Chapter 18: Comparison of boat and aerial models of seabird abundance with environmental covariates

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Chapter 18 Highlights

Comparison of habitat relationships and abundance estimates from boat and digital aerial surveys across the study area

Context[1]

Identifying the exposure of seabird species to proposed development projects often requires an understanding of how their abundance relates to environmental covariates. When multiple survey approaches are used, we must additionally determine how such sampling methods differ in estimating species' abundance in relation to these covariates. In this chapter, we focus on comparing data between survey methods for the purpose of determining how best to combine boat and digital aerial survey data for analysis. We tried to make the models as similar between survey types and species as possible, to facilitate comparison, which meant sometimes using slightly different formulations of models from other chapters. We analyzed the boat data similarly to Chapters 11-12, but with single species instead of a community. The digital aerial data are modeled similarly to Chapter 15 where generalized linear models were used.

This chapter presents a preliminary analysis of data from four seabird groups (terns, gannets, loons, and alcids) across the seasons when they were present in the study region. Remotely-collected environmental data were incorporated into separate boat and digital aerial models, to compare and contrast the estimated effects of habitat on seabird abundance using data from each sampling method. Chapter 19 builds upon these results and examines an integrated modeling approach for these taxa.

Study goal/objectives

Compare the estimated effect of habitat on the predicted abundance of marine bird species by season for models based on boat and aerial digital videography data.

Highlights

- Distance to shore was generally the most common predictor of abundance across species and surveys.
- Similar habitat relationships were estimated between the two survey types for gannets, terns, and loons; alcids were less consistent between the survey types and years.
- Accounting for imperfect detection in the boat data resulted in higher abundance for the boat-based than the aerial models.

Implications

Boat-based and digital aerial survey data provide comparable estimates of habitat relationships. This suggests that a model that can combine both data types may be the most powerful for understanding seabird distributions, although there are many ways to jointly model the data. Based on these results, caution should be taken for species like alcids, where different patterns were observed between survey types. Such differences may be due to differences in the sampling domain, detectability, or temporal variation.

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[1] For more detailed context for this chapter, please see the introduction to Part IV of this report.

Abstract

This chapter is a preliminary analysis that explores the patterns of seabird abundances observed in the shipboard and digital aerial surveys. Other chapters in this report (Chapters 11-12) focus on analysis of only the boat survey data, but the goal in this chapter is to compare the boat data with the aerial data to determine how best to combine the data types into one joint analysis. These results are not meant to be compared with other chapters that focused on abundance estimates, but instead just to evaluate the patterns and differences between the survey types. As such, this chapter uses slightly different approaches than other chapters, in order make the models as similar between survey types and species as possible and facilitate direct comparisons. The surveys have some spatial and temporal mismatch, which may cause variation in the observations. Additionally, there has been little previous work that jointly models boat surveys with distance-sampling and aerial digital videography surveys, thus demonstrating the need to conduct a preliminary exploration of the two datasets.

Our results indicate that for the species and groups included in this analysis (terns, alcids, loons, and gannets), we generally find that the habitat relationships are consistent between survey types, with distance to shore being the most common significant predictor of abundance. For alcids, we did see a lack of consistency in the patterns, both between years and survey types. We also found that the estimated abundance was generally higher for the boat surveys, likely due to the ability of our models to address imperfect detection in the boat sampling. The findings in this chapter were used to inform the development of a joint model, presented in Chapter 19.

Introduction

Shipboard and traditional aerial survey methodologies have been compared extensively in their performance at estimating species richness and abundance (for overview, see Camphuysen et al. 2004). Comparisons between shipboard and digital aerial surveys, however, remain sparse given the novelty of high resolution digital videography (Buckland et al. 2012). Digital videography covers a larger geographic area in a faster time frame, but the technology used in this study was limited by a few components: 1) only 200 meters of width was sampled, which is a small snapshot of the marine realm, 2) the angle and resolution of the video restricted most objects to being identified to family or group, as opposed to individual or species, and 3) there is no method to address issues of detection and availability, which likely vary by species, season, weather, or other factors. We evaluate the variation that may arise in digital videography data and identify issues related to inherent detection and identification constraints. We postulate that, were the digital aerial and boat surveys to provide similar parameter and abundance estimates, then both surveys would not need to be conducted simultaneously; however, if there are differences in the datasets, then finding ways that make use of the information in both datasets (a ‘joint model’) will be very informative. Before taking the next step in creating a joint model, we first aim to compare the two methods of sampling by using a suite of species (terns, alcids, loons, and gannets) and examining their habitat relationships across different seasons.

Our objectives include:

1. Compare the habitat parameter estimates from boat and aerial habitat models for various species across different seasons.
2. Based on the results of the habitat modeling, compare the predicted abundance from boat-based and digital videography estimates.
3. Evaluate the strength of association between marine mammals and seabirds, based on survey type (Appendix 18A).

It is important to note that there are methodological differences in sampling from the boat versus digital videography. Some differences are inherent to the two survey methods, such as transect width; the boat surveys sample wider transect widths for most species, and use distance sampling to account for variation in detection. Other differences are specific to the survey design utilized in this study (e.g., boat and aerial transects were located in slightly different geographic areas and occurred at different days and times). To minimize the study-specific sources of variation, we used an offset for area sampled, and compiled data from multiple surveys within each survey year. We expected that boat-based models would estimate higher abundance as a result of accounting for imperfect detection in the sampling.

Methods

Three wind energy areas (WEAs) are designated in our study area, off the coasts of Delaware (DE), Maryland (MD), and Virginia (VA; Figure 18-1). Field methods for the aerial and boat surveys are explained elsewhere in this report (Chapters 3 and 7, respectively). Aerial identification protocols for video analysis are discussed in Chapter 4. For this comparison, we used boat survey observations that were sampled from the forward quadrant on one side of the vessel, extending up to 1 km from the trackline, and digital aerial observations that were collected from 4 cameras, which each recorded a 50 m band (totaling 0.2 km strip width). For both the boat and aerial surveys, we divided survey transects into 4 km segments (‘sites’); this resulted in some shorter segments at the transect ends which is included in our analysis as an offset for ‘site’ area, the segment length by strip width (1 km for boat, 0.2 km for aerial). The number of individuals for each species was summed by 4 km segment per survey (defined as the time period over which the entire study area was sampled). Many species, including terns, gannets, and loons, are seasonally present in the study area or observed in low numbers, so surveys were combined within each year for analysis but varied depending on the species. We compared gannets, terns, loons, and alcids between the two survey methods; due to slight differences between each taxonomic group, we created group-specific models, described below.

Covariates

We used five covariates in our analyses: three static (distance to shore, slope, and grain size), and two dynamic (sea surface temperature, and salinity). We excluded chlorophyll-*a* in these analyses because it was co-linear with distance to shore in some of the surveys and we wanted to keep the covariates consistent across surveys for the purpose of comparison within each species; due to missing data at higher resolutions it also varied monthly, which is a lower temporal resolution than the other dynamic covariates. Remotely sensed covariate data corresponded to the values located at the midpoint of each transect segment. For the static covariates, we calculated distance to shore (m) within ArcGIS 10.2 (ESRI, Redlands, CA) and extracted slope (% rise, 370-m resolution) and grain size (ϕ = -og2[mean grain diameter in mm], 370-m resolution) from the data layer derived by NOAA/NOS National Centers for Coastal Ocean Science (Kinlan et al. 2013). For the dynamic covariates, we used Marine Geospatial Ecology Tools in ArcGIS (Roberts et al. 2010) to download remotely-sensed data at the highest resolution available for all segments. We compiled daily values for sea surface temperature (SST, °C, 1-km GHRSST L4) and salinity (Practical Salinity Units, 9-km HYCOM GLBa0.08 Equatorial 4D). In the boat survey analysis, we additionally included one covariate on detection: Beaufort sea state on the binary scale, which varied by segment (0 = calm seas, Beaufort state 0-2; 1 = rough seas, Beaufort state 3-6).

