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Estimated Injury of Sea Turtles in Neritic Habitats Associated with Exposure to DWH Oil

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1. SUMMARY

During the *Deepwater Horizon* (DWH) oil spill in 2010, surface oil covered more than 100,000 km^2 of surface waters from offshore areas across the continental shelf and into nearshore areas (DWH Trustees, 2015, Section 4.2). The Trustees performed several surveys to document the presence of natural resources, such as sea turtles, within the DWH footprint, as well as potential exposures and injuries to these resources caused by DHW (DWH Trustees, 2015). In this study, total abundance, potential exposures, and estimated injuries to sea turtles occupying continental shelf waters and nearshore coastal waters (i.e., "neritic" habitats) were quantified by combining data and analyses from line-transect aerial surveys, satellite telemetry studies, and analyses of the temporal and spatial overlap of individual turtles with surface oil. These estimates were combined with mortality estimates based on observed degree of oiling on turtles rescued during 2010 to quantify total injuries to sea turtles in neritic habitats.

2. INTRODUCTION

Five species of sea turtles inhabit the Gulf of Mexico (GoM): loggerheads (*Caretta caretta*), Kemp's ridleys (*Lepidochelys kempii*), green turtles (*Chelonia mydas*), hawksbills (*Eretmochelys imbricata*), and leatherbacks (*Dermochelys coriacea*). Loggerheads, Kemp's ridleys, green turtles, and hawksbills are in the Cheloniidae family (hard shells), and leatherbacks are in the Dermochelyidae family. Loggerheads are listed as "Threatened" under the Endangered Species Act (ESA), while the other four species are listed as "Endangered" under the ESA. Sea turtles in the northern GoM face multiple anthropogenic threats presently, and all populations are depleted relative to historical levels (Wallace et al., 2011).

After spending years in an open-ocean or oceanic phase, juvenile sea turtles recruit into continental shelf or neritic areas, where they continue growing to larger sizes over several additional years – or even decades (Bolten, 2003). Turtles reach adulthood and mostly remain in continental shelf areas for the rest of their lives (Bolten, 2003). The DWH oil spill overlapped with vital marine habitats for sea turtles, including continental shelf and nearshore areas occupied by neritic juveniles and adults (Wallace et al., 2015). Consequently, the Trustees conducted aerial surveys throughout the northern GoM on the continental shelf and in nearshrore areas to count neritic turtles at the surface. These surveys were designed to allow for calculation of estimates of turtle abundance across the survey area through the study period, and subsequently for calculation of overall abundances. These estimates were then used in injury quantification (DWH Trustees, 2015, Section 4.8).

3. METHODS

3.1. DESCRIPTION OF APPROACH

Line-transect aerial survey data were were analyzed using "Distance" analysis (Buckland et al., 2001, Laake and Borchers, 2004) to estimate the abundance of turtles within the surveyed area and to derive spatially explicit maps of turtle density. Double-observer methods (Laake and Borchers, 2004) were used during broadscale surveys conducted during 2011-2012 to estimate the probability of detection on the trackline and therefore correct abundance estimates for the likelihood that a turtle at the surface was detected by the survey teams (i.e., "perception bias"). These data were combined with estimates of the probability of individual turtles becoming "heavily oiled" based on statistical relationships between observed oiling status of rescued turtles and spatio-temporal proximity to satellite-derived surface oil data (Wallace et al., 2015). Based on information gathered during rescue operations, physical fouling in surface oil was determined to be the primary route of exposure and adverse effects on sea turtles (Stacy, 2012; Wallace et al., 2015). Moreover, these adverse effects of direct contact with oil were expected to increase with the degree of oiling observed. Therefore, the outcome of this analysis is an estimate of the total number of "heavily oiled" neritic turtles based on estimated degree of exposure to DWH surface oil.

The equation used to estimate the total number of turtles injured (by taxon) is given by:

$$(1) \quad nInjured = \sum_{i=1}^{n} \frac{s_i}{pd_i\, p(0)_i} \times pHeavilyOiled_i \ ,$$

and,

$$(2) \quad \widehat{NInjured} = A \cdot \frac{nInjured}{2Lw}$$

where:

n = number of turtle "groups" sighted during aerial surveys

s_i = size of group i (equal to 1 for individual turtles)

pd_i = probability of detection conditional on the animal being at the surface (Distance analysis estimate)

$p(0)_i$ = detection probability on trackline (Estimated from Mark-Recapture Distance Sampling [MRDS] analysis)

A = total extrapolation area

L = total trackline surveyed during aerial survey

w = truncation distance (1/2 strip width)

$n_{Injured}$ = estimated number of injured turtles within the surveyed area

$N_{Injured}$ = total estimated number of injured turtles (extrapolated population)

$pHeavilyOiled_i$ = probability that observed turtle is heavily oiled based on logistic regression output in Wallace et al. (2015)

The probability of "heavy oiling" (*pHeavilyOiled*) is derived from a logistic regression model that estimated the probability that a captured turtle was "heavily oiled" based on the statistical relationship between observed turtle oiling status and the satellite-derived surface oil environment [i.e., oil measured by synthetic aperture radar (SAR; Garcia-Pineda et al., 2009; Graettinger et al., 2015)] in the area around and time before turtle captures (Wallace et al., 2015). The model may be interpreted as an assessment of the probability of intersecting sufficient surface oil in order to become "heavily" oiled. However, this model was developed using data from small surface-pelagic turtles that spend nearly 100% of their time near the surface (Bolten, 2003). In contrast, larger, neritic turtles spend less time at the surface (Bolten, 2003), and therefore should have a lower probability of intersecting surface oil compared to surface-pelagic turtles. Nonetheless, all sea turtles—whether small, oceanic juveniles, or large neritic juveniles or adults— must spend time at the surface to breathe, rest, bask, and feed, and these fundamental behaviors put turtles at continuous and repeated risk of exposure anywhere that the ocean surface was contaminated by DWH oil (Wallace et al. 2015).

The parameter pd_i (equation 1) is an estimate of the probability that an animal is detected by the survey team conditional on it being at the surface. The estimated detection on the trackline ($g(0)_i$) is an estimate of "perception bias", the probability of detection on the trackline conditional on the animal being available for detection by both teams. An estimate of the probabilty of an animal being at the surface is available from tag-telemetry studies (see below). However, this probability was excluded from equation 1 to account for the reduced probability of a neretic turtle being at the surface (and thus intersecting with surface oil) compared to pelagic turtles.

The resulting injury (mortalities) for turtles in neretic habitats from this analysis are shown in Table 1. It should be noted that this includes only turtles larger than approximately 40 cm in length because smaller turtles cannot be detected reliably from the aircraft (Schroeder 1985).

3.2. FIELD METHODS AND DATA SOURCES

Aerial Survey Methods

A DeHavilland DHC-6 Twin Otter was used to conduct aerial surveys, and transects were flown at an altitude of 182 m and an airspeed of 185 km/hr. The aircraft position was recorded at 10 second intervals using a GPS, and environmental parameters were recorded including weather conditions (e.g, clear, fog, rain), visibility, water color, water turbidity, sea state, and glare. Surveys were typically flown during favorable sighting conditions at Beaufort sea states less than or equal to 4 (surface winds <12 knots).

Visual observers searched for marine mammals and sea turtles from directly beneath the aircraft out to a perpendicular distance of approximately 600m from the trackline. Due to the configuration of the observing bubble windows and the position of the belly window observer, the trackline directly under the airplane could be reliably surveyed. When the observed sea turtle or marine mammal was perpendicular to the aircraft, the observer measured the angle from the vertical to the animal (or group) using a digital inclinometer or estimated the angle based upon markings on the windows indicating 10-degree intervals. This sighting angle, θ, was converted to the perpendicular distance from the trackline (PSD) by PSD = tan(θ) x Altitude. For some marine mammal sightings, the aircraft circled at lower altitude for species identification and group size estimation. Sea turtles were identified to species visually by the observer based upon size, shell shape, shell coloration, and the relative size of the head to the body. If a reliable species identification could not be made, then the turtle was recorded as an "unidentified hardshell turtle," which included species in the Family Chelonidaee (e.g., loggerheads, Kemp's ridleys, green turtles). Leatherback turtles, the sole extant member of the Family Dermochelyidae, were not mistakable.

During the 2010 synoptic surveys, a single observer team was used including two observers stationed in bubble windows on both sides in the forward portion of the aircraft, a belly window observer, and a data recorder. During the 2011-2012 broadscale surveys, a two-team configuration was used that allowed estimation of perception bias. In this case, the forward team consisted of observers stationed in bubble windows on either side of the aircraft. The aft team consisted of a belly window observer and an observer stationed at a large bubble window on the right side of the aircraft. Both teams had independent data recorders and did not communicate with each other while actively surveying. All turtle sightings were recorded independently and then evaluated after the survey to determine if each sighting was observed by both teams based upon the time and location of the observation. During the summer 2011 survey, a different aircraft was used that did not have the downward looking aft belly window. Hence, the aft team during that survey consisted only of a recorder and an observer looking out of a large bubble window on the right side of the aircraft.

Survey Design – 2010 Synoptic Surveys

Aerial line-transect surveys were conducted between 28 April and 2 September 2010 in the north-central Gulf of Mexico ranging between 91.4°W and 86.8°W longitude covering the southern and eastern coasts of Louisiana, Mississippi Sound, Alabama, and a portion of the western Florida panhandle (Figure 1). The surveys included primarily waters from the shoreline to the 200 m isobaths with limited survey effort in waters between 400-2000 m bottom depth. Analyses for this study are limited to waters <200m in depth. Survey tracklines were spaced at regular intervals (~20 km apart) and were oriented perpendicular to the shoreline and bathymetry gradients. Survey tracklines covering the entire area were designed to be conducted in 3 to 4 flight days. However, weather conditions typically increased the length of this window, or in some cases, prevented the completion of an entire survey. The tracklines were covered during seven sampling periods that ranged between 2 and 7 days in length (Table 2). These survey periods were intended to be spaced approximately 10 days apart; however, this could not always be achieved due to weather conditions or logistical issues.

Survey Design – 2011-2012 Broadscale Surveys

The 2011-2012 broadscale surveys covered waters over the continental shelf from Brownsville, TX (U.S./Mexico border) to north of the Dry Tortugas (Figure 2). Tracklines were oriented perpendicular to the shoreline and bathymetry gradient and spaced 15 km apart throughout most of the survey. Survey tracklines followed uniform spacing from a random start point and were divided into strata to accommodate changes in the orientation of the coastline. The survey as planned encompassed approximately 16,000 km of survey effort which was covered during ~60-day flight windows during the spring (13 April-31 May, 2011), summer (11 July – 4 September, 2011), fall (12 October – 4 December, 2011) and winter (13 January – 9 March, 2012). Due to weather conditions, not all planned tracklines were covered during each survey (Table 3). In addition to tracklines over the continental shelf, "zig-zag" tracklines were flown to cover deeper waters along the shelf break. However, data from these tracklines are not included in the current analysis.

Satellite Telemetry Tag Methods

The amount of time turtles spend near the surface is critical for developing corrections for availability to the survey team given that turtles spend a significant amount of time underwater. Thus, researchers deployed Wildlife computers MK-10A telemetry tags on adult and sub-adult Kemp's ridley and loggerhead sea turtles in the Gulf of Mexico during 2011 and 2012. to provide information on movement patterns and dive-surface behavior. A total of 22 Kemp's Ridley turtles and 30 loggerhead turtles were included in the current analysis (Table 4). This included both in-water captures (i.e. captures by trawling) of sub-adults and turtles encountered on nesting beaches (Table 4, Figure 3). Twenty of these tags (10 Kemp's ridley, 10 loggerheads) were deployed on nesting females by researchers from the U.S. Geological Survey (USGS), Department of Interior under NRDA projects. The remaining tags were deployed under an interagency agreement between NMFS-SEFSC and the Beureau of Offshore Energy Management (SEFSC, unpublished data).The MK-10A tags report both ARGOS and GPS dervied location data and report summaries of dive behaviors as histograms showing the amount of time spent in designated depth "bins" during a given reporting period. For this effort, the tags reported depth summaries in four-hour intervals which allowed evaluation of potential diurnal changes in dive-behaviors. The first depth bin was defined as 0-2 m below the surface, as it was assumed that turtles are visible to the aerial survey near the surface and slightlybeneath the surface. Hence, during each reporting interval, the precentage of time the turtle spent in the first reporting bin was assumed to be equivalent to the percentage of time that the turtle is available to the survey. This metric was incorporated into the abundance estimation as described below.

Habitat Data

Spatially explicit habitat models were derived to examine spatial distribution and density of sea turtles at weekly intervals during the DWH oil spill. The synoptic aerial survey data collected during 2010 were used to derive these models, which included bottom depth, sea surface temperature, and chlorophyll a concentration as explanatory variables. Bathymetry data for the continental shelf was obtained from the ETOPO-1 global digital elevation model which provides a 1-arc minute resolution grid of bottom depth (Amante et al., 2009).

Sea surface temperature (SST) and surface chlorophyll-a (CHL) were obtained from the NASA Ocean Color MODIS platform (http://oceancolor.gsfc.nasa.gov/). Eight-day composites of SST and CHL were obtained from the level-3 products distributed from the Ocean Color website. These images are available as masked and georeferenced HDF files with global coverage. The downloaded images were parsed to the desired spatial coverage, and cells close to land or obscured by clouds were masked in the available imagery. Imagery used in this analysis was from 17, 8-day periods with the first period starting on 23 April 2010 (Table 5).

3.3. ANALYTICAL METHODS

Data were anayzed within the framework of line transect distance analysis with incomplete detection on the trackline (see Buckland et al. 2001 and Laake and Borchers, 2004 for review). Briefly, in addition to collecting information on the location and occurrence of animals along survey tracklines, the perpendicular sighting distance (PSD) is measured as described above. The distribution of the number of sightings as a function of PSD [i.e., the sighting function or $g(x)$ where x is the PSD] can be used to estimate the probability of detection of objects within the surveyed area. Standard distance analysis assumes that detection probability on the trackline [$g(0)$] is equal to 1. In the case of sea turtles, detection on the trackline is incomplete (< 1) because some animals at the surface may be missed by the observer and/or some animals may be beneath the surface and hence not available to be detected by the survey. Thus, an unbiased estimate of the number of animals within the surveyed area is calculated as:

$$(3)\ n_c = \sum_{i=1}^{n} \frac{s_i}{pa_i\, pd_i\, p(0)_i} ,$$

where n is the number of detected animal groups (sightings), s is the size of the group (number of animals in the group), pa is the probability that the group is available to the survey, pd is the probability of detection within the surveyed strip, and $p(0)$ is the probability of detection on the trackline for the group.

The abundance of animals within the entire surveyed area is thus calculated as:

$$(4)\ \hat{N} = A \cdot \frac{n_c}{2Lw} ,$$

where L is the total length (km) of trackline surveyed, w is the "truncation" distance [i.e., the maximum PSD (km) from the line at which sightings are recorded or included in the analysis], and A is the area (km^2) of the region over which the estimation of abundance is desired. Parameters to be estimated therefore include pa, pd, and $p(0)$ for each turtle sighting.

