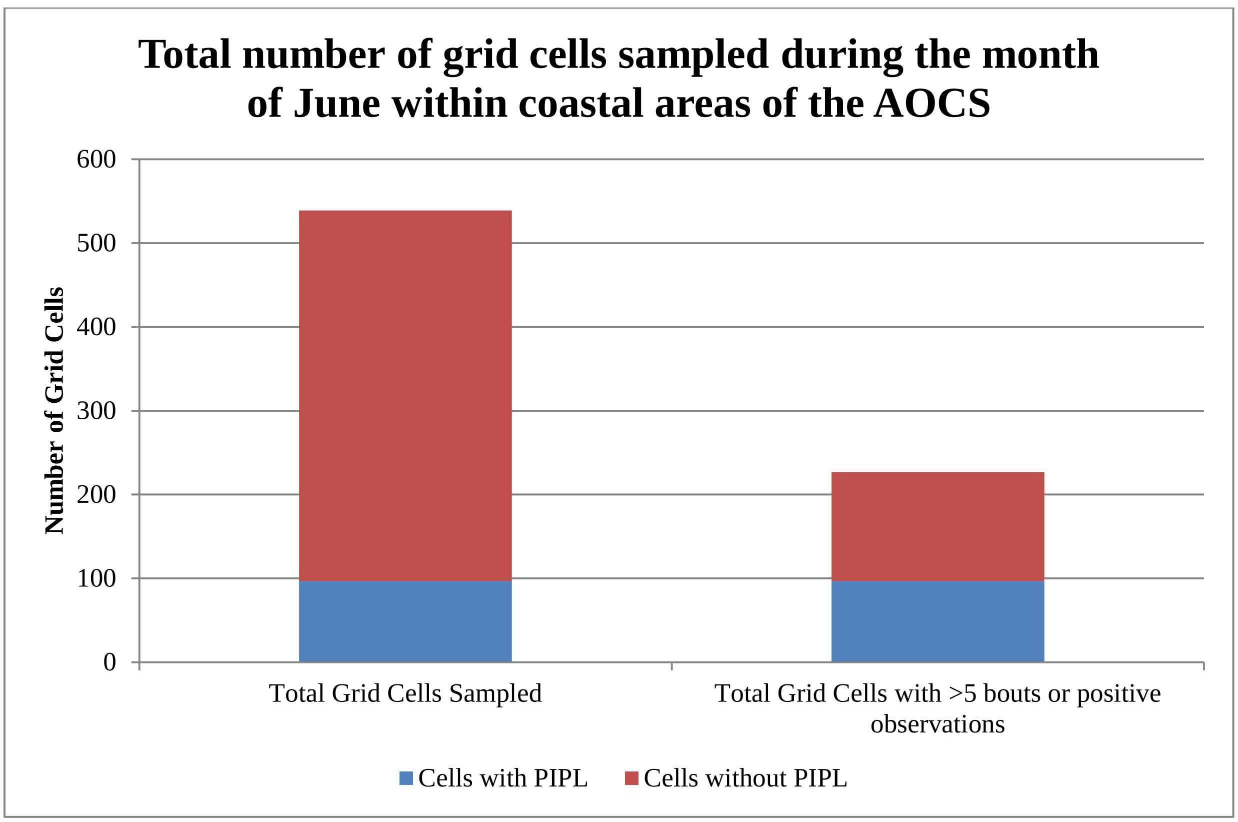

Figure 3–20. Number of grid cells sampled and containing Piping Plover observations during the month of Jun within the study area.

For our analyses, quantifying by sampling session is preferable to other units such as distance, time, or number of observers. Many observations in the AKN do not contain sufficient metadata on the duration of observations or number of observers to permit standardization of all bird abundance data by observer-hours. Furthermore, standardizing by observer-hours would be less biologically accurate than would be standardizing by the number of surveys, as the number of birds present at a given locality at a given time is unaffected by the number of observers or the duration of their observations. One hundred Red Knot present at a given time in a given place was therefore recorded as 100 in a survey regardless of the number of observers or the duration of time over which these birds were observed. In contrast, standardizing by observer-hours might yield results of 10 Red Knot/observer-hour if a group of 10 people observed this group for 1 hr, or 2.5 Red Knot/observer-hour if a group of 20 people observed this same group of birds for 2 hrs, as would be the case for an eBird report of a 2-hr field trip taken by a local Audubon chapter. Because abundance is divided by the number of surveys, there is no need to eliminate multiple observations of the same birds from a given locality in a single day (this could occur at well-known birding hotspots). A group of 10 Red Knot would hence be recorded as such whether it was recorded as 10 in one survey, 20 in two surveys, or 100 in 10 surveys.

Analytic Approach

Selecting Migrant Observations

In order to quantify Red Knot and Piping Plover migration patterns in the coastal areas of the AOCS, it was necessary to separate out the breeding or wintering individuals from the migrants. Identifying migrant individuals from breeding and wintering birds was done based on known breeding phenology information in the literature and expert opinion. For Red Knot that do not breed, but may winter, within the study region, this entailed removing observations of over-wintering birds. For Piping Plover that do not overwinter, but do breed within the study region, this entailed removing observations of known breeding birds. We used published migration information to approximate the seasons when birds would be at various stages in their annual cycle. Because Piping Plover breed and migrate in coastal areas of the AOCS, there are periods during the spring and fall where some birds may be breeding and others may still be migrating (Table 3–7). During these times, we were unable to distinguish between migrant birds, breeding birds, and young birds on natal territories. The breeding only timeframe (1 Jun–30 Jun) was used as a reference for comparisons when comparing Piping Plover distributions from other months during the annual cycle. These comparisons were done for the entire coast from Delaware to Massachusetts and for New Jersey only. New Jersey was chosen singly because it is located in the middle of our study region and represents a single location where the Piping Plover annual cycle is not likely to vary spatially.

Associating Birds with Sampling Units

To associate bird abundance with sampling units, we summed the number of birds observed of each species in each grid cell. Each summation was performed separately for each species in each season (Red Knot) or month (Piping Plover). Bird observations were summed and joined with each cell using the spatial join operation in ArcGIS 10.

Table 3–7

Timeframes used to determine Red Knot and Piping Plover large-scale annual movements in coastal areas of the AOCS.

Annual Movements	Red Knot	Piping Plover
Wintering	1 Sep–30 Mar	1 Nov–31 Jan
Spring Migration	1 Apr–30 Jun	1 Feb–31 Mar
Spring Migration/Breeding Overlap	Does not breed in AOCS	1 Apr–31 May
Breeding activity only	Does not breed in AOCS	1 Jun–30 Jun
Breeding/Fall Migration Overlap	Does not breed in AOCS	1 Jul–31 Aug
Fall Migration	1 Jul–30 Aug	1 Sep–31 Oct

Red Knot Migratory Route Evaluation

Because Red Knots do not breed in the study region, it was not necessary to separate breeding birds from migrants and account for an overlapping period when birds could be both breeding and migrating.

We evaluated the coastal migration hypothesis by (1) comparing maps of effort-corrected abundance of Red Knot between spring and fall migratory seasons; (2) evaluating total Red Knot observed, Red Knot observation frequency, mean, and maximum Red Knot observations among different states within the study region for each migratory season; and (3) comparing mean Red Knot abundance per bout in spring and fall for primary Red Knot migratory staging areas: Delaware Bay (part of New Jersey and Delaware coasts) and Massachusetts. These three types of analysis allowed us to identify spatiotemporal discontinuities in the concentration of migrating Red Knot along the coastline, which are predicted to occur if migration contains a significant noncoastal component.

In order to evaluate the shortcut hypothesis for Red Knot, we visualized maps of Red Knot effort-corrected abundance across the study region for each month, qualitatively searching for patterns that suggested gaps in coastal abundance corresponding to migratory shortcuts in each migration season. Such a pattern would be suggested by a spatial interruption in the abundance of the bird along the coast during the migratory season. Such an interruption would be regarded as an indication that a significant proportion of the birds being observed on either side of the gap were taking a migratory path over water instead of following the coastline through the gap area. In order to avoid falsely assigning gaps along the coast in areas that were poorly sampled, we regarded all grid cells with fewer than five observation bouts in a given sampling time period to represent unsampled cells, or sampling gaps, rather than true negative data, or biological gaps in the migratory route.

Piping Plover Migratory Route Evaluation

Piping Plover breed and migrate through coastal areas in the AOCS. Because of this overlap, it was necessary to distinguish between breeding and migrant birds for the purpose of evaluating various migratory distribution hypotheses. Based on available information on Piping Plover breeding phenology, we selected Jun as a month during which all observations of Piping Plover could be regarded as nonmigratory (Elliot-Smith and Haig 2004). We therefore used the Jun distribution of Piping Plover as a reference for comparison with Piping Plover distributions in other months, which represent mixes of migratory and nonmigratory birds in the late spring, late summer, and early fall, or purely migrant observations in the early spring (Mar) and late fall (Oct).

In order to identify whether or not coastal concentrations of birds were occurring during migratory seasons, we examined a variety of abundance statistics for Piping Plover within the study region, summed separately for each month for both the entire coast and for New Jersey only. We evaluated total abundance, observation frequency, mean abundance per bout, and maximum number observed in a single bout among months using observed distribution maps and descriptive statistics. Comparisons among months allowed us to examine the spatiotemporal distributions of Piping Plover during months that are partially or fully within one of the Piping Plover migration seasons and compare them to what is observed during the breeding season (Jun).

Analysis of frequency distributions and Kolmogorov-Smirnov tests were used to test for differences in the distributions of numbers of Piping Plover reported per observation bout across months for both the entire coast and for New Jersey only. Observed differences would reflect either differences in flock size or the frequency of Piping Plover observations between migration and breeding seasons, which would indicate whether or not coastal concentrations of birds were occurring at any time during the migratory seasons, relative to the breeding season.

In order to evaluate the shortcut hypothesis for Piping Plover, we visualized maps of Piping Plover effort-corrected abundance across the study region for each month and also for each week, qualitatively searching for patterns that suggested gaps in coastal abundance corresponding to migratory shortcuts in each migration season. Such a pattern would be suggested by a spatial interruption in the abundance of the bird along the coast during the migratory season. Such an interruption would be regarded as an indication that a significant proportion of the birds being observed on either side of the gap were taking a migratory path over water instead of following the coastline through the gap area. In order to avoid falsely assigning gaps along the coast in areas that were poorly sampled, we regarded all grid cells with fewer than five observation bouts in a given sampling time period to represent unsampled cells, or sampling gaps, rather than true negative data, or biological gaps in the migratory route.

Results

Red Knot

Spatiotemporal Coverage of Sampling Effort

After removing insufficiently precise observation bouts, we performed our analysis on a total of 22,504 sampling bouts that occurred within 1 km of the coast within the study region during the Red Knot migratory seasons. Of these, 13,978 occurred during the spring migration season (1 Apr–30 Jun) and 8,526 occurred during fall migration season (1 Jul–30 Aug). These sampling bouts contained 295,888 Red Knot observations, with 89,549 in spring and 206,339 in fall. The distribution of these bouts and Red Knot observations is broken down by state or coastal region in Table 3–8, which shows that a large amount of sampling occurred in coastal areas throughout the study region in both seasons at the season-state level, becoming thinner at the month-state level.

The spatiotemporal comprehensiveness of the sampling effort is also reflected in the percent of coastal grid cells in the region that contained at least five acceptable sampling bouts within a specified time period of study, which we regarded as a minimum level of effort for ascribing absence of a focal species. These percentages are displayed for selected time periods in Table 3–6 and reflect that, despite the unique spatiotemporal comprehensiveness of the AKN, this comprehensiveness breaks down significantly when time and space are partitioned finely. Based on the pattern of sampling coverage in the AKN, we restricted our analysis of coastal migration patterns to the region north of Maryland. Within that region, we note that Rhode Island is poorly sampled relative to the other coastal states. The highest degree of spatial comprehensiveness was achieved for Red Knot by lumping the different months within each migratory season (Table 3–6).

Coastal vs. Noncoastal Migration: Evidence for Migratory Concentrations and Spatial Continuity

Because Red Knots do not breed within the study region, any concentration of Red Knot on the coast can be assumed to be a migratory concentration. Red Knots are well-known to occur in large concentrations on the Atlantic Coast during both spring and fall migrations, which implies that, at a minimum, the migratory pathways of Red Knot intersect the U.S. Atlantic Coast. However, their presence in some areas along the coast during migration does not automatically imply that they follow the Atlantic coastline during a significant fraction of their migration. We analyzed the latter issue by examining the spatial distribution and continuity of Red Knot migratory abundance along the coastline in each migratory season. Our results indicate a highly discontinuous distribution of Red Knot occurrence in both migratory seasons (Figure 3–21, Figure 3–22, and Figure 3–23).

Furthermore, it is evident that these concentrations occur in different portions of the coast in the different migratory seasons. During spring migration, Red Knot occurrence is very highly concentrated in the Delaware Bay region (Figure 3–22), primarily during May, extending into Apr and Jun, whereas in the fall, Red Knot are concentrated in Massachusetts (Figure 3–21), primarily from mid-Jul through the end of Sep. The mean numbers of Red Knot observed per sampling bout are over an order of magnitude higher in these regions than they are in the surrounding states or regions during these seasons (Table 3–8, Figure 3–23). These seasonally distinct, spatially discontinuous migratory concentrations are also reflected in the frequency of Red Knot, the total number of Red Knot observations, and the maximum numbers of Red Knot observed in single bouts at these concentration spots relative to surrounding states or regions (Table 3–8).

Table 3–8

Quantitative distributions of Red Knot observations and sampling effort along the coastal areas of the AOCS.

	Total Number of Valid Observation Bouts (including without Red Knot)	Total Bouts with Red Knot	Total Red Knot Observations	Mean Red Knot/Bout of Positive Observations (±SE)	Mean Number Red Knot/Bout of Positive and Negative Observations (±SE)	Maximum Red Knot Observed in a Single Bout
Spring (1 Apr–30 Jun)						
MA	4863	313	8305	26.0 (1.9)	1.7 (0.16)	200
RI	428	22	117	5.3 (1.6)	0.04 (0.02)	30
CT	1420	25	88	3.52 (1.4)	0.13 (0.03)	20
NY	3638	79	2161	27.4 (6.6)	0.60 (0.16)	300
NJ (sans Delaware Bay	1746	91	5657	62.2 (21.65)	3.24 (1.18)	1500
Delaware Bay + Atlantic Portion of DE	1883	246	73221	297.6 (68.3)	38.9 (9.2)	10000
Fall (1 Jul–30 Aug)						
MA	4369	1017	201665	198.3 (12.4)	46.2 (3.16)	3000
RI	267	1	12	12 (12)	0.05 (0.05)	12
CT	653	67	1565	25.4 (4)	2.4 (0.5)	193
NY	1788	79	1238	15.7 (2.7)	0.69 (0.14)	150
NJ (sans Delaware Bay	679	42	1833	43.6 (11)	2.7 (0.8)	355
Delaware Bay + Atlantic Portion of DE	770	14	26	1.9 (4.9)	0.03 (0.01)	6

Shortcutters vs. Coasthuggers: Evidence for Spatial Gaps in Coastal Migratory Routes

Based on the predictions of the shortcut and coasthugger hypotheses described previously, our approach to discriminating among them was to identify spatial gaps in the abundance of coastally migrating birds within the study region. Such gaps would constitute indirect evidence of coastally moving migrants traveling over water instead of strictly along the coast during certain segments of their migration. Such segments were predicted to be most likely to occur in areas where strictly coastal routes would be much longer than would oceanic shortcuts, such as across the mouth of Delaware, Raritan, or Cape Cod bays. Because this analysis relies on the identification of gaps, it requires a spatially comprehensive sampling effort for the time period of interest so that observed gaps may be unambiguously attributed to biological causes rather than sampling artifacts.

The apparent scarcity of coastal migratory paths in this species, as well as the decomposition of sampling effort comprehensiveness with refined spatial partitioning of the data, constrained our ability to discriminate between shortcutting and coasthugging patterns in Red Knot. As discussed previously, patterns of Red Knot migratory abundance along the coast in the AOCS region exhibited extreme spatial discontinuity in both spring and fall seasons, as noncoastally migrating birds dominated the Red Knot observational data. The presence of noncoastal migration was inferred based on a paucity of Red Knot observations along the coast during migration. While a minority of birds may exhibit coastal migratory movements, we could not differentiate between such birds and the noncoastally migrating majority in the dataset; hence, we could not quantify the spatiotemporal occurrence patterns of coastally migrating individuals.

Piping Plover

Spatiotemporal Coverage of Sampling Effort

After removing insufficiently precise observation bouts, we performed our analysis on a total of 34,327 sampling bouts that occurred within 1 km of the coast within the study region during the Piping Plover migratory and breeding seasons. Because Piping Plover may occur on their breeding or natal territories within this region from Apr through Sep (Elliott-Smith and Haig 2004), few of these bouts and observations could be unambiguously assigned to purely migratory occurrence patterns. While observations from Mar and Oct were regarded as purely migratory, these months contained an order of magnitude fewer observations than did each month from Apr through Sep despite comparable sampling intensity during these months (Table 3–9), which reflects the fact that the majority of Piping Plover migration activity occurs within this region during Apr, May, Aug, and Sep, when it may overlap with the occurrence of birds on their natal or breeding territories (Elliott-Smith and Haig 2004). The sampling bouts we analyzed contained 24,830 Piping Plover observations, with 344 and 193 observations occurring in the purely migratory months of Mar and Oct, respectively, and 4,358 observations occurring during Jun, which was the only month during which all Piping Plover observations were assumed not to represent migrating individuals. The distribution of these bouts and observations is broken down by month for the entire study region in Table 3–9, which shows that a large amount of sampling occurred in coastal areas fairly consistently throughout the course of the Piping Plover spring and fall migratory seasons as well as the breeding season.

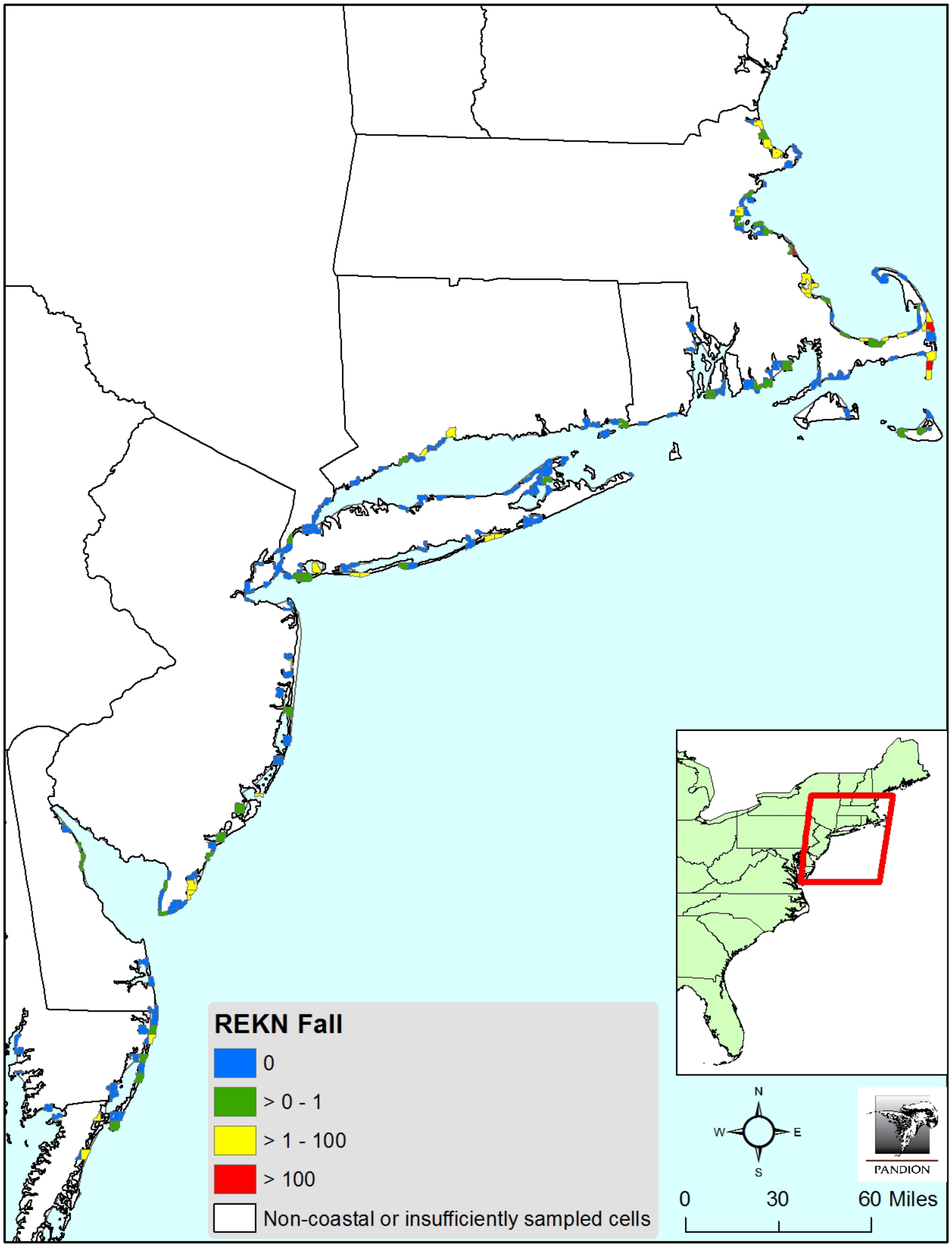

Figure 3–21. Distribution and abundance of Red Knot (REKN) in the coastal areas of the AOCS during fall (1 Jul–30 Aug) as reflected by the number of Red Knot observed per sampling bout in each grid cell.

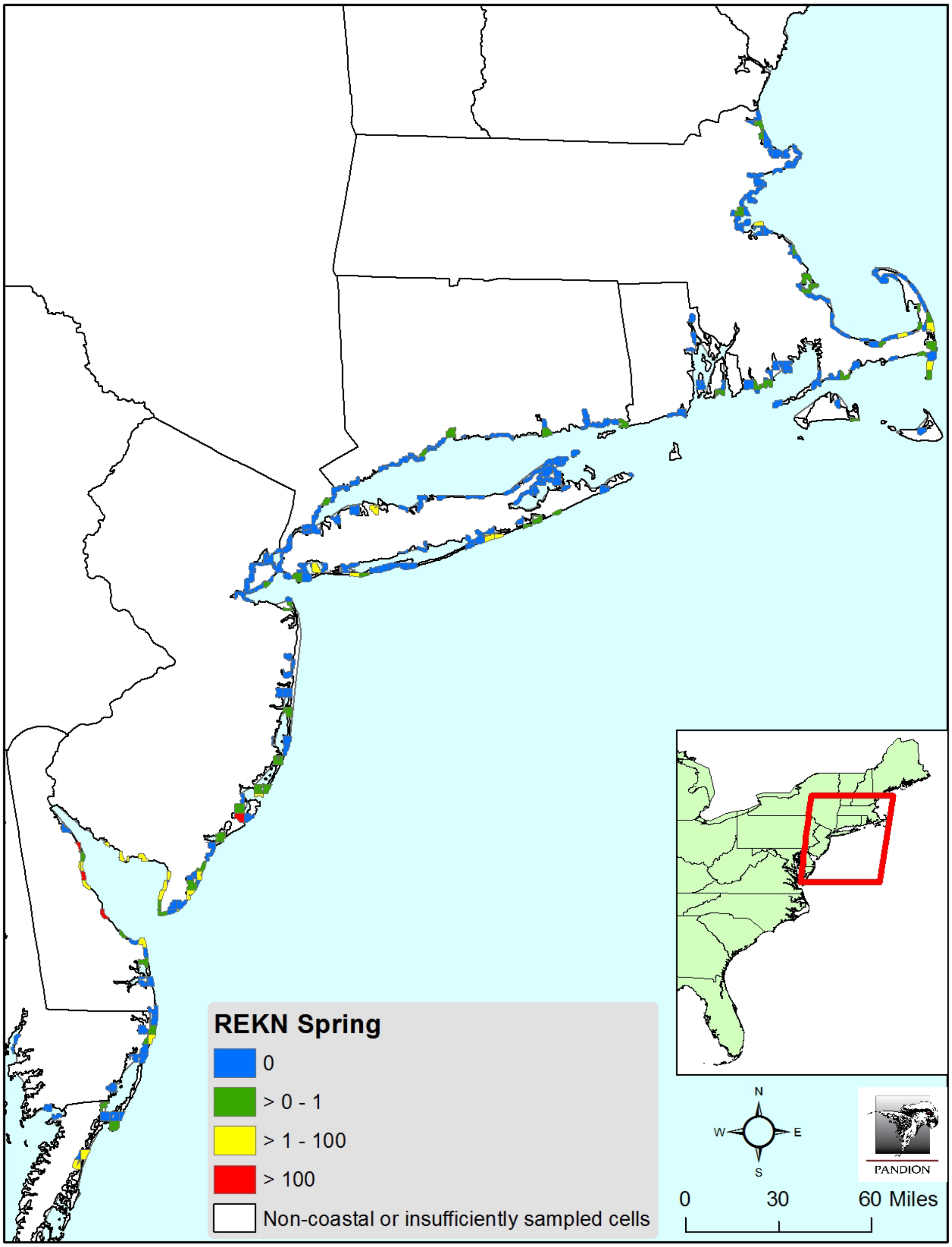

Figure 3–22. Distribution and abundance of Red Knot (REKN) in the coastal areas of the AOCS during spring, as reflected by the number of Red Knot observed per sampling bout in each grid cell.

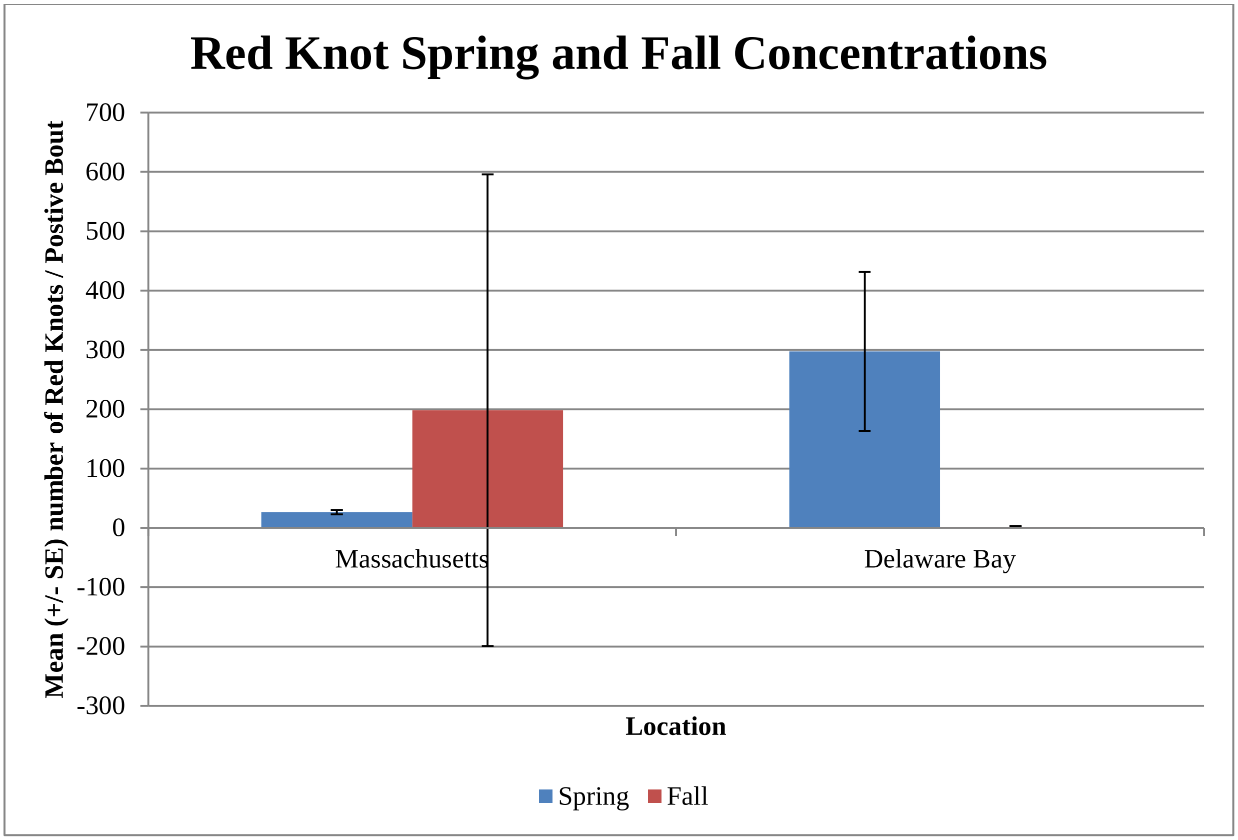

Figure 3–23. Comparison of Red Knot concentrations between spring and fall in Delaware Bay and Massachusetts.

The spatiotemporal comprehensiveness of the sampling effort is also reflected in the proportion of the coastal grid cells in the region that contained at least five acceptable sampling bouts within a specified time period of study, which we regarded as a minimum level of effort for ascribing absence of a focal species. These percentages are displayed for selected time periods in Table 3–6 and Figure 3–20 and reflect that, despite the unique spatiotemporal comprehensiveness of the AKN, this comprehensiveness breaks down significantly when time and space are partitioned finely (Table 3–9 vs. Table 3–10). Based on the pattern of sampling coverage in the AKN, we restricted our analysis of coastal migration patterns to the region north of Maryland. Within that region, we note that Rhode Island is poorly sampled relative to the other coastal states. While we explored spatiotemporal patterns of Piping Plover by month and by week, we note that the spatial comprehensiveness of the sampling is extremely thin at the level of weeks (Table 3–6); hence, we restrict most of our discussion to the monthly analysis.

Table 3–9

Quantitative distributions of Piping Plover observations and sampling effort along the coastal areas of the AOCS in the AKN analysis.

	Total Number of Valid Observation Bouts	Total Bouts with Piping Plover (% of Total)	Total Piping Plover (PIPL) Observations	Mean PIPL/Bout of Positive Observations (±SE)	Mean PIPL/Bout of Positive and Negative Observations (±SE)	Maximum PIPL Observed in a Single Bout
Mar	3749	124 (3.3%)	344	2.77 (0.29)	0.09 (0.01)	25
Apr	4422	506 (11.4%)	2630	4.66 (0.27)	0.53 (0.03)	50
May	6092	944 (15.5%)	3387	3.58 (0.12)	0.55 (0.03)	35
Jun	3464	834 (24%)	4358	5.22 (0.20)	1.25 (0.06)	40
Jul	4256	1109 (26.1%)	8933	8.05 (0.29)	2.09 (0.09)	100
Aug	4270	372 (15.7%)	3899	5.80 (0.34)	0.91 (0.06)	75
Sep	4200	211 (5%)	1086	5.14 (0.51)	0.25 (0.03)	49
Oct	3874	37 (0.9%)	193	5.21 (1.06)	0.04 (0.01)	24

Table 3–10

Quantitative distributions of Piping Plover observations and sampling effort along the coastal areas of New Jersey in the AKN analysis.

	Total Number of Valid Observation Bouts	Total Bouts with Piping Plover (% of Total)	Total Piping Plover (PIPL) Observations	Mean PIPL/Bout of Positive Observations (±SE)	Mean PIPL/Bout of Positive and Negative Observations (±SE)	Maximum PIPL Observed in a Single Bout
Mar	641	19 (2.9%)	34	1.78 (0.21)	0.053 (0.01)	4
Apr	527	36 (6.8%)	120	3.33 (0.45)	0.23 (0.04)	11
May	831	60 (7.2%)	292	4.86 (0.88)	0.35 (0.07)	35
Jun	346	21 (6.0%)	136	6.48 (1.58)	0.39 (0.12)	32
Jul	341	27 (7.9%)	171	6.33 (1.24)	0.50 (0.13)	27
Aug	310	14 (4.5%)	134	9.57 (2.78)	0.43 (0.16)	29
Sep	397	16 (4.0%)	134	8.38 (1.30)	0.33 (0.09)	22
Oct	545	10 (1.8%)	103	10.3 (2.43)	0.18 (0.07)	22

Coastal vs. Noncoastal Migration: Evidence for Migratory Concentrations and Spatial Continuity

We tested the coastal migration hypothesis for Piping Plover primarily by testing one of its principal predictions that if birds migrate along the coast, coastal concentrations should be observed during the migratory season in excess of those observed during the breeding season. Coastal concentrations of birds can be reflected in coastal occurrence data in two possible ways: (1) higher mean and/or maximum abundances per bout than what were observed during the breeding season indicating that coastally migrating birds are aggregating into migratory flocks, or (2) higher frequency of survey bouts recording Piping Plover than occurs during the breeding season indicating that large numbers of single birds or small flocks are migrating along the coast. This analysis was possible despite the spatiotemporal confoundedness of migratory and breeding activity along the Atlantic Coast because even if birds were present on their natal and breeding territories during the times and within the regions of migration activity, migratory concentrations should still be observable as the abundance and/or frequency of bird observations rises above levels present when only breeding activity is occurring.

We employed three analytic techniques designed to elucidate such coastal migratory concentrations.

(1) We created maps displaying the effort-corrected abundances of Piping Plover throughout the study region for each month from Mar through Oct (Figure 3–24 through Figure 3–31). Coastal concentrations were sought by visually comparing each map of a partially or exclusively migratory month (all months except Jun) to that of Jun (Figure 3–27). We used the same color scale to represent effort-corrected abundances in each month so that the months would be directly comparable. Qualitative, visual inspection of these maps did not reveal any easily apparent coastal migratory concentrations (as theoretically predicted in Figure 3–15) of Piping Plover observations anywhere along the coast in any of the partially or exclusively migratory months compared to that of Jun.

(2) We calculated various statistics for each month that could indicate migratory concentrations (either large-sized flocks or large numbers of single birds or small flocks) of Piping Plover along the coast of the whole region (Table 3–9) or in the Atlantic coastal portion of New Jersey (Table 3–10). The New Jersey only analysis is essential for testing the noncoastal hypothesis because whereas the whole-coast analysis might obscure migratory concentrations by lumping all birds throughout the migratory season regardless of their latitude, the New Jersey analysis should reveal coastal migratory concentrations during portions of the migration seasons when New Jersey would be expected to contain northbound or southbound migrants who breed to the north of New Jersey. These analyses included statistics that would capture coastal migratory concentrations of Piping Plover whether they were migrating in small numbers of large migratory flocks (e.g., maximum number of birds observed in a single bout) or large numbers of small flocks or solitary individuals (e.g., proportion of observation bouts containing Piping Plover). By examining these statistics on a monthly basis throughout the entire migratory and breeding seasons, on a whole-coast, and New Jersey only level, coastal migratory concentrations should have been captured in this analysis whether spring and fall migrations were broadly spread out through the migratory seasons or highly concentrated in time.

This analysis did not reveal any evidence of coastal migratory concentrations. There was no tendency toward large flock formation, as indicated by either mean birds observed per bout, large numbers of bouts recording birds, or maximum number of birds observed in a single bout, in any of the partially or exclusively migratory months compared with Jun. Abundance and frequency of Piping Plover observations peaked in midsummer, with high levels recorded in Jun and slightly higher levels recorded in Jul, consistent with increased population sizes from the production of new chicks (Table 3–9, Table 3–10). One possible exception is the somewhat large mean and maximum number of Piping Plover observations per bout observed in New Jersey in Oct relative to Jun (Table 3–10). This may indicate some tendency of this species to form southbound flocks during fall migration. There is a notable absence of any trace of such a pattern during the spring migration in New Jersey, possibly indicating that nonstop, long-distance migratory flights are more the rule in spring migration than they are in fall.

(3) We also compared the frequency distributions of Piping Plover observations (e.g., numbers of Piping Plover observed in single bouts) by month for the whole-coast and New Jersey only analyses. We then compared the observed distribution in each partially or fully migratory month to that of Jun using Kolmogorov-Smirnov tests (Table 3–11). All of the months appeared to have similarly shaped frequency distributions with a strong bias toward observations of single birds or small numbers of birds together with a small number of observations of groups of up to 40 or 50 individuals. This trend held true for both the whole-coast and New Jersey only analyses. This indicates that Piping Plover exhibited the same degree of aggregation/dispersion in all months (Figure 3–32). This pattern was generally confirmed by the Kolmogorov-Smirnov tests, which revealed that the frequency distributions of Piping Plover in all but two of the partially or exclusively migratory months were statistically indistinguishable from that of Jun (Table 3–11). The statistical differences that were observed between the frequency distributions of two of the months (Mar, Oct) compared with Jun in the whole-coast analysis did not appear to result from a higher tendency toward aggregation or flocking as the distributions were strongly left-skewed in these months as well (Figure 3–32). Instead, these differences are likely to have resulted from the overall much lower density of Piping Plover within the study region during these months as these months represent the extreme tail ends of the spring and fall migration and contained a combined 2.2% of the total Piping Plover observations in the dataset (Table 3–9).

Table 3–11

Results of Kolmogorov-Smirnov tests comparing frequency distributions of Piping Plover observations from each partially or fully migratory month against that of Jun, which is presumed to reflect breeding activity only.*

Month Comparison	Delaware to Mass. Coast		New Jersey Coast Only	
	Test Statistic (D)	P-value	Test Statistic (D)	P-value
Mar vs. Jun	0.2	0.04	0.07	0.967
Apr vs. Jun	0.08	0.91	0.04	1
May vs. Jun	0.07	0.97	0.04	1
Jun vs. Jun (reference)	0	1	0	1
Jul vs. Jun	0.15	0.21	0.01	1
Aug vs. Jun	0.05	0.99	0.04	1
Sep vs. Jun	0.14	0.28	0.03	1
Oct vs. Jun	0.21	0.02	0.04	1

* This table shows results from both the entire coast from Delaware to Massachusetts and from New Jersey only.

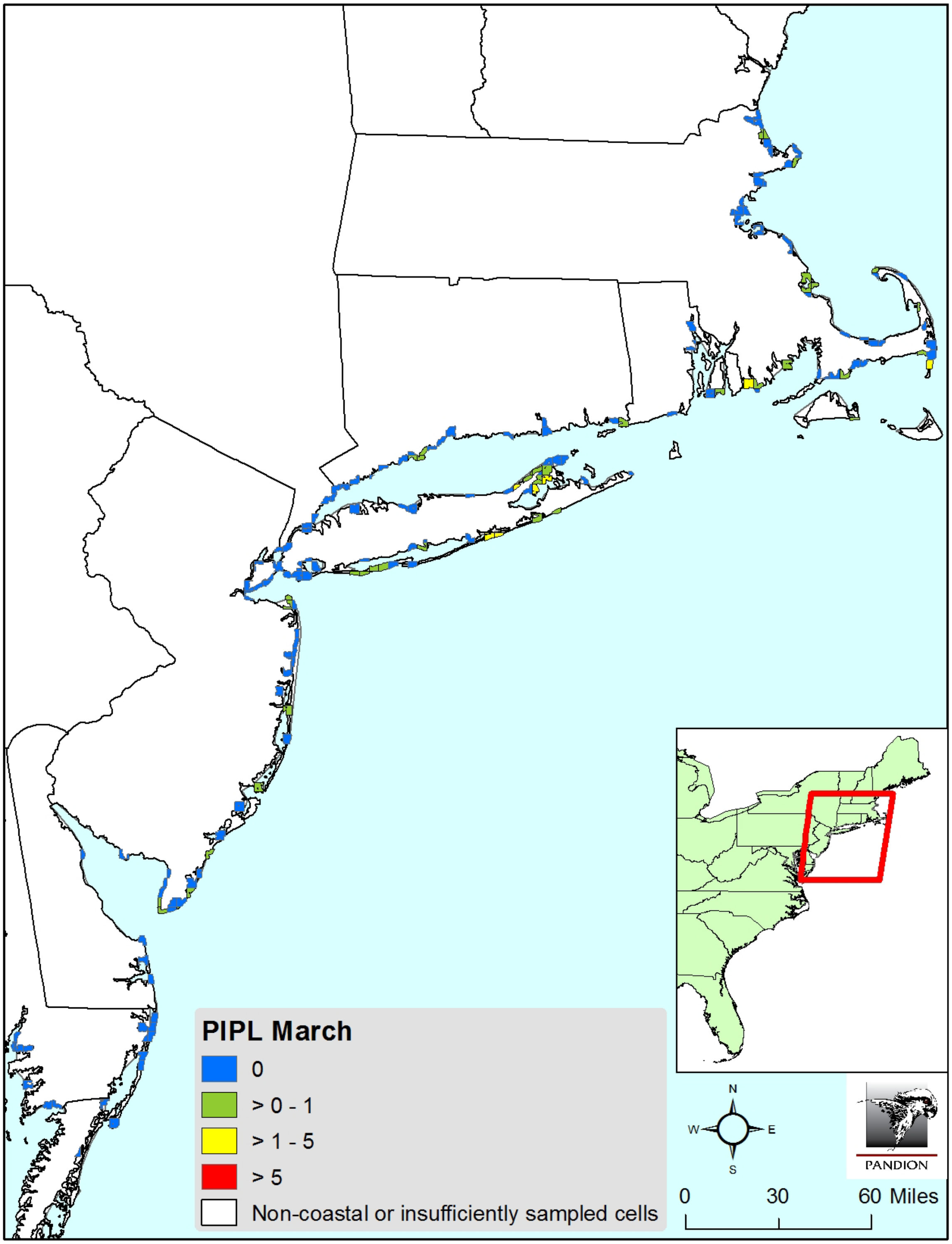

Figure 3–24. Distribution of Piping Plover observations along the Atlantic Coast in Mar.

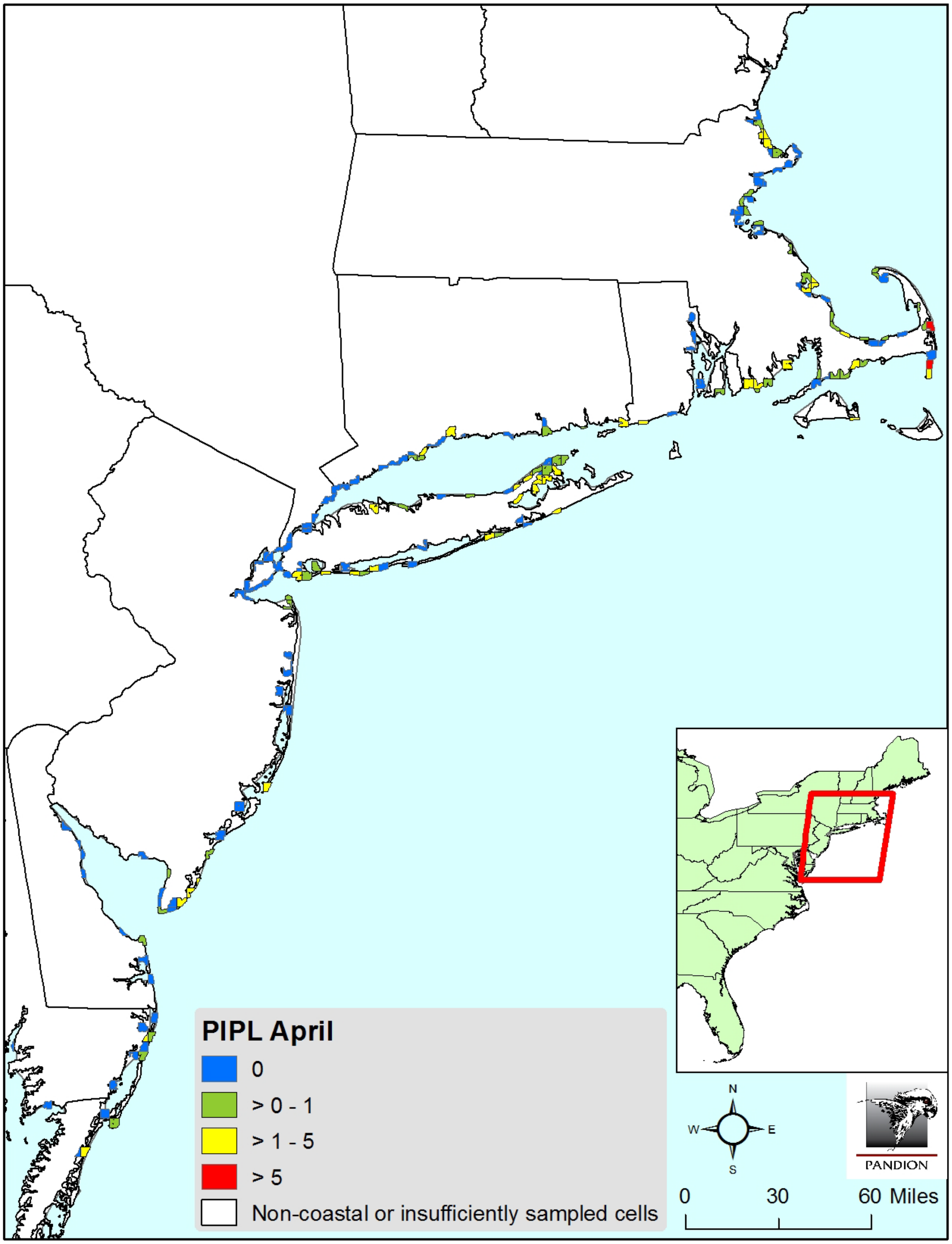

Figure 3–25. Distribution of Piping Plover observations along the Atlantic Coast in Apr.

