DENSITY ESTIMATES OF SURFACE-PELAGIC (OCEANIC) JUVENILE SEA TURTLES OILED BY THE DEEPWATER HORIZON OIL SPILL

photo credits: Blair Witherington

Prepared for:

National Oceanic and Atmospheric Administration

Prepared by:

Trent L. McDonald, Ph.D.

Western EcoSystems Technology, Inc.

Blair E. Witherington, Ph.D.

Florida Fish and Wildlife Conservation Commission

Barbara A. Schroeder

National Oceanic and Atmospheric Administration - NMFS

Brian A. Stacy, DVM, Ph.D., DACVP

National Oceanic and Atmospheric Administration - NMFS

Leigh Ann Starcevich, Ph.D.

Western EcoSystems Technology, Inc.

31 Aug 2015

Contents

Abstract

Due to threats that floating oil posed to surface-dwelling, oceanic-stage sea turtles, the National Marine Fisheries Service (NMFS) conducted sea turtle rescue activities in offshore areas during the 2010 *Deepwater Horizon* (DWH) spill event. As part of search and rescue operations, surface vessels conducted surveys in surface convergence zones known to aggregate *Sargassum* and other floating materials (including DWH oil in 2010), which provide habitat for small juvenile sea turtles In this report, we use data collected during these unstructured rescue-focused surveys to estimate densities of oceanic-stage juvenile sea turtles in the northern Gulf of Mexico. These density estimates enabled quantification of total abundance, exposures, and injuries to turtles in this life stage. A total of 646 juvenile turtles were sighted during on-transect surveys in northern portions of the Gulf of Mexico between 17 May 2010 and 9 September 2010. Of turtles captured during these activities, 81% (327 of 406) had some oil on their exterior, and 8% (31 of 406) were considered heavily oiled and had aggregations of thick, tenacious oil diffusely covering their bodies. Using line transect distance sampling methods, we estimated 0.17 oiled loggerhead turtles per km^2, 1.01 oiled green turtles per km^2, 0.05 oiled hawksbill turtles per km^2, and 1.38 oiled Kemps ridley turtles per km^2 in searched habitat. Across species and oiling categories, our analyses estimated 3.32 surface-pelagic juvenile turtles per km^2 in searched habitat. The actual density of surface-pelagic juvenile turtles affected by oil and response activities was likely higher than the numbers reported here because heavily oiled waters near the wellhead could not be surveyed, dead turtles had a low probability of detection, post-hatchlings were either not sighted or were unavailable for sampling, and sightability inflation factors were likely negatively biased.

1. Introduction

Hatchling sea turtles emerge from nests on sand beaches and disperse away from land into surface-pelagic and primarily oceanic offshore habitats (Bolten, 2003; Witherington et al., 2012). Although distribution and dispersal of open-sea juvenile turtles is influenced by currents and other oceanographic features, recent studies have shown that juvenile turtles are active swimmers and do not merely drift (Putman and Mansfield, 2015). Juvenile turtles tend to be associated with convergence zones, which accumulate *Sargassum* macroalgae and other surface-pelagic organisms, and are characterized by lines of floating material with occasionally elevated surface chlorophyll (Thiel and Gutow, 2005). *Sargassum* habitat provides a vital source of both refuge and sustenance for sea turtles (Witherington et al., 2012) and tends to form within surface-pelagic convergence zones ranging in extent from fronts at the edges of major surface currents to small-scale windrows generated by Langmuir cells (Butler et al., 1983; Butler and Stoner, 1984).

Several studies have demonstrated that pelagic *Sargassum* is an important developmental habitat for sea turtles in the Atlantic Ocean and Gulf of Mexico, and that this habitat is a focal point for threats including anthropogenic debris and petroleum ingestion (e.g., Bolten, 2003; Witherington et al., 2012). In one study, 89% of over 1800 surface-pelagic turtle sightings were found initially within one meter of floating *Sargassum* (Witherington et al., 2012). The sea turtles species sighted during that study were loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and Kemp's ridley (*Lepidochelys kempii*), and included both post-hatchlings (young of the year, 3.9-7.8 cm straight carapace length, SCL) and juveniles (13-28 cm SCL). Esophageal, lavage, and fecal samples obtained during that study revealed that juvenile surface-pelagic turtles consume a diet composed principally of *Sargassum*-community associated animals. Other dietary items included jellies, marine plants (mostly pelagic *Sargassum*), and insects. This broad diet puts turtles at risk for ingestion of many types of floating material, including petroleum. For example, Witherington (2002) found that 20% of live, post-hatchling loggerheads captured in surface-pelagic habitat had ingested tar and three dead turtles were found with ingested tar, thus supporting the hypothesis that sea turtles can and do ingest floating petroleum products within *Sargassum* habitat.

The surface-pelagic turtle population of the northern Gulf of Mexico likely receives regular influxes of new turtles originating from nesting beaches around the Gulf and Caribbean. Based on nesting distribution and abundance (Witzell, 1983; Seminoff, 2002; Bolten and Witherington, 2003; NMFS et al., 2011) and drift distance, it is possible to hypothesize rookery origins for the major assemblages of surface-pelagic turtles in the Gulf. Loggerheads, for example, likely originate on nesting beaches in northwest and southwest Florida, Yucatan Mexico, and the western Caribbean. Hawksbill and green turtles likely originate from beaches in Yucatan Mexico and the western Caribbean. Kemp's ridley turtles primarily originate from nesting beaches in northeast Mexico and south Texas. The duration of the surface-pelagic juvenile stage varies by species (Bolten 2003). Juvenile Kemp's ridley and green turtles found within *Sargassum* communities in the Gulf Mexico are thought to range from young-of-the-year (post-hatchlings) to turtles that are approximately 2 years of age (Witherington et al., 2012).

