# SPATIAL ANALYSIS FOR SEA TURTLE CONSERVATION ON THE GEORGIA COAST

Shrimp boat off the coast of Tybee Island, Georgia, July 2013

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**Project Summary**

All sea turtle species are listed as endangered or threatened under the Endangered Species Act. The Georgia Department of Natural Resources (GA DNR) oversees the sea turtle conservation effort along the Georgia coast, including recording all sea turtle strandings (or deaths) throughout the year. The interaction between shrimp boats and sea turtles as a cause of death for these turtles is well documented since the 1970s. State and federal law has required all shrimping boats to install turtle excluder devices (TEDs) since 1991 to prevent these deaths (Jenkins 2012). Unfortunately, improper installation or failure to comply still leads to sea turtle mortality. Trawling activities by the fishing industry continue to be one of the most common non-natural causes of death, accounting for more than 80% of deaths between 1990 and 2007 (Finkbeiner et al. 2011). This research used GIS to examine the spatio-temporal patterns and correlation between the locations of shrimp trawler activity, sea turtle stranding locations, and recorded TED violations on the Georgia coast. Results show that the trawler and stranding locations are clustered and not randomly distributed. Furthermore, the strandings were correlated with the TED violations, with the strongest correlation found between the no apparent injury turtles (i.e., those stranded turtles thought to have died as a result of interactions with a trawl) and the violations. These results will help guide the GA Department of Natural Resources in possible management options such as limiting the trawler fleet size, developing marine protection areas, and improving TED compliance to further sea turtle protection.

## I. Introduction

All sea turtle species are listed as endangered or threatened under the Endangered Species Act. Globally sea turtles face a number of natural and anthropogenic threats to survival, including loss of habitat, nest predation, marine pollution, and the commercial fishing industry. Five of the seven species of sea turtles can be found on the Georgia coast throughout the year, with loggerheads being the only species to nest regularly on the beaches. In cooperation with the U.S. Fish and Wildlife Service and NOAA Marine Fisheries service recovery plan for loggerhead sea turtles, the Georgia Department of Natural Resources (GA DNR) oversees the sea turtle conservation effort along the Georgia coast. During the nesting season from May through October each year, the GA DNR monitors all 14 islands on the Georgia coast for sea turtle nests. All nests are recorded and excavated following hatching. DNR staff and trained volunteers also participate in the Sea Turtle Stranding and Salvage Network by responding to all turtles found washed up, both dead or injured, to record sea turtle mortality numbers in a national database (GA DNR 2013). In addition to these activities, the DNR Sea Turtle Project is responsible for monitoring the impacts of the Georgia shrimp fishery on the sea turtle population.

The interaction between shrimp boats and sea turtles as a cause of mortality has been a concern since the 1970s and is well documented in the literature (Lewison et al. 2003; Finkbeiner et al. 2011). As a result of trawl-related mortality, state and federal laws have required all shrimping boats to install turtle excluder devices (TEDs) since 1991 in an effort to minimize mortality due to drowning (Jenkins 2012). Unfortunately, improper installation or failure to comply still leads to sea turtle mortality. Trawling activities by the fishing industry continue to be one of the most common non-natural causes of death for sea turtles, accounting for more than 80% of deaths between 1990 and 2007 (Finkbeiner et al. 2011). Because sea turtle mortality continues due to shrimp trawl interactions, the GA Department of Natural Resources is looking at possible management options of limiting the size of the trawler fleet, establishing protected areas closed to fishing, and improving the compliance of proper TED installation to further sea turtle protection.

Spatio-temporal analysis of sea turtle and shrimp trawler interactions spans a wide variety of methods and techniques that depend largely on the data available. The majority of these studies focus on live sea turtles as bycatch of the different fishing industries found around the world, drawing different conclusions as to how to limit the numbers. Gardner et al. (2008) used spatial and temporal analysis techniques to compare turtle bycatch locations with fishing locations in the long line fishing industry along the US Atlantic and Gulf of Mexico coasts. Results showed that patterns of catch did change over time and space, clustering around 30 to 200 km and over 1 to 5 days. The authors suggest boat captains use real-time bycatch data to avoid short-term hotspots to minimize the size and time of area closures. Lewison et al. (2009) looked at multispecies bycatch in both the Atlantic and Pacific with the goal of maximizing the efficiency of management strategies without promoting benefits of one species to the detriment of another. The persistent areas of bycatch were then compared to productive areas for the intended catch species. Patterns emerged in the Pacific for areas of high bycatch and low target catch; however similar areas were not found in the Atlantic. The authors suggest their detailed spatial analysis of long-term data should be a part of the overall larger framework for fishery management, including the need for fleet communication systems to respond to real-time bycatch hotspots and predictive modeling to forecast potential hotspots.

Another group of research attempted to identify specific conditions in which sea turtle-boat interactions occur. Warden (2011) attempted to identify environmental factors to predict sea turtle bycatch in the fish and scallop trawling industry from Maine to North Carolina. Using data compiled by the Northeast Fisheries Observer Program, federally permitted boats are required to report data on number of tows, average bottom depth, primary latitude/longitude, gear type, and additional data on nets. Factors that could be associated with observable sea turtle interactions were latitude, bottom depth, and surface temperature. Similar factors were found significant by Murray (2008). Researchers from the South Carolina Department of Natural Resources and the University of Georgia (Arendt et al. 2012) completed the first fishery independent, random sampling survey of sea turtle populations from St. Augustine, Florida to Winyah Bay, South Carolina. Over 4200 trawling events from 2000 to 2011 captured a total of 1227 loggerheads in 23% of the sampling events. Trends were identified for a variety of environmental factors, including geographic regions, distance from shore, mean water depth, distance from closest inlet, and seafloor habitat type.

Other research suggests reducing sea turtle bycatch rates through fleet reduction or setting maximum adult bycatch limits (Curtis and Moore, 2013). Scott et al. (2013) looked at nesting female movement using PTT transmitter signals during the nesting season from May through August in 2004 and 2005 and overlapped the calculated turtle home ranges with the bimonthly trawler location database collected by the Georgia Department of Natural Resources. They modeled the reduction in turtle boat interactions through fleet reductions and spatial closures and concluded a minimum of 50% fleet reduction was the most beneficial, with a small benefit found through a large closure of state waters in front of one specific Georgia barrier island.

Other researchers have focused on the strandings or sea turtle mortality as a result of bycatch from the fishing industries. Most of these studies use strandings to summarize and draw conclusions on the data over time and space. A study completed in the Mediterranean over a 14 year period confirmed that over half of the sea turtle strandings were a result of interaction with human activities, most commonly the local fisheries. Strandings were more frequent in summer months, and larger turtles were more likely to interact with the long line fisheries (Tomas et al. 2008). Analysis on the probable cause of green turtle strandings identified temporal and spatial patterns around the Hawaiian coasts over a 22 year period (Chaloupka et al. 2008). Similarly, the cause of stranding was differentiated for different areas of the coast in Southern Spain using stranding data recorded from 1997 to 2006 (Bellido et al. 2010). Most recently, researchers on the coast of Baja California Sur, Mexico used turtle strandings and drifter experiments to estimate the total numbers and distribution of at-sea mortality of sea turtles (Koch et al. 2013). The drifter experiments recorded an overall recovery rate of 22%, with 80% of all recoveries occurring within 10 days of the deployment.

In summary, most researchers agree that spatial analysis should be used to help inform the management decision-making process for sea turtle conservation and the shrimping fishery. The purpose, methods, and conclusions vary significantly between studies. The most limiting factor is the availability of accurate spatial data for sea turtle locations. This research project adds to the research surrounding sea turtle – fishery interactions by examining the spatial patterns in three datasets available from the GA DNR on trawler surveys, sea turtle strandings and TED violations.

## II. Research Objectives

This capstone project focused on the following research questions:

a. What spatial patterns are present in the location of shrimp trawlers and sea turtle strandings on the Georgia coast from 1999 to 2013?

b. Do these patterns change as a function of covariates, such as boat size or cause of death?

c. How have the patterns changed over time? Do they vary with season?

d. Are sea turtle strandings correlated with shrimping intensity or to TED violations?

## III. Data

This research focused on three sets of data collected by the GA DNR Non-game Wildlife Division: shrimp trawler surveys from 1999 to 2012, sea turtle strandings from 1999 to August 2013, and shrimp boat boardings from 2006 to 2011. See Appendix A for a map of each original dataset.

### A. Shrimp Trawler Survey Data

Shrimp trawler surveys are collected on a semimonthly basis by helicopter through the shrimping season each year. The exact season varies by year, but typically runs from May through October. Each survey begins at the Georgia-Florida boundary and moves north. The DNR survey staff collects geographic coordinates over each boat and records information on boat size, fishing status, tidal stage, net rack, freezer box, and additional comments. Each survey takes approximately two to three hours and is considered a snapshot of the shrimping activity on the given date of the survey. Although the goal is for the DNR to complete two surveys each month during the shrimping season, it is not always possible due to budgetary and logistical constraints. These surveys are completed for management purposes; therefore days of the month, time of day, and tidal stage are not random, however any bias is consistent over the 14 year period (M. Dodd, Interview, June 2013 and April 2014). The original dataset contained 8,816 locations, reduced to 7,906 locations when boats not actively fishing were removed for analysis. During the 2006 to 2011 time period used for distance analysis (see below), each year had between 337 and 474 observations recorded over 7 to 9 surveys, for a total of 2,381 locations.

### B. Sea Turtle Stranding Data

The stranding dataset was collected by sea turtle cooperators throughout the state for the DNR following a standard protocol from 1999 until August 2013. Recorded attributes applicable to this research included location, date found, species, sex, life stage, and probable cause of death. The full database contained 2,839 records; however, only 1,651 were included in analysis after eliminating those strandings in which the probable cause of death was unable to be assessed. Assessment is not always possible due to the stage of decomposition, only a partial carcass was found, or limited amount of data recorded by an observer. After reviewing the probable cause categories, three were identified as the major causes of strandings in Georgia: no apparent injuries at 41%, watercraft at 35%, and disease at 16%. Those turtles that were categorized as no apparent injuries are the turtles that the Georgia DNR recognize as drowned in shrimp trawl nets. Final counts of the observations used in the distance analysis can be found in Appendix D.

### C. Trawler Boardings Data

Data on trawler boardings and TED violations were available for a six year period from 2006 to 2011. Prior to 2006, standard protocols for boarding shrimp boats and collecting information did not exist. During the six year time period, DNR boarded 309 boats and found 72 TED violations. These boardings happen on a random basis, sometimes in response to an unusual number of strandings on a nearby beach. The data recorded followed a standard form created by the GA DNR. These forms are now used by National Oceanic and Atmospheric Administration to collect data on the shrimp trawl fleet for the entire Atlantic and Gulf coasts (M. Dodd, Interview, April 2014). For the distance analysis, only boats boarded while actively fishing were used to calculate nearest event, reducing the total number of boardings to 196 with 51 TED violations.

## IV. Methods

The methodology for this project is broken into three major phases: data preparation, density analysis, and distance analysis.

### A. Data Preparation

A significant amount of data preparation was necessary before completing spatial analysis. The data available from DNR was in spreadsheet format, so the first step was to create a feature class in ArcMap using the geographic coordinates provided in the raw data. See Appendix A to view the original feature classes mapped. The next step was to remove any records that were not considered to be significant to the study. For example, with the shrimp trawl surveys, only those locations recorded as fishing at the time of the survey were analyzed. With the sea turtle data, all strandings in which a probable cause of death could not be assessed were removed from the total counts and analysis. Any additional data fields necessary for analysis were calculated, such as month and year of the record. Separate feature classes were created for significant attribute values, such as the events for each individual year. Throughout the analysis process, the data was continuously reviewed to remove events no longer applicable to the analysis being completed. For example, for the distance analysis and statistical modeling, strandings that did not occur along the oceanfront islands were removed, as well as all boat boardings and TED violations that did not occur on an actively fishing vessel.

### B. Density Analysis

Once mapped, the data points for the shrimp trawlers appeared to be clustered, while the sea turtle strandings appear to be fairly evenly distributed along the coast. To identify the existence of clustering or other spatial patterns in the data, two types of density analysis were completed on the three data sets: kernel density analysis and hotspot analysis. Kernel density estimation provides a way to take the individual incidents of boats or turtles and distribute the count over the study area to better understand (visualize) the distribution. Using the kernel density tool available in the Spatial Analyst extension in ArcMap, raster density layers were created using a cell size of 1640.42, or the length of one half kilometer, along with the default value provided by the kde tool for the search radius. Square kilometers were chosen for the area units. The kde analysis maps were used to compare differences in the cluster patterns over time and the covariates appropriate to each dataset.

Because both the trawler locations and the strandings showed clustering following the kernel density estimation, the Hot Spot Analysis, found under the Spatial Statistics Toolset, was used to find the statistical significance of the clustering for these datasets. This tool calculates the Getis-Ord Gi* statistic, providing a z-score and p-value for each feature in the dataset. A statistically significant z-score occurs when a feature with an unusually high count is surrounded by other features with unusually high counts, providing a way to identify areas where the numbers of trawlers or strandings were above average or beyond one standard deviation. Because the original data contained individual events or points with a count of one, further data preparation was required before performing the hotspot analysis. The Integrate tool was used to group trawlers and strandings together within a 500 ft radius and 100 ft radius respectively; then the Collect Event tool was used to create one data point with a count field for each of the collected events, producing a feature class appropriate for the Hot Spot Analysis tool.

### C. Distance Analysis

Following the density analysis of the individual datasets, proximity analysis was used to identify correlations between the strandings and the trawler locations or the TED violations. The Near tool in the Proximity Toolset of ArcMap was used to calculate the distance of each stranding to the nearest trawl location, the nearest above average fishing location from the density analysis, and the nearest TED violation. These calculations were completed on an annual basis for each year the boat boarding data was available, 2006 through 2011. Initial review of the distance calculations showed that the No Apparent Injury strandings were closest to the TED violations in each year, with the exception of 2008. In contrast, the No Apparent Injury group was on average farther from the above average fishing locations than all strandings combined.

In order to calculate the statistical significance of the distance calculations, the datasets were fit to a Bayesian hierarchical logistic model. The model allowed the average relative probability of being stranded to vary among years and the relationship between being stranded and the predictor variable to vary among years. Identical temporal patterns in strandings related to predictors were not expected for the different years. All analyses used 2,000 randomly generated points for each year to quantify the available shoreline habitat. Random points were generated using the Create Random Points tool using an outline of the ocean front shoreline where strandings are found on Georgia’s coast. The predictor variables used in the analysis include distance to the nearest above average fishing location generated from the hotspot analyses, distance to the nearest TED violation, and distance to the nearest trawl location. These model variables were identified as potential correlations to the variation in the relative probability of being stranded for each of the three probable death categories: disease, no apparent injuries, and watercraft. Predictors were considered significant if their 95% credible intervals did not overlap zero.

With the initial results, it became necessary to refine the data used in analysis. Strandings found floating and not along the coastline used to create random points were removed, as well as the trawler boardings that occurred inland and not in the sound or ocean. Because of the repetitive process of running the near tool multiple times for each year of strandings and random points, a tool was developed using Model Builder within ArcGIS that would create each necessary field in the feature class and calculate the distance between events each time the data was refined. Parameters were built into the tool which allowed the user to choose the year of each feature class and calculate a probable cause when necessary to process for each set of data. The probable cause field was used to flag the random points from the actual strandings in the statistical model.

## V. Results

The locations of both the shrimp trawlers and the sea turtle strandings along the Georgia coast were clustered and not randomly distributed. Furthermore, the pattern of clustering was differentiated between covariates such as season, year, boat size, and probable cause of death. See Figures 6 and 7 for sample maps. All kernel density maps are found in Appendix B; hot spot analysis maps are found in Appendix C.

The shrimp trawl surveys showed clustering around the sound openings and populated areas along the coast. Differentiating by season showed more clustering during the early and late season, when white shrimp are in season, versus the mid-season when boats appeared to be more randomly distributed. Large boats are the most commonly found along the coast and closely follow the same pattern as all boats combined. The small boats were found near the shoreline, and the extra-large boats were found farthest from the coast. Map algebra was used to identify areas of overlap in the different subsets of data with the raster calculator in the Spatial Analyst extension. The map algebra results table provides the percentage and calculated area of overlap between each subset of data (Table 1). The early and late shrimping seasons showed the most overlap at 26.63%. In contrast, the small and extra-large boats showed the least amount of overlap at 0.87%. The hotspot analysis confirmed these results by identifying point locations where the number of boats were above average or more than expected when looking at the dataset as a whole. Trawl locations over the 14 year period showed clustering around the sounds near major population centers along the coast: Savannah, Darien, Brunswick and St. Mary's. The hotspot locations did vary among years (2006 to 2011); however, they still tended to increase between the major population centers along the coast. Locations with a z-score above 1.64 or one standard deviation were used to identify the above average fishing locations for the distance analysis with strandings.

**Map Algebra Results Table**

| Map Algebra | Cells | Sq Km | % of Area |
|---|---|---|---|
| **None** | **3214** | **803.5** | **100.00%** |
| **Early + Mid** | 653 | 163.25 | 20.32% |
| **Mid + Late** | 504 | 126 | 15.68% |
| **Early + Late** | 856 | 214 | 26.63% |
| **All Seasons** | 338 | 84.5 | 10.52% |
| **Small + Large** | 288 | 72 | 8.96% |
| **Large + XL** | 224 | 56 | 6.97% |
| **Small + XL** | 28 | 7 | 0.87% |
| **All Sizes** | 27 | 6.75 | 0.84% |

Table 1. The map algebra results table shows the number of raster cells with a count of 1 or higher for the trawl locations, the equivalent square kilometers, and the percentage of the overall study area for each grouping of covariates.

Density analysis for the sea turtle stranding dataset identified clustering along the southern half of the Georgia coast, starting at Little St. Simons and increasing south. Covariates analyzed separately include the probable cause of death, life stage and sex. Diseased turtles were most concentrated on Cumberland Island, or the most southern island in Georgia. The No Apparent Injuries group was concentrated in the southern half of the state, with a few more clusters found among the more northern islands. Both the Other category and the Watercraft turtles were most concentrated around Brunswick, with higher concentrations along Cumberland and Tybee Islands. The kde analysis did not identify clusters for adult turtles, but did find juvenile strandings to be denser near Brunswick and Cumberland. Finally, the patterns for male and female turtles were similar with a stronger clustering for females on Cumberland Island. Hotspot analysis was completed for all strandings with probable cause, and separately for each of the four major categories of probable cause, finding similar patterns as the kde analysis and confirming the above average number of strandings for all groups in the southern half of the state and particularly Cumberland Island.

Density analysis for the boat boardings and TED violations did not identify any statistically significant spatial patterns. The kde maps did show that the most boardings occurred near Brunswick, the location of the GA DNR Coastal Division offices, although boardings did occur along the entire coast. In contrast, the kde analysis of the TED violations pulled the center south, identifying that more violations occur in the southern half of the state. For the final distance analysis, boardings and violations that occurred inland or at a marina were removed from the dataset, leaving 51 violations and 196 boardings. Therefore, violations were found approximately 25% of the time when DNR boards an actively fishing vessel.

After completing spatial analysis for the individual datasets, distances between events were calculated to identify potential correlation between the strandings and the trawler locations, above average fishing areas, and the TED violations. Appendix D contains the maps showing these points for each study year from 2006 to 2011, as well as the tables and graph results of the statistical model. The Bayesian hierarchical logistic model was fit to the data to identify the relative probability of stranding near these predictor variables for all strandings and for loggerhead strandings. For all probable death categories and for the analysis with all sea turtles and loggerhead turtles only, there was a significant negative relationship between being stranded and the nearest TED violation.

The effect of distance to nearest TED violation was of greatest magnitude for the No Apparent Injuries death category. Interestingly, the negative direction of the relationship between strandings and TED violations was consistent across years; although the magnitude of the effect varied. In contrast, no significant relationship was found between the categories of strandings, all turtles or loggerheads only, with the trawler locations or the above average fishing locations. The statistics and one sample graph depicting these results are shown in Tables 2-3 and Figure 1.

**ALL SEA TURTLE SPECIES ANALYSIS RESULTS**

| | Posterior mean | Lower 95% CI | Upper 95% CI |
|---|---|---|---|
| Disease | | | |
| TRAWL | -0.06 | -0.63 | 0.54 |
| **TED** | **-0.91** | **-1.70** | **-0.15** |
| FISH | -0.04 | -0.68 | 0.56 |
| No apparent injuries | | | |
| TRAWL | -0.16 | -0.64 | 0.33 |
| **TED** | **-1.60** | **-2.93** | **-0.47** |
| FISH | 0.07 | -0.38 | 0.52 |
| Watercraft | | | |
| TRAWL | 0.13 | -0.38 | 0.63 |
| **TED** | **-0.94** | **-1.78** | **-0.14** |
| FISH | -0.16 | -0.76 | 0.46 |

Table 2. Population-average effects of distance to nearest above average fishing point (FISH), distance to nearest TED violation (TED), distance to nearest trawl location (TRAWL) for the all sea turtle analysis. Results are presented for Disease, No apparent injuries, and Watercraft death categories. Predictors in bold have 95% credible intervals that do not overlap zero.

**LOGGERHEAD SEA TURTLE ANALYSIS RESULTS**

| | Posterior mean | Lower 95% CI | Upper 95% CI |
|---|---|---|---|
| Disease | | | |
| TRAWL | -0.083 | -0.71 | 0.55 |
| **TED** | **-1.07** | **-1.98** | **-0.23** |
| FISH | 0.00 | -0.67 | 0.64 |
| No apparent injuries | | | |
| TRAWL | -0.31 | -0.82 | 0.20 |
| **TED** | **-1.77** | **-2.92** | **-0.77** |
| FISH | 0.00 | -0.48 | 0.48 |
| Watercraft | | | |
| TRAWL | 0.07 | 0.-0.47 | 0.58 |
| **TED** | **-0.85** | **-1.67** | **-0.12** |
| FISH | -0.09 | -0.72 | 0.56 |

Table 3. Population-average effects of distance to nearest above average fishing point (FISH), distance to nearest TED violation (TED), distance to nearest trawl location (TRAWL) for the loggerhead sea turtle analysis. Results are presented for Disease, No apparent injuries, and Watercraft death categories. Predictors in bold have 95% credible interals that do not overlap zero.

**CORRELATION BETWEEN NO APPARENT INJURY LOGGERHEAD TURTLES AND TED VIOLATIONS**

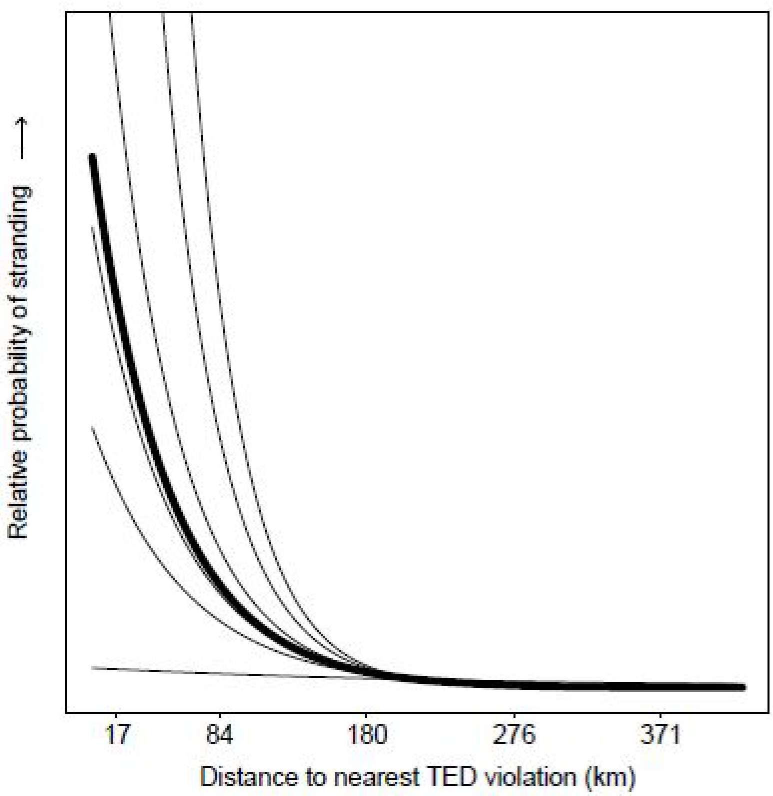


Figure 1. The relative probability of being stranded for loggerhead (*Caretta caretta*) sea turtles classified with a no apparent injury death category in relation to the distance to the nearest TED violation. Thick line is population-average effect (across all years) and thin lines are year-specific relationships.

## VI. Discussion

This research provides some insight and answers to the original research objectives proposed. Spatial patterns, specifically clustering patterns, are present in the locations of shrimp trawlers and sea turtle strandings over the study period from 1999 - 2013. These patterns change as a function of the covariates, including season, size of boat, and probable cause of death. The patterns vary some from year to year, but overall exhibit the same clustering locations. Correlations were identified between the sea turtle strandings and the TED violations, but not the general trawler locations or the areas identified as above average fishing locations. These results are very similar to those found by Lewison et al. (2003) when reviewing turtle strandings and the shrimp fishery in the western Gulf of Mexico. Although different methodology was used, the strandings analyzed were correlated with TED violations and not intensive fishing locations. By finding similar results on the Atlantic Coast the argument for TED regulations and compliance is strengthened.

The next step in this analysis will be to review the correlation found between TED violations and strandings on the Georgia coast to see how the statistical significance may change at a different spatial scale. The coast will be split into the northern and southern halves around Wolf Island or Latitude 31.3° and the same distance calculations and statistical model will be fit to see if the no apparent injury turtles continue to be statistically closer to the TED violations than other probable cause of death strandings. The stranding hot spot analyses have provided evidence to document that strandings were significantly more common for the southern portion of the state, particularly on Cumberland Island. To further investigate this spatial clustering, a number of analyses could be useful such as reviewing ocean current patterns, beach orientation, and erosion patterns to determine potential natural causes for the turtles to wash up in the southern part of the state so frequently. It could also be useful to expand the analysis to include data from the Florida coast to see if these patterns continue south. Ideally, drifter experiments such as those described by Koch et al. (2013) would be conducted to provide evidence of drifting patterns for the entire Georgia coast.

The results of these analyses and final maps will be presented to the Sea Turtle Conservation Program with the GA DNR for further evaluation. This research is the first attempt to provide any spatial analysis for these datasets beyond adding the locations to a map. The density maps will provide useful locations for boarding boats during the shrimping season, where boats are clustered during the different fishing seasons through the year. These methods and results also reinforce the importance of collecting accurate spatial information on all events impacting the Georgia Sea Turtle Project for ongoing analysis. The research results strengthen the justification for DNR to increase the frequency of boat boardings to improve TED compliance and potentially reduce the impact of the shrimp boats on the sea turtle population. Ultimately these results will assist in developing the conservation program to protect sea turtles while maintaining the economic benefits of the shrimping industry for the state of Georgia.


Figure 2. Study area map identifying the counties and islands on the coast of Georgia.