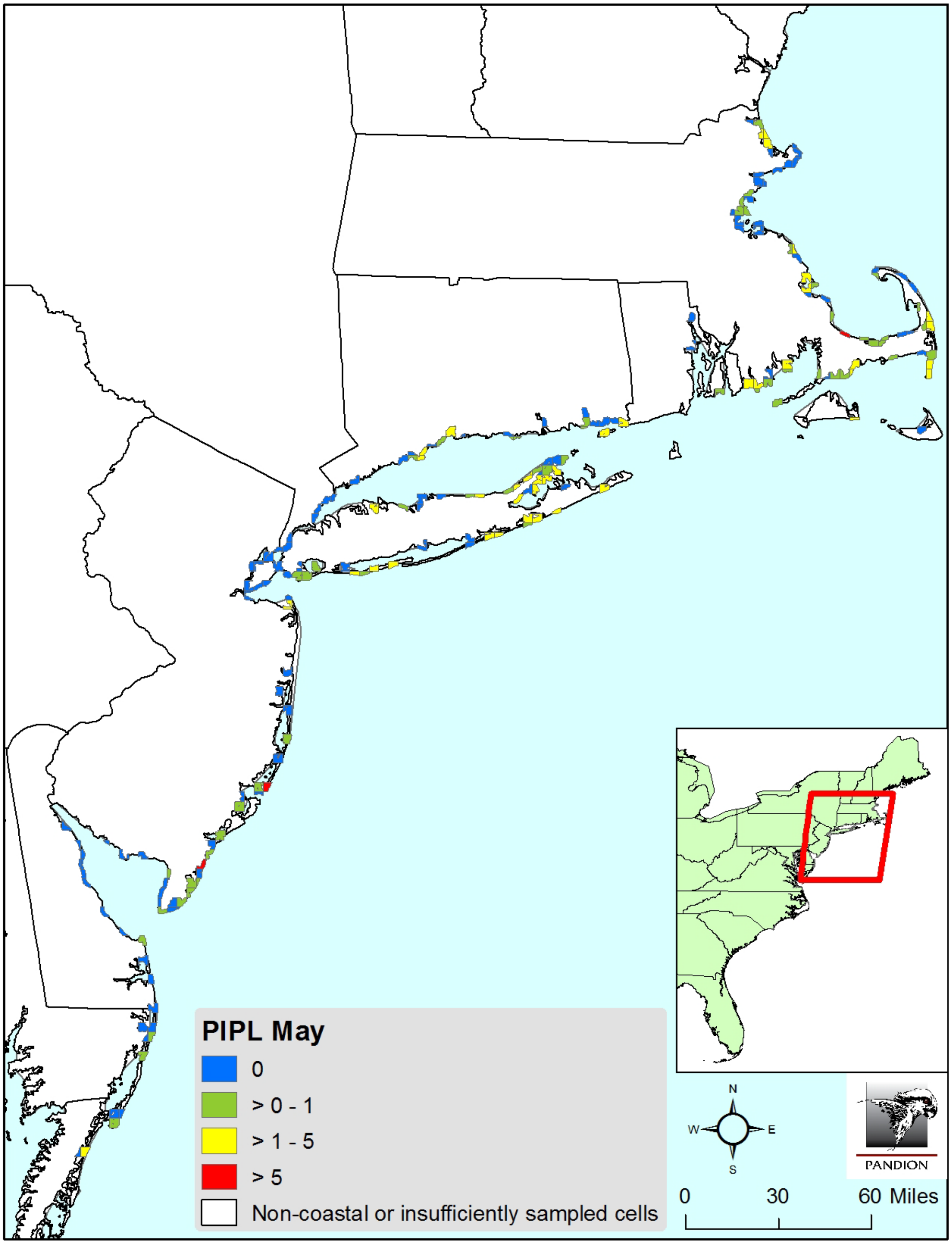

Figure 3–26. Distribution of Piping Plover observations along the Atlantic Coast in May.

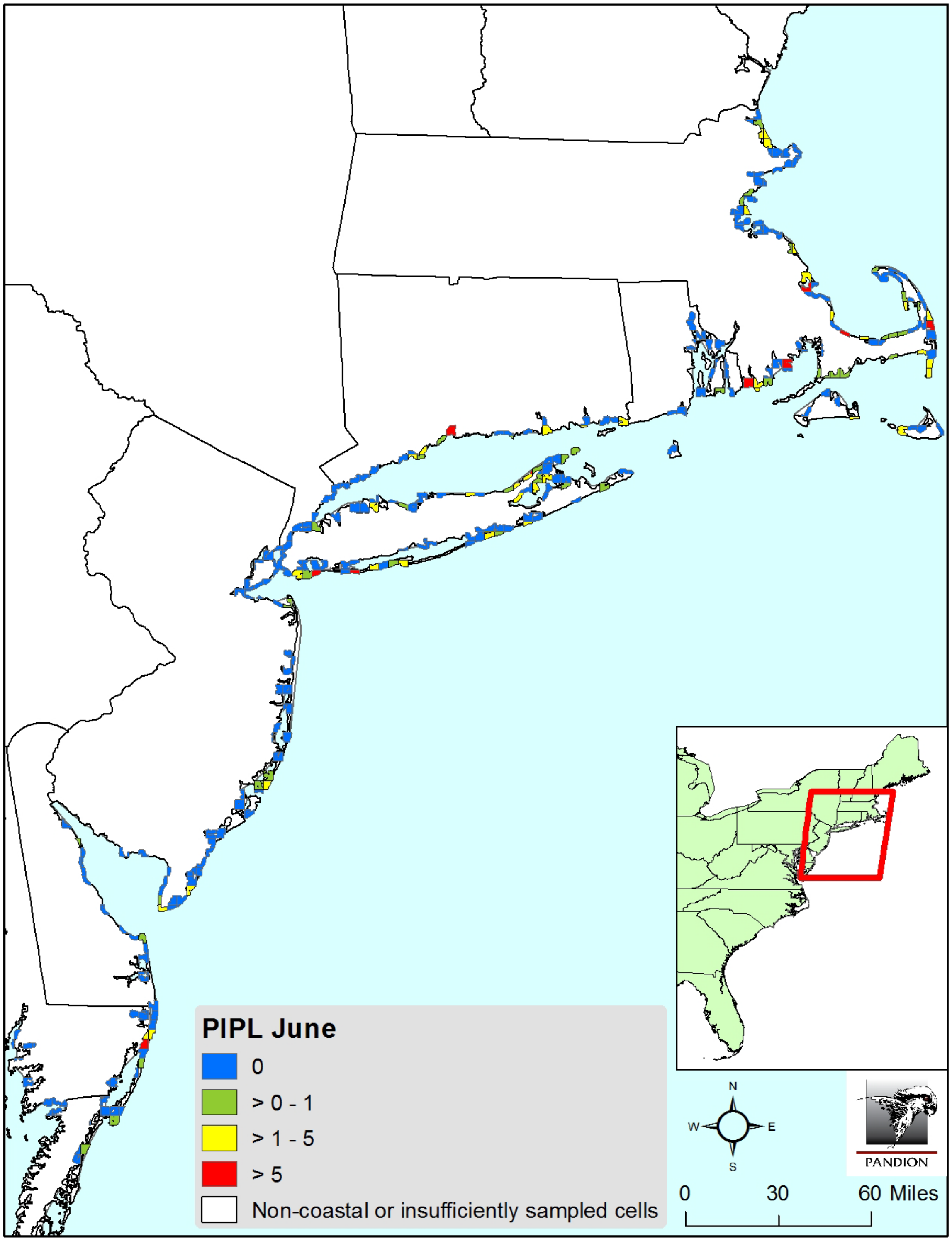

Figure 3–27. Distribution of Piping Plover observations along the Atlantic Coast in Jun.

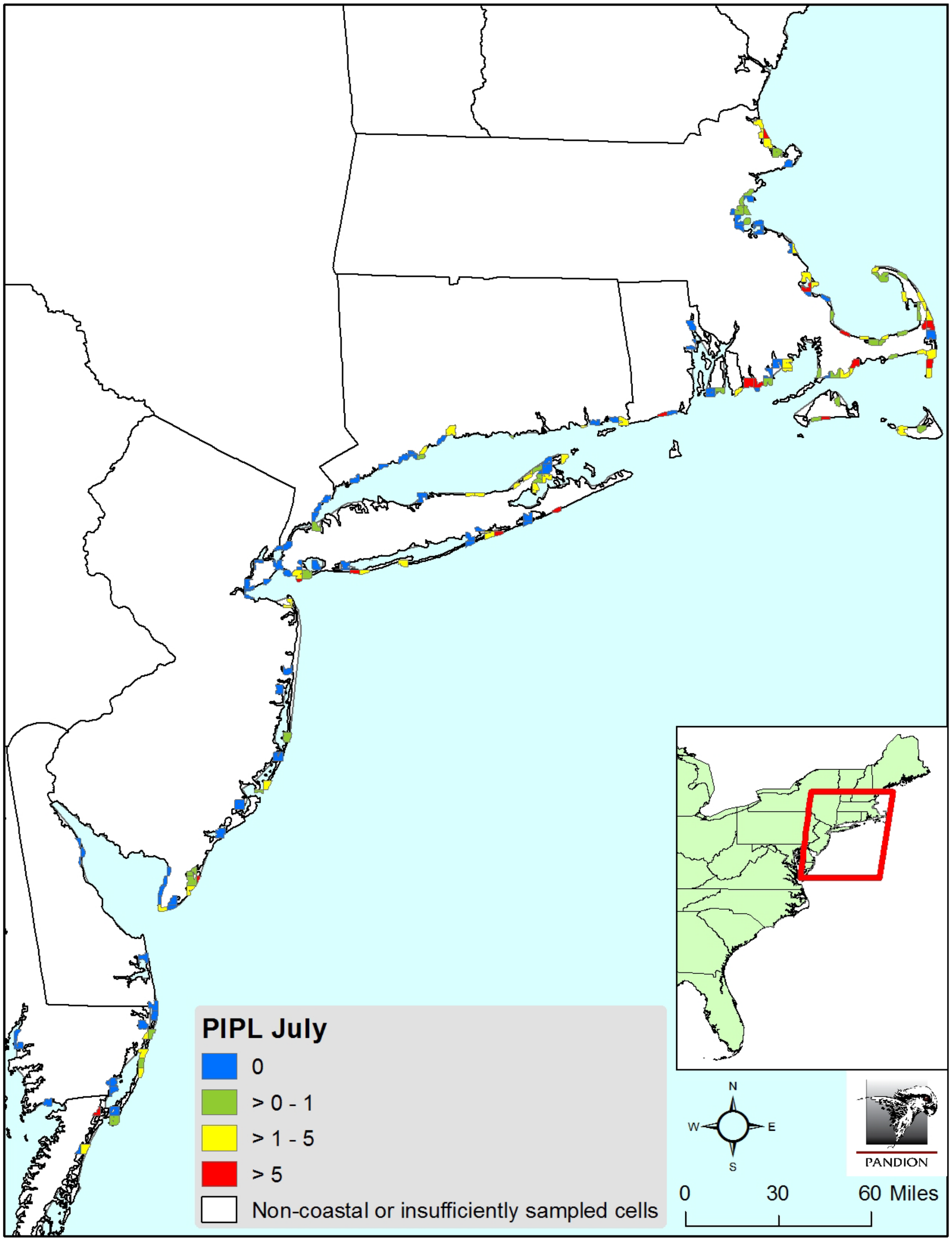

Figure 3–28. Distribution of Piping Plover observations along the Atlantic Coast in Jul.

Figure 3–29. Distribution of Piping Plover observations along the Atlantic Coast in Aug.

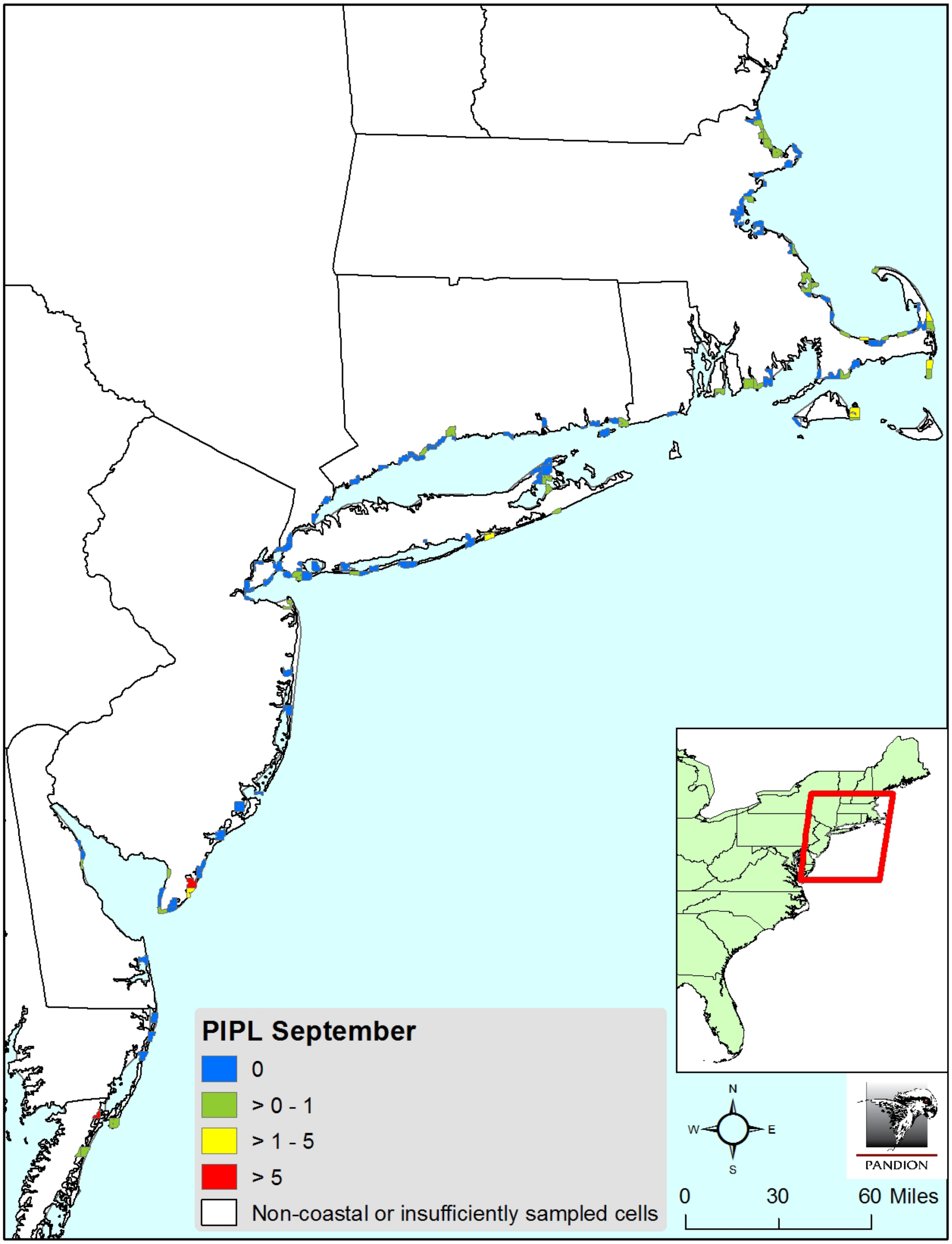

Figure 3–30. Distribution of Piping Plover observations along the Atlantic Coast in Sep.

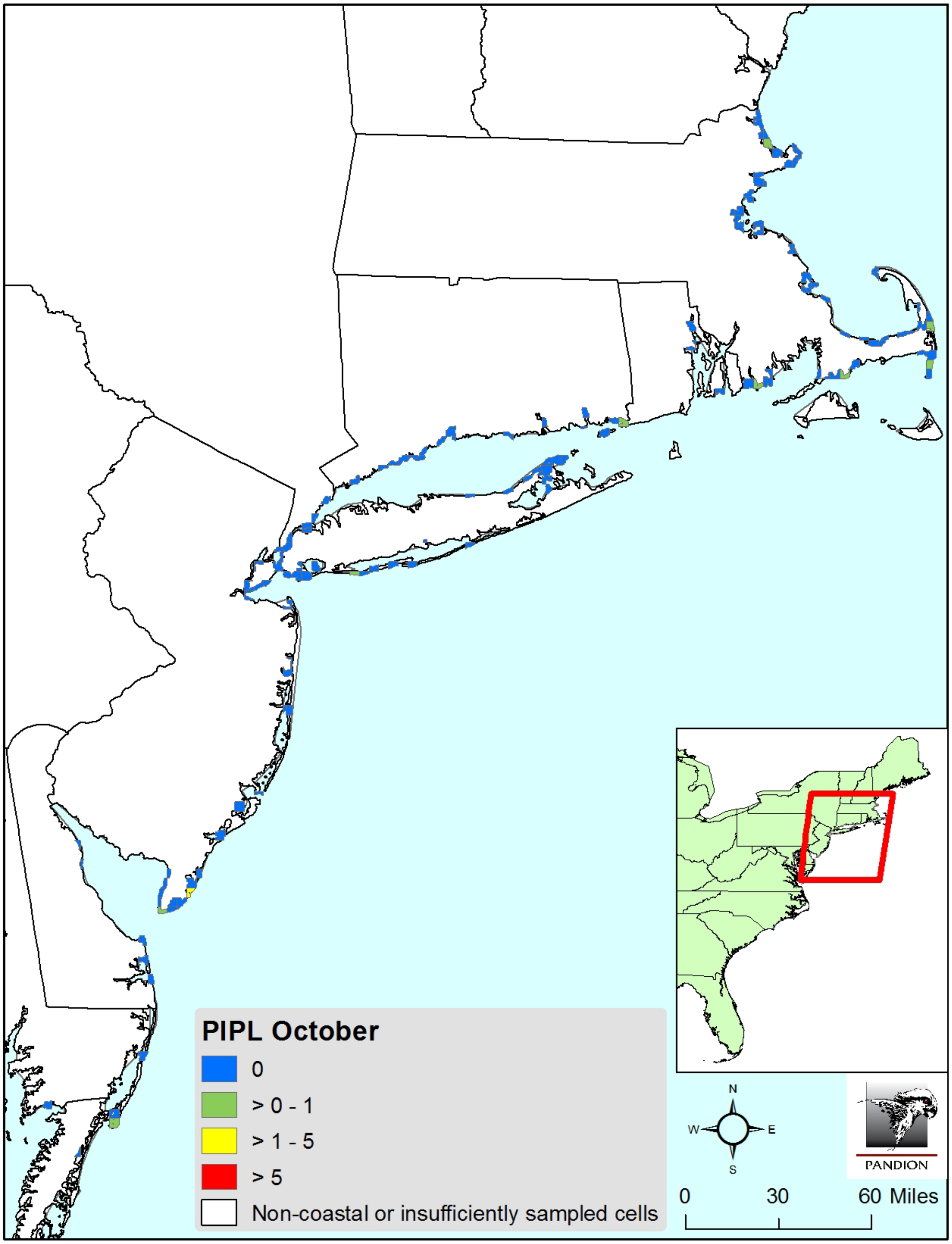

Figure 3–31. Distribution of Piping Plover observations along the Atlantic Coast in Oct.

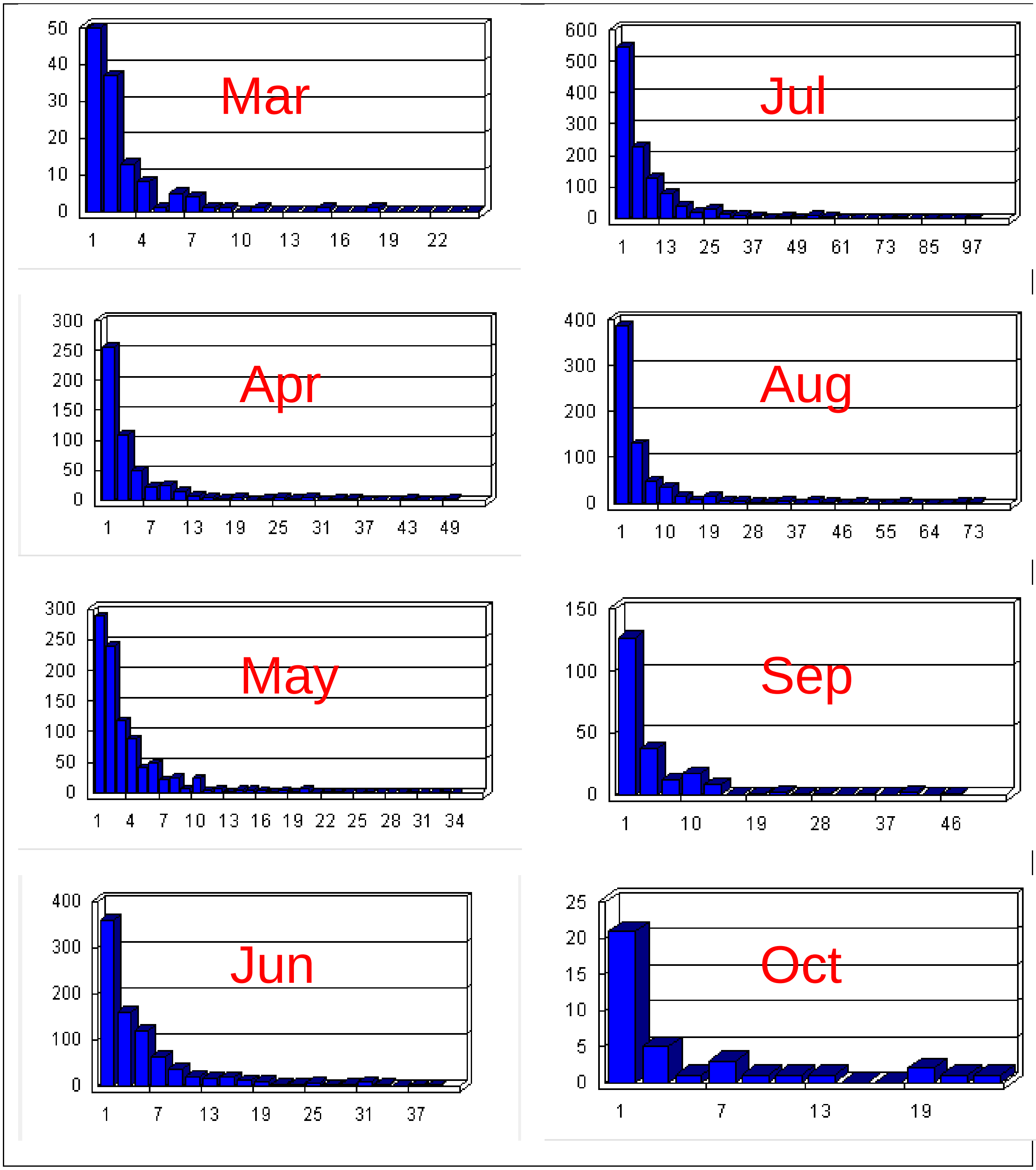

Figure 3–32. Frequency distributions of Piping Plover abundance across months in the whole-coast analysis of the AOCS. The x-axis represents numbers of birds recorded in single observation bouts; the y-axis represents the number of bouts.

Shortcutters vs. Coasthuggers: Evidence for Spatial Gaps in Coastal Migratory Routes

Based on the predictions of the shortcut and coasthugger hypotheses described previously, our approach to discriminating among them was to identify spatial gaps in the abundance of coastally migrating birds within the study region. Such gaps would constitute indirect evidence of coastally moving migrants traveling over water instead of strictly along the coast during certain segments of their migration. Such segments were predicted to be most likely to occur in areas where strictly coastal routes would be much longer than would oceanic shortcuts, such as across the mouth of Delaware, Raritan, or Cape Cod bays. Because this analysis relies on the identification of gaps, it requires a spatially comprehensive sampling effort for the time period of interest, so that observed gaps may be unambiguously attributed to biological causes rather than sampling artifacts.

Two factors constrained our ability to conduct an in-depth, quantitative evaluation of the shortcut hypothesis for Piping Plover. First, the apparent scarcity of coastal migratory paths in this species constrained our ability to discriminate between shortcutting and coasthugging patterns among the minority of Piping Plover individuals that may have exhibited coastal migratory pathways. As discussed previously, there was no quantitative evidence of the occurrence of migratory concentrations (either of large flocks or large numbers of single birds or pairs) of Piping Plover in excess of those observed during the breeding season anywhere along the Atlantic Coast during either migration season. While a minority of birds may exhibit coastal migratory movements, we could not differentiate between such birds and the noncoastally migrating majority in the dataset. Exacerbating the numerical dominance of noncoastal migrants is the spatiotemporal overlap between breeding and migratory seasons within the study region. The two months during which Piping Plover observations could unambiguously be assigned to migrating individuals, Mar and Oct, contained a very small proportion of the total Piping Plover observations in the dataset (2.2% for Mar and Oct combined). Therefore, observations that could unambiguously be assigned to coastally migrating individuals were very few and hard to separate from observations of birds that may have been on their breeding or natal territories.

The second factor that constrained our ability to test the shortcut hypothesis was the erosion of the spatiotemporal comprehensiveness of the dataset when space and time were partitioned finely for analysis. Spatially comprehensive sampling is essential for shortcut hypothesis testing, as the primary prediction of the hypothesis is that certain areas along the coast will contain spatial gaps in migratory bird abundance. If there are too many sampling gaps along the coast for a given time period of interest, it is impossible to identify such biological gaps. Figure 3–20 illustrates the drastic drop-off in the number of coastal grid cells that contained sufficient sampling effort to provide negative data when the time frame was limited to a single month. The drop-off in comprehensiveness was even more extreme when we mapped Piping Plover abundance for each week from Mar through Oct, which we had hoped would reveal migratory movement patterns at a finer temporal scale (Table 3–6). As the AKN dataset grows with increased data gathering efforts along the coast, it may be possible to test the shortcut hypothesis for coastally migrating subsets of Piping Plover and Red Knot populations in the future.

Discussion

Red Knot

Coastal vs. Noncoastal Migration

The extreme spatiotemporal discontinuity in the pattern of Red Knot migratory abundance on the Atlantic Coast of the U.S. suggests a large noncoastal component to their migration pattern, dominated by the migratory pattern of intercontinentally migrating individuals. Specifically, the data suggest that the bulk of the population arrives directly at coastal stopover sites in Delaware Bay during spring migration, presumably passing over the AOCS from the south beforehand, and then traveling over land to arctic breeding grounds afterward. During fall, the bulk of the population stops over in coastal locations in Massachusetts before departing, apparently directly, for South American wintering grounds, at which time the highest concentration of these birds presumably passes over the AOCS to the south and possibly southeast of Massachusetts (Figure 3–33). Some degree of coastal movement on the Atlantic Coast during both spring and fall migrations is indicated by the tracking study we performed during this project (Niles et al. 2010) and is not contradicted by the data in the geospatial analysis. However, the geospatial analysis provides an indication that coastal migratory movement is not a majority behavior in Red Knot on the U.S. Atlantic Coast.

These discontinuous migratory concentrations were already known qualitatively for this species (Harrington 2001), but this is the first comprehensive and quantitative compilation of observations on a region-wide and population-wide scale; hence, it renders a quantitative perspective on the extent of coastal vs. noncoastal migratory activity that is occurring among U.S. populations of Red Knot.

The specific migration scenarios described above to explain the observed spatially discontinuous and seasonally distinct patterns of migrating Red Knot along the Atlantic Coast are supported by the anecdotal evidence from the tracking studies supported by this project. Niles et al. (2010) report data for three long-distance migrant Red Knot, and Section 3.3 of this report presents data for eight individuals from the short-distance migratory population of Red Knot whose annual migration paths were tracked using light-sensitive geolocators. All three of the tracked individuals from the long-distance migrant population were initially captured during spring migration in the Delaware Bay area. Capture and recapture efforts were only undertaken in this region in spring; hence, their presence in this stopover region in both 2009 and 2010 was selected. However, migratory routes taken subsequent to capture were unconstrained and unselected and therefore may be interpreted as reflective of natural bird migration patterns, even if the sample size is small. Subsequent to release, all three of these birds moved northward and westward over land from their Delaware Bay spring stopover region toward breeding areas in the central Canadian Arctic, demonstrating a land-based noncoastal component of spring migration. In fall, two of the three birds traveled more or less directly from James Bay, Canada, to the Lesser Antilles, while one bird stopped over in coastal Massachusetts. All three of these birds apparently migrated over land between the Canadian Arctic and the Massachusetts Coast in fall and then crossed the AOCS to the south and east of Cape Cod, Massachusetts, en route to the Lesser Antilles or northeastern South America (Niles et al. 2010). It should be noted that the average error on the location calculations using this tracking technology is ±150 km (Niles et al. 2010). Latitudinal error may be particularly large near the equator (USFWS 2008a). Nonetheless, the precision of this technology is sufficient to determine that migration routes were over land between spring migratory stopover and fall return and that these birds passed over the AOCS in the general vicinity of the Massachusetts Coast during fall migration.

The eight individuals tracked from the short-distance migratory population show a varied pattern of wintering sites and migratory routes (Section 3.3), including more long flight segments and inferred AOCS crossing than was previously hypothesized for this subpopulation (Burger et al. 2011). As these birds were all initially trapped in Cape Cod, Massachusetts, their southbound departure from that region is, therefore, a bias inherent in our sampling design and cannot be taken as an indication of concentrated fall AOCS risk in that region, as is the case for the long-distance migrant birds discussed previously.

Because of the numerical dominance of Red Knot at seasonally distinct and discontinuous migratory stopover regions, we could not determine whether or not spatially continuous migration patterns might be present among short-distance migrants, which might indicate a coastal migratory pattern in this minority. Indications of both coastal and noncoastal migratory movements are contained in our small subsample of tracked birds from the short-distance migratory population of Red Knot (Section 3.3).

Shortcutting vs. Coasthugging

Both the shortcut and coasthugger hypotheses pertain only to coastally migrating birds. Because of the numerical dominance of noncoastal migration patterns in North American Red Knot, we were unable to isolate the abundance patterns of any birds that might have been exhibiting coastal migration patterns and use them to evaluate these two different hypothetical coastal migration patterns. It is possible, and it has been suggested (Burger et al. 2011), that a minority of Red Knot along the Atlantic Coast of the U.S., in particular, the short-distance migrant subpopulation, may exhibit coastal migration. Our tracking study (Section 3.3) provides some evidence of both coastal and noncoastal migratory patterns, but further study is needed to discriminate between shortcutting and coasthugging migratory routes in this subpopulation. Because such behaviors are exhibited by a minority of individuals, population-wide studies such as our geospatial analysis have lower potential than do individually based research techniques, such as tracking studies, for examining these hypotheses. This is further constrained by the decomposition of spatiotemporal comprehensiveness in the AKN collective sampling effort when time and space are finely partitioned (Table 3–8 and Table 3–6). From the point of view of risk assessment, minority behaviors are less critical as they are less likely to lead to population-level risk, yet risk to the short-distance migrating subpopulation of Red Knot may also be important, as this subpopulation is regarded as distinct and may warrant separate protection should the USFWS decide to protect this species under the Endangered Species Act (ESA).

Implications for Exposure to Offshore Wind Turbines on the AOCS

Within the limitations of the spatial precision and indirect inferences of this analysis, we have determined that Red Knot exposure to offshore wind turbines on the AOCS is likely to be concentrated to the south and southeast of Delaware Bay in spring, primarily between late Apr and early Jun, and to the south and southeast of Massachusetts in fall, primarily between late Jul and the end of Sep (Figure 3–33). These regions of the AOCS have not been precisely defined in space or time by this analysis as the geospatial analysis provides only indirect evidence of pelagic passage, and the corroborating evidence from the light-sensitive geolocators is anecdotal and spatially precise only at the ±150 km level. Nonetheless, it can be concluded that the bulk of the North American population of Red Knot is likely to fly through these broadly defined regions of the AOCS at the specified time windows. Pre- and post-construction monitoring and risk assessment efforts on the AOCS should, therefore, be targeted within these spatiotemporal windows. Exposure of Red Knot to wind turbines on the AOCS is unlikely outside of these specific time windows and portions of the AOCS.

It is important to note that the occurrence of Red Knot within the described portions of the AOCS during the indicated times of year constitutes exposure, which is a necessary, but not sufficient, condition for this species to be at risk of collision with wind turbines. This type of exposure is classified as macroscale exposure in Burger et al. (2011). There are still unknowns about the extent of exposure at other scales (Burger et al. 2011), which must be addressed with further research to determine the extent of risk of Red Knot colliding with offshore wind turbines on the AOCS. In particular, migratory flight height of Red Knot in pelagic environments must be characterized to determine mesoscale exposure (Burger et al. 2011). At present, the migratory flight height of Red Knot is largely unknown (Burger et al. 2011). Furthermore, the ability of Red Knot to avoid turbines if they do fly at rotor swept altitudes through an offshore wind facility on the AOCS must be characterized to determine microscale exposure (Burger et al. 2011). This is also currently unknown, though several avian mortality studies conducted at coastal wind facilities near very large shorebird migratory stopover sites in Europe and New Jersey suggest that the overall collision susceptibility of shorebirds in general, and Red Knot in particular, may be low (Landmark Practice 2009; Dirksen et al. 1998; New Jersey Audubon Society 2009).

Figure 3–33. Predicted spatiotemporal distribution of Red Knot exposure to offshore wind facilities in the AOCS. The downward arrow represents fall migration (generally late Jul to the end of Sep); the upward arrow represents spring migration (generally late Apr to early Jun).

Piping Plover

Coastal vs. Noncoastal Migration

The lack of substantial numerical evidence in the AKN for coastal migratory concentrations of Piping Plover suggests that the bulk of the Atlantic Coast breeding population of this species migrates in long-distance, nonstop flights, which may or may not follow the coastline. If birds in this population were using a series of coastal stopover sites en route during migration, it would be apparent in the AKN dataset either as a tendency toward larger flocks, a greater frequency of observations of smaller flocks or individual birds, or both at locations along the Atlantic Coast during one or more of the months within both the spring and fall migratory seasons compared with the observed pattern of Piping Plover abundance during the month of Jun, when no migratory activity is occurring in this species. The spatiotemporal comprehensiveness of the dataset we analyzed is such that the only plausible explanation for this result is that the majority of individual Piping Plover are not making regular use of coastal stopover sites during spring and, to a lesser extent, fall migration. Instead, the spring and fall distributional patterns of the Atlantic Coast breeding population of Piping Plover suggest that individual birds suddenly appear at the breeding locations in spring and then suddenly leave in fall without generally being observed along the coast en route, presumably making nonstop, long-distance migratory flights to travel between wintering and breeding areas.

While our suggestion of long-distance, nonstop migration behavior in the Atlantic Coast breeding population of Piping Plover is novel, it is, in some sense, not surprising given the known tendency of inland breeding populations of Piping Plover to engage in this type of migration behavior where observations of migrating birds at inland stopover sites are few and anecdotal (Elliot-Smith and Haig 2004; USFWS 2009a). It has generally been accepted that the Atlantic coastal breeding population of Piping Plover migrates coastally, making use of stopover sites along the U.S. Atlantic Coast en route between breeding and wintering grounds (USFWS 2009a). However, this conclusion is based on selected, anecdotal evidence and it is also generally acknowledged that the migratory biology of this subpopulation is poorly known (USFWS 2009a). Noel et al. (2007) found peak fall migration counts of 109 and 123 birds in 2003 and 2004, respectively, on St. Simon's Island, Georgia, compared to a smaller number of wintering birds of ~45 birds. A migratory concentration of 104 birds was observed on the north side of Ocracoke Inlet, North Carolina, where no breeding individuals occurred and where winter counts did not exceed 18 birds (NPS 2010). On Assateague Island in 1994, 81 Piping Plover were recorded on 1 Aug (presumably mostly migrations), which far exceeded the number of breeding individuals recorded at this site (NPS and MD DNR 1994). Stucker and Cuthbert (2006) and Stucker et al. (2010) also noted observations of Piping Plover presumed to be Atlantic coastal migration stopovers in New Jersey, Maryland, Virginia, and North Carolina.

Banding/resighting datasets have also been cited as evidence of coastal migration in the Atlantic Coast breeding population of Piping Plover. Birds banded in Canada and Maryland have been seen in other areas along the Atlantic Coast (Loegering 1992; Amirault et al. 2005). However, such observations are extremely limited because of the scarcity of banding studies of this Piping Plover subpopulation in the U.S. (USFWS 2009a).

Pompei and Cuthbert (2004) presented a comprehensive list of recorded stopover locations and explained the general scarcity of clear Piping Plover migratory stopover observations as a result of small migratory flocks and ephemeral stopover visit durations. However, a general tendency toward low utilization of stopover sites by migrating Piping Plover, as suggested by our geospatial analysis and as is known for inland-breeding populations of Piping Plover, is also consistent with the observations compiled by Pompei and Cuthbert (2004), USFWS (2009a), and with the acknowledgement by USFWS in the most recent 5-yr review of the population status of Piping Plover that the migration pattern and use of stopover habitat by the Atlantic Coast breeding population of this species remain poorly understood (USFWS 2009a).

It is also evident from the wintering distribution of Piping Plover that they are not constrained to taking strictly coastal or over-land migratory pathways. During the 2006 Piping Plover winter census, a wintering population of 417 individuals was discovered in the Bahamas, comprising roughly 10% of the entire wintering Piping Plover population (Elliot-Smith et al. 2009). Even larger numbers of wintering Piping Plover have been recorded in the Bahamas during the winter of 2010–2011 (A. Hecht USFWS, pers. comm.). For these birds, migratory flights of at least 160 km over pelagic environments on the AOCS during both migrations can be confidently assumed (Elliot-Smith et al. 2009; USFWS 2009a).

Shortcutting vs. Coasthugging

Both the shortcut and coasthugger hypotheses assume a predominantly coastal migration pattern; hence, the apparently noncoastal migration pattern of Atlantic Coast breeding Piping Plover limits the potential applicability of these hypotheses. To the extent that some coastal migration occurs, these hypotheses are still important for understanding patterns of macroscale exposure to offshore wind facilities. Our ability to evaluate these hypotheses was precluded by the numerical dominance of apparently noncoastal migration patterns shown in our analyses. Furthermore, discriminating between shortcutters and coasthuggers requires the identification of spatial occurrence gaps along the coast, where shortcutters are avoiding sections of coastline in favor of pelagic shortcuts. Such gaps can only be identified if sampling comprehensiveness is sufficient within the study region. While the AKN is uniquely comprehensive, the comprehensiveness broke down when space and time units were finely subdivided to a point where there were too many sampling gaps to be able to unambiguously identify biologically real gaps in the migratory distribution of Piping Plover along the coast.

Implications for Exposure to Offshore Wind Turbines on the AOCS

The extent of the potential exposure of Piping Plover to offshore wind turbines located on the AOCS is difficult to characterize. However, this analysis has provided some evidence that the bulk of migratory activity of the Atlantic coastal breeding population of Piping Plover may be noncoastal; hence, exposure to offshore wind turbines is not likely to be concentrated at certain coastal shortcut locations as was hypothesized by Burger et al. (2011) and as depicted in Figure 3–12. Instead, exposure must be regarded as being widely, even if thinly, spread across the AOCS where long-distance migratory individuals presumably travel as depicted in Figure 3–14 and Figure 3–34. Furthermore, as these figures depict, nonstop, long-distance migratory flight trajectories may also expose Piping Plover to wind facilities located on land, particularly if Atlantic Coast breeders winter along the Gulf Coast (currently poorly known).

Some degree of exposure is likely within the AOCS, as at least 10% of the wintering population of this species (Bahamian winterers) must make significant flights over pelagic environments to move seasonally between breeding and wintering grounds (Elliot-Smith et al. 2009) and other birds of the Atlantic population winter in the Carolinas, Georgia, and Florida (Gratto-Travor et al. 2009).

Based on the pattern of noncoastal, and likely nonstop migration, combined with the known wintering distributions of Piping Plover in the southeastern U.S., Mexico, and the Caribbean (Elliot-Smith et al. 2009), the most parsimonious hypothesis for where the Atlantic Coast breeding Piping Plover migrate is that they fly in the shortest trajectory between their wintering and breeding grounds. If this is the case, the majority of the population would traverse narrow segments of the AOCS en route (Figure 3–34). Bahamian, Caribbean, and southeastern U.S. Atlantic Coast winterers may be especially likely to include pelagic portions of their routes over the AOCS.

One key remaining unknown is the extent of Atlantic Coast breeders that winter along the U.S. coast of the Gulf of Mexico. According to the most recent winter census for Piping Plover, 73% of Piping Plover winter along the coast of the Gulf of Mexico (Elliot-Smith et al. 2009). This includes all inland as well as Atlantic coastal breeding populations. The very limited extent of banding and resighting data available for the Atlantic Coast breeding population of Piping Plover indicates that some of these individuals winter along the Gulf Coast of Florida (USFWS 2009a). The wintering locations for this breeding population remain largely unknown, however (USFWS 2009a), and could include significant numbers of Gulf Coast winterers. It is possible that such birds take largely inland migratory routes, which would potentially expose them to collision risk at inland migratory hazards, including wind energy facilities, as depicted in Figure 3–34.

There is, therefore, likely to be some macroscale exposure to offshore wind turbines for Piping Plover. This exposure is most likely widely dispersed throughout the AOCS, rather than concentrated in a few shortcutting spots near the coast, although elevated exposure in coastal and near-shore environments is also suggested by the well-known coastal affinities of this species with the possible exception of during migratory flights. Further research is necessary to characterize the extent and the spatiotemporal patterning of this exposure. In particular, the attachment of tracking devices such as light-sensitive geolocators has great potential to elucidate Piping Plover offshore wind exposure on the AOCS as this technology could provide direct evidence of specific migratory trajectories taken by individual birds as they pass through this region. Banding/resighting studies would advance knowledge germane to this issue by shedding light on the extent of Gulf Coast wintering by Atlantic Coast breeding individuals.

Similar to Red Knot, it is important to note that the occurrence of Piping Plover in a given portion of the AOCS during a given time of year constitutes macroscale exposure (Burger et al. 2011), which is a necessary, but not sufficient, condition for this species to be at risk of collision with wind turbines. The extent of exposure at other scales remains largely unknown (Burger et al. 2011). Such knowledge should be sought through further research efforts. In particular, migratory flight height of Piping Plover in pelagic environments must be characterized to determine mesoscale exposure (Burger et al. 2011). At present, the migratory flight height of Piping Plover is unknown (Burger et al. 2011). Furthermore, the ability of Piping Plover to avoid turbines if they do fly at rotor swept altitudes through an offshore wind facility on the AOCS must be characterized to determine microscale exposure (Burger et al. 2011). This is also currently unknown. One factor, also currently unknown, that is likely to affect the ability of Piping Plover to avoid collisions with wind turbines is whether they are diurnal or nocturnal migrants. If the latter is the case, they could be more susceptible to colliding with wind turbines, as they would be migrating under low visibility conditions. However, it is also possible that nocturnal migration behavior might be linked to higher altitude flight, in which case mesoscale exposure would be low.