*Estimation of availability (*pa*)*

For each turtle group observed during the aerial survey, the probability of availability (pa in equation 3) was calculated as a stratified mean proportion of time spent on the surface as a function of species, season, and water depth. This mean was calculated from the summarized telemetry data for each species. The proportion of time spent at depth < 2 m was reported in four-hour periods from each tag. These values are therefore nested within each turtle, as it is expected that there is dependence between the four hour periods within each turtle. Since all four hour periods are not reported due to variation in the opportunity for transmission of satellite data, this becomes equivalent to a two-stage cluster sampling of dive behaviors for calculating associated means and variances. Tag position data from both GPS and ARGOS locations were filtered to remove erroneous locations (e.g., on land) or highly uncertain positions from the ARGOS data quality flags reported with each location. The best (i.e., most reliable, highest quality) position for each day was retained. Locations oustide of the range of the aerial surveys inside estuarine waters or in deep waters were also filetered out of this analysis. The bottom depth of each best daily location was derived from the ETOPO1 digital elevation model, whch was used as the depth value for all dive data reported for that day. Based upon preliminary analyses of the depth distribution of turtle tag position, tag locations were divided into "shallow" (<25 m depth) and "deep" (>= 25m depth) locations to reflect potential dive behavior changes as a function of bathymetry. Dive behavior data was also split into "Day" (0600-1800 local time) and "Night" (1800-0600 local time) based upon the time interval of the depth summary. Finally, data were categorized into four seasons: Winter (Dec-Feb), Spring (Mar-May), Summer (Jun-Aug), and Fall (Sep-Nov). These factors (Depth, Day/Night, Region, and Season) were included as fixed factors in a Generalized Linear Mixed Model (GLMM) ANOVA with the individual turtle as a random effect to evaluate effects on dive-surface behavior (proc GLMMIX, SAS v9.2). Following the selection of significant factors, mean (and variances) of the proportion of time spent at the surface were used as estimates of *pa* for each turtle sighting as a function if its location and season of observation.

Estimation of detection probability on the trackline [p(0)]

Detection probability on the trackline [*p(0)*] was estimated using the independent-observer approach described in Laake and Borchers (2004) and using the MRDS package in R (Laake et al. 2015). The high speed of the aircraft and the resulting short viewing interval for each turtle means that turtle sightings are essentially instantaneously available to both teams at the same time. Thus, *p(0)* in this case is an estimate of the likelihood of at least one team on the survey detecting the turtle conditional on its being at the surface at the time the aircraft passed over its location. Two independent survey teams were deployed only during the 2011-2012 broadscale surveys, thus data collected from these surveys were used to model and estimate *p(0)* for the 2010 synoptic surveys. The forward survey team during the 2011-2012 surveys had the same viewing position and configuration as the team during the 2010 surveys. Hence, the relvant variable to be modelled is p*(0)* for the forward survey team.

As noted above, the aft survey team had limited visibility on the left side of the aircraft. Thus, turtles occurring at sighting angles more than 30 degrees from vertical on the left side were not available to the aft team, and were therefore removed from the analysis of *p(0)*. A single model was derived across all four surveys conducted during 2011-2012 in order to better account for variability across different survey teams. The aircraft configuration during the summer 2011 survey did not include the belly window; however, inspection of the data indicated that the trackline was effectively surveyed by the bubble window observer, therefore this survey was also included in the analysis. However, sightings on the left side of the aircraft greater than 10 degrees away from the vertical were excluded for the summer survey as they were not available to the aft team.

For each turtle sighting that was available to both teams, it was determined from the sighting record whether it was seen by the forward team only, the aft team only, or by both teams. Using the MRDS package in R, these data were modelled to derive estimates of *p(0)* as a function of sea state (Beaufort scale), glare, and observer (forward vs. aft) team using the "full independence" independent observer model

(Laake and Borchers, 2004). Additional sighting condition variables (water color, turbidity, and light conditions) were screened for inclusion in the models, but were not meaningful explanatory factors. Data were right truncated at 300m PSD for this and all subsequent analyses of detection probability. An interaction term between observer and distance was included in all models to account for different sighting functions for the two teams. The inclusion of glare, sea state, or both in the model was assessed using AIC, and the full model including all variables was selected for both loggerhead and Kemp's ridley turtles.

Variance estimation for the model parameters was accomplished through bootstrap resampling (see below for description of bootstrap methods). Model parameters were estimated for the observed data and repeated for 999 bootstrap samples. The resulting bootstrap matrix of *p(0)* model parameters was stored for use in estimating the *p(0)* for each turtle sighted as a function of viewing conditions and observer team.

Estimation of detection probability as a function of distance (pd)

The probability of detection was modelled as a function of distance from the trackline and viewing conditions (sea state, glare, etc.) using the multiple covariate distance sampling method (MCDS) as implmented in the R MRDS package. A single detection function was fit using combined data across all synoptic surveys. The sighting function was fit to all turtles observed by the forward survey team using a truncation distance of 300m and a half-normal key function. Sea state and glare were evaluated for each model as explanatory factors with variables selected based upon minimum Akaike's Information Criterion (AIC). In combination with the estimates of *p(0)* described above, the calculation of the detection probability for each sighting [*pa* * *p(0)*] is equivalent to the "point independence" approach described by Laake and Borchers (2004).

Bootstrap sampling for variance estimation

The parameters described above are not independent as they are derived from the same data, hence combining variance estimates analytically is not straightfoward. Bootstrap resampling has been recommended as an alternative method for variance estimate within the Distance framework when there is an expectation that parameters may not meet the distributional assumptions of analytical variance estimates (Buckland et al. 2001). The independent sampling unit in these surveys are the individual line transects. Therefore the bootstrap sample draws (with replacement) random line transects, and their associated sightings, to form the data set for one iteration. Further, it is generally recommended that the bootstrap sampling design conform to the original survey design in terms of stratification and the relative probability of sampling from each strata. In both the synoptic and broadscale surveys, subregions were defined for the purposes of survey design where the orientation of the coastline required changes in trackline orientation. There were five subareas in the synoptic surveys in 2010 and 7 subareas in the broadscale surveys in 2011.

The bootstrap sampling algorithm was constructed so that, for a given survey, the number of tracklines within each subarea was the same as in the actual survey. Thus, the sampling probabilities and amount of area surveyed in each area was approximately equal between the executed survey and each bootstrap sample. Similarly, bootstrap samples for derivation of *p(0)* from the broadscale 2011-2012 surveys reflected the survey design and division into 7 subareas.

Density and Abundance Estimation

Abundance estimates for the entire survey area were derived by calculating n_c (equation 3) using the parameter estimates for *pa*, *pd*, and *p(0)* as described above. The first value in the bootstrap distribution is from the observed sample. For each sighting by the forward team during each synoptic survey period, the value of *p(0)* was estimated from the fitted model. The sighting function reflecting covariates was fit to the data, and the output from that model provides *pd* for each sighting. Finally, *pa* was the mean value for availability at the surface based on the location (depth) and season of the sighting. Estimation of this value therefore provides estimates of strata or survey density and therefore abundance as shown in equation 4. For each bootstrap iteration, the sample was drawn, models were refit to this data set, and parameters were used from the resulting models for that iteration. In the case of *pa*, a random deviate from the normal distribution reflecting the mean and variance for the appropraite depth/season stratum was used. The resulting bootstrap distribution of density/abundance values provides mean values, estimates of uncertainty, and 95% confidence limits for derived paramters.

Spatial Density Models

Estimating the degree of exposure to oil during the DWH event must reflect both spatial and temporal variability in the spatial distribution of the impacted animals (Wallace et al., 2015). Animal density within the survey area is not uniform, and assuming a uniform distribution would therefore over or under-estimate the degree of intersection with oil. Likewise, the oil from the event had a widely varying spatial extent throughout its presence in surface waters of the northern GoM (DWH Trustees, 2015, Section 4.2). Therefore, spatially explicit models of animal density were derived to characterize the spatial distribution of turtles within the survey area.

The density maps were based upon a 10x10 km^2 grid (Figure 4) covering the continental shelf and nearshore coastal waters of the northern GoM. The tracklines within each synoptic survey were first divided into approximately segments that were 10 km in length. Some segments were less than 10 km due to fragmentation of the effort associated with survey conditions or other events; however, an offset term is included in the density models to allow for varying segment lengths. Very small fragments (< 1km in length) were discarded from the analysis (along with any associated sightings) to avoid significant inflation of variances. The remaining segments were treated as sampling units within the density model.

For each line segment, the average value for chlorophyll and sea surface temperature were extracted from the appropriate 8-day composite image for the parameter. Water depth and location values for the segment were based upon the location of the segment midpoint. A "day" variable (i.e., day of the year: 1- 365) was also included in the model to reflect the time frame of the sampling. The julian day was the mid-point day of the relevant survey. Second and third order parameters for each parameter were also derived to account for potential non-linearity in the response. These explanatory variables were entered into a log-linear, zero-inflated model that combined a binomial model structure to model "zero" values and a negative-binomial distribution to model the overdispersed count values in positive observations. The use of zero-inflated models was necessary because of the large number of segments with no observed turtles and the widely varying range of the "positive" values driven by variability in the detection probabilities. The ZINB model was executed in package PSCL (Jackman 2015) in R which allows different explanatory terms in the binomial and count portions of the resulting model. Model selection was accomplished through sequential deletion of terms to minimize AIC, evaluation of the prediction of the number of zeros, evaluation of residual plots, and assessments of goodness of fit between modeled and observed spatial and temporal patterns. An offset term ⌊log(segment length x strip width)⌋ was included in the count (negative binomial) portion of the model. The response variable was the number of animals observed on a particular segment, corrected for the detection probability (n_c in equation 3).

The selected model was used to generate prediction maps of animal density within 10x10 km^2 grid square for each 8-day interval. Uncertainty in density values within each prediction grid was again estimated using the bootstrap procedure described above. However, as an additional step in each bootstrap iteration, the ZINB model was re-fit to the data for the bootstrap sample, and predictions for each grid cell were generated from the resulting predicted values. Hence, for each grid cell, 1,000 bootstrap values of density were generated from which to calculate the mean and metrics of uncertainty.

4. RESULTS

4.1. AERIAL SURVEYS

Survey Effort and Sightings- 2010 Synoptic Surveys

A total of 18,624 km of trackline effort was surveyed during 35 survey days between 28 April – 02 September, 2010 (Table 2). There were seven surveys conducted during this period including tracklines over the continental shelf, nearshore coastal waters, and within Mississippi Sound (Figure 5 A-G). Survey 6 (9 August – 10 August) was only a partial survey that was severely limited by weather conditions. Since the entire area was not sampled during this period, this survey was excluded from subsequent analyses.

Loggerhead turtles were most commonly sighted in waters over the continental shelf, while Kemp's ridley sightings had a more limited spatial range and were concentrated along the outer edge of Chandeleur Sound. There were clear changes in the frequency of sightings across the surveys with higher numbers of sightings during survey 1 and 7, and fewer sightings of both species particularly during surveys 4 and 5 (Figure 5 A-G). Loggerheads were sighted at a total of 338 locations, Kemp's ridleys were sighted 212 locations, and unidentified turtles were sighted at 86 locations during survey effort in the 2010 surveys (Table 6). Nearly 90% of sightings were of single animals; between 2 (n = 46 locations) and 28 animals (n = 1 location) were sighted at the remaining 10% of locations. A total of 445 turtles were sighted during aerial surveys (Table 6)

Survey Effort and Sightings – 2011-2012 Broadscale Surveys

A total of 56,422 km of trackline was surveyed during four seasonal surveys from spring 2011 through winter 2012 (Table 3). Each of the four seasonal surveys completed the majority of planned tracklines; however, some regions could not be covered due to poor weather conditions. In particular the western Gulf during spring 2011 and winter 2012 had limited trackline coverage (Figure 6 A-D). The numbers of loggerhead and Kemp's ridley sightings during the broadscale surveys are shown in Table 7. Loggerhead turtles were obseved primarily in the eastern portion of survey range, while Kemp's ridley turtles were observed in the north central Gulf and in a region of high concentration at intermediate depths over the continental shelf in the western Gulf (Figure 6 A-D).

*Surface availability (*pa*)*

The best daily locations of tagged turtles are shown in Figure 7. The GLMM for loggerheads indicated significant effects for depth stratum and season in the amount of time spent at the surface during daylight hours. The loggerhead turtles tagged during this study generally spent a greater amount of time at the surface in the "deep" stratum (bottom depth > 25m) compared to the "shallow" stratum. The seasonal pattern is variable; however, loggerhead turtles spent the greatest amount of time at the surface during the spring, and less time at the surface during summer months in both depth zones (Table 8). The percentages of time at the surface during the spring and summer months ranged from 7.24% to 13.01%.

For Kemp's ridley turtles, there were no significant depth stratum effects, but there were significant seasonal effects. The tagged Kemp's ridley turtles in this study spent the least amount of time at the surface (9.54%) during winter months. The percentage of time at the surface during spring and summer months was 17.38% and 18.34%, respectively (Table 9).

Probability of detection on the trackline (p(0))

The sightings data from the two-team surveys conducted during 2011-2012 were used to model detection probability on the trackline [$p(0)$] for loggerhead and Kemp's ridley turtles. The best model for detection probability was selected based on the minimum AIC and included sea state, glare, observer (i.e., survey team), distance from the trackline, and the interaction between observer and distance (Tables 10-12,). The interaction term indicates that there was a difference in the detection probability with distance between the forward and aft survey teams, which is to be expected given the differences in sightability between the various positions in the aircraft. The detection probabiity models had a good overall fit to the data (e.g., fits of detection of duplicate sightings, Figure 8). For loggerhead turtles, the resulting average detection probability on the trackline was 0.55 (CV = 0.043) for the forward survey team and 0.56 (CV = 0.042) for the aft survey team. For Kemp's ridley turrtles, the forward team average detection probability was estimated as 0.43 (CV = 0.077) and 0.40 (CV = 0.082) for the aft team.

Detection Probability (p_d)

The detection probability function for the 2010 survey data for both loggerhead and Kemp's ridley turtles included the half-normal key function and sea state as a covariate, though for loggerhead turtles the sea state covariate had an overall very weak effect. The detection functions are shown in Figure 9. The resulting average detection probability within the surveyed strip for loggerhead turtles was 0.60 (CV = 0.0478) (Figure 9A) and that for Kemp's ridley turtles was 0.43 (CV = 0.052) (figure 9B). For hardshell turtles, the dection function indicated a decrease near the trackline (Figure 9C), which is to be expected since generally unidentified turtles are those where the survey teams were not able to see the turtle very well because it was underwater or diving. The detection function model included a half-normal function with no coavariates resulting in an average detection probability of 0.64 (CV = 0.115).

4.2. ABUNDANCE ESTIMATES

The resulting abundance estimates within the surveyed area are shown in Figure 10. For loggerhead turtles, the abundances were highest during the first survey period in late April-early May at 106,112 individuals (95% CI: 71,990 – 144,484) and declined to a low of 15,257 turtles (95% CI: 8,142 – 23,246) during early July. The abundance increased again in late August to 57,102 (95% CI: 34,556 – 87,799; Figure 10A). A similar pattern was observed for Kemp's ridley turtles with high abundances early in the survey period (28 April – 10 May, N = 36,344, 95% CI: 18,774 – 62,716) and declining to 5,444 (95% CI: 946 – 12,507) during early July. The abundance increased dramatically during the late August survey to 122,286 (95% CI: 54,723 – 224,433; Figure 10B). Changes in abundance of unidentified hardshell turtles followed a similar pattern (Figure 10C).