During the *Deepwater Horizon* (DWH) oil spill, surface oil was widely dispersed throughout much of the northern Gulf of Mexico and ranged from sheen to thicker layers of viscous petroleum (DWH Trustees, 2015, Section 4.2). The same areas that aggregate *Sargassum*-dominated communities within convergence fronts also accumulated petroleum (DWH Trustees, 2015, Section 4.4). Surface-pelagic juvenile sea turtles were especially vulnerable to the DWH spill because of their affinity for these convergence zones and because they spend the majority of their time (97%) within a meter of the surface (Witherington, 2002;

Witherington et al., 2012;). In recognition of this threat, the Wildlife Branch of the Unified Command formed in response to the DWH spill initiated vessel-based searches of pelagic sea turtle habitat. The objectives of these searches were to document and rescue live oiled turtles (for de-oiling and rehabilitation) and to document and recover dead oiled turtles. The data collected during these vessel-based surveys was used to quantify the injury to oceanic-stage sea turtles in the northern Gulf of Mexico caused by the DWH oil spill..

This report contains a detailed description of the field and analytical methods used to estimate species-specific densities of oiled and non-oiled turtles in convergence zone habitat searched during DWH response activities. The *Results* section contains a summary of the number of turtles sighted, the degree to which rescued turtles were oiled, and estimates of turtle density in floating material by degree of oiling and species. The *Discussion* contains an explanation of additional but unmeasurable factors that could have caused the actual density of affected turtles to be higher than the densities reported here.

2. Methods

2.1 Field Methods

Approximately one month after the beginning of the 2010 DWH spill event, wildlife response workers began searching surface waters of the Gulf of Mexico for oiled sea turtles. Many of these searches, conducted from vessels on the sea surface, were aided by observers in aircraft who communicated the location of oil and likely turtle habitat. The typical surface vessel was a 9-20 m length vessel with an elevated platform. Searches began in late May with a single vessel operating out of Venice, LA, and by July, multiple vessels originated out of three principal ports: Venice, LA; Orange Beach, AL; and Destin, FL. All vessel tracks were recorded by WAAS GPS. The longitude of searched transects ranged from approximately -89.5° (approximately 50 kilometers west of Venice, LA) to approximately -85.6° (approximately 60 kilometers east of Destin, FL). Latitude of searches ranged from approximately 30.4° (shore near Destin, FL) to approximately 28.25° (approximately 90 kilometers south of Venice, LA) (Figure 1). Directed searches for surface-pelagic sea turtles concluded on 9 September 2010.

Searches consisted of both off-transect and on-transect efforts. On-transect efforts were conducted at low-speed (i.e., approximately 5 miles per hour) parallel to or through consolidated patches of surface material. The highest priority areas targeted included floating petroleum, emulsified oil, pelagic *Sargassum*, and flotsam such as marsh reeds and plastics (Figure 2). The decision on whether to search a particular area of floating material was based on logistics (e.g., authorized area access, distance from shore, distance to the area from current position, time of day) and the perceived likelihood of observing turtles, not necessarily whether the area was oiled because we assumed oiled turtles could have moved out of oiled surface habitat. Searched areas were typically aligned as linear features, in keeping with the way floating materials define surface convergence, but non-linear scattered patches and windrows were also searched on-transect.

When turtles were observed during on-transect efforts, observers recorded the species (in all but a few cases) and geographic position of the vessel when perpendicular to the original sighting location. In addition, to permit estimates of turtle densities using line transect distance sampling methodology (Buckland et al., 2001; 2004; see Section 2.2. Statistical Methods), the turtle's perpendicular distance from the vessel's path was measured using one of two methods. Perpendicular distances were either computed from angles measured by a hand-held digital inclinometer and height of the vessel's observation platform, or were measured directly using graduated marks on the pole of a capture dip-net. When the inclinometer was not available, distances beyond the graduated pole's length (length = 4 m) were estimated visually using pole length as a reference. Following collection of sighting data, workers attempted to capture the observed turtle. Turtles were either immediately captured using a dip-net, were pursued for a short period and captured in the dip-net, or were pursued until they evaded capture by diving, often beneath surface oil and *Sargassum*. Once on board, captured turtles were examined for oil, swabbed on their surfaces, and photographed according to response protocols.

Off-transect turtle observations and captures were also made. Off-transect search effort differed significantly from on-transect effort. During off-transect effort, vessels moved at a greater speed (i.e., typically while in transit between on-transect target areas), and turtle sightings and captures were made opportunistically. On-board assessments and data collection for turtles captured off-transect were similar to those for on-transect captures. Off-transect sightings were excluded from further analysis because methodological differences precluded their use. Specifically, sightability functions for turtles captured during off-transect searches could not be determined.

Following field data collection, we reviewed field photographs and notes and assigned captured sea turtles to one of 5 oiling categories: "non-oiled," "minimally oiled," "lightly oiled," "moderately oiled," and "heavily oiled" (Stacy, 2012) (Figure 3). The "non-oiled" category was assigned to turtles with no visible signs of external oiling. Turtles assigned to the "minimally oiled" category either had oiling limited to one region of the body or oil coverage that was very light (i.e., thin smear or staining only). "Lightly oiled" was assigned to turtles with a thin layer of oil lightly covering multiple parts of the body, and to turtles in which thicker aggregated oil, if present, was focally distributed. "Moderately oiled" was assigned to turtles with heavier layers of oil covering multiple areas of the body, often accompanied by generalized brown staining. Turtles with aggregations of thick, tenacious oil diffusely covering the body were assigned the "heavily oiled" class. Turtles that were sighted but not captured were assigned an oiling category of "unknown."

A change in turtle search and rescue operations occurred as result of a Wildlife Response Unit directive on 20 July 2010 (Appendix A). Up to and including 19 July 2010, all sighted turtles were actively pursued for capture. Beginning 20 July 2010, turtles perceived to be "non-oiled" or that vigorously swam away when initially sighted were not pursued. This directive, issued after the capping of the well and when the surface oil had abated, was intended to leave apparently healthy turtles *in situ* and focus rehabilitation efforts on those animals in greatest need of medical care.