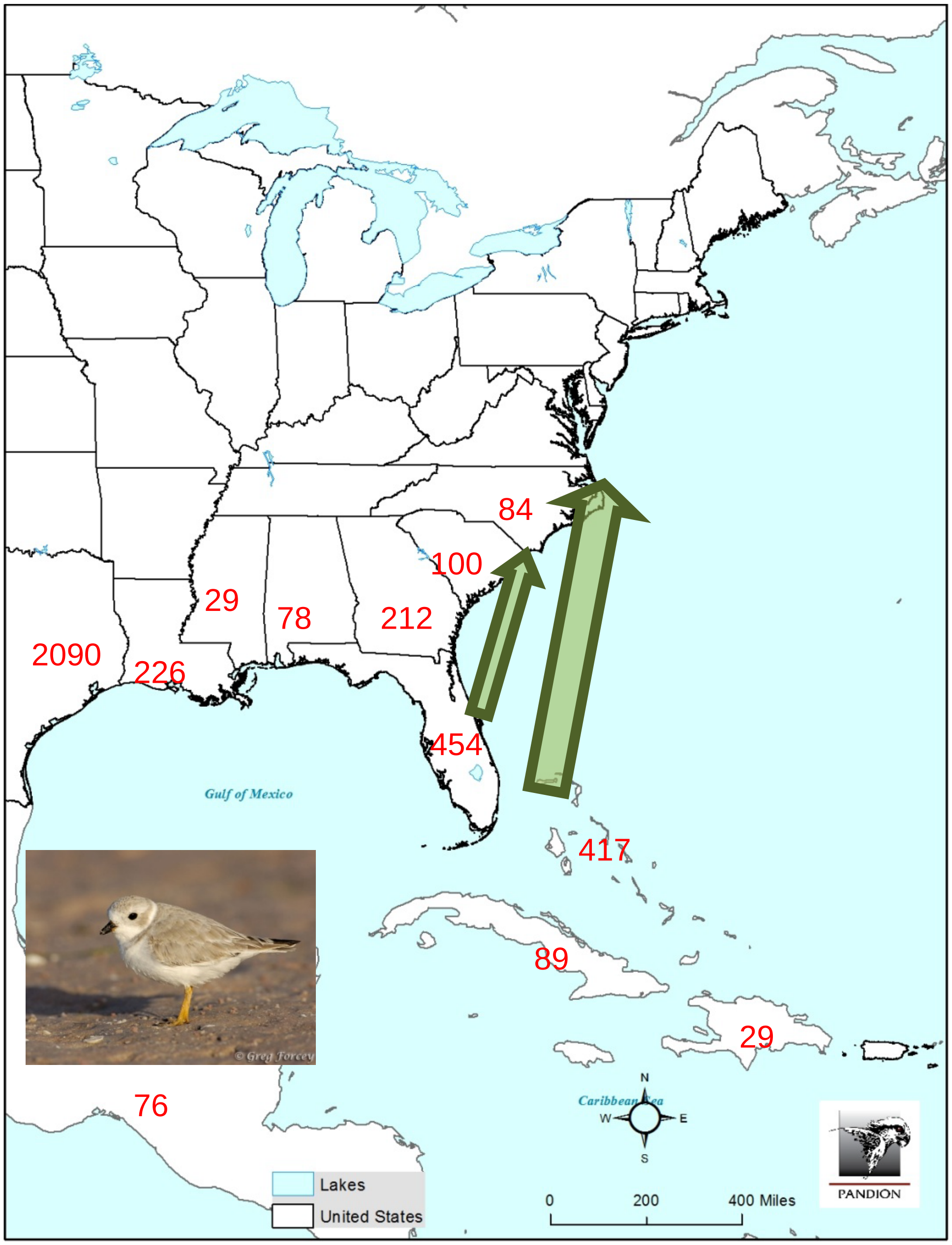

Figure 3–34. Predicted Piping Plover exposure during spring migration from winter grounds to breeding grounds. Red numbers represent numbers of Piping Plover observed in various localities in the 2006 Piping Plover Census (Elliot-Smith et al. 2009), and the green arrows are drawn roughly in proportion to these subpopulation sizes. The spatial pattern of exposure during fall migration would presumably be the same, but with arrow directions reversed.

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3.5 Avian Collision Mortality at a Coastal Wind Turbine on Cape Cod, Massachusetts[5]

3.5.1 Abstract

We characterized avian collision mortality at a 660-kW coastal wind turbine located on the shoreline of Cape Cod, Massachusetts, within 12 km of the nesting grounds of federally endangered Roseate Terns (*Sterna dougalli*). Over 3 yrs, we conducted systematic carcass searches and surveys to account for scavenger activity and searcher efficiency. Overall, we conducted 406 searches, found 4 avian carcasses, and estimated that the wind turbine caused between 1.8 and 3.3 avian fatalities/yr. These values are similar in magnitude to mortality measured at wind turbines in terrestrial environments. Our findings, combined with reports from other coastal wind farms, suggest that Osprey (*Pandion haliaetus*) may be particularly vulnerable to colliding with wind turbines. In contrast, Roseate Terns were not observed among fatalities in this study, even though they regularly forage in adjacent waters and occasionally fly in close proximity to the wind turbine. Further research will be needed to better characterize coastal bird species vulnerable to wind turbine collisions so that facilities may be sited in areas with minimal environmental impact.

3.5.2 Introduction

Collisions between birds and wind turbine rotors can pose a serious challenge to wind energy development, especially when threatened or endangered species could be at risk. Studies have shown that avian collision mortality is highly dependent upon wind turbine characteristics, topography, and characteristics of the surrounding avian community (Kuvlesky et al. 2007; Drewitt and Langston 2008), making wind farm siting an important consideration in wildlife conservation (Hüppop et al. 2006; Allison et al. 2008; Burger et al. 2011).

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[5] Vlietstra, L.S., C. Gordon, W. Warren-Hicks, J. Newman, and M.S. Patrick (*in prep*). Avian collision mortality at a coastal wind turbine on Cape Cod, Massachusetts. Manuscript in preparation for submission to peer-reviewed technical journal.

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Most information about avian collisions with wind turbines comes from studies conducted at inland wind farms where collision risk is assessed for terrestrial species (Kerlinger et al. 2000; Osborn et al. 2000; Madders and Whitfield 2006; Smallwood and Thelander 2008). This focus is particularly evident in the U.S., where all wind-generated power is produced onshore (American Wind Energy Association 2010). Numerous proposals exist, however, for wind turbine construction in coastal and offshore settings in the U.S. For example, 12 wind farms are currently under formal consideration for construction in offshore U.S. waters, one of which was recently approved by the U.S. Department of Interior for construction off Cape Cod, Massachusetts, in Nantucket Sound. This project is scheduled to become the nation's first offshore wind farm (American Wind Energy Association 2010). Several states (e.g., Massachusetts, New Jersey, and Rhode Island) have also recognized the potential for coastal regions to generate wind power and have already constructed wind turbines along their coastlines (American Wind Energy Association 2010).

Studies from coastal and offshore wind farms in Europe indicate that, like terrestrial birds, waterbirds are susceptible to colliding with wind turbine rotors (Desholm et al. 2006; Fox et al. 2006; Everaert and Stienen 2007; Desholm 2009). As wind energy development in the U.S. continues to expand along the coast, more information will be needed on collision mortality among coastal birds so that facilities can be sited in areas that minimize impacts on vulnerable species.

In this study, we characterize avian collision mortality at a single coastal wind turbine located in the northeastern corner of Buzzards Bay on the shoreline of Cape Cod (Figure 3–35). The narrow waters adjacent to the turbine are used by many coastal birds, including Roseate Terns (*Sterna dougalli*), a federally endangered species throughout its North American range (Gochfeld et al. 1998). Because nearly half of the North American population breeds on two small islands in Buzzards Bay, threats to these nesting birds can have potentially serious implications for the population as a whole. To characterize avian collision mortality at the study site, we performed systematic carcass searches around the wind turbine and conducted additional surveys to account for biases introduced by scavenging activity and searcher inefficiency.

3.5.3 Materials and Methods

This study was conducted at the 660-kW Vestas wind turbine located on the 52-ac campus of the MMA in the town of Buzzards Bay, Barnstable County (41.75 N, 70.62 W). The wind turbine tower is 50 m high and the rotor is 47 m in diameter with a maximum blade height of 73.5 m and maximum velocity of 28.5 rpm.

Constructed in Apr 2006, the wind turbine stands on land approximately 100 m from the shoreline of Buzzards Bay and 250 m from the Cape Cod Canal. Birds common in these waters include Common Loons *(Gavia immer*), Double-crested Cormorants (*Phalacrocorax auritus*), various herons (*Ardea herodias*, *Butorides virescens*), Common Eiders *(Somateria mollissima*), Roseate and Common terns (*Sterna dougalli, S. hirundo*), and numerous gulls (*Larus argentatus*, *L. delawarensis*, *L. marinus*, *L. atricilla*). Osprey (*Pandion haliaetus*) are also common and nest nearby. Seasonally abundant shorebirds include various plovers (*Charadrius* spp.), Greater Yellowlegs (*Tringa melanoleuca*), and various sandpipers (*Calidris pusilla, C. minutilla*).

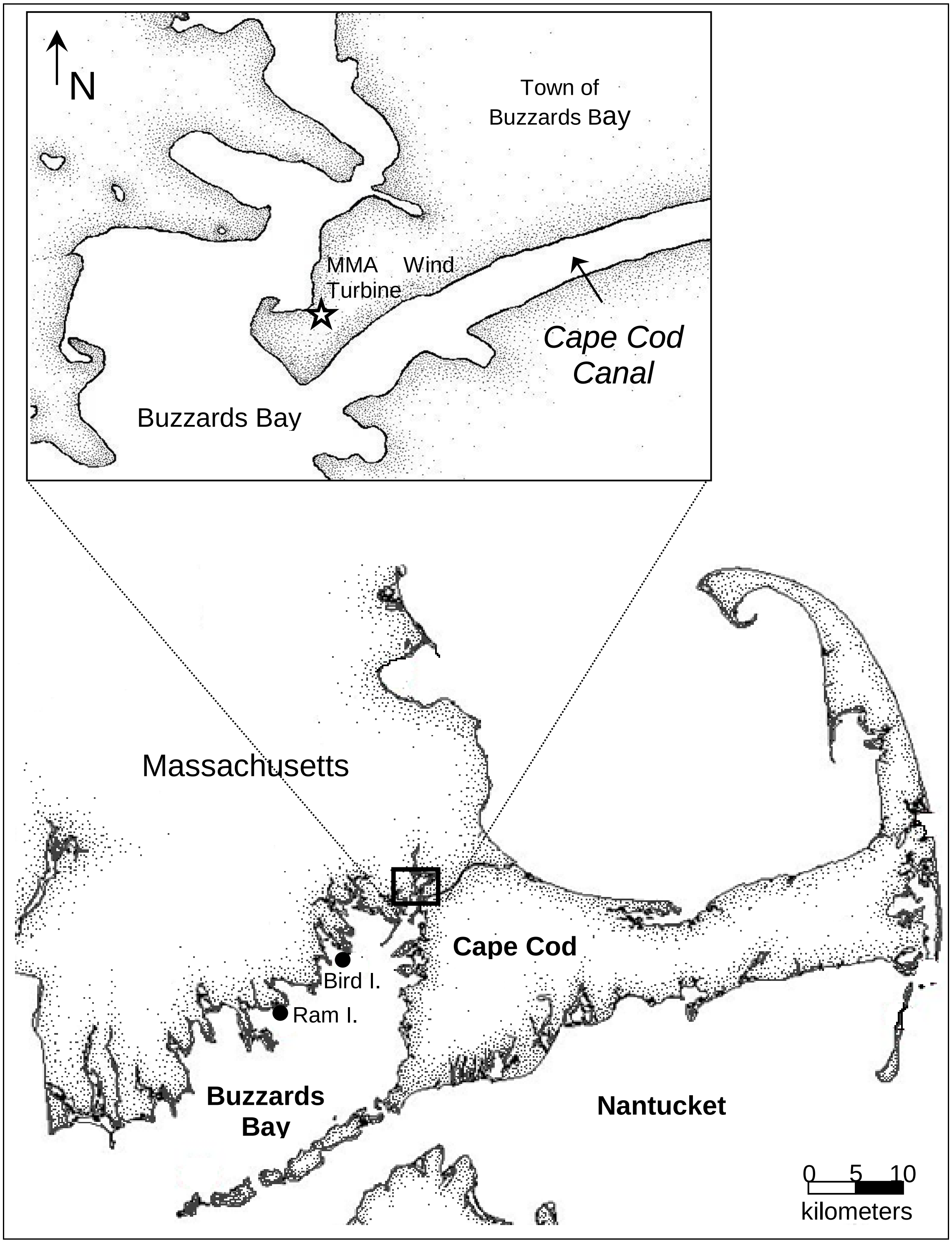

Figure 3–35. Map of study site showing the location of the 660-kW Vestas wind turbine (star) relative to Roseate Tern nesting colonies on Bird and Ram Islands, Buzzards Bay, Massachusetts.

Carcass Searches

We characterized avian collision mortality by conducting systematic searches for bird carcasses on the ground within 75 m of the wind turbine, a distance equivalent to the maximum height of the wind turbine rotor. We defined this area as the “primary search area” (PSA). Carcass searches were conducted at least 3 times/wk from 24 Apr to 30 Nov 2006, 15 Apr to 30 Nov 2007, and 15 May to 20 Sep 2009.

During each carcass search, an observer walked through the entire PSA for 30 min, inspecting the ground for dead birds. Habitats within the PSA were variable, consisting of 79% mowed lawn or paved roads, 14% salt marsh habitat, and 1% sandy beach. We also inspected the slanted rooftop of a utility building (2% of PSA; hereafter, included in mowed lawn area calculations) and the rooftops of vehicles present at the time of the search. Areas inaccessible to us and therefore not inspected included the flat roof of a second utility building (2%) and dense shrubs (*Rosa rugosa*; 2%; Table 3–12).

If no birds were found during a search, we recorded the absence of carcasses. If a carcass was found, we recorded the bird’s species and location within the search area, including its distance from the wind turbine and the type of habitat where the bird was found. We also described any visible injuries to the bird. Carcasses in good enough condition for cause of death to be evaluated were stored in a freezer before they were submitted to Tufts University Cumming School of Veterinary Medicine Wildlife Clinic, where experts determined whether injuries were consistent with a collision with the wind turbine.

Scavenging Activity

Carcass searches alone do not yield accurate estimates of avian mortality because scavengers may remove carcasses before they are detected by observers. Surveys must therefore be conducted to estimate scavenging activity and develop a correction factor for collision mortality calculations (Morrison 2002; Canadian Wildlife Service 2007; Pennsylvania Game Commission 2007). In 2006 and 2007, we characterized scavenging activity at the study site by placing 10 thawed, feathered Japanese Quail (*Coturnix japonica*) carcasses throughout the PSA and monitoring how long each carcass remained in place. An observer monitored the carcasses daily, noting the condition of each until it was no longer present. We conducted these surveys twice per year, obtaining 20 carcass persistence measurements in each year.

Table 3–12

Proportion of primary search area (PSA) covered by various habitat types and structures.

	Proportion of Entire PSA	Proportion of Searched PSA
Searched areas		
Mowed lawn and paved road (A_L)	0.81	0.84
Salt marsh (A_M)	0.14	0.15
Sandy beach (A_B)	0.01	0.01
Areas not searched (A_U)		
Shrubs	0.02	na
Rooftop	0.02	na

To develop a correction factor for scavenging activity, we determined the time (in hours) that each quail carcass remained in the field before it was removed by a scavenger. We used this information to calculate the proportion of quail removed by scavengers after 1 hr and each hour thereafter. Proportions were determined separately for 2006 and 2007. We plotted the proportion of carcasses removed over time and fitted a logarithmic function to the data from each year. We used these functions (Table 3–12) to estimate the probability that a carcass had been scavenged prior to each carcass search, $p_{scav,n}$, where n is the number of hours passing since the last search. We averaged $p_{scav,n}$ from all carcass searches conducted that year, which yielded a scavenging activity correction factor, P_{scav}.

In 2009, we used a different method for calculating P_{scav}, one that took into account habitat-specific scavenging rates and seasonal changes in the foraging habits of scavengers. Instead of monitoring quail persistence in the PSA, we placed quail throughout three “offsite locations.” Each offsite location was located within 75–400 m of the wind turbine and was presumed to support the same scavenger species active within the PSA. Locations were approximately equal in size to the PSA and each consisted of a single habitat type: mowed lawn (*L*), salt marsh (*M*), or sandy beach (*B*). Surveys were conducted three times in each offsite location with one round of surveys conducted in Jun, one in Jul, and one in late Aug–early Sep. In total, 13–17 quail were deployed in each offsite location during the study. To avoid “swamping” scavengers with prey items (Smallwood et al. 2010), we placed no more than four quail in the field at one time.

As before, we calculated the proportion of carcasses scavenged after each hour. This year, however, we calculated proportions separately for each offsite location. We plotted these proportions as a function of time and fitted a logarithmic function to each of the three datasets (Table 3–13). We used these functions to determine the probability that a carcass had been scavenged from mowed lawn ($p_{scav,n,L}$), salt marsh ($p_{scav,n,M}$), and sandy beach ($p_{scav,n,B}$) habitat since the previous carcass search was conducted. We multiplied $p_{scav,n,L}$, $p_{scav,n,M,}$ and $p_{scav,n,B}$ for each carcass search by the proportion of the PSA (*searched* habitats only) that consisted of lawn, salt marsh, and beach habitat, respectively (Table 3–12). Then we summed the products: $p_{scav,n} = (A_M \times p_{scav,n,L}) + (A_B \times p_{scav,n,M}) + (A_L \times p_{scav,n,B})$, where A, the weighted average probability, is the proportion of the PSA area covered by each habitat type (Table 3–12). To derive P_{scav} for that year, we averaged $p_{scav,n}$ from all carcass searches.

Table 3–13

Logarithmic functions used to estimate scavenging rates at the study site during 2006, 2007, and 2009.*

Period	*N*	Equation	R^2
2006	255	$p_{scav,n} = 0.29\ln(n)-0.62$	0.91
2007	481	$p_{scav,n} = 0.23\ln(n)-0.52$	0.93
Jun 2009			
Mowed lawn	199	$p_{scav,n,L} = 0.27\ln(n)-0.50$	0.78
Salt marsh	119	$p_{scav,n,M} = 0.27\ln(n)-0.41$	0.88
Sandy beach	216	$p_{scav,n,B} = 0.27\ln(n)-0.55$	0.82
Jul–Sep 2009			
Mowed lawn	41	$p_{scav,n,L} = 0.38\ln(n)-0.59$	0.71
Salt marsh	67	$p_{scav,n,M} = 0.35\ln(n)-0.57$	0.83
Sandy beach	120	$p_{scav,n,B} = 0.33\ln(n)-0.61$	0.80

* N is the number of hours for which carcass persistence was plotted
n is the number of hours since the previous carcass search

We used two-way analysis of variance (ANOVA) to determine whether scavenging activity (i.e., mean number of hours before quail were scavenged) varied among surveys conducted during three time periods—Jun, Jul, and late Aug–early Sep 2009—and whether activity varied among habitat types. If we detected variation, we calculated $p_{scav,n}$ separately for each time period or habitat type, as appropriate.

Concurrent with scavenger surveys conducted in 2009, we used remotely operated digital cameras (Moultrie®Game Spy M40, Walmart.com) to identify the type of scavengers removing quail carcasses from the study site. Cameras were attached to metal stakes placed within 1–3 m of quail carcasses that were distributed in offsite locations. When a scavenger approached a carcass, it activated an infrared trigger and the camera took a picture of the animal. Cameras were equipped with flash photography, and photographs were stamped with the time of day. We deployed no more than four cameras at one time, rotating cameras among habitats throughout the study period.

Searcher Efficiency Trials

Another source of bias in estimating collision mortality from carcass searches is the failure by observers to detect carcasses present at the time of the survey (Canadian Wildlife Service 2007; Huso 2011). Imperfect detection may occur due to such factors as carcasses being camouflaged or concealed by vegetation, poor lighting reducing visibility, or insufficient coverage of the search area. We estimated the efficiency with which observers detected carcasses by conducting “searcher efficiency trials.”

In 2006 and 2007, we conducted searcher efficiency trials simultaneously with scavenger surveys. Once an assistant had placed the quail carcasses in the PSA, observers conducted a carcass search and reported the number of quail carcasses detected. We averaged the proportion of quail carcasses detected on each trial to obtain the searcher efficiency correction factor, P_{search}.

In 2009, we used the same offsite locations described for scavenger trials to estimate searcher efficiency and develop mean searcher efficiency values for each habitat type. Instead of fresh quail carcasses, however, we used ten plastic decoys shaped and painted to resemble common shorebirds, such as large sandpipers and plovers, in resting (i.e., sitting on the ground) or feeding positions. Decoys allowed us to conduct more frequent searcher efficiency trials without attracting scavengers to the site by placing additional carcasses in the field. Searcher efficiency was evaluated two times (Jul, Aug–Sep) in one observer and three times in two other observers (Jun, Jul, Aug–Sep) in each of three offsite locations. We defined searcher efficiency at each offsite location as the mean proportion of decoys detected ($p_{search,M}$, $p_{search,B}$, $p_{search,L}$).

Before calculating P_{search}, we used two-way ANOVA to evaluate whether searcher efficiency differed among surveys conducted in Jun, Jul, and Aug–Sep and whether among habitat types. If we detected differences, we calculated $p_{search,M}$, $p_{search,B}$, and $p_{search,L}$ separately for each time period or habitat type, as appropriate.

To determine P_{search} in 2009, we multiplied $p_{search,M}$, $p_{search,B}$, and $p_{search,L}$ by the proportion of the *entire* primary search area covered by the corresponding habitat type: $E = (A_M \times p_{search,M}) + (A_B \times p_{search,B}) + (A_L, \times p_{search,L}) + (A_U \times p_{search,U})$, where searcher efficiency in habitats that were not searched ($p_{search,U}$) was 0.

Avian Collision Mortality

We used data collected from carcass searches, scavenger surveys, and searcher efficiency trials to estimate avian collision mortality (*CM*) at the wind turbine for each year that the study was conducted: CM = # observed fatalities × (1 + P_{scav}) × (1 + [1- P_{search}]). We divided CM by 0.66 mW to determine the number of avian fatalities per megawatt power capacity of the wind turbine.

3.5.4 Results

Carcass Searches

We conducted a total of 406 carcass searches (Table 3–14) and found four avian carcasses. One carcass was an Osprey that had injuries consistent with a collision, including multiple bone fractures, a crushed skull, and a severed wing. It also had a 22-cm Blue-back Herring *(Alosa aestivalis*) in its talons. The second carcass was a Laughing Gull, which also had injuries consistent with a collision: wing bone fractures and a severed head. The third carcass, that of a Great Black-backed Gull (*L. marinus*), had been heavily scavenged and its likely cause of death could not be determined. However, because this species regularly flies at the height of the wind turbine rotor (Vlietstra 2007) and because it had multiple bone fractures and occurred in close proximity (<10 m) to the wind turbine, we considered it a collision fatality. The fourth bird was a Common Grackle (*Quiscalus quiscula).* It was found on a paved road and had been run over by a vehicle, making it impossible to determine the original cause of death**.** Nevertheless, it was found within the PSA, so we included it in our analysis.

Table 3–14

Number and timing of carcass searches conducted at the MMA wind turbine, Buzzards Bay, Massachusetts.

Parameter	2006	2007	2009
No. carcass searches	209	134	63
Apr–May	23	40	10
Jun–Jul	56	31	29
Aug–Sep	67	38	24
Oct–Nov	62	25	0
% carcass searches			
00:01–08:00	45%	19%	73%
08:01–16:00	34%	51%	25%
16:01–12:00	21%	30%	2%
No. hrs between searches (*n*)			
Mean ± SE	25 ± 1	42 ± 4	49 ± 4
Range	2–136	4–247	4–144

Scavenging Activity

Overall, we monitored scavenging activity on 86 quail carcasses, which remained in the field for an average of 44.1 (±6.3) hrs before being removed by scavengers. In 2006, scavengers removed an estimated 24% (±1%, P_{scav} = 0.24) of carcasses from the primary search area before they could be detected by observers. In 2007, they removed 25% (±2%, P_{scav} = 0.25).

In 2009, carcass persistence did not differ among offsite locations, but they did persist for longer periods of time during Jun than in Jul–Sep (location: $F_{2,53} = 0.61$, $P = 0.548$, season: $F_{2,53} = 4.12$, $P = 0.023$, location × season: $F_{4,53} = 0.31$, $P = 0.870$; Figure 3–36). Therefore, we calculated $p_{scav,n}$ separately for searches conducted during those times. In 2009, scavengers removed an estimated 69% (±4%, P_{scav} = 0.69) of carcasses in the primary search area.

During the study, we deployed game cameras alongside 29 quail carcasses (Table 3–15). On 13 occasions, cameras captured images of scavengers. Six images showed quail scavenged by opossums (*Didelphis virginiana*), four by raccoons (*Procyon lotor*), two by domestic cats (*Felis catus*), and one by an American Crow (*Corvus brachyrhynchos*). Sample sizes were too small for robust statistical analysis, but we did observe general differences in the species composition of scavengers active in each habitat type (Table 3–14). The speed with which scavenger species removed quail carcasses from the field did not appear to differ among species (Table 3–14). Most (11 of 13) photographed scavengers consumed quail during the night, between 20:26 and 05:09. Scavengers active during daylight or dusk included the American Crow (15:49) and an opossum (19:44). In general, game cameras proved to be relatively inconsistent in their ability to capture photographs of scavengers, as less than half of those deployed resulted in photographs where animals could be identified (Table 3–14). In cases where photographs were not obtained, cameras failed to trigger or yielded images that did not include the scavenger.

Searcher Efficiency

In 2006, we measured searcher efficiency once for each of the two observers conducting carcass searches and calculated a searcher efficiency correction factor (P_{search}) of 0.42. In 2007, we measured searcher efficiency twice in one observer, with P_{search} = 0.70. In 2009, we measured searcher efficiency three times in two observers and twice in a third observer. Observers detected 100 ± 0% of decoys located in the mowed lawn location ($p_{search,L}$ = 1.00), 100 ± 0% in the sandy beach locations ($p_{search,B}$ = 1.00), and 76 ± 5% ($p_{search,M}$ = 0.76) in the salt marsh location. We did not detect differences in searcher efficiency among locations or seasons (location: $F_{2,32}$ = 0.46, P = 0.637, season: $F_{2,32}$ = 0.17, P = 0.845, location × season: $F_{4,32}$ = 0.01, P = 0.999). After taking into account habitat coverage in the PSA, we calculated P_{search} = 0.93.

Avian Collision Mortality

Avian collision mortality (*CM*) at the wind turbine was 2.0 fatalities in 2006, 3.3 fatalities in 2007, and 1.8 fatalities in 2009. The number of avian fatalities per megawatt capacity ranged from 2.7 to 5.0 avian fatalities/mW/yr (Table 3–16).

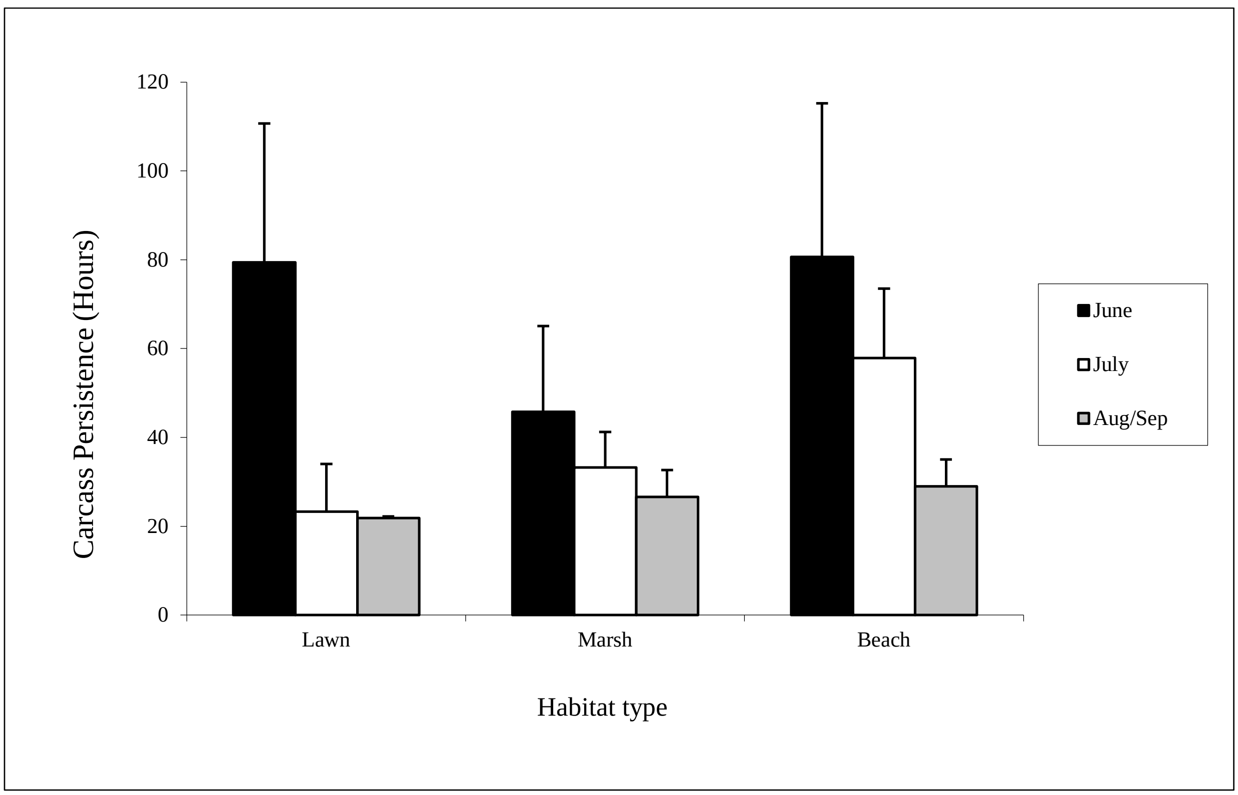

Figure 3–36. Persistence of Japanese quail carcasses in different habitat types during Jun (lawn: n = 5, marsh: n = 5, beach: n = 5), Jul (lawn: n = 3, marsh: n = 6, beach: n = 5) and Aug/Sep, 2009 (lawn: n = 5, marsh: n = 6, beach: n = 6).

3.5.5 Discussion

Avian collision mortality in this study ranged between 1.8 and 3.3 fatalities/turbine/yr, which is similar in magnitude to collision mortality measured at wind turbines elsewhere, including those in terrestrial environments. For example, Erickson et al. (2001) and Kuvlesky et al. (2007) reviewed several studies conducted in both the U.S. and Europe and found that wind turbines usually cause between 0.0 and 4.5 avian fatalities/turbine/yr. Higher values (16 to >30.0 fatalities/turbine/yr) have been recorded in locations where wind turbines are sited in areas of high avian density (e.g., Everaert and Stienen 2007; Newton and Little 2009). We recognize that comparisons among studies should be made with caution since authors have used a variety of methods to calculate collision mortality (Huso 2011). Nevertheless, our results are within the same order of magnitude as mortality measured on a per-turbine basis at most other sites, regardless of their proximity to water.

Table 3–15

Species photographed while scavenging quail carcasses at the MMA wind turbine, Buzzards Bay, MA, 2009.

Parameter	# Cameras Deployed	# Scavengers Photographed	PHOTOGRAPHED SCAVENGERS			
			Raccoon	Opossum	Domestic Cat	American Crow
Habitat						
Salt marsh	16	7	2	5	0	0
Lawn	3	2	2	0	0	0
Sandy beach	10	4	0	1	2	1
Carcass persistence (hrs)						
N	na	na	4	6	2	1
Mean	na	na	49.7	19.8	40.7	5.5
SE	na	na	3.6	23.5	2.8	0.0

Table 3–16

Annual collision mortality at the 660-kW wind turbine (2006–2007 and 2009).*

Year	# Observed Fatalities	P_{scav}	P_{search}	CM^a	CM/MW^b
2006	1	0.24	0.42	2.0	3.0
2007	2	0.25	0.70	3.3	5.0
2009	1	0.69	0.93	1.8	2.7

*(CM: no. fatalities/year)

[a] CM = # observed fatalities × (1 + P_{scav}) × (1 + (1- P_{search}))

[b] CM/MW = CM/megawatt

Differences between collision mortality at our site compared to collision mortality at inland sites were observed in the composition of avian species colliding with the wind turbine. Naturally, collision fatalities observed in this study reflected the wind turbine's coastal location, with fatalities consisting of an Osprey, Laughing Gull, and Great Black-backed Gull. A Common Grackle was also found.

Osprey are common members of coastal avian communities throughout their breeding and wintering ranges and the only raptor species in North America whose diet consists almost exclusively of fish (Poole et al. 2002). We often saw this species flying in close proximity to the wind turbine, either soaring in airspace above the rotor or taking a direct path through wind turbine airspace at altitudes consistent with the rotor swept region. Because Osprey frequently captured food in the water adjacent to campus, it was also not uncommon to see Osprey flying past the wind turbine rotor while clutching fish prey (L. Vlietstra, pers. obs.).

Similar observations of Osprey flying near wind turbine rotors have been made elsewhere along the coast. For example, Osprey were common in the wind turbine airspace of a small wind farm consisting of five turbines in coastal New Jersey, where the New Jersey Audubon Society (2009) found four Osprey carcasses after just 2 yrs of monitoring. Scientists conducting pre-construction assessments of avian collision risk at proposed coastal wind farms elsewhere also acknowledge the "high" or "significant" risk that wind turbines pose to this species (Mendelsohn and Crowley 2009; Sinclair Knight Mertz 2009).

Diurnal raptors, in general, appear to be particularly susceptible to wind turbine collisions. Several studies have shown that some eagles, hawks, kestrels, and vultures are relatively abundant among collision fatalities at wind farms throughout their inland range but especially along migration routes (Barrios and Rodríguez 2004; Smallwood and Thelander 2008). One explanation for this trend is that raptors (large species in particular) require vertical air currents to gain sufficient flight altitude for soaring, so birds concentrate in areas with consistently high winds and steep topography, such as mountain ridges or coastal bluffs. These settings also tend to be ideal locations for harvesting wind, and collision rates may reflect the high density of raptors using those areas (Barrios and Rodríguez 2004). DeLucas et al. (2008) propose that among raptors the largest species (those with high wing loading) experience the greatest collision risk because they are least likely to fly above wind turbine rotors without the help of strong updrafts.

Some authors also suggest that raptors are more susceptible to collisions than other birds because of their foraging behavior. Raptors become so focused on hunting prey that they fail to detect nearby threats, such as wind turbine blades (Orloff and Flannery 1992). We did not observe this behavior directly, but our results support the idea that Osprey are more vulnerable to collisions while engaged in certain behaviors, such as foraging. The Osprey we found was carrying a fish when it collided with the wind turbine rotor.

Another plausible explanation, however, is that raptors simply fail to perceive the turbine blades as threats. Research conducted at a 68-turbine wind farm on the island of Smøla, coastal Norway, suggests that this may be the case for White-tailed Eagles (*Haliaeetus albicilla*). Eagles flying over the island show no effort to avoid the wind turbine rotors, and eagle collision mortality is remarkably high (Bevanger et al. 2009).

In any case, wind energy development along the coast may become a real concern for Osprey if collision mortality in a local population occurs repeatedly over time. Species that are normally long-lived, such as Osprey, usually produce relatively few young per year, making populations less resilient to new sources of mortality and potentially delaying population recovery (Musick 1999). More research is needed on collision mortality at other coastal wind farms where Osprey breed and overwinter to determine whether our observations are representative of interactions between Osprey and wind turbines throughout their range.

Unlike raptors, gulls are rarely the focus of conservation efforts, even though studies suggest that they too are susceptible to collision mortality. Not only did gulls represent half of the collision fatalities detected in this study, but they are also prominent among collision fatalities at other coastal wind farms in both the U.S. (New Jersey: Mizrahi et al. 2008) and Europe (Belgium: Everaert and Stienen 2007; England: Newton and Little 2009). Gulls are often plentiful in coastal avian communities, and their prominence among collision fatalities may be a function of their relative abundance in wind turbine airspace. On the other hand, gulls may be vulnerable to collisions because do not avoid spinning blades. We are not aware of any studies evaluating flight avoidance behavior, specifically in gulls. Such information could inform management decisions in places where gulls hold a special conservation status. For example, if wind turbines were to become practical off the coast of northeastern Canada or in Arctic regions, pre-construction surveys would be advisable to determine the potential impacts of wind facilities on threatened Ivory Gulls (*Pagophila eburnea*), which breed and overwinter in those regions (Mallory et al. 2008).

Roseate Terns were not detected among collision fatalities in this study, even though nearly 3,000 of them breed on Bird and Ram islands, less than 12 km from the study site (Spendelow et al. 2008). Roseate Terns also regularly forage in shallow water adjacent to campus during midsummer. Near-shore surveys conducted in the early 1990s revealed flocks containing 10–75 Roseate Terns foraging alongside Double-crested Cormorants just 500–1,000 m away from where the wind turbine now stands (Heinemann 1992). During our study, we often saw flocks of 3–10 Roseate Terns foraging within several meters of the shoreline nearest the wind turbine.

Roseate Terns also occasionally fly within 50 m of the wind turbine, although passage rates were low relative to more abundant species at the study site. Surveyors at the MMA wind turbine recorded up to 1.5 Roseate Terns passing through wind turbine airspace per hour on days of peak activity (L. Vlietstra, unpublished data).

Common Terns, on the other hand, were much more abundant at the study site than Roseate Terns (approx. 24:1) and actively avoid the spinning wind turbine rotor (Vlietstra 2007). Consistent with observations of Common Terns avoiding the rotor, we did not detect any Common Tern carcasses during the 3 yrs of the study. Common Terns closely resemble Roseate Terns in terms of body size, flight behavior, and reproductive schedule (Burger et al. 2011), and they nest alongside Roseate Terns on Bird and Ram islands. If Roseate Terns are similar to Common Terns with respect to their response to wind turbine rotors, it is possible that we detected zero Roseate Tern fatalities because Roseate Terns also avoid the wind turbine rotor. Tern observations at Horns Rev wind farm offshore of Denmark support the view that avoidance behavior is not unique among Common Terns. Common Terns and three other tern species, including Arctic Terns (*S. paradisaea*), Little Terns (*S. albifrons*), and Sandwich Terns (*S. sandvicensis*), were significantly less abundant in post-construction surveys conducted at the 80-turbine wind farm than they were before the wind turbines were constructed (Petersen et al. 2006).

Our finding of zero Roseate and Common Tern collision fatalities in this study is important because collision risk potentially posed to these federal- and state-listed species was the focus of environmental review for two offshore wind farms proposed for the waters off Cape Cod (USFWS 2008b; USDOI 2010a). One of these proposals called for 90–120 wind turbines constructed in Buzzards Bay, with one section of the farm located 12 km from Bird Island. Ultimately, this proposal was not pursued by the developers, reportedly due to concerns associated with risk posed to both boaters and Roseate Terns (Clark 2010).

The second project, which has recently received an Outer Continental Shelf lease from the U.S. Department of Interior, calls for 130 wind turbines to be constructed in Nantucket Sound, at Horseshoe Shoal, approximately 30 km from the Roseate Tern nesting colonies. As federally endangered and federally threatened species, respectively, both Roseate Terns and Piping Plovers (*Charadrius melodus*) are of conservation concern in this region. Available research suggests that Roseate Terns could be susceptible to collision mortality if wind turbines are improperly sited. For example, at a coastal wind farm in Belgium, some wind turbines are known to cause between 10.8 and 11.2 fatalities/turbine/yr in Common Terns, Sandwich Terns, and Little Terns. This situation is somewhat unusual because the turbines are located within only 10–200 m of a seabird nesting colony containing a few thousand terns, and those turbines closest to the colony account for most tern fatalities (Everaert and Stienen 2007). Most wind farms are not sited in such close proximity to breeding colonies, but the situation underscores the importance of locating wind farms in areas of relatively low tern density.

After reviewing information on the flight behavior, breeding status, and foraging ecology of Roseate Terns in Buzzards Bay, the USFWS (2008b) concluded that the wind farm would probably have a minor impact on their survivorship, reproductive success, and distribution. Not only do Roseate Terns appear to spend little time near the proposed construction site during the breeding season, but they also appear to spend little time flying at proposed rotor swept altitudes (i.e., 23–134 m). In Apr 2010, the plan to construct a wind farm in Nantucket Sound was approved by the U.S. Department of Interior, and the facility is scheduled to become the nation's first offshore wind farm.

To the extent that observations of Roseate Terns flying near a single wind turbine on a nearby shoreline can be applied to multiple wind turbines located offshore, our observation of zero Roseate Tern fatalities is consistent with the conclusion reached by the USFWS. However, further research is needed to evaluate the strength of such comparisons, as flight behavior around solitary wind turbines may differ from flight behavior around wind farms containing multiple turbines. For example, birds may be less inclined to avoid large wind farms because doing so would require more energy (but see Desholm 2003), or because the farm overlaps with favored foraging grounds or other important habitats (Drewitt and Langston 2006). On the other hand, multiple wind turbines may be easier for birds to detect than solitary ones, making multiple turbines easier to avoid. Observations of migrating geese and eiders flying through a large, 80-turbine wind farm offshore of Denmark suggest that avian avoidance behavior in these species is influenced, at least in part, by the presence of other turbines. While most (99%) birds avoided the wind farm altogether, those that did enter the facility (mostly eiders) lowered their flight altitude as they neared the interior portion of the facility so as to fly below the RSZ (Petersen et al. 2006).

Wind turbine size and rotor speed may also influence avoidance behavior in birds. Wind turbines proposed for construction in Nantucket Sound have rotor diameters of 111 m and maximum rotor velocities of 6–18 rpm, whereas the turbine we studied has a rotor diameter of 47 m and a maximum velocity of 28.5 rpm. Wind turbines proposed for construction over the outer continental shelf are even larger, with rotor diameters of 140 m and spinning velocities of only 3 rpm (J. Woehr, BOEMRE, pers. comm.).

3.5.6 Conclusion

As wind energy development continues to expand along the coast and eventually offshore in the U.S., research into avian species vulnerable to wind turbine collisions will become increasingly important in guiding efforts to site facilities in areas where they will have minimal environmental impact. Although more research is needed to make generalizations about characteristics of vulnerable species in coastal avian communities, our findings suggest that some lessons learned from terrestrial wind farms may be applied to wind turbines in coastal settings. For example, in both environments, raptors appear to be more vulnerable to collision mortality than other species (Drewitt and Langston 2006). In addition, avian collision mortality at coastal wind turbines can be relatively low when they are not located in regions of high avian density (Kuvlesky et al. 2007). High avian densities in coastal settings often occur at breeding colonies, premigratory staging grounds, and on migration routes and foraging grounds, where feeding flocks form over large schools of fish or other prey (Schreiber and Burger 2001). The wind turbine examined in this study appears to have no detectable impact on the survivorship of Roseate Terns nesting and foraging in Buzzards Bay. Nevertheless, serious consideration should be given to the proximity of wind turbines to critical avian habitats when siting future wind energy facilities along the coast.

3.5.7 Acknowledgments

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3.6 A Probabilistic Offshore Avian Collision Risk Model Incorporating Behavioral Avoidance and Formal Uncertainty Analysis[6]

3.6.1 Abstract

A collision based risk model was developed to evaluate the probability and magnitude of avian mortality at offshore wind facilities. A simulation using observational data of Roseate Terns, including avoidance behavior, is used to illustrate the use of the model as a decision tool for siting and operational studies. The modeling approach illustrated in this paper demonstrates the use of model outputs and statistical inference in a decision making context. The paper presents a model that allows the user to test and evaluate avian risk scenarios, including uncertainty in the model inputs. In addition, the model provides a framework for explicitly including observational data on avian avoidance and demonstrates the importance of avoidance on the estimates of total mortality. The model uses observational data on tern avoidance from studies conducted at the MMA and observational data on Roseate Tern flight height from studies at Buzzards Bay, Massachusetts. The risk model enhances elements of the approach used to infer risk to Roseate Terns at the proposed Cape Wind Energy Project (USDOI 2010b), including a collision risk

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model developed and used in the Cape Wind assessment (Bolker et al. 2006), and its mortality predictions for Roseate Terns are roughly comparable (USFWS 2008b). Although data from operating offshore wind facilities are not available at the time of model development, this paper demonstrates an approach that can be used for decision making at future wind facilities. Observational data collected within concentric spheres around the MMA facility are incorporated into the model using Monte Carlo analysis, and a case study example is presented that illustrates the role of avian avoidance studies in estimating avian mortality. In addition, model selection and model parameterization approaches are discussed and illustrated, as well as the use of the probabilistic model outputs in siting decisions. The model developed in this paper can be used with any offshore species for which comparable data and/or expert opinion are available.

