

**SPATIAL AND TEMPORAL TRENDS IN SEA
TURTLE STRANDINGS IN NORTH CAROLINA, 1980-2003**

by

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Abstract

Natural and anthropogenic activities cause injured or dead sea turtles to wash ashore or strand along coastlines. In North Carolina, the NC Wildlife Resources Commission collects stranding information on sea turtles as part of the Sea Turtle Stranding and Salvage Network, which was formed in 1980. In this study, I characterized temporal and spatial trends in sea turtle strandings in North Carolina. I described temporal trends in sea turtle strandings by year, season, sex, cause of death (if known), and mean body size, overall and by species. I also looked at spatial trends in stranding locations to determine if they were uniformly or aggregately distributed, overall and seasonally, by dividing the shoreline into 10 km bins and creating histograms. Stranding numbers have increased over the past 23 years, but seem consistent since 1995 when effort is believed to have been standardized. Strandings generally increased from May through July as well as from November to December. For turtles whose sex was reliably classified by observers, all species except leatherbacks exhibited a heavy female bias; leatherbacks showed a male bias. Mean size of strandings per species appears roughly constant. With the exception of leatherbacks whose mean stranding size corresponded with adults, the mean size of all species corresponded with juvenile size classes. Spatially, strandings are not uniformly distributed, but appear clumped around several areas along the North Carolina coast including the east ends of Raleigh, Onslow, and Long Bays, and just north of Cape Hatteras. These strandings correspond seasonally with alongshore currents modeled by Hart et al. (submitted). I was unable to find any correlation between frequency of surveys and numbers of stranding reports normalized for shoreline distance, suggesting that the distribution of the stranding data are not biased by sampling effort.

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Introduction

Injured and dead sea turtles frequently strand or wash ashore due to natural and anthropogenic causes. In the US, the Sea Turtle Stranding and Salvage Network (STSSN) records sea turtle strandings in the Western North Atlantic and the Gulf of Mexico states and has done so since its inception in 1980. Several researchers have looked at portions of the stranding database in an attempt to uncover patterns in descriptive characteristics of stranded marine turtles, and to correlate causal effects. Stranding analyses conducted by the Turtle Expert Working Group (TEWG) in 2000 indicate that from 1986-1997, 25% of all reported Kemp's Ridley strandings and 65% of all loggerhead strandings occurred in the southeast region including the Atlantic facing side of Florida to North Carolina. Overall, for both species there have been increased strandings since the 1980's, which could be strongly influenced by population growth as well as levels of shrimping effort (TEWG 2000, Lewison et al. 2003). While numbers and localities are highly variable across species, seasons and years, marine turtle strandings can serve as a useful index to gauge at-sea mortality (National Resource Council 1990) as well as Turtle Excluder Device (TED) compliance (Lewison et al. 2003).

Many factors influence the occurrence of sea turtle strandings including disease, predation, boat collisions, cold stunning, and fishery bycatch, though the largest anthropogenic source is believed to be incidental catch from shrimp trawling (National Research Council 1990). Sea turtles may strand dead or alive, but often are more of the former than the latter. Decomposing turtles sink during the first day after death, but then internal gases cause carcasses to float thereafter allowing currents and winds to carry the turtle carcasses and in some cases deliver them onshore. Cause of death in turtle carcasses is often difficult to determine due to varying levels of decomposition.

A few studies have suggested that distributions of sea turtle strandings are relative to physical oceanographic factors including winds and currents (Epperly et al. 1996, Hart et al. submitted). In fact, Epperly et al. (1996) suggested that sea turtle mortality from certain fisheries may not be fully represented by strandings as the ocean currents vary seasonally and may carry many turtle carcasses out to sea. Hart et al. (submitted) modeled the currents and winds using historical data off of North Carolina and demonstrated that the presence or absence of currents and wind patterns affected the probability of strandings to occur. They correlated seasonal differences in strandings to variation in wind conditions.

While Hart et al. (submitted) were able to suggest through their model where and when strandings in North Carolina might be more likely to occur, their spatial analysis of the strandings data was limited both in scope and time frame (1995-1999). They noted seasonal variability of stranding locations, but only concluded that a greater proportion of strandings occurred on the eastern sides of Onslow and Raleigh Bays.

Geographic Information Systems (GIS) is a tool that can be used to spatially view patterns and distributions of data over an area. By using GIS to analyze stranding data, a clearer resolution as to when and where strandings occur as well as the types of species and size classes affected may aid managers in their quest to decrease human-induced stranding events.

The purpose of my study is twofold: to characterize trends in sea turtle strandings in North Carolina over the past 20 years as well as to visualize spatially where strandings occur. While the TEWG characterized loggerhead and Kemp's ridley strandings throughout the United States from 1980-1997 and Teas (1993) looked at size class and sex distributions for all species from 1985-1991, previous analyses have mainly looked at national and regional trends and have not been recently updated. This study will focus exclusively on strandings in North Carolina to better understand characteristics of turtles that strand in this state.

Factors to consider in studying trends in sea turtle strandings include seasonality, body size of stranded turtles, sex (if this information was known), and cause of stranding (if determined), overall and by species. In addition, strandings pre- and post TED implementation will be compared to see if there is a visible TED effect. Studies in other states have showed variable results. In South Carolina, Crowder et al. (1995) calculated a 44% decrease in strandings when TEDs were in use. Lewison et al. (2003) looked at strandings in Texas and found that while mortality in stranded turtles had decreased, numbers of strandings had increased markedly with the advent of TEDs. This increase was attributed to population growth and TED violations. TEDs were implemented in North Carolina in 1990 and were federally mandated by 1994. In North Carolina, TED compliance is believed to be good. As shrimping is primarily limited to the Albemarle and Pamlico Sounds, the effect may be restricted to inshore strandings. In 2003 National Marine Fisheries Service (NMFS) implemented mandates for larger TEDS as it was discovered that the original minimum TED size was insufficient to allow an adult loggerhead or leatherback to escape (Epperly & Teas 1999). Thus, for the period after the first TED regulation there may be a shift in the strandings to fewer juvenile and subadult turtles, but continued strandings of larger adults.

This study will also use GIS to conduct spatial analysis of sea turtle strandings from North Carolina. In North Carolina, stranding rates are calculated by county, which potentially could bias stranding “hotspots” to those counties with the largest coastline (Wendy Cluse, NCWRC, pers. comm.). Nationally, NMFS divides the coastline (for those states along the Atlantic) into statistical zones each representing a 0.5° segment of latitude. North Carolina spans 4 statistical zones (zones 33-36), sharing zone 33 with South Carolina and part of 36 with Virginia. The TEWG (2000) used “hotspots” to define areas with the highest numbers of strandings. While 0.5° latitude segments may be useful for looking at strandings on a national

level, the length of coastline within each statistical zone is not uniform due to the coastline's meandering nature. Thus, it may be more useful to look at strandings on a finer, and more uniform scale to better describe high stranding areas.

