

Chapter 13: Comparison of boat and aerial models of seabird abundance with environmental covariates

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Beth Gardner¹, Holly F. Goyert¹, Nathan J. Hostetter¹, Andrew T. Gilbert²,
Emily E. Connelly², and Melissa Duron²

¹North Carolina State University, Department of Forestry and Environmental Resources, Raleigh, NC

²Biodiversity Research Institute, Portland, ME

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Chapter 13 Highlights

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

Context¹

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 Chapter 9, but with single species instead of a community. The digital aerial data are modeled similarly to Chapter 12, but using generalized linear models rather than generalized additive models.

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 14 builds upon these results and examines an integrated modeling approach for these taxa.

Study goal/objectives addressed in this chapter

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 Northern 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.

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 (e.g., Chapter 9) 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 to make the models as similar between survey types and species as possible and facilitate direct comparisons. The surveys have some spatial and temporal mis-match, 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 Northern 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 saw 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 an integrated model, presented in Chapter 14.

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 high resolution digital video 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 Northern 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 high intensity surveys over Maryland waters as compared to the Mid-Atlantic Baseline Studies project area to see if there are regional differences in habitat responses (not complete; see Future Work section for preliminary analyses).

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

One wind energy area (WEA) is designated within the Maryland study area (MD), with two additional WEAs in the broader Mid-Atlantic Baseline Studies (MABS) project area, located off the coasts of Delaware (DE) and Virginia (VA; Figure 13-1). Field methods for the video aerial and boat surveys are

explained elsewhere in this report (Chapters 3 and 6, respectively). Aerial identification protocols for video analysis are discussed in Chapter 4. For this comparison, we used boat and video aerial survey data collected over the entire MABS study area (including the Maryland Project surveys), and did not separately examine data collected within the Maryland study area. 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 video aerial surveys, we divided survey transects into 4 km segments ('sites'); this resulted in some shorter segments at the transect ends, so site area was included as an offset in our analysis. The number of individuals for each species was summed by 4 km segment per survey (defined as the time period over which the entire MABS study area was sampled). Many species, including terns, Northern Gannets, and loons, are seasonally present in the region or observed in low numbers, so specific surveys were combined within each year for analysis but varied depending on the species. We compared Northern 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 collinear 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 ($\phi = -\log_2[\text{mean grain diameter in mm}]$, 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 GHRSSST 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 (Buckland et al. 1993). 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, as in Sollmann et al. (2015) and Chapter 9, so that we could compare parameters directly with the video 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 MABS study area during spring, summer and fall (Chapters 5, 7, and 9), so we compared three boat and two video aerial surveys from June 2012 – September 2012 (first year), and June 2013 – September 2013 (second year, excluding the August 2013 aerial survey, which 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 video aerial surveys was constructed such that each count of terns at segment i , y_i , was modeled as:

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

$$\log(\lambda_i) = \beta_0 + \text{offset}(\text{site area}_i) + \beta_1 \text{Dst}_i + \beta_2 \text{Slp}_i + \beta_3 \text{Grn}_i + \beta_4 \text{Sst}_i + \beta_5 \text{Sal}_i$$

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.

Northern Gannets

The only gannets in the area are Northern Gannet (*Morus bassanus*), thus we only included one species in this model. Northern Gannets were primarily present in the MABS study area in late fall to early spring (Chapters 5, 7, and 9), so we compared three boat and three video aerial surveys from October 2012 – February 2013 (first year), and October 2013 – February 2014 (second year). For the Northern Gannet models we used a Negative Binomial distribution for abundance, and a half-Normal distribution for detection (only in the boat survey models). The abundance component of the model for both boat and video aerial surveys was constructed such that each count of Northern Gannets at segment i , y_i , was defined:

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

$$\log(\lambda_i) = \beta_0 + \text{offset}(\text{site area}_i) + \beta_1 \text{Dst}_i + \beta_2 \text{Slp}_i + \beta_3 \text{Grn}_i + \beta_4 \text{Sst}_i$$

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 collinear 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. Loons were primarily present in the MABS study area from late fall to early spring (Chapters 5, 7, and 9), so we included three boat and three video 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 video aerial surveys was constructed such that each count of loons at segment i , y_i , was defined:

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

$$\log(\lambda_i) = \beta_{0, \text{survey}} + \text{offset}(\text{site area}_i) + \beta_1 \text{Dst}_i + \beta_2 \text{Slp}_i + \beta_3 \text{Grn}_i + \beta_4 \text{Sst}_i + \beta_5 \text{Sal}_i$$

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 MABS study area during winter (Chapters 5, 7, and 9), therefore we compared two boat and two video 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 video aerial surveys we defined the counts of alcids at segment i , y_i , such that:

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

$$\log(\lambda_i) = \beta_0 + \text{offset}(\text{site area}_i) + \beta_1 \text{Dst}_i + \beta_2 \text{Slp}_i + \beta_3 \text{Grn}_i + \beta_4 \text{Sst}_i + \beta_5 \text{Sal}_i$$

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 video 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 is a relatively small sample size for the number of parameters we are interested in; this particular model requires further exploration.