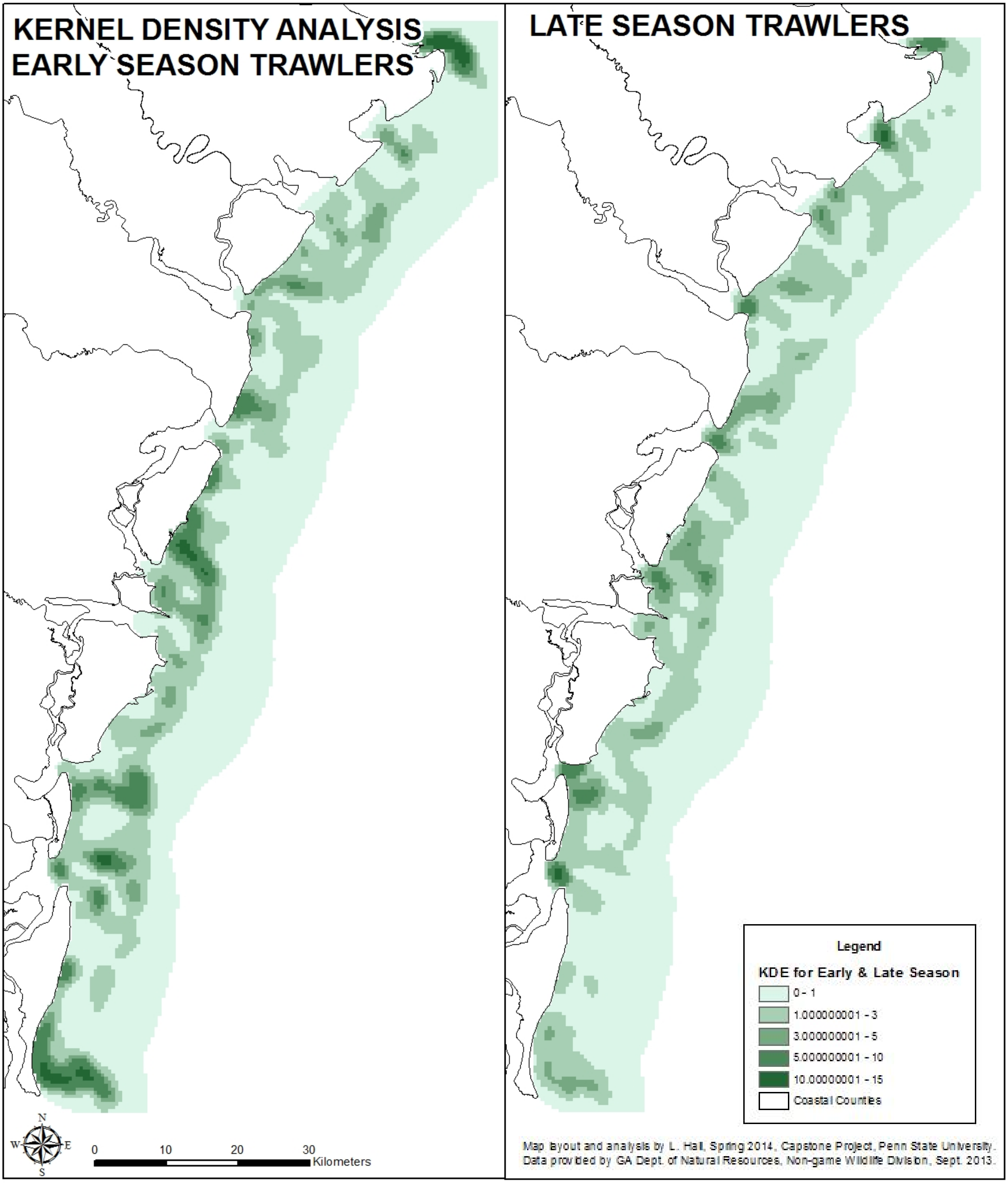


Figure 3. Kernel density analysis maps showing the trawler locations for the early and late shrimping season.

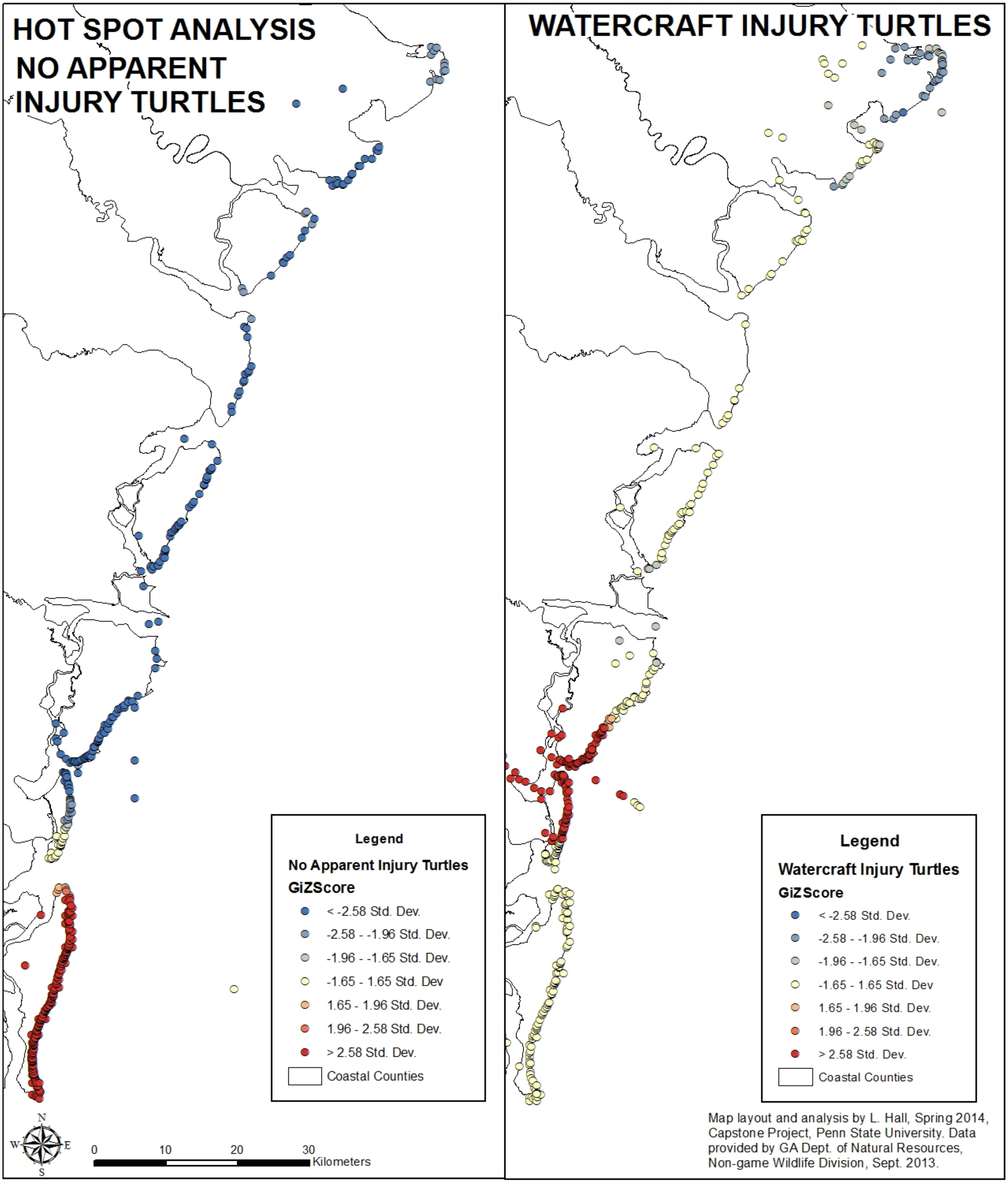


Figure 4. Hot spot analysis map showing the results for the no apparent injury turtles and the watercraft injury turtles.

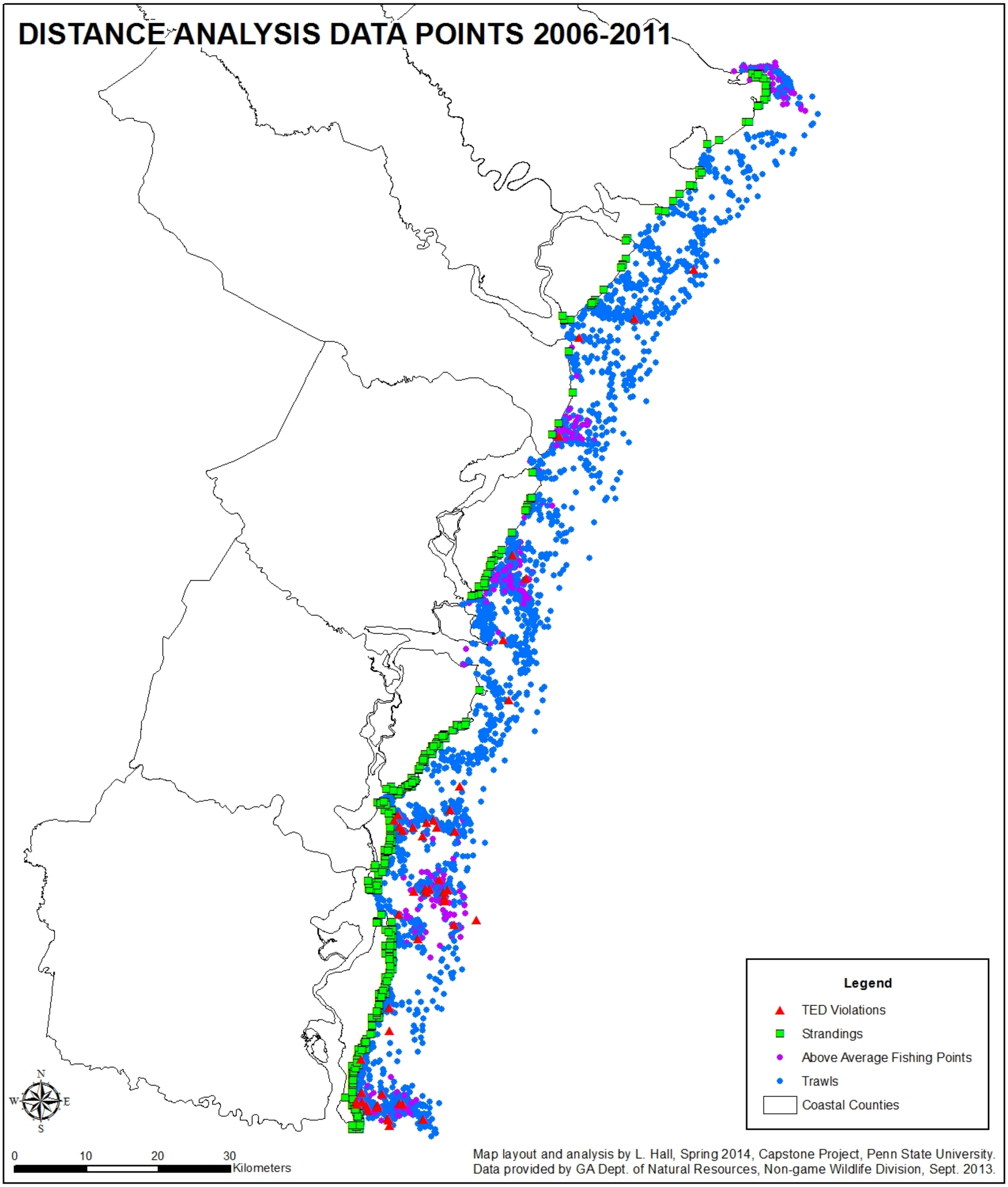


Figure 5. Data points used in the near distance analysis calculations from 2006 to 2011.

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**SPATIAL ANALYSIS FOR SEA TURTLE CONSERVATION ON THE GEORGIA COAST**
**Appendix A: Original Dataset Maps**

Contents

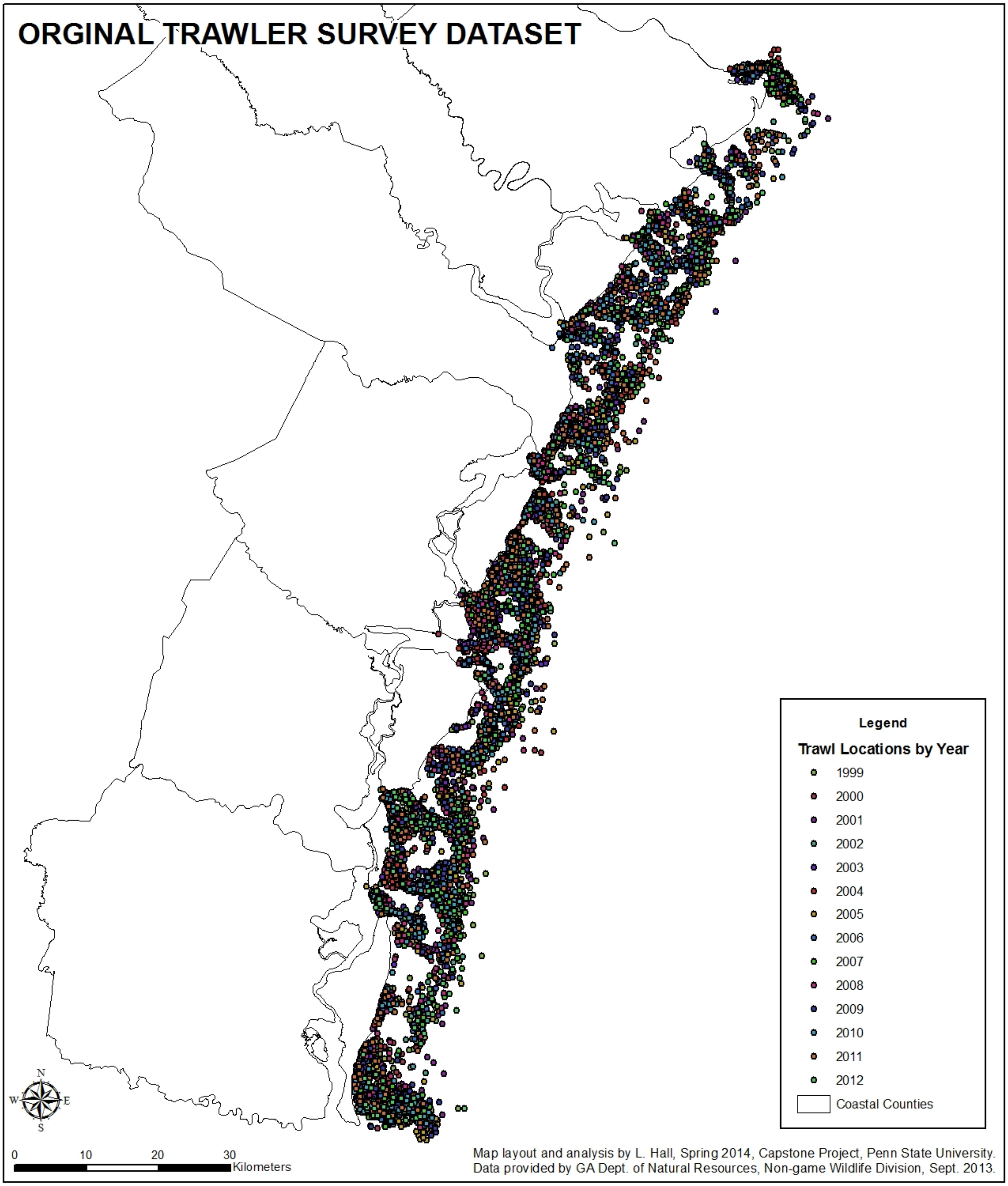


FIGURE A1. Original Trawler Dataset Map shows the locations for all trawler observations recorded in the dataset received from the Georgia Department of Natural Resources.

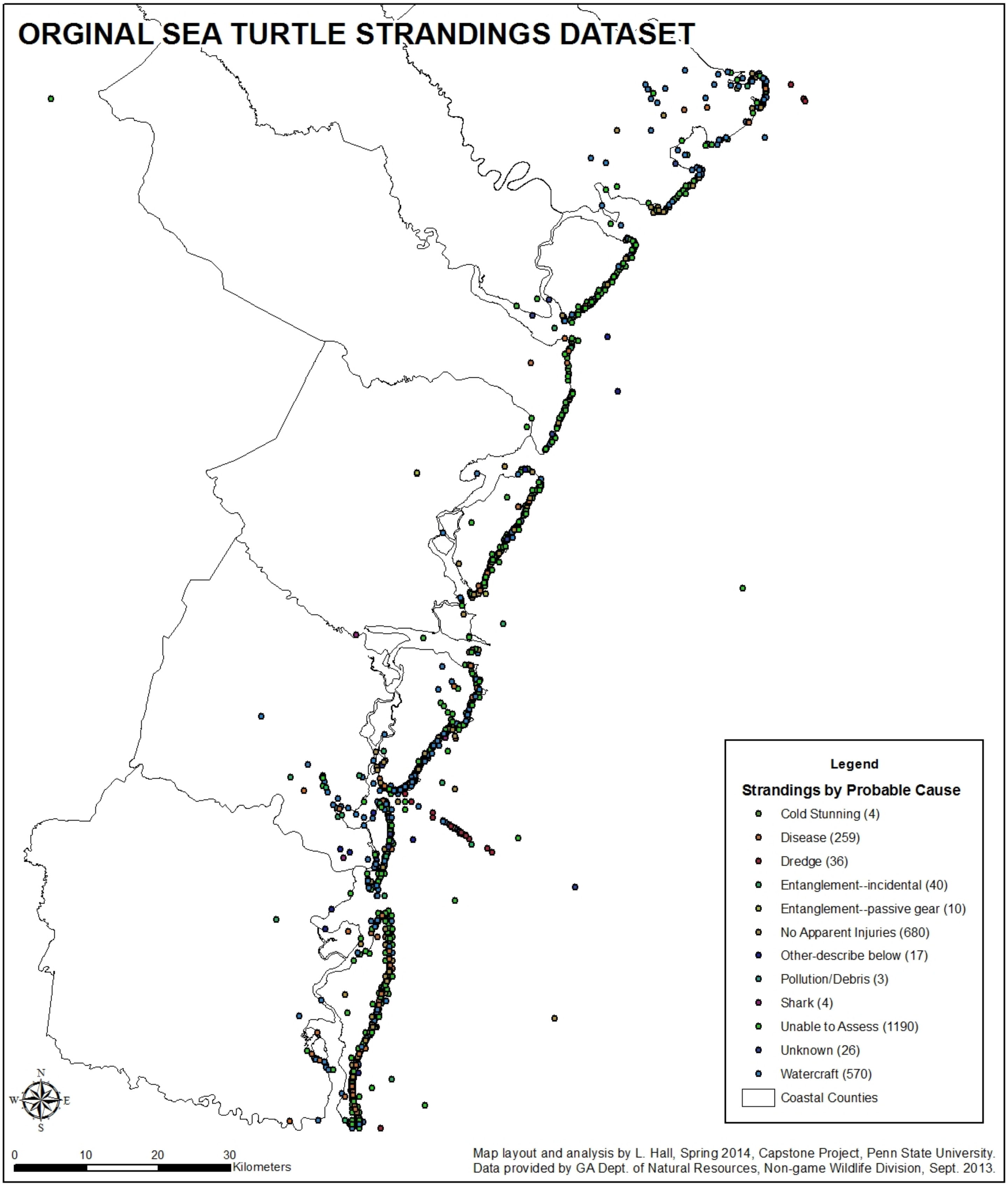


FIGURE A2. Original Sea Turtle Strandings Dataset Map shows the locations for all strandings recorded in the dataset received from the Georgia Department of Natural Resources.

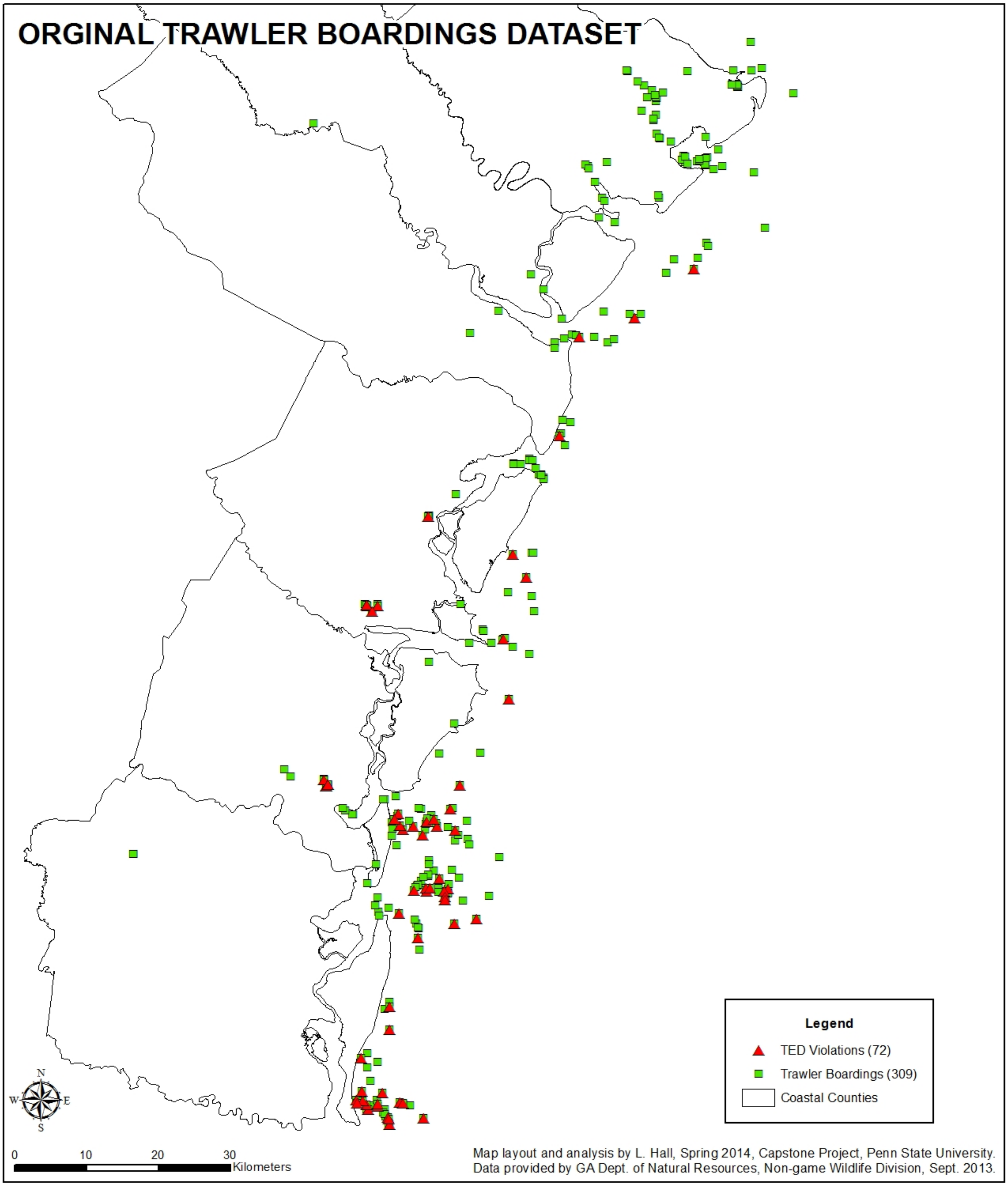


FIGURE A1. Original Trawler Boardings Dataset Map shows the locations for all trawler boardings including the TED violations recorded in the dataset received from the Georgia Department of Natural Resources.

**SPATIAL ANALYSIS FOR SEA TURTLE CONSERVATION ON THE GEORGIA COAST**
**Appendix B: Kernel Density Analysis Maps**

Contents

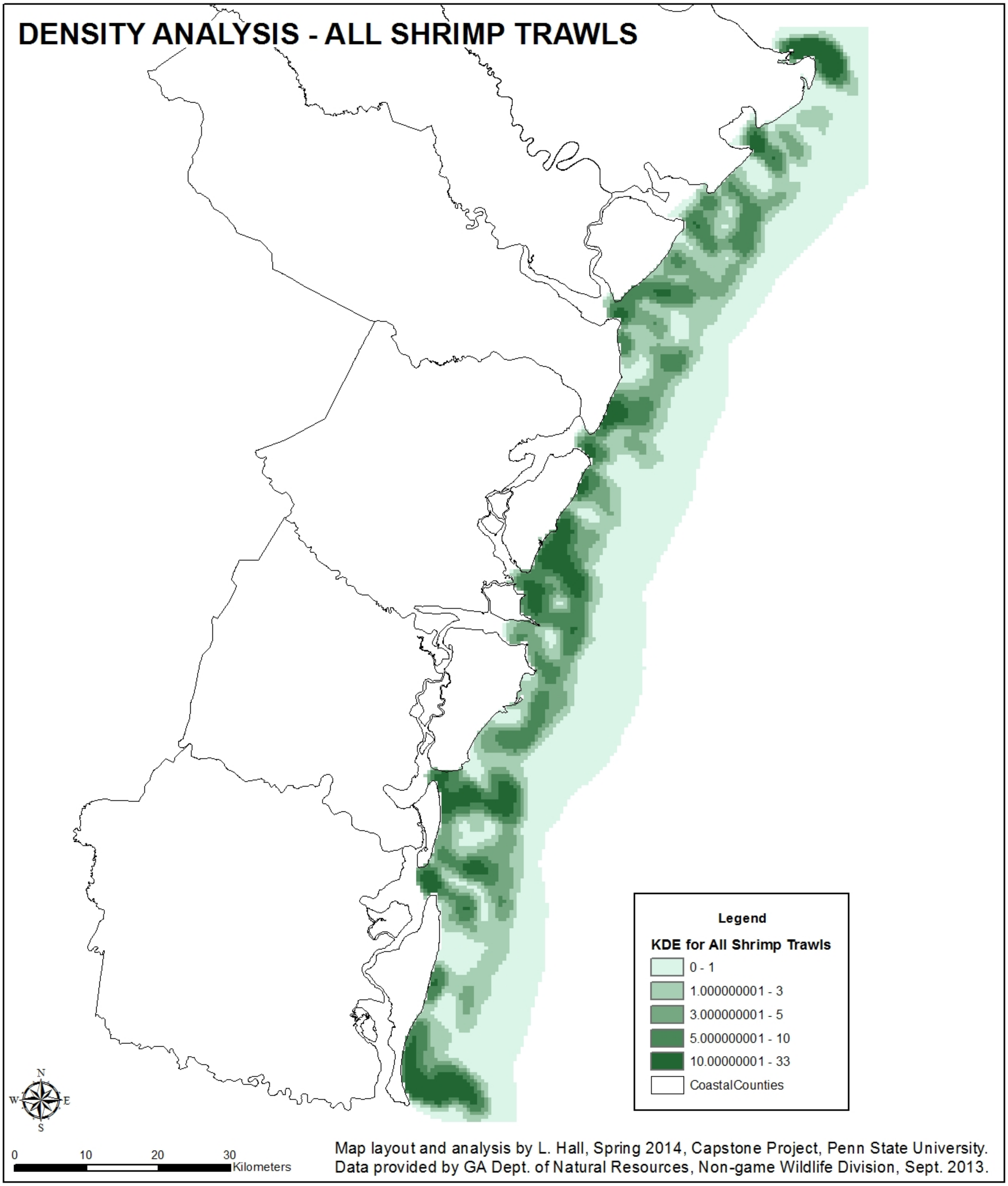


FIGURE B1. Kernel density analysis map for all shrimp trawler observed fishing during surveys from 1999 to 2012