Sea turtle managers in North Carolina believe it of interest to know where strandings occur and how they are distributed. Are they uniformly, randomly or aggregately distributed? Do locations of strandings change and if they do, how do they compare to the turtle transport model created by Hart et al. (submitted)? Where are stranding "hotspots" in North Carolina?

In addition, survey effort by volunteer groups varies greatly from daily to none at all. Are numbers of stranding reports biased by monitoring effort of the various volunteer groups? I will also look at stranding records normalized for shoreline distance and determine whether there is any bias between high survey effort and stranding records.

Methods

Sea Turtle Stranding data from 1980-2003 were obtained for the state of North Carolina from the North Carolina Wildlife Resources Commission (Matthew Godfrey, NCWRC, pers. comm.). A stranded turtle in this study is defined as any sick or diseased turtle or dead carcass or portion thereof discovered on land. Reports of turtles captured in nets, turtles caught by fishermen, turtles stranded in other states, and unconfirmed reports of turtles were excluded from the analysis to ensure that the analysis represents only stranded turtles.

Temporal

I inferred temporal or seasonal trends in strandings by creating graphs of annual and monthly strandings. I also separated strandings by species, sex, location (inshore or offshore), and cause to characterize types of turtles most commonly stranded overall and by species.

Volunteer observers record turtle measurements in a variety of ways including straight carapace length (SCL), curved carapace length (CCL) and width depending on the condition of the carcass and the measuring instrument used by the observer. Stranding records contained more measurements with CCL and thus I used CCL to calculate overall mean turtle size for those turtles that were measured. However, SCL (notch to tip) is considered the more standard measurement so I converted the resulting CCL mean to SCL for each species using species specific equations (Table 1) derived by Teas (1993) and Tucker and Frazer (1991). For each species, I created graphs summarizing the size distributions for each species as well as mean size by year and by month.

Spatial

Survey effort for stranded turtles has varied in North Carolina since the STSSN's inception though we believe that effort has been relatively consistent since 1995. To avoid false conclusions on the spatial location of strandings based upon spotty effort, only data between 1995-2003 were used in this spatial analysis. Volunteer effort in inshore areas is considered neither comprehensive nor consistent so this analysis was also limited to offshore strandings.

GIS layers on the shape of North Carolina were obtained from the Center for the Analysis and Prediction of River Basin Environmental Systems (CARES) as well as from USGS. All maps were re-projected in UTM, zone 18, North American Datum 1983. I selected out arcs representing the shoreline from the CARES shapefile on NC watersheds and created a single arc shapefile in ArcView 3.2 using the Point and Polyline Tools extension created by Soren Alsleben. Because coverages have a maximum vertice limit of 500, the single shapefile arc was split into 5 arcs upon conversion to a coverage.

Prior to 1999, turtle strandings were recorded in DMS (Degree/Minute/Second) and so I converted those locations into DD (Decimal Degrees). I created a point coverage in ArcMap 8.1

displaying stranding locations from an Access file containing all offshore stranding data from 1995-2003. I selected for strandings that fell within a 1 km radius of the shoreline to use in my analysis. This allowed for minor error due to GPS and/or human error in recording coordinates, but excluded points with recorded locations that were clearly in error.

Because strandings are limited to the coastline, their location can best be described as a point or at some distance on a line rather than a point or a cluster of points in 2D space. If strandings are uniformly located, one might expect the distance between strandings (inter-stranding distance) to display a normal distribution surrounding a median value equivalent to the length of the coastline, or approximately 536 km, divided by the number of strandings. If strandings are random, one might not expect to see any patterning in histograms of the inter-stranding distance while if strandings are clustered, one might see a peak in inter-stranding distance at a median value less than would be expected from a normal distribution. Thus, I looked at median inter-stranding distances to determine whether they were less than might be expected from a uniform stranding.

To calculate these inter-stranding distances, I calculated a stranding record's distance from the Virginia/North Carolina (VA/NC) border. I copied the coverage of the generalized shoreline and then split the copied shoreline using the densifyarc function in Arc 8.1. This function splits the arc at every vertice or every 100 m, at whichever comes first. Thus, each arc has a beginning and an end node that is nearly equally spaced along the shoreline. Stranding attributes were attached to the nearest node on the shoreline using the pointnode function (also in Arc 8.1) with a search radius of 1 km. Only the attributes for the nearest stranding are recorded with a node so it is possible for fewer strandings to be appended to the output file than the total number of strandings. To ensure that all strandings were included in my analyses, I identified

those strandings not attached to nodes and reiterated the process until every stranding had a node attribute.

Using the `nodedistance` function in ArcPlot, I calculated the distance from the VA/NC border by creating a center point at the VA/NC border and measuring the distance to all nodes using the shoreline as a network. I joined the network distance file to the attribute table of the shoreline in ArcMap and selected for the points with strandings. I exported the joined attribute table to a dBase file where I ordered the stranding distances from least to greatest and from this calculated inter-stranding distances. I compared the median inter-stranding distance to expected inter-stranding distance and deduced non-uniform stranding for those for which the median value fell below the expected value.

I also created histograms (S-Plus 6.1) showing stranding distance from VA/NC border with 10 km bins to show which areas had the greatest frequency of strandings overall as well as annually. I defined high clustering as those areas with greater than 90 strandings over 9 years for a 10 km section, which breaks down to an average of 10 strandings per year per bin. Bins with greater than 45 strandings were considered medium clustering. As these distances may seem meaningless out of context, I placed three reference bars in the histogram corresponding to notable geographic features on the North Carolina coast (Figure 1). Distances from 0-156 km correspond to the area between the VA border and Cape Hatteras. Distances from 156-281 km correspond with the area between Cape Hatteras and Cape Lookout that includes beaches within Raleigh Bay. Distances between 281- 476 km represent the area between Cape Lookout and Cape Fear or that covering Onslow Bay and distances between 476- 536 km represent the area between Cape Fear and the South Carolina border or the beaches within the North Carolina portion of Long Bay.

As numbers of strandings vary by month, I also modeled stranding distance using a density line. This normalized the data for number of strandings while allowing me to statistically compare where highest proportions of strandings occur seasonally.