Models

To facilitate comparisons, we ran the same model across both the boat and aerial data for each species, except that the boat-based model included an additional component for estimating detection using distance sampling (see Chapter 11). For each species or group, we conducted preliminary diagnostics to evaluate the data and select the best model for abundance, considering the Poisson, Negative Binomial, and zero-inflated versions of both distributions. For the boat-based models, we considered a detection as a single individual, thus breaking down each flock into separate detections of individuals (as opposed to modeling the flock, which we did previously in Chapters 11 and 12), so that we could compare parameters directly with the aerial surveys.

Terns

Terns included Least Terns (*Sternula antillarum*), Caspian Terns (*Hydroprogne caspia*), Black Terns (*Chlidonias niger*), Common Terns (*Sterna hirundo*), Roseate Terns (*Sterna dougallii*), Royal Terns (*Thalasseus maximus*), and Sandwich Terns (*Thalasseus sandvicensis*), as well as those individuals classified as "unidentified terns." Vague identifications that could have included other species such as gulls (e.g., "large tern or small gull,") were excluded. Terns were primarily present in the study area during spring, summer and fall (Chapters 5, 8, 12), so we compared three boat and two aerial surveys from Jun 2012 – September 2012 (first year), and Jun 2013 – September 2013 (second year; this did not include the August aerial surveys, as the August 2013 aerial survey covered only the MD WEA and surrounding areas). For the tern models we used a Negative Binomial distribution on abundance and a Negative Exponential distribution on detection (only in the boat survey models). The abundance component of the model for both boat and aerial surveys was constructed such that each count of terns at segment i, $\mathrm{y_i}$, was modeled as:

$$\mathrm{y_i} \sim \mathrm{NegBin}(\lambda_i,\ r)$$

$$\log(\lambda_i) = \beta_0 + offset\ (site\ area) + \beta_1 \mathrm{Dst_i} + \beta_2 \mathrm{Slp_i} + \beta_3 \mathrm{Grn_i} + \beta_4 \mathrm{Sst_i} + \beta_5 \mathrm{Sal_i}$$

where Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, and r is the overdispersion parameter.

Gannets

The only gannets in the area are Northern Gannet (*Morus bassanus*), thus all unidentified gannets were considered Northern Gannets. Gannets were primarily present in the study area in late fall to early spring (Chapters 5, 8, 12), so we compared three boat and three aerial surveys from October 2012 –

February 2013 (first year), and October 2013 – February 2014 (second year). For these gannet models we used a Negative Binomial distribution on abundance, and a Half Normal distribution on detection (only in the boat survey models). The abundance component of the model for both boat and aerial surveys was constructed such that each count of gannets at segment i, $\mathrm{y_i}$, was defined:

$$\mathrm{y_i} \sim \mathrm{NegBin}(\lambda_i,\ r)$$

$$\log(\lambda_i) = \beta_0\ + offset\ (site\ area) + \beta_1\mathrm{Dst_i} + \beta_2\mathrm{Slp_i} + \beta_3\mathrm{Grn_i} + \beta_4\mathrm{Sst_i}$$

where Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, and Sst = sea surface temperature. We removed salinity in these models because it was highly co-linear with SST and distance to shore.

Loons

We considered loons by species (Common Loons, *Gavia immer*, and Red-throated Loons, *G. stellata*) and as a group (all loons, which included both species and all unidentified loon observations), to examine whether habitat relationships varied by species (Chapter 16). Loons were primarily present in the study area from late fall to early spring (Chapters 5, 8, 12), so we included three boat and three aerial surveys from December 2012 – March 2013 (first year), and December 2013 – May 2014 (second year). For all of the loon models, we used a Negative Binomial distribution on abundance, and a Half Normal distribution on detection (only in the boat survey models). The abundance component of the model for both boat and aerial surveys was constructed such that each count of loons at segment i, $\mathrm{y_i}$, was defined:

$$\mathrm{y_i} \sim \mathrm{NegBin}(\lambda_i,\ r)$$

$$\log(\lambda_i) = \beta_{0,survey} + offset\ (site\ area) + \beta_1\mathrm{Dst_i} + \beta_2\mathrm{Slp_i} + \beta_3\mathrm{Grn_i} + \beta_4\mathrm{Sst_i} + \beta_5\mathrm{Sal_i}$$

where Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, and a survey specific intercept to address interannual variation in the survey counts.

Alcids

The alcid group included Razorbills (*Alca torda*), Dovekies (*Alle alle*), Atlantic Puffins (*Fratercula arctica*), Common Murres (*Uria aalge*), Thick-billed Murres (*U. lomvia*), and Black Guillemots (*Cepphus grille*), as well as those individuals classified as “unidentified alcids.” Alcids were primarily present in the study area during winter (Chapters 5, 8, 12), therefore we compared two boat and two aerial surveys from December 2012 – February 2013 (first year), and December 2013 – February 2014 (second year). For all alcid models we used a Negative Binomial distribution on abundance, and a Half Normal distribution on detection (only in the boat survey models). To model abundance for both boat and aerial surveys we defined the counts of alcids at segment i, $\mathrm{y_i}$, such that:

$$\mathrm{y_i} \sim \mathrm{NegBin}(\lambda_i,\ r)$$

$$\log(\lambda_i) = \beta_0\ + offset\ (site\ area) + \beta_1\mathrm{Dst_i} + \beta_2\mathrm{Slp_i} + \beta_3\mathrm{Grn_i} + \beta_4\mathrm{Sst_i} + \beta_5\mathrm{Sal_i}$$

where Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, and Sal = salinity. In the second year of the aerial surveys, we had to set the overdispersion parameter $r = 0.02$ in order to achieve convergence in the model. There were only 45 transects with observed alcids during this year, which may indicate that our model is overparameterized with five covariates and an intercept. This requires further attention and investigation.

Implementation

We implemented all models in a Bayesian framework using the package "rjags" to run the software JAGS (Plummer 2003) in program R version 2.15.3 (R Development Core Team 2014). We standardized the covariates for analysis to center them on a mean = 0, with a variance close to 1. We initialized three parallel Markov chains at different values and ran them for 30,000 iterations (boat models) or 10,000 (aerial models) following a burn-in of 1,000 iterations. We checked for chain convergence visually (posterior density and trace plots), and quantitatively using the Gelman-Rubin statistic (Gelman et al. 2014). This statistic (termed R-hat) is a measure of among-chain versus between-chain variance and values < 1.1 indicate convergence (Gelman et al. 2014). We also assessed goodness of fit by computing Bayesian p-values. We used Freeman-Tukey fit statistics to evaluate the model for abundance, and to select the Negative Exponential or Half Normal detection function (Gelman et al. 2014). Fitting the models resulted in estimated abundance to the sampled transects, summed across segments and surveys. Using the posterior means of each model parameter, we additionally predicted the abundance of each wintering species to habitat covariates from a representative day (25 Dec 2012), which covered unsampled locations in the three WEAs proposed for our study area.

Results

Overall, we found that fewer individuals were observed on the aerial surveys than the boat surveys for smaller species (e.g., terns, alcids), and the observations varied by survey date, year, and species (Table 18-1). Accounting for detection resulted in higher abundance in the boat than the aerial surveys, which carried through to the predicted number of birds in each of the WEAs. In Year 1, the estimated number of gannets was very similar for the boat and aerial surveys, with the Virginia WEA having a lower predicted number of birds from the boat survey than the aerial (Table 18-1). Similarly, in Year 2, the number of predicted alcids in all the WEAs from the aerial survey was near 40 birds, while it was near zero birds from the boat survey, though 127 alcids were predicted to the entire study region (Table 18-1). These two cases are the only situations where the boat surveys did not predict higher abundance of birds than the aerial survey, and are likely due to the strong effect of proximity to shore reducing the numbers predicted to the VA WEA (see below for more details on parameter effects).

