Chapter 15: Density modeling for marine mammals and sea turtles with environmental covariates

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Chapter 15 Highlights

Density modeling for marine mammals and sea turtles

Context[1]

Part IV of this report contains several instances in which boat survey and digital video aerial survey datasets were modeled with environmental covariates to describe populations of interest (Chapters 15-16, 18-19). Cetaceans and sea turtles are taxa of regulatory and conservation concern in the mid-Atlantic region. By combining boat and aerial survey data for these taxa with remotely sensed environmental data, we can use spatial-temporal modeling methods to estimate habitat influences on distributions and relative abundance, and explore potential overlap with offshore human interests, including Wind Energy Areas (WEAs). In some cases, one survey method was significantly better than the other for surveying a particular taxon, as with digital video aerial surveys for sea turtles. Both boat and aerial surveys were suspected to inaccurately estimate group size for cetaceans, so models were developed to identify patterns of occurrence of delphinid pods, rather than abundance of individual animals.

Study goal/objectives

Describe the distributions of cetaceans and sea turtles across the mid-Atlantic Outer Continental Shelf using boat and aerial survey data.

Highlights

- At least five different species of dolphins and porpoises were observed in surveys. Five species of baleen whales were also observed, including nine North Atlantic right whales.
- Bottlenose dolphins were observed primarily in more nearshore areas in spring through fall. Primary productivity and sea surface temperature were also important predictors; models suggest minimal presence of the species in mid-Atlantic WEAs during cooler months.
- Common dolphins were most frequently observed in offshore areas in winter and early spring.
- Five species of sea turtles were observed in boat and aerial surveys.
- Turtles were much more frequently observed in digital aerial surveys than in boat surveys.
- Sea turtles were most abundant from May to October. In addition to water temperature, primary productivity and distance from shore were important influences, and sea turtles were primarily distributed offshore. There was substantial overlap with the Virginia WEA in the spring and overlap with the more northern WEAs when turtles were more broadly distributed in the summer and fall.

Implications

Small sample sizes made modeling difficult for some taxa, but results suggest that there may be seasonal overlap between cetacean and sea turtle distributions and WEAs in the mid-Atlantic. Given the protected status of these species, additional research on their distributions may be indicated, as well as the development of potential approaches for mitigating the effects of wind power development.

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

Abstract
Marine mammals and sea turtles are often of management and conservation concern, and effective management of these large marine vertebrates requires reliable information on distribution, abundance, and trends in habitat use. This chapter utilizes observation data of cetaceans and sea turtles from boat and digital video aerial surveys to describe the distributions of these taxa across the mid-Atlantic Outer Continental Shelf, determine the habitat or environmental drivers of these distributions, and identify the locations and timing of potential overlap with Wind Energy Areas (WEAs). Dolphin, porpoise, whale, and sea turtle observations from boat and aerial surveys were assessed for species composition, relative numbers, and geographic and temporal distributions. Relative density estimates were produced for sea turtles (using digital video aerial survey data) and bottlenose dolphins (using boat survey data) using both general linear and general additive models (GLMs and GAMs, respectively). For both bottlenose dolphins and sea turtles, GAMs proved more effective at modeling the density of these animals with relation to spatial covariates then their counterpart GLMs. Bottlenose dolphins were observed primarily in more near shore areas in spring, summer, and fall, in areas with high levels of primary productivity and higher sea surface temperatures. There were few observations of the species during cooler months. Sea turtles were also most abundant from May to October, and their densities were correlated warmer water temperatures and farther distances from shore. There was substantial overlap between sea turtle distributions and WEAs, particularly in the southern part of the study area. There was also overlap between WEAs and predicted habitat usage of bottlenose dolphins and other delphinids, although the degree of this overlap was difficult to discern with the datasets used in this analysis.

Introduction
Marine mammals and sea turtles are often of management and conservation concern, as their large home ranges and habitat requirements tend to overlap and conflict with human activities such as offshore development and commercial fishing (Trites et al. 1997). Offshore explorations for oil and gas development have boomed in the United States since the 1970s (Boesch and Rabalais 1987). In recent years, it has become clear that the United States has a huge domestic resource for offshore wind energy as well. However, as these explorations have progressed, we have come to realize that these proposed development areas often occur in a very “busy” medium, as these energy resources are often located in areas where many other offshore uses occur (including important commercial fisheries, shipping lanes, recreational areas, and military areas, as well as areas of ecological importance).

Cetaceans (whales, dolphins, and porpoises) and sea turtles represent a particular challenge for population monitoring, due to their vast ranges and cryptic behaviors, resulting in only small portions of the animals’ bodies being visible (Hammond et al. 2002). However, the conservation and management of these large marine vertebrates requires reliable information on distribution, abundance, and trends in habitat use, and quantitative research is essential for overcoming these challenges. Acoustic disturbance has been recently identified as a primary concern for marine mammals and sea turtles within the marine environment (Dow Piniak et al. 2012; Bergström et al. 2014). This includes such noises as shipping, seismic surveys, blasting, pile driving, and operational wind turbines. The severity of avoidance and displacement effects appear to vary with a variety of factors, including the species being exposed as well as the frequency, intensity, and duration of noise (Goold 1996; McCauley et al. 2000; Madsen et al. 2002). These disturbances may not only deter marine species from development areas, but have the potential to be detrimental to the animals in other ways as well, including a variety of behavioral, acoustical, and physiological effects (Nowacek et al. 2007; Southall et al. 2007; Tyack et al. 2011). Current mitigation practices include "exclusion zones" around activities such as the operation of naval sonar that may cause physiological stress or other responses, to address the potential for non-displacement effects. It has been suggested that larger exclusion zones may be needed for some activities, locations, or populations, particularly for beaked whales (Wright et al. 2011). The expansion of these exclusion zones during certain development activities may be one tool marine construction operators could use to mitigate such effects.

The mid-Atlantic Outer Continental Shelf (OCS) is of key importance to many large marine species during both breeding and nonbreeding periods. This region also acts as a key migration route for one of the most sensitive and protected marine mammals, the North Atlantic Right whale (Kenney et al. 2001). The most recent marine mammal stock assessment reports (SARs) for the North Atlantic place 13 cetacean and three pinniped species within the OCS study area, all of which are protected under the Marine Mammal Protection Act (Waring et al. 2011; Waring et al. 2013). It is also important to note that sound travels long distances underwater, and just to the east of the study area (over the shelf break), a whole new range of deep diving cetaceans such as sperm and beaked whales that are highly sensitive to marine noise may also be exposed to development noise from the study area (Mate et al. 1994; Cox et al. 2006). Furthermore, five of the seven extant species of sea turtle occur in the mid-Atlantic OCS, and all five are protected under the Endangered Species Act. The abundance of large marine megafauna within the mid-Atlantic OCS makes it a potentially sensitive and challenging location for offshore development.

Given the difficulties associated with estimating animal abundance (or occurrence) based on count data from large-scale surveys (Royle et al. 2007), modeling spatial and temporal distributions of animals can help to determine areas of high and low use and inform decisions for development (Garthe and Hüppop 2004; Kinlan et al. 2012). However, distributions of animals in the offshore environment can be highly variable, and are driven by environmental and biophysical factors working at a variety of temporal and spatial scales (O'Connell et al. 2009; Zipkin et al. 2010). By combining boat and aerial survey data with oceanographic habitat and climatological data, we can use spatial-temporal modeling methods to estimate these habitat influences on the distributions and relative abundances of a species of interest, and explore potential overlap with offshore human interests. Accurately assessing such relationships is essential for predicting spatial distributions and the potential shifts that could occur in these geographic distributions. In this study, we quantify sea turtle and marine mammal densities seasonally throughout the study region; develop models to examine spatial patterns and trends based on interactions with environmental conditions; and help identify species at potential risk from turbine construction and operation due to their movements, behavior, or migration strategies.

Methods

Survey methods

Standardized boat-based surveys are a widely used method of obtaining density estimates for birds, sea turtles, and marine mammals (Thompson and Harwood 1990). In our boat-based surveys, transects extend perpendicularly to the coastline, from three nautical miles offshore to the 30 m isobath or the eastern extent of the mid-Atlantic WEAs, whichever was furthest. Boat transects were spaced 10 km apart and extend at least one transect north and south of each WEA (Figure 15-1 to Figure 15-3). We conducted eight surveys per year on a scheduled basis as the weather allowed, between April 2012 and April 2014. Eight of the 16 surveys (from March 2013 to February 2014) also included extensions of three transects farther west into Maryland state waters. Two pairs of observers alternated 2-h shifts collecting standard strip- and line-transect data using distance sampling (Buckland et al. 1993). While the recorder entered data into the program dLOG (R.G. Ford Consulting, Inc.), and regularly updated changes in environmental conditions (sea state, etc.), the observer scanned the horizon, focusing on one forward quadrant on either side of the vessel. We continuously recorded the species, count, distance, and angle to the observation (see Chapter 7 for more details on data collection methods). Cetaceans were photographed when possible. Photos were submitted for individual identification using the established North Atlantic fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*), and North Atlantic right whale (*Eubalaena glacialis*) catalogues. Surveys were conducted in “passing mode,” meaning that the boat stayed on transect and at constant survey speed (10 knots) except when complying with National Marine Fisheries Service (NMFS) rules about approaching marine mammals, including rules regarding vessel speed and encounters with endangered North Atlantic right whales.

Fifteen high resolution digital video aerial surveys were conducted by HiDef Aerial Surveying, Ltd. (hereafter HiDef) between March 2012 and May 2014 (Chapter 3). Each survey was completed using two small commercial aircraft, allowing complete coverage of the study area in two to three days (weather permitting). Aerial transects were flown at high densities within the Delaware, Maryland, and Virginia WEAs to obtain accurate abundance estimates within these specific footprints; additional high density transects were added adjacent to the Maryland WEA in the second year of surveys. The remainder of the study area was surveyed on an efficient sawtooth transect path to provide broad-scale context for the intensive WEA surveys (Figure 15-4 to Figure 15-6). Recorded images were stored on heavy duty disk drives or solid state recording devices for subsequent review and analysis. Wildlife locations, taxonomic identities, and behaviors were determined from the video footage (Hatch et al. 2013).

Data preparation

Boat-based and aerial survey observations of marine mammals and sea turtles are summarized in Table 15-1 and Table 15-2. All animals not identified to the species level were combined into an “unidentified” category. Due to the lack of data at the species level for the aerial surveys, sea turtle observations were grouped as a single taxon for all further analyses by season (Spring: Mar.-May, Summer: June-Aug., Fall: Sept.-Nov., Winter: Dec.-Feb.). The number of whale sightings from both surveys (n=51) was not sufficient to produce descriptive models, and thus this taxon was excluded from further analysis.

Effort and species observation data were modeled using the “count” method (Hedley et al. 1999). Boat and aerial survey track lines were divided into segments approximately 5 km in length. Start and end locations of these segments were calculated using the COGO proportions function in ArcMap 10.2 (ESRI 2011). The location of the midpoint of each segment (latitude and longitude) was calculated using the feature to point command in ArcMap 10.2.

Oceanographic processes were evaluated as spatial covariates to predict marine mammal and sea turtle location and density. Sea surface temperature (SST) and chlorophyll a (Chl a), were extracted using the Marine Geospatial Ecology Toolbox (MGET) data products function in order to provide spatial coverage across the study area (Roberts et al. 2010). SST and Chl a data were extracted a monthly average, for all twelve months, at a 4 km spatial resolution. The monthly averages were then averaged by season. Additionally, the distance from shore (DFS) from each transect segment’s midpoint to the nearest coastline was calculated (ESRI 2011).

Modeling detection probability

A conventional stratified analysis was conducted on the boat-based survey data in program DISTANCE to estimate the probability of detecting delphinids within a 5% truncation of the trackline (Laake 1994). In standard distance sampling a truncation limit of the largest distances, generally 5%, is set to avoid a size bias and increase the estimation of the detection function. Detection probability of bottlenose dolphin (*Tursiops truncatus*) encounters across seasons was modeled at the species level as a smooth function of perpendicular distance. Common dolphin (*Delphinus delphis*), unidentified dolphin, and sea turtle sightings were not included in this distance analysis due to the lack of total individuals. The sightings included in the line transect distance analysis only included those within the front 180 degree observation window from the boat, and thus effective strip width was used to calculate relative density of bottlenose dolphin encounters. Encounters of bottlenose dolphin groups (rather than individuals) were modeled due to uncertainty in group size estimates arising from “passing mode” surveys. Relative density modelling was stratified by season for spring, summer and fall (Figure 15-7 to Figure 15-9), as there were not enough sightings of bottlenose dolphins in winter. Candidate forms for the detection function were the half-normal model and hazard rate function with a cosine smoothing term (Buckland et al. 2001). Sea state, as recorded by observers on the Beaufort scale, was not included as a candidate covariate as no plausible detection functions were produced. Models were selected using Akaike’s Information Criterion (AIC; Akaike 1973).