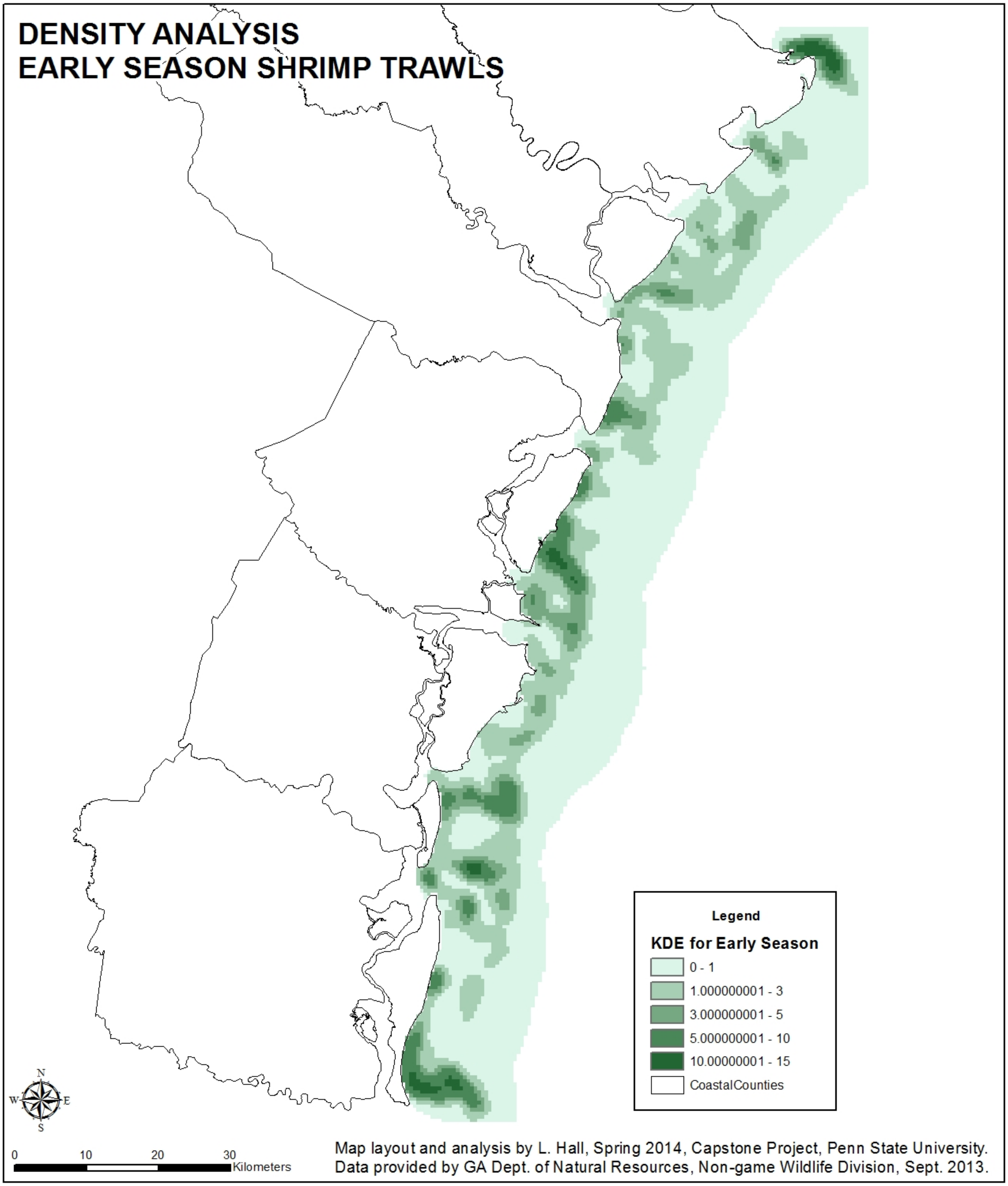


FIGURE B2. Kernel density analysis map for shrimp trawlers observed fishing in April and May from 1999 to 2012

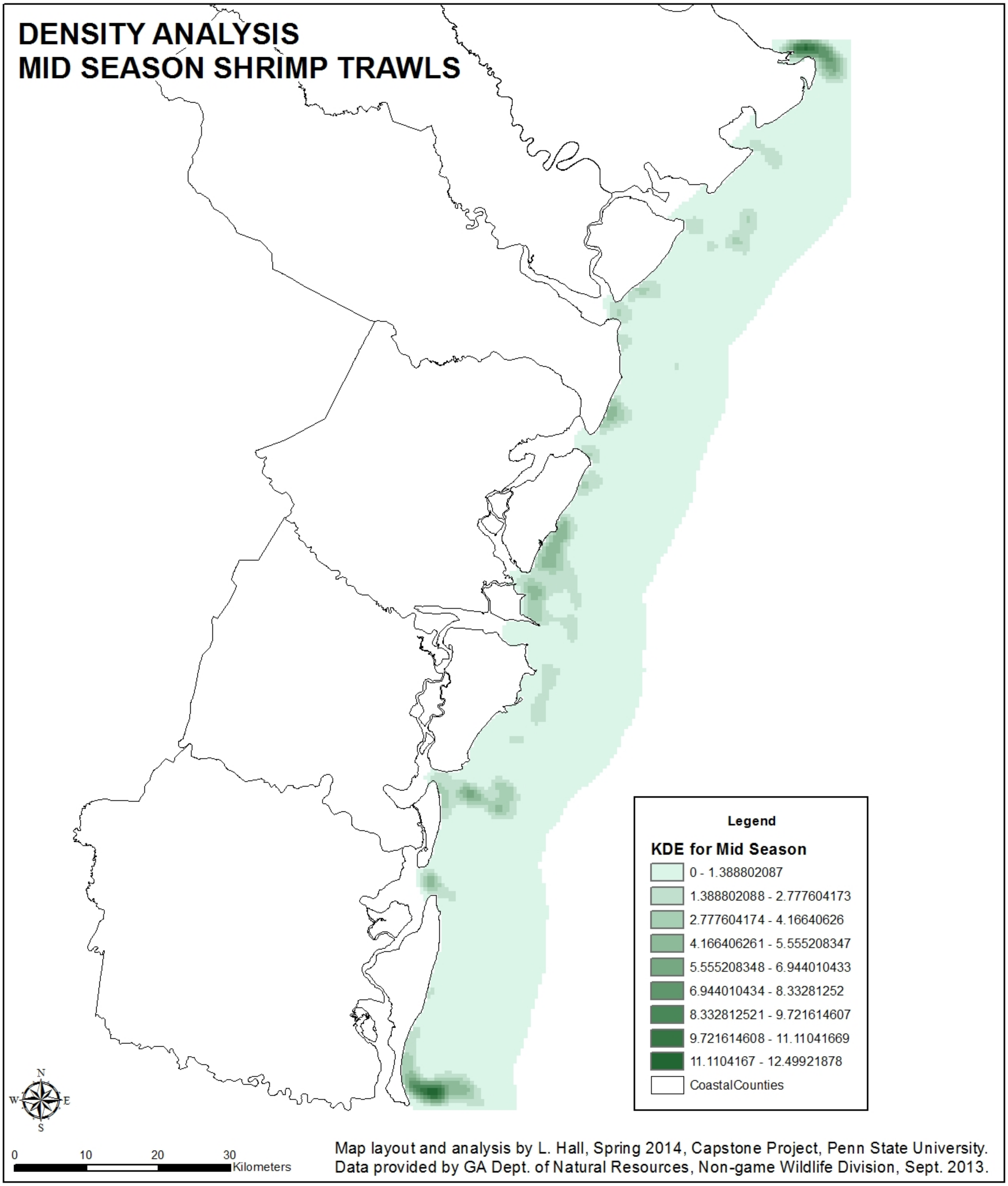


FIGURE B3. Kernel density analysis map for shrimp trawlers observed fishing in June and July from 1999 to 2012

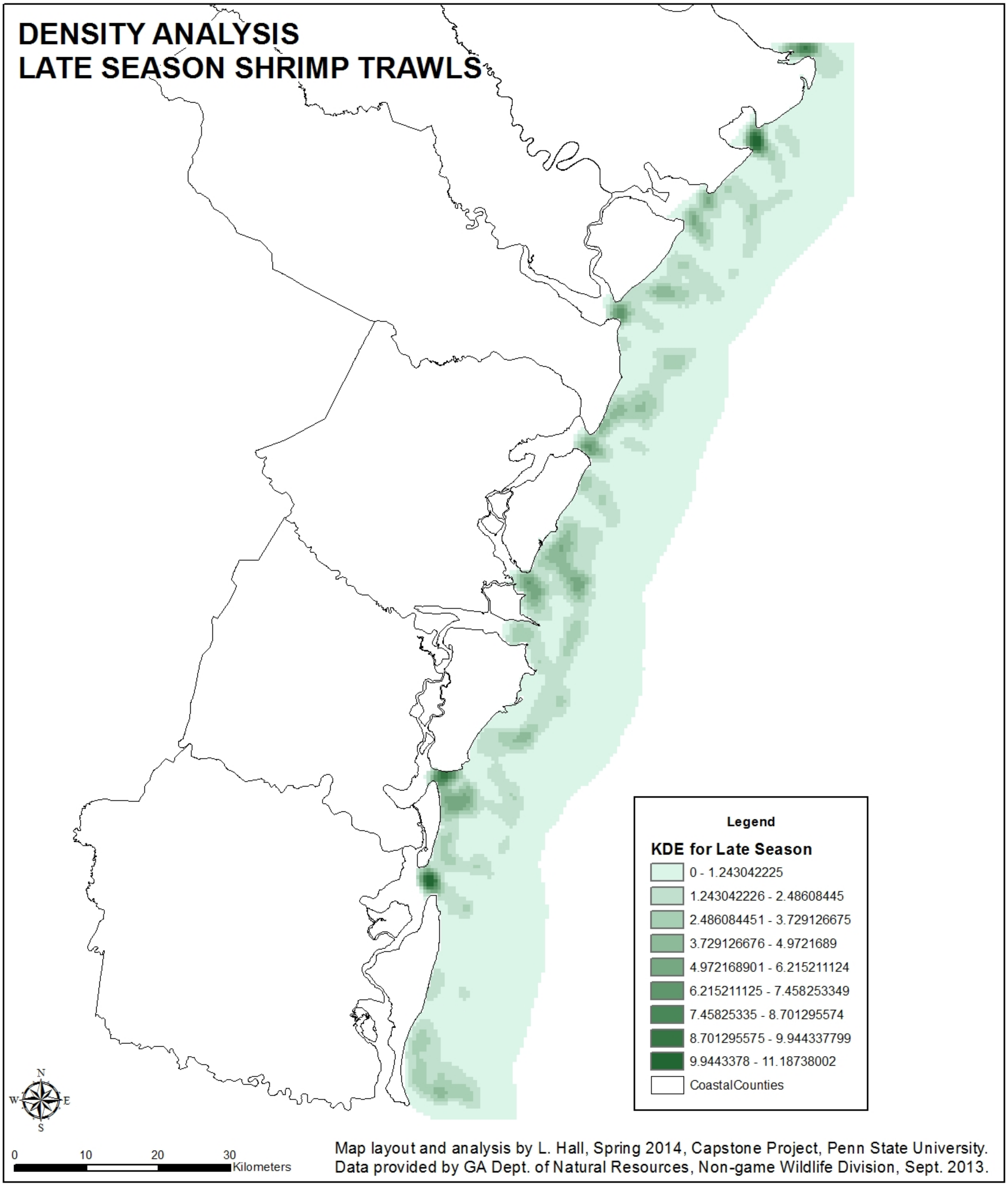


FIGURE B4. Kernel density analysis map for shrimp trawlers observed fishing in August to October from 1999 to 2012

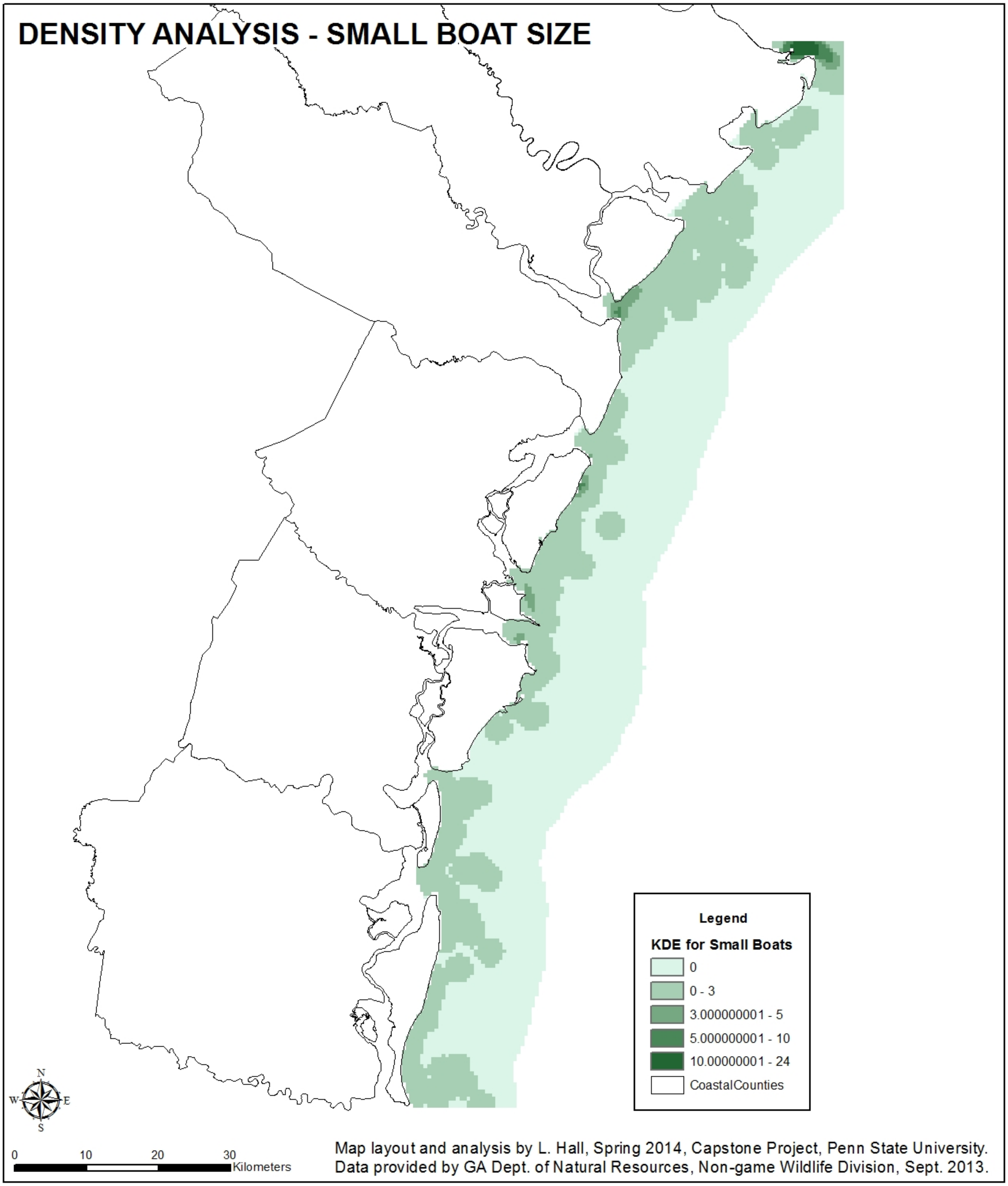


FIGURE B5. Kernel density analysis map for all small shrimp trawlers observed fishing during surveys from 1999 to 2012

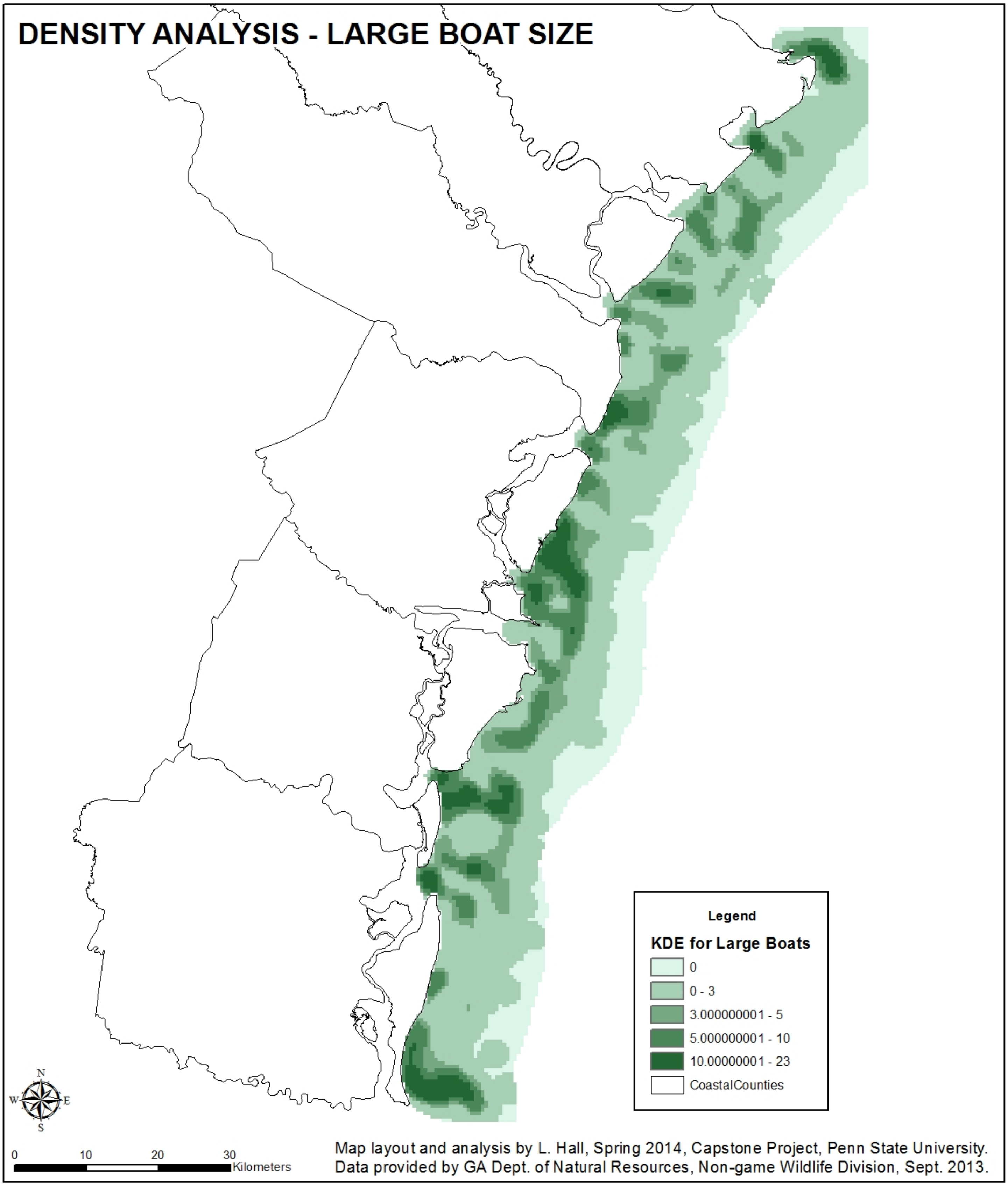


FIGURE B6. Kernel density analysis map for all large shrimp trawlers observed fishing during surveys from 1999 to 2012

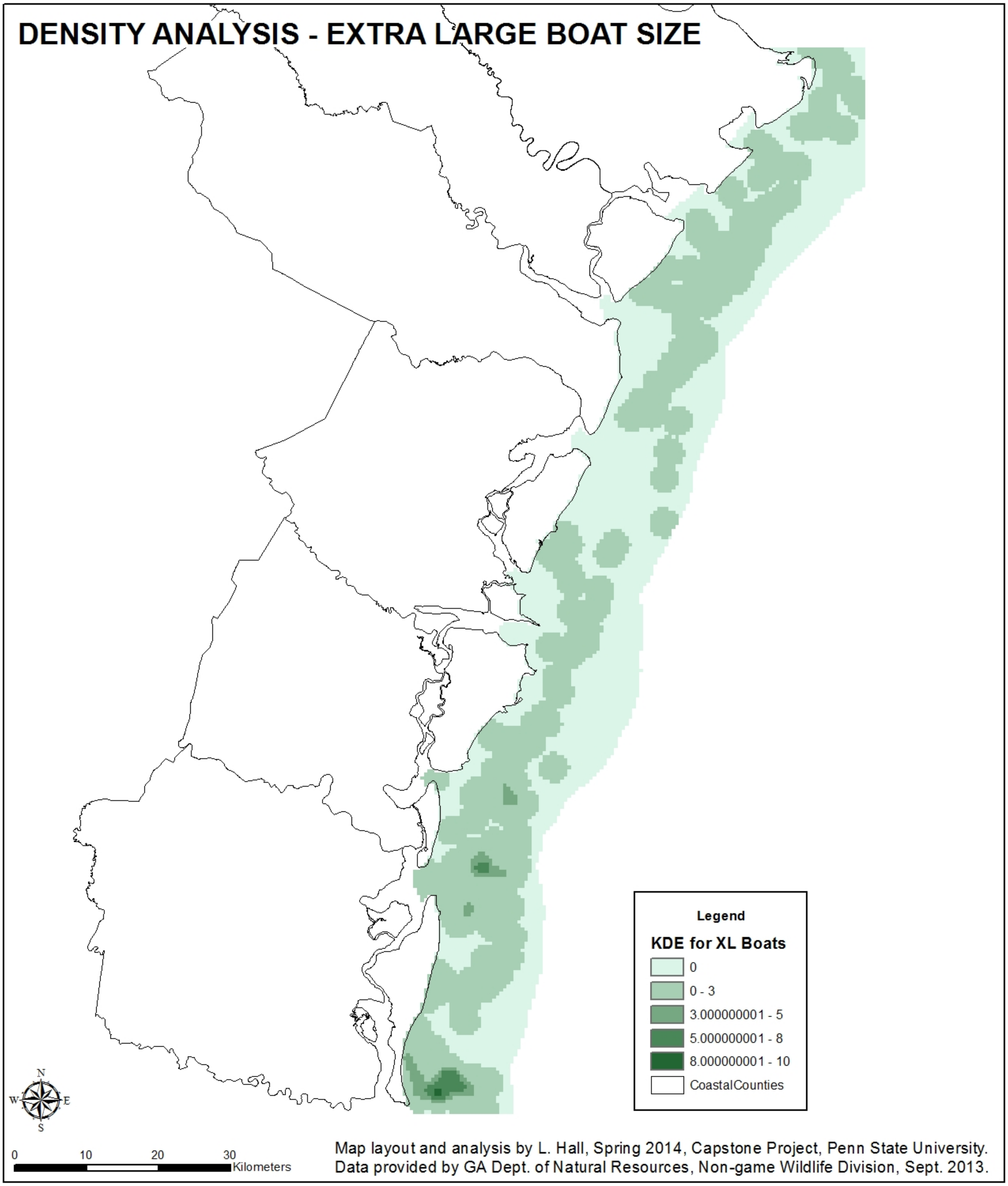


FIGURE B7. Kernel density analysis map for all extra large shrimp trawlers observed fishing during surveys from 1999 to 2012

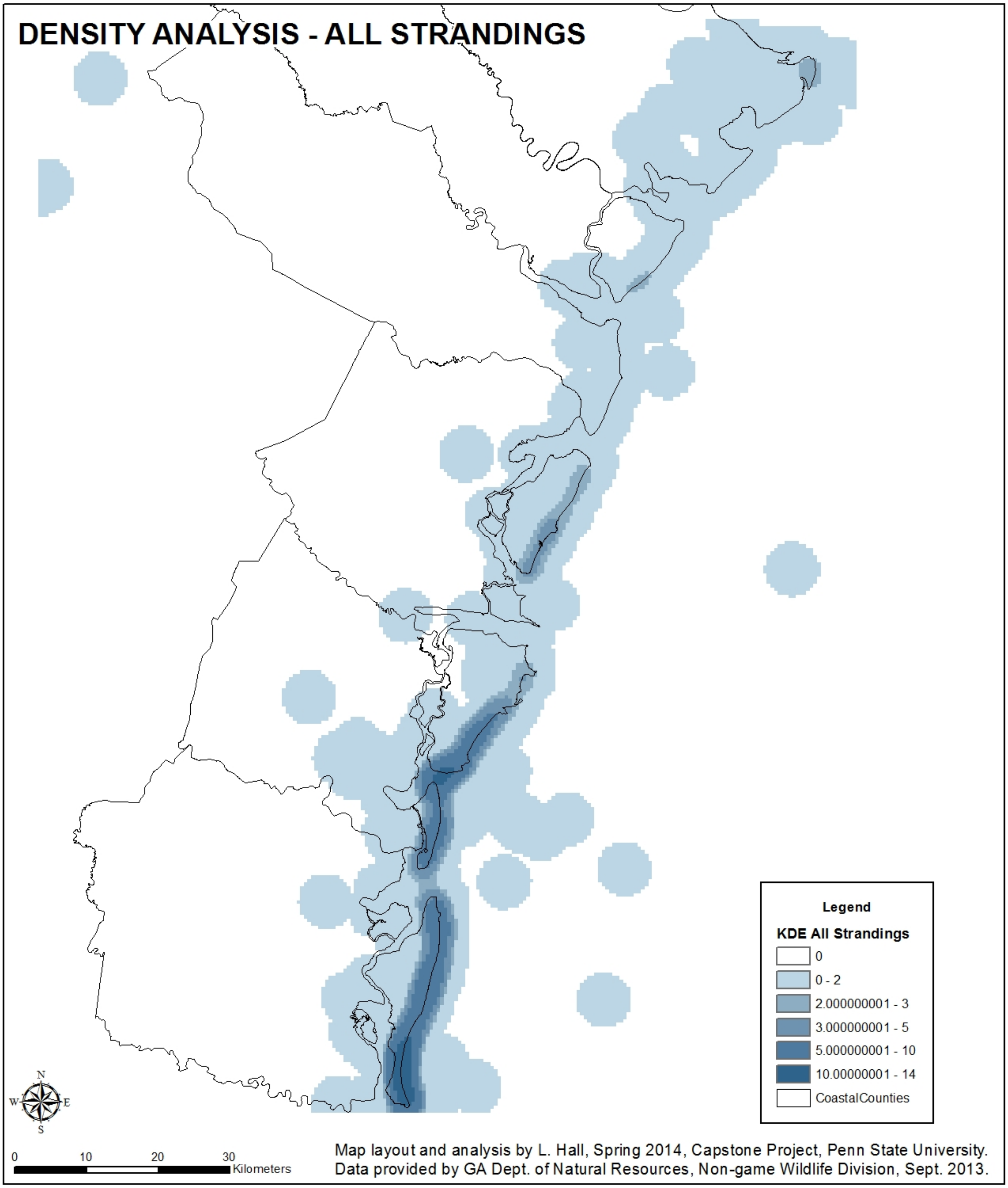


FIGURE B8. Kernel density analysis map for all recorded sea turtle strandings from 1999 to 2012