4.3. SPATIAL DENSITY MODELS

Spatial density models were derived only for loggerhead and Kemp's ridley turtles. The selected model parameters for loggerhead turtles are shown in Table 11. The zero-inflated negative binomial (ZINB) model was superior to Poisson, Quasi-Poisson, Negative binomial, and zero-inflated Poisson models based upon likelihood ratio tests. Statistically significant model terms included variables for location, day of the year, and chlorophyll in both the count and binomial components of the zero-inflated negative binomial model. The resulting predicted distribution maps aligned well with the observed distribution of sightings and the overall estimates of abundance. Loggerhead turtles were most abundant during earlier surveys and weeks and were broadly disttributed in waters over the continental shelf (Figures 11 and 12). The highest densities occurred in intermediate depth waters south of Mississippi, Alabama, and the Florida panhandle. Predicted densities declined through late July, then increased again in late August (Figure 15A).

For Kemp's ridley turtles, the selected models also included spatial and temporal terms along with Cholorphyll as important explanatory variables, but these models also included a term for distance from shore in the binomial portion of the model (Table 12). Kemp's ridley turtles had highest predicted densities in waters closer to shore and along the outer edge of the Chandeleur Islands (Figures 13 and 14). Overall densities declined dramatically through June and July, then rebounded in late August (Figure 15B).

4.4. ESTIMATES OF INJURY AND EXPOSURE

Estimates of injury and exposure were dervied by combining the parameters derived in this report with the probability of becoming "heavily" oiled based on the logistic regression model describing the relationship between the degree of spatial and temporal overlap between turtle sighting locations and DWH surface oil (Wallace et al. 2015). For each of the six survey periods, the resulting estimates of exposure were mapped onto 2-week intervals corresponding to the period of time when surface oil was present starting at 28 April and extending through 7 August (Table 13). The total number of injuries (i.e., dead turtles) for each species is the sum of highly exposed individuals across these two-week periods. In addition, it is assumed that all turtles within the surveyed area experienced some degree of lesser exposure and subsequent sub-lethal effects. The "less exposed" estimates shown in Table 13 are derived by replacing pHeavilyOiled ("heavily oiled") in equation 1 with 1-pHeavilyOiled ("less-than-heavily oiled"). A lower mortality estimate was applied to these less exposed individuals (described in Mitchelmore et al. 2015).

4.5. ESTIMATES FOR SMALL NERITIC TURTLES

As noted previously, turtles less than 40cm in carapace length are difficult to detect from a fixed wing aircraft, and hence we expect that the estimates of total neritic turtles from aerial survey data alone is negatively biased. In the case of loggerhead turtles, juveniles tend to recruit to neritic habitats at sizes (> 50 cm; Bolten, 2003) that are larger than minimum size threshold (>40 cm) that is visible from a plane. However, Kemp's ridley turtles tend to recruit to neritic habitats at approximately 25 cm (Bolten, 2003). Using an established population model (Heppell et al. 2005) for Kemp's ridley turtles, we derived estimates of exposures and injuries to smaller age classes occupying neritic waters.

The Heppell et al. (2005) model is a stage-structured model that uses data of hatchling counts from nesting beaches and information about maturity rates, clutch sizes, and survival rates to develop age specific estimates of population size. The aerial surveys conducted in 2010 resulted in an estimated abundance of 30,146 Kemp's ridley turtles averaged across weeks 2-13 (Figure 15B) when surface oil occurred in the area. This population size was assumed to represent turtles aged 4 and older (i.e., > 40 cm; Heppell et al. 2005; Avens and Snover 2013). To apportion this by age class, population abundance by age class was averaged between 2005-2010 from the Heppell et al. (2005) model, and the proportion of the population by age class for ages 4 and higher was calculated. These proportions were multiplied by 30,146 to obtain estimates of abundance by age during the DWH exposure period. The resulting estimate of age 4 population size was then divided by the appropriate age specific survival rate (0.335 for age 1 and 2, 0.871 for age 3; Heppell et al., 2005) to obtain estimates of abundance for ages 1, 2, and 3 (Table 14).

To calculate the number of exposures and injuries, an average area covered by surface oil was derived from daily summaries of surface oil percent coverage developed by the Oil On Water (OOW) technical working group (Graettinger et al., 2015). This dataset summarized available information from remote sensing platforms to quantify the percent coverage of surface oil within 5 x 5 km square spatial cells covering estuarine, coastal, and oceanic waters on a daily basis from 25 April to 28 July 2010 (Graettinger et al. 2015). The daily grids were overlaid to calculate weekly percentage coverage by surface oil within the surveyed area. This weekly area covered was then averaged across weeks resulting in an estimated average 4,430 km^2 area covered by oil. The density of turtles by age class multiplied by this area results in estimates of number of individuals exposed to surface oil. To estimate the number of heavily exposed turtles, this exposure number was then multiplied by the average probability of a turtle being "heavily oiled" based on Wallace et al. (2015). The inputs and resulting estimates of heavily oiled age 1-3 Kemp's ridley turtles is provided in Table 14. However, because age 1 and 2 Kemp's ridleys are typically in surface waters offshore (Bolten, 2003), they were the target life stage of rescue efforts (Stacy, 2012), and were therefore considered in a different analysis (McDonald et al., 2015). Only age 3 Kemp's ridleys were assumed to have been in habitats covered but not detected by aerial surveys; thus, the estimates of exposed and injured age 3 Kemp's ridleys were included injury quantification of neritic turtles (Wallace et al., 2015).

5. SUMMARY AND CONCLUSIONS

In this analysis, we combined density estimates derived from aerial survey data with probabilities of becoming heavily oiled as a funciton of estimated exposure to DWH oil (Wallace et al., 2015) to estimate the injury to turtles in neretic habitats. Analytical approaches were used to account for both the probabiity of detection of animals at the surface and the probability that animals will be available to the survey aircraft based upon dive-surface behaviors. Thus, the density and abundance estimates account for the primary known sources of bias.

Abundance, exposure, and injury estimates were based on sightings of loggerheads Kemp's ridleys, and unidentified turtles over 40 cm in length. The primary assumption of this approach is that the process of becoming "heavily oiled" involves the intersection with oil at the surface. The model describing the relationship between intersections with oil and the degree of oiling was derived for small turtles that spend nearly 100% of their time at the surface (Wallace et al., 2015). Our approach accounts for the behavioral differences of large turtles, and the probability of becoming heavily oiled is therefore reduced due to the smaller amount of time these animals spend at the surface.

In the case of Kemp's ridley turtles, we also dervied estimates of exposure and injury for ages classess that are not quantified by aerial surveys; i.e., are too small to be seen from an aircraft. The critical assumption of this analysis is that the age structure and mortality rates of the animals occupying the neritic habitat during 2010 is the same as that estimated for the entire population by Heppell et al.'s (2005) model. It was not possible to account for the potential exposure and/or injury to smaller loggerhead turtles due to lack of information on spatial distribution and population demography. In the case of both Kemp's and loggerhead turtles, the injury to the oceanic-stage juvenile age classes are evaluated elsewhere in the injury assessment (McDonald et al., 2015).

The results of this study indicate that tens of thousands of turtles in neritic habitats of the Gulf of Mexico were exposed to DWH oil. Of those, thousands experienced sufficient interaction with surface oil to have a high probability of becoming heavily oiled and dying.

LITERATURE CITED

Amante, C. and B.W. Eakins, 2009. ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24. National Geophysical Data Center, NOAA. doi:10.7289/V5C8276M

Avens, L. and M.L. Snover. 2013. Age and age estimation in sea turtles. In *Biology of Sea Turtles, Vol. III*, J.A. Musick, J. Wyneken, and K.J. Lohmann (eds.). CRC Press, Boca Raton, FL. pp. 97–134.

Bolten, A.B. 2003. Variation in sea turtle life history patterns: Neritic vs. oceanic life history stages. Chapter 9 in *The Biology of Sea Turtles Vol. II*, P.L. Lutz, J.A. Musick, and J. Wyneken (eds.). CRC Press, Boca Raton, FL.

Buckland, S.T., D.R. Anderson, K.P. Burnham, and J.L. Laake. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press.

DWH Trustees. 2015. *Deepwater Horizon Oil Spill Programmatic Damage Assessment and Restoration Plan and Programmatic Environmental Impact Statement*. Draft, October.

Garcia-Pineda, O., B. Zimmer, M. Howard, W. Pichel, X. Li, and I. MacDonald. 2009. Using SAR images to delineate ocean slicks with a texture-classifying neural network algorithm (TCNNA). *Can J Remote Sensing* 35:1–11.

Graettinger, G., J. Holmes, O. Garcia-Pineda, M. Hess, C. Hu, I. Leifer, I. MacDonald, F. Muller-Karger, Svejkovsky, and G. Swayze. 2015. Integrating Data from Multiple Satellite Sensors to Estimate Daily Oiling in the Northern Gulf of Mexico during the Deepwater Horizon Oil Spill.

Heppell, S.S., D.T. Crouse, L.B. Crowder, S.P. Epperly, W. Gabriel, T. Henwood, R. Marquez, and N.B. Thompson. 2005. A population model to estimate recovery time, population size, and management impacts on Kemp's ridleys. Chelonian Conservation and Biology 4:767–773.

Jackman, S. 2015. pscl: Classes and Methods for R Developed in the Political Science Computational Laboratory, Stanford University. Department of Political Science, Stanford University. Stanford, California. R package version 1.4.9. URL http://pscl.stanford.edu/

Laake, J.L. and D.L. Borchers. 2004. Methods for incomplete detection at distance zero. pp. 108-189. *In:* S.T. Buckland, D.R. Andersen, K.P. Burnham, J.L. Laake and L. Thomas (eds.) Advanced distance sampling. Oxford University Press, New York.

Laake, J., Borchers, D., Thomas, L., Miller, D and J. Bishop. 2015. mrds: Mark-Recapture Distance Sampling. R package version 2.1.14. http://CRAN.R-project.org/package=mrds

Mitchelmore, C., T. Collier, and C. Bishop. 2015. Estimated Mortality of Oceanic Sea Turtles Oiled during the BP Deepwater Horizon Oil Spill. DWH NRDA Sea Turtle Technical Working Group Report.

NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group; (2014): MODIS-Aqua Ocean Color Data; NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. http://dx.doi.org/10.5067/AQUA/MODIS_OC.2014.0

Schroeder, B.A. 1985. Memorandum: Size class experiment – pelagic aerial surveys. Prepared for Nancy B. Thompson, Southeast Fisheries Center, Miami, FL. April 16, 1985. Pp 4.

Stacy, B. 2012. Summary of Findings for Sea Turtles Documented by Directed Captures, Stranding Response, and Incidental Captures under Response Operations during the BP DWH MC252 Oil Spill. DWH NRDA Sea Turtle Technical Working Group Report.

Wallace, B.P., A.D. DiMatteo, A.B. Bolten, M.Y. Chaloupka, B.J. Hutchinson, F.A. Abreu-Grobois, J.A. Mortimer, J.A. Seminoff, D. Amorocho, K.A. Bjorndal, J. Bourjea, B.W. Bowen, R. Briseño-Dueñas, P. Casale, B.C. Choudhury, A. Costa, P.H. Dutton, A. Fallabrino, E.M. Finkbeiner, A. Girard, M. Girondot, M. Hamann, B.J. Hurley, M. López-Mendilaharsu, M.A. Marcovaldi, J.A. Musick, R. Nel, N.J. Pilcher, S. Troëng, B. Witherington, and R.B. Mast. 2011. Global conservation priorities for marine turtles. *PLoS ONE* 6(9):e24510. doi: 10.1371/journal.pone.0024510.

Wallace, B.P., M. Rissing, D. Cacela and B. Stacy. 2015. Estimating Oil Exposure for Sea Turtles Captured and Sighted during Response Activities during the BP Deepwater Horizon Oil Spill. DWH NRDA Sea Turtle Technical Working Group Report. Abt Associates, Boulder, CO. Prepared for: NOAA Assessment and Restoration Division. Pp 40.

Table 1. Estimated injuries of turtles (> 40 cm) in neritic habitats associated with exposure to DWH oil.

Taxon	Estimated Injuries	95% Confidence Interval
Loggerhead	2,215	800 – 3,886
Kemp's ridley	1,688	349 – 4,496
Unidentified hardshell	631	67 – 1,549

Table 2. Survey effort during 2010 synoptic surveys.

Survey ID	Survey Date	Trackline (km)
1	4/28/2010	743.0
1	4/29/2010	432.0
1	5/5/2010	449.7
1	5/6/2010	579.8
1	5/7/2010	428.8
1	5/8/2010	178.2
1	5/10/2010	354.8
2	5/20/2010	292.7
2	5/21/2010	495.2
2	5/22/2010	599.3
2	5/23/2010	806.0
2	5/24/2010	691.0
3	6/7/2010	641.6
3	6/8/2010	752.3
3	6/9/2010	569.3
3	6/11/2010	701.9
3	6/12/2010	444.7
3	6/13/2010	287.2
4	7/8/2010	500.2
4	7/9/2010	962.8
4	7/10/2010	238.9
4	7/12/2010	370.9
5	7/22/2010	707.5
5	7/27/2010	495.1
5	7/28/2010	657.9
5	7/29/2010	729.0
5	7/30/2010	121.3
5	7/31/2010	204.3
6	8/9/2010	284.1
6	8/10/2010	869.3
7	8/25/2010	700.5
7	8/26/2010	623.6
7	8/31/2010	773.8
7	9/1/2010	453.2
7	9/2/2010	485.1
	Total	**18624.9**

Table 3. Survey effort during broadscale aerial surveys. Sighting counts represent the number of turtles observed during the surveys by both teams combined.

Survey	Dates	Total Trackline (km)
Spring	4/14/11–5/31/2011	13,608
Summer	7/11/2011 – 9/4/2011	15,800
Fall	10/12/2011 – 12/4/2011	13,971
Winter	1/13/2012 – 3/19/2012	13,043

Table 4. Loggerhead (A) and Kemp's ridey (B) satellite tag deployments included in the current analysis.

(A) Loggerhead turtles

PTT	Species	Life Stage	Release Date	Last Transmission Date
100600	Loggerhead	Adult	6/13/2011	7/27/2012
100604	Loggerhead	Adult	6/12/2011	2/2/2012
100605	Loggerhead	Adult	6/12/2011	1/27/2012
100608	Loggerhead	Sub-Adult	10/27/2011	4/23/2012
100611	Loggerhead	Adult	6/12/2011	9/28/2012
100614	Loggerhead	Adult	6/13/2011	9/29/2012
106337	Loggerhead	Adult	6/11/2011	8/31/2011
106338	Loggerhead	Sub-Adult	7/12/2011	1/21/2012
106342	Loggerhead	Adult	6/12/2011	7/31/2012
106344	Loggerhead	Adult	5/26/2011	9/26/2011
106345	Loggerhead	Adult	6/9/2011	11/11/2011
106349	Loggerhead	Adult	7/1/2011	4/20/2012
106350	Loggerhead	Adult	5/22/2012	7/20/2012
106354	Loggerhead	Adult	5/21/2011	10/29/2011
106355	Loggerhead	Sub-Adult	5/18/2011	7/10/2011
106358	Loggerhead	Adult	6/14/2011	9/13/2011
106360	Loggerhead	Adult	6/7/2011	12/24/2011
106361	Loggerhead	Adult	6/13/2011	6/18/2012
106363	Loggerhead	Sub-Adult	7/12/2011	9/8/2011
106364	Loggerhead	Sub-Adult	5/23/2012	7/13/2012
119943	Loggerhead	Adult	6/4/2012	10/1/2012
119944	Loggerhead	Adult	6/7/2012	10/1/2012
119945	Loggerhead	Adult	6/9/2012	8/8/2012
119946	Loggerhead	Adult	6/9/2012	9/4/2012
119947	Loggerhead	Adult	6/13/2012	8/12/2012
119948	Loggerhead	Adult	6/11/2012	10/1/2012
119949	Loggerhead	Adult	6/11/2012	7/21/2012
119950	Loggerhead	Adult	6/11/2012	8/6/2012
119951	Loggerhead	Adult	6/11/2012	8/2/2012
119952	Loggerhead	Adult	7/23/2012	10/1/2012

Table 4 cont. Loggerhead and Kemp’s ridey satellite tag deployments included in the current analysis.