Aerial transects were treated as strip transects, whereby density was determined as the number of sightings per transect length of 5km and strip width of 200m, and detection was assumed to be perfect (Buckland et al. 2005). Relative density estimates from the aerial transects were only produced for sea turtles by season for spring, summer and fall, as there were not enough sea turtle sightings during the winter aerial surveys. Species-specific aerial density estimates for marine mammals were not modelled due to the small sample size of individuals identified at the species level. Furthermore, a general “all delphinids” model was not run due to the challenges that arise by lumping multiple species that have distinct behaviors.

Building descriptive models

The covariates for each 5 km boat and aerial transect midpoint were joined with their corresponding density and input into R for model fitting. For the purposes of this study, both general additive models, or GAMs (using R package mgcv), and general linear models, or GLMs (using the built-in glm R function), were used in model development following a negative binomial family fitting response (Wood 2006; Dobson and Barnett 2011; R Core Team 2014). Both model outputs were a result of different combinations of covariates. Seven different models were used for each model type (Table 15-4 to Table 15-9). The selection of the best model was based according to the AIC score and the percent of deviance from the null model that the model explained (Table 15-4 to Table 15-9). The higher the percent of deviance explained from the null model, the better that particular model fits the input data. In cases where the AIC values of two models were very similar, the percent deviance was solely used as the deciding criterion for model selection.

Once a model had been chosen according the selection criterion above, a 4 km square gridded data set was created for each season to act as the predicting platform for the model results. This platform extended 25-30 km east of the WEAs, 30 km south of the VA WEA and 75 km north of the DE WEA. Every grid cell centroid was assigned a distance to shore value, as well as SST and Chl a values extracted from seasonal climatologies using the MGETs data products toolbox in ArcGIS (Roberts et al. 2010). The seasonal prediction grids were then passed to the chosen descriptive model for bottlenose dolphins and sea turtles using the predict.gam command in R. The estimated encounter rates from the bottlenose dolphin detection functions and the calculated relative density of sea turtles per strip segment were used as the model response variables. The output of the model was an estimate of the predicted relative density at 1 km^2 at the center of each grid cell according to the variables used in the chosen model. These predicted densities were scaled according to the 16 km^2 prediction grid, imported in ArcMap 10.2 as a raster data set, and smoothed using the point to raster conversion function (ESRI 2011). Missing (white) cells in the interpolated relative density maps indicate areas where no covariate data were available or the prediction grid limits ended.

Results

A total of 374 marine mammal and sea turtle sightings were reported in boat-based surveys, representing 1,349 individuals. Of these, 1,211 individuals were identified to the species level (Table 15-1). Of all observed marine mammal and turtle individuals, 1,200 were dolphins, 35 were whales, and 114 were sea turtles (Table 15-1). A total of 3,808 individual marine mammals and sea turtles were observed during the aerial surveys (Table 15-2). Of these, 2,036 were dolphins, 3 were porpoises, 16 were whales, 5 were unidentified cetaceans, and 1,748 were sea turtles (Table 15-2). Locations of whales, dolphins, and sea turtles observed on the boat survey are presented in Figure 15-1 to Figure 15-3. Locations of whales, dolphins, and sea turtles observed on the aerial surveys are presented in Figure 15-4 to Figure 15-6. Aerial survey observations were highest in May and July (Table 15-3). Humpback whales were the most common large whales observed, and five species were observed overall (Table 15-1 and Table 15-2). Bottlenose dolphins were the most common of the four delphinid species observed, and were observed mainly inshore (Table 15-1, Table 15-2, Figure 15-2, Figure 15-5). Common dolphins were the next most abundant species, and were more commonly observed offshore

(Figure 15-2, Figure 15-5). Sea turtle distributions were primarily offshore (Figure 15-3, Figure 15-6), and loggerhead sea turtles (*Caretta caretta*) were the most abundant of the five species observed (Table 15-1, Table 15-2).

In all cases, GAMs outperformed GLMs (Table 15-4 to Table 15-9). The encounter rate (number of sightings per kilometer squared) model for bottlenose dolphins in the spring predicted a strong nearshore-oriented density gradient within the prediction area, and the corresponding density map correlated well with the bottlenose sighting data spatially. The highest predicted encounter rates were at the mouth of the Delaware Bay (Figure 15-10), as well as near the western edges of the Delaware and Maryland WEAs. The encounter rate model for bottlenose dolphins in the summer predicted very strong nearshore-oriented, northerly concentrated density gradient in and around the mouth of the Delaware Bay (Figure 15-11), including a density of encounters near the western edges of the Delaware and Maryland WEAs. Like the spring model, the encounter rate model for bottlenose dolphins in the fall predicted a strong nearshore-oriented density gradient along the prediction area, with the highest densities seen farther south at the mouth of the Chesapeake Bay (Figure 15-12). The fall model predicted no substantial encounter overlap with any of the WEAs.

The relative density model for sea turtles in the spring predicted a very strong off shore-oriented, southern density gradient (Figure 15-13), including high densities within the Virginia WEA. The density model for sea turtles in the summer predicted a less dense gradient across the southeastern portions of the study area, including areas near and within the Virginia WEA (Figure 15-14). In the summer density map, the relative density of sea turtles also begins to migrate north. The predicted density model for sea turtles in the fall predicted a less dense, latitudinally uniform density gradient (Figure 15-15). The corresponding fall density map predicted high densities within all three WEAs.

Discussion

Effective conservation plans require precise assessments of the spatial distributions and densities of the species they are trying to protect. With such information, policy makers, regulators, and managers can predict how a species' distribution may respond to change within their environment, including naturally occurring fluctuations and human activities. Species distribution modeling can provide a measure of a species' spatial density over a desired region. Our primary goal was to quantify sea turtle and marine mammal densities seasonally throughout the study area by developing models to examine spatial patterns and trends based on interactions with environmental conditions, in hopes of identifying species that could be exposed to future turbine construction and operation. By applying spatial modelling techniques to line transect boat-based survey data and high resolution digital video aerial survey footage, we produced relative density estimates of sea turtles and relative encounter rate estimates for bottlenose dolphins (as dolphin sightings may represent either an individual or a pod) across the study area by correlating species abundance to spatial and environmental covariates. One of the possible advantages gained by utilizing a spatial model to estimate density is an enhancement in the estimated precision, as deviation in density can be explained by relatively few spatial covariates (Hedley et al. 1999).

The combined effort of both surveys did not yield enough whale sightings to investigate potential density relationships with environmental covariates. An examination of publicly available whale data outside the study was conducted, but there were still insufficient sightings within the last ten years to allow for parameterization of a model (the 10-year temporal limit was set to avoid any variation in sighting patterns that could be caused by climate change). It is still important to note, however, that large whales were observed across the survey area during both surveys, including within each of the proposed WEAs. Of particular importance, nine North Atlantic right whales were observed during surveys. While these data were insufficient to identify geographic patterns, they corroborate data from previous studies indicating that the mid-Atlantic region is in the path of North Atlantic right whale annual migratory movements. Currently, North Atlantic right whales are among the most endangered whales in world, with an estimated 455 individuals left in the western North Atlantic (Fisheries 2015). They are protected under the United States Endangered Species Act (ESA) as well as the Marine Mammal Protection Act (MMPA). Vessel strikes and entanglement in fishing gear account for nearly half of all North Atlantic right whale mortality since 1970 (Knowlton and Kraus 2001). Considering hearing is a sensory modality for these animals, it is important to understand the potential increase in underwater noise posed by construction of offshore wind energy facilities. A study published in 2012 discovered that a decrease in underwater noise was associated with a decrease in baseline levels of stress-related hormones, such as glucocorticoids and cortisol, which are associated with chronic stress, and if not produced at proper levels can hinder the processes of a successful birth and even lead to adult mortality (Rolland et al. 2012). A recent passive acoustic study showed that North Atlantic right whales were present off the coasts of North Carolina and Georgia in all seasons, with peaks in abundance in autumn and winter, when they were not expected to be present (Hodge et al. 2015). We encourage further data collection in the region to better understand the distribution and the timing of presence of large whales, in particular the North Atlantic right whale, in relation to environmental covariates and the position of the WEAs.

For both bottlenose dolphins and sea turtles, GAMs proved more effective at modelling the density of these animals with relation to spatial covariates then their counterpart GLMs. This is due to GAMs' capacity to model the non-linear nature of ecological data and produce complex response curves (Guisan et al. 2002; Venables and Dichmont 2004). It is also important to look at the effectiveness of each models capacity to model temporal trends. GLMs are generally used in modelling long-term trends, such as annual outcomes, while GAMs are better at modelling short term responses, such as across seasons (Cheng and Gallinat 2004). However, it is also important to note that if not used carefully, GAMs can seriously over-fit data, and thus have low predictive power. GAMs also do not allow for the depiction of the interaction of two or more spatial covariates.

The relative density of bottlenose dolphin encounters within the study area during the spring was explained by Chl a and DFS, the summer model was best explained by only SST and Chl a, and the fall model was best explained by SST and DFS. The relationship with SST may be attributed to bottlenose dolphins' migratory behaviors, as the species generally moves south as temperatures decline (Barco et al. 1999; Natoli et al. 2005). It is also probable that there are permanent residents, transients, and seasonal migrants of this species that occupy estuarine, coastal, and offshore waters from Florida to

New Jersey (Urian et al. 2009). North of Cape Hatteras, North Carolina, bottlenose dolphins display a bimodal distribution with coastal and offshore components (Kenney 1990), and the mid-Atlantic study area likely contains several different coastal morphotypes at different times of year, including both Northern Migratory and Southern Migratory stocks (Waring et al. 2013). The relationship between bottlenose dolphin encounter rates and DFS in this study is likely due to the inshore distribution of the coastal ecotype of bottlenose dolphins during the spring, summer and fall seasons (Kenney 1990; Gannon and Waples 2004). It is possible that during the spring and fall months, resident coastal ecotype dolphins were surveyed more often, thus producing the very nearshore density gradient observed in this study. In summer, however, the influx of transient populations may have produced a more robust density gradient from west to east. The association with high areas of Chl a may be attributed to delphinids' capacity to utilize areas of high primary productivity for feeding, particularly in and around the mouths of the Chesapeake Bay and Delaware Bay (Young and Phillips 2002). It is important to note that the development of the bottlenose dolphin models excluded dolphins lumped into the "unidentified" category, of which some proportion were likely bottlenose dolphins.

The relative density of sea turtles during the spring was best explained by SST and DFS. The relative density of sea turtles during the summer was best explained by SST and Chl a, while the fall model was best explained by only DFS. Past aerial surveys have shown that loggerhead sea turtles, in particular, migrate into mid-Atlantic coastal waters at depths of 60 meters or less as the water warms during the spring (Shoop 1980). This would explain the higher density of sea turtles predicted in the spring, as roughly 60% of the identified sea turtles from both surveys were loggerhead sea turtles. In general, there was a decreasing trend in density from spring to fall. The most common sea turtles observed in the aerial survey were loggerhead and leatherback sea turtles. Prime nesting for these two species occurs from March to September along the east coast of the United States (Miller et al. 2003; Rabon Jr et al. 2003). As nesting of female sea turtles occurs on sandy beaches, we would expect the sexually mature females to be closer to shore during the nesting season. It is possible that the aerial survey did not efficiently survey the nesting population during the summer, as surveys did not extend within 5.5 km of shore in most locations; this could explain the lower predicted densities than in spring. Furthermore, the northern migration of predicted densities during the summer and fall could be a result of the mixing of the northern Labrador and Gulf Stream currents. The complete mixing of the these currents around the survey region occurs in late summer and early fall (Talley and McCartney 1982; Rossby and Benway 2000). The delayed uniform mixing of these currents has the potential to hinder the northern migration of these turtles. This is also likely why so few turtles were observed in the winter, as bottom temperatures in the mid-Atlantic drop to 10°C or less by mid-December, a known lethal thermal limit for some species of sea turtles (Schwartz 1978; Lutcavage and Musick 1985; Hawkes et al. 2007). It is also possible that this delayed mixing accounts for the greater number of turtles observed in the summer as it is estimated that turtles within our study area spend about 25% of the time at the surface basking during the spring (cooler water temps), as opposed to about 5% of the time during the summer and fall when current mixing has occurred (Barco et al. 1999).