2.2 Statistical Methods

The goal of this analysis was to estimate density of oiled and non-oiled surface-pelagic sea turtles in searched areas in the northern Gulf of Mexico. These density estimates are an important part of subsequent estimates of turtle abundance and oil exposure that ultimately quantify injury to turtles across the DWH footprint and time period (Wallace et al., 2015). This section describes methods by which raw counts of sighted-only and sighted-captured turtles were used to estimate turtle density.

Sighted, but not captured individuals could not be assigned an oiling category due to the inability of crews to perform a thorough examination of turtles that were not brought on-board. Nonetheless, it was clear based on visual observation that at least some non-captured turtles were oiled. Of 240 on-transect sightings of non-captured individuals, 6 were noted as being visibly oiled, 5 were noted as possibly oiled, and 19 were sighted in oiled environments. Because 1) 12.5% of non-captured turtles were visibly or likely oiled, 2) crews were unable to examine the ventrum of non-captured turtles, where oiling was often most apparent, and 3) non-captured turtles were often lost under floating debris, including oiled debris, it was highly like that some portion of non-captured turtles were oiled. In the absence of information on the specific distribution of oiling in non-captured turtles, we made the simplifying assumption that the distribution of oiling among non-captured turtles was the same as the distribution of oiling among captured turtles, and allocated non-captured turtles to oiling categories according to the proportions of oiled turtles assigned to each oiling category. For example, if 40% of captured turtles were lightly oiled, we allocated 40% of non-captured turtles to the lightly oiled category. However, due to the operational change on 19 July 2010, whereby non-visibly oiled and apparently vigorous turtles were no longer pursued, we expected the distribution of oiling among non-captured turtles to change. Thus, allocation of oiling categories to non-captured turtles was differentially applied before and after July 19th. Uncategorized turtles observed before this date were allocated based on oiling category proportions documented prior to July 19th, and those encountered after the 19th were allocated based on oiling category proportions documented after this date. Counts of turtles within oiling categories were then summed across periods. Both the original and allocated totals are reported below.

The sightability of all turtles, oiled and un-oiled, during on-transect searches could have been influenced by multiple factors including the density of *Sargassum*, floating debris, color of the turtle and surrounding material, activity level of the turtle, height of the search platform above water, and distance from the vessel. To estimate density accurately, we corrected for imperfect sightability using distance sampling methods (Buckland et al., 2001, 2004), which are based on the premise that probability of sighting individuals declines as perpendicular sighting distance increases. In addition to perpendicular distant, quantifiable sources of variation in sightability were the degree of oiling and vessel. Sightability could have varied by oiling classification because more heavily oiled turtles were more thoroughly covered by oil and therefore potentially more difficult to see within oiled habitat than more lightly oiled turtles. Sightability also could have varied by vessel due to differences in observation heights as well as number and placement of observers. However, the number of sightings was not sufficient to estimate distance functions by vessel or vessel × oiling classification. Only 4 of 14 vessels sighted sufficient numbers of turtles (>35) to support vessel-based distance functions, and only 2 of 70 combinations of vessel and oiling classification contained >35 sightings. Rather than estimate separate distance functions for 4 vessels and a combined distance function for 10 others, we choose to combine data from all vessels and estimate distance functions only by oiling category.

When a sighting was made, the perpendicular distance from the vessel's path was recorded using the graduated pole or computed based on sighting angle and the vessel's average observer's eye height above water (typically 3-10 m). Assuming h was the observer height (meters), and θ was the angle below horizontal read from the inclinometer (degrees), perpendicular distance (meters) was calculated as,

$$d = h \tan(90° - \theta)$$

Assuming turtles were randomly distributed in the search area relative to the vessel's path, sightability functions were estimated by changing the function's parameters to maximize the likelihood that the observed perpendicular distances were generated (i.e., maximum likelihood; Buckland et al., 2001). For each oiling category, 5 sightability functions (Table 1) were postulated and fitted to perpendicular sighting distances, and the best fitting function was chosen by AIC (Burnham and Anderson, 2002). All calculations were performed using `R` (R Core Team, 2015) and the add-on package `Rdistance` (McDonald et al., 2015).

Following estimation of sightability functions, density in searched areas was estimated from the total length of sampled transect, the re-allocated number of turtles observed in each oiling category, and the best-fitting distance function. Assuming L was the total length of transect (kilometers) covered by vessels during response activities, and n_{ij} was the total individuals of species j in oiling category i after allocation of non-captured turtles to oiling categories, the density of species j turtles (number per square kilometer) in searched habitat in oiling category i was estimated as,

$$D_{ij} = 1000 \frac{n_{ij}}{2L(ESW_i)} \quad (1)$$

where ESW_i (meters) was the effective strip width calculated from the best-fitting distance function for oiling category i. The effective strip width for oiling category i was computed as,

$$ESW_i = \int_0^w g_i(x)dx,$$

where w was an assumed maximum sighting distance and $g_i(x)$ was the best-fitting distance function for oiling category i (Buckland et al., 2001). Based on inspection of perpendicular sighting distance histograms, the maximum sighting distance was set to w = 100 meters. All distance functions except the Gamma assumed probability of detection on the transect line (i.e., at x=0) was 1.0. The Gamma distance function assumed that probability of detection was perfect at its maximum a few meters from the transect.

Confidence intervals for density estimates were computed by bootstrapping transects and all associated data 1000 times. Distance function selection was not re-performed during bootstrap iterations, but parameters in the final distance function for each oiling category were re-estimated each iteration. Bias corrected 95% confidence intervals (Efron, 1987) were computed from the 1000 bootstrap estimates of D_{ij}.

3. Results

A total of L = 4,213 kilometers of transect was traversed during response activities from 17 May 2010 to 9 September 2010. The areas searched were within one day travel time from one of three ports of operation (Venice, LA; Orange Beach, AL; and Destin, FL) (Figure 1).