Across both the boat and aerial surveys, proximity to shore was the most important predictor of abundance. The abundance of terns, gannets, and loons increased with proximity to shore (Table 18-2 through Table 18-6). Alcids associated more closely with the shoreline in Year 2, but they were farther from shore in Year 1 boat surveys (Table 18-7). The detectability of terns, loons, and alcids decreased as seas became rougher, whereas gannets showed no change in detectability in Year 1, and an opposite effect in Year 2 (Table 18-2 to Table 18-7).

The general patterns in habitat relationships between the aerial and boat surveys were consistent. Terns showed similar parameter estimates for the habitat covariates between survey methods, though this was not true for all parameters (Table 18-2). For example, terns were associated with warm water in the first year aerial surveys and with fine sand in the second year aerial surveys. We found that gannets had a positive relationship with cold water in all surveys except the first year of the boat surveys, when we found no significant relationship (Table 18-3). Gannets associated strongly with all four habitat covariates in the second year of surveys, with similar parameter estimates to all except that they associated with coarse sand in the aerial surveys and fine sand in the second year boat surveys.

For loons, we found similar patterns as with gannets and terns; however, it is useful to note that there were some differences when using species-level data (Table 18-4 to Table 18-6). For example, in Year 2 of the aerial survey, only one Red-throated Loon was identified, while there were 2062 total loon observations (Table 18-1). This meant that we were unable to model the distribution of Red-throated Loons that year for the aerial data; the boat data that same year had 754 observed Red-throated loons. In comparison, the Year 2 aerial survey for Common Loons had the most number of significant covariates of any of the loon analyses (Table 18-5). Looking at the boat survey results for year 1, Red-throated Loons had significant negative effects of distance to shore, slope, and salinity (Table 18-6); Common Loons also had a significant negative effect of salinity, but additionally a positive effect of sea surface temperature (Table 18-5). The model for all loons had a significant negative effect of salinity and distance to shore and a significant positive effect of sea surface temperature (Table 18-4). Thus the combined model smooths out the individual species effects, losing the importance of slope on Red-throated Loons and suggesting a relationship with distance to shore that was not detected in Common Loons. Similar results were observed in the first year aerial survey: Common Loons had no significant effects (Table 18-5), Red-throated Loons had a significant negative effect of distance to shore (Table 18-6), and all loons had a significant negative effect of distance to shore and a positive effect of sea surface temperature (Table 18-4). Here, we may be seeing some differences due to increases in sample size; as we add observations from unidentified loons, more patterns can be detected.

Bayesian p-values suggest that model fit was generally adequate for all of the abundance model components (Table 18-8); the aerial data for the gannets and the combined loons did not fit very well, and thus other distributions may be explored in these cases. Futher investigation into the detection component may be necessary, but in general the estimates of abundance have been rather insensitive to the detection model (Half Normal vs. Negative Exponential; unpublished results), so the results are not likely to change significantly even under a different detection model in these cases.

Discussion

As expected, proximity to shore was the main consistent driver of abundance patterns for all species/groups in this study. Chlorophyll concentration also increased with proximity to shore, and while it was not included in models due to this co-linearity, this suggests that distance from shore may be a proxy for primary productivity in this region. A large effect of primary productivity on predator distributions may indicate strong bottom-up forcing in this region. This is consistent with studies suggesting that, in waters off the east coast of the US where productivity and species richness are relatively high, bottom-up control dominates and resource limitation induces positive predator-prey relationships (Ainley and Hyrenbach 2010; Frank et al. 2007; Hunt and McKinnell 2006).

The boat surveys generally resulted in higher estimates of abundance compared to the aerial surveys, taking effort into account. The total length of an aerial survey's transects (3,613 km including the Maryland extensions, as stated in Chapter 3) is much greater than in a boat survey (572 km, Chapter 7). The strip width is 1/5 of the 1 km truncation distance we used for the detection function in the boat survey models. Therefore, the aerial survey effort (total area sampled) is 1.3 fold greater, so we would expect to estimate more individuals in the aerial surveys. However, our results show the opposite: that the boat survey models consistently estimated and predicted higher abundance, which is primarily due to accounting for imperfect detection. The differences are particularly noticeable with the smaller species (e.g., terns and alcids), indicating that they were more easily identified in the boat surveys.

Detection decreased with increased sea state for all species except gannets in the Year 2 boat surveys. The observer team moved into the pilot house during rough seas, following safety protocol, which likely contributed to reduced visibility. We suspect that the increased detection of gannets in rough seas was a result of differences in behavior, as gannets are less likely to sit on the water during rough seas, and flying gannets are generally considered to be more visible.

In general, habitat relationships were similar within a season and between survey types (boat and aerial), with a few exceptions. These exceptions could be due to (1) more habitat sampled between the MD and VA WEAs in the aerial surveys, or to (2) the extreme habitat values that occurred in the shipping channel to Delaware Bay, which were sampled on Transect 2 of the boat surveys (e.g., steep slopes and a strong salinity front). Gulf Stream waters on the outer edge of the continental shelf tend to be warmer than coastal waters, and salinity also tends to decrease with distance from the freshwater outlets inshore of the Delaware and Chesapeake Bays. Thus, the significant influence of warm water and fine sand on abundance of terns in the aerial surveys (unlike the boat surveys) may be due to aerial observations of them close to shore between the MD and VA WEAs. Opposite effects of sediment grain size on gannets occurred in the Year 2 boat surveys and aerial surveys, which may have been due to differences in sampling effort by survey type, where aerial surveys covered more area between the MD and VA WEA footprints. In Year 2, the boat surveys also showed that Common Loons associated with steep slope, and with more gradual slope in the aerial surveys, which again could be due to occurrences between the MD and VA WEAs, where the bottom is relatively flat. Low salinity had a strong effect on Red-throated Loons in the boat surveys, but not in the first year aerial survey. However, Red-throated Loon data from the aerial surveys should be taken with caution, since many Red-throated Loons were not identified to species (Chapter 16), which may cause biased results. Alcids were likely to be far from shore, associating with cold water in the first year boat surveys (similarly to Chapter 12), but the first year aerial surveys showed an association only with warmer water, which may be a result of co-linearity between SST and distance to shore in gulf stream waters on the outer edge of the continental shelf.

Similarities between survey types were most pronounced with proximity to shore, which had consistently significant effects on (1) terns and loons across both seasons and survey types (Chapter 12), (2) gannets across three of the four models (Ch. 11), and (3) alcids in the second year across both survey types.

Significant effects were consistent across both survey types in year 2, with respect to cold water and gannets, as well as grain size and Common Loons. Significant effects of warm water on loons occurred across both seasons and survey types. Common and Red-throated Loons also associated with low salinity in different survey types and seasons. Our results suggest that using both boat and aerial surveys can provide more complete ecological context compared to either survey type alone.

Future work

The results of this chapter suggest that combining the two survey types into one comprehensive model would be fruitful. The results between the boat and aerial surveys were generally consistent for the species we examined, and variations between the methods may be due to differences in the sampled area (larger coverage with aerial) and in detection (accounted for by distance sampling in boats). Further data exploration of yearly differences (as opposed to survey-specific) in covariate values and patterns would be useful (e.g., to address issues of co-linearity). Additionally, testing the impacts of localized habitat on the results for the entire study area would be informative, and could be achieved by removing parts of the dataset to evaluate changes in the results (for example transect 2 of the boat survey, which sampled some extreme covariate values). Teasing apart differences due to variation in survey type, inter-annual differences, and sampling space will help to better understand the differences observed in the relationships between seabird abundance and habitat covariates.

