Introduction to Part V
Individual movements and habitat use for focal bird species

Report structure

The chapters in this report represent a broad range of study efforts and goals. Some chapters are purely methodological in nature, while others present a variety of analyses and results. Generally speaking, however, chapters fall into two categories: efforts focused on population distributions, and those focused on individual movements (Figure I).

Part I of this report (the Executive Summary and Chapters 1-2) summarizes and synthesizes project results. The 25 subsequent chapters and their relationships to each other are shown in Figure I. In Parts II (Chapters 3-6) and III (Chapters 7-12), we describe methods and results for high resolution digital video aerial surveys and boat surveys, respectively. Part IV of this report (Chapters 13-19) combines data from both survey approaches to develop a comprehensive understanding of marine wildlife populations that use the mid-Atlantic study area. Part V (Chapters 20-25) focuses on individual movements and habitat use of focal avian species, tracked via satellite telemetry; and Part VI (Chapters 26-27) focuses on population-level migratory movements over the oceans, using several approaches for studying nocturnal avian migration. An additional study effort, which further explores statistical approaches for combining boat and aerial survey data to develop joint models of wildlife distributions and abundance, will be published as an addendum to this final report.

Part V: Individual movements and habitat use of focal bird species

Satellite telemetry allows us to track the movements of individual animals within their environment, and is an effective tool for understanding movement patterns and habitat use for a large number of marine species. Transmitters were only deployed on birds in this study, but there is analogous technology available for turtles and mammals (being deployed as part of the Atlantic Marine Assessment Program for Protected Species, or AMAPPS,[1] study among other efforts). With this method, temporal coverage is limited only by battery power and tag longevity. Due to power limitations such tracking is seldom continuous, but it is possible to track movements of individual birds over seasons or years regardless of weather or time of day. This level of individual temporal and spatial coverage requires expensive

[1] www.nefsc.noaa.gov/psb/AMAPPS/

technology, however, which often has the effect of limiting samples sizes, and it can be difficult to extrapolate population-wide distributions from a few individuals (Lindberg and Walker 2014).

The project team investigated the spatial and temporal patterns of offshore bird migration and winter habitat use through a combination of satellite telemetry data, and determined how these data covary with environmental conditions using remotely collected covariate information. We tracked the movements of individuals from three focal avian taxa: seabirds, including the Red-throated Loon (*Gavia stellata)* and Northern Gannet (*Morus bassanus*); sea ducks (the Surf Scoter, *Melanitta perspicillata*); and raptors (the Peregrine Falcon, *Falco peregrinus*). The six chapters in Part V of this report are:

Chapter 20. Wintering movements and habitat use of Surf Scoters in the mid-Atlantic U.S.

Chapter 21. Wintering movements and habitat use of Red throated Loons in the mid-Atlantic U.S.

Chapter 22. Wintering movements and habitat use of Northern Gannets in the mid-Atlantic U.S.

Chapter 23. Incorporating temporal variation in seabird telemetry data: time variant kernel density models.

Chapter 24. Using state-space models to identify areas of persistent winter activity and their associated environmental covariates in Northern Gannets.

Chapter 25. Offshore migration of Peregrine Falcons along the Atlantic flyway.

Animal movement modeling generally falls into two categories: more "place-based" models that can be applied to groups of individuals, and models based on random walk behavior, which are more likely to be applied to individual animals (Smouse et al. 2010). Both of these approaches were utilized in this report.

"Place-based" group models: kernel density estimates and utilization distributions

Traditional modeling approaches for tracking data are focused on predicting the probability of an animal's occurrence at a given point in space, and have historically included "home range" analyses (Smouse et al. 2010, Fischer et al. 2013). Modern variations include the development of utilization distributions, which quantify the relative frequency distribution of an animal's occurrence in space and time, and can be used to examine environmental correlates to high-use areas (Worton 1989; Smouse et al. 2010; e.g., Loring et al. 2014) and how frequency of use changes over time (Keating and Cherry 2009). In these approaches, consecutive observations are not linked (e.g., the sequences of positions are not used to add behavioral changes of individuals into the models). These modeling approaches are appropriate for understanding species' habitat use within area-confined ranges. These methods were used in this report to examine wintering movements and habitat use of seabirds in the mid-Atlantic study area, as birds were largely expected to remain within the region during the winter period.