A total of 646 juvenile turtles were sighted while "on transect" during response efforts in the Gulf of Mexico. Of these, 406 were captured and brought on board the vessel for examination. Of the 406 captured turtles, 404 were oceanic juveniles, 1 was a post-hatchling, and 1 was a subadult. The most common species encountered was Kemp's ridley (n=330, 51%), followed by green turtles (n=238, 37%) (Table 2). Observers could not determine species for 16 turtles that evaded capture. In addition to those 16 unidentified turtles, 37 loggerheads, 79 green turtles, and 108 Kemp's ridley turtles (total = 240) that evaded capture (and hence could not be examined) were reallocated to the 5 oiling status categories based on the empirical distribution of oiling before and after 19 July. Final allocated counts are in Table 3. Overall, 80.5% (= 327/406) of captured turtles were oiled.

Distance functions were estimated separately for turtles in each oiling category except for the two highest categories. Due to the relatively low number of turtles observed in the "moderately oiled" (n=35) and "heavily oiled" (n=31) categories, these categories were combined and a common distance function was estimated. Among the five distance functions fitted, the best-fitting form for "non-oiled," "minimally oiled," and the combined "moderately and heavily" categories was Gamma (Figure 4). The Gamma functions assumed perfect detection at 9.6 m for "non-oiled" turtles, 8.4 m for "minimally oiled" turtles, and 4.0 m for "moderately and heavily oiled." The best-fitting distance function for the "lightly oiled" category was the hazard rate form (Figure 4). The effective strip widths (ESW) associated with each oiling category declined consistently from 24.3 meters for the "non-oiled" class to 21.4 meters for the "moderately and heavily" oiled categories (Table 4). Estimated density of all turtles, after reallocating the "unknown" oiling category to other categories, was 3.32 turtles per km^2 (95% CI = 2.82 to 3.88 turtles per km^2, Table 4). The estimated density of "moderately oiled" and "heavily oiled" turtles was 0.32 (95% CI = 0.21 to 0.51) and 0.24 (95% CI = 0.15 to 0.39) turtles per km^2 in the sampled area, respectively. Overall, the density of oiled turtles was estimated to be 2.68 turtles per km^2 (=sum of density in positive oiling categories).

4. Discussion

The purpose of this analysis was to estimate the density of surface-pelagic juvenile sea turtles present within the DWH oil footprint and oiled by the DWH spill. This was accomplished by expanding the number of oiled surface-pelagic juvenile turtles sighted and captured during vessel-based searches in the summer of 2010 (mid-May to mid-September) to account for decreased sightability away from vessels and for variation in sightability due to oiling category. Our estimates reflect a temporal average during the survey period of individuals in sampled areas, where sampled areas were primarily convergence zones containing *Sargassum* mixed with oil.

The density estimates reported here (Table 4) are potentially negatively biased by the assumption of perfect detection either on the transect line or at some distance within 10 meters of the boat (i.e., at the mode of the Gamma function). It is likely that perfect detection was not achieved because some turtles in all oiling categories were concealed within dense oil or *Sargassum* or both and could not be observed. Furthermore, we were unable to retrospectively assess the magnitude of detection probabilities on or near transects because the presence of surface oil was an important factor influencing sightability. As guidance on the magnitude and direction of this bias, we note that if detection probability near the vessels was x ($\sim 0.6 < x < 1$), resulting densities would increase relative to those in Table 4 by a factor of approximately $1/x$.

In addition to factors discussed above, there are three reasons why the actual density of oil-spill-affected surface-pelagic juvenile turtles was higher than the numbers reported here. These reasons include: 1) the emigration of turtle carcasses out of sampled areas; 2) our inability to sample near the wellhead just after and during the spill; 3) and the fact that post-hatchlings were not sighted or were unavailable for sampling. These three factors are discussed in more depth below.

4.1. Emigration of Turtle Carcasses From Sampled Population

Several pieces of evidence suggest that dead turtles exited the sampled population relatively rapidly. The specific gravity of juvenile sea turtles is greater than seawater (Milsom, 1975). Consequently, when a turtle dies, the carcass most likely sinks . This assumption is consistent with anecdotal observations from aquaria and rehabilitation centers. Furthermore, the depth of the waters involved (generally >100m) make it unlikely that decomposition gases could expand the carcass (i.e., bloat) to an extent that it would resurface after sinking. If turtle carcasses were entrained in floating oil, they would be subject to both scavenging and relatively high decomposition rates in mid-summer temperatures (~30C). In addition, carcasses do not actively move like live turtles and therefore lack an important visual detection cue for discovery. Given these factors, the most reasonable assumption is that the vast majority of dead turtles were unavailable for sighting. This assumption implies that the true density of turtles affected by the oil spill was higher than the numbers reported in Table 4.

4.2. Initial spill period and wellhead waters not searched

During directed capture efforts, numerous operations to secure and cap the DWH wellhead were ongoing, and oil response crews were actively burning surface oil in the vicinity. Due to restrictions on vessel traffic near burn zones, and restricted access near the wellhead, few directed turtle capture surveys were performed within ~10 km of the wellhead. Thus, we poorly sampled an area where turtles had a high probability of becoming heavily oiled (Wallace et al., 2015). In addition, regular search effort was not initiated until more than a month after the blowout. Thus, turtle captures and degrees of oiling during the first month of the spill are unrepresented, and the period from 30 to 40 days is underrepresented because survey efforts were still increasing in number and extent. It is reasonable to assume that surface-pelagic juvenile turtles were present in the area of highest probability of heavy surface oiling, and had we been allowed to search there, particularly during the first month of the spill, the proportion of oiled turtles in the sample would have increased relative to the proportions observed elsewhere. This assumption further implies that the true density of turtles affected by the oil spill was higher than the densities reported in Table 4, especially for the higher oiled categories.