Sea turtles and offshore wind energy development in the mid-Atlantic

Five of the seven extant species of sea turtle occur in the mid-Atlantic study area, and all five are protected under the Endangered Species Act. As such, they are likely to be priority species for regulators during the offshore wind environmental permitting process. Sea turtles are uncommon in European waters, so no information is available about their interactions with offshore wind facilities. Sea turtles could potentially be affected by offshore wind energy development in several ways, however, including noise from seismic surveys, construction, and operations; electromagnetic fields; vessel collisions; and changes to habitat caused by artificial reef effects (Read 2013).

Construction of offshore wind facilities has been identified as the development period with the most potential risks for sea turtles, due to noise from pile driving and other activities, though the potential for injury remains largely unknown (Michel 2013). Sea turtles can detect low-frequency sounds (Lenhardt et al. 1983; Dow Piniak et al. 2012), and the frequencies emitted by seismic airguns, offshore drilling, low-frequency and mid-frequency sonar, pile driving, cargo vessels, and operational wind turbines are all within the underwater hearing range of Leatherback sea turtles (Dow Piniak et al. 2012). Sea turtles have exhibited startle responses when exposed to low frequency sounds and vibrations in a laboratory setting (Lenhardt et al. 1983), and laboratory and *in situ* studies on seismic airguns for offshore oil and gas exploration have showed changes in sea turtle swimming pattern and orientation (O'Hara and Wilcox 1990) and a range of avoidance behaviors up to at least one kilometer away from the source (O'Hara and Wilcox 1990; McCauley et al. 2000). Sea turtles are known to collide with vessels, and are also displaced from areas with vessel traffic, though observed responses to boat noise have varied with species (Samuel et al. 2005; Lester et al. 2013).

During operations of offshore wind facilities, sea turtles may be displaced due to turbine or vessel noise, or may aggregate around turbine foundations due to artificial reef effects, which change local habitats (Read 2013). Similar aggregation patterns have been observed around oil rigs in the Gulf of Mexico (Continental Shelf Associates 2004). The degree to which turbines may aggregate sea turtles will likely vary by location and other factors, and the effects on individuals or populations are unclear. Likewise, past studies have shown that electromagnetic fields (EMF) and heat signatures associated with offshore turbines have the potential to affect species such as sea turtles that use geomagnetic cues during migration (Lohmann et al. 2008). Data on the effects of EMF on sea turtles are generally lacking, however (Read 2013), and we know of no studies to date that have assessed whether EMF emissions from subsurface cables at operational facilities influence navigational decisions of turtles.

Overall, our results indicate that there is overlap between predicted habitat usage of sea turtles and the placement of proposed WEAs in the mid-Atlantic. Chesapeake Bay and the coastal waters of Virginia are known to serve as a key summer developmental habitat for juvenile sea turtles, particularly loggerheads and Kemp’s ridley sea turtles, thus placing the Virginia WEA in a potentially sensitive location (Lutcavage and Musick 1985). Winter is the time period where the likelihood of interactions between offshore construction and sea turtles is lowest, but winter is a difficult time for offshore construction, and most development activities are likely to occur in the other three seasons. During spring, summer, and fall, the relative density of sea turtles did not change drastically, though the distribution of turtles across the study area varied substantially (Figure 15-13 to Figure 15-15). As such, and given the group’s conservation status, the development of techniques to avoid or reduce interactions between sea turtles and construction activities, vessel traffic, and other development activities should be considered a priority. The development of taxon-specific effects data is also a key area for additional research.

Bottlenose dolphins and offshore wind energy development in the mid-Atlantic

All cetaceans that occur in the U.S. are protected under the Marine Mammal Protection Act. Cetaceans use sound for communication, and some, like dolphins, also use echolocation to navigate through their environment and hunt for prey. Acoustic disturbance has been recently identified as the primary concern for marine mammals with regards to offshore wind development in Europe (Bergström et al. 2014). This may include noise from seismic surveys, blasting, pile driving, and operational turbines. The severity of avoidance and displacement effects appear to vary with a variety of factors, including the frequency, intensity, and duration of noise, as well as species and time of year (Goold 1996; McCauley et al. 2000; Madsen et al. 2002). European studies have indicated that Harbor Porpoises could hear pile driving noise over 80 km from the source, and showed displacement up to 20 km away during construction (Thomsen et al. 2006; Teilmann and Carstensen 2012). Results of operational displacement studies in Denmark and the Netherlands have varied (Scheidat et al. 2011; Teilmann and Carstensen 2012). There has been little or no detectable avoidance during operations at some facilities, while in at least one instance, even nine years after construction had been completed, porpoise acoustic activity levels were at only 29% of pre-construction levels (Teilmann and Carstensen 2012). Prey availability may be an important factor affecting porpoise behavior around operational wind facilities (Teilmann and Carstensen 2012).

Overall, our results indicate that there is overlap between predicted habitat usages of bottlenose dolphins and the placement of proposed WEAs in the mid-Atlantic, although the relationship between dolphin distributions and these areas of potential offshore wind energy development may be somewhat difficult to interpret from this particular data set. Our models suggest minimal presence of bottlenose dolphins within WEAs during cooler months. However, it is important to note that other species of delphinids, such as common dolphins, are more cold-tolerant than bottlenose dolphins. Common dolphin observations increased in both the boat-based and aerial surveys during winter and early spring. Thus, it is possible that delphinids will be present in some numbers in WEAs during all seasons. Efforts to mitigate the effects of construction activities, in particular, will be important as offshore wind energy development proceeds in the mid-Atlantic.

Caveats, considerations and next steps

Conservationists and policy makers must remember that models are simply an approximation of a species' potential distribution and density. Modeling the density and distributions of marine mammals and sea turtles in the present study was challenging due to the methods employed during surveys, the limited number of sightings generated during surveys, and the difficulties of merging aerial and boat-based survey data. "Passing mode" surveys, where the research vessel does not deviate from the transect line, present significant challenges in determining species identifications and group size. Many marine mammals will form multi-species groups that often become apparent only after close approach, and the movements and dive behavior of these animals make judging group size from a distance difficult. As a result, we chose to model encounter rates (with one or more delphinid) rather than predict numbers of individual animals. Clearly, in applying any analytical technique to ecological data, tradeoffs are often involved to meet certain assumptions. Traditional distance sampling, in particular, assumes all objects on or near the transect line are detected with 100% certainty; that the animals are detected at their initial location; and that recorded distances and angles made by the observer are exact, without measurement error or bias (Thomas et al. 2002). The marine environment and the general physiology (diving behavior) of these animals make it very difficult to meet these assumptions. As previously mentioned, marine mammals were not modelled using any of the aerial data due to the small sample size of individuals identified at the species level. Furthermore, a general "all delphinids" model would not have been useful as lumping multiple species that have distinct behaviors would have likely been problematic and uninformative. Many species of marine mammals can be highly clustered in space and time, leading to difficulties in merging datasets collected under disparate methods, both of which contained methodological and technological shortcomings.

Future boat survey assessments of marine mammals in this region should be designed to best address issues associated with species identification and group size estimation, ideally using a "closing mode" approach, whereby the research vessel would deviate from the transect line to more accurately describe a sighting by allowing more time for each encounter. A dedicated dual observer approach would also be warranted, as observers searching for both birds and marine mammals must maintain an extremely high level of vigilance to achieve appropriate survey effort. Clearly, aerial surveys pose a challenge to marine mammal surveys due to behaviors such as fast surface intervals as well as species identification success. However, the aerial survey did prove useful in sea turtle relative density estimates, where unlike marine mammals, the number of species observed in our study area was limited, as is the diversity in species-specific behaviors.

Finally, small sample sizes pose challenges to any statistical analyses, and result in diminished analytical potential as compared to models developed with more data (McPherson et al. 2004). As sample size increases, accuracy and predictive power also increase, at least until reaching a maximum accuracy potential (Hernandez et al. 2006). Future surveys designed specifically for marine mammals will help address this issue and improve our understanding of marine mammal distributions and habitat use in the mid-Atlantic United States.

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Figures and tables

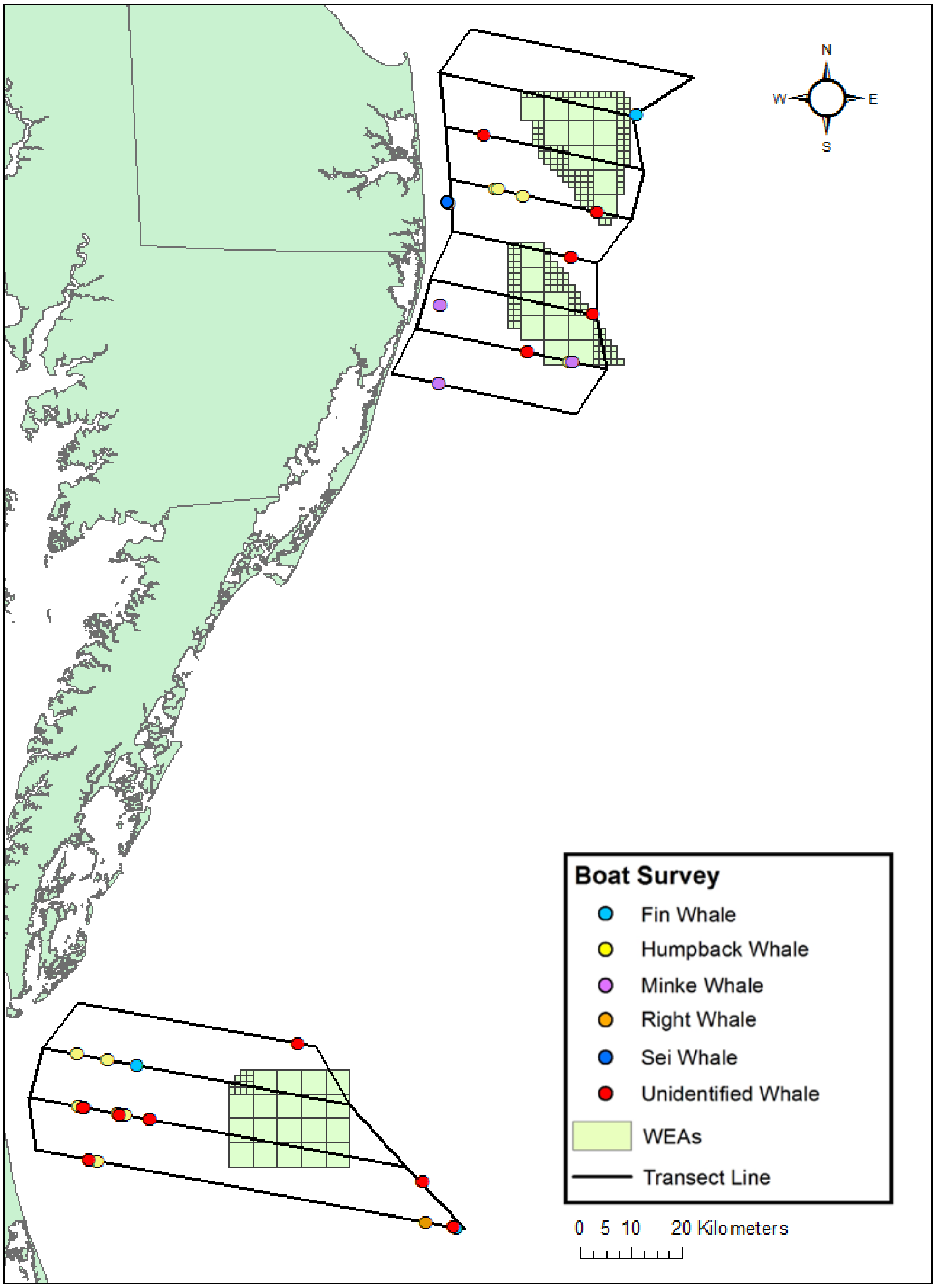

Figure 15-1. Whale sightings from boat survey transects (all surveys, 2012-2014).