Combining the data into a single model would likely play to the strengths of both survey methodologies and provide more reliable inferences about the underlying ecological drivers of seabird distributions and abundance. In a first attempt at this, we have implemented an integrated model described in Chapter 19. There are a number of approaches that can be taken when developing a joint model, and we are continuing to pursue those options in an addendum to this final report. One issue to be addressed is how to deal with availability in the digital aerial surveys (see Winiarski et al. 2014); we currently have no measure of availability, and this would be difficult to acquire for all species. Thus, in addition to a joint modeling approach to combine the survey types, we suggest also conducting an analysis of model sensitivity to availability and detection, to better understand the impact of these processes on abundance estimates for the digital aerial surveys.

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Figures and tables

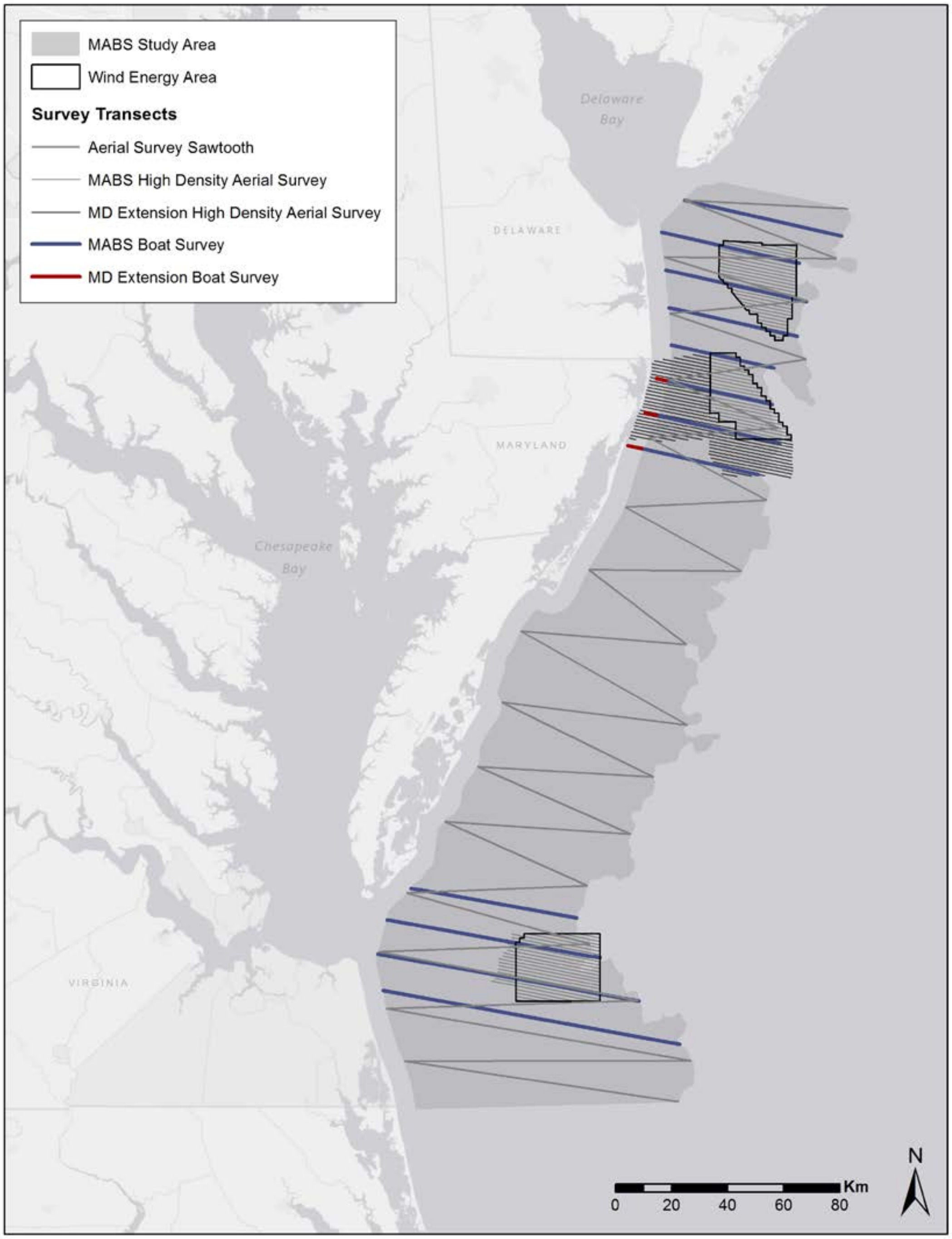

Figure 18-1. **Study area.** Boat transects are shown in blue and red, aerial transects in light and dark gray, and wind energy areas in black.

Table 18-1. Surveys used in the analysis for each species/group and the abundance of each species/group. Observed (Obs.) refers to raw counts and estimated abundance (Estim.) is fit to the sampled transects (summed across the listed surveys). We predicted (Predicted) the abundance of each species to a representative summer or winter day (25 Jul 2012 for terns; 25 Dec 2012 for gannets, loons, and alcids) in each wind energy area (WEA) by state: Delaware (DE), Maryland (MD), and Virginia (VA). [a]Predictions used first survey intercept.

Year	Boat Surveys				Aerial Surveys				Group	Boat abundance					Aerial abundance			
										Obs.	Estim.	Predicted			Obs.	Predicted		
										trans.	trans.	DE WEA	MD WEA	VA WEA	trans.	DE WEA	MD WEA	VA WEA
First	**Jun-12**	**Aug-12**	**Sep-12**			**Jun-12**	**Sep-12**		Terns	534	3,378.4	1,151.5	1,382.4	152.4	108	93.4	109.6	11.2
	Nov-12	**Dec-12**	**Jan-13**		**Oct-12**	**Dec-12**	**Feb-13**		Gannets	3,998	8,960.5	1,215.5	1,313.6	408.0	4,190	1,158.3	932.6	1,022.6
		Dec-12	**Jan-13**	**Mar-13**		**Dec-12**	**Feb-13**	**Mar-13**	Loons[a]	996	3,811.2	1,139.6	804.8	1,356.0	1,661	368.7	329.8	307.5
									Common L.[a]	517	2,094.7	647.3	462.5	1,140.0	173	74.9	59.7	67.5
									Red-thr. L.[a]	441	1,805.9	360.7	260.3	185.4	117	64.2	62.1	30.7
		Dec-12	**Jan-13**			**Dec-12**	**Feb-13**		Alcids	598	3,495.1	1,409.3	889.5	2839.9	339	122.9	191.9	201.8
Second	**Jun-13**	**Aug-13**	**Sep-13**			**Jul-13**	**Sep-13**		Terns	243	1,877.9	269.4	309.0	74.4	154	19.8	29.0	1.5
	Oct-13	**Dec-13**	**Jan-14**		**Oct-13**	**Dec-13**	**Feb-14**		Gannets	4,723	5,693.9	5,340.3	1,578.3	2,272.4	1,612	420.3	413.5	152.8
		Dec-13	**Jan-14**	**Apr-14**		**Dec-13**	**Feb-14**	**May-14**	Loons[a]	2,626	10,884.9	1,476.7	1,512.9	941.5	2,062	666.7	521.9	697.6
									Common L.[a]	1,851	8,453.8	407.2	510.5	250.6	122	55.8	42.1	105.5
									Red-thr. L.[a]	754	2,586.0	216.0	187.1	97.9	1	NA	NA	NA
		Dec-13	**Jan-14**			**Dec-13**	**Feb-14**		Alcids	578	1,769.4	0.3	0.9	0.1	102	10.8	12.6	19.6

Table 18-2. Parameter estimates by year from the boat and high resolution digital video aerial surveys, using a Negative Binomial distribution to model counts of terns. SD is the standard deviation, 2.5% and 97.5% are the respective quantiles, r is the overdispersion parameter, and all abundance parameters are on the log scale. Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, Mam = marine mammal density, and Beaufort sea state 3-6 are rough seas (as opposed to calm, 0-2). The posterior mean for covariates where the 95% Bayesian credible interval (BCI) does not overlap zero are in bold italics.