3.6.2 Introduction

The development of alternative energy resources in general, and wind power in particular, in the U.S. has been identified as a national priority. Offshore wind has been identified as an integral part of future renewable energy sources in the U.S. because of the extent of the developable resource and the close proximity that many large U.S. cities and electricity consumption load centers have to U.S. shorelines (USDOE 2008). In order to permit the development of offshore wind facilities, BOEMRE and other government agencies are currently involved with the evaluation of environmental impacts of future offshore wind facilities on the AOCS of the U.S. Such evaluations were an integral component of the recent record of decision issued by BOEMRE concerning the Cape Wind Associates' proposed offshore wind facility located on Horseshoe Shoal in Nantucket Sound (USDOI 2010b).

A major issue in the construction of any wind facility is mortality associated with birds encountering the rotating turbine blades, turbine tower, and turbine nacelle. In the Cape Wind case, and in many others, regulators and developers are required to estimate avian mortality before construction begins. In most cases, mathematical models are used to estimate or forecast mortality early in the regulatory process, and the results from the models are used in the permitting and decision making processes. Therefore, the ability of available mathematical models to simulate possible avian mortality becomes an important tool for making reasonable permitting, construction, and remediation decisions. In the case of wind facilities in general, the location of the individual turbines, including distance among turbine towers and geographical layout of the turbines, is known to affect the impact of wind energy on migrating or native birds (Madders and Whitfield 2006). In the case of offshore wind facilities in particular, models and data have been evaluated for offshore migrants (Desholm 2006; Desholm and Kahlert 2005; Desholm and Kahlert 2006). However, models and data for a large number of offshore migrating species are lacking.

Few collision risk models are available for use in assessing collision based mortality. A review of existing models that are used for inland wind facilities is found in Madders and Whitfield (2006). In general, existing mathematical models can be categorized into (1) simple correlations between the rate of mortality and turbine characteristics (Erickson et al. 2001), (2) highly detailed models requiring a large amount of information on the physical characteristics of the turbine geometry and bird size and speed (Tucker 1996a, 1996b; Podolsky 2003, 2005; Band 2000; Band et al. 2005), and (3) models using simple geometry with a minimum of information on the physical characteristics of a turbine (Hatch and Brault 2007; Bolker et al. 2006). Models in each of these categories can be useful depending on available data and the questions of interest. Although research is in progress, few species have been studied in detail, and little definitive site-specific information is available in the case of offshore wind modeling, including the number of birds encountering the wind facility, avoidance behavior of the entire wind facility or turbines individually, angle and height of flight, weather conditions and wind direction, and other variables that may be highly correlated to the probability of avian mortality. One parameter that has been identified as critically important in collision modeling and risk characterization is behavioral avoidance of turbines by birds (Fox et al. 2006; Desholm 2006; Chamberlain et al. 2006). Behavioral avoidance, which may be species-specific, can be difficult to measure accurately.

Choosing a model for offshore mortality estimation is a difficult process given that the experience gained from the use of collision models inland may not be directly translated to offshore conditions. In the risk assessment literature, under conditions of high uncertainty, simple models with a minimum of inputs are generally preferred to more complex models with a large number of inputs (Warren-Hicks and Moore 1998). Over-complication of mathematical models in situations of high uncertainty can lead to high uncertainty in the model predictions, giving decision makers a false sense of accuracy in the model predictions when positive belief may not be warranted. In those cases where many key elements of the process are not well documented, the use of simple models with a corresponding uncertainty analysis focused on the model equation as well as the model inputs can provide decision makers with an understanding of the degree of belief that can be attributed to the model outputs (Warren-Hicks 1999; Warren-Hicks and Hart 2010; Canham et al. 2003). When the model outputs are presented in a decision context, both regulators and developers can use the model as a tool for evaluating the need for remediation options, as well as possible changes in establishing turbine locations.

The Cape Wind modeling approach provides a foundation for exploring the use of models in offshore conditions where high uncertainty exists. The model developed by Bolker et al. (2006) is an example of a model requiring minimal inputs, employing simple geometry and basic probability theory to estimate avian mortality. This paper expands upon the original work of Bolker by directly incorporating observations of turbine avoidance behavior by terns into the published mathematical framework. In addition, we modify the Bolker framework by formally incorporating a risk based approach to decision making based on the model outputs, including the use of a formal uncertainty analysis.

An example of using existing collision risk models in situations of high uncertainty is presented below. At the time of this paper, detailed offshore observations of Roseate Tern behavior and population biology are unavailable. However, useful near-shore and onshore data are available and are used in a case study to illustrate the modeling approach. When data required by the model are available under actual offshore conditions, the information can be assessed and used in the model presented in this paper. The model is not specific to Roseate Terns or any specific tern species. The presented model can be used with data from any offshore species for which comparable data and/or expert opinion are available.

An initial discussion of the field program designed to obtain observations of Roseate Tern avoidance is presented followed by the development of a probabilistic model that includes a formal uncertainty analysis. Roseate Terns were selected as the focal species for this analysis because they are a federally endangered species whose populations are suspected of being negatively impacted by wind energy facilities developed along their offshore migration pathways (Burger et al. 2011).

3.6.3 Tern Avoidance Observations

Field observations of tern avoidance were conducted in the vicinity of a single Vestas 660-kW wind turbine located on the campus of the MMA in Buzzards Bay, Massachusetts. Observations were conducted from 15 May 2010 to 30 Sep 2010. The turbine, installed in Apr 2006, is located on land approximately 100 m from the Buzzards Bay shoreline and 6–12 km from Bird and Ram islands, the second and third largest breeding colonies of Roseate Terns in North America (Spendelow et al. 2008). The wind turbine tower is 50 m in height. The rotor diameter is 47 m with a maximum blade height of 73.5 m, and the maximum rotor velocity is 28.5 rpm. The proposed Cape Wind turbines used as an example in this paper, in contrast, have a nearly 137-m turbine diameter and a rotation of approximately 3 rpm. The slower and larger wind turbines may be more visible to terns in offshore environments.

Common Terns and Roseate Terns both nest on Bird and Ram islands, which are located 11 km and 20 km away from the MMA, respectively. The species are also similar in size, flight behavior, and diet (Safina 1990a; Gochfeld et al. 1998; Nisbet 2002); however, Common Terns are much more abundant at the study site with over 7,000 breeding pairs on the two islands compared to approximately 1,400 pairs of Roseate Terns (Spendelow et al. 2008). The study team observed both Roseate and Common Tern activity nearby and in the immediate vicinity of the wind turbine. Because the flight activity and behavior of the species are similar and Common Terns are more abundant, observations from both species are used to establish avoidance patterns and behaviors in terns.

Behavioral observations of both Common and Roseate Terns were conducted to determine passage rates and flight altitudes of terns in wind turbine airspace, defined as the three-dimensional area within 50 m of all sides of the wind turbine tower and the rotor blades (after Thelander et al. 2003) and to determine whether terns avoided or were attracted to the structure.

When observers detected a tern in wind turbine airspace, they recorded the species (Roseate, Common, or unidentified) and position of the bird relative to three zones pertaining to the bird’s proximity to the wind turbine rotor. Passage rates between the observational zones were calculated by dividing the number of terns observed flying through wind turbine airspace per week by the number of hours behavioral observations were conducted that week.

To determine whether terns avoided or were attracted to certain parts of wind turbine airspace, the region around the turbine was divided into three zones, and the expected frequency of birds in each zone was calculated based on observations of tern density in each zone. Zone 1 encompassed the disk shaped area through which the rotor blades pass (Figure 3–37). This zone has a radius equivalent to the length of one rotor blade (23.5 m) with the associated blade width, and is roughly equivalent to the rotor swept area, as it is often termed in wind-wildlife impact literature.

Zone 2 encompassed a spherical region centered upon the nacelle and with a radius of the rotor blade (23.5 m) minus Zone 1 (Figure 3–38).

The largest area was Zone 3, which we term the rotor airspace, or rotor vicinity, and which encompassed the entire wind turbine airspace minus Zones 1 and 2 (Figure 3–39). Significant differences between the expected frequency of terns entering each zone given the relative volume of each zone and the observed frequency of terns in each zone were used as indicators of behavioral avoidance or attraction to the rotor blades (Zone 1), airspace in the immediate vicinity of the rotor (Zone 2), and the overall wind turbine structure (Zone 3).

Behavioral observations were conducted for a total of 351 hrs during the study period. Individual surveys when wind turbine airspace was continuously monitored ranged in duration from 0.25 to 10.50 hrs with a total of 14 to 22 survey hrs conducted per week. Observations were conducted during all daylight hours and during each of the three phases of the tern reproductive cycle: nesting (15 May to 18 Jun), chick rearing (19 June to 6 Aug), and postbreeding (7 Aug to 20 Sep) periods. Behavioral observations were stratified across time of day with surveys distributed across three time strata: 0500–1100, 1100–1600, and 1600–2100 hrs.

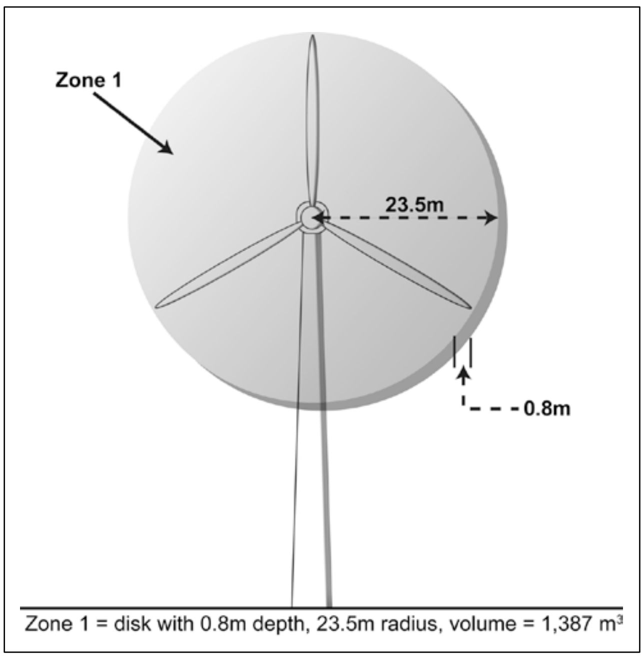

Figure 3–37. Observation Zone 1.

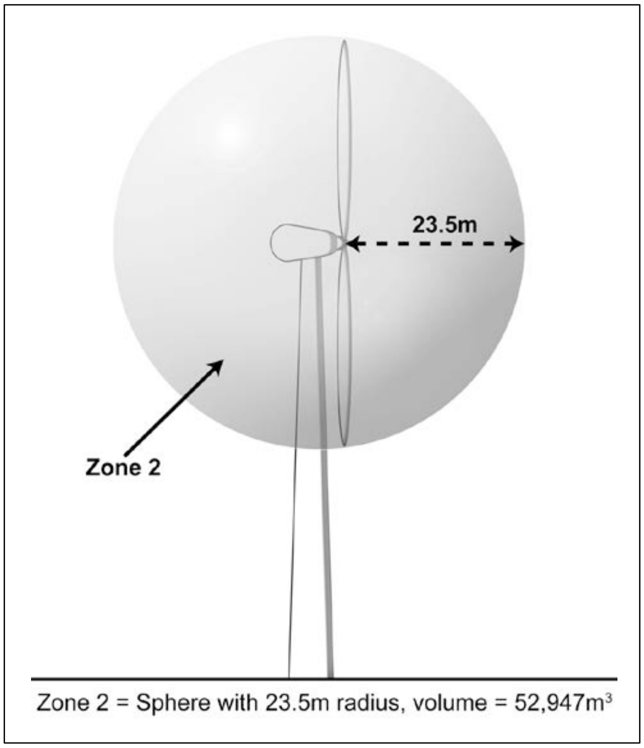

Figure 3–38. Observation Zone 2.

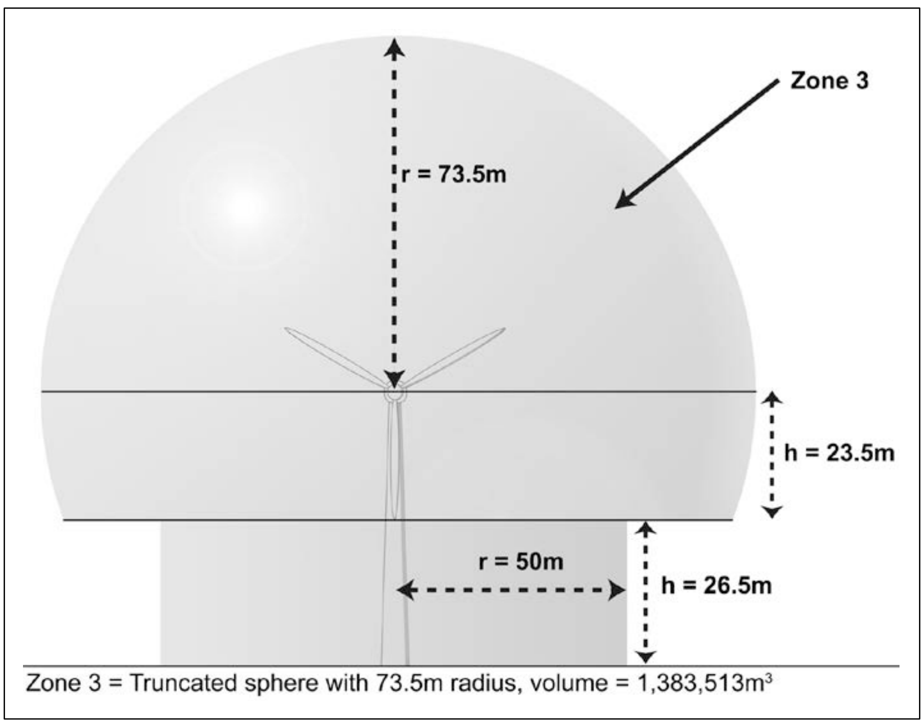

Figure 3–39. Observation Zone 3.

A total of 13,271 terns flying over the water adjacent to the wind turbine were observed. The vast majority (90.4%) were Common Terns. Only 5.2% were Roseate Terns, which were most abundant at the study site during the chick rearing period. Overall, 215 terns were detected in wind turbine airspace (Zone 3). Ten of these sightings involved Roseate Terns; all others involved Common Terns. No terns in wind turbine airspace were recorded as “unidentified” species. Most terns (94%) flew through wind turbine airspace during the chick rearing period.

Observations previously conducted at the MMA wind turbine were used to estimate tern avoidance behavior with respect to wind facilities as a whole (Vlietstra 2007). In that study, the number of terns in Zone 3 while the rotors were spinning was compared to the number of terns in the zone when the rotors were still. This calculation assumes that the terns observe the spinning rotors and change their flight path away from the wind facility. Field team observers consistently observed terns turning away from spinning rotors. During the chick rearing season there were, on average, 83.9% more terns observed in Zone 3 when the rotors were still (34% of the time) as compared with when they rotors were turning (66% of the time). During the postbreeding season, the average difference was 68.6%. Based on this observational evidence, a reasonable avoidance behavior for terns approaching a wind facility could range from approximately 69% to 84% of the individuals avoiding the entire wind facility. Additional observational studies are needed to confirm this finding, but these data are used here for illustration.

In the present study, 203 (94.2%) of the 215 terns in wind turbine airspace (Zone 3) entered when the rotor was spinning (>1 rpm). Data collected when the rotor was still (<1 rpm) were excluded from further analysis. Most of the terns in the vicinity of the MMA turbine (96.2%) flew through Zone 3 of wind turbine airspace, while none flew through Zone 1, the area swept by rotor blades (Table 3–17). Taking into account the volume of each zone, the tern density (or traffic rate) was greatest in Zone 3 (1.45 x 10^{-4} terns/m^3) and lowest (0.0%) in Zone 1 (Figure 3–40). Although no terns were observed in the RSA (Zone 1), prior observational studies at the MMA did indicate that Common Terns do occasionally fly through the RSA (Vlietstra 2008), although no mortality among Common or Roseate Terns was observed during mortality monitoring studies at the turbine location in this study.

Table 3–17

Density of Common and Roseate Terns inside wind turbine airspace.

Parameter	Region Within Wind Turbine Airspace		
	Zone 1	Zone 2	Zone 3
No. Terns[a]	0	2	201
Zone Volume (m^3)	1,387[b]	52,947[c]	1,383,513[d]
Tern Density (no./m^3)	0	3.78 x 10^{-5}	1.45 x 10^{-4}

[a]Includes both common and roseate terns

[b](width of disk) x (πr^2)

[c](4/3 x πr^3) - (Zone 1)

[d](((height of lowest blade tip to ground) x πr^2) + ((height of lowest blade tip to hub) x πr^2) + (4/3 x πr^3 x 0.5)) - (Zone 1 + Zone 2)

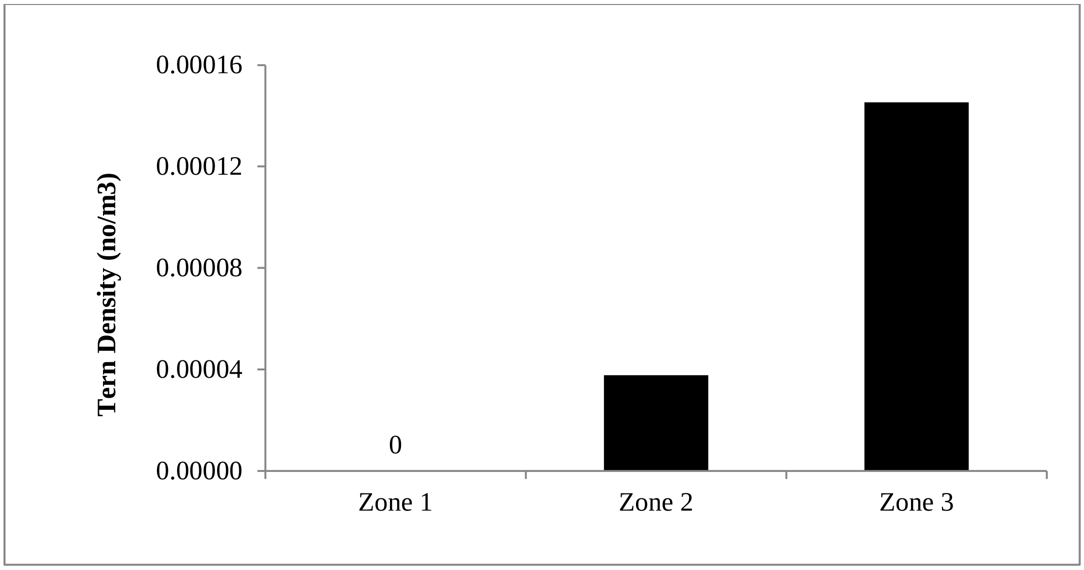

Figure 3–40. Density of terns in observation zones.

3.6.4 Roseate Tern Flight Height Observations

An important input variable to any collision risk model is flight height. If the terns fly above or below the rotor length, the model structure assumes that no encounters and subsequent mortality occur. The assumption can be modified by running the model and substituting the radius of the tower monopole for the length of the blade. Although in reality birds could collide with the tower—particularly at night—tower collisions are considered negligible for this case study.

Roseate Tern flight height data are taken from an avian collision risk assessment conducted for Buzzards Bay Roseate Terns (Podolsky 2008). Boat-based surveys were conducted along five transects running the length of Buzzards Bay during the fall of 2006 and winter, spring, and summer 2007. Cruising at speeds between 8 and 10 knots (9.2 to 11.5 mph), the transects were surveyed twice in 8 to10 hrs depending upon sea conditions. At least two transects were surveyed per week. Two observers were used on the bow with each one surveying birds on his or her side of the boat by continuously visually sweeping 180 degrees from the front to the side of the boat. A third person recorded the bird species (or the lowest possible taxonomic level possible), GPS location, group size, horizontal distance (m) from the boat’s transect line, height above the water (m), time, and behavior (whether the bird is in flight, feeding or resting on the surface, etc.). Sea state and wind speed using the Beaufort scale were also recorded. Flight height data compiled for the entire study are shown in Table 3–18. These data are used in the case study example to represent the probability of Roseate Tern flight height.

Table 3–18

Flight altitude of Roseate Terns at Buzzards Bay, MA.

Height Class (m)	Number of Roseate Terns	Percent
0–3	996	67.9
3–15	386	26.3
15–30	72	4.9
30–60	13	0.9
60 and over	0	0.0
Total	1467	100.0

3.6.5 Risk Based Model Development

The collision risk model is based on best available scientific information that included site specific empirical data as well as expert opinion and historical and current literature on Roseate Terns. Data used in the model are for illustration only and are not intended to represent actual mortality to Roseate Terns in offshore conditions. Few empirical observations on terns near wind facilities are available in the peer reviewed literature (Burger et al. 2011; Hatch and Brault 2007). Observations obtained from the MMA and Buzzards Bay's field programs provide informative data on tern avoidance and flight height and are incorporated into the model.

Figure 3–41 presents the geometry of the Bolker model (Bolker et al. 2006). The model produces two major outputs: (1) the average number of turbine encounters (i.e., the average number of turbines encountered for a specified flight height and path for a given angle of flight [θ]) and (2) the maximum number of turbine encounters for a given flight angle (θ).

In Figure 3–41, illustrative flight paths for a specific angle are shown relative to specific turbine locations (the circles with turbine blade length *B*). If turbines are widely spaced, the average number of turbine encounters for any angle ($E_{avg,\ \theta}$) can be less than one. If turbines are clustered, the average number of encounters for any angle can be greater than one. The maximum number of turbine encounters ($E_{max,\ \theta}$) is both path and angle dependent. Examination of Figure 3–41 illustrates the influence of turbine placement on $E_{max,\ \theta}$.

In the following model, the probability of encountering a turbine blade is assumed to be an independent event. Under this assumption, traditional bird flock behavior is not considered within the model structure. If, for example, groups (i.e., flocks) of birds follow a leader for flight direction and flight height while within the wind facility, the probability of mortality could be higher than provided in this model. In addition, the model does not account for "learning" behavior where birds may increase avoidance based on past experience. An area for future research is the incorporation of avian flock behavior within a probabilistic modeling concept.

Assuming that the probability of surviving any turbine encounter is an independent event and that the probability of surviving any individual encounter is *p,* then the expected mortality probability ($M_{avg,\ \theta}$) is simply

Given the maximum number of encounters as a bird passes through the wind facility (which is path dependent) and again assuming that the probability of surviving any encounter is an independent event, the maximum mortality probability ($M_{max,\ \theta}$) is simply

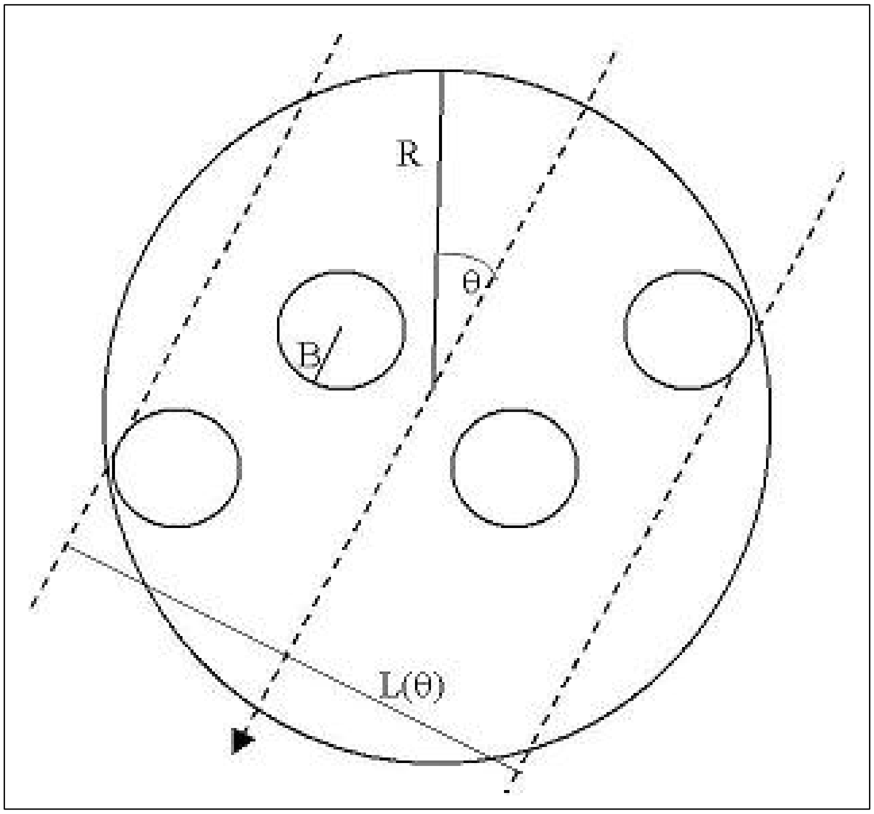

Figure 3–41. Geometry of the Bolker et al. 2006 model. Figure extracted from the original report found at http://www.cs.umb.edu/~eb/windfarm/src/paper072506.pdf. Individual turbines are shown as circles (top down view), with blade length B. Paths through the wind facility at angle θ relative to the radius (R) are shown as dotted lines. The diameter of the wind facility when birds fly on bearing θ is L(θ).

The advantage of the Bolker class of models is the simplicity of the model framework and the relatively low number of model inputs required to generate model outputs. The Bolker model treats the rotors as vertically mounted disks, without thickness, that may be oriented in any direction in response to the wind and estimates the average number of collisions as a function of the following factors:

- Turbine location
- Height of turbine center (i.e., nacelle height)
- Rotor length
- Angle of approach
- Probability of safe passage (i.e., avoidance and other causes)
- Flight height

The Bolker model calculates the average and maximum number of turbines encountered by an individual bird flying through the wind facility, conditional on the angle (θ) of movement relative to the radius of the turbine blade. Therefore, any path given θ may or may not intersect with a turbine's RSA. The chance of a collision is calculated as the average (or expected number) or maximum of turbine encounters over all possible line segments with angle θ and the probability of surviving a turbine encounter (E. Bolker, University of Massachusetts, pers. comm.). In reality, birds do not fly in straight lines for consistent periods of time. By incorporating a probabilistic approach, the model evaluates the joint probability of mortality across all possible combinations of flight height and flight path. Therefore, the model produces an "expected" mortality that is conditional on the data. The expected mortality effectively addresses the uncertainty in the many elements that affect mortality and provides a range of mortality estimates that is weighted by the observations. This approach is considered an improvement over traditional mechanistic structured models where uncertainty and sometimes even central tendency are not rigorously and formally addressed.

Observations from the MMA allow the enhancement of the original Bolker model framework by (1) incorporating tern flight height observations in a manner that influences the mortality probability, (2) incorporating the avoidance observations at various distances in a way that influences the probability of survival, and (3) incorporating data and expert judgment at all aspects of the model as a method to reflect the uncertainty in the model predictions.

Flight Height

The Bolker model produces an estimate of $E_{max, \theta}$ and $E_{avg, \theta}$ for a specific flight height range. Table 3–18 provides the proportion of time all terns were observed at various flight heights. The flight height for Roseate Terns approaching a wind facility, or flying within the boundaries of a wind facility, can be treated as an uncertain model input. This uncertainty can be incorporated into the model using probabilistic methods. An empirical probability density function (pdf) representing the relative time terns fly at various heights can be derived from Table 3–18. The proportions can be used to weight $E_{max, \theta}$ and $E_{avg, \theta}$ based on the expectation that terns will fly at various heights based on the relative proportions indicated in Table 3–18. To generate the empirical pdf, the Bolker model was run for the flight heights provided in Table 3–18, and vectors of $E_{max, \theta}$ and $E_{avg, \theta}$ for flight angles ranging from 0 to 180 degrees were compiled for each flight height.

Using a simulation approach, the chance that a bird flies at a particular height can be used to weight the average or maximum number of encounters within the turbine farm. Treating both the angle of flight and the flight height as random variables, a simple weighting approach can be used to estimate a possible number of encounters for specified values of height and angle. For any simulation run, $E_{avg, \theta}$ and $E_{max, \theta}$ can be used to generate an estimate of turbine encounters that are both flight height and angle dependent. Effectively, this approach to modeling incorporates all possible angles of flight weighted by the probability of flying at various heights. For each flight height shown in Table 3–18, a random encounter probability is drawn from the vector of turbine encounters associated with θ_i, i = 1 to 180.The contribution of this value to the overall number of expected collisions is created by weighting with the probability of flight height. If the flight height is above or below the turbine blade length, the value has no contribution. Given a random value of θ for any flight height i, a weighted average or maximum number of collisions is calculated as

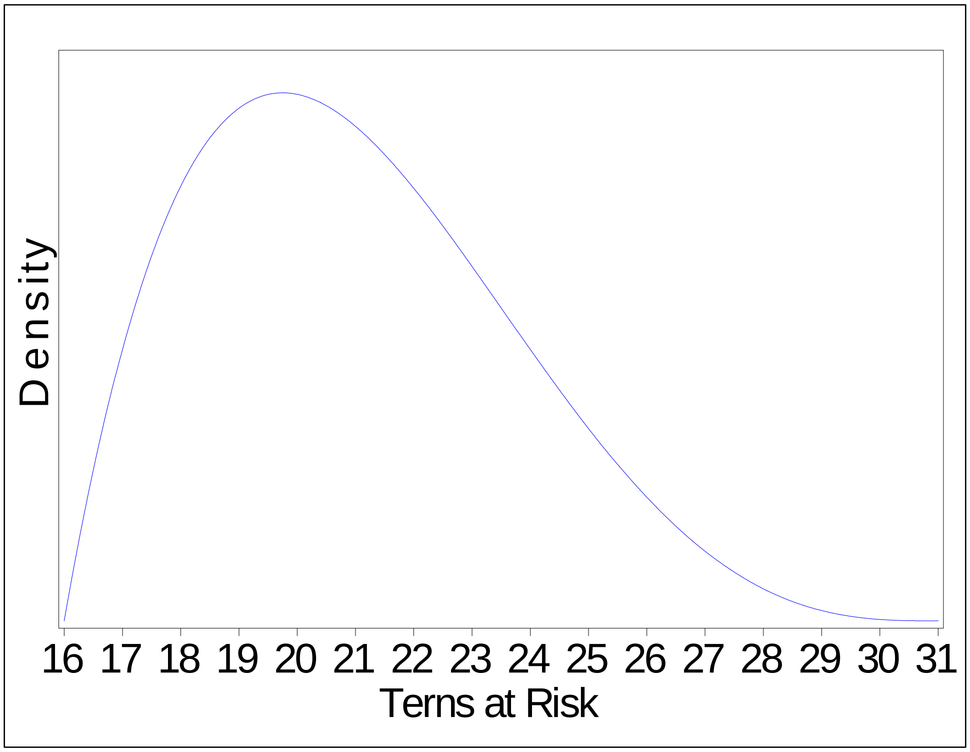

Figure 3–42. Distribution of the number of terns at risk to encounters with wind turbines [Beta (minimum=16, maximum=31, alpha=2, beta=4)].

For those birds at risk of a turbine encounter, avoidance observations at the MMA indicate that on average only 26% of the birds in the wind turbine vicinity (Zone 3) will enter an area near the rotor (i.e., Zone 2; see Figure 3–40 and Table 3–17, calculated as a percent change in tern density from Zone 3 to Zone 2). Birds that enter Zone 2 are clearly at risk of turbine blade collision (which would occur in Zone 1). The variation in the percentages of birds moving from Zone 3 to Zone 2 varied during the observation periods. While on average 74% of the terns exhibited avoidance behaviors as they neared the MMA turbine, the actual number varied within observation periods. Therefore, there is uncertainty associated with the number of terns that use avoidance behavior in the turbine air space. In addition, the probability that an individual tern avoids the RSA may be inconsistent between turbines. Although on average across all turbines, the model implementation assumes that the mean avoidance of the rotor swept area is 74%, consistent with the MMA observations. To represent this uncertainty, the avoidance probability was considered a random variable for the purpose of simulation. Figure 3–43 represents the probability of tern avoidance of Zone 2, which corresponds to a sphere around the rotor, with the radius of a rotor blade. The population of individual terns that fail to avoid the wind facility on initial approach may again choose to avoid the turbine as they approach Zone 2.

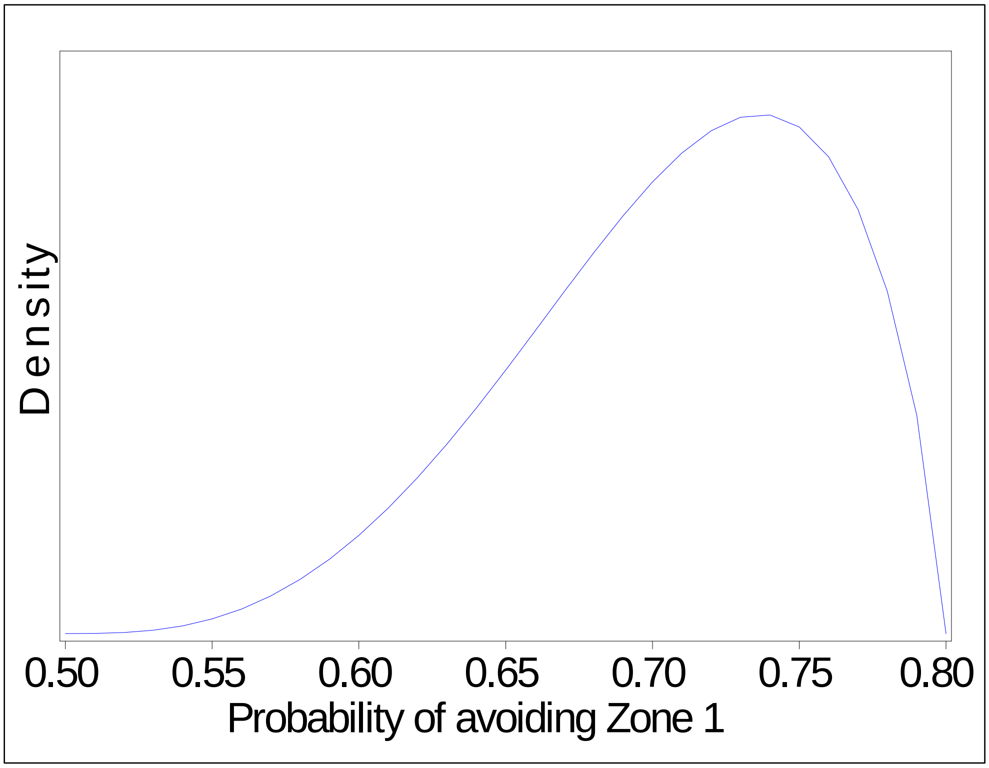

Figure 3–43. Probability of avoiding the rotor swept zone (Zone 1) [Beta (minimum=0.5, maximum=0.8, alpha=4, beta=1.8)]

During the observation period, no terns were observed within the rotor swept area (Zone 1), although terns have been observed flying through the turbine blades in earlier studies. Those birds near the RSA are at a clear risk of collision. Observations at the MMA indicate that even close to the turbine rotors, terns generally avoid flying through the RSA. Besides clear avoidance of the turbine blades, collision can be avoided by the bird simply flying through the area unharmed. In some models, this process is represented by equations that factor in bird size, flight speed, rotor spin rate, rotor angle, wind angle relative to the rotors, and other factors. Generally, empirical data are missing for these key model parameters or the values change in a time dependent manner. The Bolker model minimizes the data requirements with the use of a survival probability, *p*. In the construction of the model in this paper, *p* is the chance of birds in Zone 1 surviving an imminent collision with a turbine rotor. Note that the parameter, *p*, is the only term in the model that does not effectively reduce the total mortality by reducing the number of individual terns that may be at risk (Pop, see above equations). In the notation of the Bolker model, *p* is an indicator of survival when an individual bird is at risk, effectively within striking distance of a rotor blade. The Cape Wind study assumed constant values for *p* of 0.953 or 0.983. Hatch and Brault (2007) note that terns are agile birds so a probability of survival due to avoidance while in the RSA (Zone 1) is high. Because the MMA studies observed no birds in the RSA, and therefore provide no observational evidence of survival probability, the Cape Wind assumptions are used as an example to construct a formal pdf for survival. Future observational studies or possibly modeling studies may provide additional information of the probability of survival within the RSA (Zone 1). With no empirical evidence based on the MMA study, the probability of survival in the RSA is considered a random variable in the model. The median survival probability used in this simulation is 0.8 and ranges from zero to one (i.e., the distribution is not truncated and maintains the formal characteristics of a pdf), reflecting that avoidance outside of the RSA may occur; therefore, terns arriving in the zone of immediate risk (Zone 1) may be less prone to avoidance. However, as with the other random variables in the model, sensitivity studies using various shape and scale parameters for the distribution of *p* should be evaluated. The distribution of *p* used in the current simulation is shown in Figure 3–44.

3.6.6 Model Implementation and Discussion

Crystal Ball software[7] (an Excel add-on) was used to implement a Monte Carlo analysis in which the uncertainty in the model inputs was propagated through the model equation into the model mortality predictions. In this example, a hypothetical offshore wind facility was created using 213 turbine location coordinates similar to those used in the Cape Wind assessment (USDOI 2010b). Figure 3–45 shows the placement of turbines at the simulated wind facility.

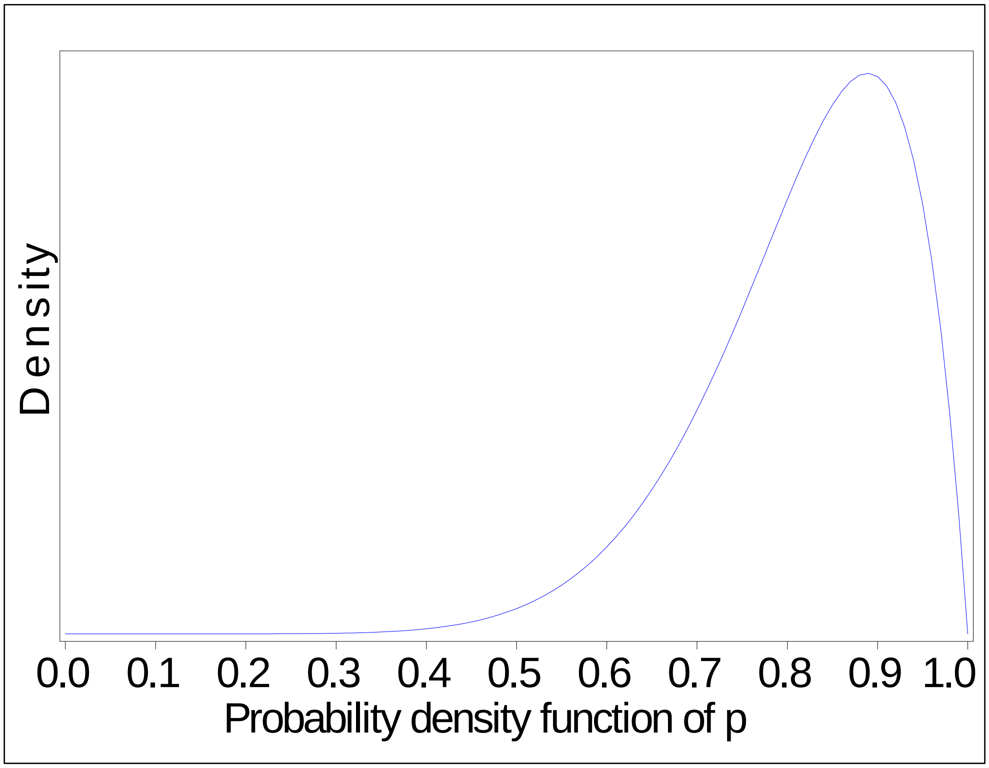

Figure 3–44. Probability density function of p [Beta(minimum=0, maximum=1, alpha=9, beta=2)]

Nacelle height and rotor length in the model runs were set to match the MMA turbine associated with the empirical field data. The model was run assuming the wind turbines rotated into the wind and the terns were flying parallel with the wind direction, which results in the highest number of possible collisions and is thus conservative. Terns that do not avoid the wind facility completely and enter the facility at a specified angle are assumed to completely cross an area

[7]http://www.oracle.com/us/products/middleware/bus-int/crystalball/index-066566.html. Provided by Oracle Corporation.

circling the wind facility (see Figure 3–41). Since no observational evidence of crossings by terns in the open ocean is available, no attempt is made to simulate the impact of terns repeatedly crossing the wind facility. However, a reasonable assumption can be made that the number of turbine encounters may be linear with the number of crossings. Therefore, on average, terns only partially crossing the wind facility may reduce the chance of an encounter proportional to the percent of the wind facility traversed. The mathematical relationship between multiple full or partial crossings and resulting mortality is an area of future research. For example, with enough crossings mathematically an individual tern could be killed more than once if simple linear relationships are assumed and simple proportional mathematics is used. The evaluation of mathematical structures that are consistent with the actual process of tern crossings while ensuring the mathematics produce tractable results is also an area for future research.

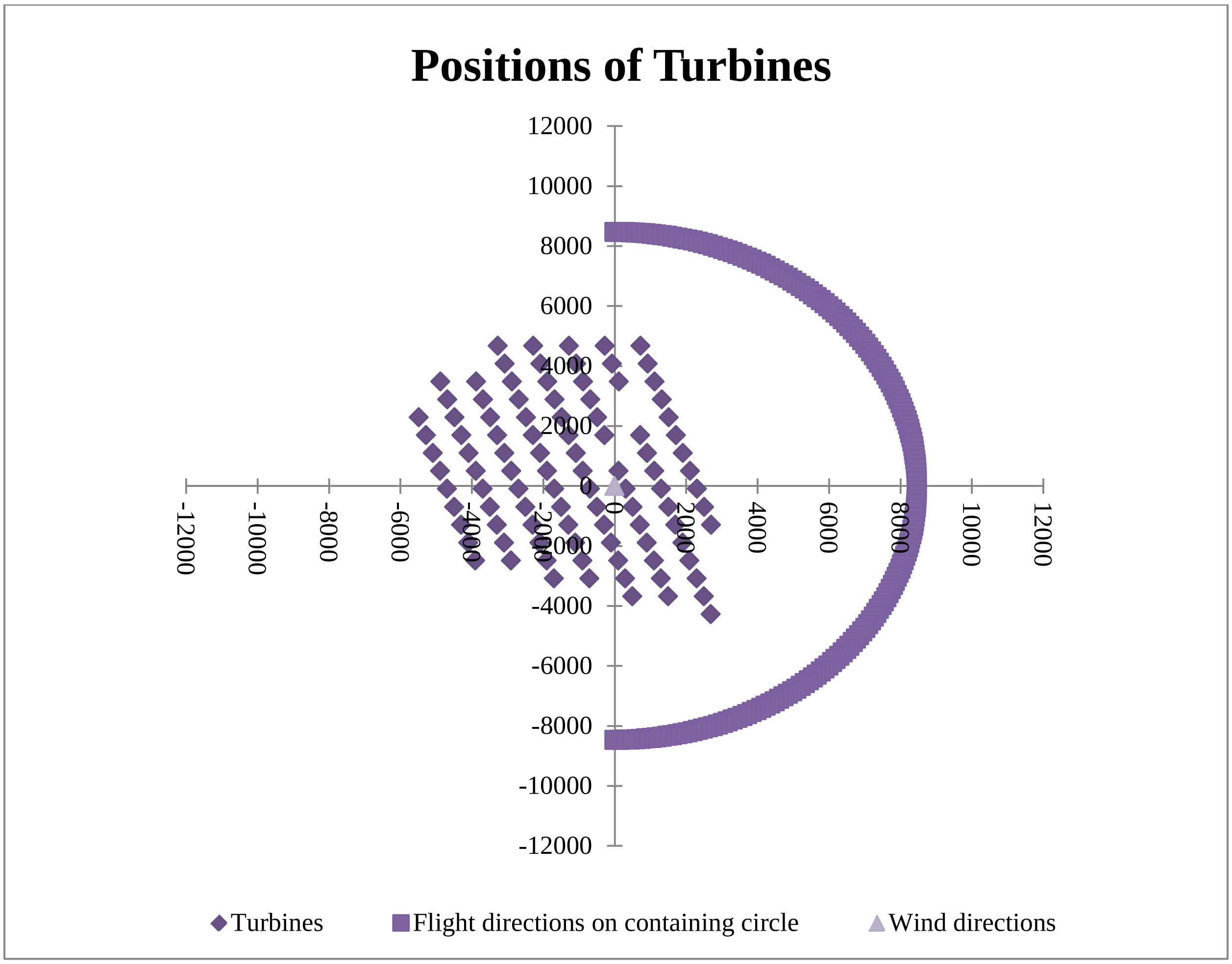

Figure 3–45. Offshore wind turbine locations.