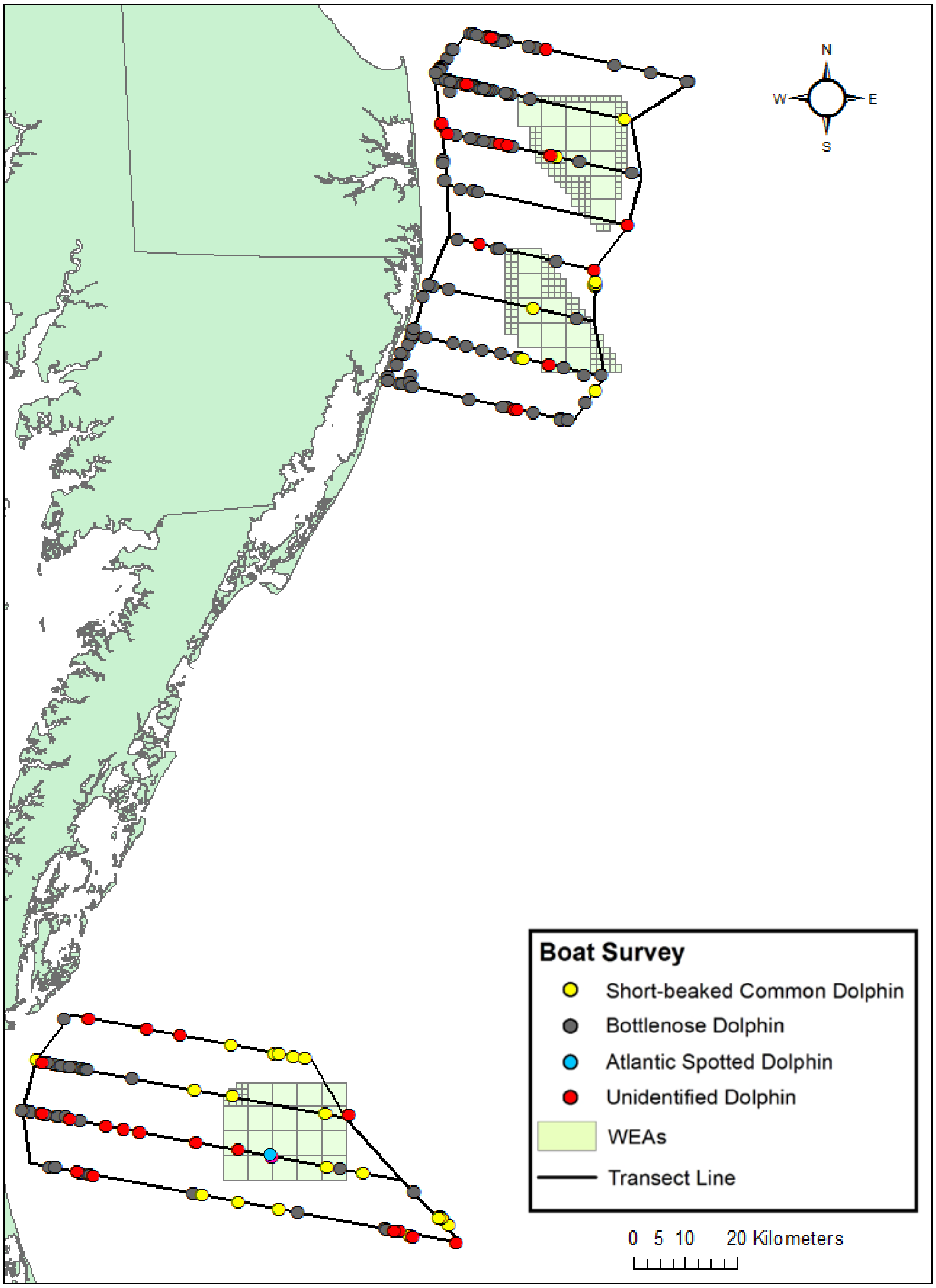

Figure 15-2. Delphinid sightings from boat survey transects (all surveys, 2012-2014).

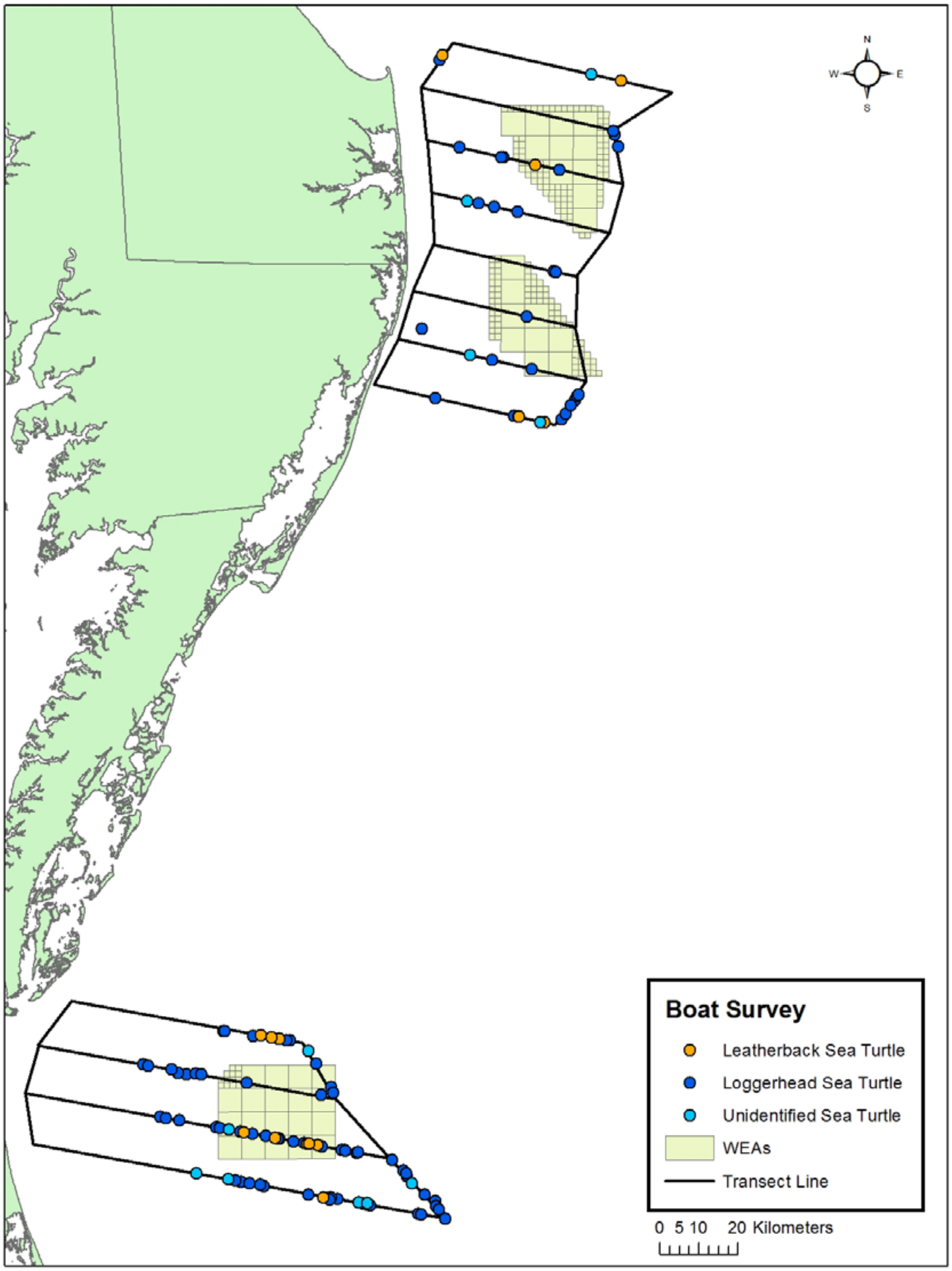

Figure 15-3. Sea turtle sightings from boat survey transects (all surveys, 2012-2014). Unidentified sea turtles are non-Leatherback Sea Turtles that were not definitively identified to species.

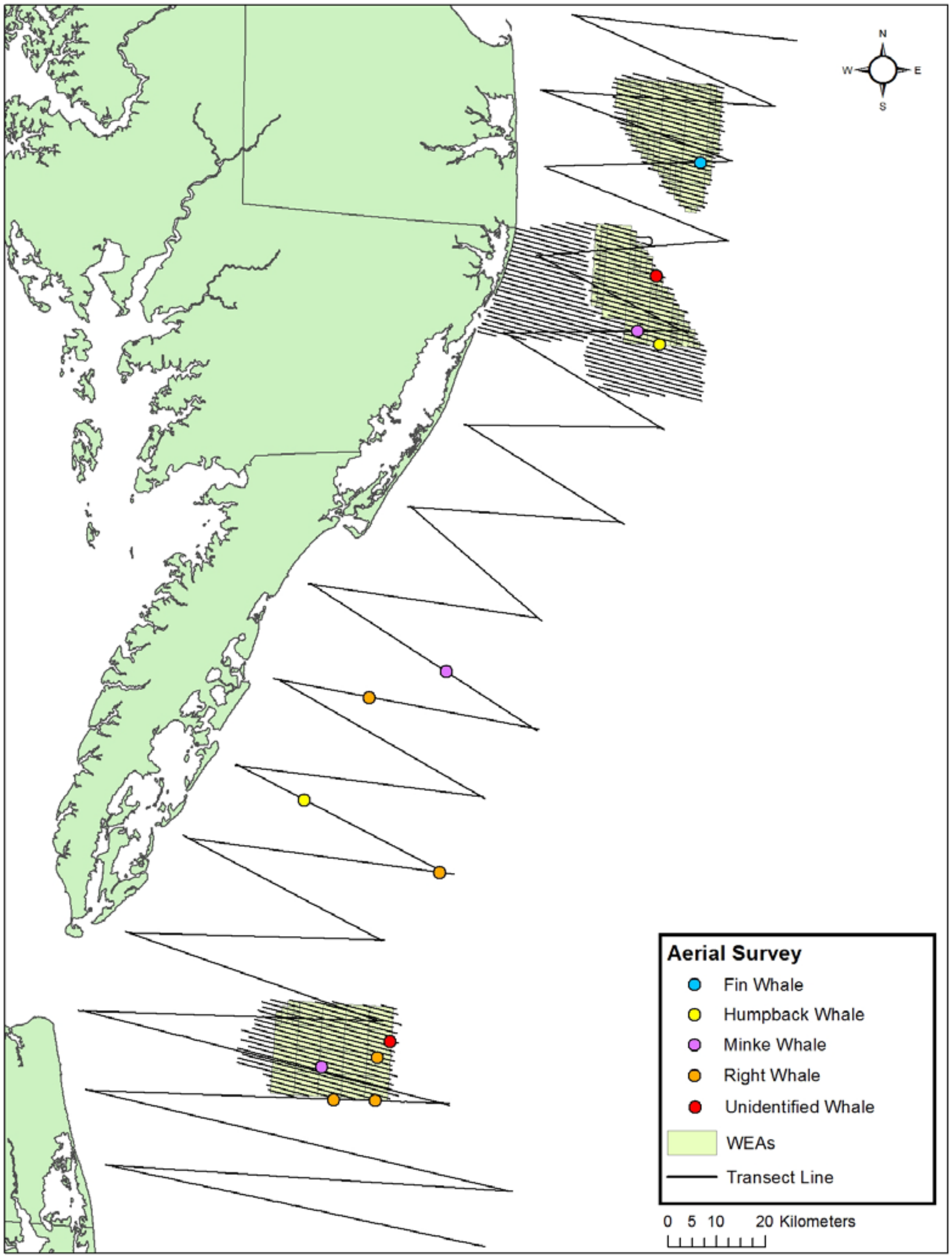

Figure 15-4. Whale sightings from aerial survey transects (all surveys, 2012-2014).