Terns		**Boat**								**Aerial**							
		First year				**Second year**				**First year**				**Second year**			
Component	**Term**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**
Abundance	**Intercept**	-0.33	0.21	-0.74	0.08	***-0.94***	0.21	-1.33	-0.53	***-3.81***	0.24	-4.31	-3.36	***-4.18***	0.26	-4.70	-3.70
	Dst	***-1.96***	0.33	-2.64	-1.35	***-1.42***	0.20	-1.83	-1.05	***-1.61***	0.22	-2.05	-1.19	***-2.14***	0.20	-2.55	-1.77
	Slp	-0.32	0.19	-0.71	0.07	-0.02	0.17	-0.36	0.32	0.01	0.13	-0.24	0.26	0.08	0.10	-0.12	0.28
	Grn	-0.12	0.19	-0.48	0.25	0.24	0.19	-0.13	0.62	0.18	0.14	-0.11	0.45	***0.37***	0.13	0.13	0.63
	Sst	0.62	0.37	-0.10	1.33	0.17	0.16	-0.15	0.49	***0.64***	0.22	0.20	1.07	0.02	0.12	-0.21	0.25
	Sal	-0.31	0.32	-0.90	0.32	-0.08	0.18	-0.44	0.26	-0.39	0.25	-0.87	0.09	-0.30	0.16	-0.63	0.02
	Overdisp; r	0.12	0.02	0.09	0.15	0.21	0.04	0.14	0.31	0.22	0.07	0.12	0.38	0.31	0.08	0.18	0.49
Detection	**Beaufort 0-2**	***5.25***	0.07	5.12	5.38	***5.16***	0.09	5.00	5.33								
	Beaufort 3-6	***4.84***	0.07	4.70	4.98	***4.46***	0.11	4.24	4.68								

Table 18-3. Parameter estimates by year from the boat and high resolution digital video aerial surveys, using a Negative Binomial distribution to model counts of gannets. SD is the standard deviation, 2.5% and 97.5% are the respective quantiles, r is the overdispersion parameter, and all abundance parameters are on the log scale . Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, and Beaufort sea state 3-6 are rough seas (as opposed to calm, 0-2). The posterior mean for covariates where the 95% Bayesian credible interval (BCI) does not overlap zero are in bold italics.

Gannets		**Boat**								**Aerial**							
		First year				**Second year**				**First year**				**Second year**			
Component	**Term**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**
Abundance	**Intercept**	***0.92***	0.10	0.72	1.13	***1.07***	0.09	0.89	1.26	***-0.14***	0.07	-0.28	0.01	***-0.80***	0.06	-0.92	-0.67
	Dst	***-1.21***	0.12	-1.43	-0.97	***-1.08***	0.13	-1.34	-0.83	0.11	0.08	-0.05	0.27	***-0.78***	0.07	-0.92	-0.65
	Slp	-0.11	0.11	-0.30	0.11	***0.30***	0.09	0.12	0.48	-0.09	0.07	-0.23	0.05	***0.26***	0.05	0.15	0.37
	Grn	0.13	0.10	-0.07	0.31	***-0.29***	0.12	-0.54	-0.07	***0.20***	0.07	0.05	0.34	***0.15***	0.06	0.03	0.26
	Sst	-0.02	0.12	-0.25	0.21	***-0.76***	0.10	-0.96	-0.56	***-1.87***	0.10	-2.06	-1.68	***-0.65***	0.08	-0.80	-0.50
	Overdisp; r	0.28	0.02	0.23	0.32	0.25	0.02	0.22	0.30	0.14	0.01	0.13	0.16	0.14	0.01	0.13	0.16
Detection	**Beaufort 0-2**	***5.86***	0.02	5.82	5.89	***5.67***	0.02	5.63	5.72								
	Beaufort 3-6	***5.91***	0.02	5.87	5.95	***5.82***	0.01	5.80	5.85								

Table 18-4. Parameter estimates by year from the boat and high resolution digital video aerial surveys, using a Negative Binomial distribution to model counts of all loons (Common, Red-throated, and unknowns combined). SD is the standard deviation, 2.5% and 97.5% are the respective quantiles, r is the overdispersion parameter, and all abundance parameters are on the log scale (from the count process). Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, and Beaufort sea state 3-6 are rough seas (as opposed to calm, 0-2). The posterior mean for covariates where the 95% Bayesian credible interval (BCI) does not overlap zero are in bold italics.

Loons		Boat								Aerial							
		First year				Second year				First year				Second year			
Component	**Term**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**
Abundance	**Intercept (survey 1)**	0.04	0.23	-0.40	0.50	***1.20***	0.24	0.72	1.70	**-0.95**	0.21	-1.36	-0.54	**0.13**	0.06	0.01	0.25
	Intercept (survey 2)	***0.56***	0.15	0.28	0.85	***1.32***	0.21	0.92	1.74	**0.67**	0.10	0.48	0.87	**0.72**	0.08	0.55	0.88
	Intercept (survey 3)	***1.37***	0.19	1.01	1.74	***1.31***	0.15	1.01	1.61	0.01	0.18	-0.35	0.35	**-2.06**	0.13	-2.31	-1.82
	Dst	***-0.25***	0.10	-0.45	-0.05	***-0.76***	0.17	-1.10	-0.43	**-0.65**	0.06	-0.76	-0.54	**-0.28**	0.04	-0.35	-0.20
	Slp	-0.11	0.08	-0.26	0.04	***0.21***	0.08	0.06	0.37	-0.02	0.04	-0.09	0.05	-0.07	0.04	-0.14	0.00
	Grn	-0.08	0.08	-0.23	0.07	***0.37***	0.09	0.20	0.57	-0.06	0.04	-0.13	0.02	0.00	0.03	-0.06	0.07
	Sst	***0.35***	0.12	0.12	0.57	***0.53***	0.12	0.30	0.76	**0.75**	0.11	0.53	0.96	**0.45**	0.07	0.32	0.58
	Sal	***-0.50***	0.12	-0.74	-0.26	-0.12	0.21	-0.53	0.30	-0.09	0.12	-0.33	0.14	**-0.23**	0.05	-0.32	-0.13
	Overdisp; r	0.67	0.07	0.54	0.82	0.44	0.04	0.37	0.52	0.51	0.03	0.46	0.58	0.66	0.04	0.58	0.75
Detection	**Beaufort 0-2**	***5.38***	0.03	5.32	5.43	***5.61***	0.03	5.56	5.66								
	Beaufort 3-6	***5.28***	0.04	5.21	5.36	***5.14***	0.02	5.10	5.17								

Table 18-5. Parameter estimates by year from the boat and high resolution digital video aerial surveys, using a Negative Binomial distribution to model counts of Common Loons. SD is the standard deviation, 2.5% and 97.5% are the respective quantiles, r is the overdispersion parameter, and all abundance parameters are on the log scale. Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, and Beaufort sea state 3-6 are rough seas (as opposed to calm, 0-2). The posterior mean for covariates where the 95% Bayesian credible interval (BCI) does not overlap zero are in bold italics.