4.3. Post-hatchlings not sampled

In years without an oil spill, post-hatchling loggerhead, green, and Kemp's ridley turtles are known to inhabit the northern Gulf because their nests are located on Gulf beaches. However, in 2010 the majority of loggerhead nests on Northern Gulf beaches were transported to the east coast of Florida for release away from oiled areas. After relocation efforts stopped, loggerhead young-of-the-year entering the northern Gulf from nests left *in situ* in Alabama and Florida could have encountered oil and been harmed. At least one oiled post-hatchling loggerhead was recovered in the northern Gulf in 2010 (Stacy, 2012).

The flow of oil from the wellhead stopped prior to cessation of nest relocation efforts, but tar balls and other oil derivatives lingered. This persistent surface oil could have affected post-hatchling loggerhead and green turtles dispersing from late-season nests in the northern Gulf. Post-hatchling Kemp's ridleys likely drift from the western Gulf eastward and may have encountered petroleum west of search locations. Post-hatchlings are vulnerable to surface oil and have a propensity to ingest tar balls (Witherington, 2002), so therefore might be expected to ingest oil at higher than expected rates when compared to a year without an oil spill. If post-hatchlings ingested tar balls, it is reasonable to assume that some portion died and sank or otherwise became unavailable to sampling efforts. Furthermore, live post-hatchlings are not included in our estimates of density and abundance because post-hatchlings are small (19-100 g) and difficult to see, especially if oiled and in oiled surface habitats. These factors support the notion that the true density of oil-affected turtles was higher than the densities reported here.

References

Bolten, A. B. 2003. Variation in sea turtle life history patterns: neritic versus oceanic developmental stages. Vol. 2. Boca Raton, Florida: CRC Press. Pages 243-257.

Bolten, A. B., and Witherington, B. E. 2003. Loggerhead sea turtles. Washington, D.C., USA.: Smithsonian Institution Press.

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

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., and Thomas, L. 2004. Advanced distance sampling. Oxford University Press.

Burnham, K. P., and Anderson, D. 2002. Model Selection and Multi-Model Inference. 2nd edn. Springer.

Butler, J. N., and Stoner, A. W. 1984. Pelagic *Sargassum*: has its biomass changed in the last 50 years? Deep-sea research, 1259-1264.

Butler, J. N., Morris, B. F., Cadwallader, J., and Stoner, A. W. 1983. Studies of *Sargassum* and the *Sargassum* Community. Special publication no. 22 edn. Bermuda Biological Station for Research.

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

Efron, B. 1987. "Better Bootstrap Confidence Intervals". Journal of the American Statistical Association, **82** (397): 171–185.

McDonald, T. L., Nielson, R., and Carlisle, J. (2015). Rdistance: Distance Sampling Analyses. R package version 1.3.2. URL https://github.com/tmcd82070/Rdistance/wiki

Milsom, William K. 1975. Development of Buoyancy Control in Juvenile Atlantic Loggerhead Turtles, Caretta c. caretta. Copeia, 1975(4), 758+.

NMFS, USFWS, and SEMARNAT. 2011. Bi-National Recovery Plan for the Kemp's Ridley Sea Turtle (Lepidochelys kempii). Tech. rept. National Marine Fisheries Service, Silver Spring, Maryland.

Putman, N.F. and Mansfield, K.L. 2015. Direct evidence of swimming demonstrates active dispersal in the sea turtle "lost years". Current Biology 25: 1221-1227.

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Seminoff, J. 2002. IUCN Red list global status assessment, green turtle Chelonia mydas. Tech. rept. IUCN Marine Turtle Specialist Group Review.

Stacy, B.A. 2012. Summary of findings for sea turtles documented by directed captures, stranding response, and incidental captures under response operations during the BP Deepwater Horizon (Mississippi Canyon 252) oil spill. NOAA, NMFS, Office of Protected Resources. DWH NRDA technical report.

Thiel, M., and Gutow, L. 2005. The ecology of rafting in the marine environment. II. The rafting organisms and community. Oceanography and marine biology, 42, 279-418.

Wallace, B.W., M. Rissing, D. Cacela, and B.A. Stacy. 2015. Estimating degree of oiling of sea turtles and surface habitat during the *Deepwater Horizon* oil spill. Technical Report Prepared for: NOAA Assessment and Restoration Division. Pp 41.

Witherington, B. E. 2002. Ecology of neonate loggerhead turtles inhabiting lines of downwelling near a Gulf Stream front. Marine biology, 140, 843-853.

Witherington, B. E., Hirama, S., and Hardy, R. 2012. Young sea turtles of the Pelagic *Sargassum*-dominated drift community: habitat use, population density, and threats. Marine ecology progress series, 463, 1{22. December 18, 2012 11

Witzell, W. N. 1983. Synopsis of biological data on the hawksbill turtle Eretmochelys imbricata (Linnaeus, 1766). FAO Fisheries Synopsis 137.

Tables

Table 1: Distance functions fitted to histograms of perpendicular distance from vessel track to turtle sighting. Minimum sighting distance was 0. Maximum sighting distance was set to w = 100 meters. Symbols a, b, and c are parameters to be estimated. Functions were fitted in `R` using `F.automated.CDA` in the `Rdistance` package.

Distance Function	**Form (f(x))**
Half normal	$f(x)=e^{x^2/a^2}$
Hazard rate	$f(x)=1-e^{-(x/a)^b}$
Uniform	$f(x)=\dfrac{e^{-b(x-a)}}{1+e^{-b(x-a)}}$
Negative exponential	$f(x)=e^{-ax}$
Gamma	$f(x)=\dfrac{1}{\lambda^a\Gamma(a)}x^{(a-1)}e^{-(x/\lambda)}$ where $\lambda=\dfrac{b}{\Gamma(a)}\left(\dfrac{a-1}{e^1}\right)^{(a-1)}$

Table 2: Number of juvenile sea turtles sighted and captured on-transect during Deepwater Horizon oil spill response efforts. Turtles sighted on transect but not captured were assigned the "unknown" oiling category. All other turtles were captured and assigned into an oiling category based on the extent of oil coverage. During period 31 May to 19 July, all turtles sighted were actively pursued for capture. During the period 20 July to 17 September, vigorously swimming turtles and those thought to be non-oiled were not pursued for capture, but those believed to be oiled were pursued.