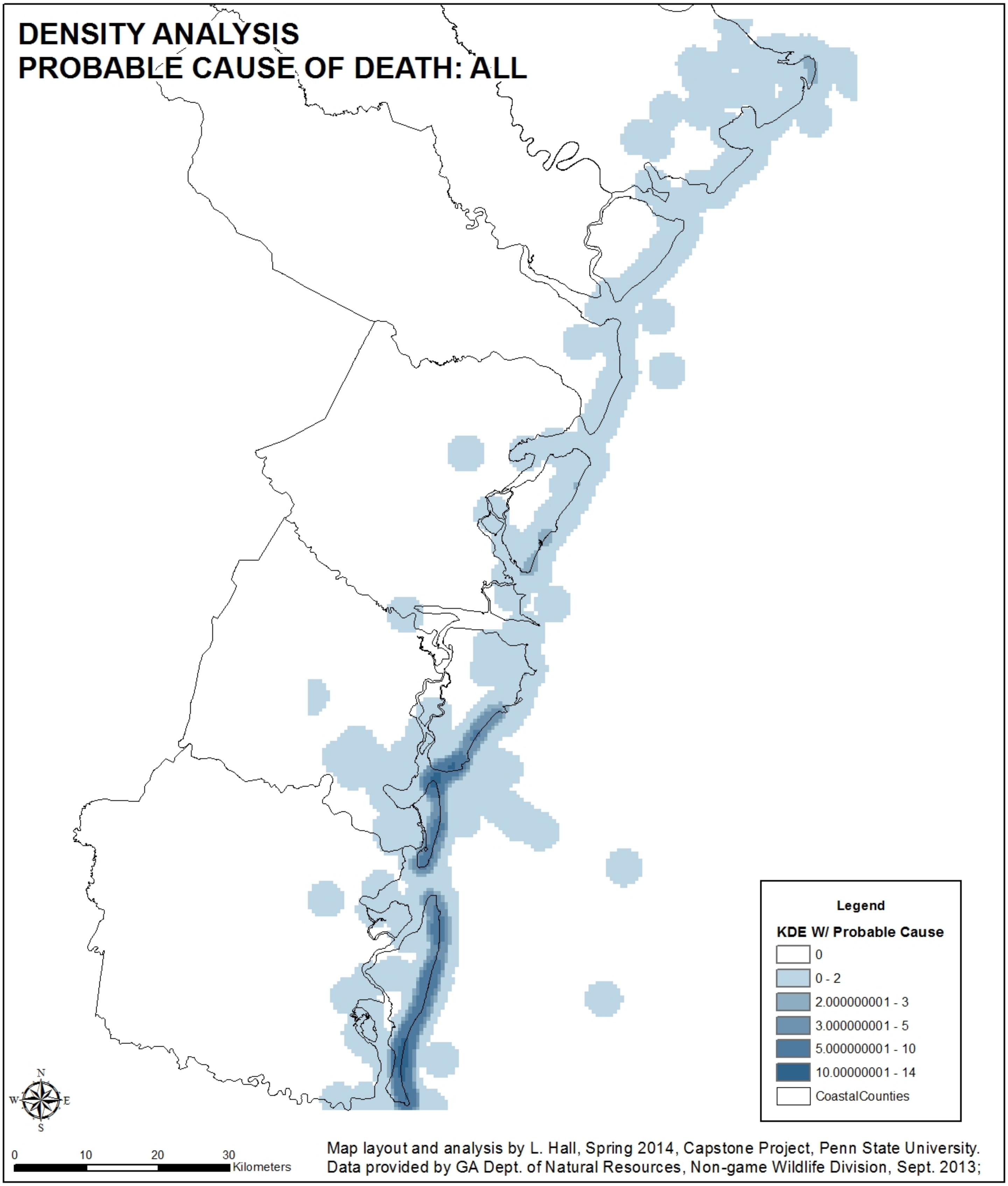


FIGURE B9. Kernel density analysis map for all sea turtle strandings with an identifiable cause of death from 1999 to 2012

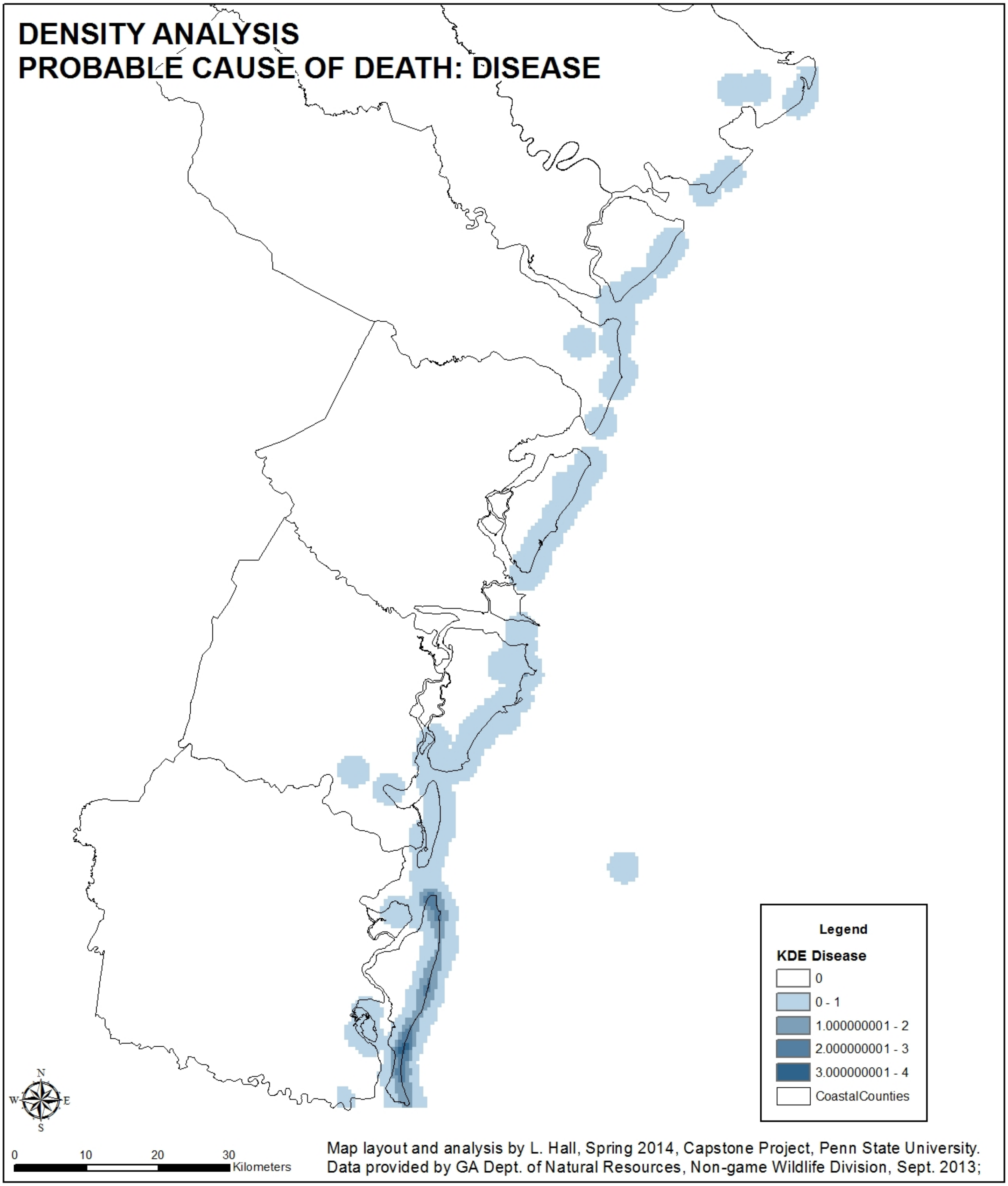


FIGURE B10. Kernel density analysis map for all sea turtle strandings caused by disease from 1999 to 2012

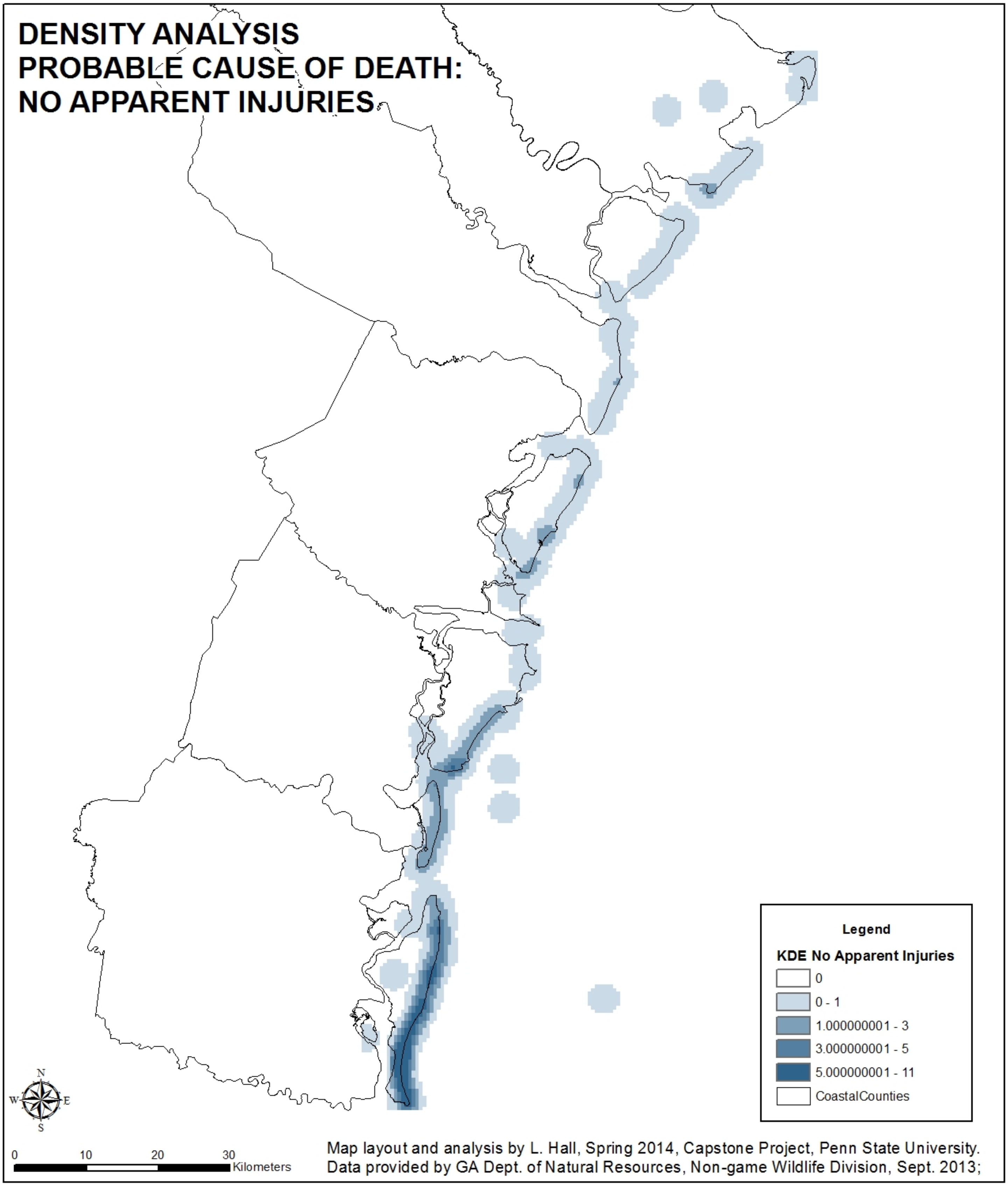


FIGURE B11. Kernel density analysis map for all sea turtle strandings no apparent injuries from 1999 to 2012

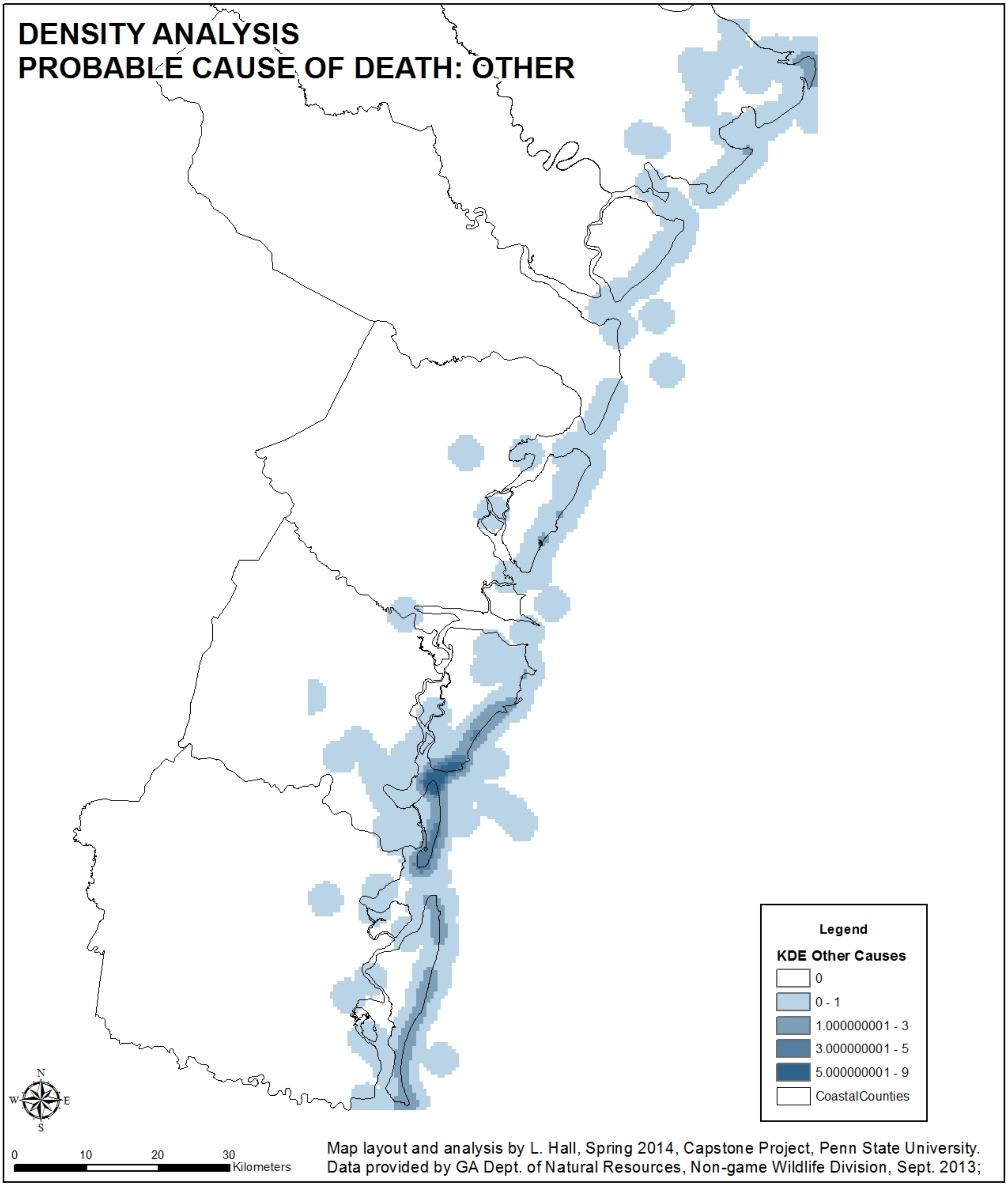


FIGURE B12. Kernel density analysis map for all sea turtle strandings caused by other known causes from 1999 to 2012

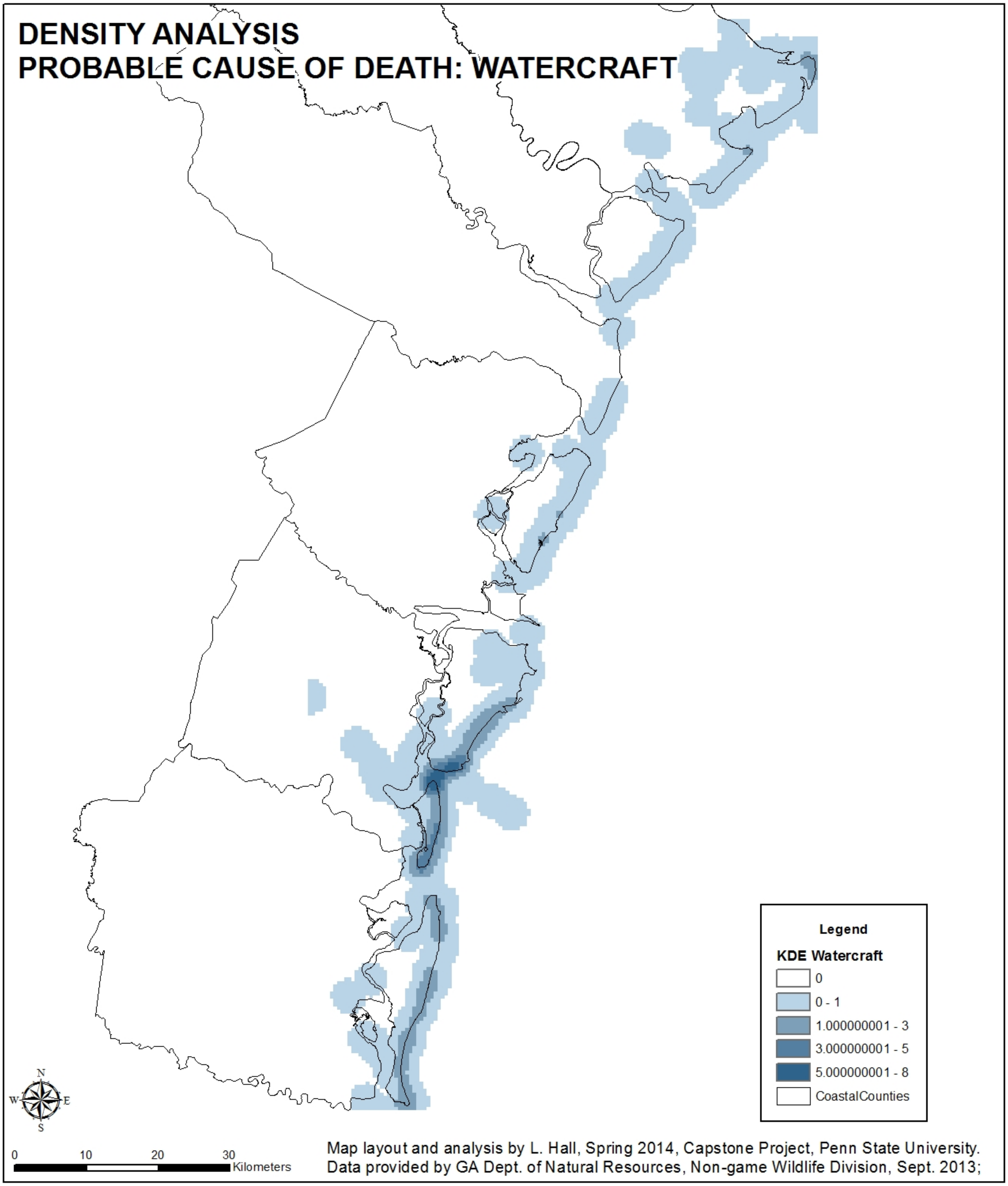


FIGURE B13. Kernel density analysis map for all sea turtle strandings caused by watercraft injury from 1999 to 2012

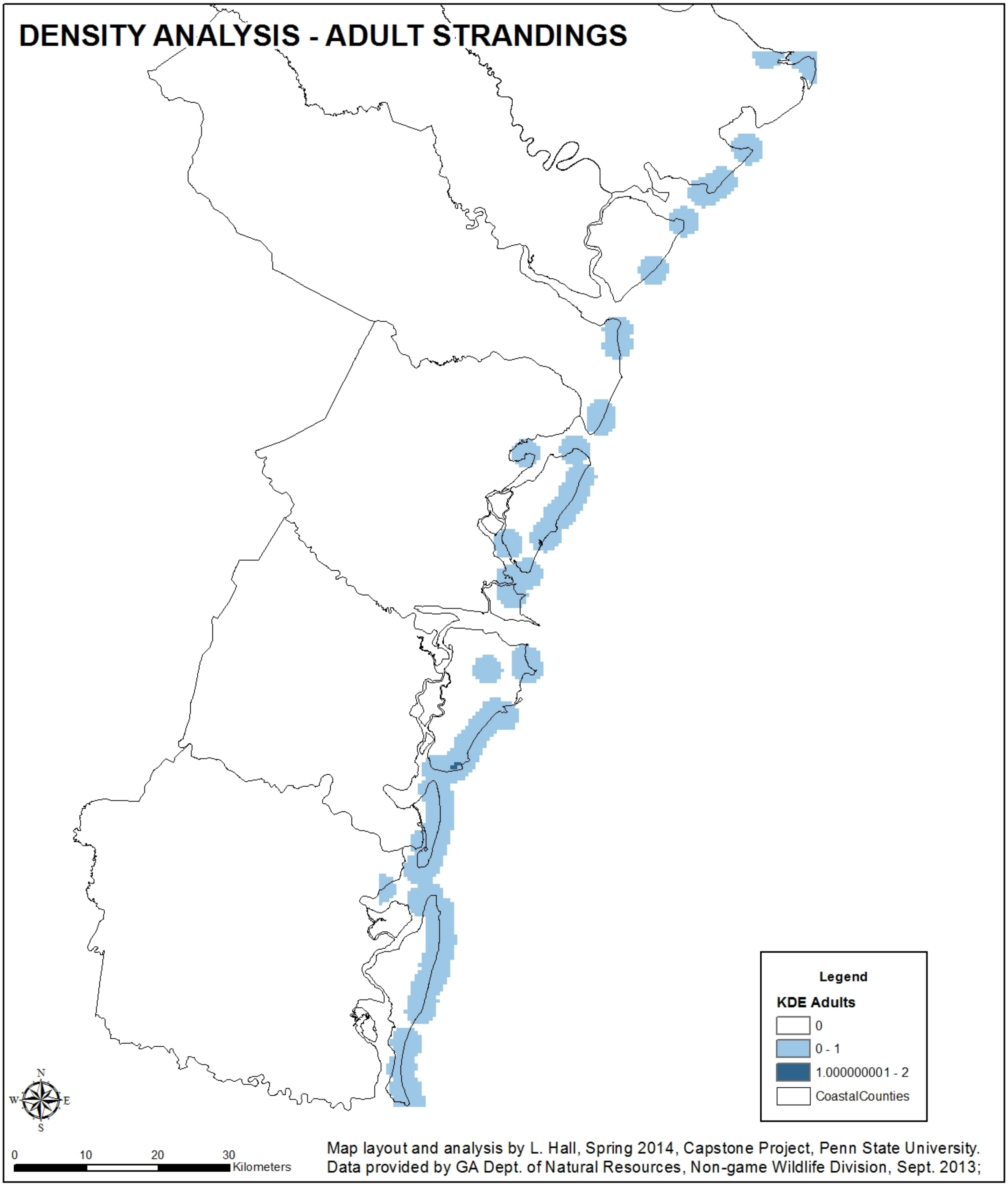


FIGURE B14. Kernel density analysis map for all adult sea turtle strandings from 1999 to 2012

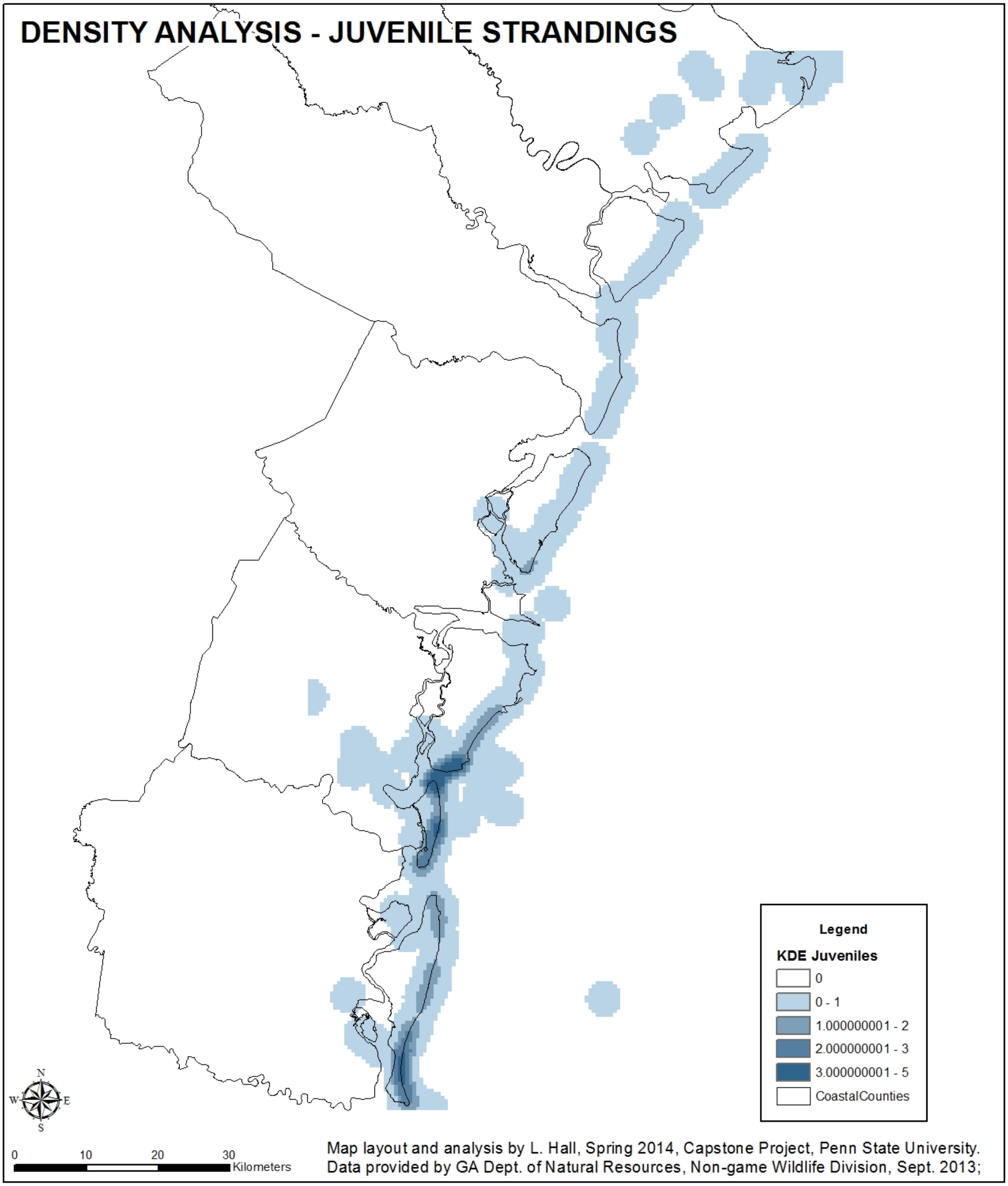


FIGURE B15. Kernel density analysis map for all juvenile sea turtle strandings from 1999 to 2012

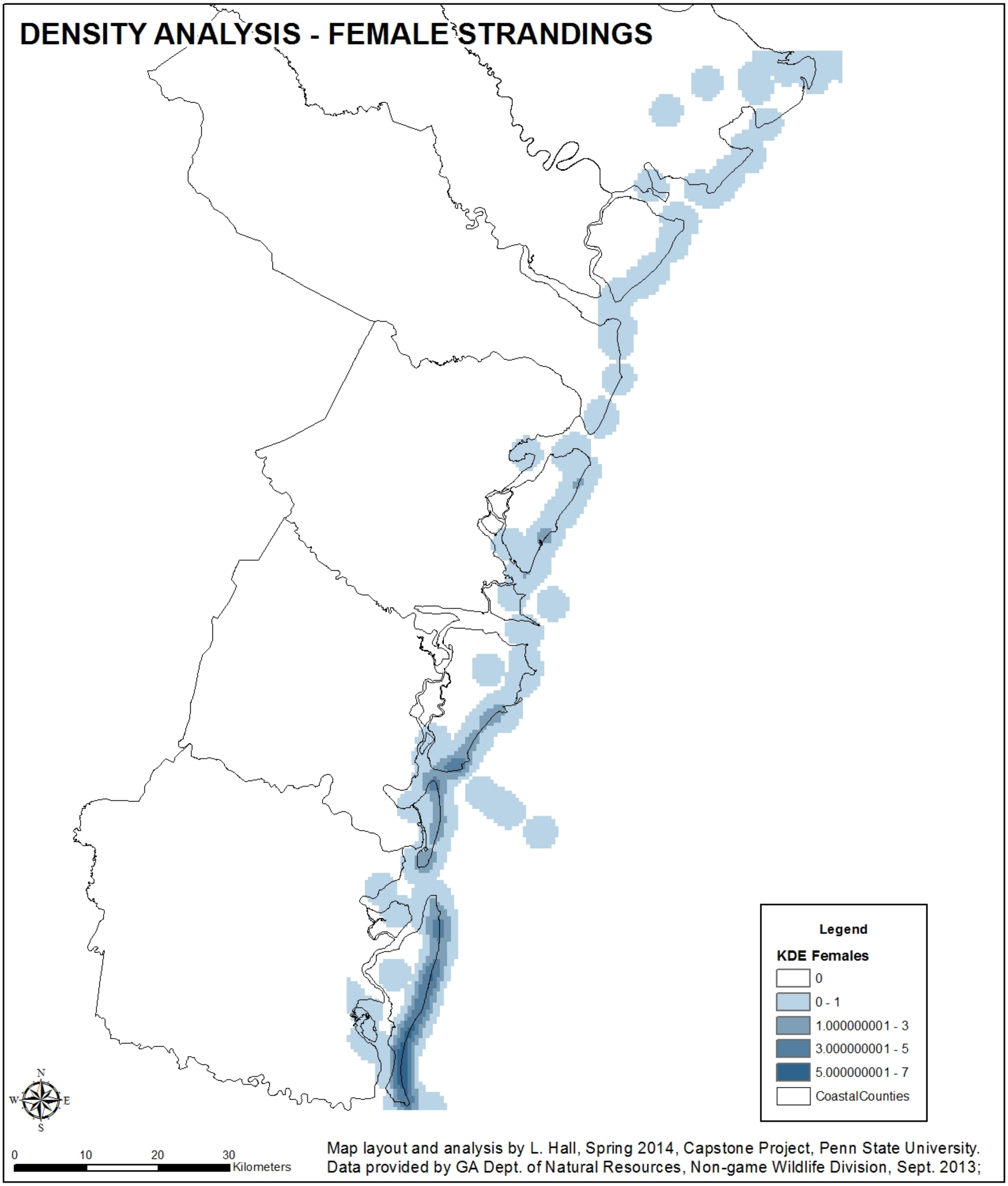


FIGURE B16. Kernel density analysis map for all female sea turtle strandings from 1999 to 2012