Using the above equations, distributions, and linkages among model inputs, a Monte Carlo simulation of 100,000 iterations was implemented. Avoidance observations from the MMA study were used to adjust (i.e., reduce) the total number of birds at risk of a turbine encounter (model term Pop). The average and maximum number of encounters were weighted at each iteration as described above, and the final survival probability distribution, combined with both the adjusted average and maximum number of turbine encounters, was used to generate a distribution representing possible mortality of a tern traversing the wind facility.

Figure 3–46 and Figure 3–47 provide an illustration of the difference in mortality probability between using the maximum number of turbine encounters and the average number of turbine encounters. The figures are produced from the Monte Carlo simulations and have not been smoothed. The advantage of model distributional outputs is that decision makers can visualize not only the mean or expected mortality probability, but can also view the occurrence probability of larger mortality rates. In those cases where public or regulatory concern is high, the mortality probability in the tails of the distribution may be of importance.

Using the average number of encounters, as was used in the Cape Wind Project, the mortality probability ranges from near zero to approximately 0.05 (Figure 3–46). Near zero, the probability mass indicates there is a relatively high chance (approximately 26%) that no terns will be killed. The median (50^{th} percentile) probability of mortality is approximately 0.007 (or 0.7%). Therefore, with 100 terns at risk, the expectation is that less than a single tern would be killed. As evident from these figures, the shape of the mortality probability distribution is non-normal, and the tails of the distribution may be of interest to decision makers. Again, integrating under the area of Figure 3–46, there is at least a 10% chance that 2 or more terns are killed. While this event has a very low chance of occurrence, the results may be interesting to decision makers or the general public. This example illustrates the difference between simply reporting the average expected or mean value assuming normality and reporting and interpreting the area under the curve of model output distributions. For collision risk models, the output distribution will never be normal, and sufficient statistics derived from the assumption of normality may not characterize the distribution well. In addition, while the centrality metric of the distribution is certainly of interest, for some decisions, measures of centrality may not be sufficient.

Examination of Figure 3–47 indicates the median probability of mortality using the maximum number of encounters is approximately 0.07 with a probability mass near zero in the same range as found using the average number of turbine encounters. With 100 terns at risk, the expectation is that less than 7 terns would be killed assuming the maximum number of encounters. The maximum values assume the tern stays on a flight path that leads directly to turbine encounters, an assumption that is probably overly conservative but may be of interest during regulatory or permitting discussions.

Figure 3–48 and Figure 3–49 provide an illustration of the total mortality after adjusting for avoidance using the maximum number of turbine encounters and the average number of turbine encounters. The scale of these distributions is a direct function of the total number of terns at risk distribution described above and represents an integration of the mortality probability distribution and the terns at risk distribution after adjusting for avoidance. Because avoidance plays a large role in the mortality calculations, the shape and scale of the mortality distribution are highly weighted by the avoidance calculations described above.

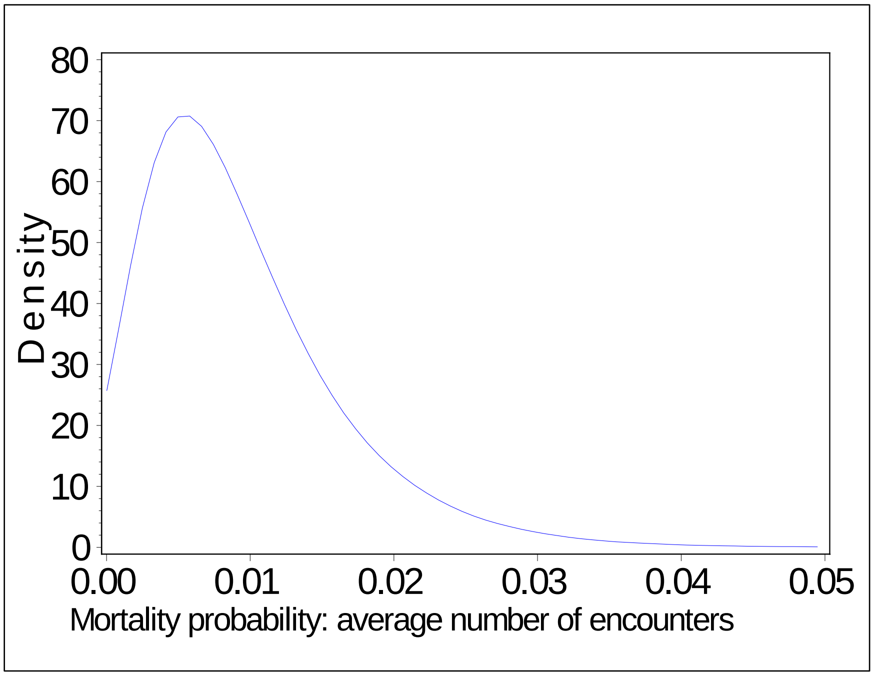

Figure 3–46. Distribution of mortality probability using the average number of encounters.

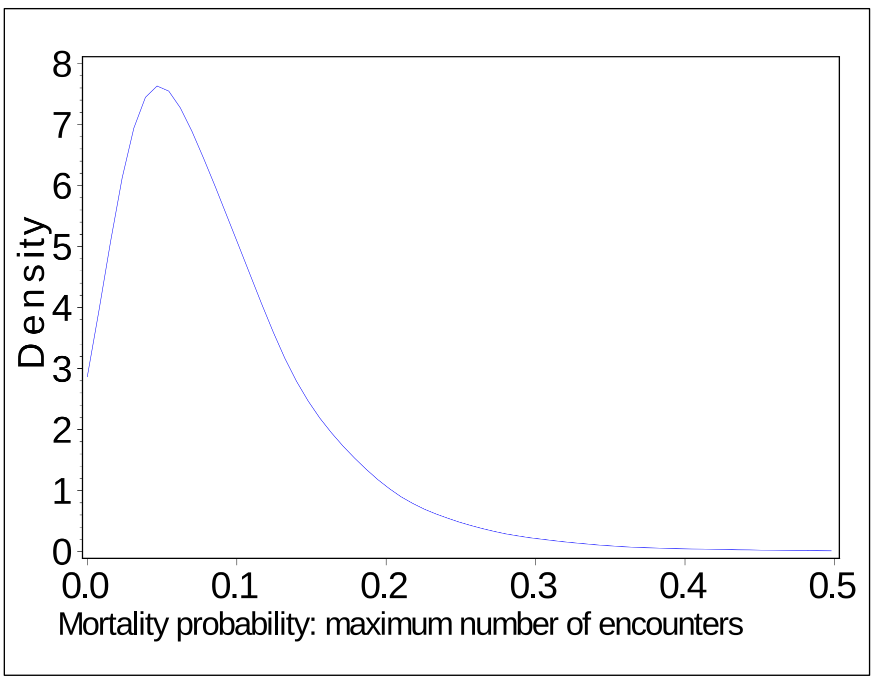

Figure 3–47. Distribution of mortality probability using the maximum number of encounters.

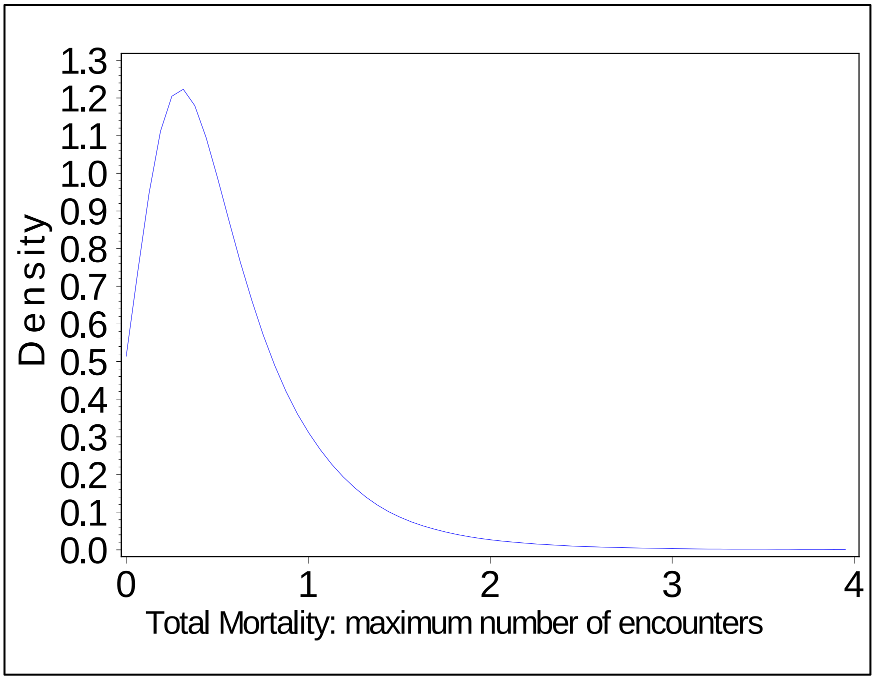

Figure 3–48. Distribution of total mortality using the maximum number of encounters.

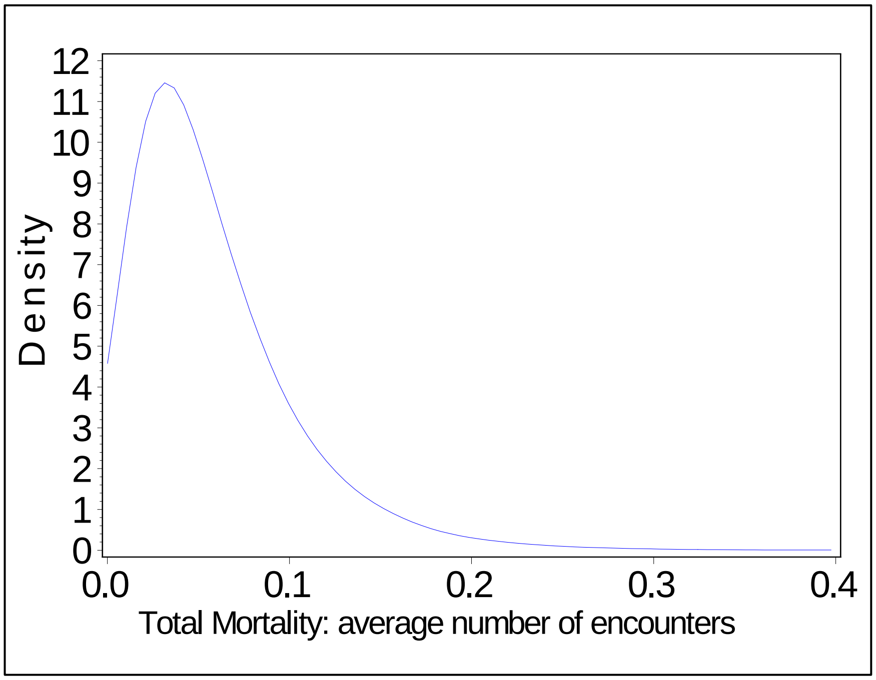

Figure 3–49. Distribution of total mortality using the average number of encounters.

Based on the maximum number of turbine encounters (Figure 3–48), the number of terns killed has a median of 0.4 terns given the number of birds at risk and avoidance distributions with a 50% chance of no kills and ranging from 0 to approximately 4 birds killed (Figure 3–48). From a decision perspective, the chance of killing at least 1 tern is approximately 11.5% based on the maximum chance of a turbine encounter. Using the average number of turbine encounters (Figure 3–49), the median number of terns killed is approximately 0.05 (Figure 3–49) with a negligible chance of killing a single tern given the number of terns at risk and avoidance calculations. The relative risk increases by about a factor of 10 when using the maximum number of turbine encounters.

The USFWS's Biological Opinion on impacts from the proposed Cape Wind Project to endangered Roseate Terns and Piping Plovers (USFWS 2008b) predicted a mortality rate of 4 to 5 Roseate Terns/yr from the project based on 1,773 to 4,089 terns at risk. Using simple scaling factors, our model results are consistent with this prediction, providing mortality estimates ranging from 4.25 to 10.2 terns/yr for the same number of terns at risk. However, these values are based on the average expected number of collisions, not the maximum number of collisions. A ten-fold increase in mortality is predicted from our model based on worst case conditions. An important element of modeling is ensuring that the model results are consistent with the question of interest. Reporting median mortality values does not answer questions like "what is the probability that one or more terns are killed per year?" To answer such questions, the model outputs must be displayed as a probability distribution. Uncertainty in the mean or median estimate of mortality is informative; however, if regulations specifically target the number of birds taken, then the centrality statistics are not specific to the question of interest. For this reason, the use of formal probability distributions may provide additional information that is interpretable within the context of the decisions under evaluation.

Decision oriented collision risk models provide users with a method for interpreting and evaluating the relative consequences of specific processes inherent in the model. For example, the relative change in risk that occurs by incorporating avoidance at multiple levels within the model structure can be evaluated. Users of the model can set the risk reduction associated with avoidance at any of the three observation zones described above to zero and evaluate the relative change in mortality as a result of these changes. The resulting mortality estimates, at any level of probability, can be evaluated by fixing one or more of the avoidance probabilities associated with distance from the turbine and evaluating the relative impact on mortality. For example, assuming that all terns pass between Zone 3 into Zone 2 increases the expected number of terns killed by a factor of three. The wind farm avoidance values, as used in this model, reduce mortality by a constant proportion of the total number of birds at risk, and the survival probability in the near blade region (Zone 1) can reduce mortality exponentially with the degree of mortality reduction dependent upon the shape and scale distribution parameters. For example, modifying the distribution of survival probability (p, see Figure 3–44) to have a median value of 0.7 (instead of 0.8 as shown in Figure 3–44) reduces mortality by approximately 40%. Taken together, the interactions among the avoidance and survival probabilities have a very large influence on the final mortality estimates.

The above simulation illustrates the need for additional observational data on specific avian avoidance and the need to directly reflect the resulting avoidance information in statistical models. In addition, the simple model structure coupled with a formal uncertainty analysis is shown to provide additional information to decision makers interested in the probability of tern survival. Mean mortality values, which are typically used in avian risk assessments, may not adequately reflect the overall risk associated with a wind facility. A formal uncertainty analysis, incorporating both available information and expert judgment, is a useful tool for communicating the degree of belief that can be placed in the model results. In addition, models requiring minimum inputs are a preferred tool when attempting to mimic the true amount of available data and also provide a means for environmental decision making. These types of models should be preferred when little experimental evidence is available in the published literature or when site specific data are lacking.

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3.7 Pilot Study A: Developing and Testing an Offshore Remote Bird Monitoring Device That Combines Acoustic and Thermal Image Detection (Remote Avian Detection Device)

3.7.1 Summary/Abstract

In this pilot study, Normandeau Associates, Inc. (formerly Pandion Systems, Inc.) designed, built, and tested an offshore bird monitoring system that collects and remotely transmits acoustic and thermographic data on flying wildlife. The study fills a major need in offshore wind environmental analysis. Pilot Study A was one of three conducted as a separately contracted component of the overarching project, Potential for Interactions between Endangered and Candidate Bird Species with Wind Facility Operations on the Atlantic Outer Continental Shelf, contract M08PC20060. The objectives of the overarching project, as stated in contract M08PC20060, are as follows:

- Objective 1 (Risk assessment objective): “to evaluate the potential for the three endangered, threatened, and candidate species of interest (Red Knots, Piping Plovers, and Roseate Terns) to be impacted by wind facilities located on the Outer Continental Shelf (OCS)”
- Objective 2 (Methodological objective): “to determine the best methods to evaluate locations of future wind facilities to minimize risks to the species”

This pilot study was designed to address the second of these objectives by designing a remote sensing system capable of gathering the data needed to evaluate locations of future wind facilities on the AOCS to minimize risks to the three focal species. The remote sensing system that could fill this need was conceived as a self-powered, remote operating acoustic/thermographic detector that could be deployed on meteorological platforms or wind turbine towers on the AOCS for long periods of time to collect data continuously over the course of full annual (seasonal) cycles during both day and night and under a wide variety of weather conditions. The use of acoustic sensing was designed to produce species-specific information as the focal species are not easily identified to the species level by other data gathering methods. The use of sound was also intended to provide nocturnal data as the focal species may migrate at night. The use of thermographic imaging was intended to allow the system to function in dark and foggy conditions as well as daylight and also to provide increased quantification of flying targets, as acoustic data alone are not easily quantified. In particular, thermographic signal is capable of providing certainty that no animals passed through a given detection beam during a given period of time, whereas acoustic data can never provide such “zero” data as animals may have been silent as they passed through the microphones’ detection range. The software portions were designed to analyze audio and video data collected by the system hardware and translate the data into a quantifiable format that can be employed in wildlife risk assessment. The system was designed to monitor animal passage through the potential rotor swept altitudes of an offshore wind turbine with flight altitude of observed animals being calculated using thermographic signal, acoustic signal, or both.

<u>Background</u>

The idea for this pilot study was generated during the first midterm meeting of contract M08PC20060 held at the Paramount Hotel and Suites in Gainesville, Florida, on 5 and 6 Feb

2009. Specifically, this pilot study idea was one of three generated and selected by the entire project team during that meeting on the basis of its ability to address high priority questions or needs in order to satisfy the objectives of the overarching project (contract M08PC20060). The initial idea for this pilot study was then further developed during a breakout session held at that same meeting. Participants in that breakout session were Caleb Gordon (Normandeau), Mark Desholm (Danish National Environmental Research Institute), Chris Ribe (Normandeau), Greg Forcey (Normandeau), and Andrew Farnsworth (Cornell Laboratory of Ornithology).

Subsequent to that meeting, Caleb Gordon further developed this initial idea, as well as the other two pilot study ideas selected and originally developed by the group, into a full proposal for three one-year pilot studies. This proposal was approved and funded by the BOEMRE under M08PC20060, CLIN 0002. This separate contract, and all three of the pilot studies for which it provided, were initiated in late May 2009. The provisions of CLIN 0002 extended until 31 Aug 2010 and were intended to lead to the completion of all technical work on all three pilot studies by summer 2010, as well as the initial analysis and interpretation of the results by each of the pilot studies' principal authors. At this time the initial contract (CLIN 0001) was to resume, providing for a project midterm meeting in fall 2010 where all three pilot studies would be presented by the principal authors and discussed by the entire project team.

In parallel to the pilot study described above, Normandeau was continuing to develop its preexisting Remote Bat Acoustic Technology (ReBAT™) system, which provided synergistic contributions to the development of the remote acoustic/thermographic offshore system for BOEMRE under contract M08PC20060, CLIN 0002. ReBAT™ is a patented technology that supports remote acoustic wildlife monitoring with a focus on combining the system with analysis as a service to provide risk assessments to bat habitats for existing or potential wind farm sites. In 2010, there were 32 installations in 10 states. There are many directly overlapping or largely similar technologies between ReBAT™ and the system being developed for BOEMRE under this pilot study. Specific advancements in technology for ReBAT™ are highlighted in this report when and to the extent that they contributed to the development of the acoustic/thermographic offshore wildlife detection system under this BOEMRE pilot study.

Key People Involved

While many people have contributed in various ways to the progression and completion of the pilot study and underlying technology, the key contributors are listed below.

Person	Agency	Role
Andrew Farnsworth	Cornell Laboratory of Ornithology	Conceive pilot study
Mark Desholm	Danish National Environmental Research Institute (NERI)	Conceive pilot study
Caleb Gordon	Normandeau Associates, Inc.	Conceive pilot study, pilot project lead, develop proposals, project oversight, avian ecologist
Chris Ribe	Normandeau Associates, Inc.	Conceive pilot study, lead technical designer and engineer, system prototype field testing
Christian Newman	Normandeau Associates, Inc.	Project director
James Ribe	Normandeau Associates, Inc.	Hardware and software installation
John Cox	Independent Consultant	Contractor, initial acoustic/thermographic system development and planning
Ian Baldwin	Normandeau Associates, Inc.	Technology development planning and supervision, prototype field testing, pilot study synthesis
Greg Forcey	Normandeau Associates, Inc.	Conceive pilot study, avian ecologist, prototype field testing
John Carter	Rhinosys, Inc.	Video analysis software development, prototype field testing
Mike Harvey	Cornell Laboratory of Ornithology	Cape Cod field study – Bird fieldwork
Don and Erica MacArthur	Innovative Automation Technologies, LLC	Bird simulation technology for system prototype field tests
Akela Ribe	Akela Ribe Production	Video editing

3.7.2 Technology Development Timeline

From Initiation to First Field Test (Jun 2009–Aug 2009)

In Jun 2009, we purchased, setup, and configured most of the key hardware components and installed the appropriate software, including the thermographic cameras, analysis workstations, cellular modem, and remote detection computer. The system's basic functions and cameras were validated when connected to the analysis workstations. Work continued on setting up the hardware, operating system, hardware drivers, and video and audio capture programs.

With the basic functions in place, Chris Ribe took the lead role and we prepared the equipment for the first field test. The computer and associated hardware were installed in a portable waterproof box. Mounts were constructed for mounting a microphone, camcorder, and thermographic camera together on a tripod. A preliminary field test of the system took place at Lake Alice in Gainesville, Florida, on 11 Aug 2009, which confirmed the successful functioning of the sensors and basic command and control software.

During the week of 16 Aug 2009, in collaboration with CLO personnel, we conducted the first major field test at various locations on Cape Cod, Massachusetts. This site had already been selected for the occurrence of the three avian species included in the pilot study: Red Knots, Piping Plovers, and Roseate Terns.

We spent the first full day onsite establishing baseline acoustic, thermal, and visual information at the MMA coastal wind turbine at Buzzard's Bay. During the next 2 days, we recorded data on Red Knots, Piping Plovers, and Roseate Terns at South Beach. On the fourth day, we recorded data on Red Knots in Pleasant Bay and spent the last full day on Chatham Beach between Pleasant Bay and South Beach with the goal of catching birds in flight between foraging areas in Pleasant Bay and roosting areas on South Beach. Table 3–19 identifies the focal species and surrogate species recorded as part of the field test.

Table 3–19

Summary of field test survey on Cape Cod, Massachusetts, 17–21 Aug 2009.

Date	Location Surveyed	Observation Time	Focal Species Recorded	Surrogate Species Recorded
Aug 17	MMA turbine	3 hours	MMA turbine baseline data	N/A
Aug 18	South Beach	8 hours	Roseate Tern, Piping Plover, and Red Knot	Common Tern, Semipalmated Plover, Short-billed Dowitcher, Black-bellied Plover
Aug 19	South Beach	5 hours	Roseate Tern, Piping Plover, and Red Knot	Common Tern, Semipalmated Plover, Short-billed Dowitcher, Black-bellied Plover
Aug 20	Pleasant Bay	4 hours	Roseate Tern and Red Knot	Common Tern, Semipalmated Plover, Short-billed Dowitcher, Black-bellied Plover
Aug 21	Chatham Beach	3 hours	Red Knot	Common Tern, Semipalmated Plover, Short-billed Dowitcher, Black-bellied Plover

During each recording session, simultaneous recordings were made using three devices: a FLIR A320 thermographic camera, a Canon HF200 camcorder, and a Røde NTG-3 shotgun microphone. The A320 was set to stream data at 60 Hz and a resolution of 320x240 to a computer where it was captured to a hard drive. The camcorder recorded AVCHD encoded video at its "MXP" setting. The observer audio track was captured from the camcorder's built-in microphone and encoded with the video. The shotgun microphone was attached to an M-Audio Delta 1010LT audio encoder card and encoded at 96 KHz/24 bits.

Follow Up from Field Test (Sep 2009–Dec 2009)

After the field test, we focused on supporting the data processing, storage, and manipulation to handle all of the recorded information. The majority of the manipulation involved transcoding/integrating the data collected. In this process, three separate time-stamped sets of recordings that were made concurrently were initially processed separately and then integrated into single QuickTime multimedia files.

The separate recordings consisted of the following: thermographic recordings, two separate audio recordings (different microphones), and video recording with expert ornithologist vocal annotation for bird identification. Transcoding was necessary only for the thermographic recordings, which were in the proprietary file format produced by the thermographic cameras. C. Ribe developed software to translate these files into sequences of pictures and then recreated the video sequences from these pictures in file formats that could be manipulated and integrated with the other channels into QuickTime sequences.

Once the video tracks were converted, the camcorder audio and video tracks were used to identify birds in the thermographic video. The video was divided into clips of individual birds/groups of birds in order to also support the future evaluation of the performance characteristics of the camera system and the development of event filters.

In Dec 2009, we implemented the basic audio filter, which rejects only near-silence, and began work on a more advanced audio filtering and recording program. We used video footage from the Cape Cod trip to evaluate the usefulness of various analysis options. Audio and video samples of study species were identified in field recordings. These samples were used to quantify and evaluate the range and performance of the system.

Development, Integration, and Testing of Signal Processing Algorithms (Jan 2010–Jun 2010)

In early 2010, we made significant progress in filtering both audio and video signals. We wrote a configurable audio filtering program, which takes input from either microphones or recorded audio files. The program scans an audio stream for sound of a specified frequency and intensity and can be configured to output a file for each segment of the input stream that matches the criteria. We made advances in video filtering, mainly focused around discrimination between flying birds and other airborne objects.

In addition, we evaluated two possible software packages to analyze the video: National Instruments LabVIEW and the OpenCV Toolkit. LabVIEW with the Vision Development Module integrated well with the thermographic cameras, but was focused more on static image analysis than motion analysis. The OpenCV Toolkit was more difficult to interface with the cameras, but provided more advanced support for motion analysis and was deemed to be the superior choice because of that support.

We used approximately 45 seconds of the video that best represented a mixed flock of birds flying by an offshore monitoring station to compare video analysis options. Initial results indicated that static image analysis works well for identifying birds that are close to the camera, but in order to maximize the range of the system, more complex motion analysis techniques were needed.

To that end, we reviewed specific motion analysis tools based on the OpenCV toolkit. Eventually, SwisTrack was selected, which is an open source implementation of OpenCV with powerful real time motion analysis capabilities and the ability to identify biological targets within a video stream. A custom implementation of SwisTrack was implemented for this project based on SwisTrack revision 995.

As part of the follow up to the Cape Cod field test, the requirements for monitoring system health (system up-time, power usage, basic data capturing statistics to validate system efficiency and usage, etc.) were clearly emerging. This validated the original assumption that a similar set of diagnostic measures that would be needed for the system were already planned to be implemented in the production of the ReBAT™ system.

ReBAT™ systems were improved with the addition of features that allowed for the monitoring and performance of these remote acoustic detection devices, including developing software with self-diagnostic and reporting routines to monitor system performance and health. Additionally, system management and status monitoring tools were incorporated into the analyst interface. This enabled remote monitoring of key indicators and the ability to perform system functions remotely such as changing parameters on the remote system and rebooting various system components to support troubleshooting.

During the spring of 2010, we continued to focus on implementing SwisTrack effectively and established the development environment to create a driver specifically for the FLIR A320 camera. Once that functionality was validated and tested, data could be captured directly from the camera and played back. In addition, we wrote two components: one that allowed the raw incoming data from the camera to be stored and one that fed the stored data back into SwisTrack. Together, these components provided the capability to record and analyze a sequence of video and then later adjust the analysis parameters and rerun the analysis on the same incoming data stream.

In May 2010, we continued the development of an advanced video filter implemented using SwisTrack. This process included converting various SwisTrack filters to handle 16-bit gray scale video and testing various filter implementations by recording bird activity during low light conditions at a field site in Gainesville, Florida.

We developed a new camera-capture component for SwisTrack that took feeds from two cameras, synchronized the captured frames as closely as possible, and stitched one frame from each camera into a composite frame that was then passed on for further processing. This technique provided the ability to evaluate a basic stereo vision setup to obtain distance-to-object information.

We also made progress in the area of data handling. We created processes for tagging and storing video and audio data. The video data from the thermographic camera were stored in an uncompressed format for later analysis and for use during algorithm development. Tracking data from SwisTrack were summarized and sent to an external application for further analysis and storage. We modified and configured the SwisTrack software to take the data from the IR cameras and process it in stages to yield useful information for discrimination of flying birds from other objects.

Now that the majority of the in-system software processing had been established, we began work on measuring the computational load imposed by raw data capture and data manipulation. We completed system monitoring to check the system performance relating to CPU load, disk load, etc., while running the video portion of the development. There were initial concerns over the potential of extra computing resource requirements to support the real time tasks necessary in a fully deployed field system. These concerns were proven to be unwarranted through the system monitoring effort.

Thermal Image Processing Algorithm Field Testing, Initial Stage (Jun 2010–Jul 2010)

On 16 Jun 2010, we tested the system in an urban, fairly wooded setting in downtown Gainesville, Florida. Figure 3–50 shows an object in the scene, most likely a small bird at fairly high altitude. To display the captured data, we converted the file from 16-bit to gray 8-bit scale.

For the next step in processing the data, we filtered out clouds and any other slow-moving, large objects using background subtraction techniques. After that, we used thresholding, which is a method used in object identification that takes a gray scale image and turns every pixel to either black or white based on a defined level of brightness in order to more clearly filter target objects from nontarget objects. Particle or blob detection techniques were applied to identify objects of interest. The output of thresholding and particle detection is shown in Figure 3–51.

In the next step, we created tracks based on a nearest-neighbor algorithm across multiple frames to distinguish between moving objects, such as birds, and miscellaneous anomalies in the images. The track of the target object is shown in Figure 3–52.

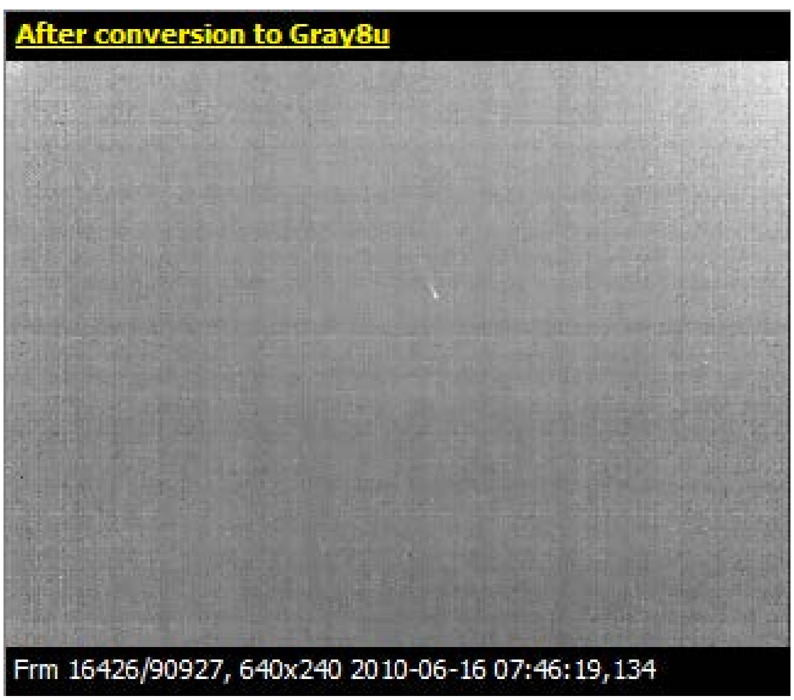

Figure 3–50. After conversion from 16-bit raw data from cameras to the 8-bit gray scale format for display.

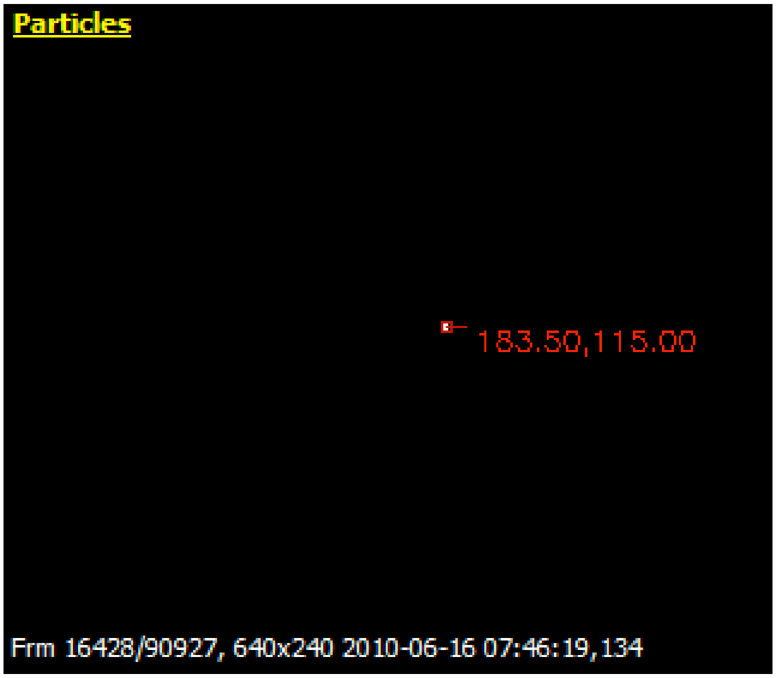

Figure 3–51. Output of particle or blob detection step.

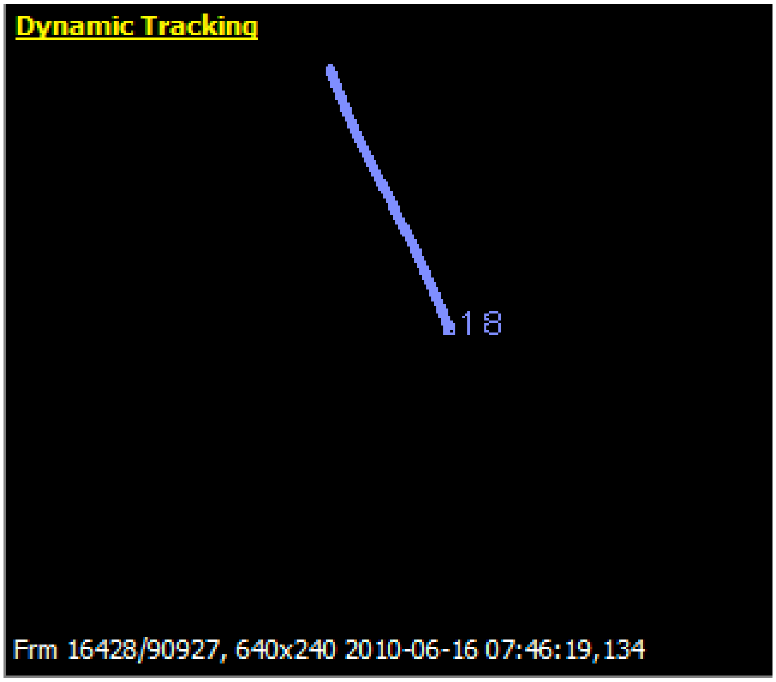

Figure 3–52. Output of tracking step.

We conducted tests of the stereo vision setup using a flyover of a radio controlled aircraft to simulate a bird at known altitudes. We performed the test on 25 Jun 2010 at a large field in Gainesville, Florida. The aircraft was equipped with thermal pads set to approximate the body temperature of a bird (approximately 100°F). In the initial test, we spaced the thermographic cameras 6.4 m apart and flyovers were done at 62 m, 70 m, and 100 m. Figure 3–53 shows an image of the initial gray scale data captured at 100 m in the top half of the diagram, and the corresponding manipulated image is visible in the bottom half of the diagram.

This field test validated a number of key system functions. The networking and computing setup to gather data from two cameras worked well, as did the custom developed dual camera-capture component for SwisTrack. The image processing techniques were successful in distinguishing objects of interest. The data collected suggested that the cameras were not exactly parallel; therefore, precise distances to objects could not be determined. However, even though the alignment of the cameras was not ideal, the configuration was sufficient to validate that distances could be determined accurately once the alignment issue was addressed.

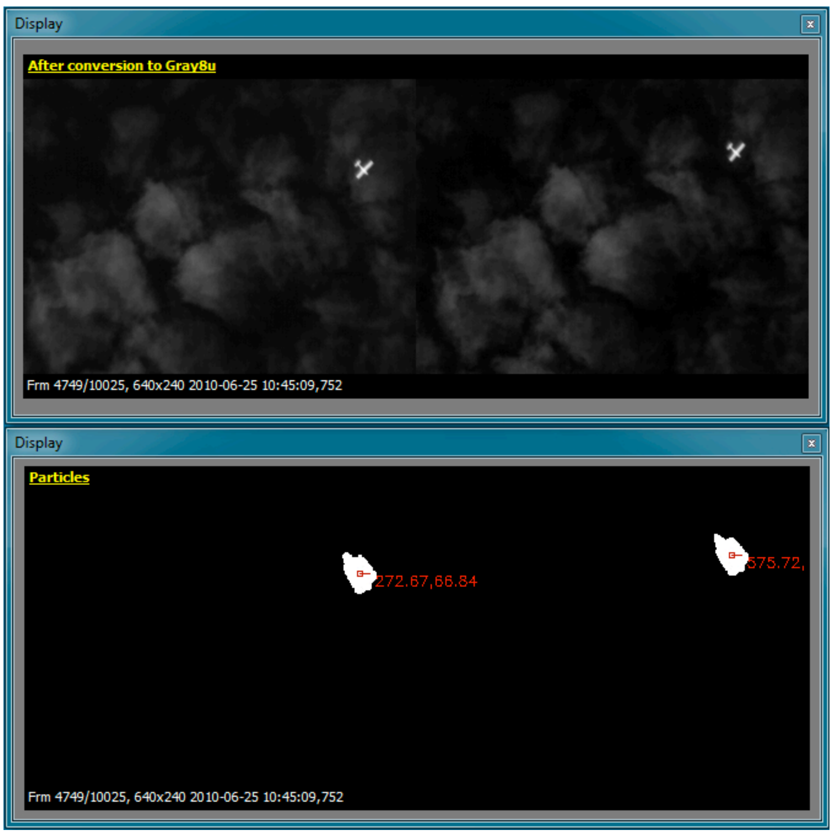

Figure 3–53. Thermal imagery (above) and filter-detected objects (below) from 100 m flyover test.

Thermal Image Processing Algorithm Field Testing, Second Stage (Aug 2010–Oct 2010)

The next steps were to make the system as close as possible to a deployable system. We added focus control to the video analysis program. We also constructed a frame and mount to test the alignment of the dual mounted cameras, which enabled the stereoscopic range finding. After testing different widths for optimum alignment, a 60-cm distance was used.

An object tracking algorithm for determining target distance using stereoscopic thermal images was developed and validated in a controlled indoor test. The system was able to accurately determine the range of a stationary object (a coffee mug) to within 15 cm at a range of up to 25 m (the maximum possible distance within the indoor test space).

Also during this time, additional progress was made with ReBAT™, especially in the area of reliability and usability of the system, with additional crossover synergy and progress for the pilot study. An audio playback was added to the ReBAT™ web interface, providing analysts with an opportunity to listen to recordings while viewing spectrograms, which aids in species identification. Additionally, further controls were put into place to determine whether microphones were working correctly.

Following our controlled indoor test of the object tracking algorithm, we improved the performance of the algorithm through continued work on the automated video analysis program. We wrote command and control software to communicate with the video analysis program and to extract video clips identified as potential bird tracks by the video analysis software. The command and control software could also extract portions from the audio stream corresponding to the times when video events were in progress. This synching of the two data sets was critical in species determination.

We completed construction of the final prototype with the goal of a successful final controlled field test at the end of Sep. The test took place on 30 Sep 2010 to validate the calibration of the system to achieve flight height calculations. The same test location in Gainesville was used. This time, the radio controlled aircraft did not have the heating pad to simulate the temperature of a bird.

Ten flyovers were conducted at heights ranging from 30 m to 190 m. The height of the radio controlled aircraft was calculated by the altimeter on the aircraft and was compared to the height of the aircraft as calculated by the stereoscopic thermographic cameras. One of the flyovers was not in the field of view of the cameras, so a height calculation was not performed for that flyover, which meant nine successful flyovers and corresponding data were captured. The resulting data are shown below in Table 3–20. The same data are shown graphically by ascending flight height in Figure 3–54.

Table 3–20

Flight height comparisons (actual to calculated).

Clip Time	Actual Flight Altitude	Calculated Flight Altitude	Level of Accuracy
10:32:30	48.31	52.43	9%
10:34:11	46.41	40.97	-12%
10:35:21	86.39	80.65	-7%
10:36:56	51.5	38.64	-25%
10:38:23	66.65	63.34	-5%
10:39:21	42.56	32.17	-24%
10:40:06	29.48	17.84	-39%
10:42:33	153.64	207.31	35%
10:45:12	190.6	196.51	3%

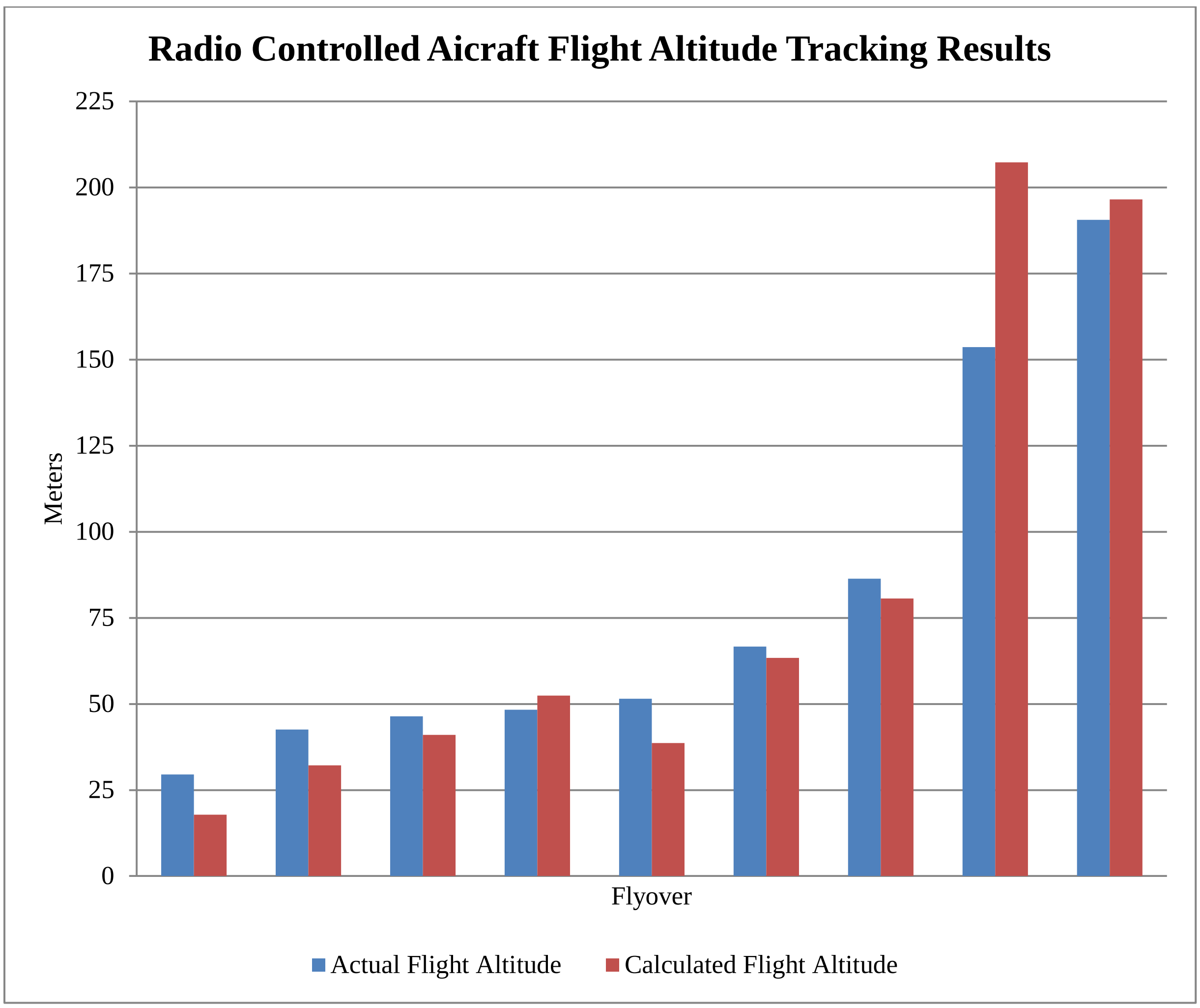

Figure 3–54. Actual flight altitude vs. calculated flight altitude.