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 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 within the MABS study area.

Results

Overall, we found that fewer individuals were observed on the video aerial surveys than the boat surveys for smaller species (e.g., terns, alcids), and the observations varied by survey date, year, and species (Table 13-1). Accounting for detection resulted in higher abundance in the boat than the video aerial surveys, which carried through to the predicted number of birds in each of the WEAs. In Year 1, the estimated number of Northern Gannets was very similar for the boat and video aerial surveys, with the Virginia WEA having a lower predicted number of birds from the boat survey than the aerial (Table 13-1). 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 0 birds from the boat survey, though 127 alcids were predicted to the entire MABS study region (Table 13-1). 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). Predicted abundance within the Maryland WEA for both boat and video aerial surveys were generally similar to predicted counts within the Virginia and Delaware WEAs (Table 13-1). Boat and aerial counts for the MD WEA showed similar patterns by year and species group, though aerial predictions for the MD WEA were consistently lower than boat predictions for the same years and species.

Across both the boat and video aerial surveys, proximity to shore was the most important predictor of abundance. The abundance of terns, Northern Gannets, and loons increased with proximity to shore (Table 13-2 through Table 13-6). Alcids associated more closely with the shoreline in Year 2, but they were farther from shore in Year 1 boat surveys (Table 13-7). The detectability of terns, loons, and alcids decreased as seas became rougher, whereas Northern Gannets showed no change in detectability in Year 1, and an opposite effect in Year 2 (Table 13-2 through Table 13-7).

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 13-2); 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 Northern 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 13-3). Northern Gannets were significantly related to all four habitat covariates in the second year of surveys, with similar parameter estimates between all models 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 Northern Gannets and terns; however, it is useful to note that there were some differences when using species-level data (Table 13-4 to Table 13-6). For example, in Year 2 of the aerial survey, only one Red-throated Loon was identified, while there were 2062 total loon observations (Table 13-1). 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 13-5). Looking at the boat survey results for year 1, Red-throated Loons had significant negative effects of distance to shore, slope, and salinity (Table 13-6); Common Loons also had a significant negative effect of salinity, but additionally a positive effect of sea surface temperature (Table 13-5). 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 13-4). 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 13-5), Red-throated Loons had a significant negative effect of distance to shore (Table 13-6), and all loons had a significant negative effect of distance to shore and a positive effect of sea surface temperature (Table 13-4). 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 13-8); the aerial data for the Northern Gannets and the combined loons did not fit very well, and thus other distributions may be explored in these cases. Further 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 primary driver of abundance in this study. Chlorophyll concentration also increased with proximity to shore and was not included due to this collinearity, which suggests that distance to 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 video aerial surveys, taking effort into account. The total length of an aerial survey's transects (3,613 km including the Maryland extensions, Chapter 3) is much greater than in a boat survey (571 km including the Maryland extensions, Chapter 6). 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 video 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 estimating detection bias is important for smaller species.

Detection decreased with increased sea state for all species except Northern 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 Northern Gannets in rough seas was a result of differences in behavior, as Northern Gannets are less likely to sit on the water during rough seas, and flying Northern 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 Northern 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 areas 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 video aerial survey. However, Red-throated Loon data from the video aerial surveys should be interpreted with caution, since many Red-throated Loons were not identified to species (Hostetter et al., 2015), 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 9), but the first year video aerial surveys showed an association only with warmer water, which may be a result of collinearity 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 9), (2) Northern Gannets across three of the four models (Chapter 9), 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 Northern 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 video 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 video 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 video 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 collinearity). Additionally, testing the impacts of localized habitat on the results for the entire MABS 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 14. There are a number of approaches that can be taken when developing a joint model, and we will continue to pursue these options in future work. 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.