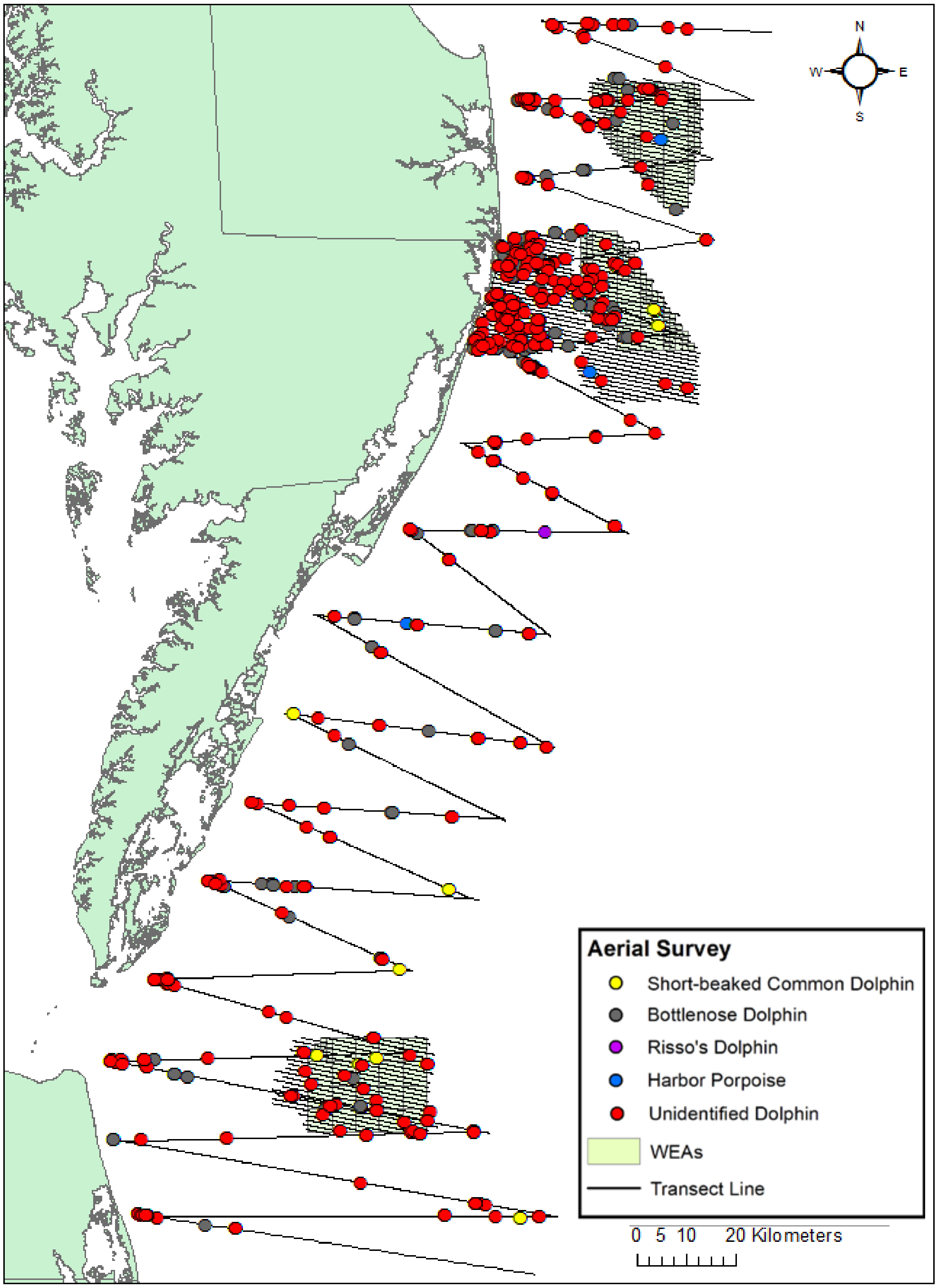

Figure 15-5. Delphinid and porpoise sightings from aerial survey transects (all surveys, 2012-2014).

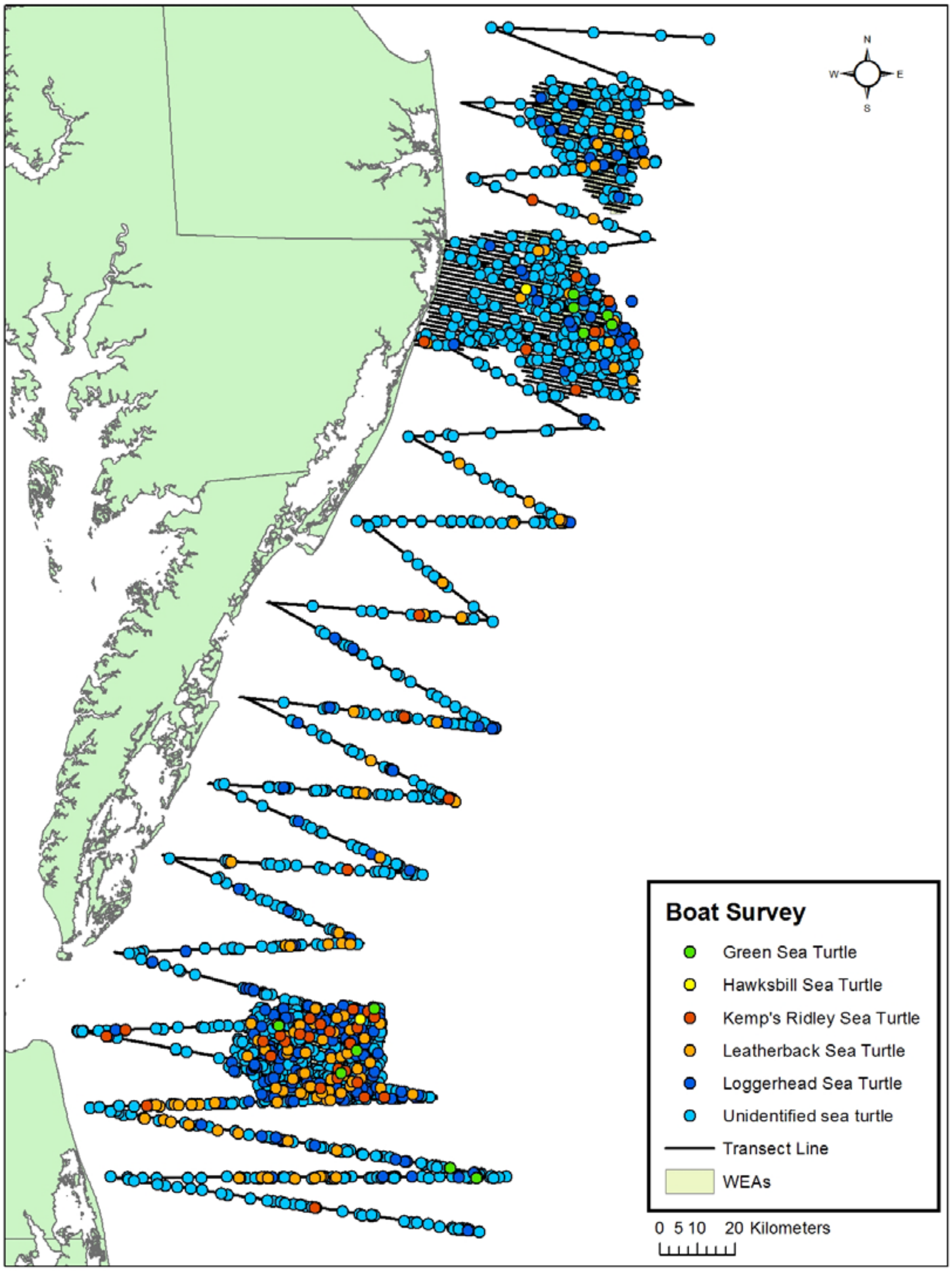

Figure 15-6. Sea turtle sightings from aerial survey transects (all surveys, 2012-2014). Unidentified sea turtles are non-Leatherback Sea Turtles that were not definitively identified to species.

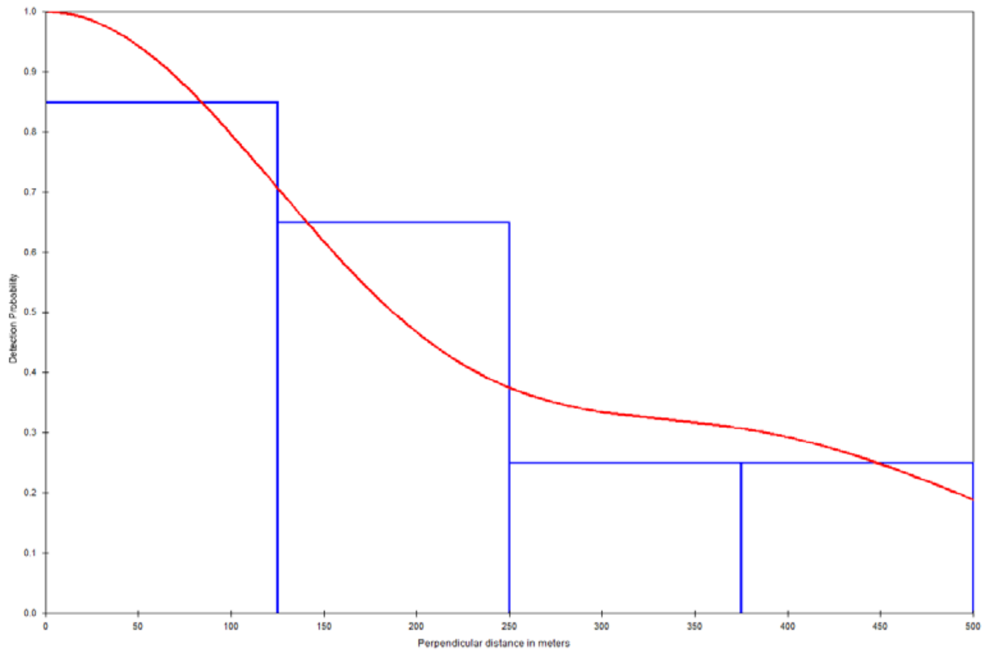

Figure 15-7. Spring global detection function used in boat survey bottlenose dolphin line transect distance density analysis.

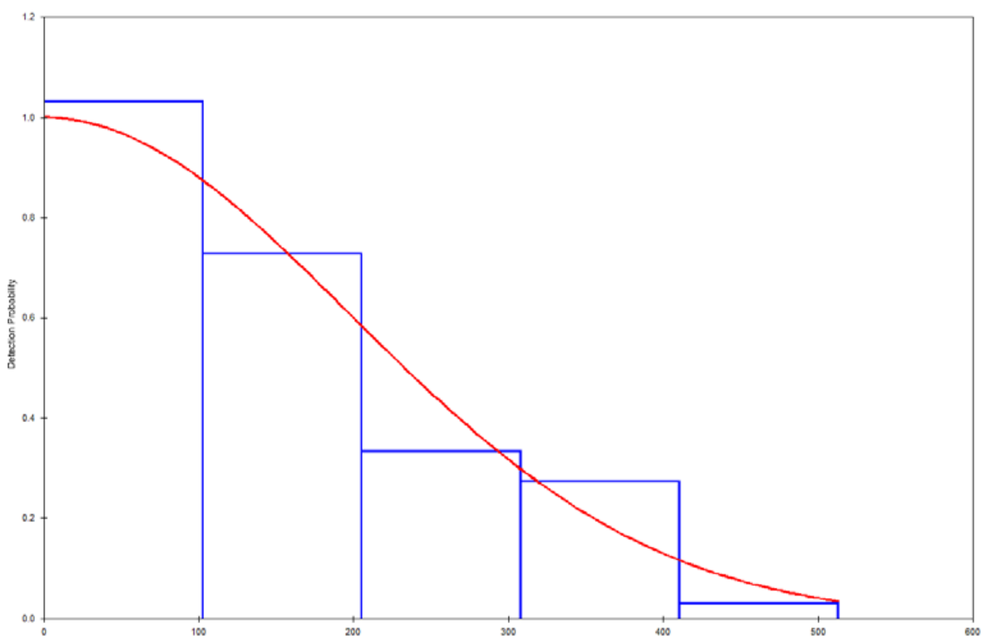

Figure 15-8. Summer global detection function used in boat survey bottlenose dolphin line transect distance density analysis.

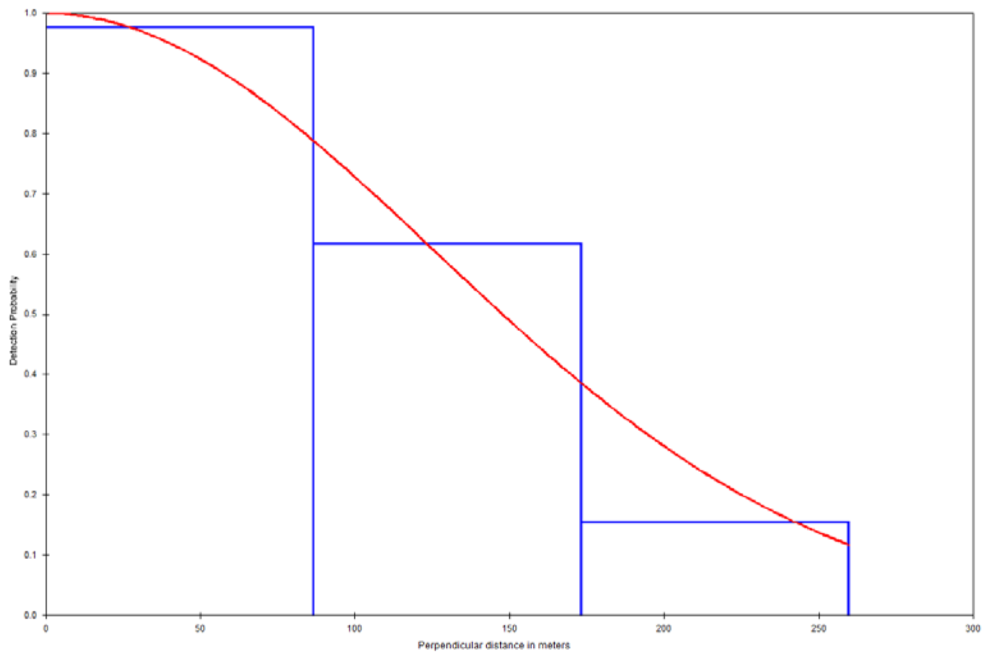

Figure 15-9. Fall global detection function used in boat survey bottlenose dolphin line transect distance density analysis.