COLO		**Boat**								**Aerial**							
		First year				**Second year**				**First year**				**Second year**			
Component	**Term**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**
Abundance	**Intercept (survey 1)**	***-0.94***	0.31	-1.54	-0.35	***1.23***	0.29	0.66	1.80	**-1.98**	0.48	-2.93	-1.03	**-2.37**	0.16	-2.70	-2.06
	Intercept (survey 2)	0.26	0.17	-0.06	0.60	***0.78***	0.26	0.27	1.28	**-2.00**	0.24	-2.47	-1.54	**-2.24**	0.25	-2.74	-1.76
	Intercept (survey 3)	***0.54***	0.24	0.08	1.02	***0.52***	0.19	0.15	0.90	**-4.37**	0.51	-5.41	-3.40	**-5.73**	0.46	-6.67	-4.86
	Dst	-0.15	0.13	-0.41	0.11	***-0.79***	0.22	-1.22	-0.34	-0.21	0.15	-0.52	0.08	0.07	0.11	-0.14	0.29
	Slp	-0.04	0.09	-0.21	0.14	***0.28***	0.10	0.09	0.48	0.05	0.10	-0.14	0.24	**-0.30**	0.14	-0.57	-0.04
	Grn	-0.07	0.09	-0.25	0.11	***0.42***	0.12	0.18	0.67	-0.06	0.10	-0.26	0.13	**0.22**	0.11	0.01	0.46
	Sst	***0.88***	0.16	0.57	1.21	***0.71***	0.15	0.41	1.00	-0.04	0.26	-0.55	0.46	**0.81**	0.20	0.41	1.21
	Sal	***-0.45***	0.15	-0.76	-0.15	0.23	0.26	-0.28	0.71	-0.07	0.28	-0.62	0.49	**-0.39**	0.13	-0.65	-0.14
	Overdisp; r	0.51	0.07	0.39	0.66	0.29	0.03	0.24	0.35	0.26	0.07	0.17	0.42	0.40	0.21	0.17	0.97
Detection	**Beaufort 0-2**	***5.32***	0.04	5.25	5.40	***5.47***	0.04	5.41	5.54								
	Beaufort 3-6	***5.20***	0.06	5.09	5.31	***5.09***	0.02	5.05	5.13								

Table 18-6. Parameter estimates by year from the boat and high resolution digital video aerial surveys, using a Negative Binomial distribution to model counts of Red-throated Loons. SD is the standard deviation, 2.5% and 97.5% are the respective quantiles, ***r*** is the overdispersion parameter, and all abundance parameters are on the log. Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, and Beaufort sea state 3-6 are rough seas (as opposed to calm, 0-2). The posterior mean for covariates where the 95% Bayesian credible interval (BCI) does not overlap zero are in bold italics. There was only 1 observed Red-throated Loon in the second year aerial surveys, so no model was fit to these data.

RTLO		**Boat**								**Aerial**							
		First year				**Second year**				**First year**				**Second year**			
Component	**Term**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**
Abundance	**Intercept (survey 1)**	***-0.99***	0.37	-1.72	-0.30	***-2.29***	0.33	-2.94	-1.66	**-1.88**	0.90	-3.66	-0.15	NA	NA	NA	NA
	Intercept (survey 2)	***-1.43***	0.27	-1.98	-0.91	0.01	0.22	-0.42	0.44	**-2.60**	0.45	-3.48	-1.72	NA	NA	NA	NA
	Intercept (survey 3)	***0.85***	0.32	0.24	1.50	0.33	0.16	0.03	0.64	**-6.12**	0.87	-7.88	-4.48	NA	NA	NA	NA
	Dst	***-0.78***	0.17	-1.12	-0.46	***-1.13***	0.18	-1.50	-0.80	**-0.62**	0.31	-1.25	-0.03	NA	NA	NA	NA
	Slp	***-0.30***	0.12	-0.53	-0.07	-0.12	0.09	-0.30	0.06	-0.26	0.17	-0.59	0.06	NA	NA	NA	NA
	Grn	-0.08	0.13	-0.33	0.17	***0.23***	0.09	0.05	0.41	-0.05	0.17	-0.38	0.26	NA	NA	NA	NA
	Sst	-0.22	0.17	-0.56	0.11	***0.33***	0.12	0.09	0.58	-0.34	0.46	-1.22	0.58	NA	NA	NA	NA
	Sal	***-0.92***	0.25	-1.43	-0.45	***-0.54***	0.22	-0.98	-0.08	0.21	0.54	-0.85	1.28	NA	NA	NA	NA
	Overdisp; r	0.35	0.05	0.26	0.46	0.65	0.09	0.50	0.84	0.06	0.01	0.04	0.08	NA	NA	NA	NA
Detection	**Beaufort 0-2**	***5.34***	0.05	5.25	5.44	***5.70***	0.04	5.63	5.77								
	Beaufort 3-6	***5.20***	0.05	5.10	5.30	***5.26***	0.04	5.19	5.33								

Table 18-7. Parameter estimates by year from the boat and high resolution digital video aerial surveys, using a Negative Binomial distribution to model counts of alcids. SD is the standard deviation, 2.5% and 97.5% are the respective quantiles, r is the overdispersion parameter, and all abundance parameters are on the log scale. Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, and Beaufort sea state 3-6 are rough seas (as opposed to calm, 0-2). The posterior mean for covariates where the 95% Bayesian credible interval (BCI) does not overlap zero are in bold italics. There was only 1 observed Red-throated Loon in the second year aerial surveys, so no model was fit to these data.

Chapter 19 Alcids		**Chapter 20 Boat**								**Chapter 21 Aerial**							
		First year				**Second year**				**First year**				**Second year**			
Component	**Term**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**
Abundance	**Intercept**	***1.00***	0.12	0.78	1.24	***-0.51***	0.16	-0.83	-0.19	***-1.71***	0.12	-1.95	-1.47	***-2.95***	0.21	-3.35	-2.52
	Dst	***0.54***	0.15	0.24	0.84	***-1.45***	0.24	-1.93	-0.94	0.04	0.13	-0.20	0.29	**-0.61**	0.28	-1.18	-0.07
	Slp	0.13	0.10	-0.06	0.34	-0.03	0.14	-0.30	0.27	-0.19	0.12	-0.43	0.05	-0.43	0.23	-0.88	0.02
	Grn	-0.20	0.12	-0.44	0.04	0.13	0.19	-0.23	0.50	0.26	0.14	-0.02	0.53	0.02	0.25	-0.47	0.50
	Sst	***-0.28***	0.13	-0.54	-0.02	0.00	0.18	-0.37	0.34	***0.65***	0.15	0.36	0.95	***-0.58***	0.23	-1.03	-0.13
	Sal	-0.09	0.11	-0.30	0.13	***2.06***	0.26	1.53	2.54	***0.79***	0.12	0.55	1.03	0.38	0.29	-0.18	0.95
	Overdisp; r	0.38	0.05	0.29	0.49	0.25	0.04	0.18	0.33	0.08	0.01	0.06	0.10	0.02	fixed		
Detection	**Beaufort 0-2**	***5.19***	0.04	5.12	5.27	***5.61***	0.05	5.52	5.72								
	Beaufort 3-6	***4.56***	0.06	4.45	4.67	***5.54***	0.04	5.46	5.61								

Table 18-8. Bayesian p-values for the abundance and detection components of the models. Values close to 0.5 indicate good model fit.

		Boat				Aerial	
		First year		Second year		First year	Second year
Group	**Sub-group**	**Abundance**	**Detection**	**Abundance**	**Detection**	**Abundance**	**Abundance**
Terns		0.58	0.50	0.51	0.39	0.39	0.58
Gannets		0.66	0.45	0.71	0.75	0.99	0.72
Loons	All	0.5	0.81	0.6	0.99	0.85	0.65
	COLO	0.53	0.55	0.63	0.88	0.42	0.42
	RTLO	0.55	0.62	0.55	0.97	0.51	NA
Alcids		0.52	0.54	0.51	0.58	0.48	0.49

Supplementary Material

Appendix 18A. Evaluating species and habitat associations in a marine bird community, using shipboard and digital video aerial surveys

Abstract

Marine spatial planning efforts have recently brought attention to the need for baseline studies of marine wildlife in relation to proposed offshore wind energy development on the US Atlantic Outer Continental Shelf. From March 2012 to May 2014, we collected line transect data from 16 shipboard surveys, and novel high resolution digital videography data from 15 aerial surveys, off the coast of Delaware, Maryland, and Virginia. We implemented hierarchical models to evaluate the relationships between marine birds and mammals, while accounting for variation in habitat covariates and observed seabird behaviors. We selected six covariates on avian abundance: three static (distance to shore, slope, and grain size), and three dynamic (sea surface temperature, salinity, and marine mammals). We hypothesized that aerial foragers would show positive associations with marine mammals, and found support for this in a subset of surveys and species. Video aerial surveys detected more submerged animals compared to boat surveys, which detected more smaller seabird species and accommodated variability in detection using distance sampling. This resulted in higher abundance estimates than those derived from video aerial surveys. Our results are consistent with a growing body of research suggesting that facilitative interactions occur among pelagic communities, where subsurface predators drive shared prey upwards for increased detectability and accessibility to surface-feeding seabirds. Our study highlights the importance of quantifying behavioral and ecological influences on avian abundance, particularly in predicting the potential exposure of protected marine birds and mammals to offshore development.