Period	Oiling Category	Loggerhead	Green	Hawkbill	Kemps	Unknown	Total
31May - 19Jul	Unknown	15	11	0	20	4	50
31May - 19Jul	Non-oiled	0	3	0	4	0	7
31May - 19Jul	Minimally Oiled	1	7	0	16	0	24
31May - 19Jul	Lightly Oiled	1	8	0	19	0	28
31May - 19Jul	Moderately Oiled	1	4	0	10	0	15
31May - 19Jul	Heavily Oiled	0	4	0	24	0	28
20Jul - 17Sep	Unknown	22	68	0	88	12	190
20Jul - 17Sep	Non-oiled	4	26	4	38	0	72
20Jul - 17Sep	Minimally Oiled	3	74	8	88	0	173
20Jul - 17Sep	Lightly Oiled	1	22	1	12	0	36
20Jul - 17Sep	Moderately Oiled	0	10	1	9	0	20
20Jul - 17Sep	Heavily Oiled	0	1	0	2	0	3
Total		48	238	14	330	16	646

Table 3: Number of surface-pelagic juvenile turtles sighted in oiling categories after allocation of turtles not captured (i.e., unknown oiling status) to oiling categories based on relative proportions of oiling categories of among captured turtles (see text).

Oiling Category	Loggerhead	Green	Hawkbill	Kemps	Unknown	Total
Non-oiled	15	43	4	65	3	130
Minimally Oiled	17	122	8	160	8	315
Lightly Oiled	10	44	1	43	2	100
Moderately Oiled	6	21	1	28	2	58
Heavily Oiled	0	8	0	34	1	43
Total	48	238	14	330	16	646

Table 4: Effective strip width (ESW, meters) and estimated densities (turtles per km^2) by oiling category during response efforts. Densities computed using Equation 1 with number of turtles (n_{iji}) equal to the corresponding number in Table 3. Numbers in parentheses are 95% bias-corrected bootstrap confidence intervals based on 1000 replications and do not sum across rows or down columns.

Oil Category	ESW	Loggerhead	Green	Hawksbill	Kemps	Unknown	Total Density
Non-oiled	24.3	0.0732 (0.0196,0.1509)	0.2098 (0.1264,0.3043)	0.0195 (0.0043,0.0422)	0.3171 (0.2054,0.455)	0.0146 (0.005,0.0278)	0.6343 (0.446,0.8557)
Minimally	23.5	0.0857 (0.018,0.1811)	0.6148 (0.4648,0.7821)	0.0403 (0.0163,0.0751)	0.8063 (0.6344,1.0084)	0.0403 (0.0216,0.067)	1.5875 (1.2612,1.8981)
Lightly	22.1	0.0538 (0,0.1491)	0.2366 (0.1422,0.3349)	0.0054 (0,0.0192)	0.2312 (0.141,0.3325)	0.0108 (0.0031,0.0181)	0.5377 (0.336,0.7309)
Moderately	21.4	0.0332 (0,0.1259)	0.1162 (0.0652,0.1929)	0.0055 (0,0.0237)	0.155 (0.0945,0.2776)	0.0111 (0.0055,0.0211)	0.3211 (0.2147,0.5129)
Heavily	21.4	0 (0,0)	0.0443 (0.0178,0.1118)	0 (0,0)	0.1882 (0.1125,0.3099)	0.0055 (0,0.0133)	0.238 (0.1526,0.3873)
Total	NA	0.2458 (0.1701,0.3222)	1.2218 (1.0133,1.4745)	0.0707 (0.0388,0.1161)	1.6979 (1.4055,2.0019)	0.0823 (0.0435,0.1357)	3.3186 (2.8185,3.8754)