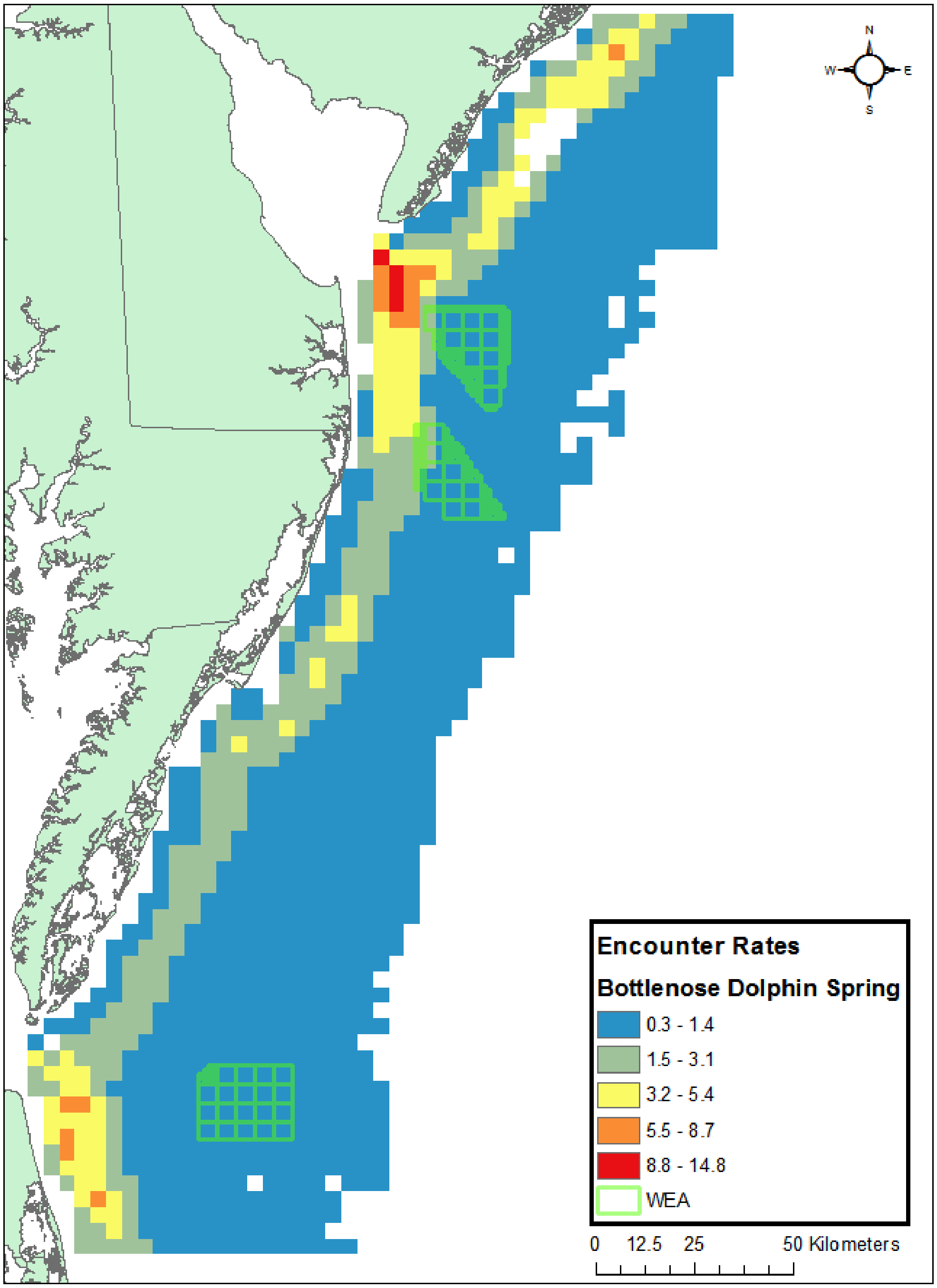

Figure 15-10. Interpolation of encounter rates of bottlenose dolphins in the study area during the spring (Mar.-May), based on two years of boat survey data (2012-2014).

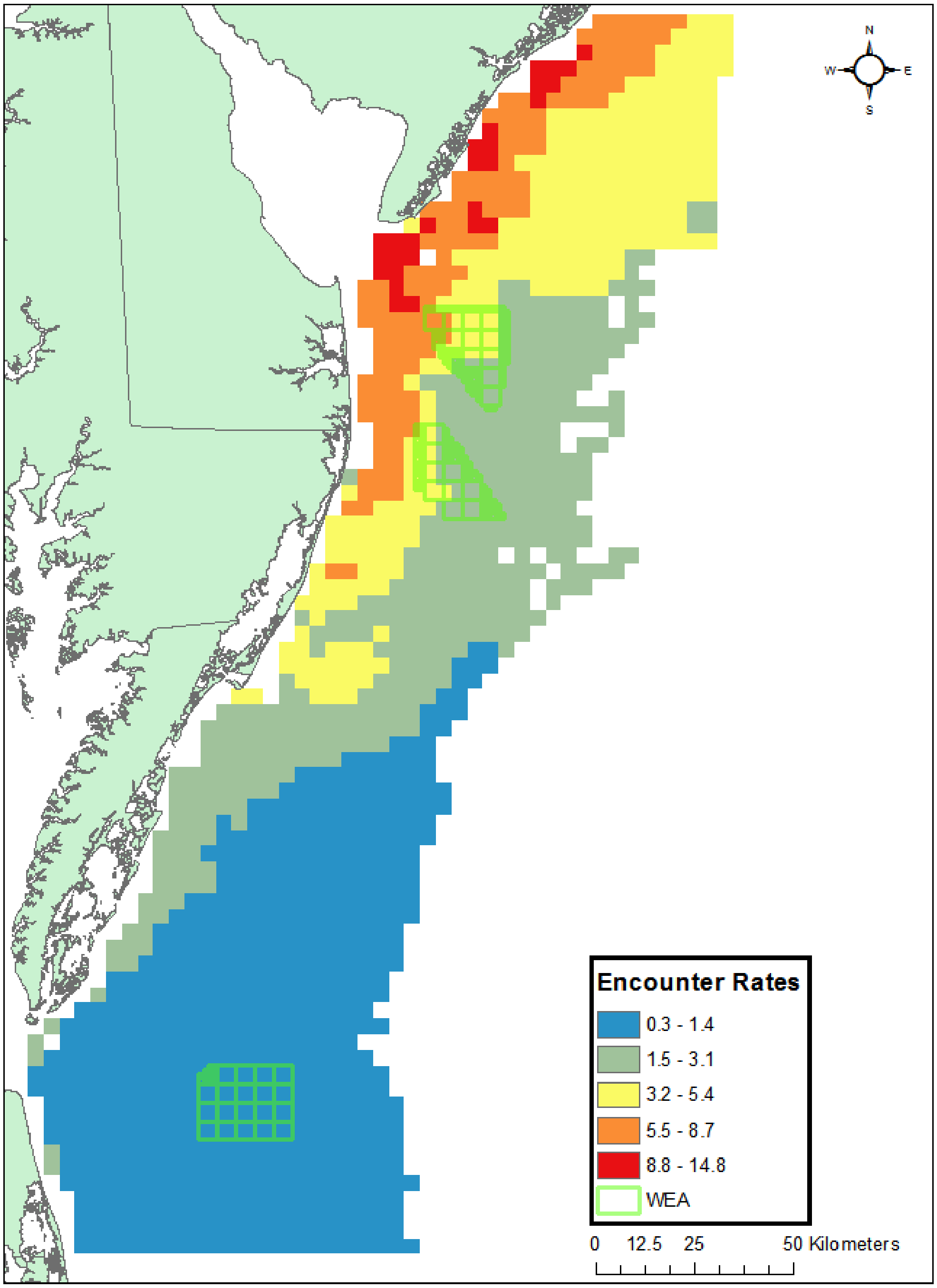

Figure 15-11. Interpolation of encounter rates of bottlenose dolphins in the study area during the summer (Jun. –Aug.), based on two years of boat survey data (2012-2014).

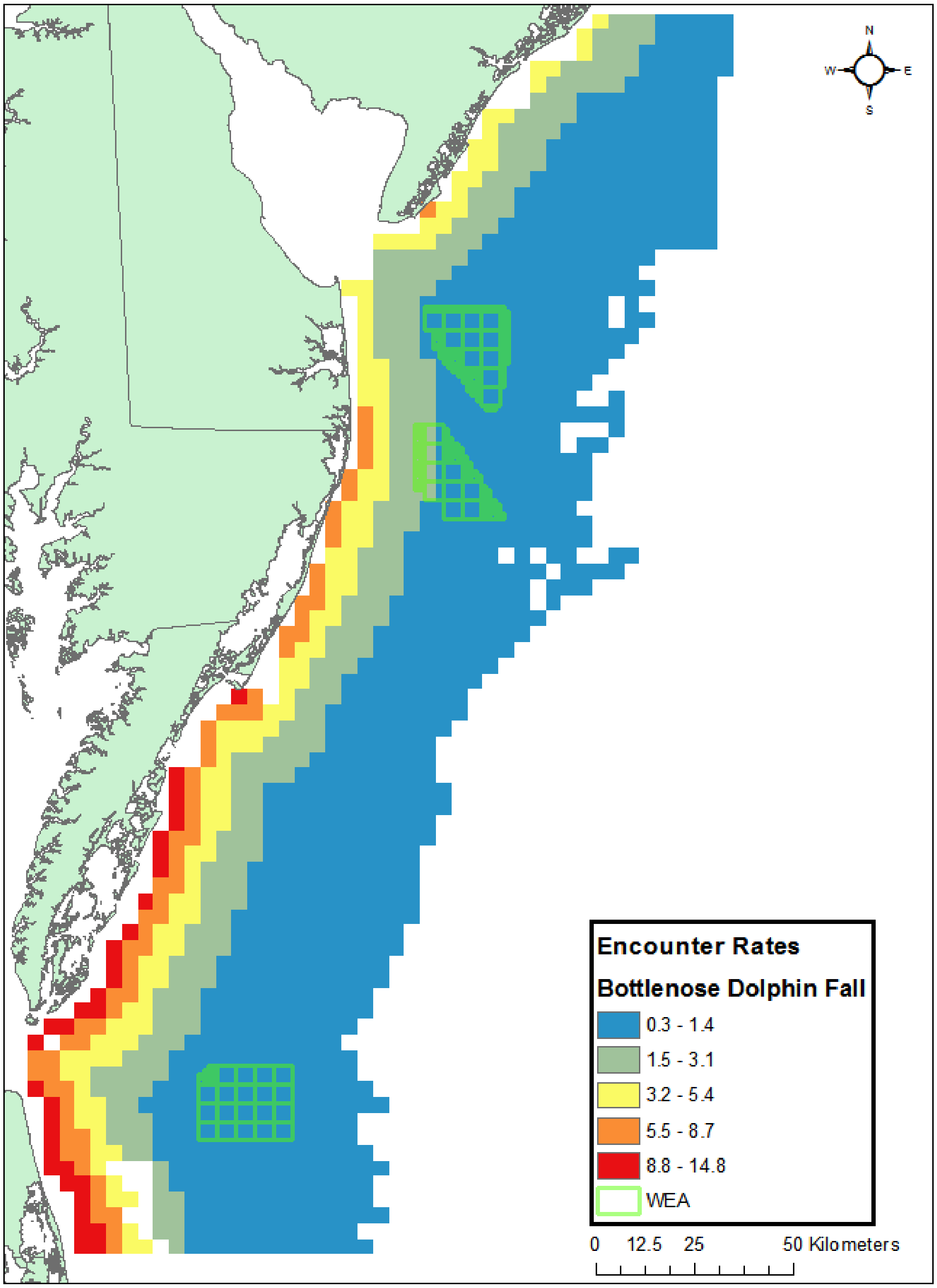

Figure 15-12. Interpolation of encounter rates of bottlenose dolphins in the study area during the fall (Sep.-Nov.), based on two years of boat survey data (2012-2014).