Strandings records are opportunistic as they rely on volunteers to monitor beaches and record strandings. Thus, strandings records may be heavily influenced by the number of times volunteer groups survey the beaches for strandings. To detect whether there is any measurable difference between areas of beach with high observer coverage and low observer coverage, I divided a coverage of the generalized shoreline by volunteer monitoring group using longitude and latitude coordinates (Matthew Godfrey, pers. comm.). I created a shapefile of a 1km buffer around each individual arc excluding the end points and counted the number of strandings that fell within each buffered area. I limited strandings for this analysis to those that occurred in 2003 since effort within groups has likely varied over time. Strandings efforts not only differ in intensity but also in extent with some volunteer groups covering large distances such as the Cape Hatteras National Seashore while other groups monitoring only a couple miles of a particular beach. Thus, to normalize the data, I divided the number of strandings found in each region by the distance monitored and plotted this normalized stranding against effort. Effort is defined by the number of beach surveys completed in a two-week period with highest effort in those areas with daily surveys and lowest effort in areas with no scheduled surveys. I also differentiated between those areas with an existing turtle volunteer group that did not have scheduled beach surveys by labeling their effort a value of 0 and those areas without any formal turtle volunteer group by labeling them with “no effort.” As geography may play a role in stranding numbers and intensities, I distinguished by color the corresponding bay the monitoring group covered. For those groups whose monitoring covers two bays, I separated their strandings and calculated two densities based upon the coverage in each bay.

Results

Temporal

Between 1980-2003, 6,997 turtles stranded in North Carolina. Annual stranding numbers have in general increased over the past 23 years (Figure 2). However, effort in monitoring strandings is considered consistent only since 1995 (Matthew Godfrey, NCWRC, pers. comm.). Since then, lowest strandings occurred in 1998 with 318 recorded strandings while highest strandings occurred in 2000 with 778 strandings. Seventy-four percent of strandings are found on offshore facing beaches while 26% are found in inshore beaches and sound areas.

Five species of sea turtle were recorded in the strandings including loggerhead (*Caretta caretta*), Kemp's ridley (*Lepidochelys kempii*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*) and hawksbill (*Eretmochelys imbricata*). Loggerheads comprised a dominant portion of the strandings (75.9%) followed by green (10%), Kemp's ridley (9.1%), leatherback (2.8%) and hawksbill (0.04%). For 2% of the turtles, observers were unable to determine the species of the stranded carcass.

Overall stranding numbers vary seasonally with a peak in strandings usually occurring from May-July and smaller increase in November and December (Figure 3). Lowest offshore stranding rates typically occurred in the late winter between February and March whereas highest stranding rates were seen in May. For inshore strandings, stranding numbers peak between May and August, and exhibit a lower peak between November and January.

Sex was only determined in 16% of the stranding records and of those determined, 71% were found to be female and 29% were found to be male resulting in a nearly 3:1 female to male ratio.

Observers were unable to determine cause of strandings for most (87%) of the records. However, for those with identified cause of stranding, 6.7% were attributed to boat collisions, 1.7% were attributed to cold stunning, 0.7% were attributed to disease, 1.8% were attributed to entanglements in fishing gear, 0.2% were attributed to gunshots, and 1.4% were attributed to mutilation. Fewer than 0.1% were attributed to either pollution or shark attack. Between 1980-2002, relative proportions in causes of strandings have been fairly constant though there has been a rise in the proportion attributed to boat collisions since 2001 (Cluse 2002).

Loggerheads

Loggerheads are the primary species found stranded in North Carolina as well as the most abundant. Loggerhead strandings are highly variable, but may be increasing since 1995 (Figure 4). A longer time series dataset is necessary to adequately analyze trends. A peak in strandings occurred in 2000 with 570 strandings, of which half occurred during a mass stranding event in April and May that was later linked to an offshore monkfish gillnet fishery. Seasonally, the highest peak in strandings occurs from May-July though there is also a small rise in November (Figure 5). Sex could only be determined for 14% of the strandings, from which there was a 2:1 female to male ratio. Loggerheads primarily stranded on offshore facing beaches (80%), but some also stranded inshore areas (20%). Size of loggerheads has ranged from 3.39 -140.76 cm SCL (Figure 6) with mean size of 67.75 cm SCL (n = 3,952). Mean stranding size has been relatively constant over the past 23 years (Figure 7). Mean size seasonally ranges between 60.8-72.8 cm (Figure 8). Lower mean size occurs in the winter and higher mean size occurs from April to October.

Green Sea Turtles

Green sea turtles were the second most commonly stranded species found in North Carolina. Their strandings have been higher in recent years, but may be declining as 2003

strandings were the lowest they had been since 1997 (Figure 4). Seasonally, the highest strandings for green turtles appear from November to December (Figure 5). Sex was determined for 16% of strandings and again we see a 2:1 female to male ratio. Unlike other species, the majority of green turtle strandings are inshore (58%), which is likely due to their feeding preferences for seagrass that is common in inshore waters of North Carolina. Overall mean body size of green turtles is 33.93 cm SCL (n = 569) and has been roughly constant annually (Figure 7) and seasonally (Figure 8). Individual size has ranged from 7.91 - 100.25 cm SCL (Figure 6).

Kemp's Ridleys

Kemp's ridleys are the third most commonly stranded species in North Carolina. Greatest strandings were observed in 1999 with 114 strandings. Kemp's ridleys also strand year-round with highest stranding rates in November (Figure 5). Sex was identified for 34% of strandings and there appears to be a nearly 3:1 ratio of females to male. More Kemp's ridleys strand offshore (59%) than inshore (41%). Kemp's ridley sizes have ranged from 17.9 - 74.9 cm SCL (Figure 6), but the overall average is 37.25 cm SCL (n = 469). Mean SCL has fluctuated between 29 - 43 cm annually since the late 1980's (Figure 7). Seasonally, lowest mean SCL occur in March and highest mean SCL occurs in October. (Figure 8)

Leatherbacks

Leatherbacks strand in North Carolina though considerably less often than loggerheads, greens and Kemp's ridleys. The highest number of leatherback strandings happened in 2002 with 28 strandings (Figure 4). Leatherbacks have been found to strand year-round except in March though there are very few stranding records in the winter months; most strandings occur between May and June (Figure 5). Sex has been identified in few leatherbacks (n = 31), but contrary to the female bias in other turtles, leatherbacks records display a bias towards males with 3:2 male to female ratio. Leatherback strandings are found mainly on offshore beaches

(86%). Average stranded leatherback size is 144.99 cm SCL with individual sizes ranging from 36.19-195.23 cm SCL (Figure 6). Mean size has a greater deviation over time likely as a result of small sample size (Figure 7,8).

Hawksbills

Hawksbills are rarely seen in North Carolina and as such there are only 3 records of hawksbill strandings from 1980-2003. All three occurred in March; 1 was in 1999 and the other 2 were in 2003. All were found on offshore facing beaches and were between 15.9 and 10.4 cm SCL indicating that they were small juveniles. Cold stunning was the cause of two of the strandings and the cause of the third was not identified. Sex could not be determined for any of these strandings.