Introduction

Over the past few decades, the field of community ecology has evolved from a focus on competition to the function of facilitation in species interactions (Bruno et al. 2003). While negative (competitive) and positive (facilitative) species interactions can co-occur, competition is more likely to dominate when resources are limited, and facilitation may eclipse competition when resources are abundant (Stachowicz 2001). The spatial and temporal patterns of marine habitat and organisms tend to be highly dynamic and aggregated, which can result in areas of limited resources and high interference competition, or ephemeral patches of superabundant resources that promote positive, facilitative species interactions (Camphuysen and Webb 1999; Fauchald et al. 2011; Poysa 1992). Marine birds face the challenging task of searching for inconspicuous prey located below the sea surface. A growing body of research has documented positive associations of high density marine fish, mammals, and birds near the sea surface, where the subsurface predators drive shared prey upwards from deeper strata (Evans 1982; Hebshi et al. 2008; Skov et al. 1995). This has shaped the hypothesis that subsurface predators increase the accessibility and visibility of prey to marine birds, via commensal relationships and local enhancement (Ashmole and Ashmole 1967; Au and Pitman 1986). Local enhancement is a social mechanism by which individuals cue into the act of other foraging for food for improved detectability in an otherwise relatively “featureless” ocean environment (Grünbaum and Veit 2003; Silverman et al. 2004).

We hypothesized that aerial-foraging seabird species would show positive associations with marine mammals at the sea surface in our study area. By aerial foragers, we refer primarily to plunge-divers that usually initiate feeding bouts from the air, thereby excluding species that sit on the water prior to dives (e.g., benthivores such as scoters that dive to the bottom, and pursuit-divers such as alcids and loons that swim across the water column at substantial depths). Aerial foragers such as terns and gannets are highly visual predators and can rely on social foraging cues seen from high flight heights at substantial distances (Haney et al. 1992; Tremblay et al. 2014). Therefore we expected them to associate positively with marine mammals. Several studies have compared shipboard and traditional aerial survey methodologies and shown that boat surveys are better at detecting smaller seabird species (for overview, see Camphuysen et al. 2004). However, aerial observers often perform better at detecting fully submerged animals located at or just below the sea surface (Chapter 5, Chapter 14), so we expected the aerial digital video surveys to show stronger positive seabird-mammal associations.

Methods

Models of tern and gannet abundance used a similar model formulation to that described in the main text of Chapter 18, but also included in the abundance model a covariate of ‘observed marine mammals’ to explore the potential relationship between seabird abundance and marine mammal counts. We used raw counts of marine mammals along each transect segment. For the boat surveys, this included only those observations in the sampled quadrant (forward, on one side of the vessel, extending up to 1 km from the trackline); for the aerial video surveys, observations occurred within a strip width of 200 m. For the boat survey data, we used seabird foraging behavior as a covariate on detection, rather than Beaufort sea state. Foraging behaviors included feeding, diving, pattering, kleptoparasitizing, and milling (i.e., flying along a circular path), while non-foraging behaviors included those classified as traveling (i.e., flying along a straight path) and resting.

As described in Chapter 18, for the boat surveys, we used a Negative Exponential distribution on detection and a Negative Binomial distribution on abundance. The intercept on abundance, however, was behavior-specific, as we observed some differences in detection between foraging and non-foraging individuals. Counts at segment i, $\mathrm{y_i}$, were modeled such that:

$$\mathrm{y_i} \sim \mathrm{NegBin}(\lambda_i,\ r)$$

$$\log(\lambda_i) = \beta_{0,behavior} + offset\ (site\ area) + \ \beta_1 \mathrm{Dst_i} + \beta_2 \mathrm{Slp_i} + \beta_3 \mathrm{Grn_i} + \beta_4 \mathrm{Sst_i} + \beta_5 \mathrm{Sal_i} + \beta_6 \mathrm{Mam_i}$$

where $site\ area$ is the transect segment length multiplied by its width (one km for the boat surveys, 0.2 km for the digital aerial surveys), Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, and Mam = observed marine mammal counts.

For gannets, we used the same formulation as the tern model above, except with a Half Normal detection function and without salinity as a covariate on abundance, due to its co-linearity with SST (especially in the aerial and second year winter boat surveys).

Results

Gannets were more abundant than terns, and accounting for detection resulted in higher estimates in the boat than the aerial video surveys (Table 18A-1). The Negative Binomial distribution fit well to tern and gannet abundance (except for some aerial surveys), the Negative Exponential foraging behavior model fit well to tern detection, and the Half Normal foraging behavior model component fit well to gannet detection (Table 18A-2). Across all boat surveys, foraging individuals had significantly higher detection probabilities, except in the second year boat surveys when non-foraging gannets were more detectable.

Between survey methods, terns and gannets showed comparable patterns in response to the habitat covariates, though this was not true for all parameters. For example, across all summer boat and aerial video surveys, terns associated in close proximity with the shoreline (Table 18A-3). However, SST was found to be significant in the first year of the aerial survey whereas slope and salinity were significant in the second year of the aerial survey. We found that gannets also responded to colder water in all winter surveys except the first year of the boat surveys, when we found no significant relationship (Table 18A-4). We again found some differences between the results for the two survey methodologies, where gannets associated in close proximity with the shoreline across all except the first year aerial video survey, when they showed no significant association with the coast. Gannets responded similarly to all four habitat covariates in the second year aerial and boat surveys, except for the second year boat survey where they associated with coarse sand, rather than with fine sand as in both aerial surveys. During the first year, terns and gannets associated positively with marine mammals (terns in the summer aerial surveys and gannets in the winter boat surveys; Table 18A-3, Table 18A-4).

Discussion

We expected that the aerial video surveys would show stronger positive associations between surface-feeding seabirds and marine mammals than the boat surveys, as a result of better detectability of predators located below the sea surface. Results were not consistent with this hypothesis. Instead, our results suggest that boat and aerial video surveys are both useful in identifying community associations (Camphuysen et al. 2004; Camphuysen and Garthe 2004), and that the information derived from one survey complements that derived from the other, depending on species or survey. For example, in the first year, we found that high abundance of seabirds associated positively with high marine mammal counts, for gannets in the boat surveys and terns in the aerial video surveys. This lends considerable support to our hypothesis for facilitative interactions between these taxa (i.e., via local enhancement and commensalism; Ashmole and Ashmole 1967; Au and Pitman 1986). In the pelagic realm, facilitative and competitive interactions can co-occur, yet vary in degree, depending on scale and resource availability (Fauchald et al. 2011; Goyert et al. 2014; Safina 1990). Presumably, higher densities would stimulate interference competition, especially with limited resources in small prey patches; however, facilitative interactions are feasible when resources are abundant, even at small scales.