Kernel-based utilization distributions and resource selection functions identified important habitat use areas for Surf Scoters (Chapter 20). Scoters are likely to utilize more geographically stable prey resources than are Red-throated Loons or Northern Gannets, however (Chapter 18, Appendix 18A), and modifications to this approach using different resource selection methods and temporally variable environmental covariates were applied to these two species (Chapters 21 and 22, respectively). Surf Scoters in core-use areas utilized shallow (<40 m) areas within 4.5 km from shore. Red-throated Loons also tended to use nearshore areas, and in our sample, the greatest chance for interaction between Red-throated Loons and potential wind energy areas generally occurred during the spring migration period (late March to early May). In contrast, Northern Gannets ranged widely over the Outer Continental Shelf during winter (Chapter 22). Though core habitat within the study area included the protected inshore waters of the major bays and bay mouths, individual birds displayed extensive movements up and down the eastern seaboard between the core use areas, increasing the likelihood that they would encounter offshore wind developments in the region repeatedly throughout the winter.

Chapters 20-22 explored spatial patterns and movement of three target species using fairly traditional methods, which collapse the temporal component of movement data into a single period for analysis. Time-variant kernel density analysis allows for a more explicit presentation of habitat use areas through time (Keating and Cherry 2009; Chapter 23), which may prove useful for understanding the timing of these species' presence in and around development areas. Time variant kernel density maps proved to be an effective tool for showing use of the study area at fine temporal scales. Analysis showed limited overlap of habitat use with wind energy areas, with the most overlap occurring for Northern Gannets.

Individual-based models of movement and behavior

Individual-based models attempt to estimate the detailed movements of an animal through the landscape, rather than aggregating observations into home ranges or similar distributions. These approaches are often based on correlated random walk models, in which stochastic differential equations are used to predict animal movements between observed locations (Smouse et al. 2010). State-space models can infer positions of animals where data gaps are present by modeling the underlying individual behavior that is used to move through space (Patterson et al. 2008, Schick et al. 2008, Smouse et al. 2010). Dynamic Brownian Bridge Movement Models (dBBMM) are data-intensive, but can serve as a useful "hybrid" approach that uses animals' movement paths to develop more refined utilization distributions than traditional place-based approaches (Kranstauber et al. 2012).

State-space models

Satellite telemetry can provide the opportunity to understand more detailed behaviors, as well as movements and general habitat use. Northern Gannet interactions with offshore wind energy development are hypothesized to largely occur as a result of their foraging behaviors, which include a large proportion of time spent soaring at or near the altitude of the rotor-sweep zone for offshore wind turbines (Garthe et al. 2000, Langston 2010). Being able to differentiate between foraging and other behaviors in telemetry data will allow us to better determine areas of potential conflict between offshore wind energy development and Northern Gannet habitat use, and could inform the siting and permitting of offshore wind energy development.

In Chapter 24, we use positional data in a behavioral state switching state-space model (SSSM) in a Bayesian modeling framework (Jonsen et al. 2007), to analyze telemetry data from the nonbreeding period. This more complex version of a correlated random walk model allows us to identify when these seabirds were employing "area-restricted search" foraging behavior versus transient searching behavior (when animals were likely moving between areas of high foraging availability). This analysis provides information on locations that were consistently used by Northern Gannets for foraging, and what habitat characteristics (e.g., water depth and sea surface temperature [SST] front density) defined these foraging areas. Weekly SST front density was a very strong predictor of foraging activity, which indicates that Northern Gannets dynamically responded to either the change in water temperature itself, or to the increase in prey availability that is likely occurring in areas with high front density. In order to understand what locations are most important for this species, it will be important to develop accurate models for predicting temperature fronts.