(B) Kemp’s ridley turtles

PTT	Species	Life Stage	Release Date	Last Location
100596	Kemp's Ridley	Sub-Adult	10/28/2011	11/5/2011
100597	Kemp's Ridley	Sub-Adult	10/14/2011	11/7/2011
100601	Kemp's Ridley	Sub-Adult	10/22/2011	2/1/2012
100609	Kemp's Ridley	Juvenile	11/16/2011	4/1/2012
100613	Kemp's Ridley	Sub-Adult	10/15/2011	11/13/2011
106339	Kemp's Ridley	Adult	4/23/2011	9/8/2011
106340	Kemp's Ridley	Adult	9/23/2011	12/19/2011
106341	Kemp's Ridley	Adult	4/25/2011	9/8/2011
106343	Kemp's Ridley	Adult	4/26/2011	7/31/2012
106346	Kemp's Ridley	Adult	4/28/2011	10/17/2011
106347	Kemp's Ridley	Adult	4/28/2011	9/29/2011
106356	Kemp's Ridley	Sub-Adult	9/21/2011	10/29/2011
106357	Kemp's Ridley	Sub-Adult	5/25/2012	6/16/2012
106365	Kemp's Ridley	Sub-Adult	8/15/2011	2/20/2012
110809	Kemp's Ridley	Sub-Adult	5/24/2012	6/10/2012
110810	Kemp's Ridley	Sub-Adult	5/24/2012	6/16/2012
110811	Kemp's Ridley	Sub-Adult	11/18/2011	3/24/2012
117512	Kemp's Ridley	Adult	5/23/2012	9/22/2012
117513	Kemp's Ridley	Adult	5/23/2012	7/30/2012
117514	Kemp's Ridley	Adult	5/24/2012	7/18/2012
117515	Kemp's Ridley	Adult	6/8/2012	8/20/2012
117516	Kemp's Ridley	Adult	6/10/2012	9/22/2012

Table 5. 8-day intervals used during habitat model analyses.

Interval	Start Date	End Date	Day of the Year (midpoint)
1	23 April	30 April	117
2	1 May	8 May	125
3	9 May	16 May	133
4	17 May	24 May	141
5	25 May	1 June	149
6	2 June	9 June	157
7	10 June	17 June	165
8	18 June	25 June	173
9	26 June	3 July	181
10	4 July	11 July	189
11	12 July	19 July	197
12	20 July	27 July	205
13	28 July	4 August	213
14	5 August	12 August	221
15	13 August	20 August	229
16	21 August	28 August	237
17	29 August	5 September	245

Table 6. The numbers of on effort sightings and individuals of (A) loggerhead, (B) Kemp's ridley, and (C) Unidentified turtles during the 2010 synoptic aerial surveys

(A) Loggerhead turles

Survey	Number of Sightings	Number of Turtles
1	146	195
2	48	66
3	37	67
4	17	17
5	18	21
6	8	11
7	64	68
Total	338	445

(B) Kemp's ridley turltes

Survey	Number of Sightings	Number of Turtles
1	50	55
2	18	18
3	24	28
4	4	4
5	29	30
6	10	12
7	77	103
Total	212	250

(C) Unidentified hardshell turles

Survey	Number of Sightings	Number of Turtles
1	30	33
2	15	15
3	7	7
4	7	10
5	8	8
6	8	12
7	11	12
Total	86	97

Table 7. Sightings of loggerheads (A) and Kemp's ridleys (B) by survey team during seasonal broadscale surveys. These counts include "on effort" sightings only during flights when the two teams were operating independently of one another in survey mode.

(A) Loggerhead turtles

Season	Forward Team Only	Aft Team Only	Both Teams	Total
Spring	100	57	83	240
Summer	194	61	99	354
Fall	247	169	126	542
Winter	147	47	120	314

(B) Kemp's ridley

Season	Forward Team Only	Aft Team Only	Both Teams	Total
Spring	6	3	4	13
Summer	89	22	20	131
Fall	166	107	47	320
Winter	112	55	55	222

Table 8. Mean percentage (and SE) of time spent at surface during daylight hours for loggerhead turtles. N indicates the number of 6-hour periods included in the estimation of the mean and SE. The “shallow” stratum indicates waters <= 25m depth, the deep stratum includes depths from 25m – 200m.

Depth Stratum	Season	Mean	Std. Error	N
Shallow	Winter	7.44	0.85	96
Shallow	Spring	10.89	1.71	111
Shallow	Summer	7.24	0.65	547
Shallow	Fall	8.8	2.03	193
Deep	Winter	7.57	1.29	318
Deep	Spring	13.01	2.05	213
Deep	Summer	11.18	1.45	754
Deep	Fall	11.64	1.57	481

Table 9. Mean percentage (and SE) of time spent at surface during daylight hours for Kemp’s ridley turtles. N indicates the number of 6-hour periods included in the estimation of the mean and SE.

Season	Mean	Std. Error	N
Winter	9.54	2.87	170
Spring	17.38	2.78	263
Summer	18.34	6.6	539
Fall	15.23	3.05	333

Table 10. Parameter and uncertainty (SE) estimates for the mark-recapture component of the distance anlaysis to estimate detection probability on the trackline for (A) loggerhead turtles and (B) Kemp's ridley turtles.

(A) Loggerhead turtles

Parameter	Estimate	Std. Error	Bootstrap Mean	Bootstrap SE
Intercept	0.769	0.263	0.950	0.275
Observer	0.034	0.125	-0.062	0.134
Distance	0.002	0.002	0.0009	0.001
Sea State	-0.316	0.089	-0.316	0.107
Glare	-0.017	0.137	-0.0005	0.223
Observer x Distance	-0.002	0.001	-0.0014	0.001

(B) Kemps ridley turtles

Parameter	Estimate	Std. Error	Bootstrap Mean	Bootstrap SE
Intercept	0.362	0.376	0.354	0.397
Observer	-0.110	0.158	-0.112	0.169
Distance	0.001	0.003	0.001	0.004
Sea State	-0.296	0.128	-0.288	0.145
Glare	0.132	0.217	0.126	0.232
Observer x Distance	-0.003	0.002	-0.003	0.002

Table 11. Loggerhead turtle habitat model parameters and selction. Explanatory terms for the count and binomial components of the zero-inflated negative binomial model were selected based upon the minimum Akaike's Information Criterion (AIC) among competing models. Model terms indicated in bold were statistically significant ($p < 0.05$).

Model	Count Model Terms	Binomial Model Terms	AIC	ΔAIC
0	z + z.2 + **X** + x.2 + y + y.2 + dfs + sst + **CHL** + jul + **JUL.2** + jul.3	z + z.2 + x + x.2 + y + **Y.2** + dfs + sst + **CHL** + **JUL** + **JUL.2** + jul.3	3104	10
1	z + z.2 + **X** + x.2 + **Y** + y.2 + **CHL** + jul + **JUL.2** + jul.3	z + z.2 + x + x.2 + y + **Y.2** + **CHL** + **JUL** + **JUL.2** + jul.3	3101	7
2	**X** + x.2 + **Y** + y.2 + **CHL** + jul + **JUL.2** + jul.3	x + x.2 + **Y** + **Y.2** + **CHL** + **JUL** + **JUL.2** + jul.3	3124	30
3	**X** + x.2 + **Y** + y.2 + **CHL** + jul + **JUL.2** + jul.3	z + z.2 + x + x.2 + y + **Y.2** + **CHL** + **JUL** + **JUL.2** + jul.3	3097	3
4	**X** + x.2 + **Y** + y.2 + **CHL** + jul + **JUL.2** + jul.3	z + **Z.2** + y + **Y.2** + **CHL** + **JUL** + **JUL.2** + jul.3	3094	0

Model term defintions:
z, z.2 – depth and depth squared; x, x.2 – east-west coordinate and squared term; y, y.2 – north-south coordinate and squared term; dfs – distance from shore; sst – sea surface temperature; chl – surface chlorophyll; jul, jul.2, jul3 – julian day and second and third order terms.

Table 12. Kemp's ridley turtle habitat model parameters and selction. Explanatory terms for the count and binomial components of the zero-inflated negative binomial model were selected based upon the minimum Akaike's Information Criterion (AIC) among competing models. Model terms indicated in bold were statistically significant ($p < 0.05$).

Model	Count Model Terms	Binomial Model Terms	AIC	ΔAIC
0	z + z.2 + x+ **X.2** + y + y.2 + dfs + sst + **CHL** + **JUL** + jul.2 + jul.3	z + **Z.2** + **X** + **X.2** + y + **Y.2** + **DFS** + sst + **CHL** + jul + **JUL.2** + jul.3	2264	9
1	z + z.2 + x+ **X.2** + y + y.2 + dfs + chl + **JUL** + jul.2 + jul.3	z + **Z.2** + **X** + **X.2** + y + y.2 + **DFS** + **CHL** + jul + **JUL.2** + jul.3	2263	8
2	z + z.2 + x+ **X.2** + y + y.2 + **CHL** + jul + **JUL.2** + jul.3	z + **Z.2** + **X** + **X.2** + y + y.2 + **DFS** + **CHL** + jul + **JUL.2** + jul.3	2261	6
3	x + **X.2** + CHL + jul + JUL.2 + jul.3	z + **Z.2** + **X** + **X.2** + y + y.2 + **CHL** + **DFS** + jul + **JUL.2** + jul.3	2260	5
4	chl + **JUL** + jul.2 + jul.3	**Z**+ **Z.2** + **X** + **X.2** + y + y.2 + **CHL** + jul + **JUL.2** + jul.3	2263	8
5	**X** + **X.2** + **CHL** + jul + **JUL.2** + jul.3	z + **Z.2** + **X** + **X.2** + **CHL** + dfs + jul + **JUL.2** + jul.3	2255	0

Model term defintions:
z, z.2 – depth and depth squared; x, x.2 – east-west coordinate and squared term; y, y.2 – north-south coordinate and squared term; dfs – distance from shore; sst – sea surface temperature; chl – surface chlorophyll; jul, jul.2, jul3 – julian day and second and third order terms.

Table 13. Estimates of injured and exposed turtles in the neritic habtiat for (A) loggerhead turtles, (B) Kemp's ridley turtles, and (C) unidentified hardshell turtles.

(A) Loggerhead turtles

Weeks	Survey	High Exposed	95% CI	Less Exposed	95% CI
28Apr-13May	28Apr-10May	0	-	12552	8610 - 17695
14May-28May	20May-24May	249	129 - 375	3913	1932 - 7629
29May-11Jun	07Jun-13Jun	412	143 - 725	3742	1255 - 8991
12Jun-26Jun	07Jun-13Jun	412	143 - 725	3742	1255 - 8991
27Jun-10Jul	08Jul-21Jul	484	193 - 827	1089	698 - 1570
11Jul-24Jul	08Jul-21Jul	484	193 - 827	1089	698 - 1570
25Jul-7Aug	22Jul-31Jul	174	0 - 410	1498	945 - 2098
Total		2215	799 – 3887	27624	15391 - 48453

(B) Kemp's ridley turtles

Weeks	Survey	High Exposed	95% CI	Less Exposed	95% CI
28Apr-13May	28Apr-10May	0	-	6319	3315 - 10844
14May-28May	20May-24May	148	0 – 403	1692	914 – 2610
29May-11Jun	07Jun-13Jun	592	174 - 1499	2732	1482 – 4544
12Jun-26Jun	07Jun-13Jun	592	174 - 1499	2732	1482 – 4544
27Jun-10Jul	08Jul-21Jul	149	0 – 440	651	171 – 1230
11Jul-24Jul	08Jul-21Jul	149	0 – 440	651	171 – 1230
25Jul-7Aug	22Jul-31Jul	59	0 - 215	4169	2533 – 6439
Total		1689	349 - 4496	18945	10068 - 31441

(C) Hardshell turtles

Weeks	Survey	High Exposed	95% CI	Less Exposed	95% CI
28Apr-13May	28Apr-10May	0	-	1940	917 – 3252
14May-28May	20May-24May	0	-	809	341 – 1503
29May-11Jun	07Jun-13Jun	71	0 - 168	393	177 – 691
12Jun-26Jun	07Jun-13Jun	71	0 - 168	393	177 – 691
27Jun-10Jul	08Jul-21Jul	244	34 - 607	595	164 – 1181
11Jul-24Jul	08Jul-21Jul	244	33 – 607	595	164 – 1181
25Jul-7Aug	22Jul-31Jul	0	-	510	148 – 975
Total		631	67 - 1550	5235	2088 - 9473

Table 14. Estimates of injured and exposed turtles in the neritic habtiat for ages 1-3 Kemp's ridley turtles.

Age	Estimated Abundance	Total Area (km^2)	Density (N/km^2)	Avg Oil Area (km2)	Number Exposed	Probability of being heavily oiled	Number heavily oiled
1	77122	38900	1.98	4430	8783	0.044	3393
2	25836	38900	0.66	4430	2942	0.044	1137
3	8655	38900	0.22	4430	986	0.044	381

Figure 1. Spatial extent of synoptic aerial surveys conducted during April – September 2010. All "on effort" trackline segments are shown. Portions of tracklines in waters > 200m depth were excluded from this analysis.

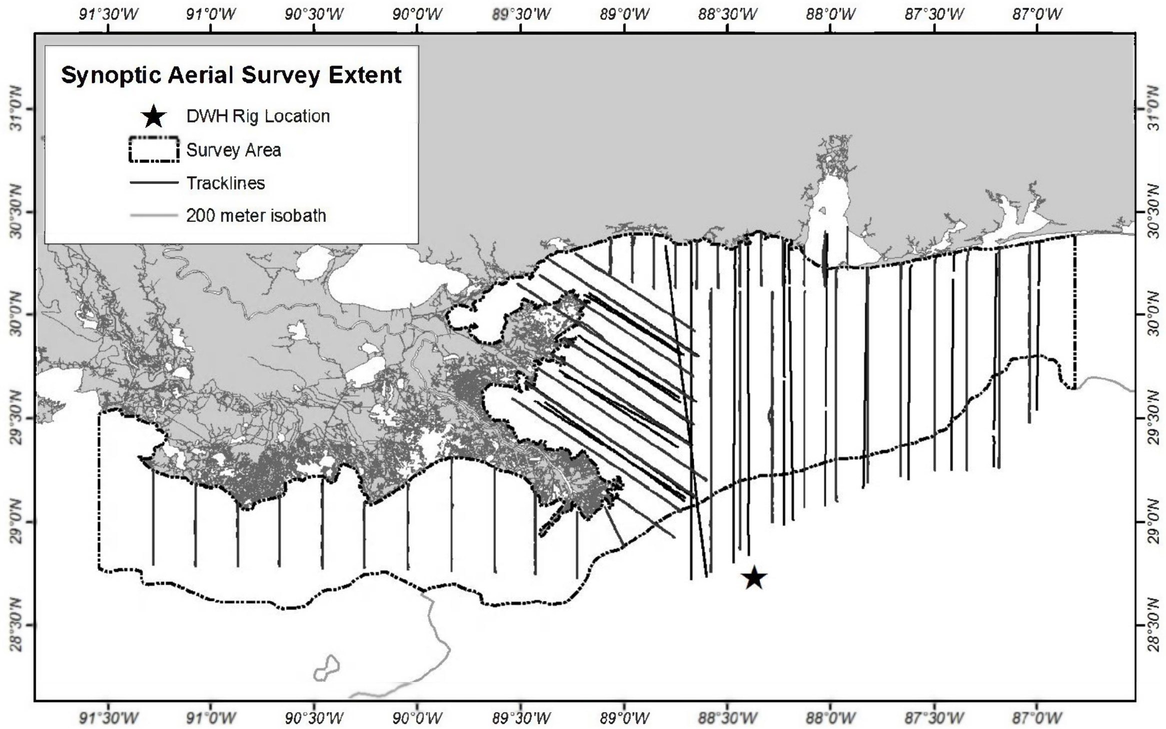

Figure 2. Spatial extent of seasonal broadscale aerial surveys flown during 2011-2012.