Spatial

In all cases, inter-stranding distances were less than those expected from a uniform stranding pattern and histograms reveal a heavy skew towards short inter-node distances (Table 2).

A histogram containing all strandings from 1995-2003 as a function of distance from the VA border shows high variability in strandings along the coast of North Carolina with some distinct valleys and peaks in stranding rates (Figure 9). Greatest strandings occur 110-120 km from the VA border near Oregon Inlet while lowest strandings are found at a distance 420-430 km in Onslow Bay. Hotspots of strandings occur on both sides of Cape Hatteras roughly between Oregon Inlet and Ocracoke Inlet, and in one section of Long Bay near Holden Beach. Medium strandings occur north of Oregon Inlet to the VA Border as well as on the eastern sides of Raleigh Bay, Onslow Bay, and Long Bay.

Breaking down the strandings by year, hotspots of stranding locations are not always consistent year by year though some patterns do persist (Figure 10). Strandings in 2000 were highly concentrated spatially between 100-140 km and 180-190 km. Stranding patterns were similar in 1996, 1998, 2001 and 2002. In general, there are consistent strandings north of Cape Hatteras to the VA Border as well as on the eastern sides of Raleigh, Onslow, and Long Bays.

If stranding locations are broken down by month, there are some dominant areas where greatest proportions of strandings occur (Figure 11). In January, the greatest proportion of strandings occurs in Raleigh Bay and persists throughout the winter to early spring when the peak starts to shift more towards Cape Hatteras in March and April. By May, the greatest proportion of strandings occurs just north of Cape Hatteras and persists till November when it shifts back towards Raleigh Bay in December. Beginning in April, Onslow and Long Bays begin to receive more strandings. Strandings off of Long Bay continue to increase through the summer peaking in July and then decreasing steadily into the fall. Strandings in Onslow Bay also rise in the summer and decrease in the fall.

Stranding numbers reported per volunteer monitoring area normalized for length of shoreline show little correlation with effort (Figure 12).

Discussion

Temporal

Overall strandings have increased in North Carolina over the past 23 years. This is consistent with the findings of the Turtle Expert Working Group (1998, 2000), which noted increased strandings in both their assessments of loggerhead and Kemp's ridley populations.

Strandings for loggerheads while increasing have been highly variable annually. Nationally, loggerhead nesting populations have increased (TEWG 2000) and this greater

abundance could contribute to larger numbers of strandings (Figure 13). A direct link between increased numbers of nests laid in the US and annual stranding numbers is complicated by several factors, including variable observation effort and the life-cycle of loggerheads that includes the first several years post-hatching being spent in the Northeast Atlantic (Bolten 2003). Nearly half the strandings found from the peak in 2000 were linked to an offshore gillnet fishery for monkfish, which occurs primarily in federal waters off the northeast and mid-Atlantic states. NMFS made swift regulation changes and strandings dropped to less than normal levels the following year (Wendy Cluse, NCWRC, pers. comm.). Some of these regulations have since been rescinded by court ruling and modified by recommendations from the Northeast and Mid-Atlantic Fisheries Management Councils. While NMFS has enacted more temporary protective measures, there still may be some unknown number of loggerheads still being caught in this fishery (NOAA 2003). NMFS regulations only cover this fishery in federal waters. However, state regulations prohibit the use of large mesh gillnets at all times except between December 15-February 15 and between March 15-April 15. With restrictions to the Fishery Management Plans in federal waters, the monkfish fishery has declined substantially in state waters (Chris Batsavage, NCDMF, pers. comm.). A few boats (between 3-7 a year) continue to set gillnets for monkfish during the gap between March 15-April 15, but added regulations associated with the Bottlenose Dolphin Take Reduction Plan will likely close this loophole when the Plan comes into effect (Chris Batsavage, NCDMF, pers. comm.).

Stranding levels for green and Kemp's ridley turtles appeared to rise and peak in 2000 and 1999 respectively. However, stranding numbers of both species have been decreasing to low levels. Scientists have linked rising numbers of strandings of Kemp's ridleys in Texas to population growth (TEWG 2000, Lewison et al. 2003). As juvenile Kemp's ridleys are known to migrate by North Carolina, it is possible that their increased abundance may influence their

numbers of strandings (Figure 14). Rising numbers of nesting green turtles are also believed to indicate a growing green turtle population, but this cannot be substantiated from the stranding data (NMFS & USFWS 1991).

Leatherback strandings have been consistently low though an all-time high of 28 stranded leatherbacks were found in 2002. Similar increases in stranded leatherbacks have been seen in other Atlantic states such as South Carolina, and the number of leatherbacks nesting in Florida and the northern Caribbean seem to be on the rise (S. Eckert pers. comm.). However, it is impossible to know if these increased strandings can be attributed to an overall increase in abundance of leatherbacks in the Atlantic.

While stranding numbers of loggerhead, green, Kemp's ridley and leatherback sea turtles have all increased over time, the distribution of overall strandings per species overwhelmingly fell to loggerheads. As the inshore and coastal waters of North Carolina provide good foraging opportunities for sea turtles, the high occurrence of loggerhead strandings is unsurprising. Green, Kemp's ridley and leatherback sea turtles are also known to migrate by and forage around North Carolina. Hawksbills are quite uncommon. Teas's (1993) analysis of species composition in the southeast United States from 1985-1991 support these findings though she found fewer loggerhead and Kemp's ridley strandings.

Based on size class, juvenile turtles compose the majority of stranded turtles for all species except leatherbacks, for which adults make up most of their strandings. Mean body size fluctuates little annually and seasonally. Though there are fluctuations in part of the stranding record, most are likely as a result of fewer records of strandings than anything else.

Strandings appear to be highly seasonal with peak strandings in May-July and in November-December. In other states such as South Carolina and Texas, peaks in strandings have been linked to the shrimp trawl fishery with especially heavy stranding events occurring

within the first few weeks of the season (NMFS 1994, Crowder et al. 1995, Lewison et al. 2003). While shrimp trawling also occurs in North Carolina, it mainly occurs inside the Sound so it is likely not the primary cause of increased strandings. However, North Carolina boasts many other fisheries that could be affecting strandings such as the summer flounder bottom trawl fishery, which occurs from November to February as well as the spring monkfish fishery mentioned above (Epperly et al. 1995). Currently, federal and state agencies are looking into different fisheries that may have interactions with turtles. Sea turtles are not afforded the same protection measures as marine mammals, which are covered by the Marine Mammal Protection Act. However, all species of turtle are listed as either threatened or endangered under the Endangered Species Act. North Carolina has been proactive in considering sea turtle and fishery interactions and has recently convened a Sea Turtle Advisory Committee comprised of various stakeholders charged with finding ways to reduce sea turtle bycatch in North Carolina waters. This committee is modeled similarly to the take reduction teams used in developing plans for marine mammals.