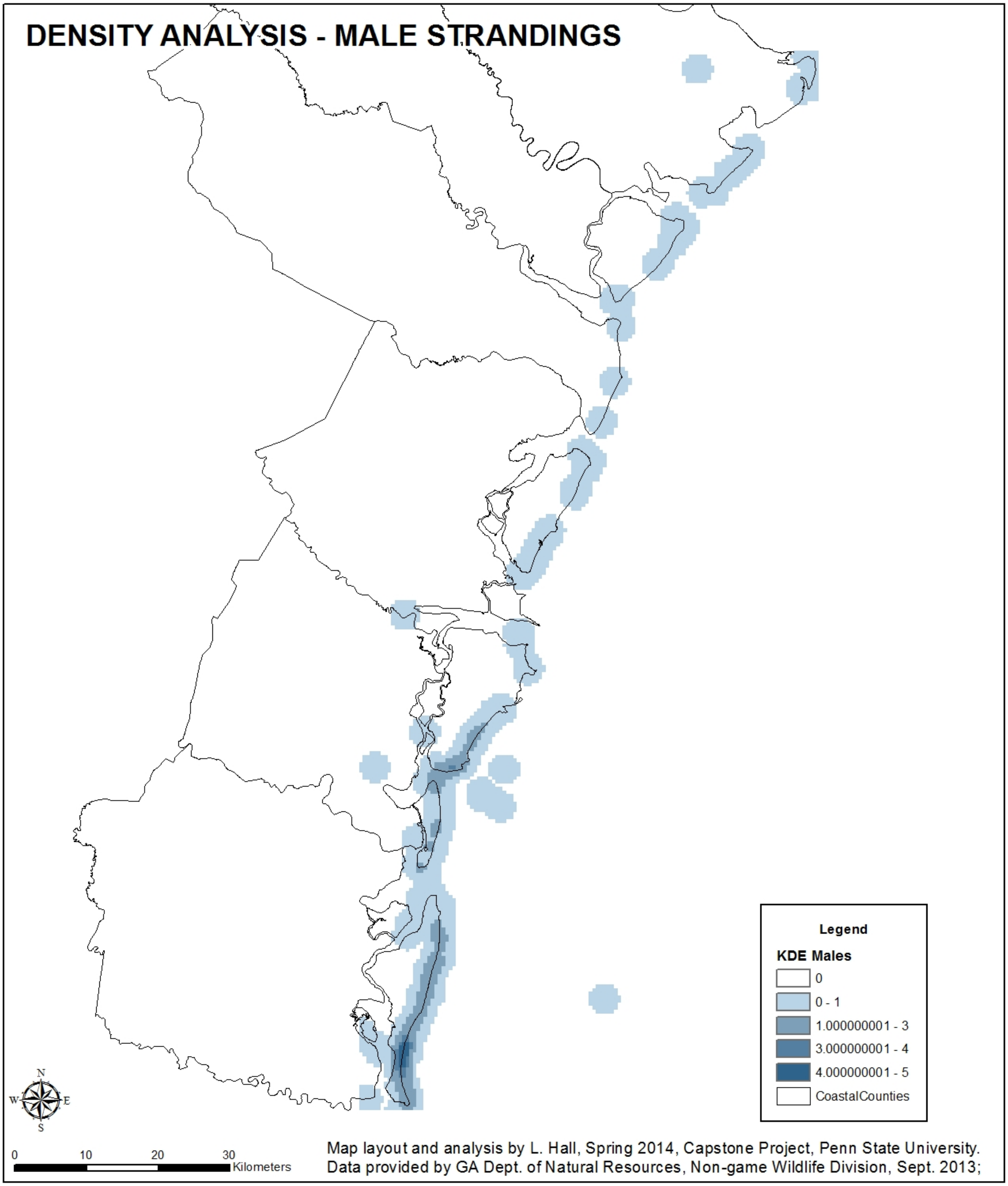


FIGURE B17. Kernel density analysis map for all male sea turtle strandings from 1999 to 2012

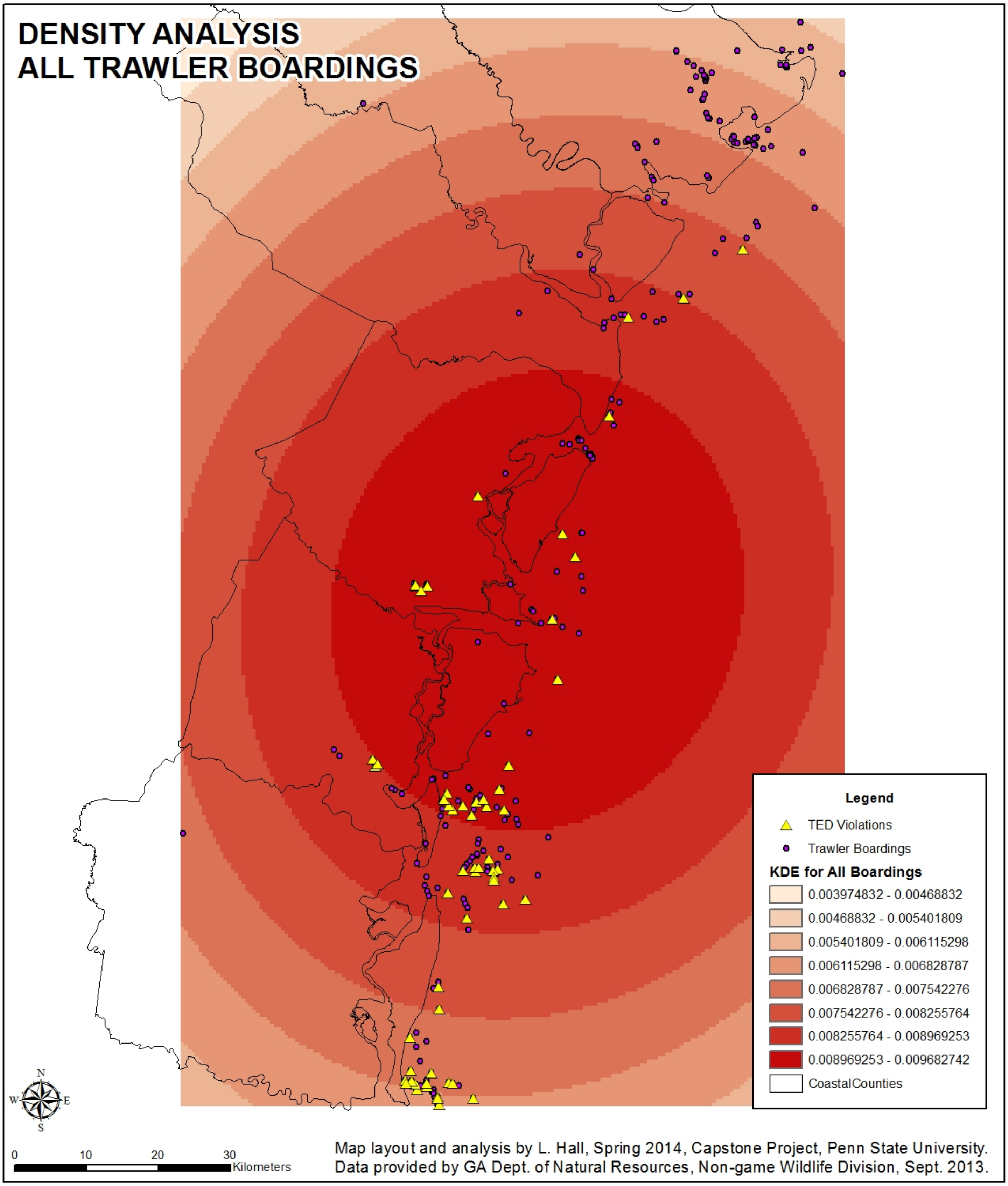


Figure B18. Kernel density analysis map for all shrimp trawler boardings by GA DNR from 2006 to 2011

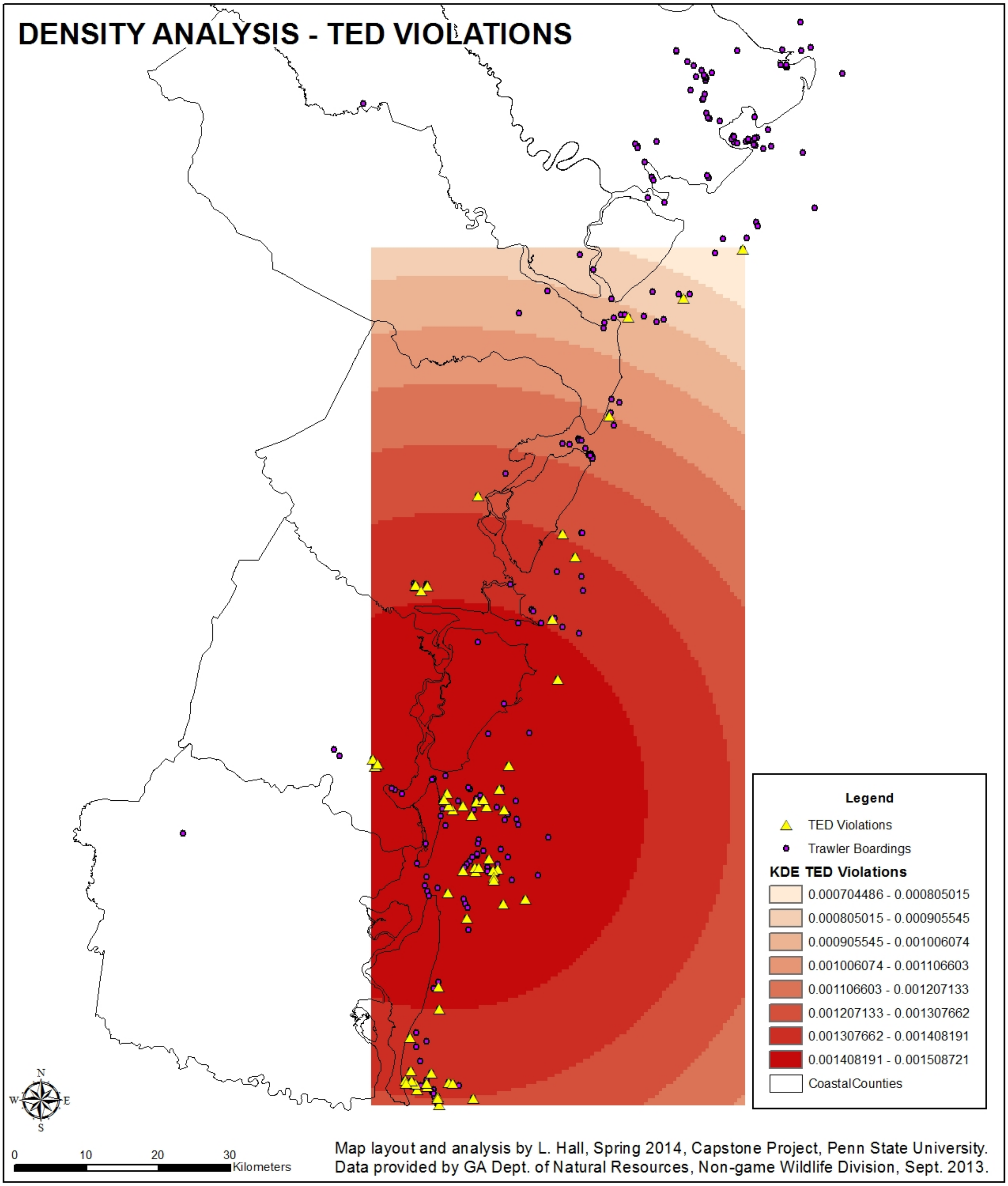


Figure B19. Kernel density analysis map for all TED violations found by GA DNR from 2006 to 2011

**SPATIAL ANALYSIS FOR SEA TURTLE CONSERVATION ON THE GEORGIA COAST**
**Appendix C: Hot Spot Analysis Maps**

Contents

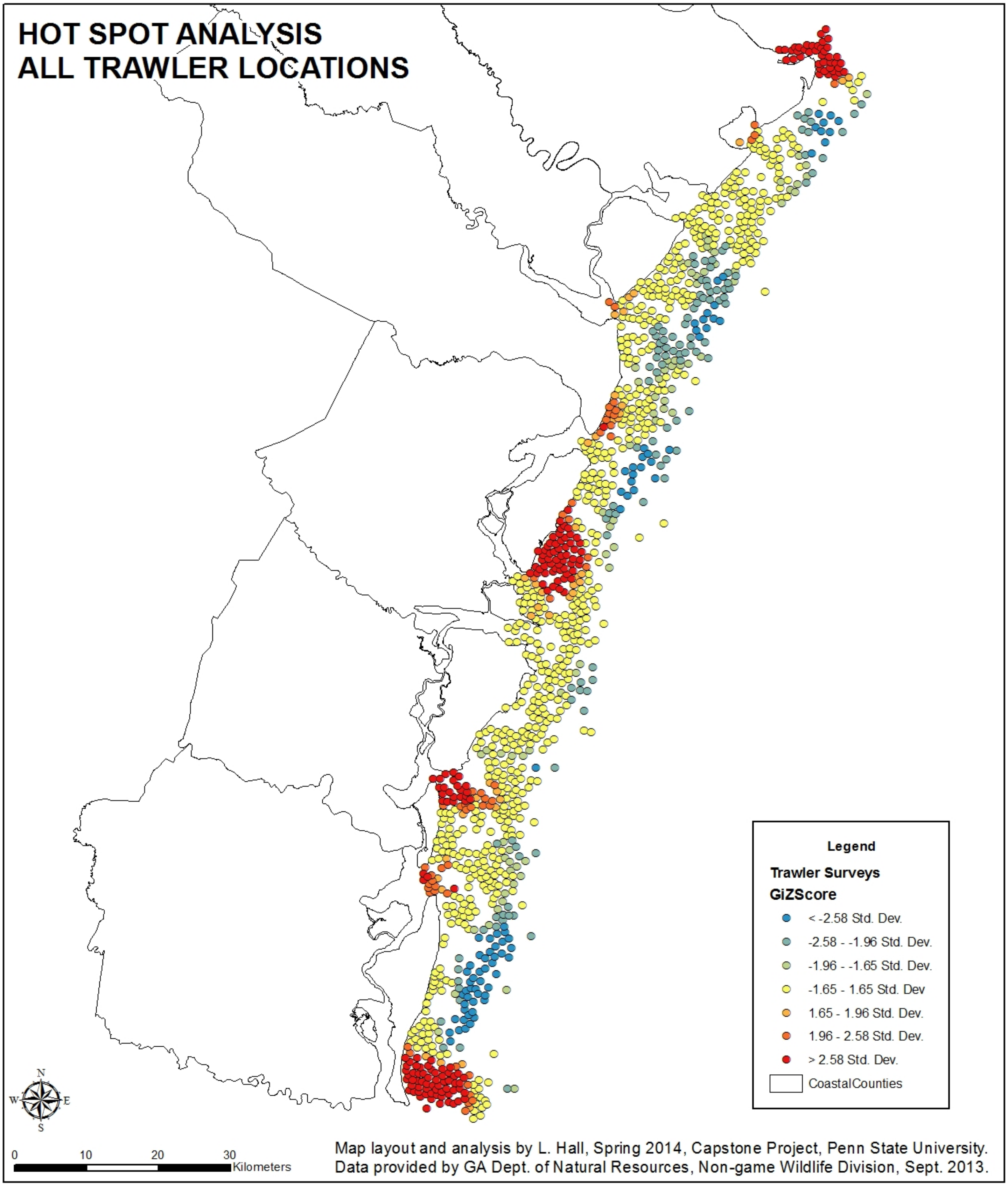


FIGURE C1. Hot spot analysis map for all shrimp trawlers observed fishing during surveys from 1999 to 2012