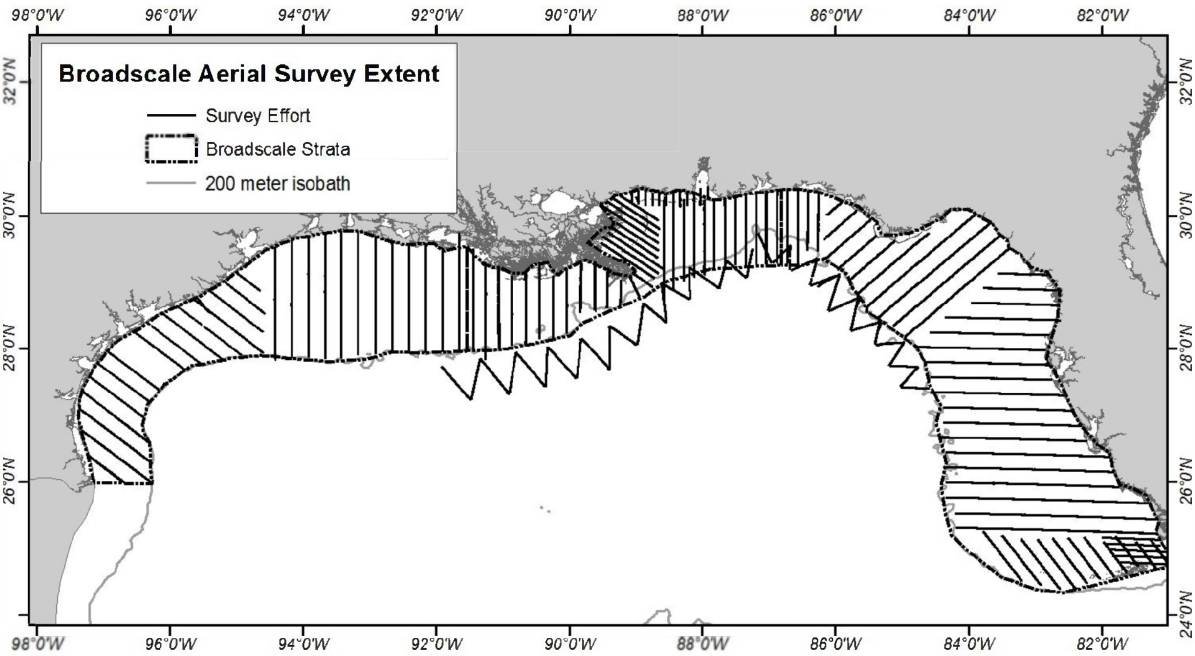

Figure 3. Initial tagging locations of loggerhead and Kemp's ridley turtles included in the analysis of dive-surface behaviors.

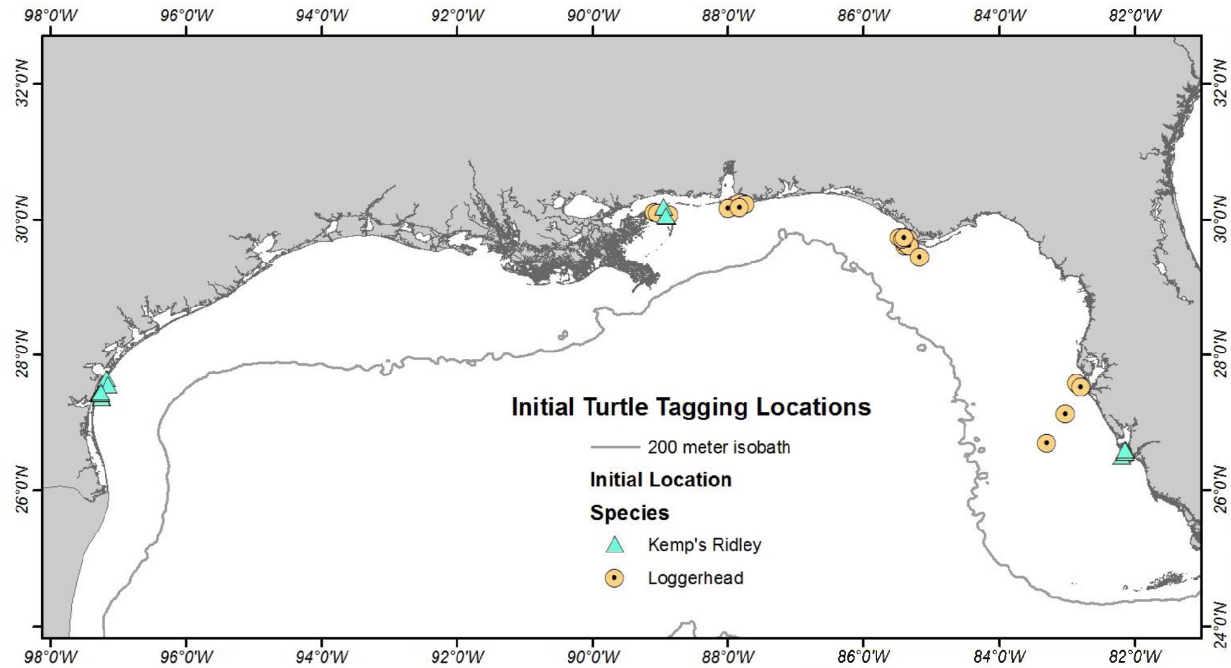

Figure 4. Grid area (10 x 10 km cells) used for habitat models of animal density.

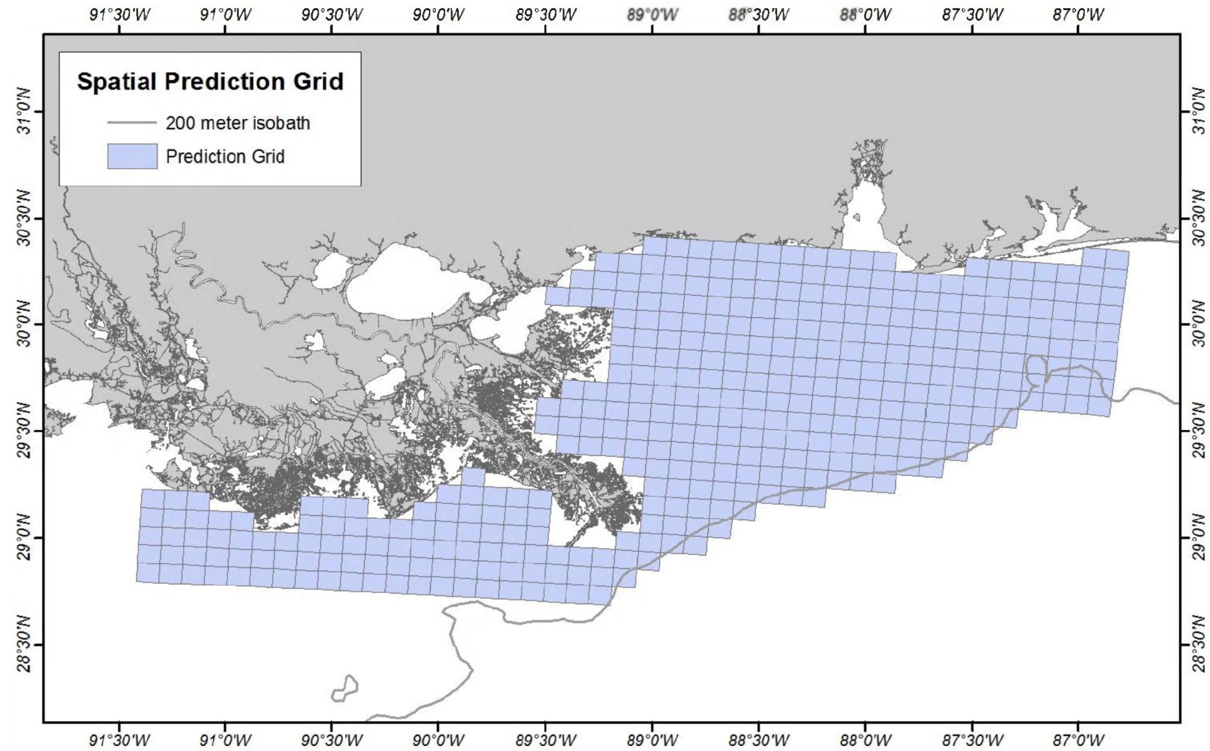

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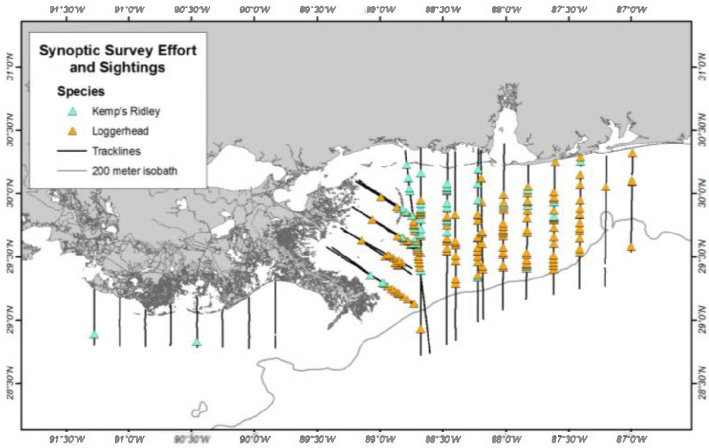
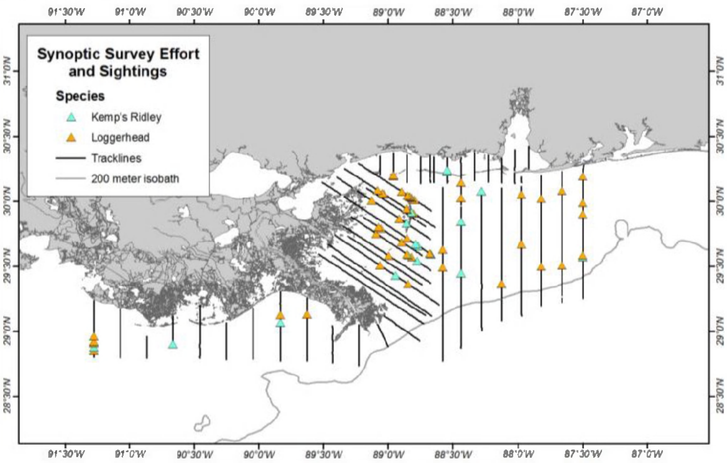
Figure 5. Survey effort and turtle sightings for synoptic surveys.
(A) Survey 1



(B) Survey 2



(C) Survey 3

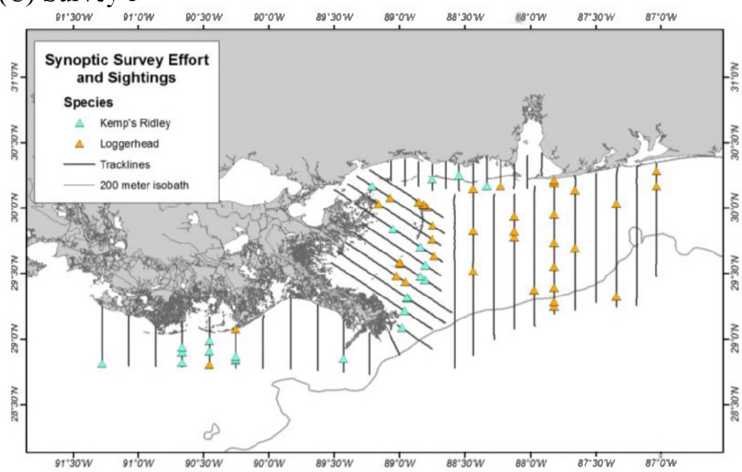


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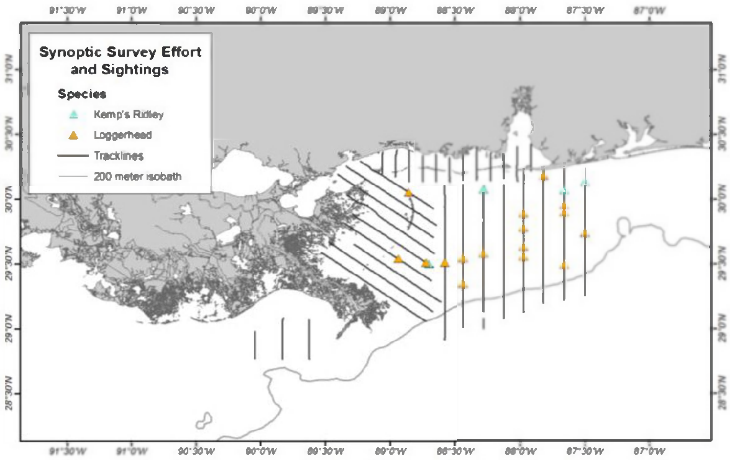
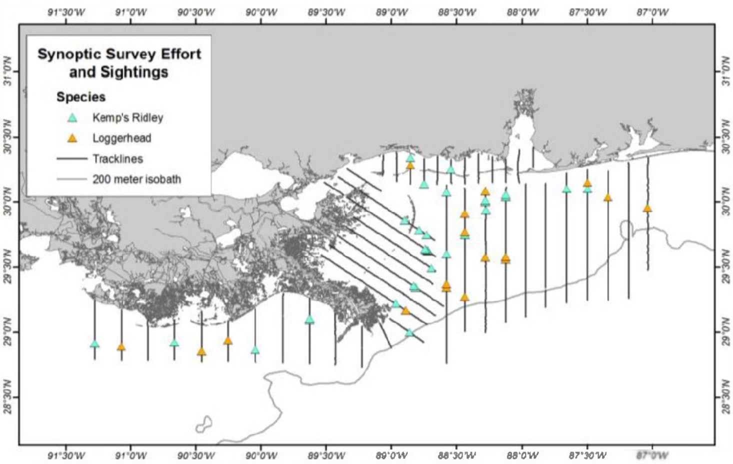
Figure 5 cont. Survey effort and turtle sightings for synoptic surveys.
(D) Survey 4



(E) Survey 5



(F) Survey 6

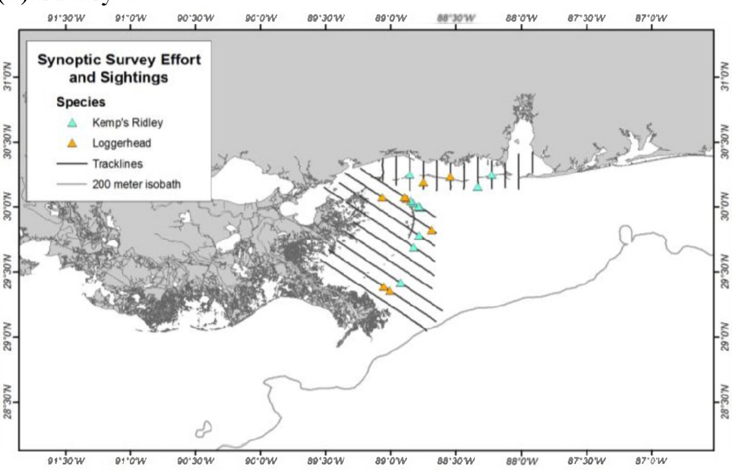


Figure 5 cont. Survey effort and turtle sightings for synoptic surveys.