We validated progress on the flight height calculation algorithms and the stereoscopic cameras through the controlled field test. The system was able to establish flight height calculations on target objects at heights within the target height of a wind turbine RSZ. All of the data points were within ±40% accuracy with an average absolute accuracy of just under 18%. The correlation coefficient was 0.9757.

The main issue in the controlled field test was that due to the relatively large size of the radio controlled aircraft (wingspan: 58 in.; overall length: 37 in.), the aircraft was identified as multiple points in the processed video, instead of a single point. The points were not consistently tracked between frames relative to their original position, meaning that point A on the left wing and point B on the right wing might switch between frames, which created challenges in height calculations. The average of all data point heights was used in calculating the flight height.

After making some final adjustments to the object tracking algorithm, as well as addressing issues in the audio recording system to ensure the audio would record continuously and in sync with the video, we performed a final field test on the morning of 13 Oct 2010.

The goals of the test were to validate that the system could successfully track actual birds (and potentially bats as well) in different background light conditions and to ensure that the system would track biological targets as a single point. The system was put up before dawn and data were recorded for 2 hrs, from approximately 6 A.M. to 8 A.M. The timing of the test produced a variety of background lighting, which enabled a variety of test scenarios for background subtraction and thresholding for the thermographic images.

There were a few key results from that test. The system's command and control algorithms were successful in triggering the recording of thermographic video. The system recorded target objects that were identifiable in the resulting video as birds, even in darkness. In some cases where the target object was relatively close to the cameras, the clarity on the thermographic video output was sufficient to identify wing beats. While it is unlikely the wing beat data could be used in species identification, it may help in differentiating a bird from a bat and could be considered another possible variable to investigate. The issue of multiple target points on a single target was not problematic for the target tracking algorithm, presumably because of the significantly smaller target size with a more uniform temperature. Finally, preliminary analysis suggested that the audio component of the system worked as designed, but the birds in the target area were silent.

3.7.3 Final Summary

In conclusion, the final system developed under this pilot study achieved successful functioning in the following components:

- thermographic video recording and tracking of target objects in flight, at various altitudes, and in different background lighting conditions
- command and control software creation to trigger event based data recordings
- stereoscopic camera alignment configuration that enabled the system to calculate flight heights
- raw data manipulation and processing into a consumable format
- audio data capture and synchronization with video data to show a complete picture of information to the analyst to aid in species identification

Looking ahead to the next stages of system development, we identify the following as additional key components and/or functions of the system that will be necessary to develop/refine in order for the system to be deployable in a marine environment:

- remote connectivity for either cellular or satellite transmittal of data from the remotely operating device to a home office for analysis
- meteorological data to be used as supporting information for the species identification process and will also support decision making about system health
- improvement in the accuracy of height calculations which includes establishing a base-line level of acceptable accuracy
- fabrication of the system in a weatherized and deployable configuration
- testing the systems for reliability and weatherization to ensure proper functioning under challenging conditions
- testing that the final system configuration accurately captures data and manipulates it appropriately and that the resultant data can be used effectively

4 Final Risk Characterization

4.1 Scope of this Section

In this chapter, we present a characterization of risk to the three focal species of this study (Roseate Tern, Piping Plover, and Red Knot) from offshore wind facility operations on the U.S. AOCS. We follow the concept of risk characterization, as it is defined in formal Ecological Risk Assessment (ERA) (USEPA 1998). ERA served as a framework for the design, execution, and interpretation of the original research initiatives and technical literature syntheses of this project. The ERA framework, and its relation to the project's objectives and activities, is described in the Preface. Section 1 of this report presents a summary of the problem formulation phase of ERA, whose purpose is to identify the key risk questions and then synthesize existing knowledge to produce conceptual risk models, identify knowledge gaps, and determine the data needed to fill the knowledge gaps relevant to the key risk questions. The problem formulation of this project is further elaborated in Section 2 (Burger et al. 2011), which presents a synthesis of existing technical knowledge relevant to the project's risk assessment objective in the format of a preliminary risk assessment. In formal ERAs, problem formulation is followed by the characterization of effects and exposure, normally endeavored through original efforts to gather the data needed to address the key risk questions that have been identified during the problem formulation (USEPA 1998). This phase of our risk assessment is described in Sections 3.2–3.6. Risk characterization is the final phase of ERA consisting of an interpretation of the risk issue of interest in light of the new data that has been brought to bear on the key risk questions of the study and placed in the context of the relevant pre-existing information.

We conducted the risk characterization for this project in two phases. The initial phase was to characterize the risk of adverse impacts to the focal species from AOCS wind power development based on pre-existing information. This included published and unpublished technical literature, including the Final Environmental Impact Statement (USDOI 2009) and Biological Opinion on Roseate Tern and Piping Plover (USFWS 2008b) for the proposed Cape Wind facility. This information was synthesized by our project team with technical input from the project's co-principal investigators, SRG, advisors, and liaisons and was produced in the form of an initial risk characterization contained within the preliminary risk assessment (Section 2 of this report; Burger et al. 2011).

The second and final phase of risk characterization, presented in the current chapter of this report, focused on new information gained subsequent to the first risk characterization phase. This information came from two primary sources: (1) the original research initiatives of this project and (2) newly published and unpublished relevant technical literature made available subsequent to the preliminary risk assessment. We have structured this final risk characterization to cover the full range of possible effects and exposure to the focal species from AOCS offshore wind development. However, for risk issues that have not been addressed by this project's original research initiatives or in recent technical literature, we refer the reader to the initial risk characterization (Section 2; Burger et al. 2011) for a synthesis of risk to the focal species from AOCS wind development based on pre-existing information.

4.2 Noncollision Risk Issues

One outcome of the problem formulation was a focus on the risk of birds colliding with wind turbine associated structures as the primary issue of importance for assessing the risk of possible adverse impacts on the three focal species from wind facility operations on the AOCS. Other possible stressors and effects, such as boat traffic or habitat displacement, were identified and included in the general conceptual risk model we developed during the problem formulation, (Section 2, Figure 2–1; Burger et al. 2011), and there is significant uncertainty about most of these stressors and effects as there exists little scientific information with which to evaluate them. Nonetheless, based on the limited extent of exposure and the general low likelihood of severe adverse impacts that the project team determined during the project's problem formulation stage, the project team achieved general consensus that noncollision risk issues were not likely to be biologically significant. On this basis, all of the research and technology development efforts of this study were directed at gaining insights into collision-related risk for the three focal species (Sections 1 and 2; Burger et al. 2011).

4.3 Risk of Colliding With Offshore Wind Turbine Structures

We have organized our characterization of the focal species' risk of collision with AOCS offshore wind turbines using the scale-based exposure classification that we developed during the problem formulation phase of this project (Section 2; Burger et al. 2011). In this classification, three distinct scales of exposure are defined as follows:

- **Macroscale exposure** occurs if individuals occur within the geographic region of interest, in this case, on the AOCS ≥3 mi from shore. Macroscale exposure is therefore governed by biogeography, as well as habitat use patterns that manifest at geographic scales, such as preference for different distance zones from shore (e.g., near-shore, offshore, pelagic). Furthermore, the temporal dimension of macroscale exposure is determined by species' geographic movements over the course of seasonal (e.g., migration) or interannual (e.g., range shifts) time.

- **Mesoscale exposure** occurs if individuals are exposed at the macroscale and if they fly within the RSZ of marine wind turbines (generally 20–130 m above the water's surface). Mesoscale exposure is therefore governed by flight altitude.

- **Microscale exposure** occurs if individuals are exposed at macro- and mesoscales and if they fly within the RSA of wind turbines. Microscale exposure is governed by behavioral avoidance or susceptibility factors such as visual acuity, visibility conditions, flight morphology and maneuverability, and behavioral patterns that may impact susceptibility such as courtship or foraging activities that may decrease individuals' ability to perceive and avoid the RSA of wind turbines.

It is important to note that these scales of exposure are nested. Exposure at a given scale is limited by the species' exposure at all higher scales. For example, if a species' macroscale exposure is low, it is impossible for that species to have a high degree of overall exposure even if meso- and microscale exposure factors are high because the species does not frequently occur within the geographic area of potential exposure.

It is also important to note the distinction between exposure and risk. Risk can be defined as the likelihood of a hazardous event occurring. By contrast, exposure refers to the potential for risk to occur on the basis of the co-occurrence of a given stressor and a given receptor in time and space. Exposure is, therefore, a necessary, but not sufficient, condition for the occurrence of risk. If exposure occurs at a given scale, risk is possible, but it is also possible that exposure can be high and risk can nonetheless be low. This may occur in cases where high exposure occurs at some scales, but not others. For example, a species with a high degree of macroscale exposure (frequently occurs in a geographic region with wind turbines) may have low risk if its exposure is lower at other scales (e.g., if it tends to fly outside of rotor swept altitudes or has a high capacity for behavioral avoidance of wind turbines).

In the following section, we characterize collision risk from AOCS wind development for each of the three focal species and for each distinct exposure scale, individually, focusing on new information gained through the original research efforts of this project as well as other information that has become available subsequent to this project's preliminary risk characterization.

4.3.1 Roseate Tern

Macroscale Exposure

Little new insight into Roseate Tern macroscale exposure to AOCS wind facilities has been gained subsequent to the preliminary risk assessment. The North Atlantic breeding population of this species is known to migrate pelagically between its breeding colonies and its wintering areas along the northeastern coast of South America and therefore potentially experiencing macroscale exposure to wind facilities all along the U.S. AOCS during migration. During the breeding season, macroscale exposure of Roseate Terns to AOCS wind facilities is restricted to the immediate vicinity of its breeding colonies during nesting season (up to 25 km away, but generally close to shore) and to a somewhat broader area encompassing its postbreeding staging areas in the late summer and early fall (see Section 2; Burger et al. 2011).

Recent bird survey efforts conducted in portions of the AOCS off of New Jersey (NJDEP 2010) and Rhode Island (Paton et al. 2010) produced little new information germane to this risk characterization. Both of these efforts consisted of extensive, year-round diurnal survey efforts using boat- and plane-based visual observers plus extensive gathering of radar data. The former study produced no observations of Roseate Tern (NJDEP 2010) and the latter produced eight, mostly in the western portion of the Rhode Island study area during late summer (Paton et al. 2010). The scarcity of Roseate Tern observations in the portions of the AOCS covered by these studies indicates that diurnal macroscale exposure of Roseate Terns to AOCS wind facilities is highly limited. However, well-known limitations of the methodologies employed by these studies prevent a robust and comprehensive characterization of AOCS Roseate Tern macroscale exposure for several reasons: (1) distinguishing between Roseate Terns and similar-looking congeners is virtually impossible from an aircraft and extremely difficult from a boat; (2) flying targets recorded in radar observations were not identified to species; (3) no nocturnal observations were conducted; (4) sampling effort was not continuous; hence, ephemeral bouts of macroscale exposure, such as are predicted for migrating individuals, could have gone undetected.

The inferred migratory paths of two Roseate Terns tracked between 2007 and 2008 with light-sensitive geolocators added some information relevant to this issue, but it is limited as the sample size is extremely small. During fall migration, two individuals moved over the span of several days in late Aug between Cape Cod, Massachusetts, and Puerto Rico. In spring migration, a single individual spent over a month moving in an erratic pattern between the Dominican Republic, offshore areas of the AOCS near the Carolinas, and then arrived at its Massachusetts breeding colony on 10 Jun (USFWS 2008a). Because this bird arrived in Massachusetts roughly 1 mo later than did most birds in its breeding colony, its migratory behavior may have been an aberration and its path may not represent a normal path for birds in this population. The inferred AOCS crossing pathways of these tracked birds must be viewed with further caution based on the spatial imprecision of geolocations calculated from light-sensitive geolocator data. Such calculations may contain up to 300 km of error for locations where birds remained stationary for periods of at least a day, and the paths taken by individual birds between such stationary points are primarily inferred by assuming that birds are most likely to have travelled the shortest, most direct route between them.

Our geospatial analysis revealed a total of 86 offshore observations of Roseate Tern, of which as few as 13 could be unambiguously ascribed to locations ≥3 mi from shore. These were scattered throughout the area of study (AOCS from Massachusetts to North Carolina). However, we note that the spatial pattern of these observations is severely limited and is furthermore affected by the spatial patterning of where the limited sampling has been conducted. We therefore suggest that these observations do not shed significant new light on Roseate Tern spatiotemporal distribution on the AOCS. The limited extent of available geospatial records of Roseate Terns on the AOCS precluded any more refined characterization of macroscale exposure patterns in this region for this species.

Determining the specific migration paths of Roseate Terns in the AOCS region remains a significant knowledge gap for characterizing the macroscale exposure of Roseate Terns to AOCS wind facilities.

Mesoscale Exposure

Some additional information on Roseate Tern flight altitudes has generally confirmed prior information to suggest that mesoscale exposure of this species to AOCS wind turbines is low. One out of the eight total offshore observations of Roseate Tern during ship-based transect surveys for the Rhode Island Special Area Management Plan (SAMP) study (Paton et al. 2010) was of a bird flying at rotor swept altitude. None of the 125 land-based observations of Roseate Tern were of birds flying within rotor swept altitudes (Paton et al. 2010). Flight altitudes are not reported for the 29 Roseate Terns that were observed during boat-based, near-shore surveys specifically targeted at Roseate Terns for the Rhode Island SAMP study (Paton et al. 2010).

In the application of our new collision risk model to Roseate Terns, we incorporate previously unpublished data on flight altitudes of Roseate Terns from offshore surveys in Buzzards Bay, Massachusetts. Of the 1,467 offshore Roseate Tern observations in this data set, 13 (0.9%) occurred at altitudes ≥30 m above the water's surface. This corroborates previous information on Roseate Tern flight altitude synthesized in the preliminary risk assessment (Section 2; Burger et al. 2011).

The flight altitude of migrating Roseate Terns continues to be an unanswered question of high importance, as migration is the only period during which Roseate Terns are likely to experience any macroscale exposure to AOCS wind turbines outside of the immediate vicinity of their breeding colonies and postbreeding staging areas. Further research into the migratory flight altitude of Roseate Terns, including potential altitudinal shifts in response to various wind and other climatic conditions during migration, is necessary in order to resolve current uncertainties in our understanding of potential risks to Roseate Terns from offshore wind energy development on the AOCS.

Microscale Exposure

There remains very little information that can be brought to bear to characterize the microscale exposure of Roseate Terns to AOCS wind facilities. No wind turbine-related mortality has been reported in this species, but there are no wind facilities currently located along this species' pelagic migration environment, and available information is extremely limited for any coastal wind facilities occurring within the region this species occupies during its breeding and postbreeding staging periods. Our carcass searching effort at the MMA coastal wind turbine, located roughly 12 km from a Roseate Tern breeding colony, did not record any turbine-related mortality for Roseate Tern. However, Roseate Tern passage rates in the vicinity of the wind turbine at this site are low; hence, the observation of no mortality at this site is not necessarily a strong indication of low microscale exposure. Some inference of relatively low microscale exposure can be derived from the observation of no mortality of Common Terns during the MMA carcass searching effort conducted for this study, as the Common Tern is a congener of Roseate Tern and the two species are very similar in size, morphology, and ecology. Common Terns are over 10 times as abundant at the MMA study site as are Roseate Terns; hence, the lack of observed mortality in this species provides a greater indication of lower collision risk than does the lack of observed mortality in Roseate Tern. The lack of observed mortality also precluded extensive quantitative analysis of Common Tern collision risk or microscale exposure.

The collision risk model developed in this study presents a novel approach for incorporating behavioral avoidance and, therefore, microscale exposure into wind turbine risk analysis. Our application of this model to offshore wind turbine risk in Roseate Tern produced an overall Roseate Tern mortality prediction comparable to that of the final model considered by the USFWS in the Biological Opinion on Roseate Tern and Piping Plover impacts from the proposed Cape Wind Project (USFWS 2008b; Section 3.6).

While the limited available evidence suggests that the microscale exposure of Roseate Terns to offshore wind turbine collision risk is low, it must be noted that there is still a great degree of scientific uncertainty regarding this issue. This is primarily because all of the existing evidence requires the application of certain questionable assumptions in order to apply it specifically to Roseate Tern offshore wind risk considerations. These assumptions include, but are not necessarily limited to, the following: Common Terns serve as a suitable surrogate for Roseate Terns; behavior in the vicinity of a wind turbine on land is comparable to such behavior in the offshore environment; and modeled collision risk parameters are an accurate representation of biological reality. Microscale exposure questions such as visibility impacts and behavioral avoidance of offshore wind turbines by Roseate Terns therefore remain as significant gaps in our knowledge. Empirical studies of Roseate Tern behavior in the vicinity of offshore wind turbines must be conducted in order to fill these gaps and develop a scientifically rigorous and valid characterization of risk to Roseate Tern from AOCS wind energy development.

4.3.2 Piping Plover

Macroscale Exposure

Significant new insights into patterns of Piping Plover macroscale exposure to wind facility development on the AOCS have been gained since the completion of the preliminary risk assessment, though knowledge gaps still remain. New information comes primarily from two sources: (1) the 5-yr status review of Piping Plover recently completed by the USFWS and sources cited therein (USFWS 2009a) and (2) the geospatial analysis conducted under the auspices of this project using existing and acquired data from the AKN. On the basis of the new evidence contained in these two sources, it can now be concluded that Piping Plovers do regularly make long migratory flights over water within the AOCS region, resulting in potential macroscale exposure of this species to wind facilities on the AOCS. Furthermore, there is also evidence to suggest that such exposure is likely to be widely but thinly spread over the region, not necessarily restricted to the mouths of certain bays and inlets as would be predicted if migrants exhibited coasthugging migratory routes. New evidence is wholly consistent with the previously derived conclusion that overall macroscale exposure of this species to AOCS wind facilities is extremely temporally limited. This is because such exposure is only possible during brief portions of spring and fall migration when long migratory flights over water occur, with Piping Plovers spending the remainder of their life cycles largely or wholly restricted to coastal habitats. The specific migration pathways of Piping Plovers over the AOCS remain unknown and a topic for future research.

We note that recent bird survey efforts conducted in portions of the AOCS off of New Jersey (NJDEP 2010) and Rhode Island (Paton et al. 2010) produced no new information germane to the risk characterization for Piping Plovers. Both of these efforts consisted of extensive, year-round diurnal survey efforts using boat- and plane-based visual observers plus extensive gathering of radar data. Neither of these studies produced any observations of Piping Plover in the offshore environment (NJDEP 2010; Paton et al. 2010). Shore-based observations in the

Rhode Island study produced nine observations of Piping Plover (Paton et al. 2010), but these observations do not inform a consideration of offshore macroscale exposure. The lack of Piping Plover observations in the portions of the AOCS covered by these studies can be taken to some degree as corroborative support for the conclusion that macroscale exposure of Piping Plovers to AOCS wind facilities is highly limited. This is corroborated by the paucity of offshore records of Piping Plover discovered in our geospatial analysis of AKN data (11 total offshore observations, none unambiguously from a truly offshore location as reflected by metadata). However, well-known limitations of the methodologies employed by these and other existing AOCS bird survey efforts prevent a robust and comprehensive characterization of AOCS Piping Plover macroscale exposure for several reasons: (1) observing Piping Plovers flying over the water and distinguishing between them and similar-looking congeners is virtually impossible from an aircraft and extremely difficult from a boat; (2) flying targets recorded in radar observations were not identified to species; (3) no nocturnal observations were conducted; and (4) sampling effort was not continuous; hence, ephemeral bouts of macroscale exposure, such as are predicted for migrating individuals, could have gone undetected. The lack of nocturnal observations in these data sets is particularly problematic for Piping Plover AOCS macroscale exposure characterization. Although the specific time of day of Piping Plover migratory flights is not well-known (A. Hecht, USFWS pers. comm.), the most likely scenario, based on general patterns of shorebird migration biology, is that most migratory flight activity may be nocturnal in this species.

The information reviewed by the USFWS in its recent 5-yr status review of Piping Plover confirms that migratory flight over portions of the AOCS, and hence macroscale exposure of Piping Plovers to AOCS wind facilities, does occur as a normal part of this species' life cycle (USFWS 2009a). This conclusion can be drawn on the basis of significant portions of the population wintering in the Bahamas and various Caribbean Islands because significant portions of AOCS waters must be traversed by these birds at least twice per year. While researchers have known for more than 15 yrs that Piping Plover winter in the Bahamas and elsewhere in the Caribbean, wintering populations numbering greater than 100 individuals were first documented during the 2006 International Piping Plover Census when 417 Piping Plovers were discovered in the Bahamas, along with 89 in Cuba, and 28 in other Caribbean Islands (Elliott-Smith et al. 2009). These individuals comprised 14% of the wintering Piping Plover individuals observed during that entire census. Though the authors note that the results of this census contain inherent sampling biases, and though the breeding ground provenance of the Bahamian and Caribbean winterers is still unknown, this observation stands as definitive evidence that a substantial fraction of the Piping Plover population must regularly cross the AOCS at some point at least twice per year during migrations (Elliott-Smith et al. 2009; USFWS 2009a).

The specific migratory paths and AOCS crossing points taken by Bahamian and Caribbean wintering individuals remain unknown. Furthermore, the extent to which Piping Plovers that overwinter in other areas may make AOCS crossing flights remains unknown. The 5-yr Piping Plover status review also presents a recent compilation of evidence on migratory observations of Piping Plovers. The extent of such observations continues to be extremely limited and the USFWS notes that the specific migration routes taken and migratory stopover patterns in this species remain poorly characterized (USFWS 2009a).

Our geospatial analysis contains the first evidence that Atlantic coastal breeding Piping Plovers may not move incrementally along the coast during migration, as has been previously suggested in literature, but may have a tendency to make single, long-distance, nonstop migratory flights, as inland-breeding populations are known to do. The absence of coastal stopovers implied by this migratory pattern opens the possibility that birds do not necessarily remain close to the coast during their migratory flights. A plausible scenario is that birds fly the shortest possible route between wintering and breeding areas, which in some cases would take birds far offshore over the AOCS, and, in other cases, may take birds significant distances inland. Such a pattern has significant implications for macroscale exposure of Piping Plovers to AOCS wind facilities. Taken together with the observation that a significant fraction of the Piping Plover population overwinters on islands located significant distances from the Atlantic Coast of mainland North America, it suggests that macroscale exposure of this species is likely to occur broadly, if thinly and ephemerally, over the AOCS. Further study is needed to elucidate the specific locations of AOCS migratory crossings in Piping Plover. In particular, tracking studies of individual birds have great potential to provide important new insights into specific AOCS crossing migration paths in this species.

Mesoscale Exposure

The migratory flight altitude of Piping Plover remains unknown; hence, no new information can be brought to bear to characterize the mesoscale exposure of this species to AOCS wind facilities.

Microscale exposure

There remains very little information that can be brought to bear to characterize the microscale exposure of Piping Plovers to AOCS wind facilities. No wind turbine-related mortality has been reported in this species, but available information is extremely limited for any wind facilities occurring along potential Piping Plover migration routes. At the Jersey Atlantic Wind Energy facility, three collision-related mortalities have been documented in the first 2 yrs of fatality monitoring for all shorebird species combined (one Dunlin, one Short-billed Dowitcher, and one unidentified shorebird: NJAS 2008a, 2008b, 2009). This, plus evidence from some European coastal wind facilities (e.g., Landmark Practice 2009), is suggestive of low collision susceptibility for shorebirds in general, as such facilities are located in close proximity to major shorebird migratory stopover concentration points. However, more study is needed before microscale exposure to wind turbine collisions can be robustly characterized for Piping Plovers or other shorebirds.

4.3.3 Red Knot

Macroscale exposure

Our study rendered significant new insights into patterns of Red Knot macroscale exposure to wind facility development on the AOCS. It was known previously that Red Knots, at least from the long-distance migrant population, regularly make long migratory flights over water within the AOCS region, resulting in macroscale exposure of this species to wind facilities on the AOCS (Burger et al. 2011). However, the specific locations of such flights were not known, and it had been suggested that the migratory pathways of individuals from the short-distance migrant population might be largely or wholly restricted to coastal areas (Burger et al. 2011). We present new evidence that suggests that Red Knot migratory crossings of the AOCS are likely to occur broadly throughout the region with possible concentrations in the region south of Cape Cod in fall and south of Delaware Bay in spring. This conclusion comes from the combination of two complementary research efforts within the present study. The migratory routes taken by 11 individual Red Knots were revealed by a 1-yr tracking study using light-sensitive geolocators. This produced highly detailed information on AOCS macroscale exposure for a small sample size of birds, including three birds from the long-distance migrant population and eight birds from the short-distance migrant population. The former were tracked for 1 yr between spring captures on the Delaware Bay shore of New Jersey and tended to cross the AOCS to the south of Cape Cod, Massachusetts, in fall and to the south of Delaware Bay in spring. The latter were tracked for 1 yr between fall captures in Cape Cod, Massachusetts, and displayed a more irregular and variable pattern of migration routes, including several presumed AOCS crossings at a variety of locations throughout the region. The specific inferred AOCS crossing pathways of these tracked birds must be interpreted with caution based on the spatial imprecision of geolocations calculated from light-sensitive geolocator data. Such calculations may contain up to 300 km of error for locations where birds remained stationary for periods of at least a day, and the paths taken by individual birds between such stationary points are primarily inferred by assuming that birds are most likely to have travelled the shortest, most direct route between them.

Our geospatial analysis provided an essential complement to the tracking study because the comprehensiveness of the data contained within the AKN renders a population-wide, even if somewhat crude, perspective on this species' pattern of spatiotemporal distribution within the AOCS region. The geospatial analysis revealed that migratory stopover distributions of Red Knots along the Atlantic Coast of the U.S. are highly concentrated in certain regions of the coast: in the Delaware Bay during spring migration and along the coast of Massachusetts, and particularly Cape Cod, during fall migration. The non-uniformity of these distributions along the coast suggests that significant portions of Red Knot migratory pathways are noncoastal. One obvious noncoastal portion of Red Knot migratory pathways is the migration segment that occurs between Atlantic Coast stopover and breeding areas in the Canadian Arctic. Such flight segments almost certainly occur over inland portions of northeastern North America. To the south of the Atlantic Coast migratory stopover locations, migratory pathways may be either coast-following, AOCS-crossing, or a mixture of both. While some extent of coast-following is likely to occur in Red Knots migrating within the AOCS region, the distinct concentrations of birds within certain regions of the coast suggest that a large fraction of the population undertakes long-distance flight segments within this region that are likely to cross the AOCS and take birds significant distances offshore as they follow parsimonious pathways between widely separated migration stopping points.

Taken together, the two sources of new information presented in this study revealed that macroscale exposure of Red Knots to wind facilities is likely to be widely but thinly spread over the AOCS region. Furthermore, our data suggest that such exposure also occurs, at least to some degree, in individuals from the short-distance migratory population, whose migratory movements over the AOCS had been previously hypothesized to be restricted to the mouths of certain bays and inlets (Burger et al. 2011). The new evidence we present is consistent with the previously derived conclusion that overall macroscale exposure of this species to AOCS wind facilities is extremely restricted temporally. This is because such exposure is only likely during brief portions of spring and fall migration when long migratory flights over water occur, with Red Knots spending the remainder of their life cycles largely, or wholly, restricted to coastal and near-shore habitats. More study of the specific migration pathways of Red Knots over the AOCS is needed before macroscale exposure of this species to AOCS wind facilities can be systematically and robustly characterized.

We note that recent bird survey efforts conducted in portions of the AOCS off of New Jersey (NJDEP 2010) and Rhode Island (Paton et al. 2010) produced no new information germane to the Red Knot risk characterization. Both of these efforts consisted of extensive, year-round diurnal survey efforts using boat- and plane-based visual observers plus extensive gathering of radar data. Neither of these studies produced any observations of Red Knots in the offshore environment (NJDEP 2010; Paton et al. 2010). The lack of Red Knot observations in the portions of the AOCS covered by these studies can be taken to some degree as corroborative support for the conclusion that macroscale exposure of Red Knots to AOCS wind facilities is highly limited. This is further corroborated by the paucity of offshore records of Red Knot discovered in our geospatial analysis of AKN data (all offshore records derived from 38 total AOCS locations, none unambiguously from a truly offshore location as reflected by metadata). However, well-known limitations of the methodologies employed by these, and other existing AOCS bird survey efforts, prevent a robust and comprehensive characterization of AOCS Red Knot macroscale exposure for several reasons: (1) observing Red Knots flying over the water and distinguishing between them and similar-looking congeners is virtually impossible from an aircraft and extremely difficult from a boat; (2) flying targets recorded in radar observations were not identified to species; (3) no nocturnal observations were conducted; and (4) sampling effort was not continuous; hence, ephemeral bouts of macroscale exposure, such as are predicted for migrating individuals, could have gone undetected. The lack of nocturnal observations in these data sets is particularly problematic for Red Knot AOCS macroscale exposure characterization, as significant nocturnal portions of migratory flights can be inferred from the duration and distance of recorded migratory flight segments (Niles et al. 2010; Burger et al. 2011; Section 3.3).

Based on the original analyses presented in this study, it can be concluded that macroscale exposure of Red Knots to wind facilities is likely to occur broadly, if thinly and ephemerally, over the AOCS. This exposure is likely to be concentrated, at least to some degree, in portions of the AOCS to the south of Massachusetts in fall and in portions of the AOCS to the south of Delaware Bay in spring. However, further study is needed to obtain a robust and systematic characterization of the spatiotemporal patterning of AOCS crossings by migrating Red Knots.

Mesoscale Exposure

The migratory flight altitude of Red Knots remains unknown; hence, no new information can be brought to bear to characterize the mesoscale exposure of this species to AOCS wind facilities during migratory flights.

Microscale Exposure

There remains very little information that can be brought to bear to characterize the microscale exposure of Red Knots to AOCS wind facilities. No wind turbine-related mortality has been reported in this species, but available information is extremely limited for any wind facilities occurring along potential Red Knot migration routes. At the Jersey Atlantic Wind Energy facility, three collision-related mortalities have been documented in the first 2 yrs of fatality monitoring for all shorebird species combined (one Dunlin, one Short-billed Dowitcher, one unidentified shorebird: NJAS 2008a, 2008b, 2009). This, plus evidence from some European coastal wind facilities (e.g., Landmark Practice 2009), is suggestive of low collision susceptibility for shorebirds in general, as such facilities are located in close proximity to major shorebird migratory stopover concentration points. However, more study is needed before microscale exposure to wind turbine collisions can be robustly characterized for Red Knots or other shorebirds.

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Appendix A: “Offshorebird Project” Kickoff Meeting Summary

"Offshorebird Project" Kickoff Meeting Summary

October 29, 2008, 12:15-3:50pm
U.S. Minerals Management Service Procurement Branch Headquarters
381 Elden St., Herndon, VA

MMS contract # M08PC20060 with Pandion Systems, Inc.
"Potential for Interactions Between Endangered and Candidate Bird Species with Wind Facility Operations on the Atlantic Outer Continental Shelf"

Meeting Minutes

***12:15* – Welcome**
Caleb Gordon welcomed meeting participants and introduced Mary Boatman.

***12:20* – Introductions**
Mary Boatman made introductory remarks, expressing the MMS goals for this project.

***12:25* – Overview of the Project**
Caleb Gordon presented an overview of the project, reviewing the project objectives and scope, introducing all of the members of the project team and their roles, describing the risk assessment framework for the project, and walking through the project timeline with its distinct phases, meetings, and tasks.

***1:00* – The Avian Knowledge Network and Its Application to this Project**
Marshall Iliff and Caleb Gordon presented information on the application of the Avian Knowledge Network (AKN) to the project. Marshall Iliff described the nature of the AKN, identifying its basic architecture, purpose, size, scope, contributors, and proprietary data protection mechanisms. He also presented a list of project-relevant data sets that the Cornell Laboratory of Ornithology (CLO) has targeted for inclusion in the AKN under this project (see Kickoff Meeting Appendix). Caleb Gordon described how the AKN can help accomplish project goals as a tool to characterize macroscale exposure of the three study species to offshore wind facilities in the region of interest. He presented a series of maps containing AKN level 5 data (unlimited public access) that illustrated the spatial distribution of each of the three study species along the entire Atlantic Coast of the U.S. in each month of the year. Meeting participants asked questions about the nature and coverage of the existing AKN data and briefly discussed priorities and procedures for incorporating additional project-relevant data sets into the AKN under the project. Allan O'Connell described how the AKN-based component of this project could be linked to the USGS seabird data compendium. All meeting participants were encouraged to offer suggestions for additional project-relevant data sets that should be sought for inclusion in the AKN under this project.

***1:55* – Break**

***2:00* – Problem Formulation Introduction**
Jim Newman described the problem formulation stage of the risk assessment in more detail, presenting a preliminary conceptual model of risk and a preliminary list of research questions that could be addressed by pilot studies under this project. He then introduced the instructions for the problem formulation breakout discussion groups.

***2:10* – Breakout Discussion Groups**
The group was divided into three breakout groups, one for each study species, each charged with discussing, identifying, and prioritizing species-specific research questions that could be addressed by pilot studies under this project (see discussion summaries below).

***3:00* – Whole Group Discussion**
The entire group reconvened to discuss priorities for pilot study research questions, using the prioritized lists from the breakout groups, which were written on butcher paper and posted on the wall (see discussion summaries below).

***3:45* – Closing Remarks**
Caleb Gordon presented closing remarks, highlighting the need for continued conversation and input from the whole group and commenting on how the project's species-specific focus influences the process of developing research hypotheses and methodologies to be tested in the pilot study phase of the project.

***3:50* – Adjourn**

Discussion Summaries for Pilot Study Research Priorities

Roseate Tern Breakout Group (L. Vlietstra, E. Zillioux, G. Forcey, R. Podolsky, S. Valdes)
The Roseate Tern (ROST) breakout group produced a list of four key research questions related to the objectives of this study for this species. These four questions follow a hierarchy of Exposure > Behaviors > Behaviors that relate to risk > Demographics. The questions below are presented in this small-scale to large-scale hierarchy.

1. What is the spatial and temporal distribution of ROST in the Atlantic Outer Continental Shelf (AOCS)?
2. What behaviors are ROST exhibiting in the AOCS?
    a. How high are ROST flying within the AOCS? What proportion is flying within the Rotor Swept Zone (RSZ)?
    b. Where and when are ROST foraging in the AOCS? To what extent are they foraging during migration?
    c. To what extent will attraction and avoidance behavior be exhibited by ROST?
    d. When are ROST migrating through the AOCS and where are their routes of travel?
3. What are the risks of different behaviors in the AOCS?
    a. How will ROST flight heights within the RSZ affect risk?
    b. Will foraging behavior put ROST at increased risk?
    c. How will ROST avoidance and attraction behaviors influence risk?
    d. How will migratory behavior affect risk to ROST?

4. What population-level effects will occur from interactions between ROST and wind turbines?

In addition to the questions proposed above, the group had some discussion on the issue of artificial attraction of wind turbines. This is known as the artificial reef attraction effect. It can occur if the turbines attract ROST either because the underwater support structures of the turbines increase ROST food supply by providing shelter or food resources for prey (small fish) and/or if the turbine platforms provide perches for ROST. There is existing literature regarding the artificial reef effect on offshore oil rigs that may be useful as background material for the current project.

There was also discussion on the temporal variation of different behaviors. It was suggested that the questions be focused separately for three different time periods: April-May (arrival), May-August (breeding), and August-September (departure). Addressing the questions in these temporal categories will allow us to tease out behavioral variation during these time periods. Breeding season was when the majority of feeding occurs, so this may put ROST at increased risk. Migration likely happens quickly and less feeding occurs, so ROST may be at lower risk during this time. Flight height might also be higher (above RSZ) during migration which may further lower risk.

The ROST group also discussed if there was more or less risk for non-breeding adult ROST, as compared with breeding adults. A percentage of the ROST population consists of non-breeding adult birds which are not tied to a nesting colony. What is the behavior of the non-breeding adults? Do they forage further away from land because they are not tied to a nesting colony? How does flight vary for non-breeding vs. breeding adults? Does migratory behavior vary for non-breeding adult ROST compared to breeders?

Piping Plover Breakout Group (J. Burger, J. Newman, D. Mizrahi, M. Iliff)

The Piping Plover breakout group developed the following list of research questions in order of highest to lowest priority of importance for the objectives of this study:

1. What is the likelihood that Piping Plovers will occur in the AOCS?
2. If mortality does occur, what will be the population level effects, especially to geographical populations that apparently have declining numbers?
    a. There are geographically distinct Piping Plover populations along the Atlantic Coast. Some populations have low numbers (e.g., the New Jersey Population of ~ 100 pairs). This population does not appear to be increasing. Massachusetts population is larger and increasing.
    b. Does risk of AOCS offshore wind turbine development differ significantly among these geographically distinct populations? (If Piping Plover does fly over the AOCS (macroexposure) and this risk differs for different geographical populations then different management strategies may be appropriate.)
    c. Suggested Piping Plover Pilot Study: Conduct modeling studies (population viability analyses) that incorporate effects of AOCS offshore wind turbine mortality for geographical populations of Piping Plovers

3. Will the Piping Plover show behavioral avoidance to wind turbines?
4. Even if Piping Plovers normally hug the coast, might catastrophic events bring large numbers of them offshore causing periodic episodes of high risk from offshore wind turbines in the AOCS?

Red Knot Breakout Group (L. Niles, W. Warren-Hicks, C. Gordon, M. Boatman, A. Farnsworth)

The Red Knot breakout group produced a list of four key research questions related to the objectives of this study for this species. Two of these were deemed to be of highest priority (both labeled with a 1 below), and two were deemed to be of secondary priority (labeled with a 2 below). All of these four questions were regarded as very high priority questions.

1-1. Exactly when and where do Red Knots cross the AOCS?

1-2. When in the AOCS, do Red Knots fly at the altitude of the RSZ?

a. Migratory flights (either to, from, or in between stopover sites) are the highest risk times to study this species, compared with commuting flights (e.g., between low and high tide feeding and roosting areas) during a stay at a single stopover site, though there is still potentially some risk of crossing the AOCS during the latter type of flights as well.
b. How is flight height in the AOCS affected by covariables including weather, proximity to ascent/descent point, physical condition of the birds, landform physiography, and seasonality?

2-1. To what degree can/will Red Knots avoid the Rotor Swept Area (RSA) of wind turbines when they are flying within the RSZ? In other words, can/do Red Knots exhibit behavioral avoidance of wind turbines while flying at turbine height?

2-2. Is there a difference between long- and short-distance populations of Red Knots with respect to any of the above questions? In particular, do individuals of the short-distance migrant population hug the coastline during migration, thereby reducing the likelihood of macroexposure to offshore wind turbines on the AOCS?

In addition, the Red Knot group decided that the question of whether or not alteration or blockage of migration routes by offshore wind turbines in the AOCS could cause significant impacts to Red Knots, such as increased energy expenditure, was less important than questions related to collision mortality, except if such blockages caused disruption of key elements of Red Knot stopover biology, such as preventing them from being able to exploit the key horseshoe crab larvae feeding grounds in the mid-Atlantic coast during their spring migration. The group also noted that studying the energetics of Red Knots would potentially involve completely different methodology than would studying collision mortality factors, hence the former was unlikely to be a cost-effective option for pilot studies.

The Red Knot group discussed developing a model that would map collision risk over the entire AOCS region of interest as a function of the various factors that influence collision likelihood (as in part b of question 1-2 above).

The group noted that general birdwatcher observations suggest that the cruising altitudes of Red Knot migratory flights are well above the RSZ of wind turbines, which would mean that the period of most risk when this species is normally crossing the RSZ is during initial ascent or final descent. However, the group also noted that this idea is not a known fact, but a hypothesis in need of testing at this point. In a similar vein, the group discussed the idea that bad weather conditions may bring normally high-flying Red Knots down lower into the RSZ during migratory flights, also noting that this was a hypothesis in need of testing, rather than a known phenomenon.

Whole Group, All Species Discussion Summary

The idea was suggested, and met with general agreement, that the three study species can be ranked as follows in terms of most to least likely risk posed by wind facility development in federally regulated waters of the Atlantic Outer Continental Shelf:

- Roseate Tern > Red Knot (long distance migrant population) > Piping Plover > Red Knot (short distance migrant population)

This ranking was based on the general observation that Roseate Terns and long distance migrant Red Knots are the only groups who certainly cross this region on a regular basis. In contrast, there is a strong possibility that Piping Plovers and short distance migrant Red Knots may not regularly occur over the Atlantic Ocean greater than three nautical miles from the coast, with the possible exception of certain areas, such as Delaware Bay or the Long Island Sound, where "coasthugging" behavior may bring these birds over federally regulated waters as they pass from one coastal promontory to another. Another factor in this ranking was the general feeling that Roseate Terns may spend large periods of time at the general height of wind turbine blades (in the Rotor Swept Zone) while migrating pelagically, whereas long distance migrant Red Knots are more likely to be flying at higher altitudes while flying over the ocean, potentially only becoming exposed to risk during a more limited window of time and space. Based on this ranking of likely risk, the group concluded that the most important subjects for field pilot studies under this project were first Roseate Tern and second Red Knot.

The group also arrived at general agreement over a different ranking of these three species from most to least "threatened" in terms of population size and status, as follows:

- Piping Plover > Roseate Tern > Red Knot

This ranking may be useful in determining priorities for population viability analyses (PVA), because the central issue for such studies is population persistence/sustainability. Some agreed that the species should be prioritized as above for PVA. Others suggested that PVA should be done for all three species, and some suggested that PVA would be difficult for Red Knots given the larger population size. It was suggested that the key goal of PVA under this project would be to determine the specific level or threshold of collision mortality that could be sustained by the population without causing the population to trend downward toward extinction, such as has been done for the Roseate Tern population of Buzzards Bay with respect to a proposed offshore wind development. The latter information is proprietary, but will be sought by this group for use in this project. One participant noted that PVA should be a lower priority than risk-characterization field methodologies for pilot studies under this project.

The group observed that all three species-focused breakout groups had identified determining macroscale exposure as a top priority for pilot studies under this project.

The group discussed the desirability of developing a spatially explicit risk model, which would map out bird risk over the entire region of interest as a function of the species-specific factors that affect it. It was suggested that defining such a model would help define priorities for pilot studies to gather biological, geographic, meteorological, and other data necessary to quantify risk in the model.

There was a very brief discussion of some ideas relating to specific field methodologies that would or would not be useful toward achieving the goals of this project. The utility of using NEXRAD radar data to quantify general density of flying targets over the study region was suggested, but it was noted that its application to the current project is limited because the data is not species-specific.

In closing, it was noted that the species-specific focus of this project necessitates an approach somewhat different from most wind-wildlife studies to date. Specifically, the issue of using surrogate species must be carefully considered. Some components of risk, such as behavioral avoidance of operational turbines, may be more amenable to the use of surrogate species data than others, such as macroscale exposure, where species-unspecific information may have limited applicability.