Figures

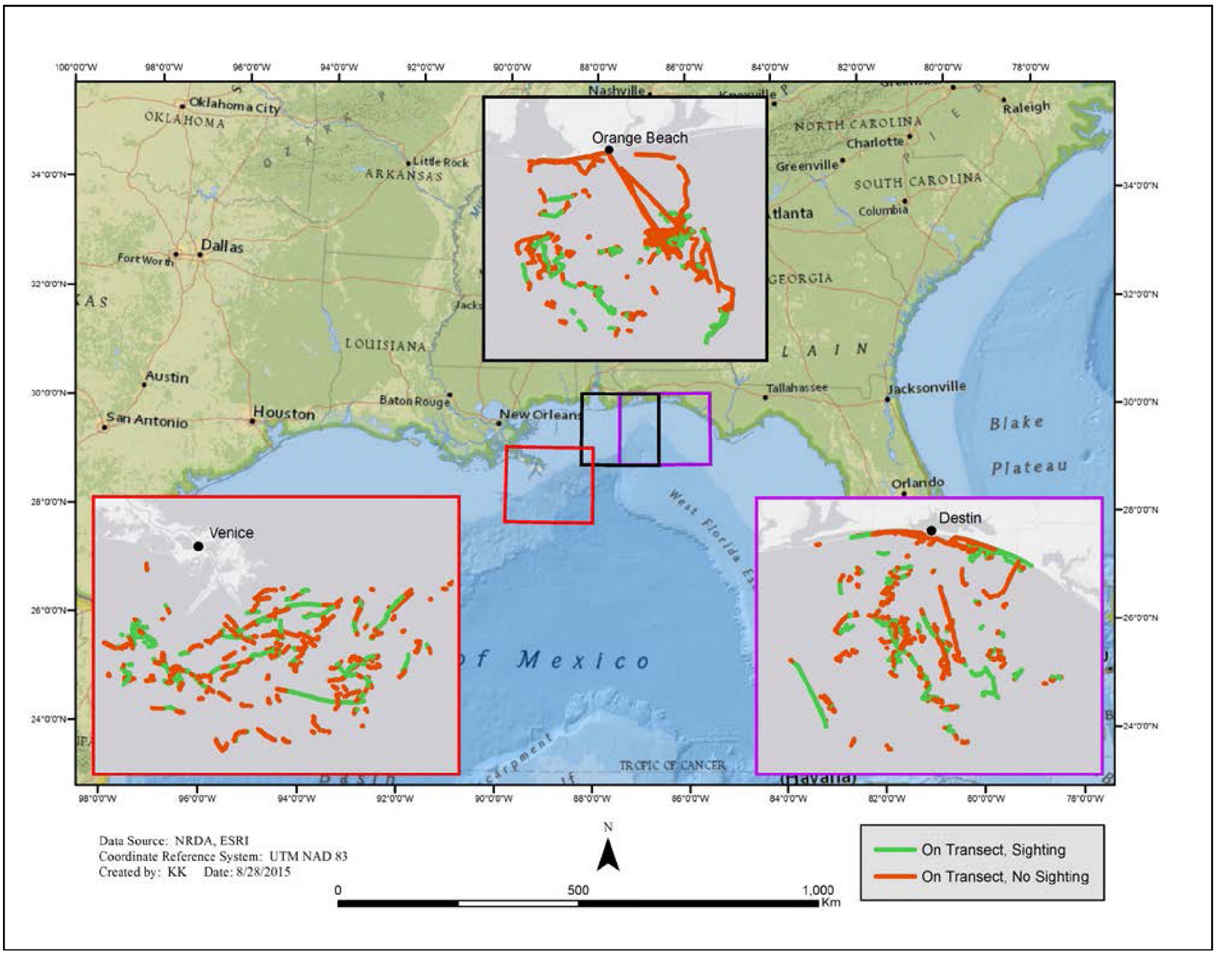

Figure 1: Transects searched during sea turtle response efforts (insets), colored by whether any turtles were sighted (green) or were not sighted (red). The three inset maps correspond to the port of operations: Venice, LA (red square), Orange Beach, AL (black square), and Destin, FL (purple square).

Figure 2: An area of consolidated oil and flotsam selected as an on-transect search area for sea turtles during Deepwater Horizon spill response efforts. Image recorded on 1 June 2010.

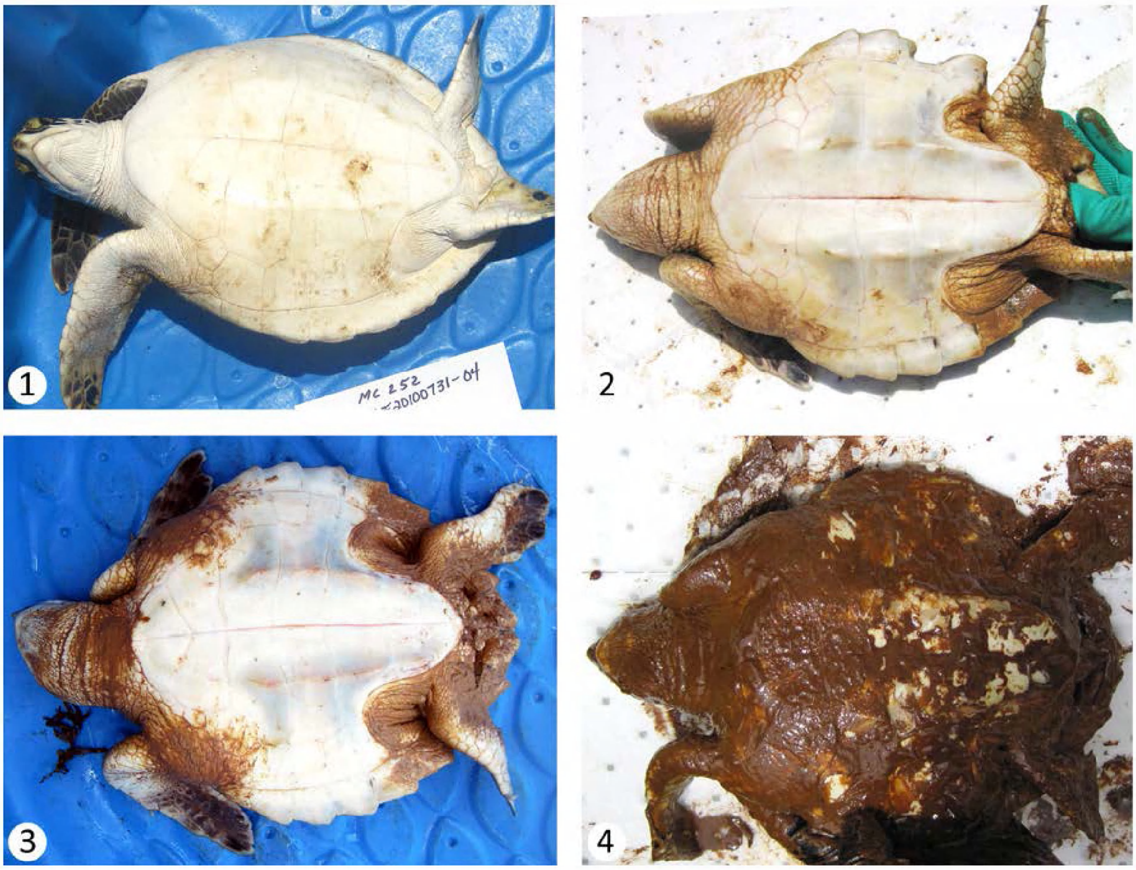

Figure 3: Representative photos of the ventral side of captured turtles subsequently assigned a positive oiling category. Categories are as follows: (1) minimally oiled; (2) lightly oiled; (3) moderately oiled; (4) heavily oiled (reproduced from Stacy, 2012).