In addition, oceanographic conditions should also be taken into account when looking at stranding records. Sudden drops in temperature in the early winter can stun turtles that have not yet migrated out to the warmer waters of the Gulf Stream. Thus, some of the increased strandings in November-December can be attributed to cold-stunned turtles. Furthermore, wind and current patterns play an enormous role in whether turtle carcasses are even carried onshore or offshore. Hart et al. (submitted) modeled oceanographic currents in North Carolina using mean wind and current data and found that summer patterns were more favorable to carry strandings landward than winter patterns. I will come back to this later in the discussion on spatial trends.

Stranding records were primarily offshore though inshore strandings are being reported with increasing frequency in recent years. Inshore strandings are difficult to monitor as the marshy and riverine environments of the Albemarle-Pamlico Sounds are large and often difficult to navigate. Furthermore, private property rights can extend to the water such that public monitoring is nearly impossible. Nevertheless, it is important to push for greater monitoring so that we might get a more adequate picture of strandings inshore. Reports of turtles entangled in fishing gear are already present in the stranding record within the Sound, but there are likely many more incidents unreported. Fishermen are already encouraged to report any sightings of sea turtles, but perhaps the state needs to enact greater incentives to get a more accurate picture of inshore strandings.

Within the small portion of turtles necropsied for sex, females were the dominate sex identified for all species except leatherbacks. Sex ratios in sea turtles are assumed to be near 1:1 (Turtle Expert Working Group 1998) though many studies of hatchling sea turtles observe a female bias (Larry Crowder, pers. comm., Wibbels 2003). Studies of immature loggerheads using blood testosterone (Wibbels et al. 1987) along the U.S. Atlantic and necropsy of strandings along the Georgia coast (Shoop et al. 1998) show a 2:1 female to male sex ratio. Preliminary findings of hatchling sex ratios from the southeast Atlantic using laproscopy echo the 3:1 female to male sex ratios found in this study (Larry Crowder, pers. comm.). However, sex-specific behavioral differences could also play a part in the observed sex ratio of stranded turtles. For instance, nesting females are theorized to spend more time in coastal waters than males and this may contribute to the female bias seen in the stranding record (Stabeneau et al. 1996). While sex could be identified in only a few leatherbacks, the male bias is still interesting to note. Though few studies of Atlantic leatherback hatchling sex ratio production have been published, the overall sex ratio of leatherback hatchlings from Suriname is estimated to be close to 1:1

(Godfrey et al. 1996). Tagged leatherbacks from this nesting colony have been observed as strandings in North Carolina (Matthew Godfrey, NCWRC, pers. comm.)

Mean SCL overall exhibited a slightly downward trend though mean SCL on a species level was fairly constant between 1980-2002. Variation in mean size for greens and Kemp's ridleys in the early 1980's is likely influenced by the small sample size. Consistent mean SCL does not support any indication of an effect of TED introduction in the early 1990's, which should have shown an increase in mean size of stranded turtles, nor after TED enlargement in 2003, which should have shown a decrease in mean size of stranded turtles. As mentioned earlier, shrimping in North Carolina occurs mainly inshore so this effect may be muted though there may be strandings in the southern part of the state from shrimping effort from South Carolina. Also, mean turtle size indicates that most of the strandings are benthic juveniles for all species except the leatherback. Mean leatherback size indicates that leatherback strandings are mainly adults. Thus, while there may have been a decrease in turtle strandings after TEDS were first implemented, we might not see a strong decrease after TED modification in early 2003 since adult hard-shelled turtles do not typically strand in North Carolina.

As usual, cause of death could not be determined for a majority of the strandings. However, evidence of clear anthropogenic sources such as boat collisions, entanglements with both active and passive gear were found. Cluse (2002) noted an increase in the proportion of strandings with boat injuries in recent years. With further development of the North Carolina coastline, this could become a greater issue.

Spatial

Stranding locations of marine turtles are clearly not uniformly distributed along the coast of North Carolina. Aggregate data indicate stranding hotspots south of the Oregon Inlet around Cape Hatteras to Ocracoke Inlet, and near Holden Beach in Long Bay. Higher incidences of

clustering also appear north of Oregon Inlet to the VA Border and on the eastern sides of Raleigh, Onslow, and Long Bays. Locations of strandings fluctuated annually, but besides the mass stranding in 2000, most years appeared roughly similar to histogram of all strandings.

Though there is high seasonality in numbers of strandings, patterns persist where the greatest proportions of strandings occur. Generally, high proportions of strandings occurred around Cape Hatteras starting in Raleigh Bay in the winter and moving north in the spring, summer and fall. Strandings also increased markedly in the spring and summer in Long Bay and also on the eastern sides of Onslow Bay. Mooreside (2002) showed dominant alongshore flows nearly year-round north of Cape Hatteras in his ocean current models, which may explain the consistency in strandings in that area year-round. Other areas show fluctuations in current patterns. For example in Onslow Bay, higher strandings occur in June than December. Alongshore currents predominate in summer months in Onslow Bay whereas in December there are largely offshore patterns. Thus, it is possible that there are many unseen carcasses carried out to sea that we are unable to count.

The intensity of monitoring effort does not appear to greatly affect numbers of strandings reported by each volunteer group. While effort varies considerably and there may be unreported strandings from areas with little effort, I was unable to find any correlation between effort and stranding numbers after normalizing for shoreline distance, at least based on data from 2003. This indicates that for at least 2003 and later (assuming effort remains the same) we may be actually getting a good picture of offshore stranding numbers in North Carolina. However, this also brings up the issue that there are still some areas offshore that are not monitored, as well as quite a few places inshore that are not monitored. Further monitoring efforts should include increased surveys of inshore areas to get a better representation of inshore strandings.

In general, the patterns presented here match those predicted by Hart et al. (submitted) through models of average current directions and speed. Stranding locations did not appear to change much when their 5 year analysis was expanded to my 9 year analysis. This supports their assertion that stranding locations are influenced by oceanographic patterns of winds and currents though it must be acknowledged that offshore causes of mortality also play a significant role.

Conclusion

Patterns in turtle strandings in North Carolina appear to be relatively consistent over the past 23 years. There are fluctuations in strandings, which may in part be largely influenced by fishery interactions. These are numerous both inshore as well as offshore. North Carolina as well as the Atlantic States Marine Fisheries Commission and the Fisheries Management Councils are beginning to take steps to identify those fisheries that could potentially interact with sea turtles. Loggerheads are the most predominant species stranded with green turtles and Kemp's ridleys a distant second and third. Juvenile turtles are the most likely size class to be stranded. Boat collisions are also becoming a greater sign of trauma to turtles and efforts should be focused on reducing this take.