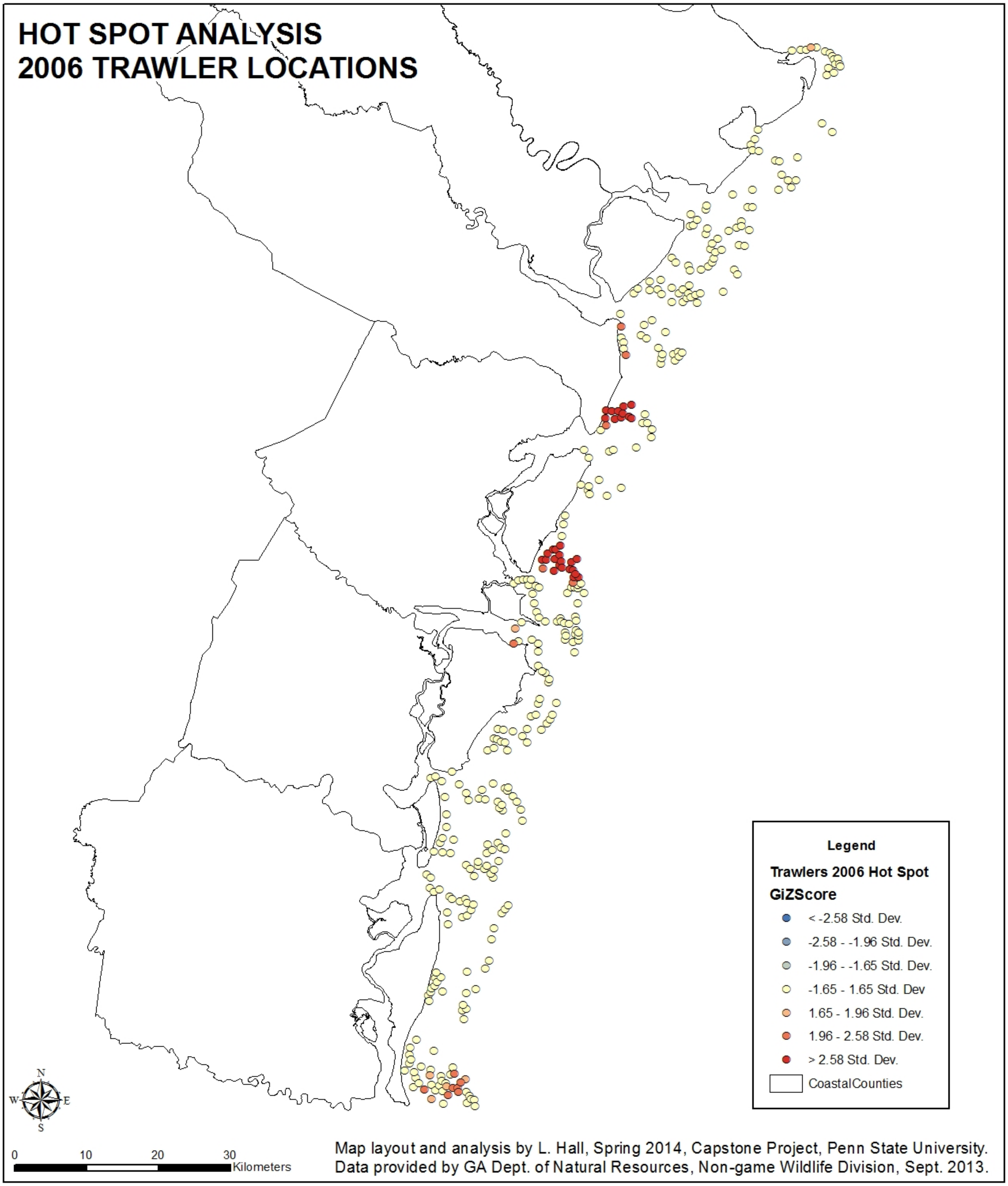


FIGURE C2. Hot spot analysis map for shrimp trawlers observed fishing in 2006

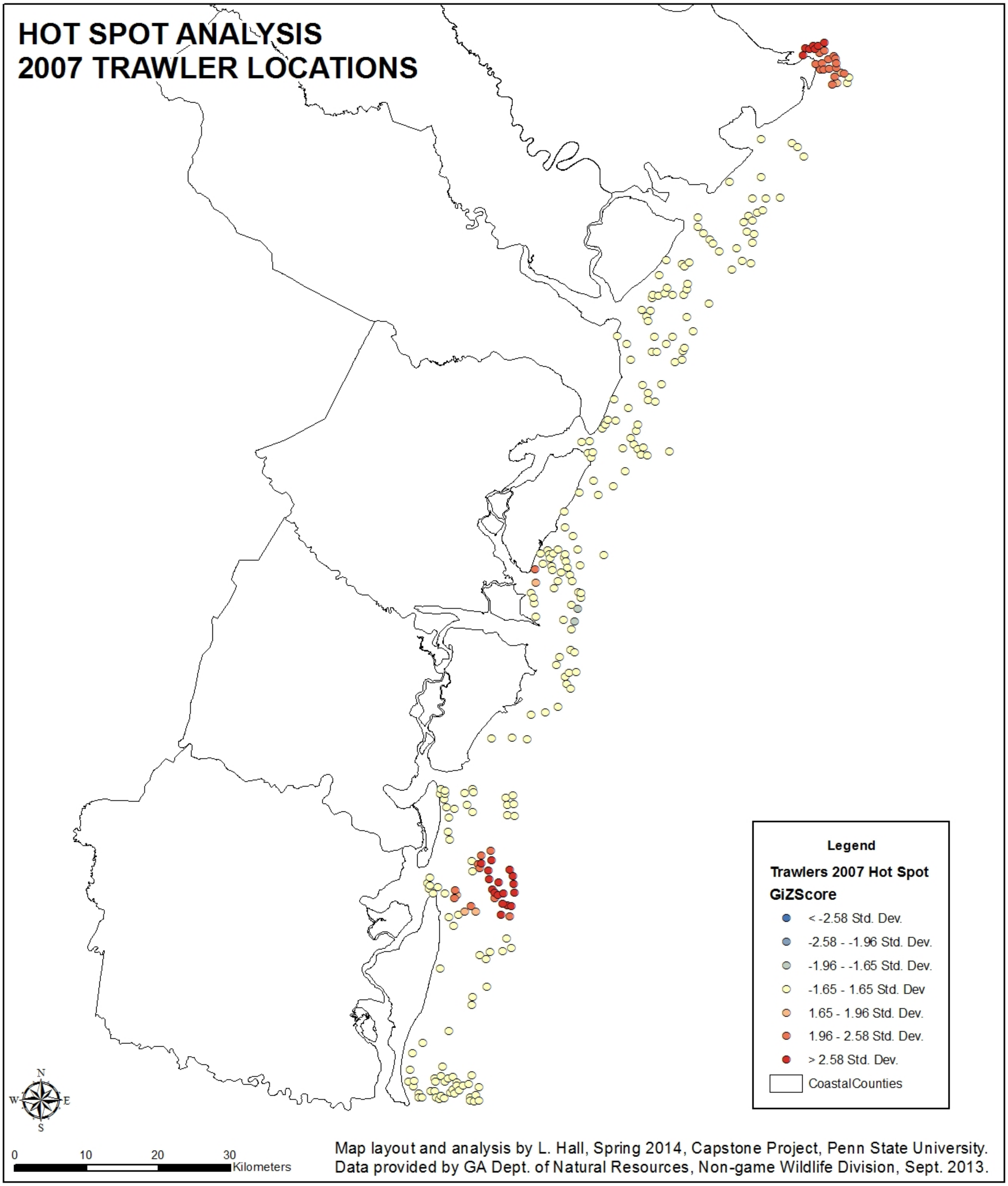


FIGURE C3. Hot spot analysis map for shrimp trawlers observed fishing in 2007

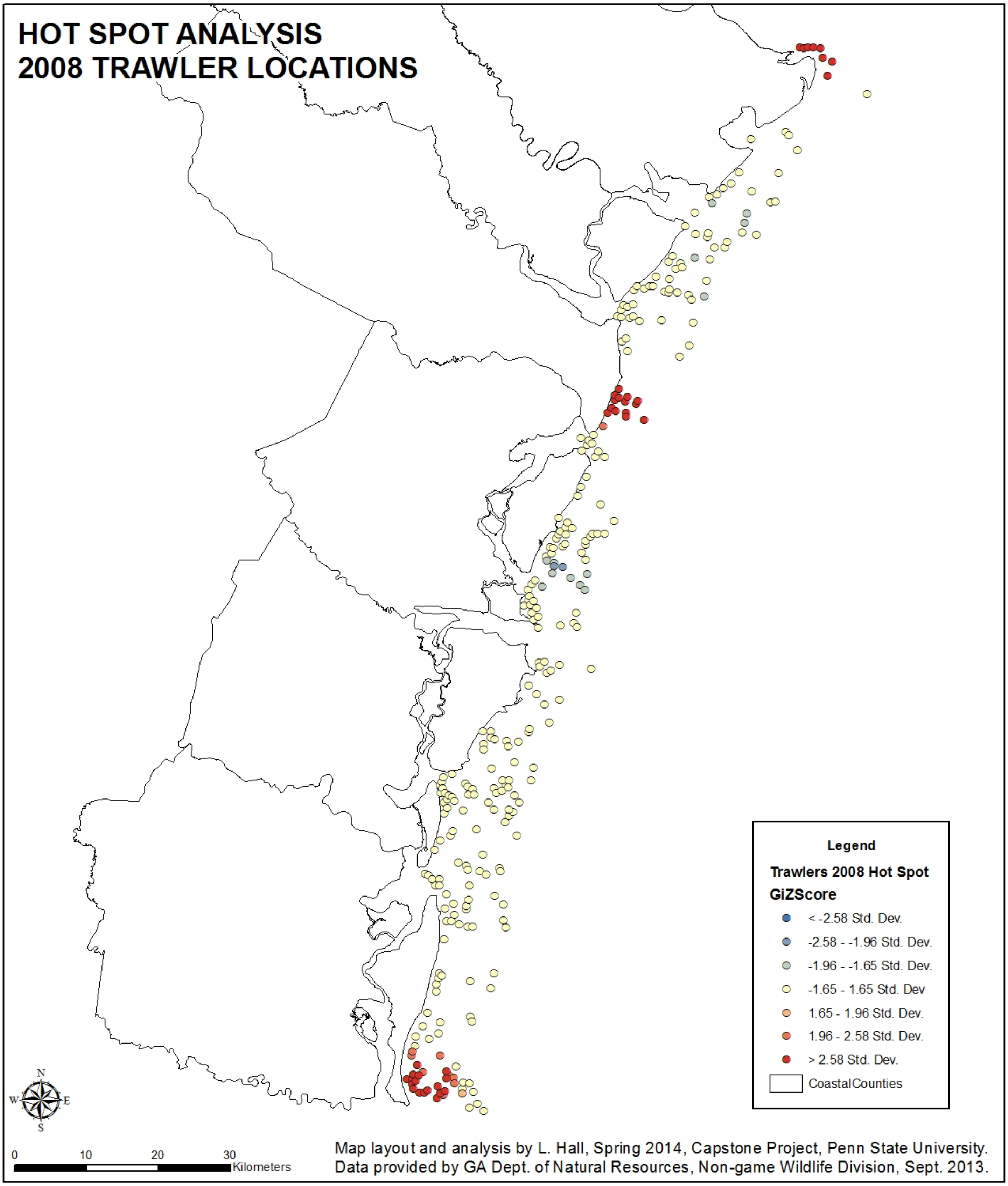


FIGURE C4. Hot spot analysis map for shrimp trawlers observed fishing in 2008

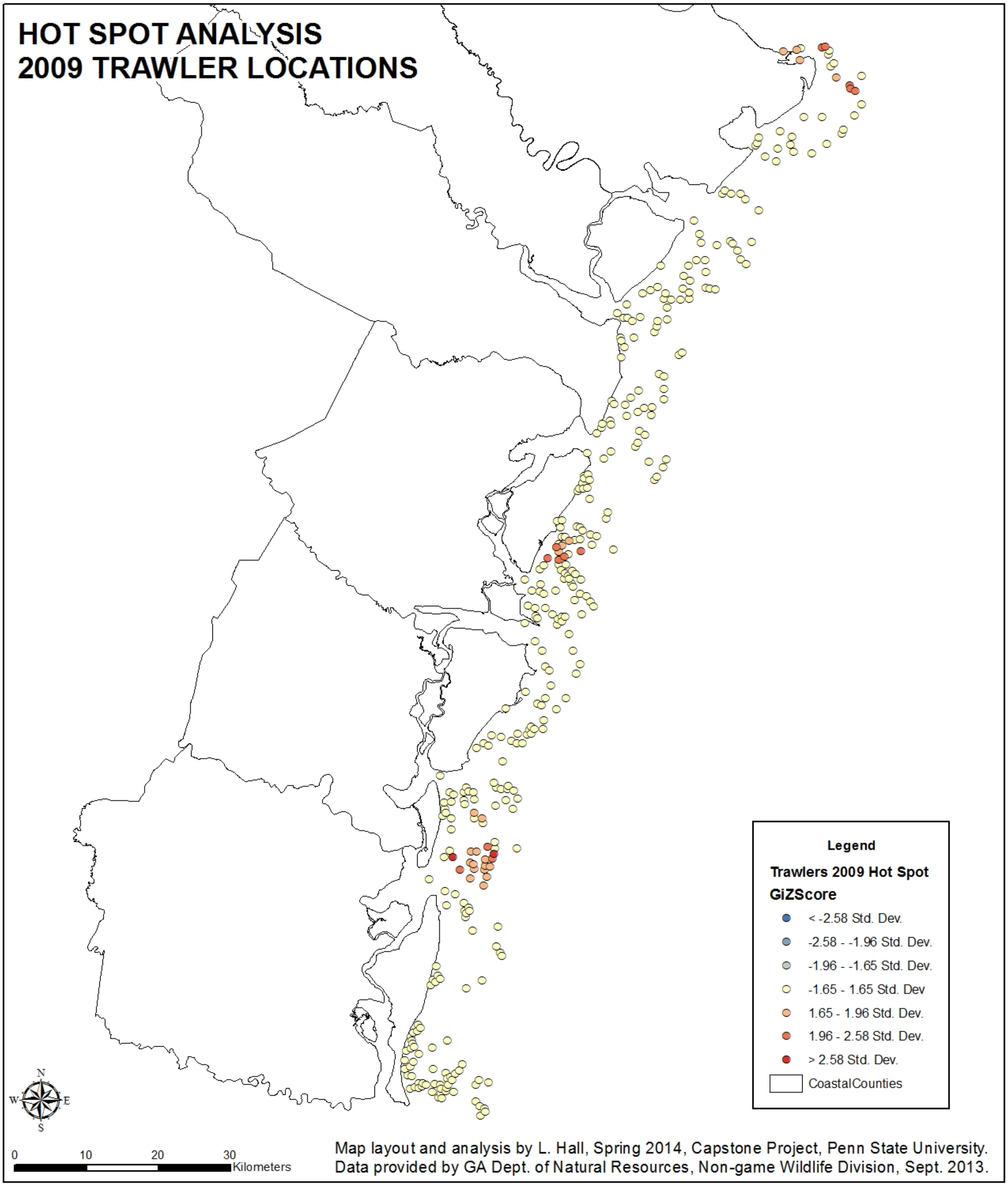


FIGURE C5. Hot spot analysis map for shrimp trawlers observed fishing in 2008

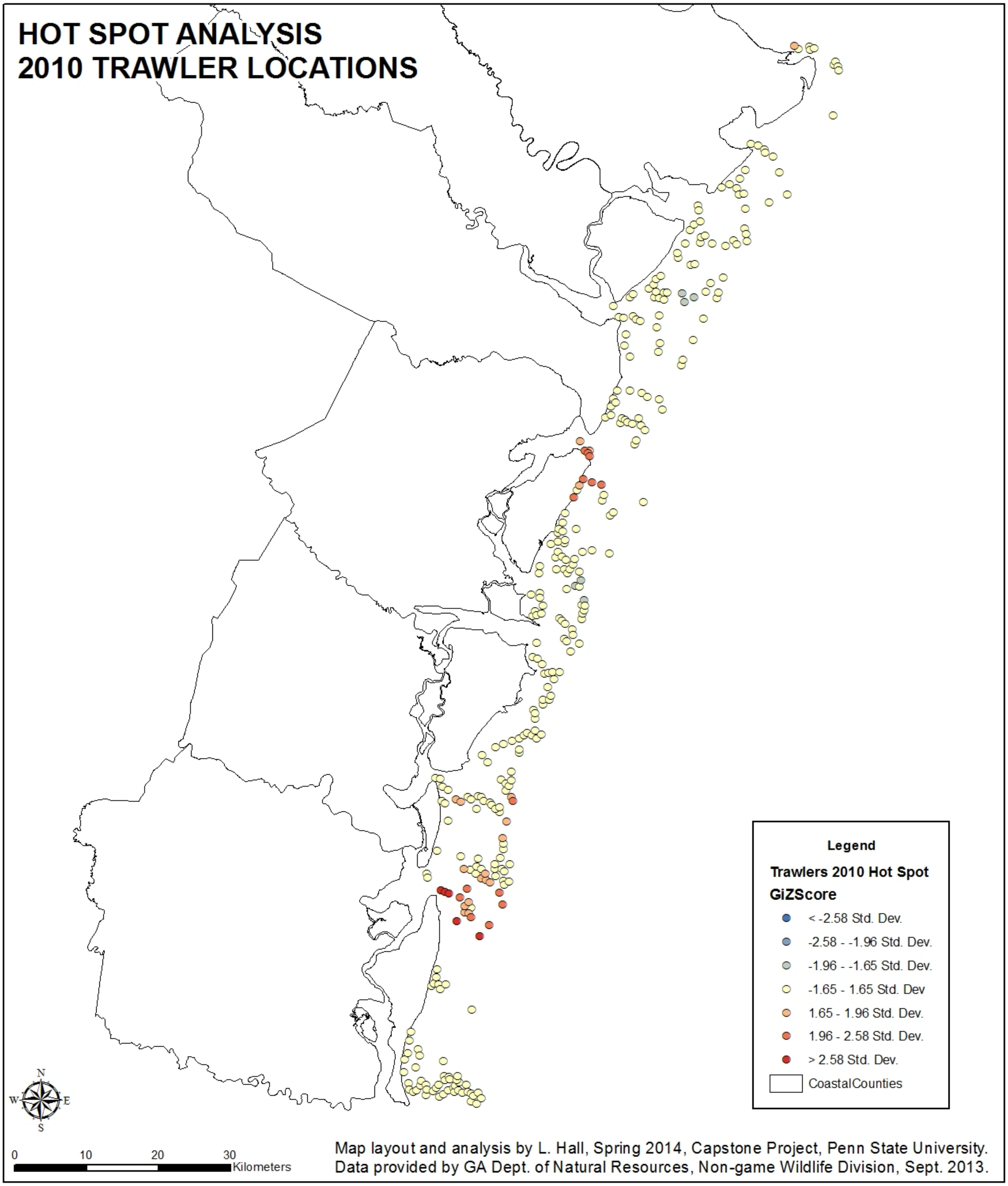


FIGURE C6. Hot spot analysis map for shrimp trawlers observed fishing in 2010

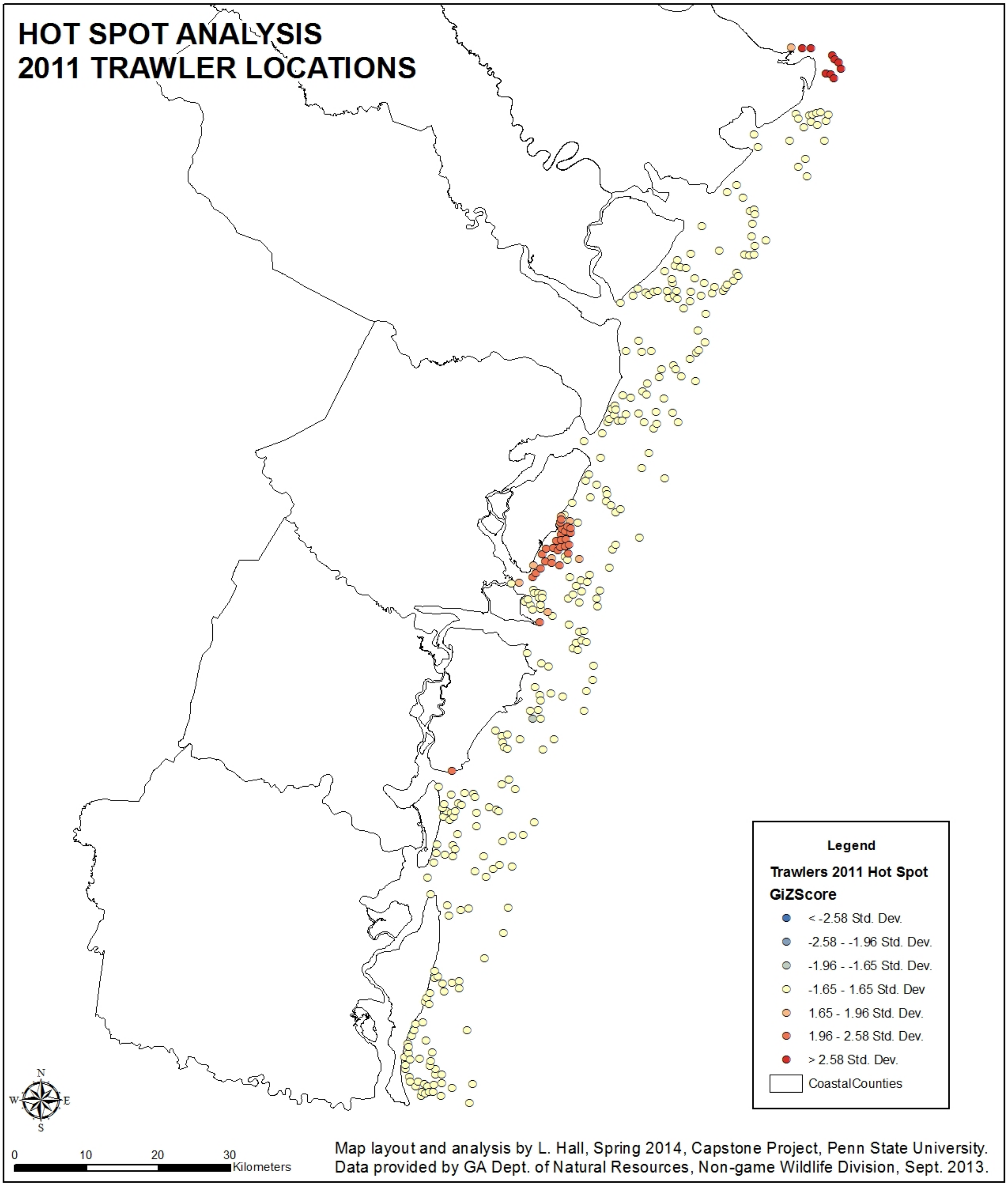


FIGURE C7. Hot spot analysis map for shrimp trawlers observed fishing in 2011

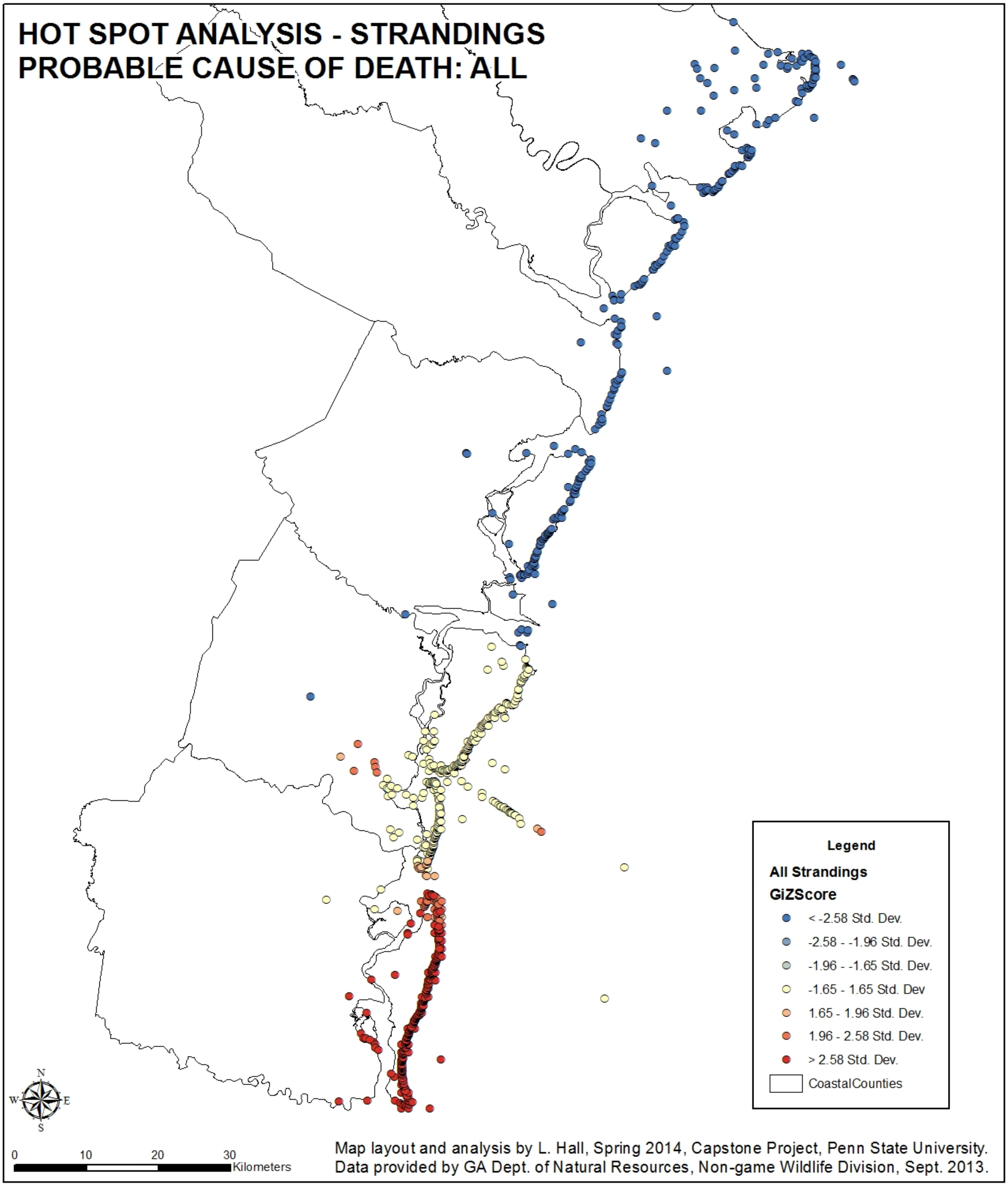


FIGURE C8. Hot spot analysis map for all sea turtle strandings with an identifiable cause of death from 1999 to 2012

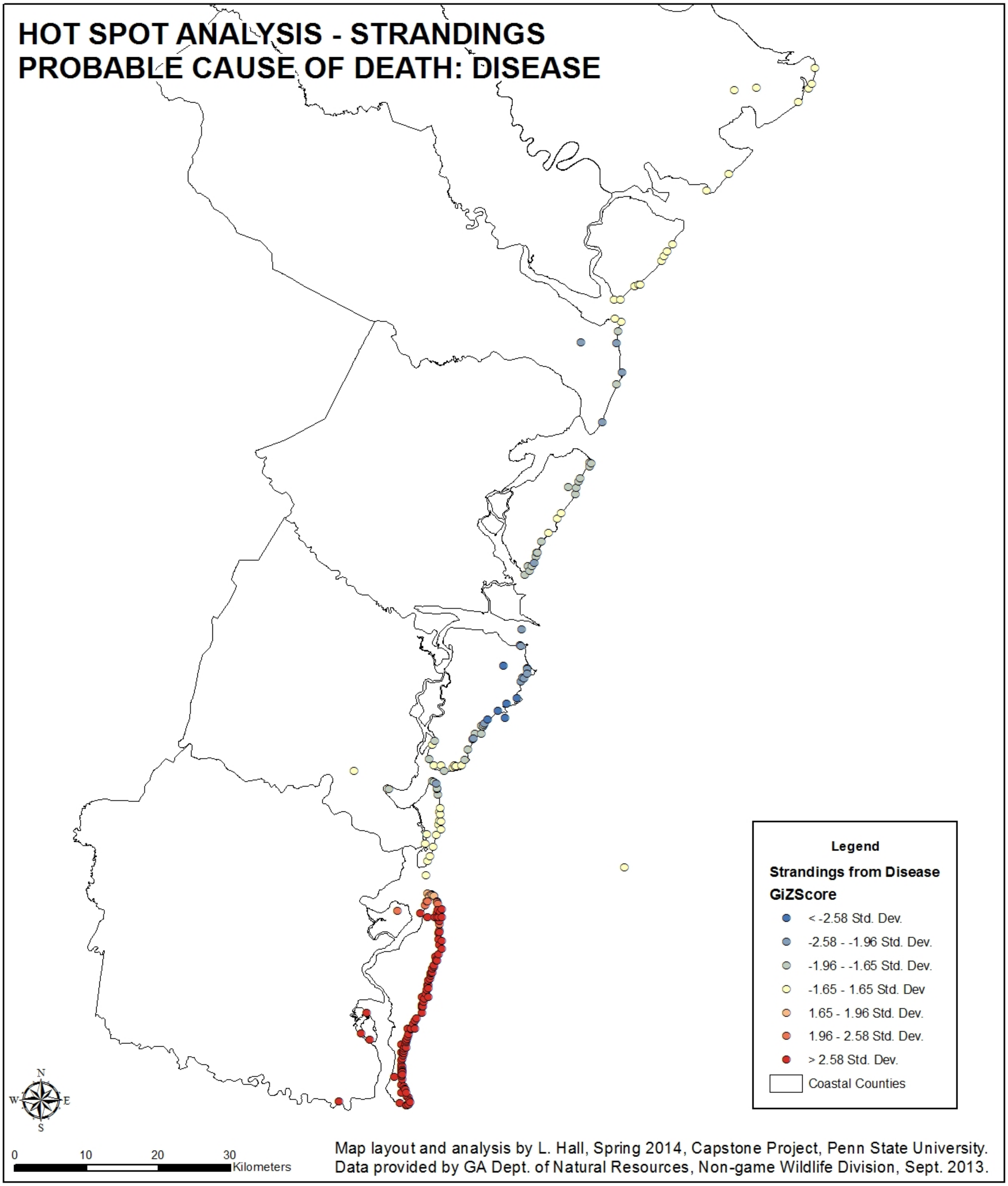


FIGURE C9. Hot spot analysis map for all sea turtle strandings caused by disease from 1999 to 2012

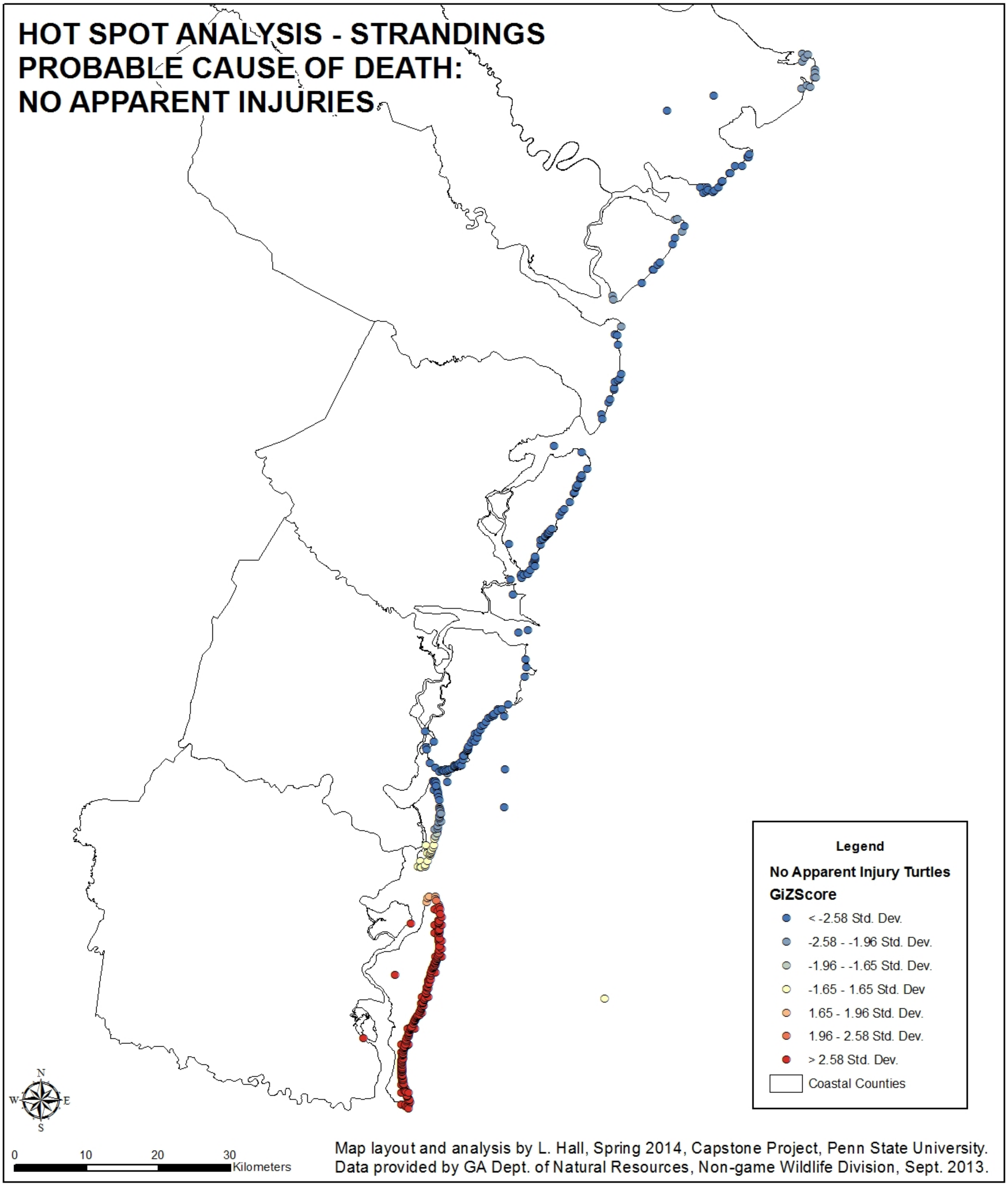


FIGURE C10. Hot spot analysis map for all sea turtle strandings no apparent injuries from 1999 to 2012

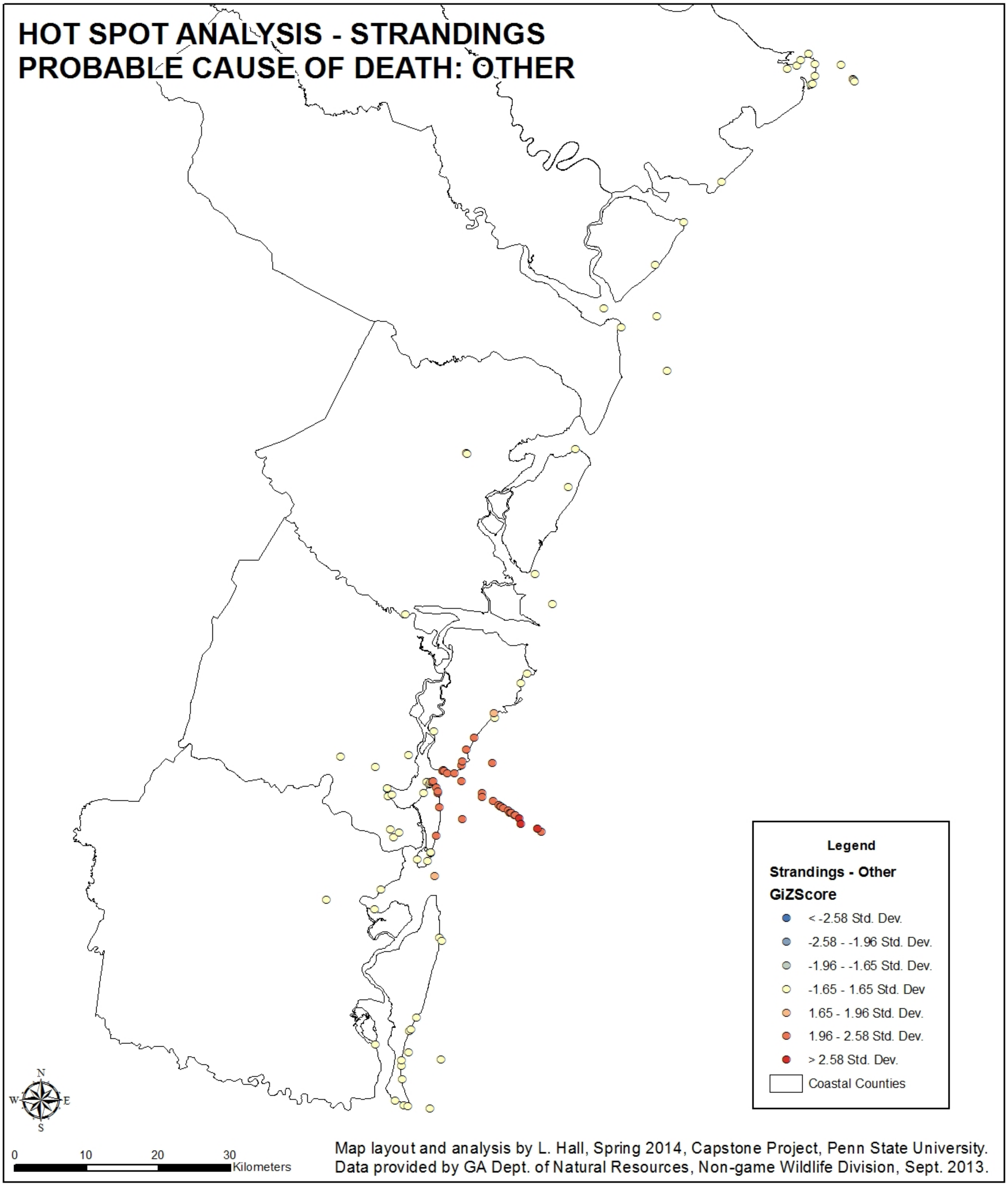


FIGURE C12. Hot spot analysis map for all sea turtle strandings caused by other known causes from 1999 to 2012