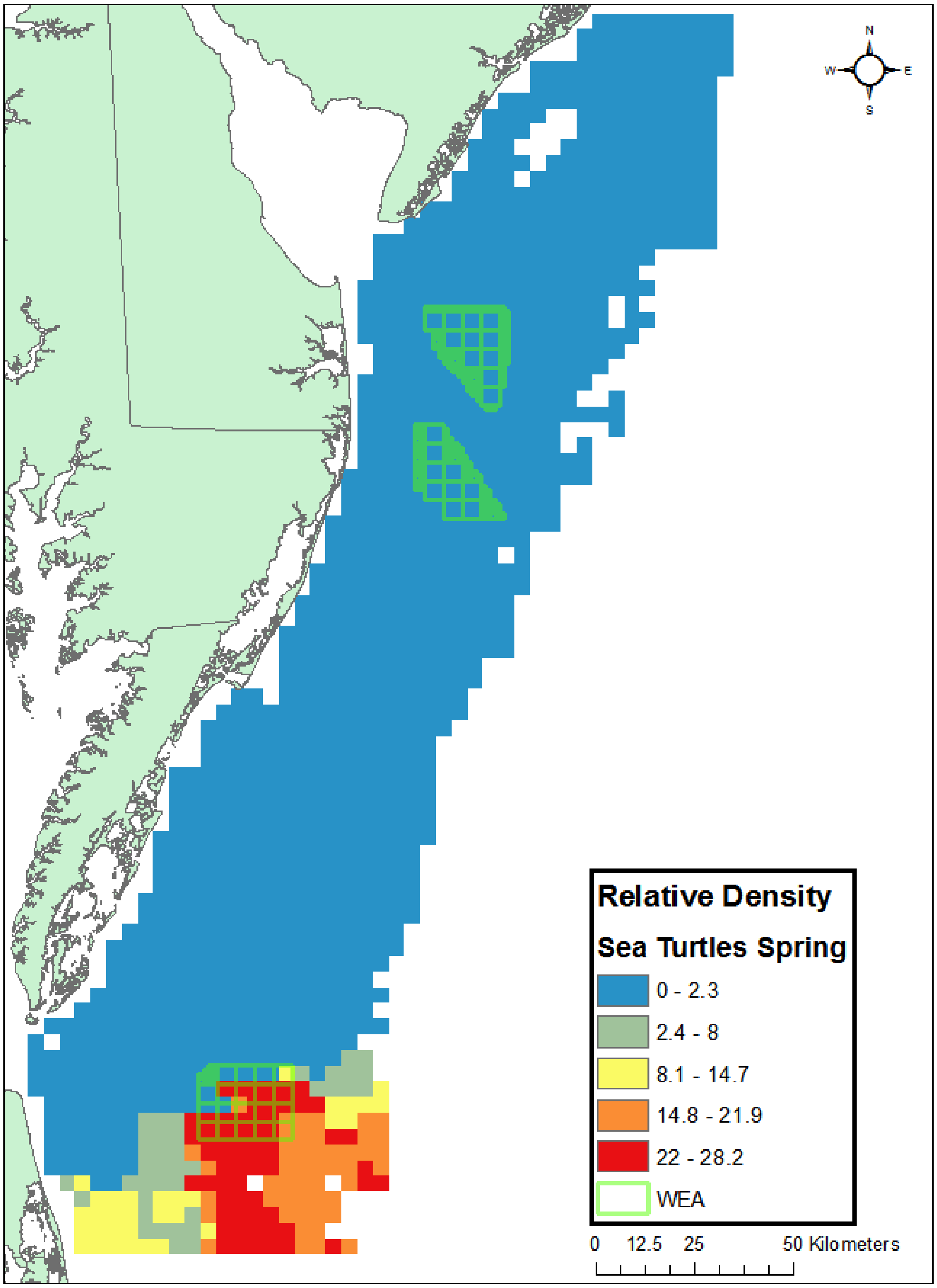

Figure 15-13. Interpolation of predicted relative density of sea turtles in the study area during the spring (Mar.-May), based on two years of aerial survey data (2012-2014).

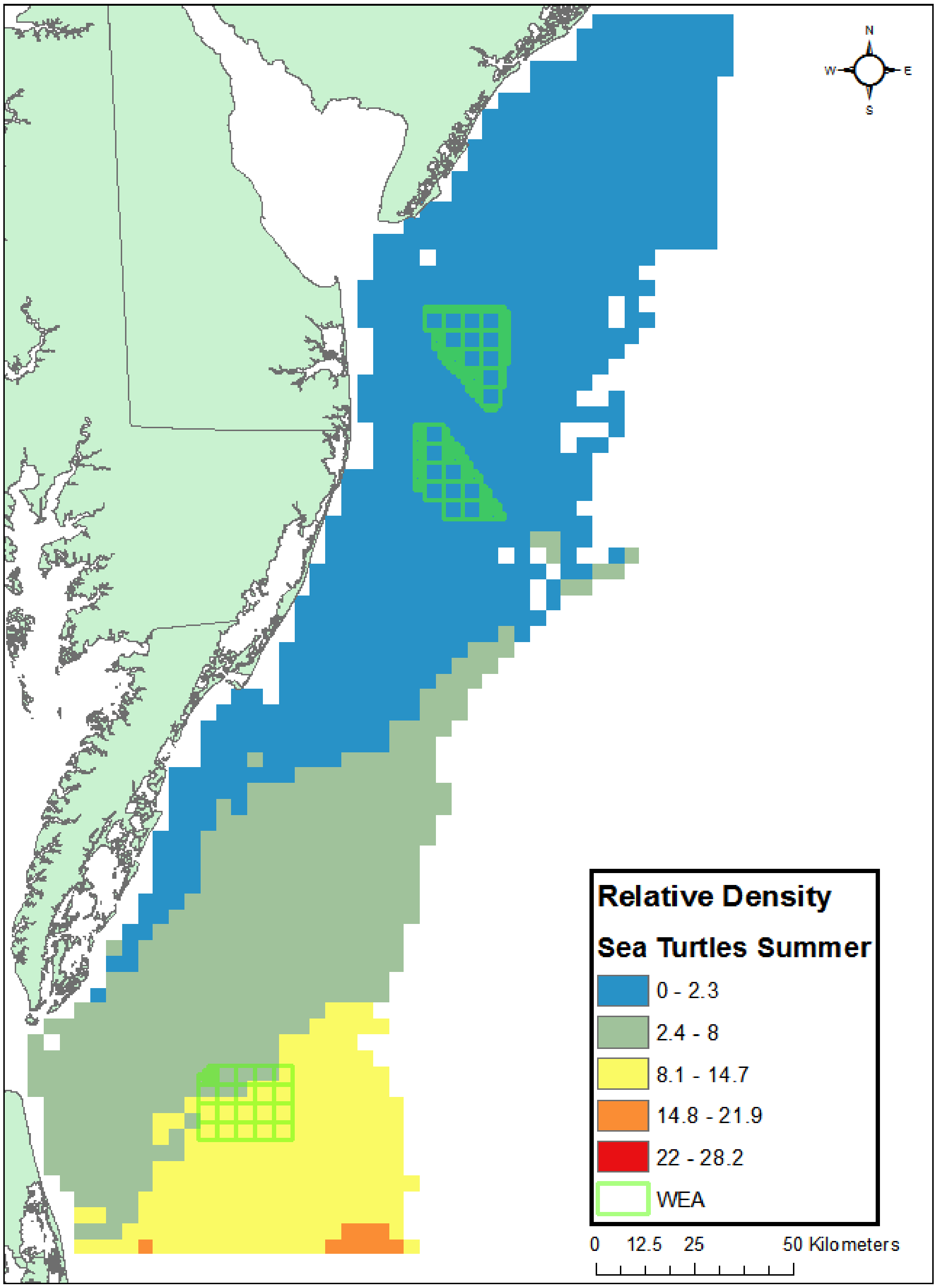

Figure 15-14. Interpolation of predicted relative density of sea turtles in the study area during the summer (Jun.-Aug.), based on two years of aerial survey data (2012-2014).

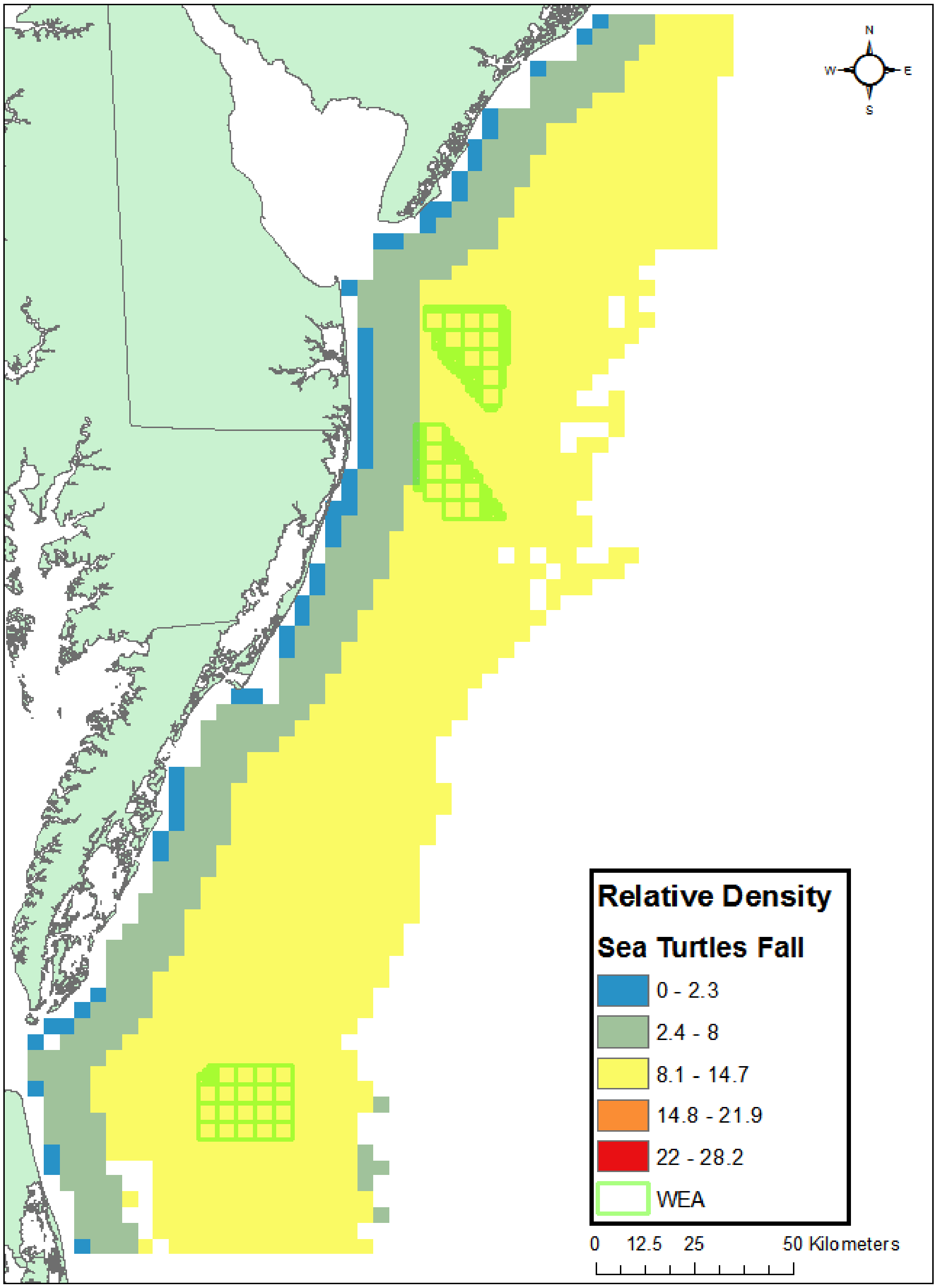

Figure 15-15. Interpolation of predicted relative density of sea turtles in the study area during the fall (Sep.-Nov.), based on two years of aerial survey data (2012-2014).

Table 15-1. Summary data for boat surveys by season. (Spring: March - May; Summer: June - August; Fall: September - November; Winter: December – February). Counts include all observed individuals on the survey transects.