(G) Survey 7

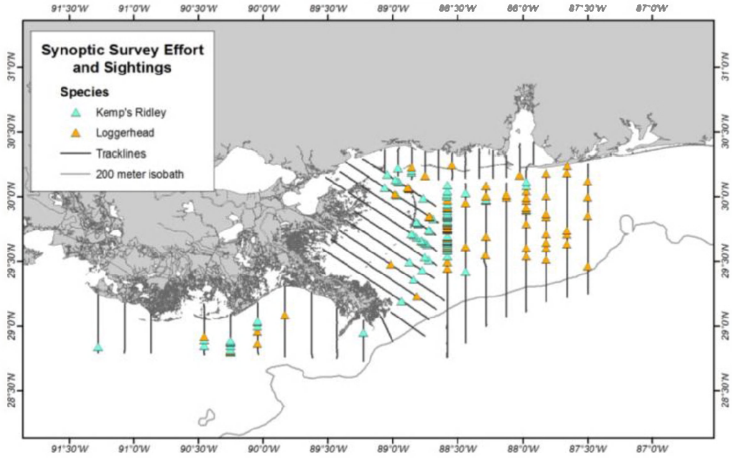
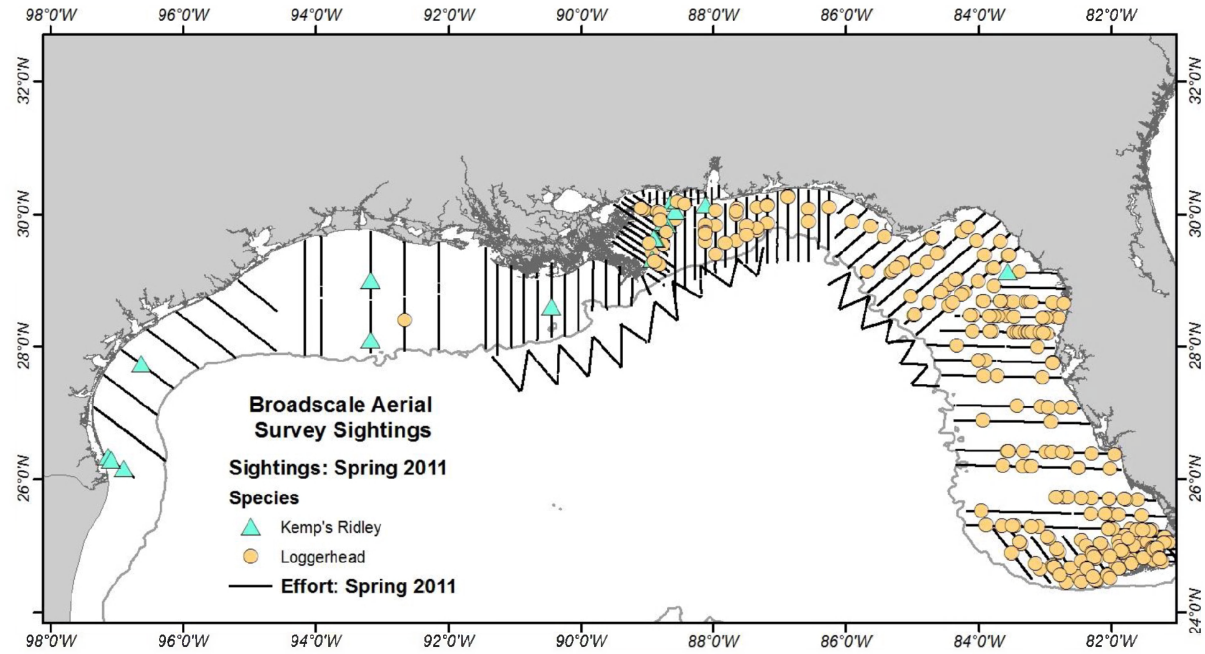


Figure 6. Survey effort and turtle sightings for seasonal broadscale surveys.

(A) Spring 2011



(B) Summer 2011

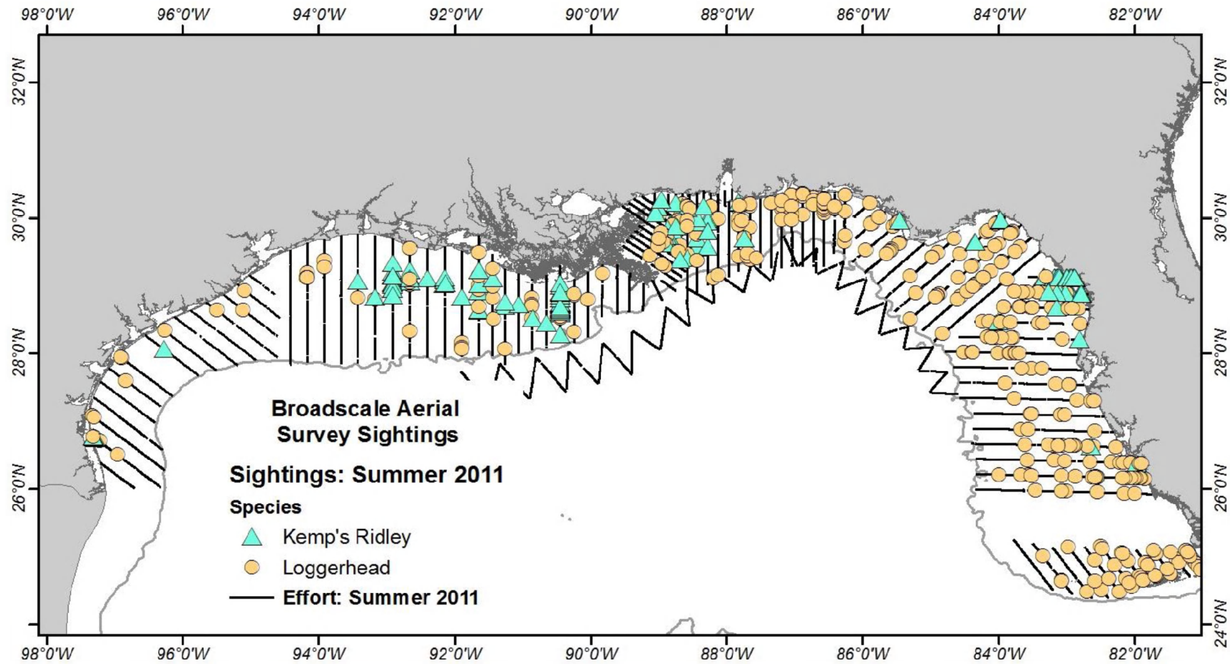


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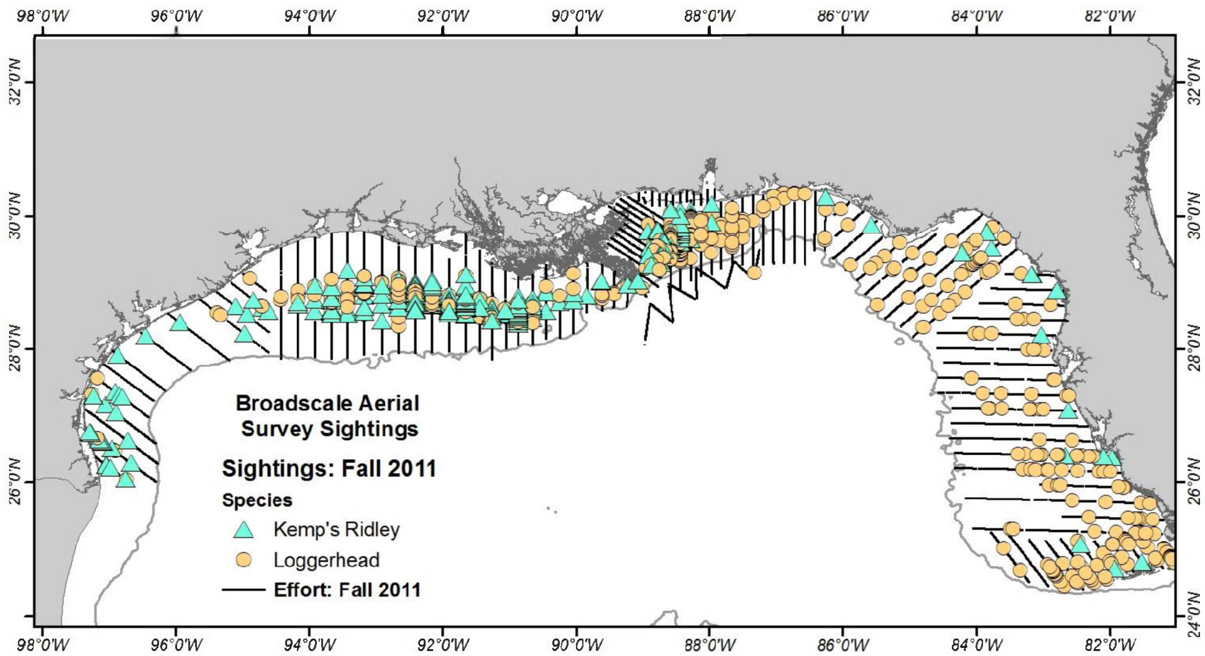
Figure 6 cont. Survey effort and turtle sightings for seasonal broadscale surveys.

(C) Fall 2011



(D) Winter 2012

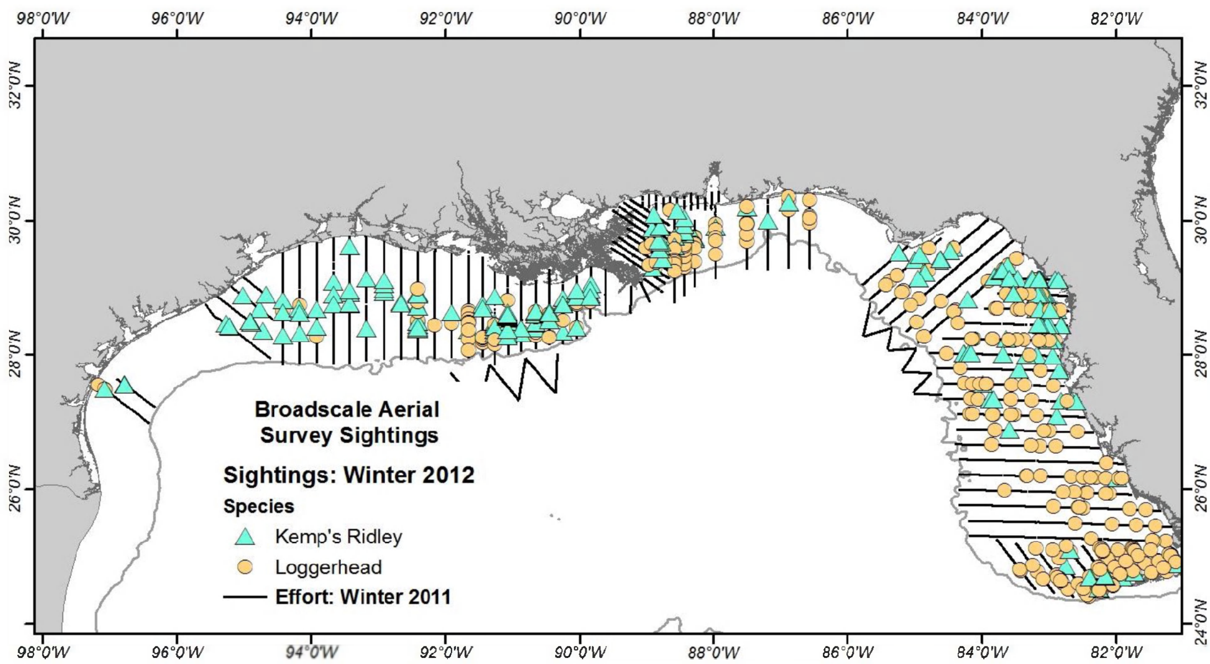


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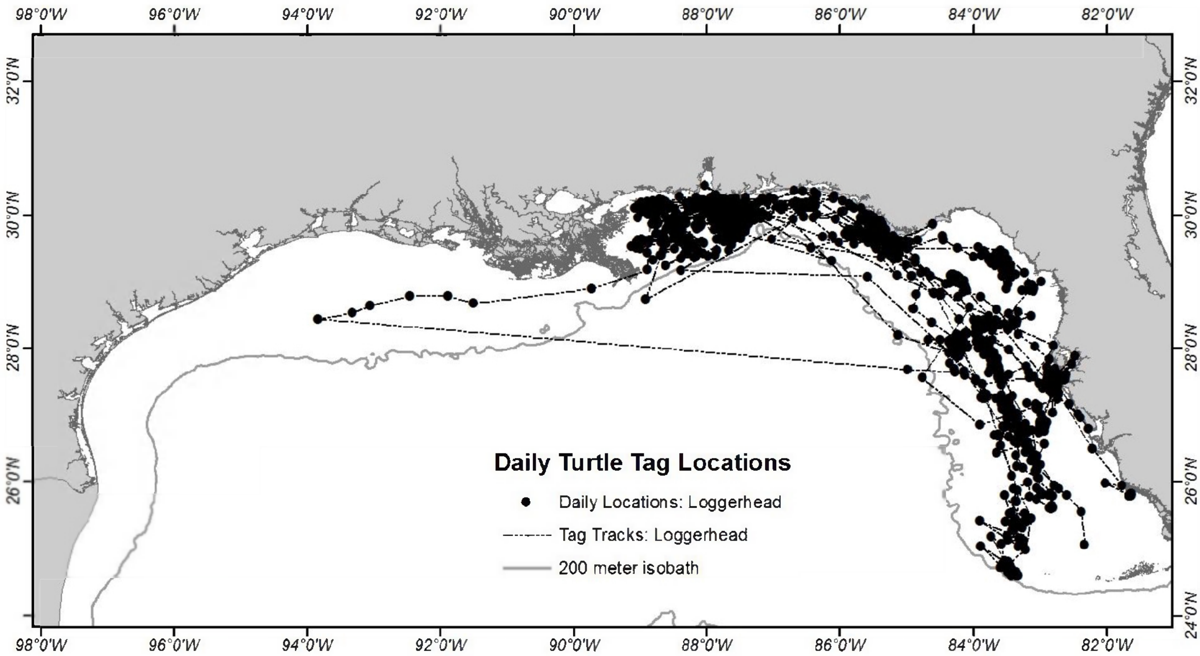
Figure 7. Daily best tag locations and tracks for loggerhead (A) and Kemp's ridley (B) turtles.