Recent studies have shown that species in disparate locations can respond very differently to habitat covariates, even in study areas that are in close proximity (Flanders et al. 2015). When enough observations are recorded for a species, a reduced area or ‘regional’ model can be fit, though this is not common, as marine birds tend to be sparsely distributed over large regions of the ocean. This ‘regional’ type model is likely possible for a few select species groups in the Maryland study area, because of the high intensity of aerial surveys in the MD WEA and surrounding waters. Using the same model described above, we conducted a simple preliminary analysis of the high density aerial surveys in the Maryland study area for terns, Northern Gannets, and loons observed in year 2 (when the high-density coverage was expanded in Maryland; only data from the MD WEA and MD extension transects were included). Alcids were not included in this because only 7 observations were made in Maryland waters in year 2 (Table 13-9). For the tern analysis, we included the August 2013 survey, which covered exclusively Maryland waters; we also added this survey to the MABS analysis, so that the two were more directly comparable. Terns had a similar number of observations between the MABS and MD study areas (Table 13-9), suggesting that most terns were observed in MD waters; this likely resulted in the two models (MABS and MD only) having similar parameter estimates (Table 13-10). Northern Gannets and loons had a reduced number of observations in MD waters, which is expected given that this was a subset of the full data (Table 13-9). The reduction in data, i.e., number of observed birds, along with what are likely regional effects due to different sampled areas, resulted in differences for the two species between the two models (Table 13-10). For example, in MD waters, loons did not show a significant response to distance to shore, and showed an opposite response to grain size (Table 13-10). These results suggest that while there are some main consistencies between the larger MABS study area and MD waters, there may be some fine scale variation that is important for making localized decisions. In this latter case, and when the data are sufficient, further exploration of regional or local models may prove useful in determining the sources of fine scale variation in seabird abundances.