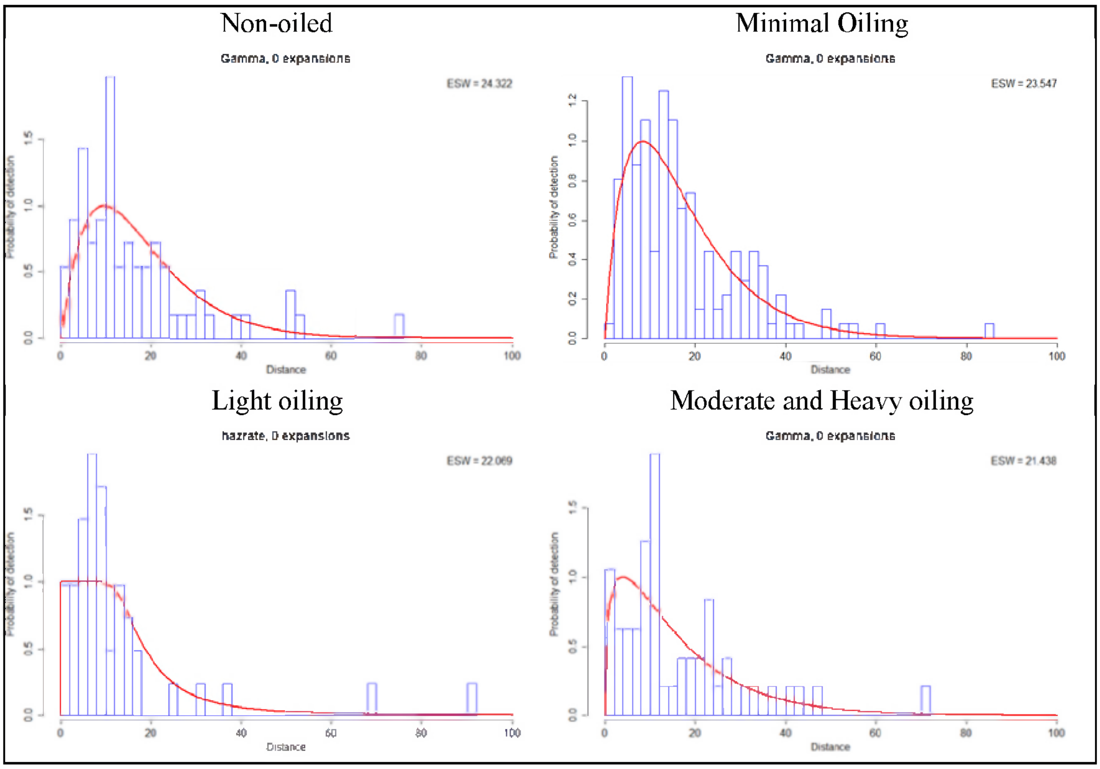

Figure 4: Best fitting distance functions (red lines) for captured turtles by oiling category. Histograms (blue) indicate the distribution of perpendicular sighting distances.

Appendix A- Directive for change in pursuit criteria

The following directive took effect 20 July 2010.

MC 252 SEA TURTLE CAPTURE PROTOCOL
REQUIREMENTS FOR VESSELS WORKING UNDER UNIFIED COMMAND – WILDLIFE BRANCH

Note: All media requests must be referred to the Wildlife Branch and the Joint Information Center.
Note: Activities not explicitly described below are not authorized or permitted under the Endangered Species Act. Deviations from the explicit protocols below are not authorized or permitted.

1. **EQUIPMENT and DATA FORMS NEEDED**
   a. Boat's GPS, long-handled dip nets, numbered plastic bins, towels, PPE, kiddie pool, oil absorbent pads, satellite phone, chain of custody forms.

2. **SEARCH and CAPTURE**
   a. Target search area is <u>oil lines and oiled weedlines ONLY</u>.
   b. When a turtle is observed, mark and record the waypoint. Using a long-handled dipment capture the turtle if it is seen to be oiled. Do not chase or capture vigorously swimming turtles or turtles that are not visibly oiled.
   c. If the turtle is captured, bring it aboard in the net and set it within the net on a clean, unused absorbent pad in a kiddie pool.
   d. Using a designated camera (for oil-spill turtles only), place a pre-labeled photo card near the turtle and take dorsal and ventral photos. On the photo card writethe captain's name, capture date, capture position (lat/lon), and "Deepwater Horizon." Do not download the photos, they must remain on the photo card which will be turned over to the Wildlife Branch.
   e. Put on PPE and nitrile gloves. Carefully remove the turtle from the net and, using clean sorbent pads, wipe the oil from the shell, skin, and head. Do not attempt to remove every bit of oil,the goal is to wipe the majority of the loose oil from the turtle, including from the head and external mouth.
   f. Place the turtle on a wet towel in a clean (non-oiled), numbered plastic bin. Cover the bin with a clean (non-oiled) wet towel. The bin must be sufficiently ventilated. Do not allow the towel to fall into the bin and cover the turtle. Tape the photo card securely to the outside of the bin. Place the bin in ventilated shade.
   g. The Captain initiates the chain of custody form and records turtle capture position, turtle bin number, and notes about the turtle's condition (active, inactive, associations with oil at capture location).
   h. If a turtle is observed but not captured, mark and record the waypoint, and note the turtle's condition (active, inactive, associations with oil at capture location).
   i. If a captured turtle is determined to be unoiled, it must be immediately released and the release location and time recorded.
   j. As soon as possible after a turtle is captured, call the Wildlife Branch, sea turtle unit at 985-860-5430. You must call this number <u>upon capture of each turtle</u> throughout the day. Return to the fuel dock, at Cypress Cove Marina, Venice, **<u>no later than 5:30 PM</u>** to transfer turtles to the transport vehicle that the Wildlife Branch will organize when you call in that you have captured an oiled turtle.