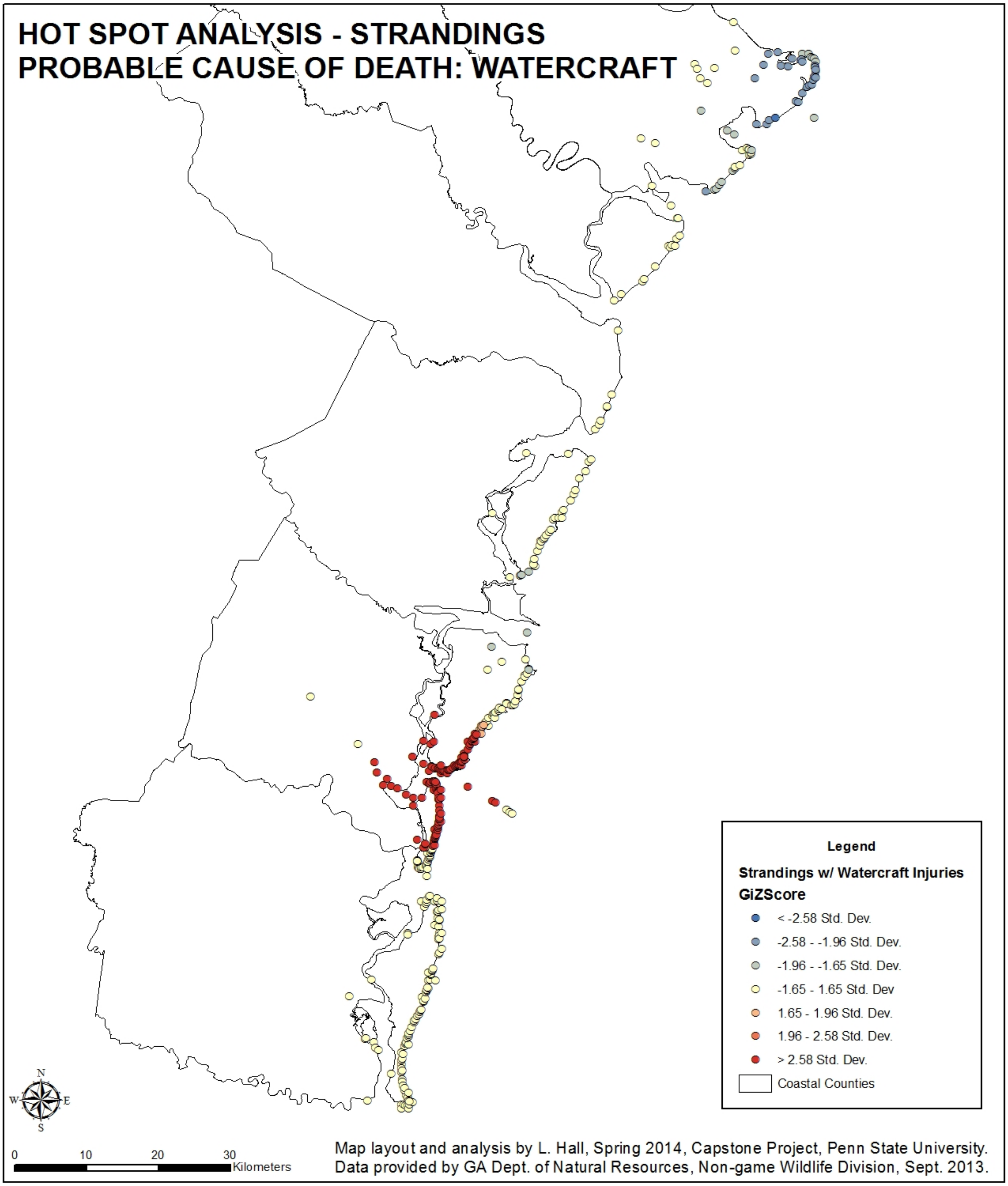


FIGURE C12. Hot spot analysis map for all sea turtle strandings caused by watercraft injury from 1999 to 2012

**SPATIAL ANALYSIS FOR SEA TURTLE CONSERVATION ON THE GEORGIA COAST**
**Appendix D: Distance Analysis Maps & Model Results**

Contents

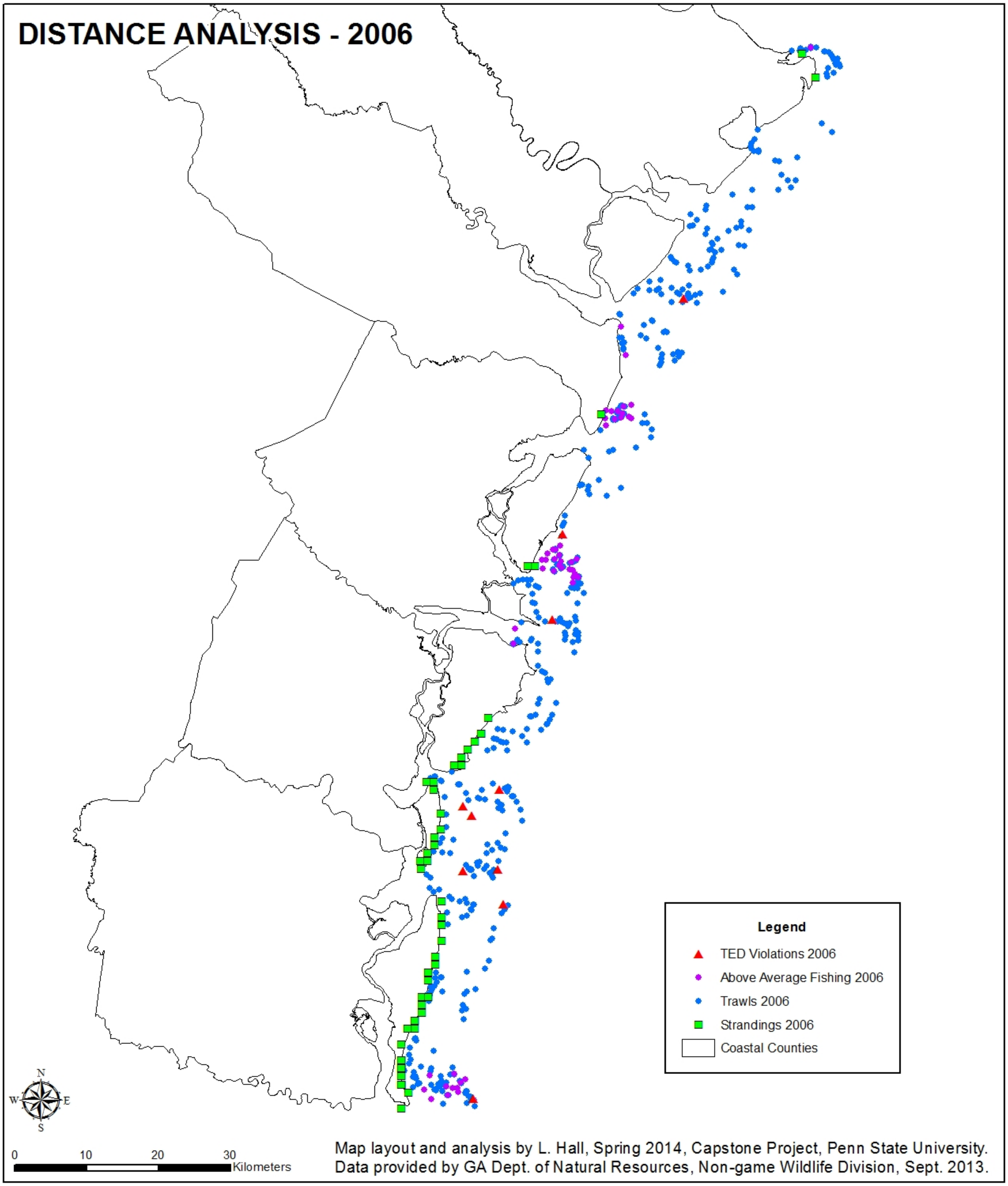


FIGURE D1. Point locations for the data used in the 2006 near distance analysis calculations.

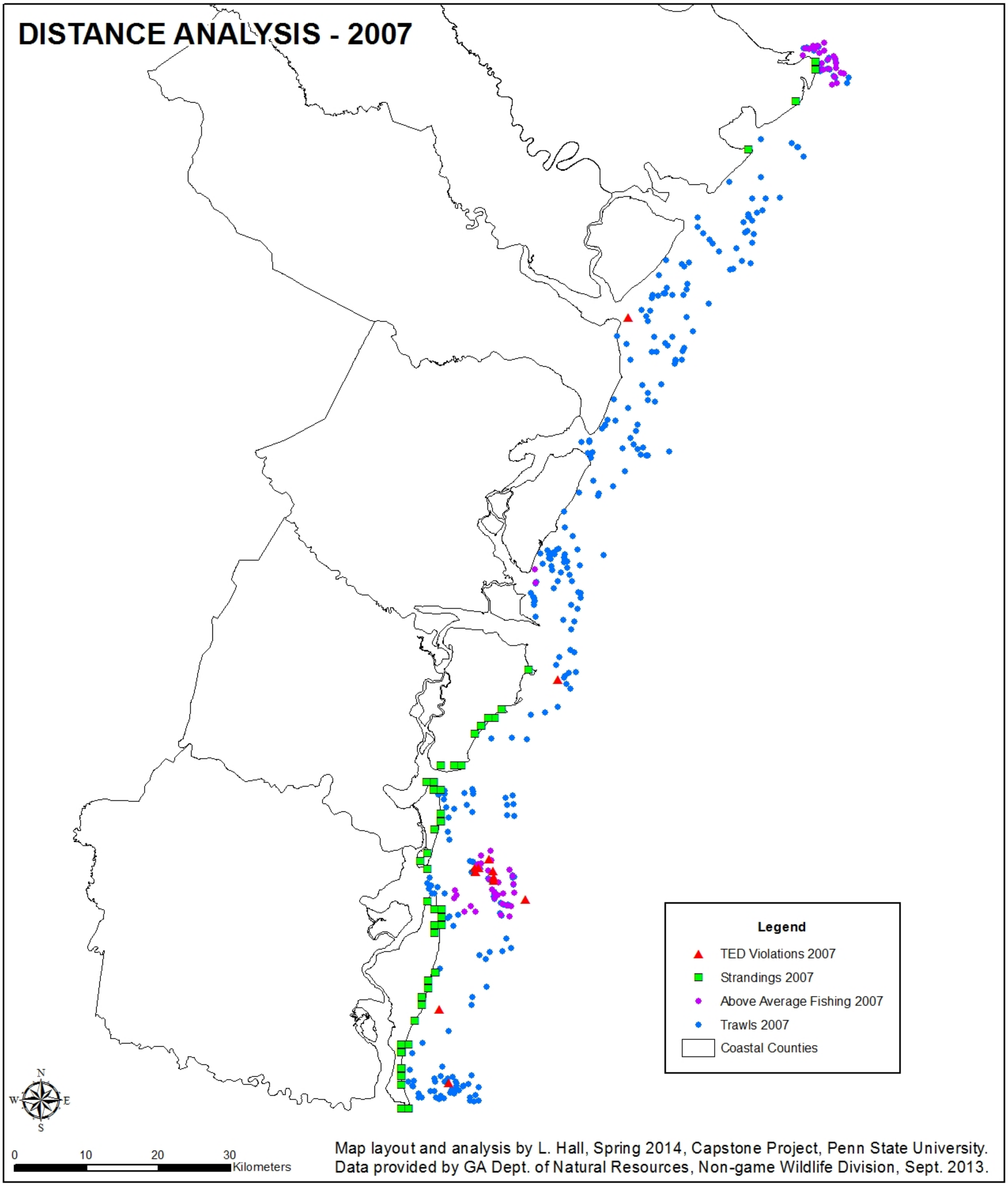


FIGURE D2. Point locations for the data used in the 2007 near distance analysis calculations.

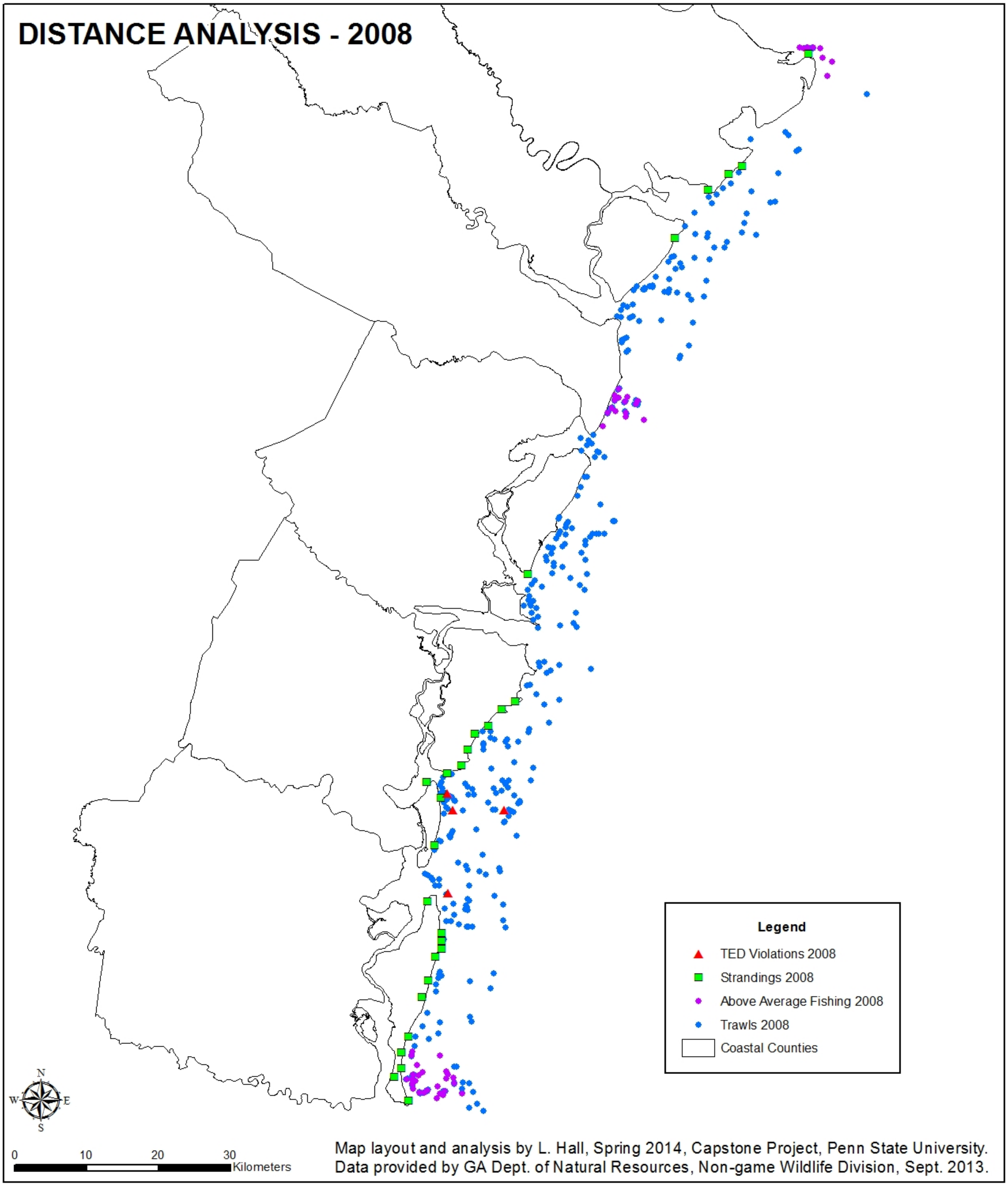


FIGURE D3. Point locations for the data used in the 2008 near distance analysis calculations.

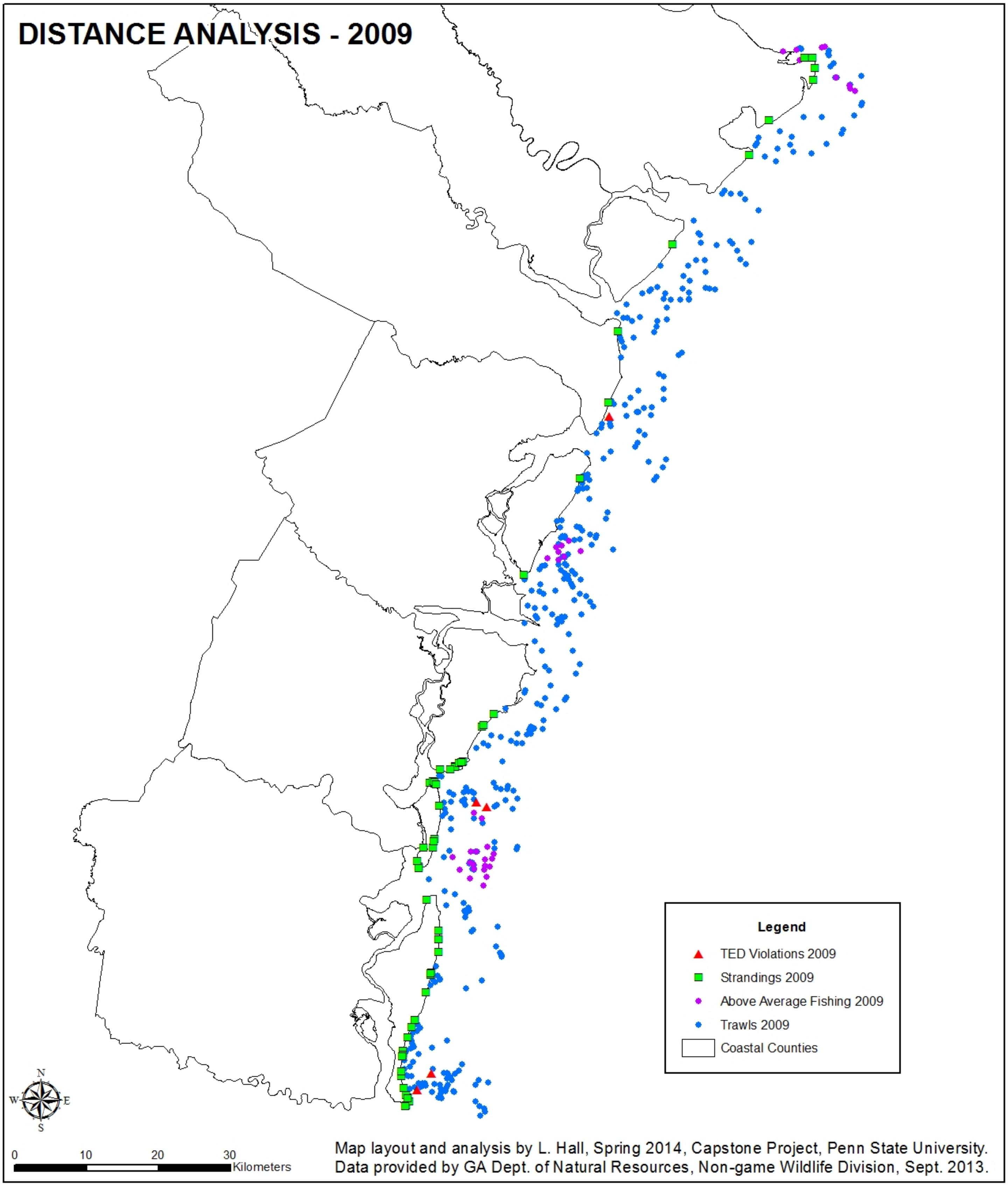


FIGURE D4. Point locations for the data used in the 2009 near distance analysis calculations.

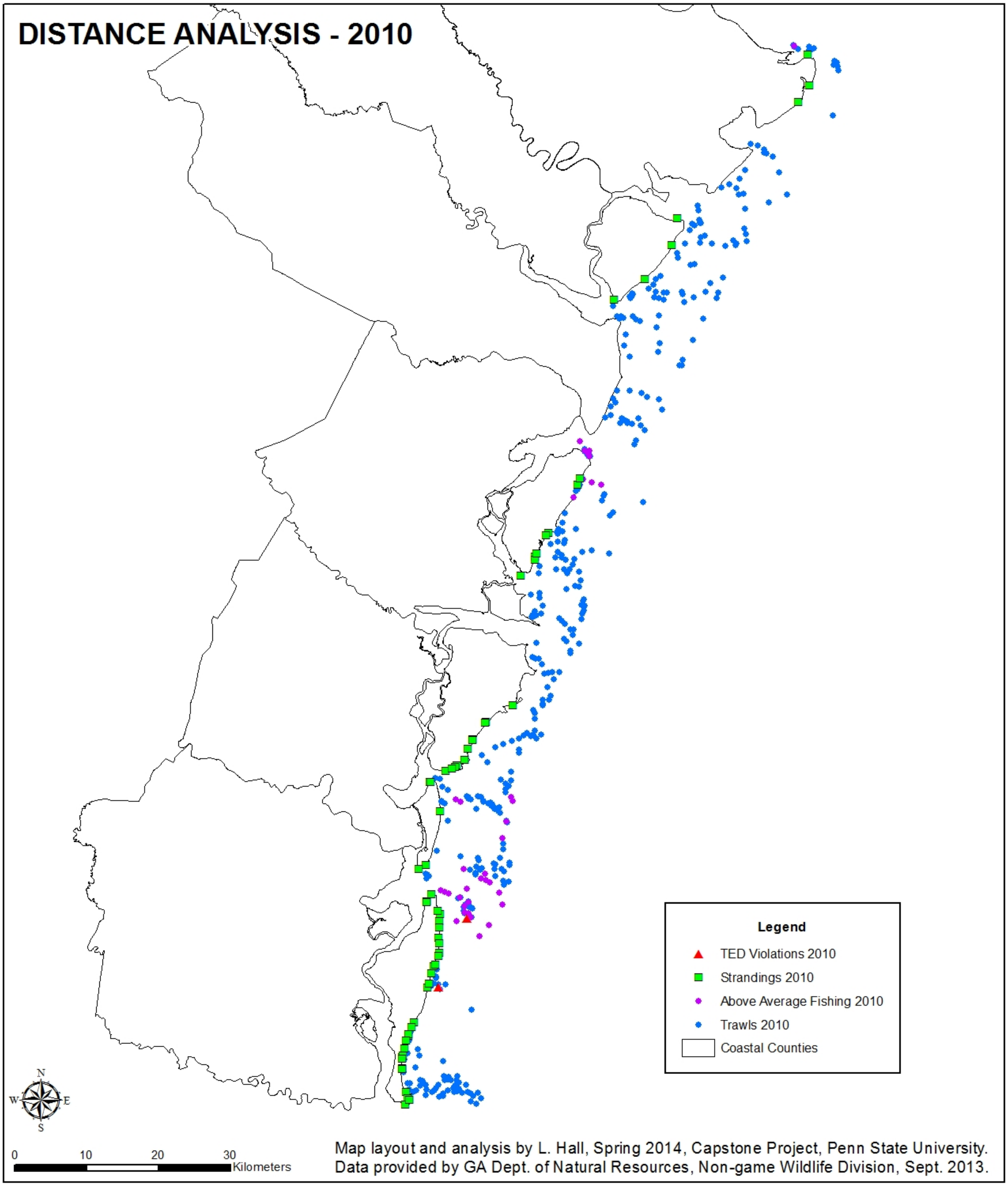


FIGURE D5. Point locations for the data used in the 2010 near distance analysis calculations.

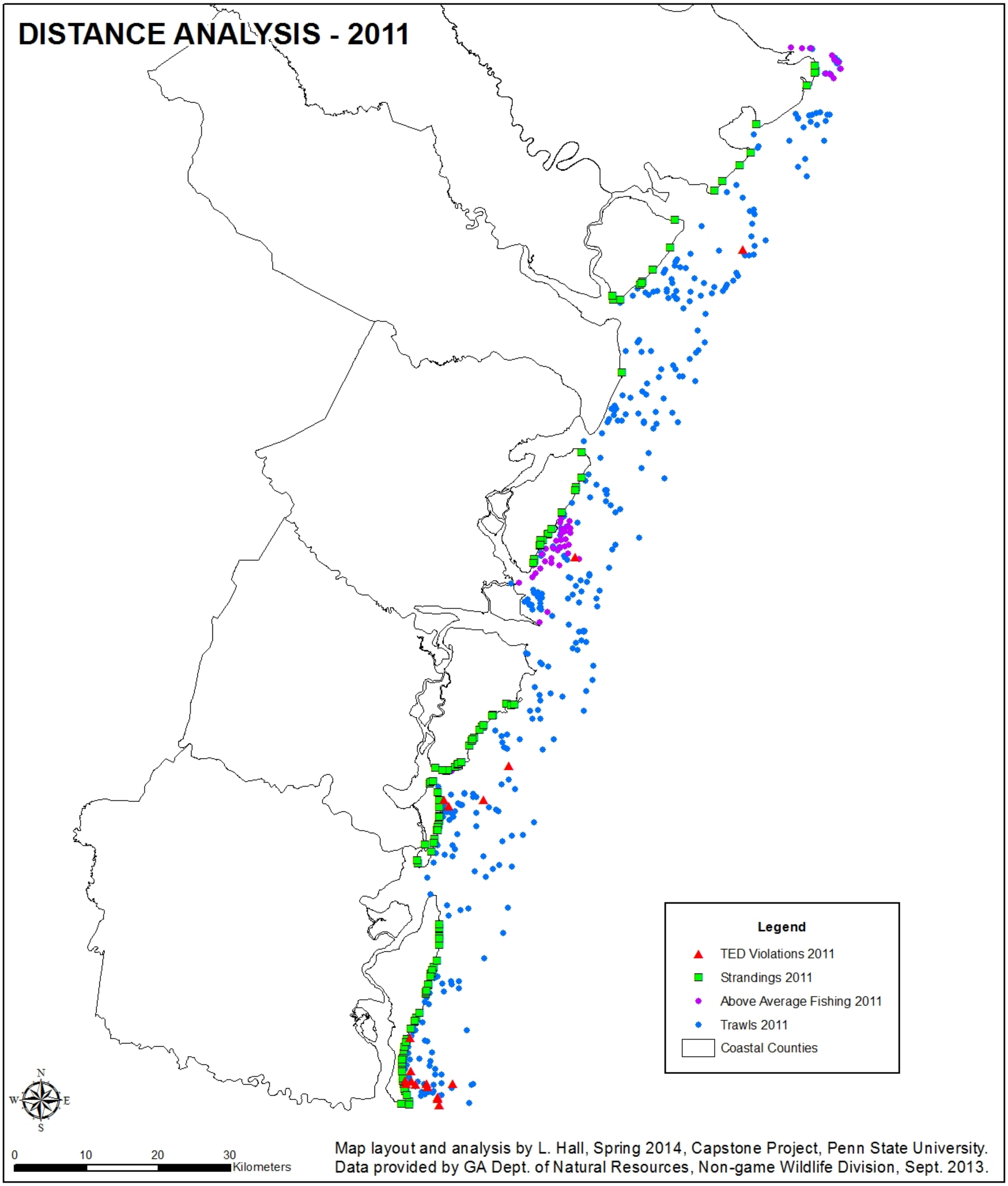


FIGURE D6. Point locations for the data used in the 2011 near distance analysis calculations.