Spatially, strandings occur all along the ocean facing coast of North Carolina though they predominantly occur just north of Cape Hatteras as well as on the eastern ends of Raleigh, Onslow, and Long Bays. These high stranding areas correspond well with seasonal alongshore currents modeled by Hart et al. (submitted) and support their claim that physical oceanographic conditions primarily determine stranding location. No correlation was found between volunteer effort and strandings recorded which gives credence to the assumption that current stranding observations in North Carolina are representative of actual turtle strandings.

Table 1 Equations used to calculate SCL from CCL

From Teas (1993)

Green

$$\text{SCL} = 0.294 + (0.937 * \text{CCL})$$

Hawksbill

$$\text{SCL} = -0.212 + (0.955 * \text{CCL})$$

Kemp's Ridley

$$\text{SCL} = 0.013 + (0.945 * \text{CCL})$$

Loggerhead

$$\text{SCL} = -1.442 + (0.948 * \text{CCL})$$

From Tucker & Frazer (1991)

Leatherback

$$\text{SCL} = -1.96 + (\text{CCL}/1.04)$$

Figure 1 Coastline of North Carolina. The three lines denote coastline geography, which are referenced in Figures 9-12.

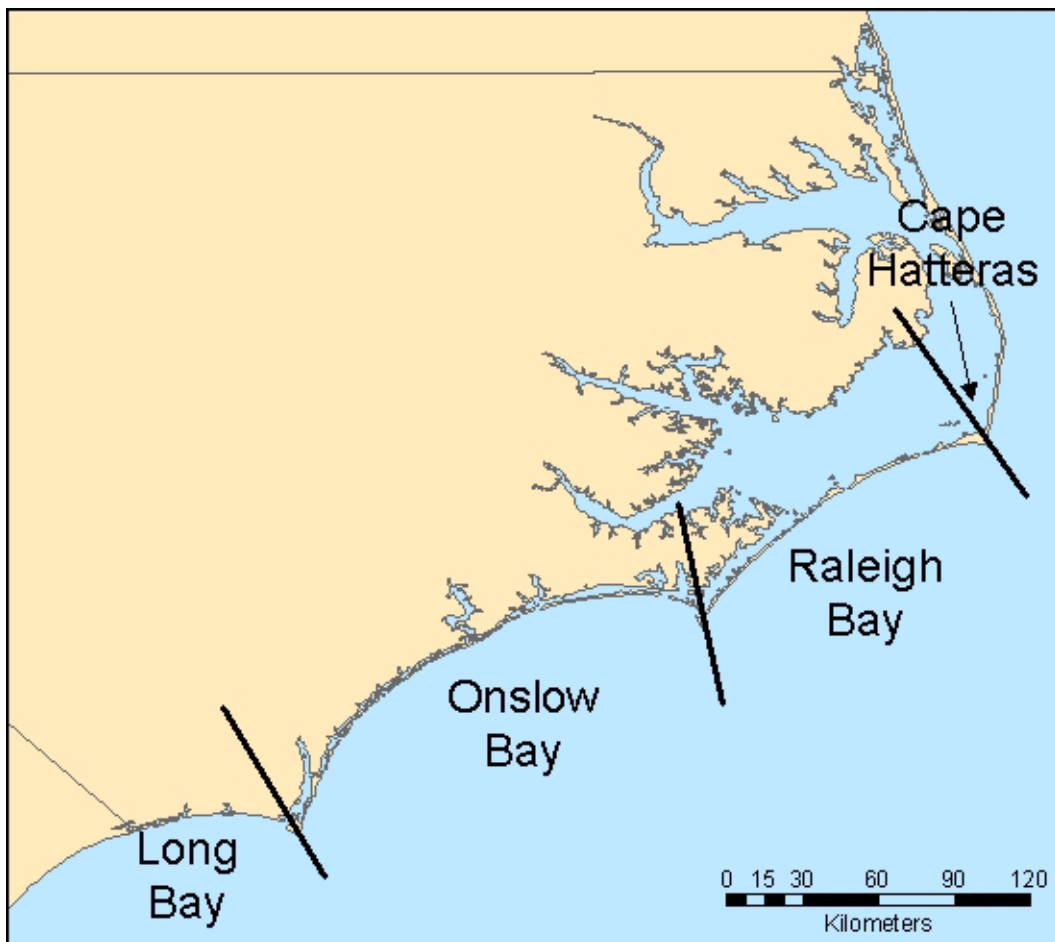


Figure 2 Annual strandings of all species of sea turtle in North Carolina between 1980-2003. Effort in observation has been standardized since 1995.