(A) Loggerhead



(B) Kemp's ridley

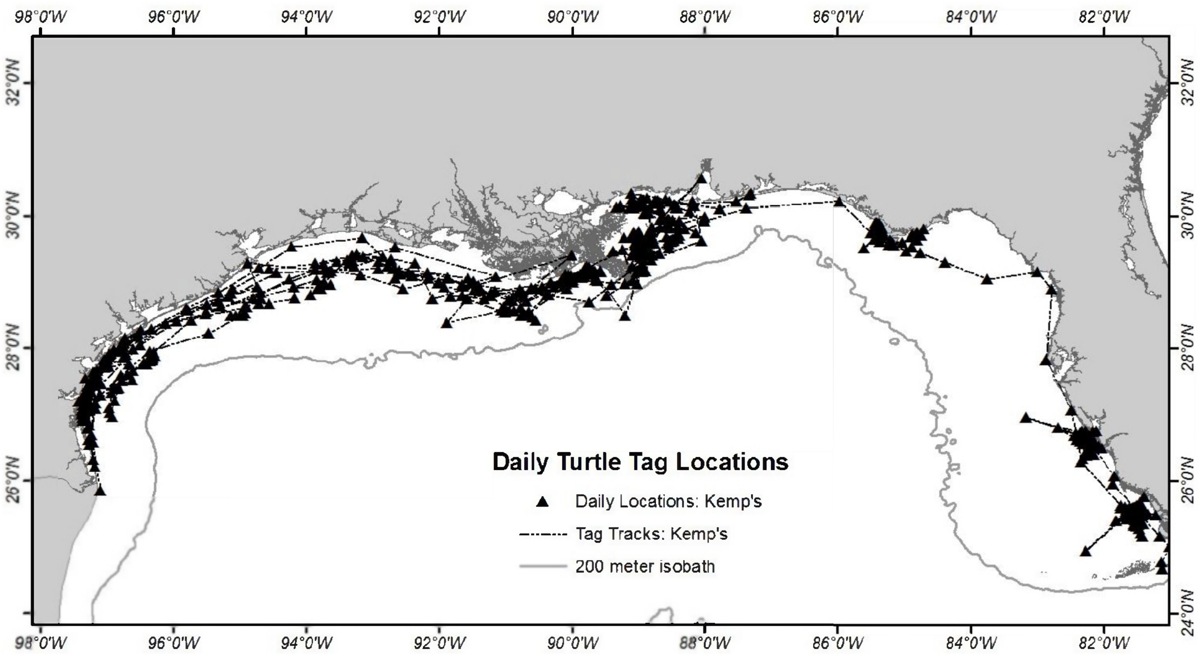
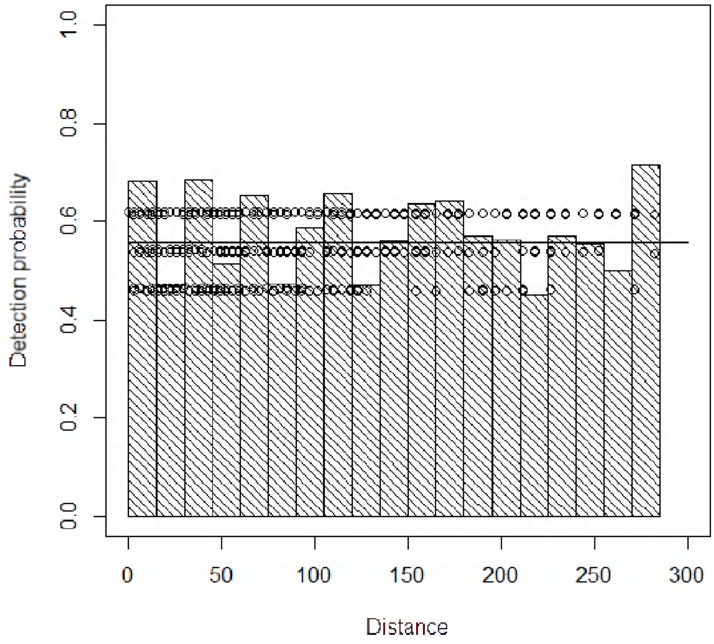


Figure 8. Fitted and observed detection probabilities for duplicate sightings of (A) loggerhead and (B) Kemp's ridly turtles during broadscale aerial surveys. The line indicates the population mean detection probability while points indicate predicted detection probability for covariate combinations (i.e., sea state, glare).

(A) Loggerhead turtles



(B) Kemp's ridley turtles

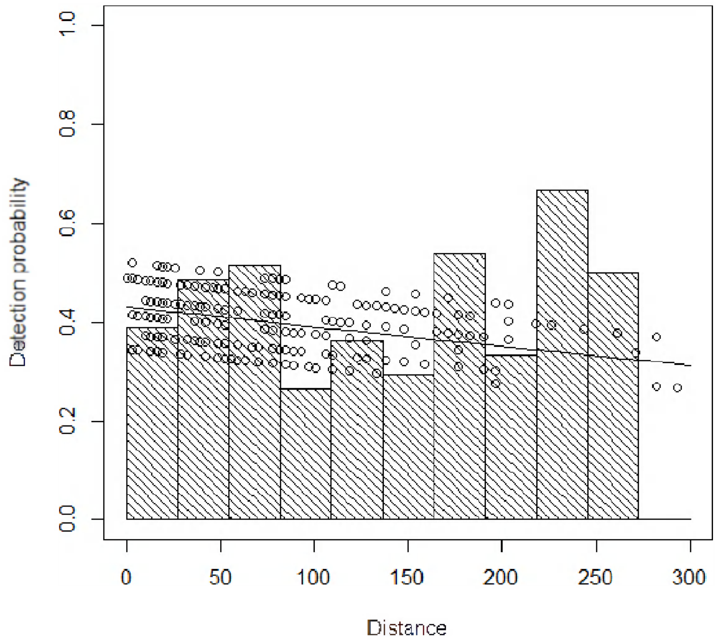
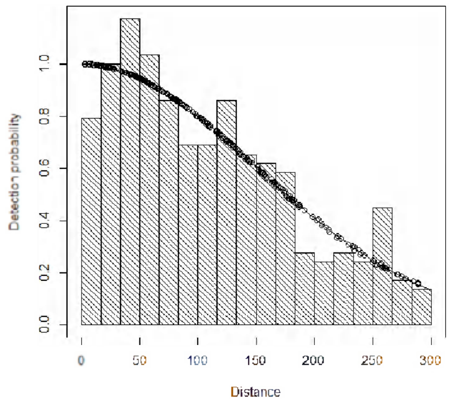
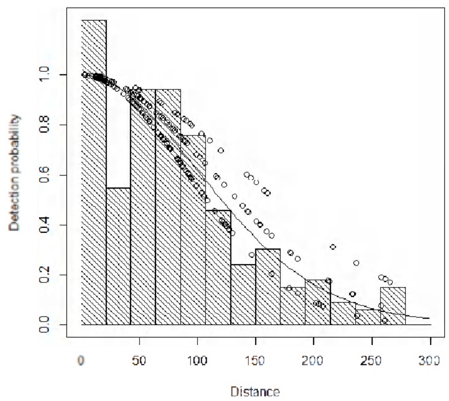


Figure 9. Detection functions for (A) loggerhead turtles and (B) Kemp's ridley turtles during synoptic surveys.

(A) Loggerhead turtles



(B) Kemp's ridley turtles



(C) Unidentified hardshell turtles

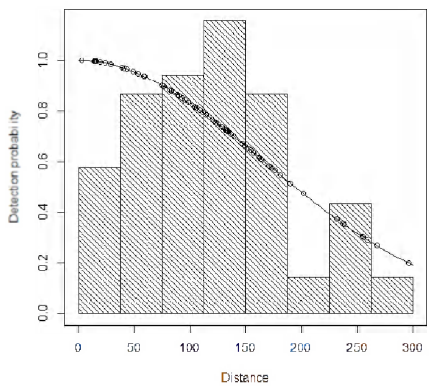
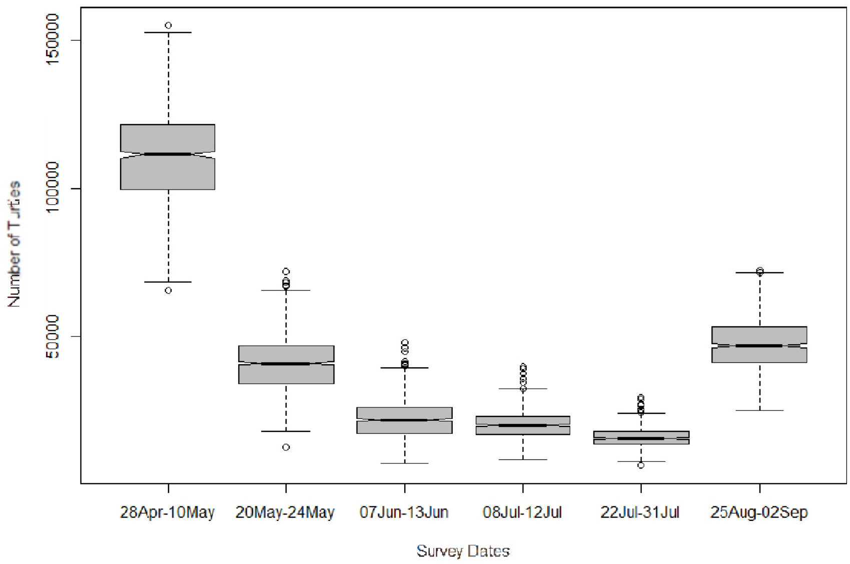
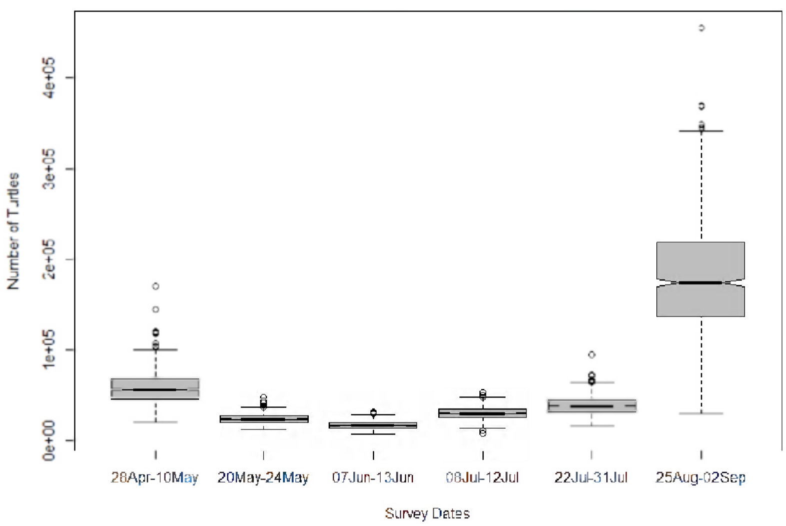


Figure 10. Box-whisker plots of (A) loggerhead turtle, (B) Kemp's ridley turtle, and (C) unidentfieid hardshell turtle abundance during the 2010 synoptic surveys from the bootstrap distribution of estimates. The upper and lower borders of the boxes reflect the 75th and 25th percentiles, and the dark line is the median. The "notch" in each box reflects the range of the 95% confidence interval while the "whiskers" reflect the range of the data exlcuding outliers (points).

(A) Loggerhead turtles



(B) Kemp's ridley turtles



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(C) Unidentified hardshell turtles

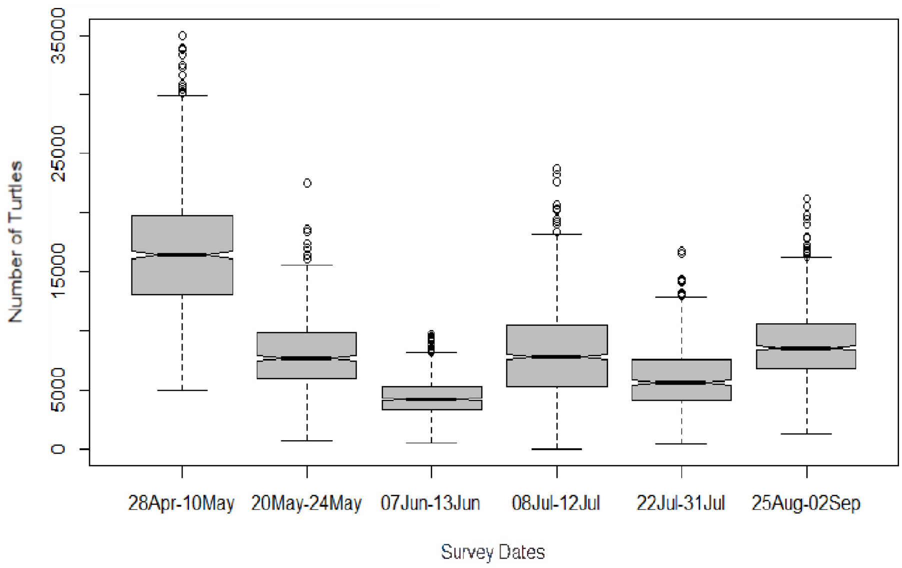

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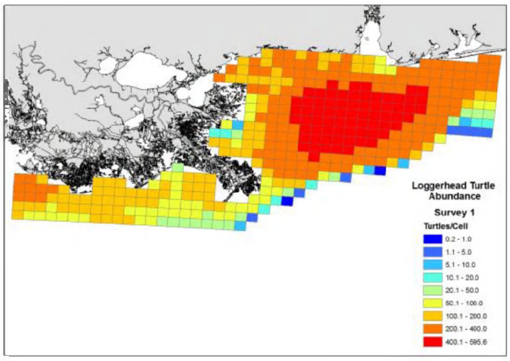
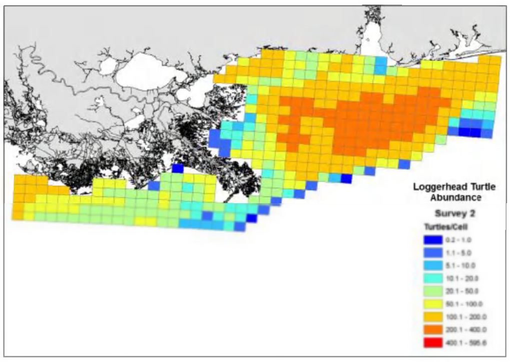
Figure 11. Predicted loggerhead turtle abundance in 10 x 10 km grid cells during synoptic surveys.