Our results suggest that the distributions of resources and marine mammals can drive high abundance of seabirds, which likely associate with suitable habitat until other predators become available to exploit for improved foraging success. Across both seasons and surveys, terns adhered tightly to the shoreline (Chapter 12). Additionally, terns associated with cold water, which could be due to their distribution along the coast, away from the warm Gulf Stream waters on the Outer Continental Shelf. Gannets associated in close proximity with the shoreline across all except the first year aerial video survey; they also responded to cold water in all except the first year boat surveys. Primary productivity increased with proximity to shore in our study region, which suggests that terns and gannets may have associated with marine mammals in productive areas.

Northern Gannets and Common Terns are examples of feeding generalists that rely heavily on social or opportunistic strategies in search of food (Goyert 2015; Montevecchi et al. 2009). As aerial foragers, their use of visual cues and behavioral mechanisms such as local enhancement may be especially advantageous (Goyert 2014; Thiebault et al. 2014; Tremblay et al. 2014; as in Cape Gannets, *Morus capensis*). Spatial or temporal variability (i.e., seasonality) may play a role in whether associations result as positive or negative between seabirds and marine fish or mammals (Goyert et al. 2014). Predictability or persistence of resource hotspots can also drive the formation of facilitative feeding assemblages, as shown in gannets (Davoren et al. 2010). Our results suggest that aerial video surveys complement boat surveys in documenting competitive or facilitative species interactions between marine mammals and birds, with facilitative interactions contributing to increased detectability and accessibility of shared prey. Such dynamic associations between seabirds and marine mammals suggest that their exposure to offshore wind energy development depends on either the persistence or volatility of shared resource hotspots.

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Tables

Table 18A-1. Surveys used in the analysis for each species/group and the abundance of each species/group. Observed (Obs.) refers to raw counts and estimated abundance (Estim.) is the predicted abundance for the sampled transects (summed across the listed surveys).

Year	Boat Surveys			Aerial Surveys			Group	Boat abundance		Aerial abundance	
								Obs.	Estim.	Obs.	Estim.
First	**Jun-12**	**Aug-12**	**Sep-12**	**May-12**	**Jun-12**	**Sep-12**	Terns	534	3,447.33	238	238.50
	Nov-12	**Dec-12**	**Jan-13**	**Oct-12**	**Dec-12**	**Feb-13**	Gannets	3,998	8,962.84	4,190	4189.45
Second	**Jun-13**	**Aug-13**	**Sep-13**	**Jul-13**	**Aug-13**	**Sep-13**	Terns	243	1,751.09	223	223.27
	Oct-13	**Dec-13**	**Jan-14**	**Oct-13**	**Dec-13**	**Feb-14**	Gannets	4,723	11,910.73	1,612	1612.17

Table 18A-2. Bayesian p-values for the abundance and detection components of the models with marine mammals as a covariate. Values close to 0.5 indicate good model fit.

Group	Boat		Boat		Aerial	Aerial
	First year		Second year		First year	Second year
	Abundance	Detection	Abundance	Detection	Abundance	Abundance
Terns	0.59	0.43	0.52	0.42	0.46	0.68
Gannets	0.70	0.42	0.67	0.48	0.99	0.71

Table 18A-3. Parameter estimates by year from the boat and high resolution digital aerial videography for terns. SD is the standard deviation, 2.5% and 97.5% are the respective quantiles, ***r*** is the overdispersion parameter and all abundance parameters are on the log scale.. Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, Mam = marine mammal density, and Beaufort sea state 3-6 are rough seas (as opposed to calm, 0-2). The posterior mean for covariates where the 95% Bayesian credible interval (BCI) does not overlap zero are in bold italics.

Terns		**Boat**								**Aerial**							
		First year				**Second year**				**First year**				**Second year**			
Component	**Term**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**
Abundance	**Intercept (Foraging)**	***-3.2***	0.3	-3.8	-2.5	***-2.5***	0.3	-3.1	-2.0	***-3.1***	0.2	-3.5	-2.8	***-3.9***	0.2	-4.3	-3.5
	Intercept (Not Foraging)	-0.3	0.2	-0.8	0.2	***-1.2***	0.2	-1.7	-0.8								
	Dst	***-1.9***	0.3	-2.5	-1.4	***-1.4***	0.2	-1.8	-1.0	***-1.5***	0.2	-1.9	-1.2	***-2.1***	0.2	-2.5	-1.8
	Slp	-0.2	0.2	-0.6	0.2	-0.1	0.2	-0.4	0.2	0.0	0.1	-0.3	0.2	***0.2***	0.1	0.0	0.3
	Grn	-0.1	0.2	-0.4	0.3	0.3	0.2	-0.1	0.7	0.0	0.1	-0.2	0.3	0.1	0.1	0.0	0.3
	Sst	0.6	0.4	-0.2	1.3	0.1	0.2	-0.2	0.4	***-0.5***	0.1	-0.7	-0.2	0.0	0.1	-0.2	0.2
	Sal	-0.5	0.3	-1.2	0.1	0.0	0.2	-0.4	0.3	-0.2	0.2	-0.6	0.2	***-0.4***	0.1	-0.7	-0.1
	Mam	0.1	0.2	-0.3	0.4	-0.1	0.1	-0.3	0.2	***0.3***	0.2	0.0	0.7	0.1	0.1	0.0	0.2
	Overdisp; *r*	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.2	0.1	0.0	0.1	0.1	0.4	0.1	0.3	0.7
Detection	**Foraging**	***5.7***	0.2	5.4	6.0	***5.2***	0.1	5.0	5.5								
	Not Foraging	***5.0***	0.1	4.9	5.1	***4.8***	0.1	4.7	5.0								

Table 18A-4. Parameter estimates by year from the boat and high resolution digital aerial videography for gannets. SD is the standard deviation, 2.5% and 97.5% are the respective quantiles, r is the overdispersion parameter, and all abundance parameters are on the log scale (from the count process). Dst = distance to shore, Slp = slope of the seafloor, Grn = sediment grain size, Sst = sea surface temperature, Sal = salinity, Mam = marine mammal density, and Beaufort sea state 3-6 are rough seas (as opposed to calm, 0-2). The posterior mean for covariates where the 95% Bayesian credible interval (BCI) does not overlap zero are in bold italics.

Gannets		**Boat**								**Aerial**							
		First year				**Second year**				**First year**				**Second year**			
Component	**Term**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**
Abundance	**Intercept (Foraging)**	***-0.6***	0.1	-0.9	-0.4	***0.4***	0.1	0.2	0.7	-0.1	0.1	-0.3	0.0	***-0.8***	0.1	-0.9	-0.7
	Intercept (Not Foraging)	***0.7***	0.1	0.4	0.9	***0.6***	0.1	0.3	0.8								
	Dst	***-1.4***	0.1	-1.6	-1.2	***-1.0***	0.1	-1.2	-0.8	0.1	0.1	0.0	0.3	***-0.8***	0.1	-0.9	-0.6
	Slp	-0.1	0.1	-0.3	0.2	***0.3***	0.1	0.1	0.5	-0.1	0.1	-0.2	0.0	***0.3***	0.1	0.2	0.4
	Grn	0.1	0.1	-0.1	0.2	***-0.3***	0.1	-0.6	-0.1	***0.2***	0.1	0.1	0.3	***0.1***	0.1	0.0	0.3
	Sst	0.0	0.1	-0.2	0.2	***-0.7***	0.1	-0.9	-0.6	***-1.9***	0.1	-2.0	-1.7	***-0.6***	0.1	-0.8	-0.5
	Mam	***0.4***	0.1	0.2	0.7	0.2	0.1	0.0	0.5	-0.2	0.2	-0.6	0.1	0.0	0.2	-0.4	0.5
	Overdisp; r	0.2	0.0	0.1	0.2	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.2	0.1	0.0	0.1	0.2
Detection	**Foraging**	5.9	0.0	5.9	6.0	5.4	0.0	5.4	5.5								
	Not Foraging	5.9	0.0	5.8	5.9	5.9	0.0	5.8	5.9								