Dynamic Brownian bridge movement models

Unlike the above seabird species, Peregrine Falcons migrate through the project study area but seldom winter in or near the mid-Atlantic. Peregrine Falcons are sometimes thought of as a terrestrial species, but they are probably the most commonly encountered non-piscivorous raptor in marine settings. Peregrines are commonly observed foraging or perching far from shore at offshore islands, oil drilling platforms, and large offshore vessels (Voous 1961, Cochran 1975, 1985, Russell 2005, Johnson et al. 2011, Desorbo et al. 2012). Their migratory movements, as well as the higher number of data points afforded by solar transmitters, led to the use of different methodological approaches to understand falcon movements and use of space within the project study area during fall migration (Chapter 25).The dBBMM was well-suited for this scenario as it accounts for the changing probabilities of space-use as the speed of animal also changes. For migratory species like the Peregrine Falcon, this method generates utilization distributions that are more accurate in depicting high and low use areas and migratory corridors compared to traditional methods (Kernohan et al. 2001, Kie et al. 2010, Kranstauber et al. 2012, Fischer et al. 2013).

During this study, falcons regularly used habitat hundreds of kilometers offshore along the Atlantic coast, including within and east of the mid-Atlantic study area. Twelve of the 13 tracked falcons that continued their fall migration beyond the mid-Atlantic coast initiated a significant transoceanic flight from coastal North Carolina to the Caribbean or South America. Birds tracked in this study were all captured on offshore islands, and it remains unclear what proportion of the full Peregrine Falcon population ventures offshore. However, findings from this study are consistent with observations elsewhere (Cochran 1975, Fuller et al. 1998, Desorbo et al. 2012), and suggest that this species commonly uses offshore habitats along the Atlantic flyway.

Implications

The inclusion of satellite telemetry provides information on broad-scale movements of specific species in the environment, including nocturnal movements and habitat use, which is missing from our survey data. Depending upon the chosen analytical approach, satellite telemetry data can provide information at a variety of scales. The SSSM in Chapter 24 focuses on individual foraging decisions, for example, and thus examines Northern Gannet behavior at a different scale than the utilization distributions of Chapters 20-23 (which are "populations" of tagged birds), or boat or aerial surveys of population distributions (Parts II-IV of this report). Our ability to combine broad-scale analyses of population distributions and important habitat areas with finer-scale analyses of behavioral data may have implications for assessing risk. Predictions of the effects of offshore wind energy development on Northern Gannets in the mid-Atlantic, for example, must consider exposure (e.g., whether they are present in an area in large numbers) as well as well as hazards (that is, whether they are foraging, a behavior which has been suggested to be linked to collision risk as well as displacement; Lindeboom et al. 2011, Furness et al. 2013, Vanermen et al. 2014). Within the core use areas and persistent habitat use areas identified elsewhere in this report (shallower waters closer to shore; Chapters 12, 17, 19, and 22), gannets seem to be preferentially foraging in deeper portions of these areas with high numbers of temperature fronts; as a result, these may be the highest risk areas for interactions with offshore wind, even if population-level abundance is lower in those areas than in some shallower locations.

Acknowledgments: Part V of this report includes data from several collaborative field studies focused on the movement patterns of Red-throated Loons, Northern Gannets, Surf Scoters, and Peregrine Falcons in the Atlantic flyway, carried out by numerous principal investigators and agencies.

The work reported in Chapters 20-24 constitutes part of two multi-year collaborative projects: 1) Determining Offshore Use of Diving Bird Species in Federal Waters of the Mid-Atlantic United States Using Satellite Tracking, developed by the Bureau of Ocean Energy Management (BOEM) and the U.S. Fish & Wildlife Service (USFWS) and 2) the Atlantic and Great Lakes Sea Duck Migration Study, developed by the USFWS, Canadian Wildlife Service (CWS), and other state and federal partners. The first study was designed in partnership with the U.S. Geological Survey (USGS)-Patuxent Wildlife Research Center, Biodiversity Research Institute (BRI), and Memorial University of Newfoundland (MUN), and funded by BOEM, DOE, BRI, MUN, and The Bailey Wildlife Foundation. The second project was primarily funded by the USFWS through their support of the Sea Duck Joint Venture, as well as by DOE and by BOEM. In addition to these funding entities and the authors of these chapters, other partners that provided logistical or financial support include the Maryland Department of Natural Resources, Virginia Department of Game and Fisheries, University of Rhode Island, Delaware Division of Fish and Wildlife, and North Carolina Wildlife Resource Commission. Chapters 20-23 cover all data through the end of 2013, including the first two years of the BOEM/USFWS study and all prior years of the SDJV study. Chapter 24 includes Northern Gannet data through the end of 2014, including the first three years of the BOEM/USFWS study.

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Figure I. Organization of chapters within this final report.