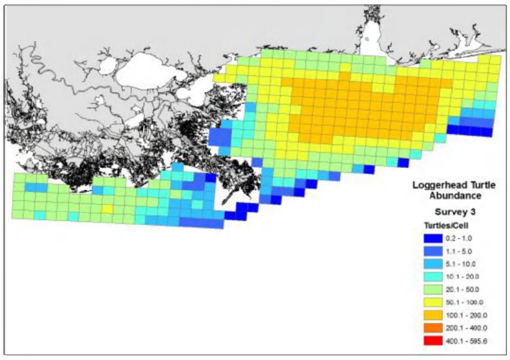
(A) Survey 1



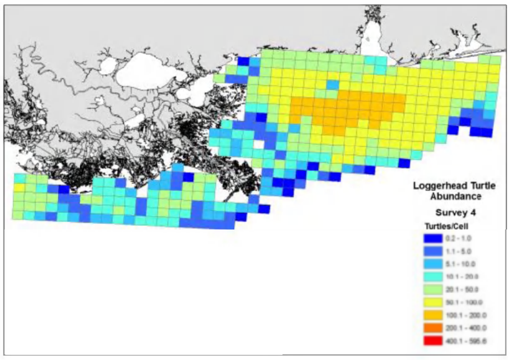
(B) Survey 2



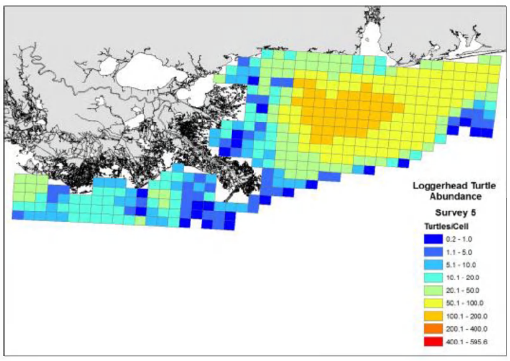
(C) Survey 3



(D) Survey 4



(E) Survey 5



(F) Survey 7

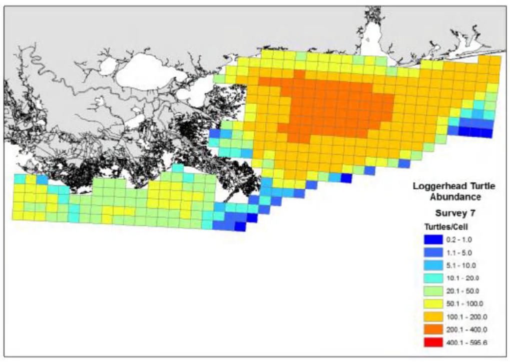
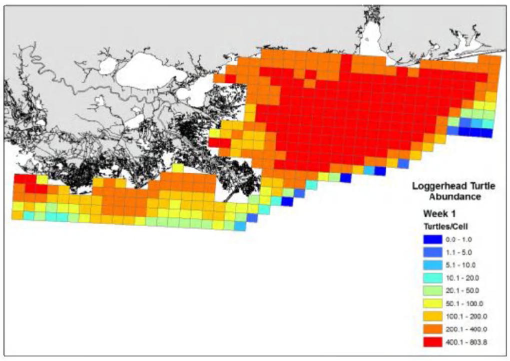
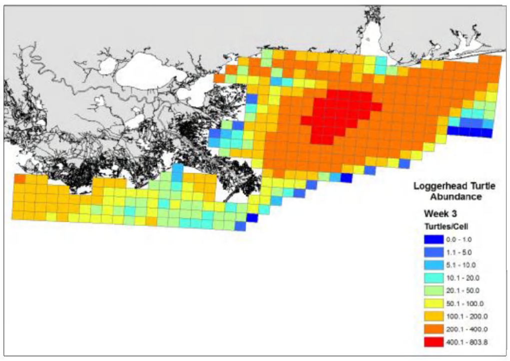


Figure 12. Weekly loggerhead turtle abundance.

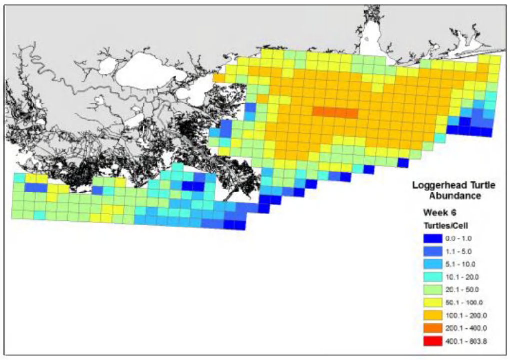
(A) Week 1



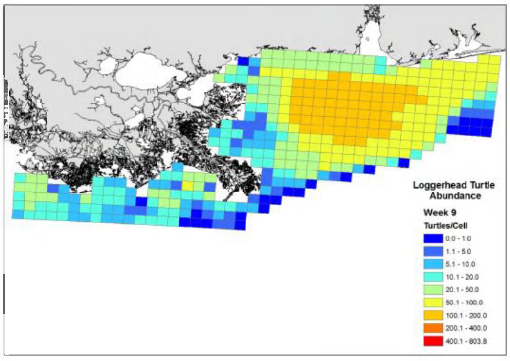
(B) Week 3



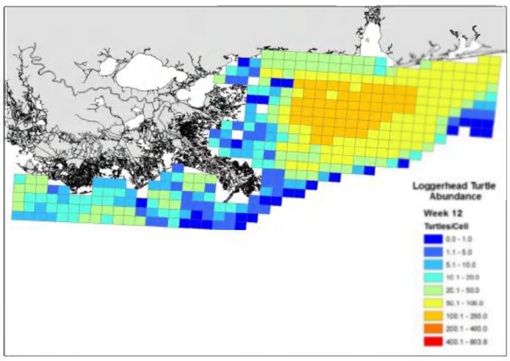
(C) Week 6



(D) Week 9



(E) Week 12



(F) Week 15

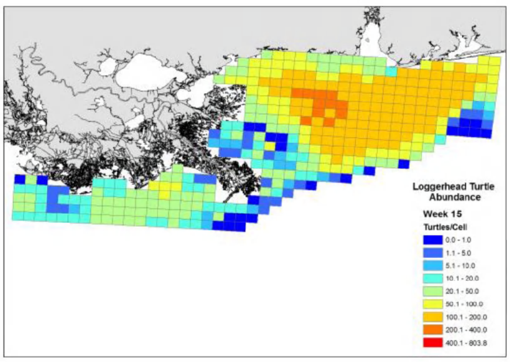
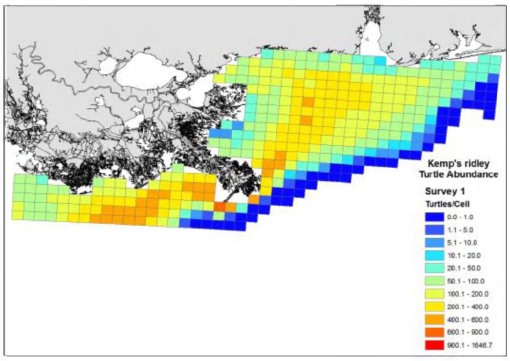
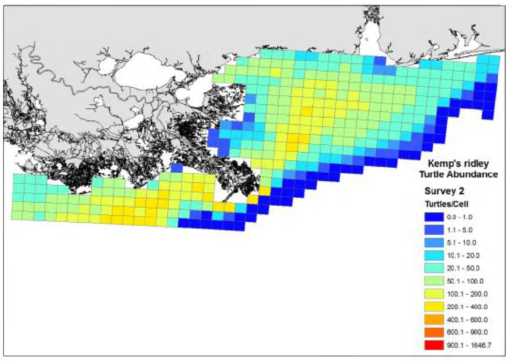


Figure 13. Predicted Kemp's ridley turtle abundance in 10 x 10km grid cells during synoptic surveys.

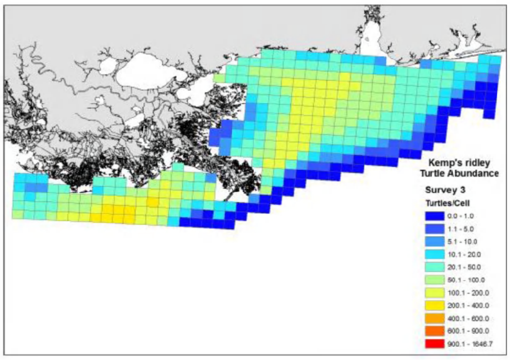
(A) Survey 1



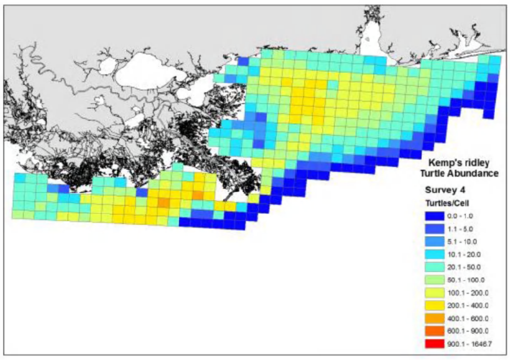
(B) Survey 2



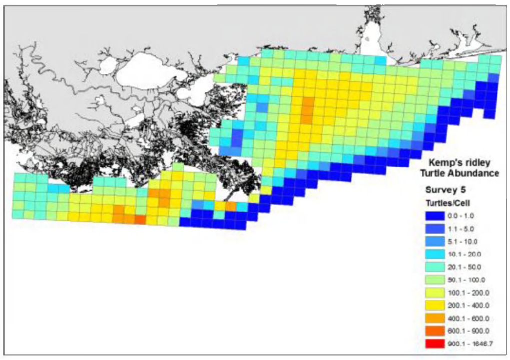
(C) Survey 3



(D) Survey 4



(E) Survey 5



(E) Survey 7

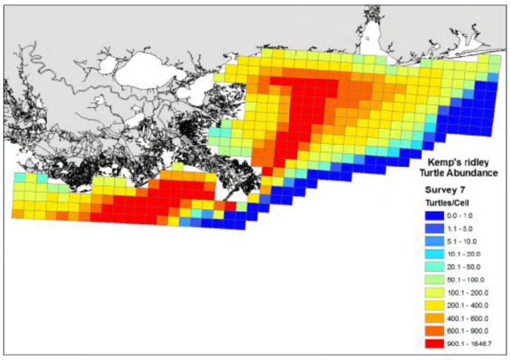
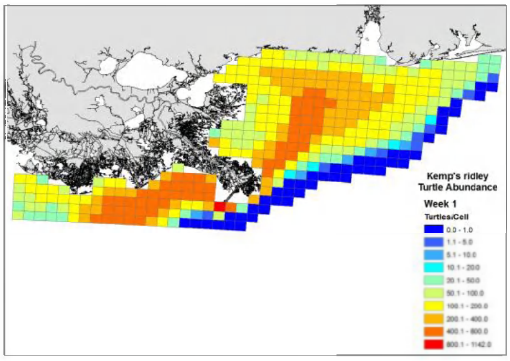
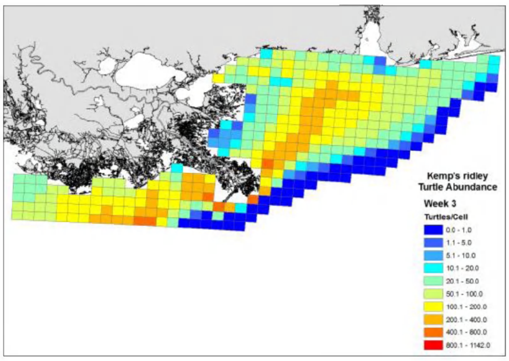


Figure 14. Weekly Kemp's ridley turtle abundance.

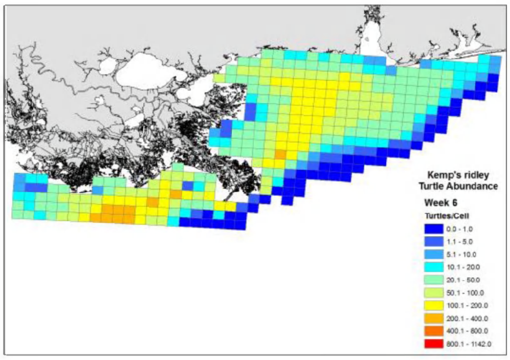
(A) Week 1



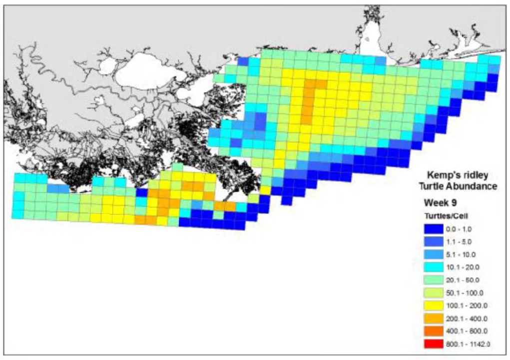
(B) Week 3



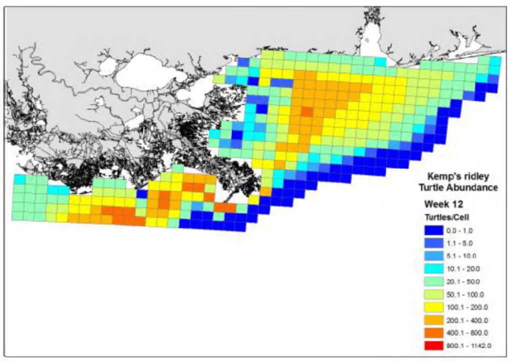
(C) Week 6



(D) Week 9



(E) Week 12



(F) Week 15

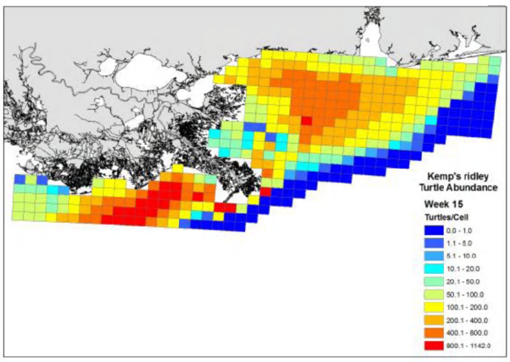
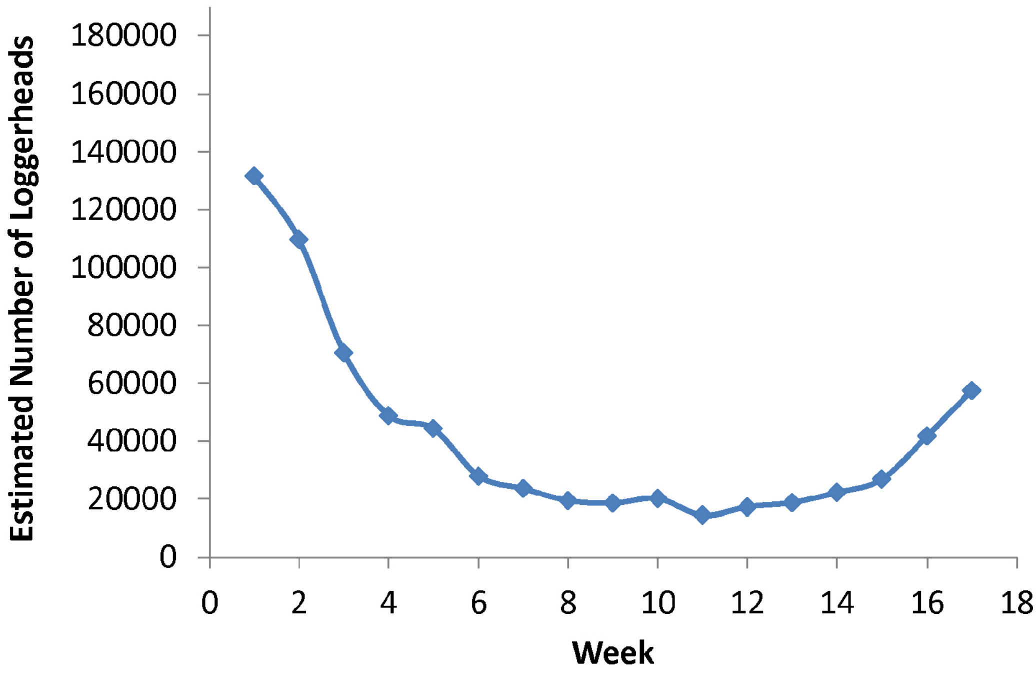


Figure 15. Weekly abundance of (A) loggerhead and (B) Kemp's ridley turtles predicted from spatial habitat models.

(A) Loggerhead



(B) Kemp's ridley