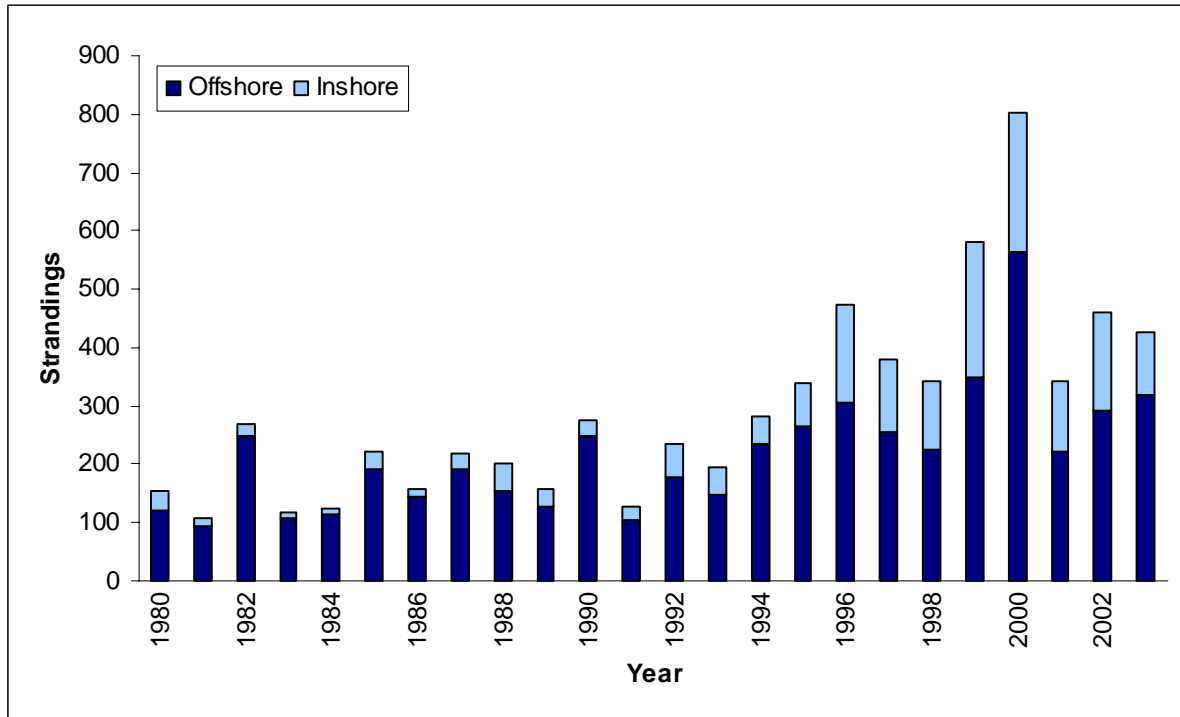


Figure 3 Average strandings per month between 1980-2003

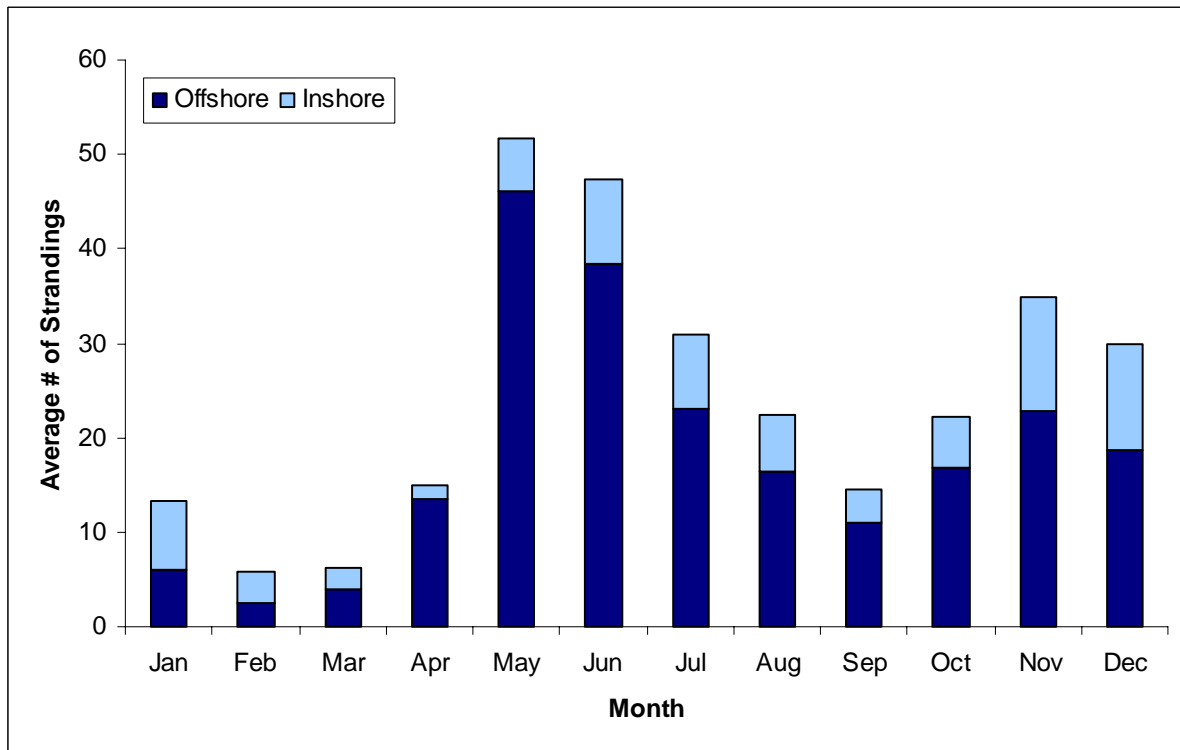


Figure 4 Annual strandings from 1980-2003 by species

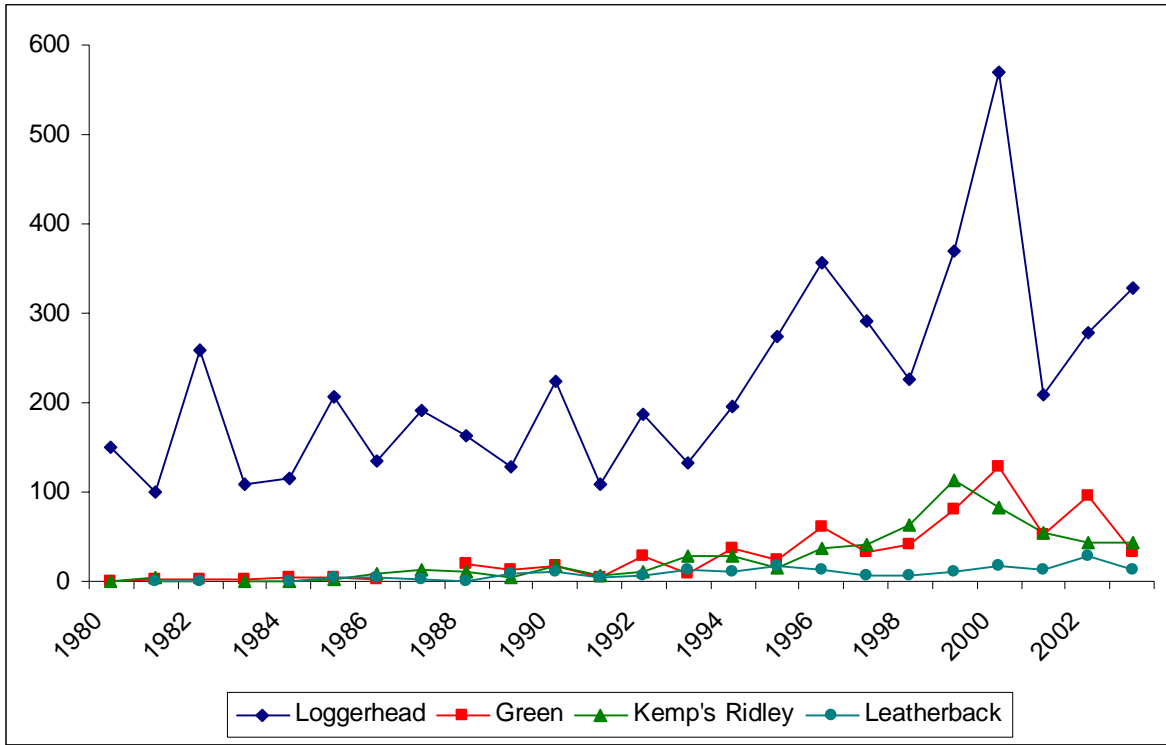


Figure 5 Average number of seasonal strandings from 1980-2003 by species