Species Group	Spring	Summer	Fall	Winter	Total Count (Ind.)
Tursiops truncatus (Bottlenose)	239	400	227	8	874
Delphinus delphis (Common)	65	0	0	144	209
Stenella frontalis (Spotted)	0	4	0	0	4
Unidentified Delphinid	11	35	54	13	113
Dolphins Total	**315**	**439**	**281**	**165**	**1200**
Balaenoptera physalus (Fin)	2	0	0	1	3
Balaenoptera borealis (Sei)	0	0	0	1	1
Balaenoptera acutorostrata (Minke)	0	0	1	2	3
Eubalaena glacialis (Right)	1	0	0	0	1
Megaptera novaeangliae (Humpback)	0	1	4	7	12
Unidentified Whale	2	0	3	10	15
Whales Total	**5**	**1**	**8**	**21**	**35**
Caretta caretta (Loggerhead)	11	52	26	0	89
Dermochelys coriacea (Leatherback)	0	9	6	0	15
Unidentified Sea Turtle	2	4	4	0	11
Sea Turtles Total	**13**	**65**	**36**	**0**	**114**
Percent of Total by Season:	24.68	37.44	24.09	13.79	100
Grand Total	***333***	***505***	***325***	***186***	***1,349***

Table 15-2. Summary data for aerial surveys by season. (Spring: March - May; Summer: June - August; Fall: September - November; Winter: December - February). Counts include all observed individuals on the survey transects.

Species Group	Spring	Summer	Fall	Winter	Total Count (Ind.)
Tursiops truncatus (Bottlenose)	226	265	176	10	677
Delphinus delphis (Common)	11	7	4	39	61
Grampus griseus (Risso's)	0	0	1	0	1
Unidentified Toothed Whale	282	420	454	141	1297
Dolphins Total	**519**	**692**	**635**	**190**	**2036**
Phocoena phocoena (Harbor Porpoise)	2	0	0	1	3
Porpoises Total	**2**	**0**	**0**	**1**	**3**
Balaenoptera physalus (Fin)	0	0	0	1	1
Balaenoptera acutorostrata (Minke)	1	0	1	1	3
Eubalaena glacialis (Right)	3	0	0	5	8
Megaptera novaeangliae (Humpback)	0	0	0	2	2
Unidentified Whale	1	0	0	1	2
Whales Total	**5**	**0**	**1**	**10**	**16**
Unidentified Cetacean (Whale or Dolphin)	2	1	2	0	5
Unidentified Cetaceans Total	**2**	**1**	**2**	**0**	**5**
Caretta caretta (Loggerhead)	60	50	78	0	188
Dermochelys coriacea (Leatherback)	2	78	42	0	122
Chelonia mydas (Green)	3	1	7	0	11
Eretmochelys imbricate (Hawksbill)	0	0	2	0	2
Lepidochelys kempii (Kemp's)	13	10	14	1	38
Unidentified Sea Turtle	523	438	425	1	1387
Sea Turtles Total	**601**	**577**	**568**	**2**	**1748**
Percent of Overall Total by Season:	29.65	33.35	31.67	5.33	100
Grand Total	***1129***	***1270***	***1206***	***203***	***3808***

Table 15-3. Individual marine mammal and sea turtle aerial survey sightings by month in relation to survey effort. Sightings are summarized by linear transect km, as well as per hour of survey time based on a constant flight speed of 250 km/hr.

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Avg
Number of Sightings/km	0.00	0.06	0.07	0.00	0.61	0.25	0.77	0.31	0.38	0.18	0.00	0.10	0.23
Number of Sightings/hr	0.00	15.00	17.50	0.00	152.50	62.50	192.50	77.50	95.00	45.00	0.00	25.00	56.88

Table 15-4. Model selection criterion for bottlenose dolphins in the spring. The chosen model is highlighted in green. (AIC-Akaike's Information Criterion, % Dev-Percent of deviance explained from the null model, Mean-average predicted density, SE-Standard error, SST-Sea Surface Temperature, Chl a-Chlorophyll a, DFS- Distance from shore)

#	GAM Model Covariates	AIC	% Dev	Mean	SE
1	s(SST) + s(Chl a) + s(DFS)	92.43	43.00	0.09	0.67
2	s(SST) + s(Chl a)	92.45	42.10	0.10	0.56
3	s(SST) + s(DFS)	92.89	37.90	0.10	0.65
4	s(Chl a) + s(DFS)	90.49	42.70	0.10	0.67
5	s(SST)	103.40	16.90	0.10	0.33
6	s(Chl a)	93.24	31.90	0.10	0.51
7	s(DFS)	92.72	33.70	0.10	0.66
#	**GLM Model Covariates**	**AIC**	**% Dev**	**Mean**	**SE**
8	s(SST) + s(Chl a) + s(DFS)	100.60	20.52	0.10	2.29
9	s(SST) + s(Chl a)	100.73	17.57	0.11	2.26
10	s(SST) + s(DFS)	99.74	18.95	0.10	2.15
11	s(Chl a) + s(DFS)	98.90	20.12	0.10	0.94
12	s(SST)	107.91	4.81	0.10	2.23
13	s(Chl a)	99.59	16.38	0.11	0.50
14	s(DFS)	98.12	18.42	0.10	0.37

Table 15-5. Model selection criterion for bottlenose dolphins in the summer. The chosen model is highlighted in green. (AIC-Akaike's Information Criterion, % Dev-Percent of deviance explained from the null model, Mean-average predicted density, SE-Standard error, SST-Sea Surface Temperature, Chl a-Chlorophyll a, DFS- Distance from shore)

#	GAM Model Covariates	AIC	% Dev	Mean	SE
1	s(SST) + s(Chl a) + s(DFS)	153.67	23.90	0.20	0.32
2	s(SST) + s(Chl a)	152.63	24.10	0.20	0.30
3	s(SST) + s(DFS)	159.96	17.20	0.20	0.25
4	s(Chl a) + s(DFS)	155.81	23.20	0.20	0.31
5	s(SST)	157.24	19.70	0.20	0.29
6	s(Chl a)	158.36	17.30	0.20	0.24
7	s(DFS)	164.66	12.50	0.20	0.25
#	**GLM Model Covariates**	**AIC**	**% Dev**	**Mean**	**SE**
8	s(SST) + s(Chl a) + s(DFS)	157.75	23.16	0.20	5.75
9	s(SST) + s(Chl a)	156.63	22.29	0.20	0.59
10	s(SST) + s(DFS)	165.98	13.18	0.20	0.60
11	s(Chl a) + s(DFS)	155.82	23.09	0.20	5.62
12	s(SST)	171.80	5.56	0.20	0.52
13	s(Chl a)	157.24	19.75	0.20	5.30
14	s(DFS)	164.66	12.52	0.20	0.29

Table 15-6. Model selection criterion for bottlenose dolphins in the fall. The chosen model is highlighted in green. (AIC-Akaike's Information Criterion, % Dev-Percent of deviance explained from the null model, Mean-average predicted density, SE-Standard error, SST-Sea Surface Temperature, Chl a-Chlorophyll a, DFS- Distance from shore)

#	GAM Model Covariates:	AIC	% Dev	Mean	SE
1	s(SST) + s(Chl a) + s(DFS)	126.54	23.50	0.14	0.31
2	s(SST) + s(Chl a)	125.45	22.10	0.14	0.31
3	s(SST) + s(DFS)	125.09	22.30	0.14	0.31
4	s(Chl a) + s(DFS)	127.43	19.9	0.14	0.3
5	s(SST)	138.00	10.10	0.14	0.25
6	s(Chl a)	126.35	18.20	0.14	0.30
7	s(DFS)	125.71	19.10	0.14	0.30
#	GLM Model Covariates	AIC	% Dev	Mean	SE
8	s(SST) + s(Chl a) + s(DFS)	128.57	18.31	0.15	4.04
9	s(SST) + s(Chl a)	127.67	17.02	0.16	3.63
10	s(SST) + s(DFS)	127.99	16.65	0.14	5.07
11	s(Chl a) + s(DFS)	128.69	15.82	0.14	1.27
12	s(SST)	139.48	0.88	0.14	4.17
13	s(Chl a)	127.22	15.20	0.15	0.46
14	s(DFS)	127.89	14.42	0.14	0.41

Table 15-7. Model selection criterion for sea turtles in the spring. The chosen model is highlighted in green. (AIC- Akaike's Information Criterion, % Dev-Percent of deviance explained from the null model, Mean-average predicted density, SE-Standard error, SST-Sea Surface Temperature, Chl a-Chlorophyll a, DFS- Distance from shore)

#	GAM Model Covariates	AIC	% Dev	Mean	SE
1	s(SST) + s(Chl a) + s(DFS)	1572.07	31.40	0.72	0.08
2	s(SST) + s(Chl a)	1572.56	30.90	0.73	0.08
3	s(SST) + s(DFS)	1570.71	31.00	0.72	0.08
4	s(Chl a) + s(DFS)	1625.67	24.30	0.72	0.07
5	s(SST)	1589.60	27.40	0.73	0.07
6	s(Chl a)	1633.23	21.30	0.73	0.06
7	s(DFS)	1649.61	18.40	0.72	0.06
#	GLM Model Covariates	AIC	% Dev	Mean	SE
8	s(SST) + s(Chl a) + s(DFS)	1604.50	24.47	0.73	0.80
9	s(SST) + s(Chl a)	1602.80	24.43	0.73	0.70
10	s(SST) + s(DFS)	1609.10	23.50	0.74	0.70
11	s(Chl a) + s(DFS)	1663.00	15.52	0.72	0.40
12	s(SST)	1627.60	20.47	0.74	0.65
13	s(Chl a)	1667.60	14.54	0.72	0.12
14	s(DFS)	1669.20	14.31	0.74	0.10

Table 15-8. Model selection criterion for sea turtles in the summer. The chosen model is highlighted in green. (AIC- Akaike's Information Criterion, % Dev-Percent of deviance explained from the null model, Mean-average predicted density, SE-Standard error, SST-Sea Surface Temperature, Chl a-Chlorophyll a, DFS- Distance from shore)

#	GAM Model Covariates	AIC	% Dev	Mean	SE
1	s(SST) + s(Chl a) + s(DFS)	1725.07	34.60	0.89	0.07
2	s(SST) + s(Chl a)	1723.65	34.20	0.89	0.07
3	s(SST) + s(DFS)	1724.79	34.70	0.89	0.07
4	s(Chl a) + s(DFS)	1780.89	27.80	0.89	0.06
5	s(SST)	1744.02	30.90	0.89	0.06
6	s(Chl a)	1781.20	26.80	0.89	0.07
7	s(DFS)	1813.78	21.90	0.09	0.06
#	GLM Model Covariates	AIC	% Dev	Mean	SE
8	s(SST) + s(Chl a) + s(DFS)	1725.80	33.49	0.90	2.20
9	s(SST) + s(Chl a)	1729.30	32.72	0.89	2.19
10	s(SST) + s(DFS)	1725.90	33.21	0.90	2.14
11	s(Chl a) + s(DFS)	1821.50	19.88	0.89	0.31
12	s(SST)	1749.90	25.59	0.90	1.95
13	s(Chl a)	1840.20	17.00	0.87	0.11
14	s(DFS)	1827.00	18.84	0.91	0.13

Table 15-9. Model selection criterion for sea turtles in the fall. The chosen model is highlighted in green. (AIC- Akaike's Information Criterion, % Dev-Percent of deviance explained from the null model, Mean-average predicted density, SE-Standard error, SST-Sea Surface Temperature, Chl a-Chlorophyll a, DFS- Distance from shore)

#	GAM Model Covariates	AIC	% Dev	Mean	SE
1	s(SST) + s(Chl a) + s(DFS)	1494.74	8.31	0.56	0.07
2	s(SST) + s(Chl a)	1501.47	5.42	0.56	0.06
3	s(SST) + s(DFS)	1492.79	8.40	0.56	0.07
4	s(Chl a) + s(DFS)	1493.04	8.02	0.56	0.07
5	s(SST)	1512.83	4.74	0.56	0.06
6	s(Chl a)	1500.29	5.29	0.56	0.06
7	s(DFS)	1491.42	7.98	0.56	0.07
#	GLM Model Covariates	AIC	% Dev	Mean	SE
8	s(SST) + s(Chl a) + s(DFS)	1501.20	5.80	0.56	3.11
9	s(SST) + s(Chl a)	1501.50	5.42	0.56	2.67
10	s(SST) + s(DFS)	1509.50	4.11	0.56	2.90
11	s(Chl a) + s(DFS)	1501.80	5.36	0.56	0.34
12	s(SST)	1517.10	2.52	0.56	1.57
13	s(Chl a)	1500.30	5.29	0.56	0.11
14	s(DFS)	1507.90	4.04	0.56	0.13