Attendance List

In person, unless otherwise indicated

Mary Boatman, U.S. Minerals Management Service
Christian Newman, Pandion Systems, Inc.
Caleb Gordon, Pandion Systems, Inc.
James Newman, Pandion Systems, Inc.
Greg Forcey, Pandion Systems, Inc.
Joanna Burger, Rutgers University
Lawrence Niles, Conserve Wildlife Foundation
Lucy Vlietstra, Massachusetts Maritime Academy
Ed Zillioux, Environmental Bioindicators Foundation, Inc.
William Warren-Hicks, EcoStat, Inc.
Richard Podolsky, Independent Consultant
Andrew Farnsworth, Cornell Laboratory of Ornithology
David Mizrahi, New Jersey Audubon Society
Marshall Iliff, Cornell Laboratory of Ornithology
Allan O’Connell, USGS
Andrew Gilbert, USGS (via phone and Webex)
Scott Johnston, USFWS (via phone and Webex)

Appendix: List of Data Sets Identified for Inclusion in the Avian Knowledge Network under this Project

Title	Lead Agency / Organization	Contact
eBird	Cornell Lab of Ornithology	Brian Sullivan
International Shorebird Survey	Manomet Center for Conservation Sciences	Brian Harrington
Gulf of Maine Seabird Monitoring (including Project Puffin)	Gulf of Maine Seabird Working Group (GOMSWG)	Scott Hall
Gulf of Maine Tern Monitoring	Gulf of Maine Seabird Working Group	Steve Kress
International Shorebird Banding Project	Western Atlantic Shorebird Association	Allan Baker
Red Knot records from misc journals (RNEB, etc.)	Manomet Center for Conservation Sciences	Brian Harrington
Roseate Tern Monitoring	Northeastern Roseate Tern Recovery Team	Michael Amaral
Shorebird records from Am. Birds	Manomet Center for Conservation Sciences	Brian Harrington
Avian Influenza Monitoring	USDA Animal and Plant Health Inspection Service (APHIS)	
Christmas Bird Count	National Audubon Society	Geoff LeBaron
Colonial Waterbird Inventory and Monitoring Program	US Geological Survey Patuxent Wildlife Research Center	R. Michael Erwin
Important Bird Areas Site Assessment	National Audubon Society	John Cecil (for State IBA Coord.)
USGS Point Count Database	USGS	Mark Wimer
NatureServe (endangered and threatened species sighting reports)	NatureServe	Nicole Capuano
North American Bird Banding	US Geological Survey Patuxent Wildlife Research Center, Bird Banding Laboratory	Kathy Klimkiewicz
North American Migration Count		Jim Stasz
Program for Regional and International Shorebird Monitoring (PRISM) migration counts	Manomet Center for Conservation Sciences	Stephen Brown
Connecticut Breeding Bird Atlas		
Connecticut Piping Plover and Least Tern Survey	CT DEP-Wildlife Division	Julie Victoria
Connecticut Summer Bird Count	Connecticut Ornithological Association	Joe Zeranski
Beach-nesting Bird Surveys	Delaware Division of Fish and Wildlife	
Delaware Breeding Bird Atlas	Delaware Museum of Natural History	Rick West
Delaware Bird Records Committee	Delmarva Ornithological Society	Frank Rohrbacher
Delaware Forest Bird Surveys	Delaware Division of Fish and Wildlife	Christopher Heckscher
Delaware Shorebird Project	Delaware Division of Fish and Wildlife	Holly Neiderriter
Bird Observer Database		Marj Rines
Historical Red Knot data (notes from Griscom, Hill etc.)	Manomet Center for Conservation Sciences	Brian Harrington
Massachusetts Breeding Bird Atlas	Mass Audubon	Joan Walsh
Massachusetts Division of Fisheries and Wildlife: Piping Plover banding/monitoring	Massachusetts Division of Fisheries and Wildlife	
Ian Nisbet data		Ian Nisbet
Mass Audubon Coastal Waterbird Program	Mass Audubon	Becky Harris
Mass Audubon Sanctuary Breeding Bird Survey	Mass Audubon	Chris Leahy
Red Knot aerial sightings from AMOY surveys	Manomet Center for Conservation Sciences	Brian Harrington
Assateague Island National Seashore Piping Plover Research and Monitoring	National Park Service	Jack Kumer
Maryland / DC Breeding Bird Atlas	Maryland / DC Audubon Society	Walter Ellison
Maryland Rare Species Reporting	Maryland Department of Natural Resources	Lynn Davidson
Chesapeake Bay Island Restoration Projects	US Army Corps of Engineers	R. Michael Erwin
Maryland / DC Bird Records Committee	Maryland Ornithological Society	Phil Davis (Secretary)
Maryland Colonial Waterbird Project	Maryland Department of Natural Resources	
Maryland database		Bob Ringler

Title	Lead Agency / Organization	Contact
Maryland Fall Count	Maryland Ornithological Society	Chuck Stirrat
Maryland May Bird Count	Maryland Ornithological Society	Wanda Diane Cole
Chincoteague National Wildlife Refuge Piping Plover Research and Monitoring	US Fish and Wildlife Service	Amanda Daisey
North Am. Birds Database		Marshall Iliff
Maine Breeding Bird Atlas	Maine Department of Inland Fisheries and Wildlife	Tom Hodgman
Maine Piping Plover and Least Tern Monitoring	Maine Department of Inland Fisheries and Wildlife	Lindsay Tudor
Maine records		Jody Despres
Gulf of Maine Salt Marsh Monitoring	Gulf of Maine Council on the Marine Environment	
Isle of Shoals Tern Restoration Project	New Hampshire Fish and Game Department	Diane DeLuca
New Hampshire Bird Records	Audubon Society of New Hampshire	Becky Suomola
New Hampshire Breeding Bird Atlas	Audubon Society of New Hampshire	Pam Hunt
New Hampshire Piping Plover Monitoring	New Hampshire Fish and Game Department	John Kanter
New Hampshire Shorebird Monitoring	Audubon Society of New Hampshire	Peter McKinley
Delaware Bay Shorebird Count	New Jersey Division of Fish and Wildlife Endangered and Nongame Species Program	Kathy Clark
Delaware Bay Spring Shorebird Banding	New Jersey Division of Fish and Wildlife Endangered and Nongame Species Program	Amanda Dey
New Jersey Beach-Nesting Bird Monitoring	New Jersey Division of Fish and Wildlife Endangered and Nongame Species Program	Chris Kisiel
New Jersey Breeding Bird Atlas	New Jersey Audubon Society	
New Jersey Red Knot Telemetry	New Jersey Division of Fish and Wildlife Endangered and Nongame Species Program	Amanda Dey
New Jersey DEP--baseline offshore surveys	New Jersey DEP	
New Jersey DEP--Red Knot banding/monitoring program	New Jersey DEP	
Great Gull Island Project	American Museum of Natural History	Helen Hays
Long Island Colonial Waterbird and Piping Plover Survey	New York State Department of Environmental Conservation	Michelle Gibbons
New York Breeding Bird Atlas	New York State Department of Environmental Conservation	Kim Corwin
New York State DEC/AMNH: Roseate Tern banding/monitoring	NY Dep. Of Environemental Concervation/AMNH	
Montauk seawatch		
New York Bird Monitoring Program	Wildlife Conservation Society	Michael Klemmins
New York June Count	Eastern Long Island Audubon Society, Cayuga Bird Club	
New York Natural Heritage-ranked Species Modeling	New York Natural Heritage Program	Jeff Corser
Bird Banding Lab	Bird Banding Lab	
Breeding Bird Survey	USGS	
USFWS Endangered Species Program	USFWS	
Rhode Island Breeding Bird Atlas	Rhode Island Natural Heritage Program	Rick Enser
Rhode Island Piping Plover Monitoring	US Fish and Wildlife Service	Chris Raithel
Prudence Island Bird Surveys	Narragansett Bay National Estuarine Research Reserve	Tom Kutcher
Rhode Island Colonial Waterbird Survey	Rhode Island Division of Fish and Wildlife	Chris Raithel
Rhode Island historic ornithological surveys		Dick Ferren
Cape Charles Seawatch	Center for Conservation Biology, College of William and Mary	Bryan Watts
Virginia Migrant Shorebird Surveys	Center for Conservation Biology, College of William and Mary	Bryan Watts
Virginia Piping and Wilson's Plovers Productivity	Virginia Department of Game and Inland Fisheries	Ruth Boettcher

Title	**Lead Agency / Organization**	**Contact**
and Population Monitoring		
Virginia Seaside Lagoon System Waterbird Survey	The Nature Conservancy	
USFWS Offshore Database		
Partial list of the 50+ datasets being organized by A. O'Connell and A. Gilbert		
Seabird Ecology Assessment Network (SEANET)	Tufts University	Julie Ellis (Alan O'Connell?)
PIROP	Programme Integre Recherches sur les Oiseaux Pelagiques	Alan O'Connell?
Northeast Fishery Observer Program (NEFOP)	Northeast Fishery Observer Program (NEFOP)	Alan O'Connell?
NOAA Southeast Fisheries Science Center		Alan O'Connell?
Pelagic birding observations		Alan O'Connell?
Avalon Sea Watch	New Jersey Audubon Society	David Mizrahi

Appendix B: “Offshorebird Project” First Mid-Term Meeting Summary

"Offshorebird Project" First Mid-Term Meeting Summary

February 5-6, 2009
Paramount Plaza Hotel and Suites
2900 SW 13th Street
Gainesville, Florida

MMS contract # M08PC20060 with Pandion Systems, Inc.
"Potential for Interactions Between Endangered and Candidate Bird Species with Wind Facility Operations on the Atlantic Outer Continental Shelf"

Meeting Minutes

Thursday, February 5, 2009

***9:00 am* – Welcome, Introductions, and Meeting Overview**
Caleb Gordon welcomed meeting participants, described the goals and structure of the meeting, and introduced those present who had not attended the project kickoff meeting. All attendees then introduced themselves.

***9:30 am* – Finalization of the Problem Formulation**
Jim Newman, Christian Newman, and Caleb Gordon described the process of problem formulation and presented the working draft of the completed problem formulation document. This document contains four principal components: 1) a description of the risk assessment and problem formulation tasks associated with this study, 2) conceptual risk models for the overall problem and for each of the three focal species specifically, 3) tables containing all project-relevant technical information gathered to date by the project team, and 4) tables containing prioritized lists of all research questions that could be asked to address the risk assessment objective of the study, classified into three priority tiers (1 = highest priority, 2 = intermediate, 3 = lowest priority). The priority tiers are based on two criteria: 1) How important is the question to the risk assessment objective of the project? and 2) How much is already known about the answer to the question? This document was distributed to all attendees one week prior to the meeting.

The group then provided feedback, focusing on the tables containing prioritized lists of possible risk-related research questions. This discussion extended through what became a working lunch and concluded at 1:00 pm. The finalized problem formulation document, including all commentary received during this session, is included among the first midterm meeting outcomes.

***1:30 pm* – Invited Seminar and Discussion of Implications of European Studies for Project**
After a short recess, Caleb Gordon introduced Dr. Mark Desholm of the Danish National Environmental Research Institute. Dr. Desholm presented a one-hour PowerPoint presentation titled, "Lessons from Europe about the impacts of offshore wind on birds." Dr. Desholm agreed to make his PowerPoint presentation available to the group via the project SharePoint site. The seminar led into a question and answer period with Dr. Desholm, which evolved into a general discussion facilitated by Gordon of the strengths and limitations of various monitoring and

modeling methodologies to address risk to the project's three focal species from offshore wind development in the AOCS. This discussion incorporated information from the Cape Wind Biological Opinion issued by the USFWS in November, 2008, and the Cape Wind Final Environmental Impact Statement issued by the MMS in January 2009.

***3:45 pm* – Elimination of Potential Pilot Study Methodologies**
After a short recess, the group reconvened to discuss which potential pilot study methods could be eliminated based on their low potential to address the objectives of this study cost effectively. This discussion was facilitated by Greg Forcey and utilized the "potential pilot study methodologies…" table that had been distributed to the group two weeks before the meeting. In the course of this discussion, the group discussed each of the listed methods, eliminating some, and making notes on the applicability of others. The results of this discussion will be included among the first midterm meeting outcomes.

***5:00 pm* – Day One Adjournment**

Friday, February 6, 2009

***9:00 am* – Pilot Study Nominations and Discussion**
Facilitated by Christian Newman, meeting attendees were asked to verbally nominate ideas for pilot studies, justifying them based on five criteria that were provided. These criteria included feasibility and cost effectiveness in addition to ability to satisfy the objectives of the study. Nominated ideas were recorded by Pandion personnel, and attendees asked nominators clarifying questions about their nominated study ideas. Eight nominations were produced and clarified, after which attendees asked additional questions about the nominated ideas and debated the pros and cons of each.

***11:30 am* – Voting on Nominated Pilot Study Ideas**
Attendees then voted for their preferred studies, basing their votes on the studies' ability to satisfy the five criteria. Each attendee (except as noted below) voted by indicating on a piece of paper his or her first, second, and third choices. All of the nominated studies, the criteria used to nominate and vote on them, and the voting results are included in the "pilot study nomination-voting" document among the first midterm meeting outcomes. Voting attendees were C. Gordon, G. Forcey, J. Burger, W. Warren-Hicks, L. Niles, M. Desholm, L. Vlietstra, S. Kelling, and A. Farnsworth.

***12:00 pm* – Lunch Break**

***1:00 pm* – Proposal Sketching Breakout Groups**
The three front-runner pilot study ideas were selected for further development as proposal sketches. Based on a brief discussion and the group's consensus, two of these ideas included elements of additional ideas that had been originally nominated as separate ideas. Pandion divided the meeting attendees into three breakout groups, each charged with developing a nominated pilot study idea into a pilot study proposal sketch, complete with eight points of information requested on a proposal-sketching guidelines sheet provided by Pandion. The

proposal sketches will be finalized by the groups listed below subsequent to the meeting. The finalized proposal sketches will be among the first midterm meeting outcomes.

The proposal sketching groups were as follows:

Group 1: "Methodological Smorgasbord," M. Desholm, A. Farnsworth, C. Gordon, C. Ribe, G. Forcey

Group 2: "Shorebird Extravaganza," J. Burger, L. Niles

Group 3: "Collision Risk Case Study," W. Warren-Hicks, J. Newman, L. Vlietstra, S. Kelling

***3: 30 pm* – Presentations of Proposal Sketches**
Each group presented a brief outline of its proposal sketch to the rest of the group. Each of these presentations was open to questioning from all meeting attendees.

***4:30 pm* – Adjournment**

Attendees of the Offshorebird Project First Midterm Meeting

James Woehr, U.S. Minerals Management Service
Christian Newman, Pandion Systems, Inc.
Caleb Gordon, Pandion Systems, Inc.
James Newman, Pandion Systems, Inc.
Greg Forcey, Pandion Systems, Inc.
Chris Ribe, Pandion Systems, Inc. (Friday only)
Alexis Teran, Pandion Systems, Inc.
Joanna Burger, Rutgers University
Lawrence Niles, Conserve Wildlife Foundation
Lucy Vlietstra, Massachusetts Maritime Academy
Ed Zillioux, Environmental Bioindicators Foundation, Inc. (Thursday morning only)
William Warren-Hicks, EcoStat, Inc.
Andrew Farnsworth, Cornell Laboratory of Ornithology
Steve Kelling, Cornell Laboratory of Ornithology
Mark Desholm, Danish National Environmental Research Institute

Appendix C: Final Results Interpretation and Discussion Meeting

Final Results Interpretation and Discussion Meeting

"Offshorebird" Project

"Potential for Interactions Between Endangered and Candidate Bird Species with Wind Facility Operations on the Atlantic Outer Continental Shelf" BOEMRE-Pandion contract M08PC20060

November 4-6, 2010

Paramount Plaza Hotel and Suites, 2900 SW 13th Street, Gainesville, FL, 32608

Agenda

Outcomes
By the end of the meeting, the group will

- ❑ Understand the objectives, methods, results, and conclusions of each of the five separate research or technology development initiatives that were conducted under this project, as they relate to the overarching objectives of the project as a whole.

- ❑ Identify strengths and weaknesses in, as well as suggestions for improving the analyses and results interpretations that have been performed to date by the principal investigators of each of the five research or technology development initiatives that were conducted under this project.

- ❑ Submit written comments to guide the revisions of the technical manuscripts/reports that have been drafted for each of the five research or technology development initiatives that were conducted under this project, to be incorporated by the principal investigators into the final revisions of the draft manuscripts, reports, and other technical products of this research.

Schedule for Thursday, November 4th

What	Who	When
Welcome, Introductions, Overview of Meeting Format, Content, Objectives	Christian Newman, Caleb Gordon, Pandion Systems, James Woehr, BOEMRE	9:00-10:15am
Refreshment Break		10:15-10:30
Technical Results Workshop #1: Tracking Red Knot AOCS crossings using light-sensitive geolocators	Larry Niles, Conserve Wildlife Foundation and Joanna Burger, Rutgers University	10:30am-12:30pm
Lunch		12:30-1:30pm

What	Who	When
Technical Results Workshop #2: Geospatial analysis of Avian Knowledge Network data to characterize focal species' macroscale exposure to offshore wind facilities on the AOCS	Greg Forcey and Caleb Gordon, Pandion Systems	1:30-3:30pm
Refreshment Break		3:30-3:45pm
Special Seminar: Recent developments in offshore wind wildlife monitoring in Europe	Mark Desholm, Danish National Environmental Research Institute	3:45 - 4:45pm
Adjourn technical sessions		4:45 pm
Dinner at Christian and Jodie Newman's House, 2140 NW 7th Lane, Gainesville, FL 32603	Transportation from Hotel provided	6:30 pm

Schedule for Friday, November 5th

What	Who	When
Technical Results Workshop #3: Initial development and testing of an acoustic/thermographic detection device	Ian Baldwin, Chris Ribe, Pandion Systems	9:00-10:45am
Refreshment break		10:45-11:00am
Technical Results Workshop #4: Avian mortality monitoring and behavior observations at a coastal wind turbine in Massachusetts	Lucy Vlietstra, US Coast Guard Academy	11:00-12:45pm
Lunch		12:45-1:45pm
Technical Results Workshop #5: Modeling tern collision risk based on empirical observations at a coastal wind turbine in Massachusetts	William Warren-Hicks, EcoStat, Inc., and Lucy Vlietstra, US Coast Guard Academy	1:45 - 3:30pm
Refreshment Break		3:30-3:45pm
Synthesis and Risk Characterization Discussion: What have we learned?	Whole group	3:45-5:00pm
Adjourn technical sessions		5:00pm

Saturday, November 6th

What	Who	When
Optional Field Trip to La Chua Trail entrance of Payne's Prairie Preserve State Park	Pickup at hotel at 7:00am, delivery to Gainesville regional airport at 1:00pm	7:00 am-1:00pm

Appendix D: Pilot Study Proposal

“Potential for interactions between endangered and candidate bird species with wind facility operations on the Atlantic Outer Continental Shelf”

Pilot Study Proposal

"Potential for interactions between endangered and candidate bird species with wind facility operations on the Atlantic Outer Continental Shelf"

MMS Contract M08PC20060

Prepared by

Pandion Systems, Inc.
102 NE 10th Ave., 1st Floor
Gainesville, FL 32601
352-372-4747
www.pandionsystems.com

March 18, 2009

Table of Contents

1 Summary

This document describes three studies that are designed to address the two primary study objectives for the contract entitled "Potential for interactions between endangered and candidate bird species with wind facility operations on the Atlantic Outer Continental Shelf" (MMS contract # M08PC20060).

The study objectives for this contract are:

- Objective #1 (Risk assessment objective): "to evaluate the potential for the three endangered, threatened, and candidate species of interest to be impacted by wind facilities located on the Outer Continental Shelf (OCS)"
- Objective #2 (Methodological objective): "to determine the best methods to evaluate locations of future wind facilities to minimize risks to the species."

The three focal species of interest are Roseate Tern, Piping Plover, and Red Knot.

These pilot studies were selected and designed by the project team managed by Pandion Systems, Inc., (the Pandion Team) to address the highest priority questions (Table 1) for accomplishing the study objectives, as identified through a risk assessment process. These three studies are complementary, each addressing different, high-priority needs and collectively providing a solution to the problems articulated in the study objectives for this contract.

The three pilot studies are:

- Pilot Study A. Remote Avian Detection Device
- Pilot Study B. Mapping Ocean Crossings With Tracking Devices
- Pilot Study C. Risk/Exposure Modeling

The pilot studies represent distinct methodologies to be performed by the Pandion Team, and are designed to address the different research needs of the overall project. The Pandion Team is capable of conducting all three studies simultaneously, if requested by MMS. The essence of these three projects is discussed in brief below.

Pilot Study A. Remote Avian Detection Device

In this study, we would design, build, and deploy a device that collects and remotely transmits acoustic and thermographic data on flying wildlife within the rotor swept zone of possible or actual offshore wind facility locations. This device would fill a major need in offshore wind environmental analysis, embodied in the project's first objective. The lack of such data has hampered offshore wind development because it has limited the ability to characterize risk to these endangered, threatened, and candidate bird species from offshore wind facilities. This device would also accomplish the project's second objective because the data it would gather would be site-specific. Site-specific data are perfectly suited for making impact and risk assessment decisions of offshore wind facilities. This device would provide necessary, reliable, and species-specific occurrence data.

Pilot Study B. Mapping Ocean Crossings of the Three Focal Species With Tracking Devices
In this pilot study, we would map the movements of individual birds of the three focal species across the AOCS region using lightweight devices that can be attached to captured birds, and then gather geospatial data during the birds' normal movements in the wild for up to a year. Such information would fill a critical gap in our current knowledge of when and where the three focal species of this study intersect the AOCS, which is a top priority need for accomplishing the project's first objective.

Three different types of tracking technologies are proposed: one low-precision technology that is currently available and two optional additional technologies that manufacturers expect to be available by the end of 2009. These two additional technologies are several orders of magnitude higher than the first in terms of the geographic precision of the data rendered. This difference in precision is so great that the higher precision technologies would generate information of much greater relevance to offshore wind risk characterization (Objective #1) and siting decisions (Objective #2).

Pilot Study C. Collision Risk and Exposure Modeling
This pilot study consists of efforts to develop predictive models of risk and/or exposure of the three focal species from offshore wind facilities in the AOCS at two distinct spatiotemporal scales. Each of these modeling efforts would be built upon an extensive base of empirical data. The microscale models would predict the risk of Roseate Terns (and Common Terns as a surrogate) colliding with an operational wind turbine as a function of behavioral and morphological characteristics of the birds, as well as environmental parameters, such as visibility and wind speed and direction.

This pilot study is designed to evaluate the potential for behavioral avoidance of individual wind turbines. Preliminary studies indicate that this may be the case for Roseate Terns. Probabilistic collision models would be built from two seasons of extensive behavioral observations of birds at an operational wind turbine where Roseate and Common terns are known to occur, as well as from additional empirical data on collision rate gathered from mortality monitoring and carcass searching/carcass removal experiments conducted at the site.

The macroscale models would be used to forecast all three focal species' occurrence in time and space throughout the AOCS region. These models would be built from the extensive observational datasets of the Avian Knowledge Network, a continent-wide compendium of public and private datasets on bird distribution. This effort would complement and extend the results of the second pilot study, Mapping Ocean Crossings, as well as the other geospatial analyses to be conducted in the non-pilot study portion of this project. Both of the modeling efforts proposed in this pilot study would provide answers to important risk/exposure questions directly relevant to study objective #1.

Key Research Questions for Accomplishing the Study Objectives
These questions were identified by the Pandion Team as an outcome of the problem formulation phase of the risk assessment. These questions need to be addressed to accomplish the study objectives for this contract. Table 1 shows the current state of knowledge and priority level of the questions.

Table 1. Key research questions to address the study objectives.

Question	Species, Populations*	Current State of Knowledge	Importance for Study Objectives	Priority Level
Where and when do migrating birds intersect the AOCS? (Affected by weather?)	ROST, REKN, PIPL	Poor to moderate	High	1 (top priority)
Do the flight trajectories of migrating birds intersect the RSZ of wind turbines? (cruising altitudes vs. ascent/descent)	ROST, REKN, PIPL	Poor	High	1
How is the height of migratory flight trajectories affected by weather conditions? (Spring vs. fall differences?)	ROST, PIPL, REKN	Moderate to poor	High	1
Will the structures associated with offshore wind facilities attract birds, either because of lights, "artificial reef" effect, or perch availability for either courtship flights or resting spots, and will this occur to a greater degree in adverse weather?	ROST, PIPL, REKN	Poor to moderate (some evidence from oil platforms)	High	1
Would the various phenomena associated with bird exposure to, and effects from, offshore wind turbines in the AOCS exhibit scale dependency? Would there be any nonlinearities such that certain (high) buildup scenarios might generate effects not predicted by impact levels observed under other (low) buildup scenarios?	ROST, PIPL, REKN	Poor	High	1
When bird flight trajectories do occur within the RSZ, can birds avoid the RSA of offshore wind turbines through behavioral avoidance? If so, to what degree and under what conditions?	ROST, PIPL, REKN	Poor to moderate (some ROST avoidance at MMA turbine on land)	High	1-2
What are the movement patterns of nonbreeding adults during breeding season and migration?	ROST, PIPL, REKN	Poor	Moderate	2
Will the presence of offshore wind turbines or boat/helicopter traffic associated with maintenance activities from wind facility operation cause birds to avoid feeding areas or migratory routes?	ROST, PIPL, REKN	Poor	Low	2
Would the presence and operation of offshore wind turbines in the AOCS	ROST, PIPL, REKN	Poor to moderate	Moderate to high	2

Question	Species, Populations*	Current State of Knowledge	Importance for Study Objectives	Priority Level
impact the viability of the populations of birds that occur in this region?				
Do the flight trajectories of birds intersect the RSZ of wind turbines as they commute between breeding areas, feeding areas, and staging areas?	ROST, REKN	Moderate	High	2
Do migrants venture greater than 3 miles offshore into AOCS areas? If so, when, in what number, and where?	PIPL, REKN-SD	Poor	High	1
Assuming that migration is primarily coastal, do peninsulas and large bays along the coast create "shortcuts" where normally coastal migrants regularly cross federally regulated waters rather than taking circuitous routes along the coast (e.g., across Delaware Bay, southbound from Monomoy Island)? If so, where are the shortcuts? Is their use affected by weather?	PIPL, REKN-SD	Poor (but we strongly suspect that shortcuts do exist)	High	1
Where and when do ROST encounter the AOCS during movements either to or from postbreeding and oceanic staging areas?	ROST	Moderate to poor	High	1
What numbers of ROST feed in the AOCS and how far out will they feed during the breeding season? (Affected by weather?)	ROST	Moderate to good	High	3
Do the flight trajectories of foraging birds intersect the RSZ of wind turbines?	ROST	Very good	High	3
Do Red Knots' commuting flights between roosting and feeding sites within a migratory stopover ever bring them ≥3 miles from shore?	REKN	Poor to moderate (unlikely)	High	3

Source: Adapted from final problem formulation document.
Key: 1 = highest priority, ROST = Roseate Tern, REKN = Red Knot, PIPL = Piping Plover
*LD = long-distance migrant populations, SD = short-distance migrant populations.

2 Pilot Study A: Developing and Testing an Offshore Remote Bird Monitoring Device That Combines Acoustic and Thermal Image Detection (Remote Avian Detection Device)

2.1 Summary of Pilot Study A

The objectives of this pilot study are:

1. To design and build a device capable of operating unmanned for periods of up to a year, gathering and remotely transmitting acoustic and thermographic data on flying wildlife within an area that approximates the rotor swept zone of a commercial offshore wind turbine, enabling species-specific characterization of risks posed by offshore wind turbines to flying wildlife at offshore locations.
2. To field-test this device at a proposed offshore wind power facility location in the Atlantic Outer Continental Shelf, providing a preliminary characterization of the risks posed to Red Knots, Roseate Terns, and Piping Plovers at that location from March through July.

The most important contribution of this study would be to provide a device capable of gathering species-specific data on the threatened and endangered bird species that possibly occur in the locations of proposed wind power facilities in the AOCS. No other tools or techniques currently exist to gather such data. The lack of such data caused major delays in the approval of the Cape Wind Project and is currently a major need for the development of offshore wind in the AOCS. This study follows up on the recommendations of the Cape Wind Biological Opinion and Final Environmental Impact Statement to employ acoustic monitoring to gather species-specific information on these three bird species, and further improves this technique by combining it with thermographic imaging, which corrects for limitations inherent in acoustic data, and also provides an additional tool for post-construction collision monitoring.

The design, software development, construction, and 4-month oceanic deployment of this device would all be conducted under Phase 1 of this project, as would the preliminary characterization of risk to the three focal species at the AOCS location chosen for the oceanic deployment. The optional component of the project would enable the development of automated bird identification software, a tool that would speed and facilitate the application of the remote avian detection device to siting decisions and/or other risk assessment studies in the AOCS.

2.2 Relation of Pilot Study A to the Project's Objectives

This project will primarily be directed at study objective #2, to create a new method for characterizing risk to the focal species in a manner that is highly applicable to siting decisions. The offshore deployment planned for March-July of 2010 will also help accomplish project objective #1 in providing a preliminary, site-specific characterization of risk posed to the three focal species at the AOCS location chosen for deployment.

2.3 Key Project Research Questions Addressed by Pilot Study A

Macro-Scale Exposure (Occurrence within AOCS)

Questions

- Where and when do migrating birds (all three focal species) intersect the AOCS? (Affected by weather?)
- What numbers of Roseate Terns feed in the AOCS and how far out will they feed during the breeding season? (Affected by weather?)
- Where and when do Roseate Terns encounter the AOCS during movements either to or from postbreeding and oceanic staging areas?
- Do migrants (all three focal species) venture greater than 3 miles offshore into AOCS areas? If so, when, in what number, and where?
- Assuming that migration is primarily coastal for Piping Plover and short distance migrant populations of Red Knot, do peninsulas and large bays along the coast create "shortcuts" where these normally coastal migrants regularly cross federally regulated waters rather than taking circuitous routes along the coast (e.g., across Delaware Bay, southbound from Monomoy Island)? If so, where are the shortcuts? Is their use affected by weather?

Pilot Study Answers

Data gathered will be site-specific and useful for characterizing risk at the deployment site only.

Meso-Scale Exposure (Flight Height Within RSZ of Turbines)

Questions

- Do the flight trajectories of migrating birds (all three focal species) intersect the RSZ of wind turbines? (cruising altitudes vs. ascent/descent)
- Do the flight trajectories of foraging Roseate Terns intersect the RSZ of wind turbines?
- Do the flight trajectories of Roseate Terns intersect the RSZ of wind turbines as they commute between breeding areas, feeding areas, and staging areas?
- How is the height of migratory flight trajectories affected by weather conditions? (all three focal species, spring vs. fall differences?)

Pilot Study Answers

Offshore location adds power of oceanic evidence of flight height rather than assuming that land-based observations reflect behavior in the oceanic environment.

Operational Exposure

Question

- Will the structures associated with offshore wind facilities attract birds, either because of lights, "artificial reef" effect (Roseate Terns), or perch availability for either courtship flights (Roseate Terns) or resting spots (all three focal species), and will this occur to a greater degree in adverse weather?

Pilot Study Answers

Roseate Tern courtship flights as well as roosting or lingering behavior of all three species is detectable if birds vocalize.

2.4 Specific Hypotheses to be Tested in Pilot Study A

During the offshore deployment scheduled for March-July 2010 (Phase 1), this study will test the hypotheses listed below for each of the three focal species.

1. The species occurs in an area of the AOCS (a single location comparable to the rotor swept area of a single, commercial-scale wind turbine) during the study period (March-July).
2. The species flies within the rotor swept zone of commercial wind turbines at a single oceanic location within the AOCS during the study period (March-July).
3. The species uses an offshore platform, such as a meteorological tower, as a roosting or lingering spot at a single oceanic location within the AOCS during the study period (March-July).

2.5 Principal Method(s) Employed by Pilot Study A

The study will develop and deploy the hardware and software portions of a remote bird detection and identification system. The hardware portion will consist of a weatherproof solar-powered computer system with attached arrays of microphones and thermographic cameras. The software portion will be capable of analyzing the audio and video data collected by the system hardware to determine the species, height, and number of birds flying within the detection range of the system. The use of acoustic sensing and thermographic imaging will allow the system to function in dark and foggy conditions as well as daylight. The detection range of the system will cover the potential rotor swept altitudes of an offshore wind turbine. The components of the system are listed in Table 2.

Further characteristics of the completed system include the following:

1. The device will be able to gather presence/absence data as well as limited abundance data
2. The device will be able to detect birds in an area approximately the size, shape, and position of the rotor swept area of a single, commercial, marine wind turbine (greater for acoustic, lesser for thermal imaging, see Figure 1)
3. Thermal cameras will record the passage of silent birds that fly within the detection beam, and will also render abundance, flight height, and flight direction data, and to a limited degree, data on bird size and shape. Acoustic recordings will be able to render species-specific identification of any birds that vocalize while passing through the detection beam. Identifications will be generated manually, or automatically if the bird identification software option is elected.
4. The device will triangulate information from different sensors to capture flight height information for birds that pass through the detection beam
5. The device will be designed to operate unmanned for periods of up to a year. Users will be able to remotely log on to determine if it is functioning properly and to make adjustments to

various detection parameters. The device will continuously transmit data back to a data store through its internet connection.

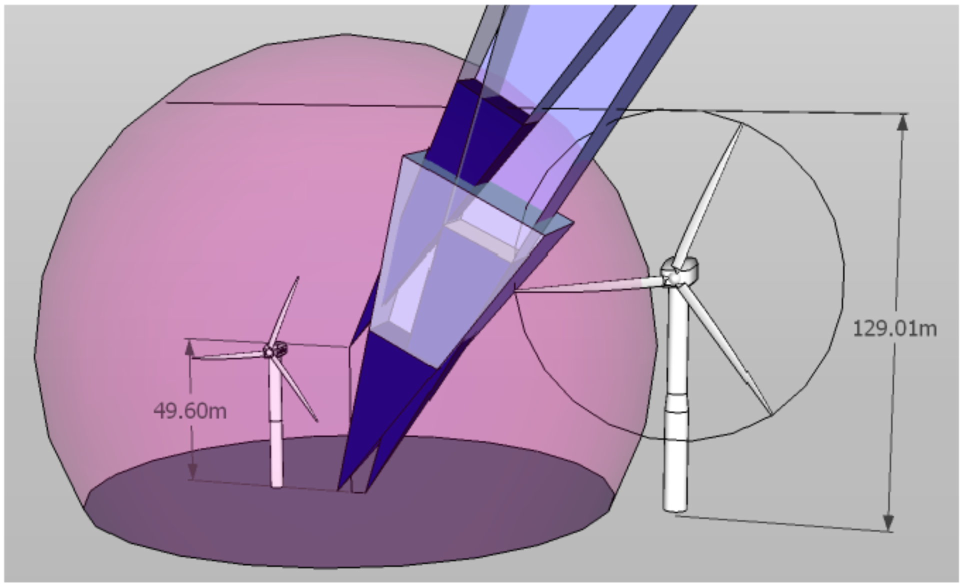

Figure 1: A depiction of the potential acoustic and thermographic coverage areas of the system. Dark blue regions represent the area observable by thermographic cameras at a resolution greater than 1 pixel/8cm. Light blue areas indicate extended thermographic coverage areas where resolution is greater than 1 pixel/16cm. The pink sphere represents the space covered by acoustic monitoring at a range of 100m. The two turbines are pictured to provide scale. The smaller turbine is a model of the turbine located at the Massachusetts Maritime Academy; the larger is approximately the size of the proposed Cape Wind Project turbines.

Table 2. Components of the remote bird detection and identification device.

#	System Components
1	Computer
2	Wireless networking device (for internet connectivity)
3	Thermographic camera array
4	Microphone array
5	Solar-battery power system
6	Tower mounting hardware
7	Command and control software
8	Event filtering software
9	Video analysis software
10	Spatial audio filtering software
11	Data storage server (permanently located at Pandion Systems)
12	Automatic bird identification software (optional)

2.6 Study Site(s)

Staged deployments during the process of developing the device will take place in Gainesville, Florida; Massachusetts Maritime Academy; Monomoy Island, MA; the northern Gulf Coast of Florida; and an offshore platform located in the AOCS (see "system deployment tasks" below).

2.7 Data to be Collected and Analysis to be Conducted

During system deployment stages 1-4 (see below), preliminary acoustic and thermographic data will be gathered using the device. This data will be used in conjunction with observational data and normal-light videography to ground-truth the event filtering and bird detection/classification software (optional). In the offshore deployment (stage 5), acoustic and thermographic data will be collected by the system at an offshore location in the AOCS, and the data will be analyzed using the system's software combined with manual sound identification to generate species-specific identification, occurrence data, abundance data, flight height data, and data on the direction of flight of birds that cross the detection beam. These data will be analyzed to generate risk information on the study species at the offshore location for the spring/early summer period.

2.8 Personnel Required for Pilot Study A

Personnel:

- Project director: Christian Newman
- Project manager: Caleb Gordon
- Risk assessment director: Jim Newman
- Pilot study director: Greg Forcey
- QA/QC manager: Ed Zillioux
- Project coordinator: Alexis Teran
- Accountant: Jenny Carter
- Technical editor: Karen Hill
- Chief information technology specialist (principal system designer): Chris Ribe
- Information technologist/system deployment (TBA)
- Information technologist/system deployment (TBA)
- Field ornithologists: Caleb Gordon, Greg Forcey, Lucy Vlietstra

Additional Cornell Laboratory of Ornithology personnel for optional bird identification software development:

- Chief analyst/software designer: Andrew Farnsworth
- Analyst (TBA)
- Computer programmer (TBA)
- Computer programmer (TBA)

2.9 Equipment Required for Pilot Study A

Table 3. Major equipment required for Pilot Study A.

Equipment	Description	Price
Storage server	Server for storing raw data collected from microphone and camera arrays	$6,000
Data analysis workstation	Computer workstation for analyzing acquired data during software development, system testing, and system evaluation	$4,000
Thermographic cameras	3 FLIR A325 cameras, 3 15° lenses, outdoor housings, camera control software, and camera control SDK	$70,500
Visible light video camera	A computer-controlled video camera for use alongside human observer during development stages	$2,300
Solar power kit	PV panels, deep cycle batteries, and charge controllers for powering system at remote or offshore location	$8,000
Data acquisition computer	Computer and cellular modem used for onsite data acquisition, analysis, and remote control of system	$3,500
Microphones and associated hardware	Various microphones, digitizers, microphone mounts, and housings	$15,000
Total		**$109,300.00**

2.10 Task List and Timeline for Pilot Study A

Task	Resource
Software Development Tasks:	
Command and control software	1 person (Pandion IT), 15 days
Develop event filtering software	2 people (Pandion IT), 25 days total
Video Event Analysis Software	1 person (Pandion IT), 30 days
Spatial audio filtering software	1 person (Pandion IT), 35 days
Bird identification software (optional)	4 people (Cornell Laboratory of Ornithology), 286 days total
System Deployment Tasks:	
Deployment Stage 1 - Gainesville FL	
Source system components	2 system technicians, 8 days total
Preliminary Testing	2 system technicians, 7 days total
Deployments Stage 2 - MMA	
Deployment Engineering	3 system technicians, 12 days total
Initial deployment at MMA	2 system technicians, 1 avian observer, 21 days total
Subsequent avian observations for ground-truthing	1 avian observer, 5 days
Post deployment data review	1 system technician, 1 avian ecologist, 8 days total
Deployment Stage 3 - Monomoy Island	
Monomoy deployment	1 system technician, 1 avian observer, 5 days per person.
Post deployment data review and system evaluation	1 system technician, 1 avian ecologist, 24 days total
Deployment Stage 4 - Florida Gulf Coast	
Florida Winter deployment	2 system technicians, 1 avian observer, 15 days total
Post deployment data review and system evaluation	1 system technician, 1 avian ecologist, 8 days total
TaskDeployment Stage 5 - Offshore	
Offshore deployment engineering	3 system technicians, 15 days
Offshore deployment	4 system technicians, 16 days total plus boat
Offshore service visit	2 system technicians, 10 days total plus boat
Offshore decommissioning	2 system technicians, 8 days total plus boat
Post deployment data review and system evaluation	1 system technician, 1 avian ecologist, 12 days total
Avian data analysis:and risk characterization	1 avian ecologist, 20 days

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2.11 Task Descriptions for Pilot Study A (all Phase 1)

Software Development Tasks

Command and Control Software

Command and control software will enable the computer system to autonomously operate the cameras and microphones, organize and store acquired data, record manually triggered events, and monitor and report on its operation. For example, rather than relying on a human operator to start an image acquisition program and an audio filtering program, the system will automatically perform these tasks and report its status in case problems are encountered.

This task may involve writing software that is specific to the cameras, audio devices, or other electronic hardware that is used with the system. It will also involve writing processes for exporting data in a standard format for analysis external to the system.

Event Filtering Software

Event filtering software will be used to separate uninteresting sequences of video and audio (e.g., nothing but clouds and wind noise) from potentially interesting sequences in real time. This will greatly reduce the data storage and transmission requirements, as uninteresting sequences can be immediately discarded. The remaining interesting sequences can then be analyzed by more time-consuming automated processes, or processed manually by biologists.

The development of the event filtering software will proceed continuously throughout the project as more advanced filters are developed. For example, the video filtering software may initially discard only motionless scenes, and then a filter for slow-moving clouds or near-camera insects may be added after data from the initial deployment is available.

Video Event Analysis

Video event analysis software will combine video event data from multiple cameras to estimate size, number, and flight path of detected birds or classify events as nonavian. As this processing may be time consuming, it will only be performed for those events classified as “interesting” by the event filtering software. The video event analysis software will output its results in a format suitable for use by other analysis software. As the project progresses, some aspects of the video event analysis software may be incorporated in the event filtering software. The video event analysis software will incorporate existing open source software tools as applicable.

Spatial Audio Filtering Software

Spatial audio filtering software will be developed to process raw audio data collected from the microphone array for the purpose of source isolation and source localization.

Source isolation will allow us to isolate from the background noise the sounds created by a bird whose position is known to us by video analysis. Given knowledge of a bird’s flight path, it may also allow us to attribute sounds to an individual that is about to enter or has recently left the cameras’ field of view. Isolating calls from other sounds will improve the accuracy of species identification efforts.

Source localization is the similar process of associating a known sound with a specific direction or location in space. Source localization will aid in event filtering (by allowing us to discard noise emanating from the mounting structure itself, for instance) and at its most advanced may allow us to track the flight paths of birds that do not cross the cameras' field of view.

The spatial audio filtering software will be implemented using known statistical signal processing techniques. Elements of the spatial audio filtering software will be integrated into the event filtering software.

Evaluate Bird Identification Software for Assisting Manual Identification

During the course of the project, available bird identification software tools will be evaluated for use with the system. These software tools will be evaluated on their efficacy and accuracy on a species by species basis. They will be considered for their potential to be integrated with the system for automated use, as well as for inclusion in a manual species identification toolkit.

Automated Bird Identification Software (Optional)

We will search datasets for recordings and evaluate quality of these recordings. For software, Cornell Laboratory of Ornithology has focused flight call detection and classification research on band-limited energy detection, matched filter template detection, nearest-neighbor-based library condensation methods, and characterizing signal features with frequency modulated contour extraction. We will focus our applications to template and nearest-neighbor-based approaches that begin by condensing a large library of target exemplars into a small, manageable set that performs as well as the original library (Harold Figueroa, in preparation); and a measurement-based approached that uses a novel method of frequency modulated (FM) contour extraction (incorporating parametric frequency estimation and dynamic track building) to characterize the structure of signals extracted via a permissive energy detection process (Kathryn Cortopassi, in preparation). Our goal is to pursue detection and classification approaches that maximize the rate of flight call detection and correct identification, while simultaneously minimizing the number of missed calls and false detections.

Subtasks

- Develop a comprehensive training and testing dataset of sound clips consisting of expertly labeled flight calls from target species and additional potential confounding species with similar vocalizations to provide a realistic challenge for discrimination tasks
- Accumulate training and testing datasets of sound streams consisting of expertly labeled calling events and to identify sources of recordings from field data that may be available to acquire in spring 2009
- Manually identify and label the exemplars for all species, creating as specific a library of tags for each clip as possible
- Generate expertly marked ground-truth logs for long-term sound data to evaluate how detectors perform in real sound streams; use this ground-truth to determine: 1) our probability of detection for the first (detector) stage of processing to generate candidate events (i.e., what percentage of true positives in the data stream does the detection process actually extract?); and 2) the recall / precision of the classification process applied to the candidate detections (i.e., what percentage of the candidate events were correctly labeled to class?)

- Explore variation in flight call samples using spectrogram cross correlation and to condense large training sets into smaller sets completely representative of the larger set for use in nearest-neighbor-based detection and classification
- Explore signal measurement and feature extraction for use in model-based classifiers as a means to label and screen sound events generated by a permissive energy (or other) detection process
- Process long-term data from passive acoustic recording devices – that is, to extract (detect) migrant flight calls and to classify those calls to species with high accuracy (minimizing false positives and false negatives)
- Augment and refine the set of expertly labeled training-testing clip data so that numbers are more representative of natural patterns of call occurrence and thus species occurrence; having training exemplar numbers reflect actual class priors should help to improve model performance
- Augment and refine tagging of the training-testing data set and add exemplars for additional classes of confounding, nontarget species signals
- Rebuild and reevaluate random forest models using the previously described contour measures on the expanded and more complete set of target species flight call and other exemplars; determine if model performance has improved or if further refinement would be fruitful
- Explore other measure sets for model building, other models for classification, and other measure-model combinations using the expanded training-testing set; other measures, models, or measure-model combinations may turn out to provide more discriminating power for separating call classes
- Run bird identification software on audio files from all deployment stages to compare automated and manual identifications of birds and refine identification software.

Deployment Tasks

The system will be deployed in whole or in part at five different locations during the proposed pilot study. The system will initially be deployed in incomplete form, and thereafter each of the remaining system components (numbered as per Table 2) is scheduled for introduction at one of the later stages.