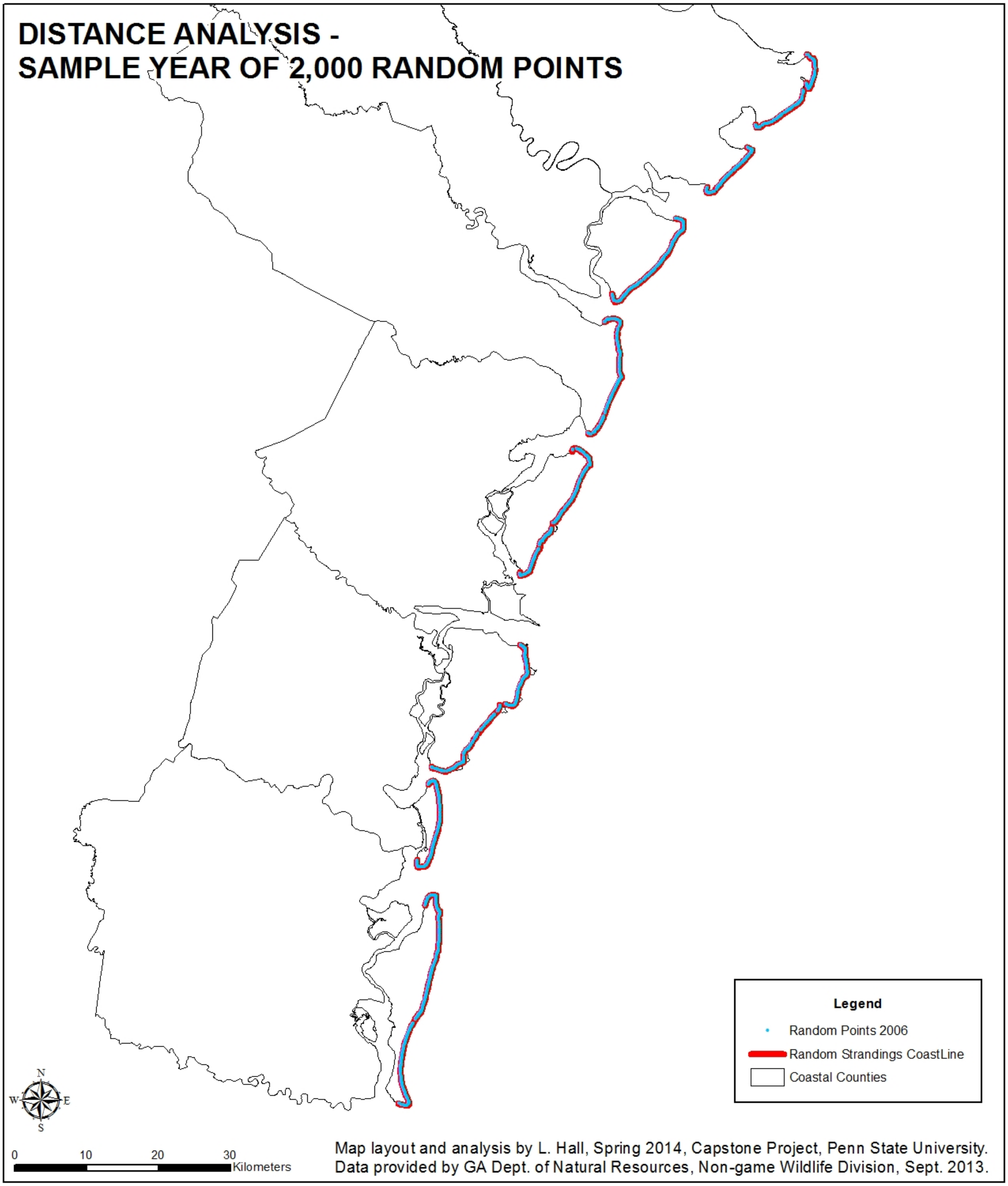


FIGURE D7. Map showing the coastline and sample 2,000 random points generated for each year of distance analysis.

| Year | Disease | No apparent injuries | Watercraft |
|---|---|---|---|
| 2006 | 16 | 34 | 14 |
| 2007 | 7 | 36 | 21 |
| 2008 | 8 | 13 | 15 |
| 2009 | 12 | 19 | 32 |
| 2010 | 12 | 33 | 22 |
| 2011 | 19 | 63 | 45 |
| Total | 74 | 198 | 149 |

FIGURE D8. Table providing the summary of the number of strandings of all species of sea turtles by probable death category and year.

| Year | Disease | No apparent injuries | Watercraft |
|---|---|---|---|
| 2006 | 15 | 27 | 9 |
| 2007 | 6 | 26 | 12 |
| 2008 | 7 | 7 | 11 |
| 2009 | 11 | 13 | 20 |
| 2010 | 8 | 16 | 12 |
| 2011 | 14 | 33 | 27 |
| Total | 61 | 122 | 91 |

FIGURE D9. Table providing the summary of the number of strandings of loggerhead sea turtles by probable death category and year.

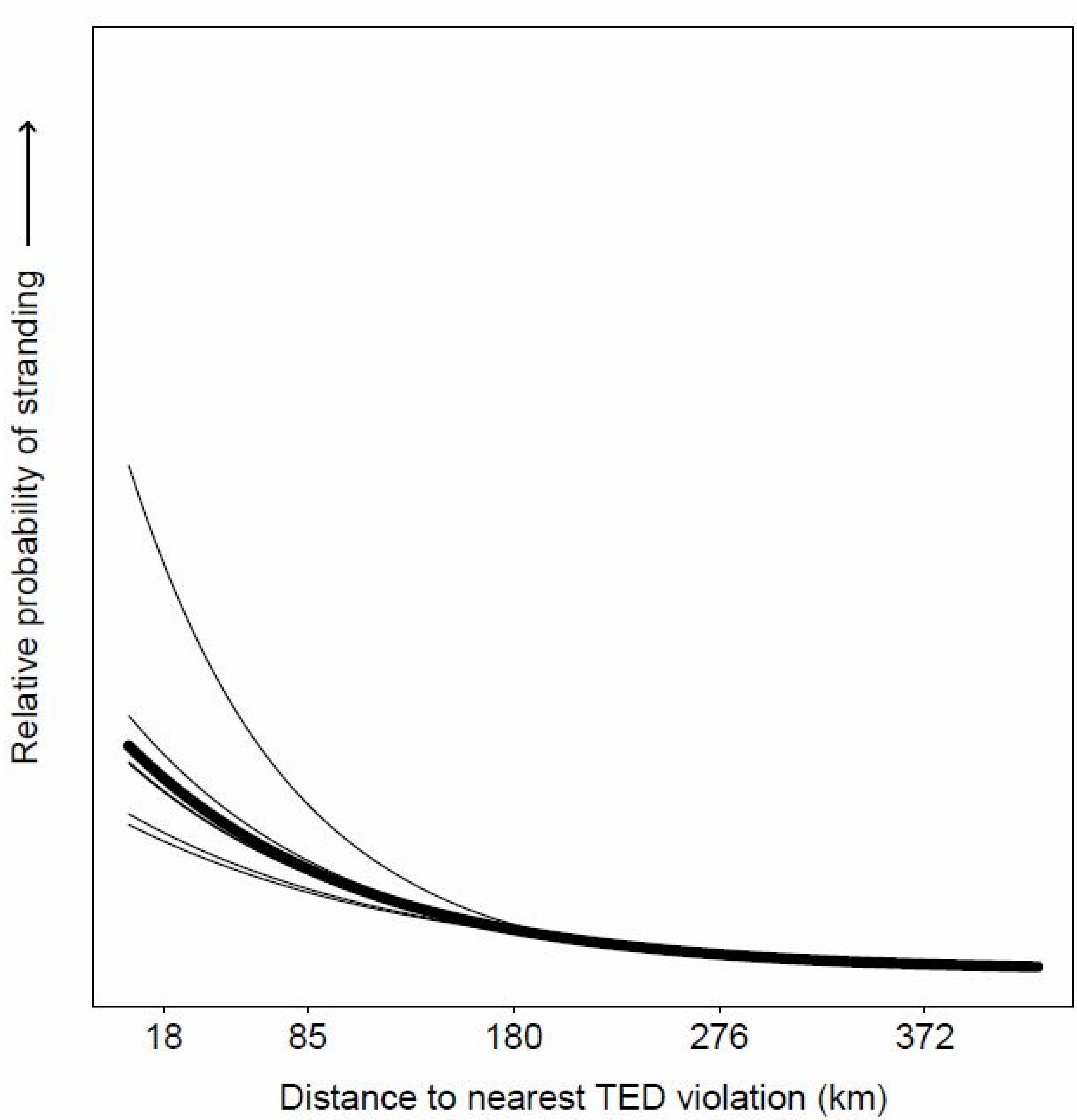


FIGURE D10. Graph showing the relative probability of being stranded for all sea turtles with disease as probable cause of death in relation to the distance to the nearest TED violation. Thick line is population average effect (across all years) and thin lines are year-specific relationships.

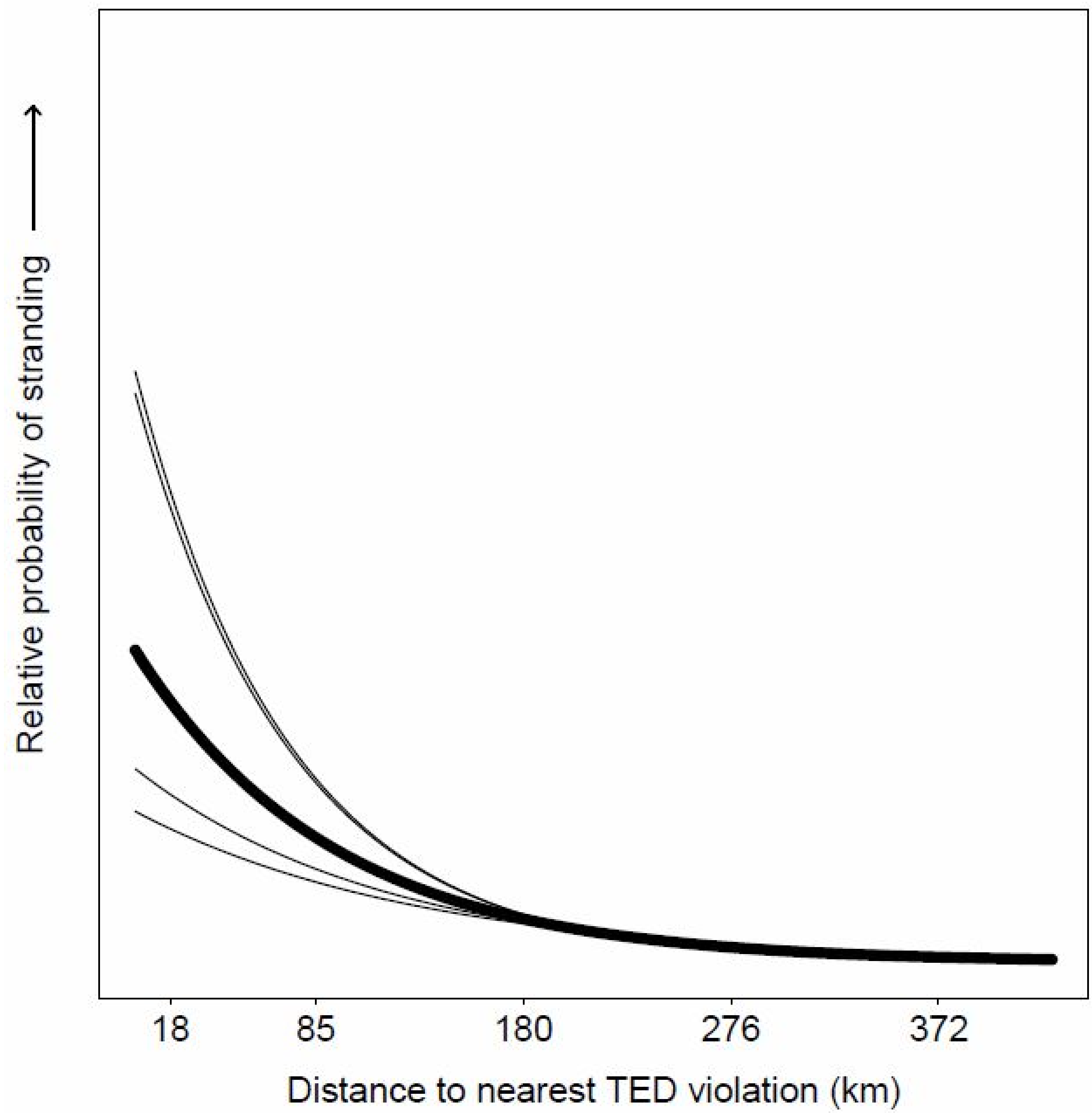


FIGURE D11. Graph showing the relative probability of being stranded for loggerhead sea turtles with disease as probable cause of death in relation to the distance to the nearest TED violation. Thick line is population average effect (across all years) and thin lines are year-specific relationships.

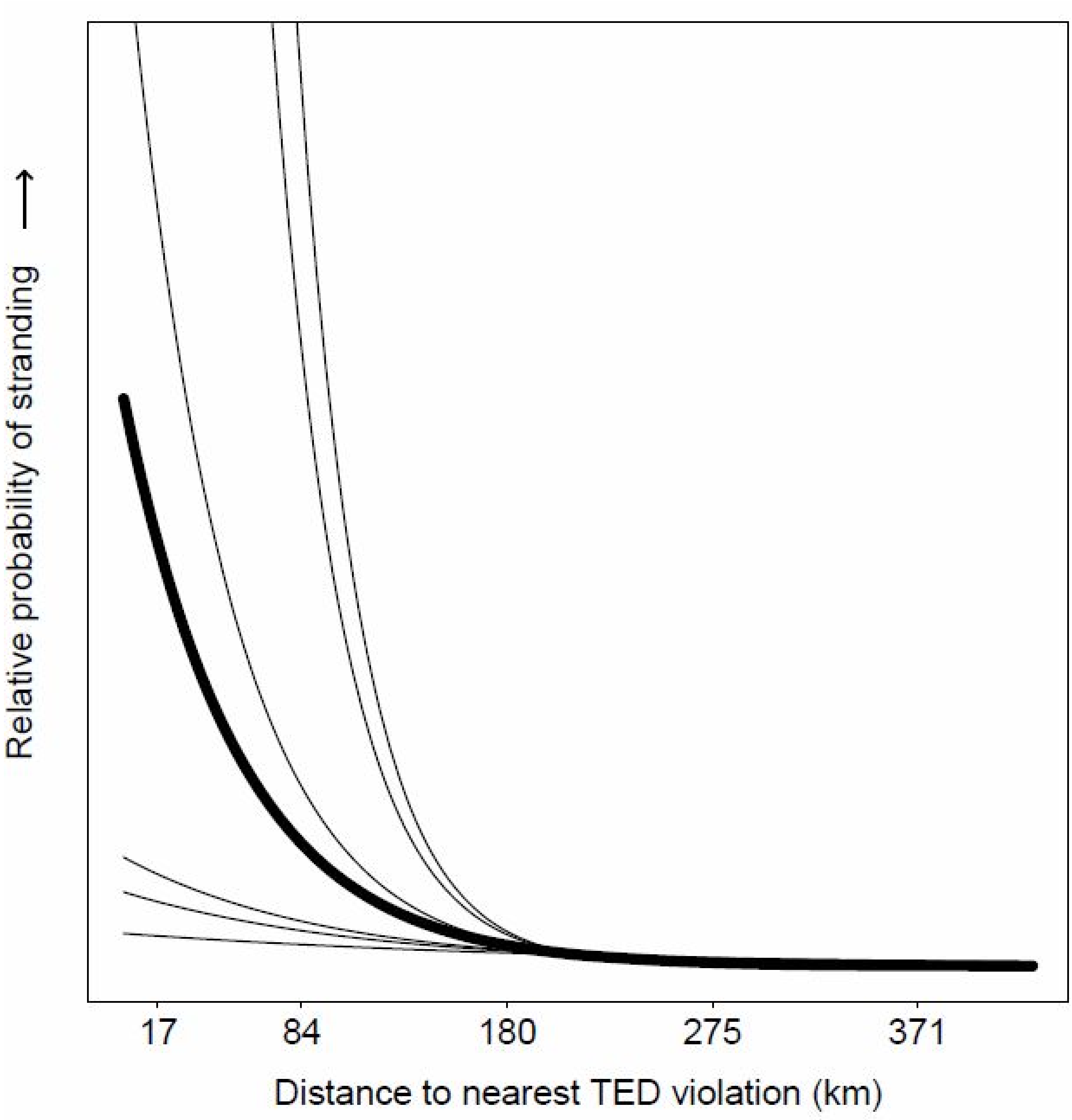


FIGURE D12. Graph showing the relative probability of being stranded for all sea turtles with a no apparent injury in relation to the distance to the nearest TED violation. Thick line is population average effect (across all years) and thin lines are year-specific relationships.

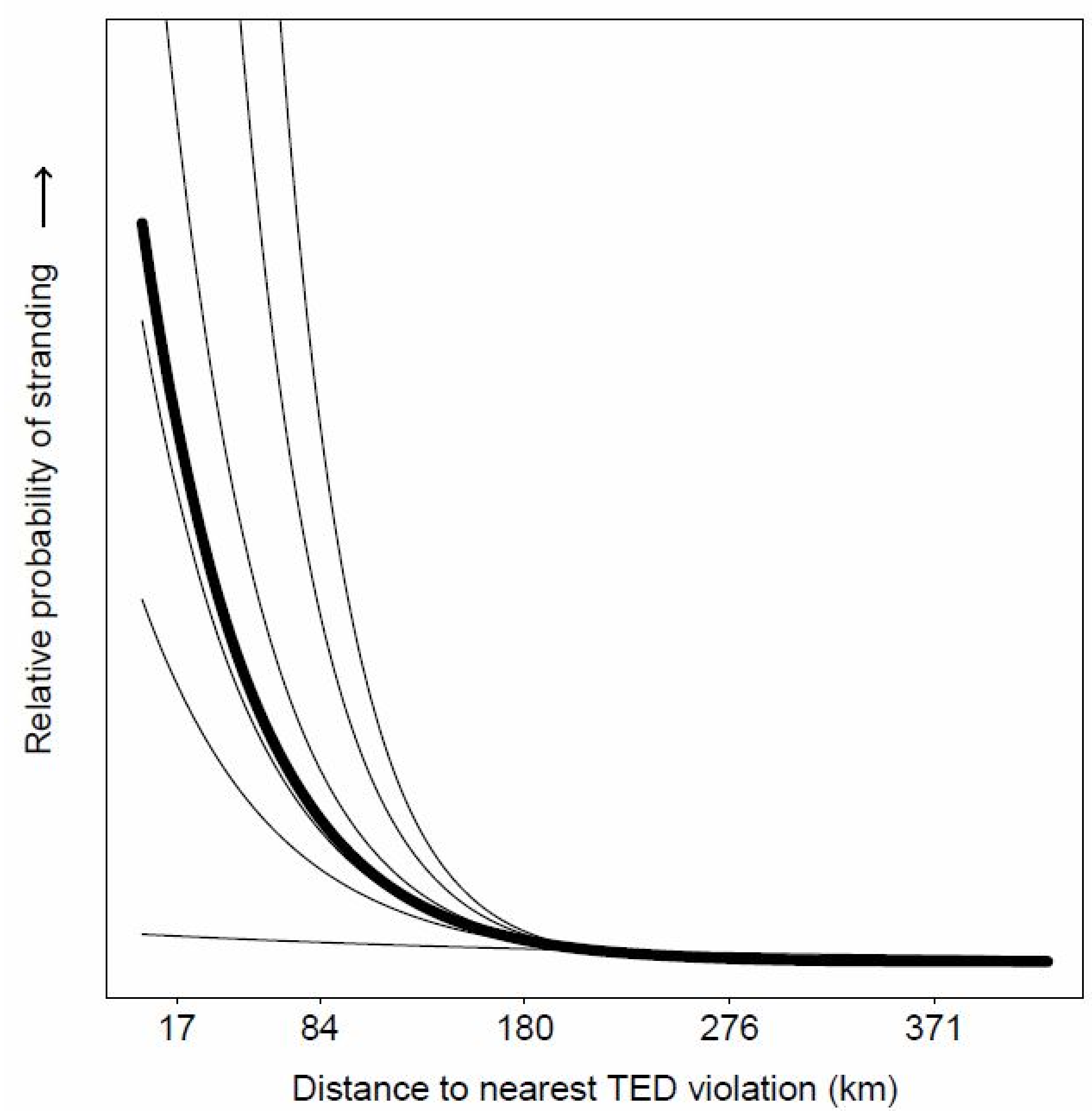


FIGURE D13. Graph showing the relative probability of being stranded for loggerehead turtles with a no apparent injury in relation to the distance to the nearest TED violation. Thick line is population average effect (across all years) and thin lines are year-specific relationships.

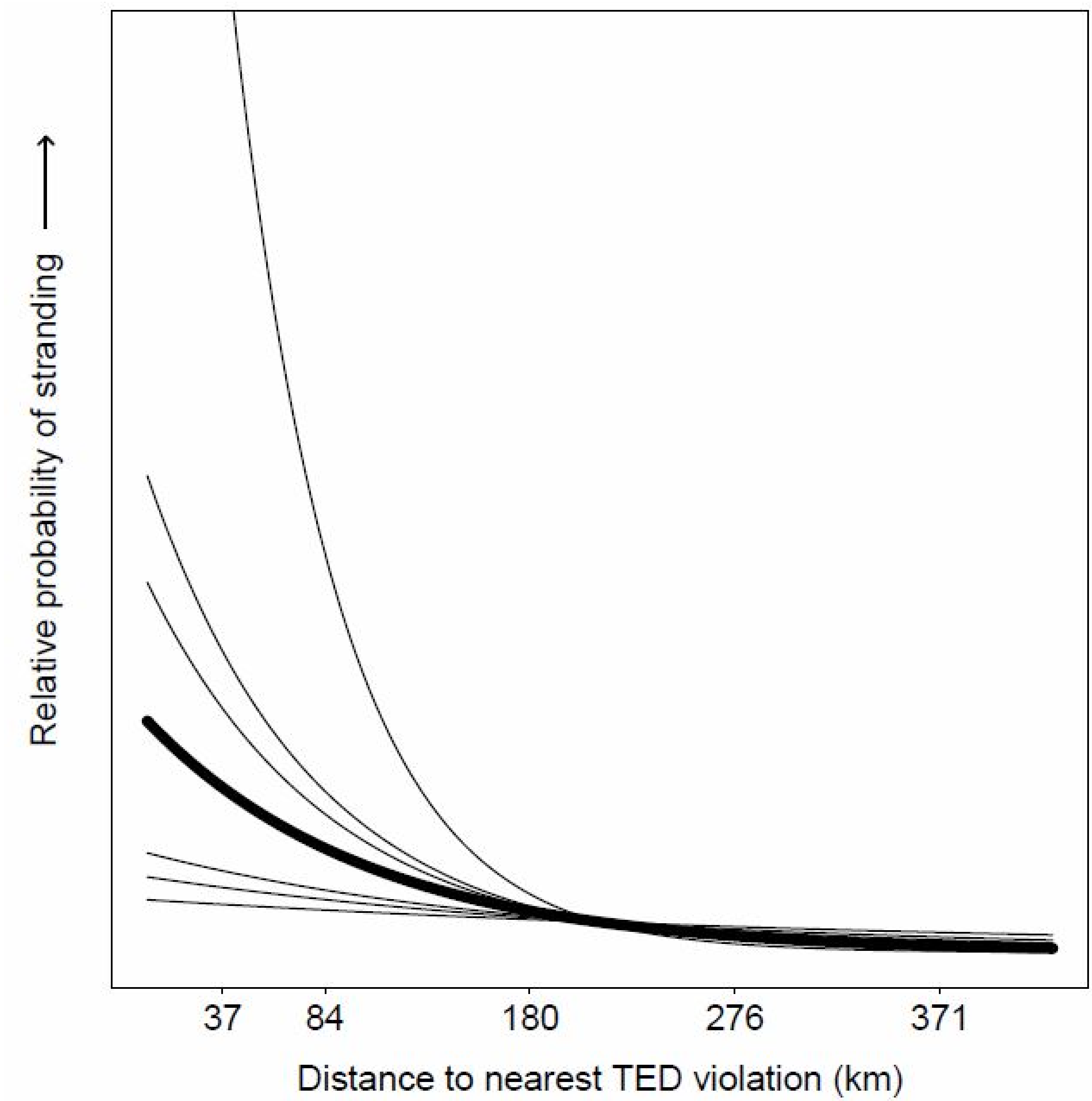


FIGURE D14. Graph showing the relative probability of being stranded for all sea turtles with watercraft injury in relation to the distance to the nearest TED violation. Thick line is population average effect (across all years) and thin lines are year-specific relationships.

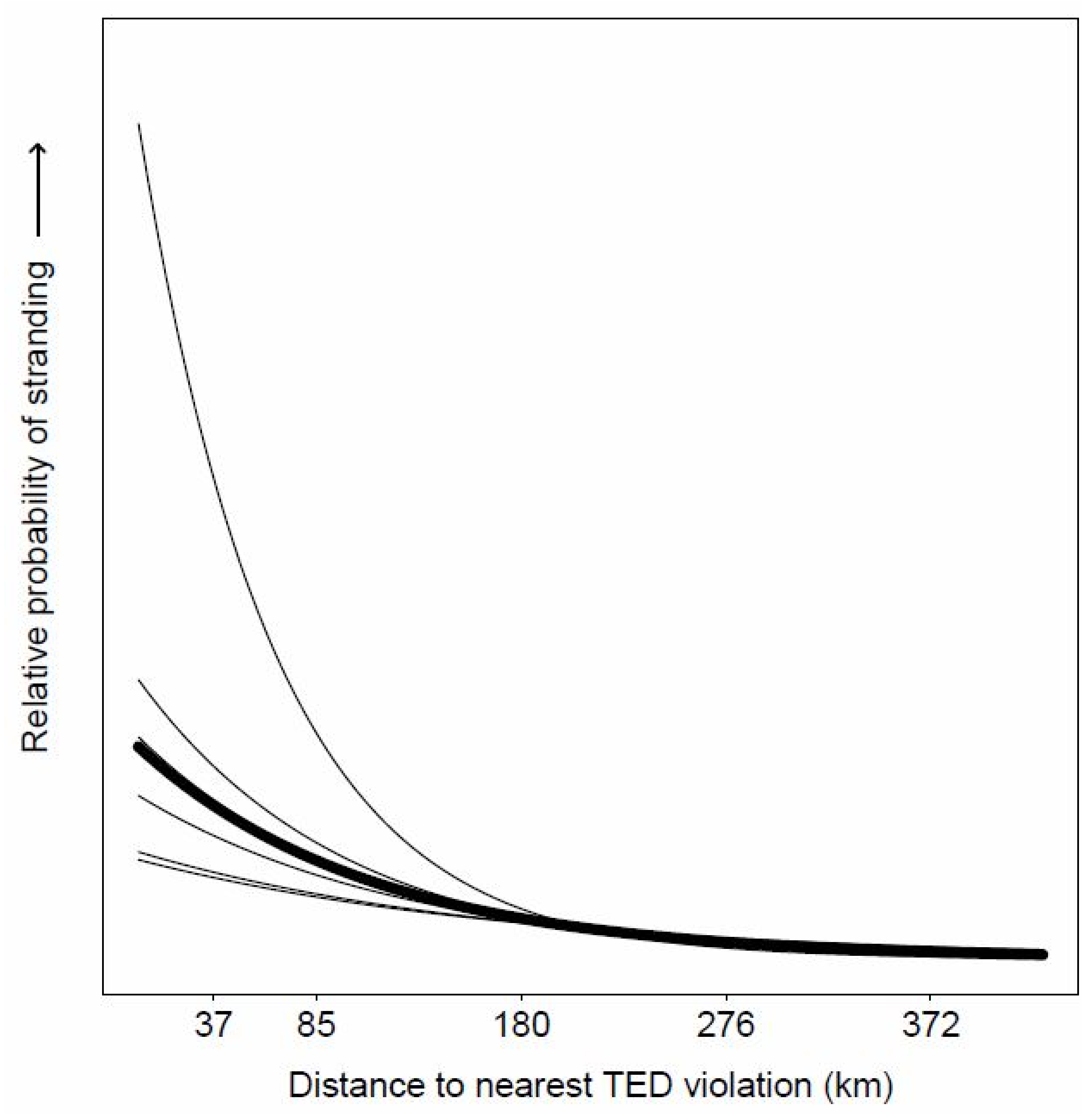


FIGURE D15. Graph showing the relative probability of being stranded for loggerhead turtles with a watercraft injury in relation to the distance to the nearest TED violation. Thick line is population average effect (across all years) and thin lines are year-specific relationships.