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Figures and tables

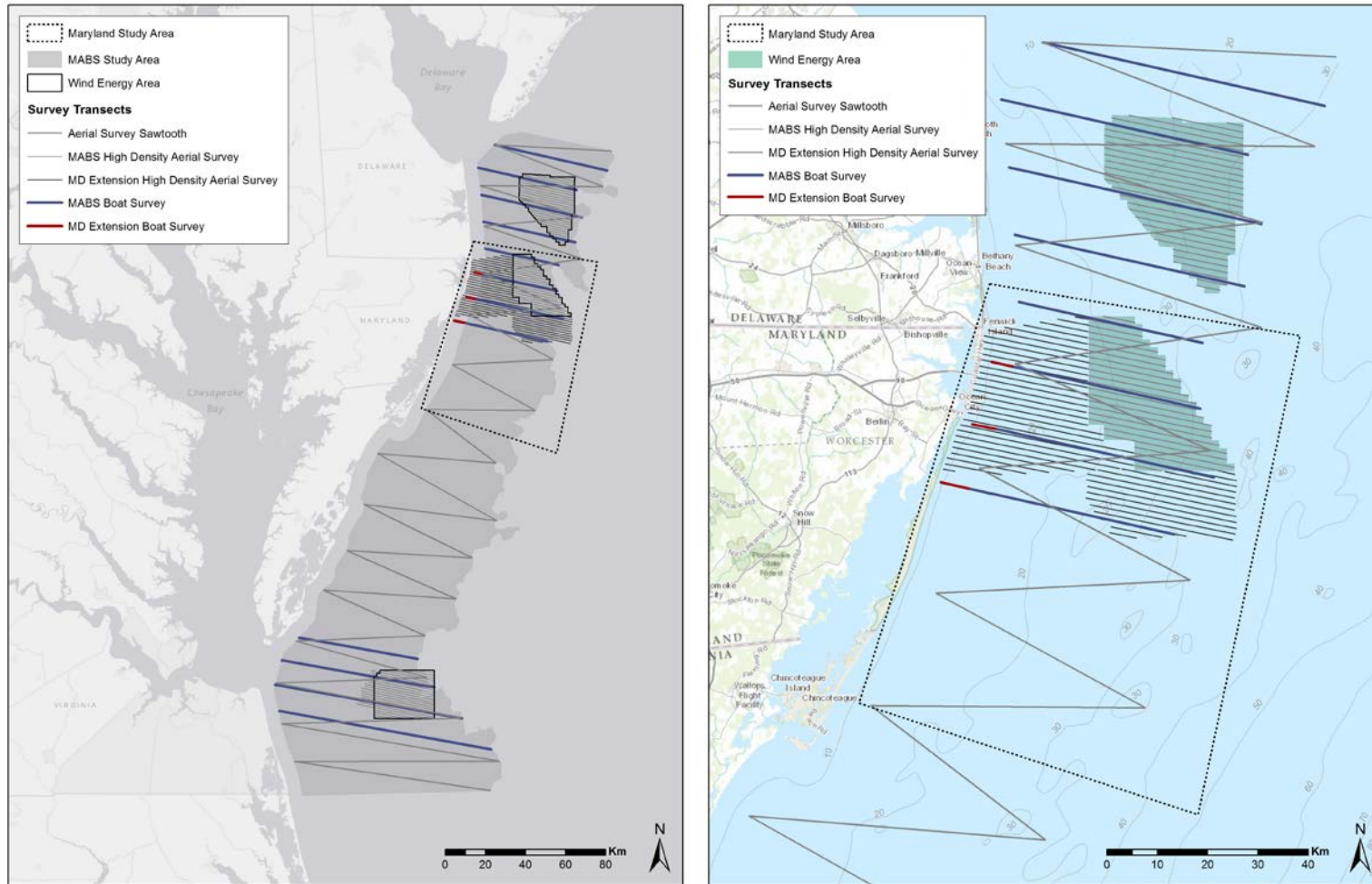


Figure 13-1. Boat and aerial survey transects for the Mid-Atlantic Baseline Studies (MABS) and Maryland Projects. The broader Mid-Atlantic study area, or MABS study area (left), includes surveys funded by both DOE and Maryland (2012-2014). The “Maryland study area” (right, black dashed line) includes all boat and aerial survey transects in waters offshore of Maryland (both DOE and Maryland-funded surveys, 2012-2014). The Maryland Project surveys are a subset of the surveys within the Maryland study area that were specifically funded by the state of Maryland in 2013-2014. These surveys included boat survey extensions into state waters (red bars), aerial survey high-density transect extensions west and south of the Maryland WEA (charcoal lines), and a 15th aerial survey of the Maryland WEA and Maryland extension high-density transects in 2013.

Table 13-1. 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 **Northern Gannets**, loons, alcids) in each wind energy area (WEA) by state: Delaware (DE), Maryland (MD), and Virginia (VA). ^aPredictions 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	419.3	412.8	152.2
	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 13-2. 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, 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	<i>-0.94</i>	0.21	-1.33	-0.53	<i>-3.81</i>	0.24	-4.31	-3.36	<i>-4.18</i>	0.26	-4.70	-3.70
	Dst	<i>-1.96</i>	0.33	-2.64	-1.35	<i>-1.42</i>	0.20	-1.83	-1.05	<i>-1.61</i>	0.22	-2.05	-1.19	<i>-2.14</i>	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	<i>0.37</i>	0.13	0.13	0.63
	Sst	0.62	0.37	-0.10	1.33	0.17	0.16	-0.15	0.49	<i>0.64</i>	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; <i>r</i>		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
Detection	Beaufort 0-2	<i>5.25</i>	0.07	5.12	5.38	<i>5.16</i>	0.09	5.00	5.33								
	Beaufort 3-6	<i>4.84</i>	0.07	4.70	4.98	<i>4.46</i>	0.11	4.24	4.68								

Table 13-3. Parameter estimates by year from the boat and high resolution digital video aerial surveys, using a Negative Binomial distribution to model counts of Northern 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	-0.93	-0.68
	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	-0.79	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	0.06	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	0.12	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 13-4. 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; <i>r</i>		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 13-5. 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.

Common 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)	-0.94	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 13-6. 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.

Red-throated 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)	-0.99	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; <i>r</i>		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
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 13-7. 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.

Alcids		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	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; <i>r</i>		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 13-8. Bayesian p-values for the abundance and detection components of the models. Values close to 0.5 indicate good model fit.

Group	Sub-group	Boat				Aerial	
		First year		Second year		First year	Second year
		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

Table 13-9. Observed values in the digital aerial surveys for year 2, comparing the larger study area (MABS) to surveys of Maryland (MD WEA and MD extension transects). Note the tern analysis here includes the August 2013 surveys.

Group	MABS	MD
Terns	223	155
Gannets	1612	506
Loons	2062	423
Alcids	102	7

Table 13-10. Parameter estimates for terns, gannets, and loons for the larger study area (MABS) and surveys including only Maryland (MD WEA and MD extension transects). Estimates considered significantly different from 0 are in bold. All results are for the same seasons as Table 13-1, but only the aerial data for the second year results are shown here. For this analysis of terns, we included the August 2013 survey because it included all of the Maryland waters (the survey is also included in the MABS study area analysis, which changed the parameter estimate slightly from those presented in Table 13-1). Salinity was not included in the Northern Gannet model.

Term	Terns				Gannets				Loons			
	MABS		MD		MABS		MD		MABS		MD	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Intercept; α_0	-3.88	0.21	-2.86	0.22	-0.80	0.06	-0.62	0.10	-0.21	0.04	-0.54	0.07
Dst; α_1	-2.17	0.17	-1.77	0.17	-0.79	0.07	-0.74	0.11	-0.23	0.04	0.00	0.08
Slp; α_2	0.16	0.08	0.27	0.10	0.26	0.06	0.13	0.09	-0.15	0.04	-0.11	0.07
Grn; α_3	0.13	0.09	0.07	0.09	0.15	0.06	0.03	0.09	0.11	0.04	-0.21	0.07
Sst; α_4	0.03	0.1	-0.19	0.14	-0.65	0.08	-0.62	0.12	-0.41	0.04	-0.42	0.07
Sal; α_5	-0.42	0.14	-0.43	0.14	-	-	-	-	0.16	0.04	-0.05	0.06
Overdisp.	0.43	0.09	1.02	0.46	0.14	0.01	0.19	0.02	0.49	0.03	0.83	0.15