Each of the deployment stages will involve the following tasks:

Deployment Engineering

Site-specific restrictions and logistical challenges associated with each deployment will first be determined, and then resolved. For instance, if the system is to be deployed on an existing turbine, we will determine where and how cameras and microphones can be mounted on the tower. We will then optimize the locations of cameras and microphones given site-specific restrictions. We will then determine power requirements and adapt the system to run off of grid power or solar power as necessary. We will select or fabricate mounting hardware specific to the deployment.

Deployment

Deployment involves several subtasks:

- Transporting hardware to the deployment location

- Mounting hardware to structures as necessary
- Setting up the power subsystem
- Testing system hardware for correct operation
- Conducting avian observations during system operations to evaluate system function
- At the end of the deployment stage, equipment must be removed and shipped to the next destination

Post Deployment Data Review

Following the deployments involving an observer, the observer-flagged video and audio sequences will be extracted from the collected data for further review and use in the software development processes. The collected data set as a whole will also be used for ongoing testing and development of each of the various software components of the project, and the performance of each of the deployed system components will be reviewed.

The five deployment stages, all to be conducted in Phase 1 of this study, are described below. Dates and times do not include post-deployment data review or pre-deployment engineering.

Deployment Stages

Stage 1 – Pandion Systems, Gainesville, FL, April-May, 2009
Description: Each of the hardware components will be tested for proper operation.
System components deployed (see Table 2): 1-5, 7, and 11

Stage 2 – Massachusetts Maritime Academy, June-July, 2009
Description: This location affords us a tall structure for mounting the cameras and microphones, Roseate Terns and Common Terns for observing and recording, and wind turbine background noise for testing and improving the audio filtering software.

Deployment will involve installing the cameras and microphones at positions on the turbine tower and on the ground. During this deployment, multiple alternative microphone systems will be installed and operated simultaneously to gather performance data on the various systems.

Once the system is in place and running, an avian observer accompanied by a visible-light video camera will record the presence, flight height, and species of birds passing through the detection beam of the system, which will roughly correspond to the rotor swept zone of the turbine. After the initial deployment and observation period, the system will be left in place and operated remotely for the next two months, with periodic continued avian observation periods totaling 5 days of additional observation until the next deployment.

The solar power subsystem will be omitted in favor of running off of grid power for this deployment.

System components deployed (see Table 2): 1-4, 6, 7, and 8

Stage 3 – Monomoy Island, MA, August-September, 2009
Description: In August, 2009, the system will be moved from MMA to a site at Monomoy Island, where all three of the study species should be present and detectable. Comparisons of

recordings gathered at this deployment with previously generated template recordings for the three study species will enable the refinement of the bird identification and event filtering software. The system will operate there, accompanied by an observer, for 4 days. After the observation period, the system will be returned to the Pandion Systems offices.

System components deployed (see Table 2): 1-5, 7, 12

Stage 4 – Winter Deployment, Northern Florida Gulf Coast, November 2009- January 2010
Description: The system will be deployed for remote operation on the northern Gulf coast of Florida during the winter of 2009-2010. Red Knots, Snowy and Piping Plovers, and Royal and Sandwich Terns should be present and detectable at this location during this time period. The deployment will last approximately 3 months, during which an avian observer will conduct ground-truthing observations alongside the system for 5 days total to perfect all of the software and hardware functionality of the system.

System components deployed (see Table 2): 1-8, 12 (first half), 1-10, 12 (second half).

Stage 5 – Offshore Deployment, AOCS, March-July 2010
Description: The completed system will be deployed at an offshore site within the study region (e.g., meteorological tower of the Cape Wind project). During this deployment, the assembled system and software suite will perform automated detection and species analysis of any birds passing through the monitored area. Three visits to the offshore site will be required, each requiring renting a boat for transportation to and from the offshore site from a nearby site. The three visits and their additional requirements are as follows:

1. Initial deployment (4 system technicians, 16 days total)
2. Service visit (2 system technicians, 10 days total)
3. Decommissioning (2 system technicians, 8 days total)

System components deployed (see Table 2): 1-12.

3 Pilot Study B: Using Tracking Devices to Map Out Where and When the Focal Species Intersect the AOCS (Mapping Ocean Crossings With Tracking Devices)

3.1 Summary of Pilot Study B

The objective of this pilot study is to develop and deploy new and emerging lightweight bird tracking devices to characterize the geographic scale movement patterns of the three focal species within the AOCS region. Our approach will be to evaluate, develop deployment methodology, and deploy up to three technologies (one currently available, two additional optional technologies currently under development) that collectively represent the best current and anticipated technologies available to track birds' large-scale movements: light sensitive data loggers (available), GPS data loggers with remote downloading capability (optional: under development), and solar-powered satellite transmitters (optional: under development). While light sensitive data loggers are the only one of these technologies currently available in sizes small enough to safely use on any of the three focal species of this study, manufacturers expect to be able to produce GPS data loggers and satellite telemetry devices small enough to be deployed safely on Red Knots and Roseate Terns by the end of 2009. Light-sensitive data loggers are the only technology that can be made small enough in the foreseeable future to be used on Piping Plovers.

The GPS data logger and satellite telemetry devices are listed as optional primarily because it is not yet certain that such technologies will be available for deployment on Red Knots and Roseate Terns within the time frame of this study. However, should these technologies become available as the manufacturers expect, this option would be highly desirable, as it would increase the precision of the geospatial information retrieved by several orders of magnitude (from 30-300 km to 10 m or below), allowing much more precise mapping of oceanic movement patterns. In particular, this would greatly increase our power to address the "shortcut" hypothesis (see Table 1). Both research questions related to this hypothesis were identified as high (level 1) priority questions related to the project's risk assessment objective.

3.2 Relation of Pilot Study B to the Project's Objectives

This project is primarily directed at the project's risk assessment objective (#1), and within that, at the macroscopic (geographic) scale issue of characterizing when and where the focal species intersect the AOCS. This question was unanimously determined to be the top priority research question that needed to be addressed to accomplish the study's objectives. The optional portion of this pilot study will also help accomplish objective #2 by providing evaluation and testing of new and emerging tracking device technologies that are designed to provide the spatiotemporal data on birds' movements necessary to characterize the spatial distribution of risk to these species from offshore wind facilities in the AOCS.

3.3 Key Project Research Questions Addressed by Pilot Study B

General Macro-Scale Exposure (Occurrence Within AOCS)

Questions

- Where and when do migrating birds (all three focal species) intersect the AOCS? (Affected by weather?)
- What numbers of Roseate Terns feed in the AOCS and how far out will they feed during the breeding season? (Affected by weather?)
- Where and when do Roseate Terns encounter the AOCS during movements either to or from postbreeding and oceanic staging areas?
- What are the movement patterns of nonbreeding adult Roseate Terns during breeding season and migration?

Pilot Study Answers

In Phase 1 these questions will be tested for Red Knots only, and with lower geographic precision (30-300 km). In Phase 2, they will be tested for all three species, and with higher geographic precision (10 m) for Red Knot. In Phase 3, these questions will be addressed for Roseate Terns only, and higher geographic precision (10 m).

For Red Knot, no distinction will be made between breeders and non-breeders, though failure to return to Arctic will be taken as an indication of non-breeding status if it is observed. For Roseate Tern and Piping Plover, breeding individuals are likely to be selected as they are the best candidates for successful tracking.

The data produced will be bird-specific, not site-specific. Sample sizes are a limiting factor inherent to using tracking technologies.

"Shortcut" Hypothesis

Questions

- Do migrants (all three focal species) venture greater than 3 miles offshore into AOCS areas? If so, when, in what number, and where?
- Assuming that the migration of Piping Plovers and short-distance migrant populations of Red Knot is primarily coastal, do peninsulas and large bays along the coast create "shortcuts" where the normally coastal migrants regularly cross federally regulated waters rather than taking circuitous routes along the coast (e.g., across Delaware Bay, southbound from Monomoy Island)? If so, where are the shortcuts? Is their use affected by weather?

Pilot Study Answers

This study provides a unique opportunity to shed light on these high priority questions. It has higher precision, and hence power, for Red Knot than for Piping Plover.

3.4 Specific Hypotheses to be Tested in Pilot Study B

Because of the sample size limitations inherent in studies where tracking devices are used to record the movements of individual birds, this study will be capable of providing positive evidence to support, but not negative evidence to refute, the hypotheses listed below. The power of the different tracking technologies to test these hypotheses is affected by the variation across technologies in the precision of the geospatial data collected (see "methods").

- Roseate Terns (Phases 2 and 3), Piping Plovers (Phase 2), and Red Knots (Phases 1 and 2) cross the AOCS on pelagic (far from shore) routes during their spring and fall migrations.
- Piping Plovers (Phase 2) and individuals in the short-distance migrant populations of Red Knots (Phases 1 and 2) mainly stay within 3 miles of the coast during migratory stopovers and while migrating.
- Migrating Piping Plovers (Phase 2) and individuals in the short-distance migrant populations of Red Knots (Phases 1 and 2) regularly cross the AOCS in certain isolated "shortcuts," where water-crossing routes are much shorter than strictly coastal routes would be (e.g., the mouths of large bays or inlets, regions with large islands and peninsulas).
- Roseate Terns regularly intersect the AOCS during feeding/foraging movements during the breeding season (Phase 3).
- Roseate Terns regularly intersect the AOCS during movements to and from post-breeding and/or oceanic staging areas (Phases 2 and 3).

3.5 Principal method(s) employed by Pilot Study B

Methods Common to all Phases

1. We will consult with groups of experts in tracking and handling the three target species to determine the best techniques to capture birds, attach tracking devices, and subsequently recapture birds, if removal of the tracking device is necessary given the technology. Different techniques will be required for the different species and technologies given the differences in tracking device weight and function, and bird life history, habitat location, and body size.
2. We will augment an existing, extensive observer network to track individually marked birds throughout the Atlantic coast and locate birds with tracking devices for recovery.
3. We will use statistical and geospatial modeling techniques with the data gathered by tracking devices to characterize the spatial and temporal use of the AOCS by tracked individuals.

Phase 1 Tracking

150 Light-Sensitive Data Loggers on Red Knots

Light sensitive data loggers record ambient light as well as time, and units as small as 1.5 grams are currently available. Light-sensitive data logger technology has been applied successfully to track the movements of Roseate, Common, and Arctic terns, all of which are lighter than Red Knots. We have determined that the 1.5 gram devices attached to permanent leg bands of the species listed above is also an optimal attachment format for Red Knots. We will consult European and American biologists with experience using this technology, as well as USFWS

Endangered Species recovery team leaders to determine the optimal specific protocols and design for attaching these devices to Red Knots.

Red Knots will be captured using cannon nets at several sites in the Delaware Bay where there is an existing trapping effort and an extensive resighting network that results in 60% of all birds trapped being resighted annually. After deploying 50 units early in May 2009 in the Delaware Bay, we will then deploy the remaining 100 in Massachusetts and/or Mingan Islands, Quebec during July-August 2009, where there are significant concentrations of Red Knots during fall migration. All of these locations contain a good balance of individuals from the short- and long-distance migrant populations. Throughout the year, we will then use resightings to target cannon net retrapping efforts to recover the data loggers at various migratory stopover locations, as well as sites located in the wintering areas of both long- and short-distance migrant populations, where individuals from the selected initial trapping sites are known to overwinter. We expect at least a 10%-20% recapture rate, based on previous mark-recapture efforts conducted at these localities.

Light and time data will be downloaded from the devices retrieved from retrapped birds, and these data will be used to calculate latitude and longitude from sunrise and sundown times. Precision of such estimates ranges from 30-300km, depending on latitude and bird behavior. With this technique, we expect to map the fall migratory routes taken by 15-30 individual Red Knots, as well as the spring migratory routes taken by roughly half of these birds.

Phase 2 Tracking

1. 50 light-sensitive data loggers each on Roseate Terns and Piping Plovers
2. 50 GPS data loggers on Red Knots (optional)
3. 30 satellite telemetry devices on Red Knots (optional)

50 light-Sensitive Data Loggers Each on Roseate Terns and Piping Plovers

Light sensitive data loggers (described above) are the one type of tracking technology small enough to potentially be used on 60 gram Piping Plovers without causing undue stress or harm to the birds, and they have also been used successfully to track Roseate Terns as well as other similarly sized congeners. After consulting with experts, including the USFWS recovery team leaders for each species, we will determine the optimal site(s), trapping methods, and device attachment methods for using this technology on Piping Plovers and Roseate Terns. We then expect to collaborate with banders at existing banding programs at breeding sites for these species in order to trap birds and attach the data loggers. With each species, we will initially trap 10 birds at the selected breeding site in spring 2010 and attach light-sensitive data loggers. We will then observe these birds for a 10-day period immediately following device attachment to determine whether or not behavior has been affected. If not, we will proceed with trapping and attaching the devices to an additional 40 birds at each site. Birds that carry these devices will also be marked with individually recognizable color bands and/or flags to enable resightings of these birds on their migratory routes.

These birds will then be retrapped at the same sites the following spring (2011) to retrieve the devices, download the data, and then map the movements of these birds during the intervening year. Because initial device attachment and subsequent recovery efforts will be conducted at breeding sites, we expect very high site fidelity of individual birds, and hence device recovery rates of ≥50% (≥ 25 birds for each species).

50 GPS Data Loggers on Red Knots (Optional)

GPS data loggers are heavier but more precise than either light-sensitive data loggers or satellite transmitters. These devices record geospatial position information by communicating with GPS satellites. Remote downloading technology enables the retrieval of data from the device without having to recapture the bird, facilitating much higher information retrieval rates. GPS data loggers with remote downloading are available but are currently too heavy for our species. Several manufacturers expect to develop a prototype GPS data logger with remote download capability of up to 100m before the end of 2009. We will purchase fifty of these devices, and then attach them to individual Red Knots at migratory stopover sites in the Delaware Bay region in May 2010. Using the known wintering locations from previously banded individuals, we will select individuals that represent a balance of short- and long-distance migrant populations. For one year following device attachment, we will retrieve data from these birds at migratory stopover sites as well as overwintering sites in Florida and Argentina. Because recapture of device-carrying birds is unnecessary, we expect to generate maps of the annual migratory routes taken by up to 40 individual Red Knots by spring 2011.

30 Satellite Telemetry Devices on Red Knots (Optional)

Satellite telemetry devices employ the same system of GPS satellites as do the GPS data loggers. The difference is that unlike data loggers, which merely record geographic position information from the satellite, telemetry devices are capable of communicating back to the satellite, enabling data on the position of the tracking device to be retrieved from anywhere, and hence, much higher information return rates than with the other two tracking technologies. This technology is heavy enough that it cannot be powered by a battery and stay within the 3% of body weight upper limit for safe operation of any of the focal species of this study. However, solar-powered satellite transmitters are rapidly approaching weights suitable for birds as small as 120 grams, such as Red Knots and Roseate Terns. There is current controversy among experts on whether it is efficient and effective to save additional weight by forgoing the leg-loop harnesses commonly used with tracking devices and attaching these transmitters to the back feathers of birds, as is also currently done with VHF radio transmitters. This controversy, as well as this tracking technology, is evolving rapidly. Several manufacturers have suggested that they would be able to produce a working prototype of a solar-powered satellite telemetry device weighing less than 5 g by as early as midsummer or early fall 2009.

We propose to purchase 30 of these devices and then install them on individual Red Knots captured with cannon netting at migratory stopover sites in the Delaware Bay region in May 2010. We will consult with experts to determine the best attachment method, and test it in advance on captive shorebirds at a zoo or aquarium facility. Using the known wintering locations from previously banded individuals, we would select individuals that represent a balance of short- and long-distance migrant populations. Data from these devices would then be retrieved continuously throughout the ensuing year, resulting in the maps of the migratory routes of up to 30 Red Knots by spring 2011.

Phase 3 Tracking

20 GPS Data Loggers and 20 Satellite Telemetry Devices on Roseate Terns (optional)

Based on current manufacturers' estimates, we expect devices that employ these two, satellite-based, highly precise tracking technologies (see above) to be small enough to use safely on Roseate Tern, but not Piping Plover during the period of the expected completion of this project. During the spring of 2011, each of these technologies will be deployed on 20 Roseate Terns, captured in conjunction with existing banding efforts at breeding colonies (see under Phase 2 Roseate Tern methods). Information will then be retrieved either in the following breeding season at the initial trapping location (GPS data loggers), or continuously throughout the year at an office (satellite telemetry devices), resulting in maps of the movements of up to 30 individual Roseate Terns during the ensuing one-year period.

3.6 Study Site(s)

Red Knot

We will apply tracking technology to Red Knots at migratory stopover locations along the Atlantic Coast of the U.S. in the Delaware Bay region (spring), and coastal Massachusetts and/or Quebec (fall). Resighting and retrapping efforts will be conducted at additional locations along the Atlantic Coast of the U.S., plus the Gulf Coast of Florida, Tierra del Fuego, Chile, and Canada. These locations were chosen to allow access to both short- and long-distance migrant populations, and also to ensure adequate opportunities for resighting and recapture of data loggers, given that we will not be trapping birds on their breeding grounds where site fidelity is higher. An additional advantage of using these sites is that they contain existing volunteer-based resighting and trapping programs. The only way to retrieve data from birds carrying data loggers is to resight them (and retrap them, in the case of light-sensitive data loggers). Currently, nearly 60% of all birds marked on the Delaware Bay are resighted by existing observer networks. Nearly 40% of all birds tagged in Florida and Tierra Del Fuego are resighted. Augmenting these programs will allow us to generate significant cost savings for the current project, and will result in recapture rates high enough to permit robust characterization of migratory routes from the retrieved data.

Piping Plover

All field work with Piping Plovers will be conducted at the breeding sites used by, and in conjunction with, the efforts of the only current banding program for this species, located in coastal Massachusetts. The pre-existing volunteer-based observer network described above will also provide additional data through resightings of individually marked birds carrying light-sensitive data loggers.

Roseate Tern

All field work with Roseate Terns will be conducted at breeding colonies used by, and in conjunction with, the efforts of current banding/monitoring programs for this species at Great Gull Island, NY (H. Hayes/American Museum of Natural History) or in Massachusetts (Ian Nisbet/Massachusetts Audubon Society). The pre-existing volunteer-based observer network described above will also provide additional data through resightings of individually marked birds carrying tracking devices.

3.7 Data to be Collected and Analysis to be Conducted

Expected Data

Red Knot

1. Location and timing of the entire annual migratory routes of both long- and short-distance migrant populations, collectively covering the entire AOCS region.
2. Data on the feasibility of using light sensitive and GPS data loggers (optional), as well as satellite telemetry devices (optional) to track the movements of Red Knots in the AOCS region.

Piping Plover

1. Location and timing of the entire annual migratory route of individually marked Piping Plovers from Massachusetts breeding colonies, collectively covering the entire AOCS region.
2. Data on the feasibility of using light-sensitive data loggers to track the migratory movements of Piping Plovers.

Roseate Tern

1. Location and timing of breeding season usage areas, migratory routes, and coastal and oceanic staging locations, collectively covering the entire geographic range of the Northwestern Atlantic population of this species, including the entire AOCS region.
2. Data on the feasibility of using light-sensitive and GPS data loggers (optional), as well as satellite telemetry devices (optional) to track the movements of Roseate Terns in the AOCS region.

Data Analysis

1. For all three species, standard, GIS-based geospatial statistical methods will be used to map and statistically characterize the migratory pathways of the tracked birds.
2. The depth of the data analysis will depend upon both the sample sizes achieved and the geospatial precision of the tracking technology used.
3. Ultimately, these data will be used to model exposure and potential risk and will be integrated with the other geospatial analysis components of this project.

3.8 Personnel Required for Pilot Study B

Personnel:

- Project director: Christian Newman
- Project manager/co-principal investigator: Caleb Gordon
- Pilot study director/co-principal investigator: Greg Forcey
- Risk assessment director/co-principal investigator: Jim Newman
- Co-principal investigator for Pilot Study B: Larry Niles
- Co-principal investigator for Pilot Study B: Joanna Burger
- QA/QC manager: Ed Zillioux

- Technology consultants: Humphrey Sitters, Ron Porter
- GIS mapping consultant: Richard Lathrop
- Species experts/consultants: Helen Hays, Ian Nisbet, (additional TBA)
- Project coordinator: Alexis Teran
- Accountant: Jenny Carter
- Technical editor: Karen Hill

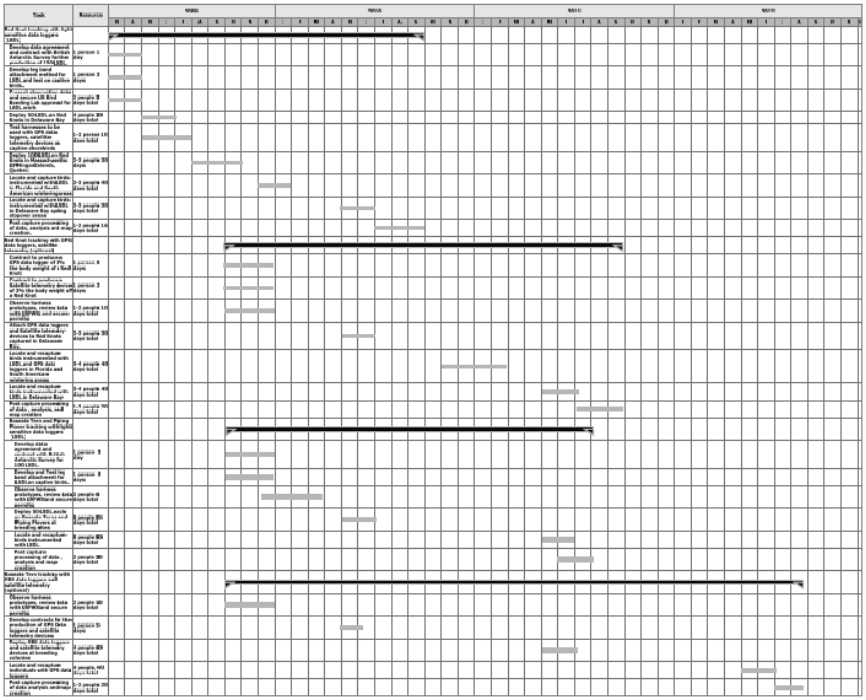
In-kind support:
- Amanda Dey (State of NJ)
- Kevin Kalaz (State of DE)
- Delaware Bay Shorebird Team (NJ and DE)
- Resightings project resightings team (volunteers located throughout the flyway supported by a variety of sources)
- Yves Aubry (Canadian Fish and Wildlife Service)
- Allan Baker and Patricia Gonzales (Royal Ontario Museum)
- Collaborators throughout the project; States of NJ, DE, VA, NC, SC, GA, FL. Most of these states are already collaborating on trapping, banding, and resightings.

3.9 Equipment Required for Pilot Study B

Table 4. Equipment required for Pilot Study B.

Equipment	Description	Phase 1	Phase 2	Phase 3
Cannon net and treadle	Construction of a new cannon net for quick deployment and small targeted catches	$5,000		
Spotting scopes, tripods	6 spotting scopes and tripods to use for resighting/recapture efforts	$5,000	$5,000	
Light-sensitive data loggers	150 for Red Knots (Phase 1), 50 for Roseate Terns (Phase 2), and 50 for Piping Plovers (Phase 2); $150 ea.	$22,500	$15,000	
GPS data loggers (optional)	50 for Red Knots (Phase 2), 20 for Roseate Terns (Phase 3); $2,000 ea.		$100,000	$40,000
Satellite telemetry devices (optional)	30 for Red Knots (Phase 2), 20 for Roseate Terns (Phase 3); $3,000 ea., $2,000 download processing fee.		$92,000	$62,000
Aviary use fees	Existing zoo/aquarium facility containing captive shorebirds		$15,000	
Computer and software (optional)	Station to download all data logger and satellite telemetry data, software for data logger and telemetry data	$5,000		
Total		$37,500	$227,000	$102,000

3.10 Task list and timeline for Pilot Study B



4 Optional Pilot Study C: Wind Turbine Exposure Analysis (Risk/Exposure Modeling)

Option A: Microscale collision risk analysis for Roseate and Common terns

Option B: Macroscale exposure analysis for Roseate Tern, Red Knot, and Piping Plover in the AOCS region

4.1 Summary of Pilot Study C

The objective of this pilot study is to develop models that predict:

- Microscale collision risk for Roseate Terns flying near a wind turbine as a function of environmental and behavioral variables (Option A)
- Macroscale exposure of all three focal species to offshore wind facilities in the AOCS, as determined by forecasted spatiotemporal occurrence patterns based on empirical data (Option B)

The predictions of both sets of models generated by this study are directly related to top priority information needs for assessment to the focal species associated with offshore wind development in the AOCS, including forecasts of when and where the birds will intersect the AOCS (Option B) and the collision risk of Roseate Terns flying in the vicinity of a wind turbine as affected by behavioral and environmental factors (Option A). As with any modeling study, the utility of the models generated by this pilot study will be constrained by the assumptions inherent in the model structures, as well as the inherent limitations in the data sets used to generate the models.

The primary strength of the microscale models generated in option A will be their basis in rich empirical data sets on bird behavior from Roseate Terns at a commercial wind turbine, as well as Common Tern, a closely related surrogate species. The coastal wind turbine located at the Massachusetts Maritime Academy on the coast of Buzzards Bay, MA, is 12 km from the large Roseate Tern breeding colony at Bird Island, is known to have Roseate Terns flying in the vicinity of the turbine, and as such, represents a globally unique opportunity to gather empirical data on this species' flight behavior in the vicinity of a wind turbine for use in modeling. The applicability of this model to the project objectives is constrained by the fact that this turbine is located over land, as well as the likelihood that our data gathering, and hence modeling efforts, will be much more robust for Common than for Roseate terns, based on expected sample sizes.

The strength of the macroscale models generated in option B will be their basis in the large, comprehensive dataset of the Avian Knowledge Network (AKN), augmented by microscale and macroscale data gathering efforts within this project. This modeling effort will also synergize with NSF-funded bird occurrence forecasting efforts already underway at the Cornell Laboratory of Ornithology. An important limitation of this modeling effort is the general lack of occurrence data, as well as information on important bird habitat parameters in oceanic environments.

4.2 Relation of Pilot Study C to the Project's Objectives

This study is directed at study objective #1: to assess risk to the focal species associated with the operation of offshore wind facilities in the Atlantic Outer Continental Shelf. The analysis of risk in this study will occur at two distinct scales.

- Option A consists of a microscale risk analysis to be conducted for Roseate Tern and Common Tern (as a surrogate for Roseate). This analysis will consist of extensive behavioral observation of terns, mortality monitoring, and carcass searching efficiency/scavenging rate experiments conducted at a single, coastal wind turbine, followed by statistical modeling of behavioral, meteorological, and other factors that affect the collision risk of terns at a wind turbine. Both of these components would be conducted during both Phases 1 and 2 of the project.
- Option B consists of a macroscale exposure analysis to be conducted for all three species over the entire AOCS region during Phase 3 of the project. Geospatial data on bird occurrence will be analyzed in conjunction with variables that may influence macroscale distribution (e.g., water depth/temperature, proximity to breeding colony for Roseate Tern). Bagged decision tree modeling will be used to forecast the probability of occurrence of each species in time and space, rendering maps of potential exposure to offshore wind facilities for each species for the entire AOCS region. This effort will synergize with an existing NSF-funded research initiative based at the Cornell Laboratory of Ornithology and will be integrated with the other geospatial analyses conducted under this project.

4.3 Key Project Research Questions Addressed by Pilot Study C

Macro-Scale Exposure (Geographic Occurrence within AOCS)

Questions

- Where and when do migrating birds (all three focal species) intersect the AOCS? (Affected by weather?)
- Where and when do Roseate Terns encounter the AOCS during movements either to or from postbreeding and oceanic staging areas?
- Do migrants venture greater than 3 miles offshore into AOCS areas (all three focal species)? If so, when, in what number, and where?
- Assuming that migration of Piping Plovers and short-distance migrant populations of Red Knot is primarily coastal, do peninsulas and large bays along the coast create "shortcuts" where these normally coastal migrants regularly cross federally regulated waters rather than taking circuitous routes along the coast (e.g., across Delaware Bay, southbound from Monomoy Island)? If so, where are the shortcuts? Is their use affected by weather?

Pilot Study Answers

In Option B, models will allow us to predict when and where all three species intersect the AOCS, and how these may change under different weather conditions. Models will include known coastal staging areas and associated movements, as well as insight into the likelihood of coast-hugging migrants taking oceanic "shortcuts" across large bays or inlets.

Meso-Scale and Micro-Scale Exposure (Flight Height Within RSZ of Turbines and Behavioral Avoidance of Turbines)

Questions

- Do the flight trajectories of migrating Roseate and Common terns intersect the RSZ of wind turbines? (cruising altitudes vs. ascent/descent)
- Do the flight trajectories of foraging Roseate and Common terns intersect the RSZ of wind turbines?
- Do the flight trajectories of Roseate and Common terns intersect the RSZ of wind turbines as they commute between breeding areas, feeding areas, and staging areas?
- When Roseate and Common tern flight trajectories do occur within the RSZ, can birds avoid the RSA of offshore wind turbines through behavioral avoidance? If so, to what degree and under what conditions?

Pilot Study Answers

Option A provides high power to study flying Roseate and Common terns as they fly near an operational wind turbine near a feeding area, within 12 km of a breeding colony. This study provides a unique opportunity to characterize terns' behavioral avoidance of an operational wind turbine. It has somewhat limited power to study migratory flights and foraging, as terns are not likely to be foraging on land.

4.4 Specific Hypotheses to be Tested in Pilot Study C

The macroscale exposure analysis (option B) conducted for all three species will not test specific hypotheses, but will describe the geographic and temporal patterns of exposure to wind turbines located in the Atlantic Outer Continental Shelf.

For Roseate Terns (and Common Terns as a surrogate), the microscale component of this study (option A) will test the following null hypotheses, or sets of null hypotheses:

- The flight height of terns is unaffected by weather conditions (separate tests for various factors such as visibility, cloud ceiling height, wind speed and direction).
- Terns do not exhibit behavioral avoidance of the rotor swept area of an operational wind turbine.

4.5 Principal Method(s) Employed by Pilot Study C

The macroscale component of this study (option B) will employ spatially explicit bagged decision tree modeling, using pre-existing data on bird occurrence, weather, and various biophysical environmental variables that may influence the occurrence of the three focal species to forecast the species' occurrence within the AOCS region at a geographic scale.

The microscale component of this study (option A) will employ extensive field observation of tern behavior in the vicinity of a commercial wind turbine, followed by statistical analysis to produce a microscale model of the factors that influence the likelihood of terns colliding with a wind turbine. Mortality monitoring and carcass searching/scavenging rate experiments will also be incorporated into the microscale collision risk model.

4.6 Study Site(s)

All field observations and experiments for the microscale collision risk analysis (option A) will be conducted in the vicinity of the single wind turbine located on the campus of the Massachusetts Maritime Academy in Buzzard's Bay, Massachusetts. This turbine is located within 100m of the coast of Buzzard's Bay, and the site is approximately 12 miles from the Roseate Tern colony at Bird Island. Roseate Terns are known to occur in the immediate vicinity of this turbine, though Common Terns are much more abundant.

The macroscale modeling components of this study (option B) consist of desktop analyses that will incorporate pre-existing data from the entire eastern seaboard and Atlantic Outer Continental Shelf.

4.7 Data to be Collected and Analysis to be Conducted

Microscale Data Collection (Option A)

Field data to be incorporated in the microscale analysis include:

- Flight height of terns in the vicinity of the turbine
- Flight behaviors (e.g., flight feather flaring to indicate rapid braking or direction change)
- Flight trajectory (direction, directional shifts)
- Abundance of each species in different height zones
- Observed tern mortality rate at the turbine
- Carcass searching efficiency and scavenging rate at the turbine
- Wind speed and direction
- Cloud cover
- Time of day (angle of insolation, amount of ambient light)
- Visibility (fog)
- Temperature

Microscale Analyses (Option A)

A Bayesian statistical modeling approach will be taken to model the likelihood of Roseate Tern and Common Tern collision risk as affected by various behavioral and meteorological factors.

Macroscale Data Collection (Option B)

The following types of data will be collected from pre-existing sources and mapped over the entire AOCS:

- Occurrence data for each focal species for the eastern seaboard plus AOCS (from Avian Knowledge Network and associated data gathering under task 3 of main project)
- Water depth
- Aquatic nutrient levels (chlorophyll concentration)
- Fish distribution data
- Water temperature
- Ocean currents
- Meteorological data (prevailing wind speed and direction, frequency and pattern of precipitation, cloud cover)

Macroscale Analyses (Option B)

Spatially explicit bagged decision tree modeling will be used to create a spatiotemporal occurrence map for each species for the entire AOCS region. These models will forecast the patterns of occurrence of each species within the AOCS as functions of meteorological, aquatic, and biological influences.

4.8 Personnel Required

Pandion Systems, Inc. (both options):

- Project director: Christian Newman
- Project manager/principal investigator: Caleb Gordon
- Pilot study director/principal investigator: Greg Forcey
- Risk assessment director/principal investigator: Jim Newman
- Project coordinator: Alexis Teran
- Accountant: Jenny Carter
- Technical editor: Karen Hill

Non-Pandion personnel:

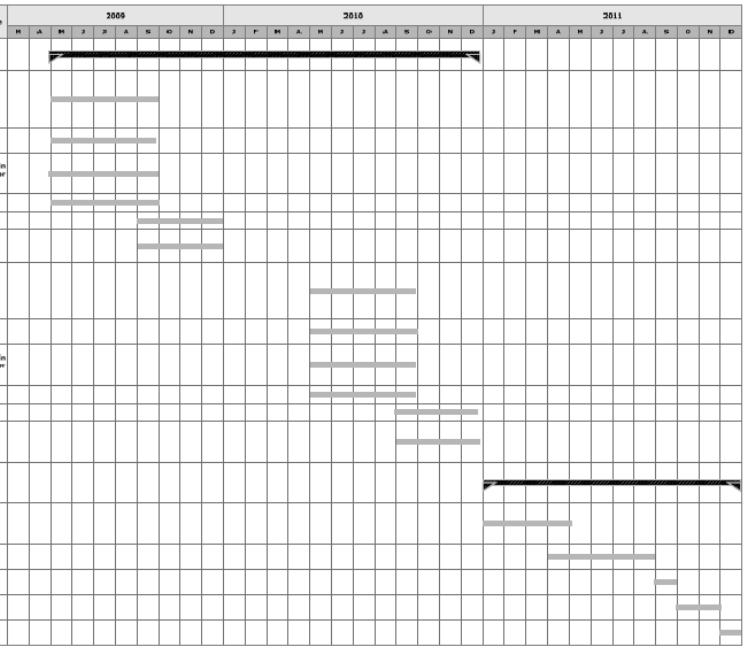
- (Option A) Bayesian statistical modeling/principal investigator: William Warren-Hicks
- (Option B) Spatially explicit bagged decision tree modeling/principal investigator: Steve Kelling
- (Option A) Tern field work/principal investigator: Lucy Vlietstra
- (Option A) Tern field work: Technician (Massachusetts Maritime Academy)
- (Option A) Tern field work: Assistant (Massachusetts Maritime Academy)
- (Both Options) QA/QC manager: Ed Zillioux

4.9 Equipment Required for Pilot Study C

No major equipment will need to be purchased to conduct this study. The field work component of option A will require a small supply budget for general field work supplies ($2,000) and funds to cover bird necropsy fees at Tufts University (20 @ $150 ea = $3,000) as well as quail carcasses for the carcass searching efficiency/scavenging rate experiments (200 @ $1.50 ea = $300). Option B will require $2,000 to purchase weather data from NOAA.

4.10 Task List and Timeline for Pilot Study C

Task	Resource
Option A: Micro-scale collision risk analysis for Roseate and Common Terns	
Conduct behavioral observations of Roseate and Common terns at Massachusetts Maritime Academy (MMA) wind turbine	1 PI 70 days 1 tech 50 days
Conduct mortality surveys below MMA wind turbine	1 Asst 38 days
Conduct searcher efficiency and scavenging rate experiments at MMA wind turbine	(included in task 2 labor amount)
Perform necropsies on dead birds	1 tech 2 days
Data compilation, analysis, write-up	1 PI 13 days
Develop micro-scale collision risk models for Roseate and Common Terns	1 PI 30 days
Conduct behavioral observations of Roseate and Common terns at Massachusetts Maritime Academy (MMA) wind turbine	1 PI 70 days 1 tech 50 days
Conduct mortality surveys below MMA wind turbine	1 Asst 38 days
Conduct searcher efficiency and scavenging rate experiments at MMA wind turbine	(included in task 2 labor amount)
Perform necropsies on dead birds	1 tech 2 days
Data compilation, analysis, write-up	1 PI 13 days
Test and refine micro-scale collision risk models for Roseate and Common Terns	1 PI 30 days
Option B: Macro-scale exposure analysis for Roseate Tern, Red Knot, and Piping Plover in the AOCS region	
Compile and standardize pre-existing bird occurrence data for three focal species	1 PI 60 days
Construct occurrence models for three focal species	1 PI 90 days
Integrate bird occurrence data from tracking studies	1 PI 10 days
Integrate macro- and micro-scale models for Roseate Tern	3 PIs, 100 days total
Analyze model performance, write-up results	3 PIs, 58 days total



4.11 Task Descriptions for Pilot Study C

Option A: Microscale collision risk analysis for Roseate and Common terns

Conduct Behavioral Observations

Systematic field observations will be conducted to determine passage rates and flight heights of Common and Roseate terns in the vicinity of a single coastal wind turbine. Field observations will be made under various weather conditions so that the influence of weather conditions on avoidance behavior, if any, can be evaluated. Weather conditions will be measured by an observer at the study site and recorded every 15 minutes.

Conduct Mortality Surveys

Systematic searches for avian carcasses around the base of the wind turbine will be conducted several (4-7) times per week to estimate avian collision mortality at the wind turbine. Any carcasses found will be collected and sent to Tufts University Cumming School of Veterinary Medicine Wildlife Clinic for necropsy to determine most likely cause of death.

Conduct Searcher Efficiency Trials and Scavenger Trials

To estimate the number of collision mortalities overlooked on mortality surveys, we will conduct searcher efficiency trials and scavenger trials. For searcher efficiency trials, the field technician will distribute a known number of domestic fowl (quail) carcasses throughout the mortality survey region. Immediately thereafter, the field assistant, who conducts mortality surveys but is unaware of the number and location of carcasses placed in the field, will be asked to conduct a mortality survey and report the number of quail carcasses they detect. Differences between actual and observed number of carcasses detected will be used to correct annual mortality estimates for searcher efficiency. Trials will be conducted six times each year.

We will also use these quail to estimate the rate at which scavengers remove avian carcasses from the study site. Once quail have been placed in the field, their presence will be monitored on a daily basis to determine temporal patterns of predator removal and/or biological decay. Information on the rate at which scavengers remove carcasses from below the wind turbine will also be used as a correction factor for estimates of annual collision mortality.

Perform Necropsies on Birds Found Dead at Turbine

Bird carcasses encountered in the vicinity of the wind turbine during the mortality surveys will be taken to Tufts University, where necropsies will be performed by experts to identify the most likely cause of death of the birds.

Data Compilation and Summary

Field data will be compiled, checked for quality assurance, and summarized in a format appropriate for input into the microscale model.

Develop Microscale Collision Risk Models for Roseate and Common Terns

These models will use engineering operational information, bird abundance information, mortality information, flight height information, and avoidance information to forecast the risk of mortality to Roseate and Common terns at wind turbines.

Test and Refine Microscale Collision Risk Models for Roseate and Common Terns

Data from the second year of field observations will first be used to test the accuracy of the models generated from the first year's data. Models will then be refined by combining both years of data and incorporating any other necessary adjustments indicated by the model testing and analysis.

Option B: Macroscale exposure analysis for Roseate Tern, Red Knot, and Piping Plover in the AOCS region

Compile and Standardize Pre-Existing Bird Occurrence Data

The first step in creating the models is bringing together bird observational data. This is very challenging because data collection techniques within the Avian Knowledge Network are diverse, the original data resources were widely dispersed and owned by a variety of organizations, and the data formats varied dramatically. But we are successfully building the largest compilation dataset for these species in the "fractionated" Northeast. While bird observation data come from multiple sources, each environmental attribute (i.e., predictor variable) associated with a bird observation comes from a single, uniformly collected data set. Collection mechanisms for these variables are varied and include remote sensing (e.g., weather) and surveys (fish densities). Because all bird observations and attributes have latitude, longitude, and date as shared context, we can join observations of species with observations of environmental features at individual locations.

Construct Occurrence Models for the Three Focal Species

We will then develop models for each species that will illustrate the presence or absence of the species of interest throughout the Northeastern U.S., including the entire AOCS region that will allow the prediction of pathways in which these birds may move through the region. The bird occurrence data will be collected from a variety of resources and will be linked to the predictor variables, which will allow us to explore the relationship between the occurrences of these species across the region.

Integrate Bird Occurrence Data From Tracking Studies

In each species' model, we will incorporate data from the tracking studies (Pilot Study B) as additional predictor variables in our predictive model of species occurrence. In our machine learning analysis, the best strategy is to include as many uncorrelated predictors as possible. Doing this broadens the scope of our ecological exploration, opening the door for unanticipated discoveries. It also provides a mechanism for assessing and accounting for biases caused by the observation process. Thus, it is best if we include predictors that describe the data collection, measurement, and organization processes in addition to predictors that describe important ecological and environmental processes.

Integrate Microscale and Macroscale Models for Roseate Tern

This task will result in the development of a comprehensive, multiscale model of risk to Roseate Terns from offshore wind facility operations in the AOCS. This model will include terms from both macroscale and microscale models that have both spatial and temporal components. Additional model terms may include areawide measures of wind speed and direction, abundance in various height zones, spatial and temporal probabilities of bird occurrence, local abundance of Roseate Terns, and other variables that affect the mortality risk. Bayesian statistical methods have been shown to be useful for estimating model parameters when input data represents different scales, and Bayesian approaches may be used to merge information into probability distributions for use as model inputs.

Analyze Model Performance and Write-Up

Once the models are complete, we will conduct sensitivity analyses as well as other tests to determine how robust they are to the violation of various assumptions and to small changes in various parameter values. The performance of the models will then be summarized in a written report.

5 Budget and Chronological Summaries for Pilot Studies

5.1 Budget Summaries

A budget summary table is presented below (Table 6). This budget incorporates funding and contracting constraints, covering a scope of work that is a reduced version of the work described elsewhere in this proposal. The specific differences between the work outlined in this summary budget, and that described elsewhere in this proposal are as follows:

- Pilot study A will include everything as described in the proposal except for the oceanic deployment stage, and the development of bird acoustic identification software.
- The only component of Pilot study B that will be performed will be to track Red Knots with light sensitive data loggers.
- The only component of Pilot study C that will be performed will be a single year of data collection and modeling of micro-scale risk (Option A).

Table 6. Summary budget by pilot study for constrained funding scenario.

Pilot Study	Total
Pilot Study A: Remote Avian Detection Device	**$302,959**
Device development and preliminary (non-Oceanic) deployments	$302,959
Pilot Study B: Mapping Ocean Crossings With Tracking Devices	**$146,580**
Light Sensitive Data Loggers	
Red Knots	$146,580
Pilot Study C: Risk/Exposure Modeling	**$116,880**
Micro Scale	$116,880
Total	**$566,419**

5.2 Proposed Payment Schedule

A proposed payment schedule is presented below (Table 7). This schedule includes 10% withholding, and evenly distributed labor and travel costs throughout. Equipment costs are all included in the first month, as the equipment will need to be purchased as a first step in two of the three proposed pilot studies.

Table 7. Proposed Payment Schedule for Pilot Studies

Month	Total Cost	Payment
1	$172,762.75	$155,486.48
2	$26,243.75	$23,619.38
3	$26,243.75	$23,619.38
4	$26,243.75	$23,619.38
5	$26,243.75	$23,619.38

6	$26,243.75	$23,619.38
7	$26,243.75	$23,619.38
8	$26,243.75	$23,619.38
9	$26,243.75	$23,619.38
10	$26,243.75	$23,619.38
11	$26,243.75	$23,619.38
12	$26,243.75	$23,619.38
13	$26,243.75	$23,619.38
14	$26,243.75	$23,619.38
15	$26,243.75	$23,619.38
16	$26,243.75	$23,619.38
End of project		$56,641.90

5.3 Chronological Summary of the Three Proposed Pilot Studies