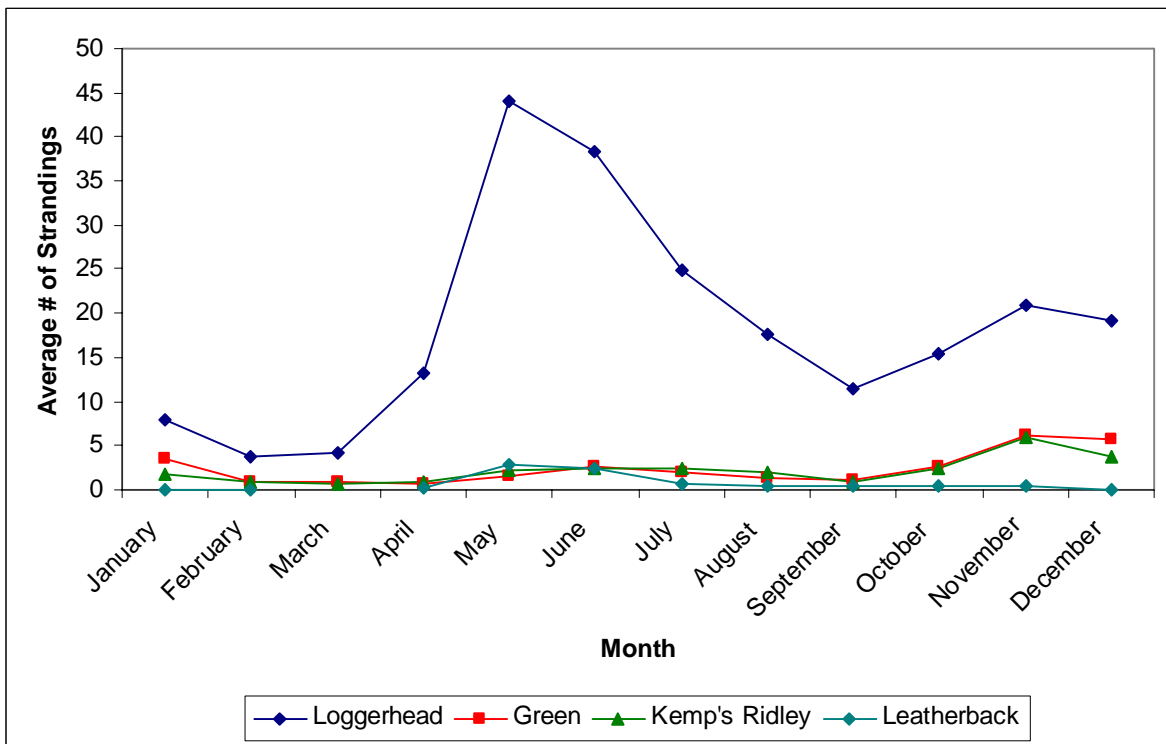


Figure 6 Size distribution of strandings by species from 1980-2003. Bins represent 5 cm increment.

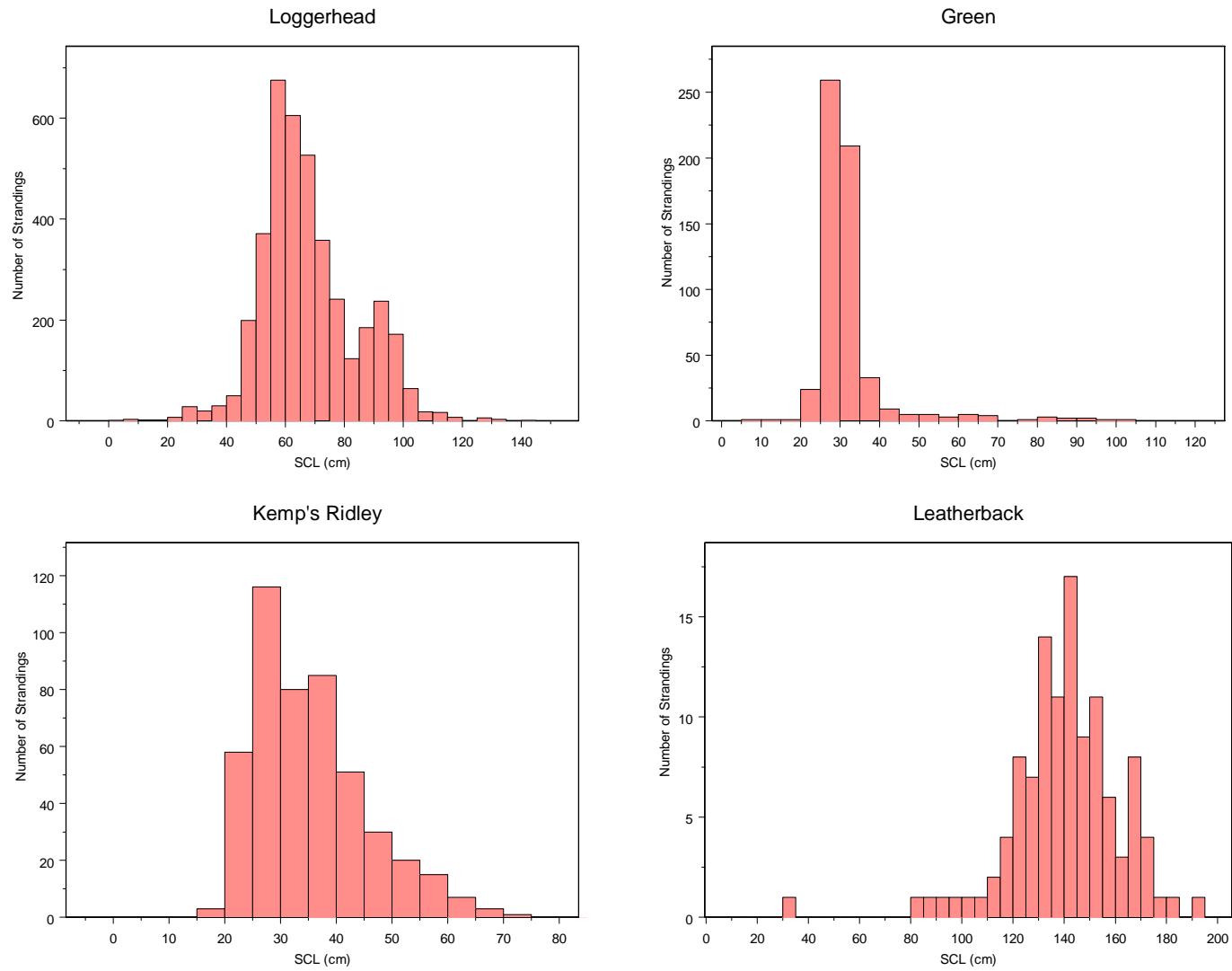


Figure 7 Boxplots of annual mean SCL size by species from 1980-2003.

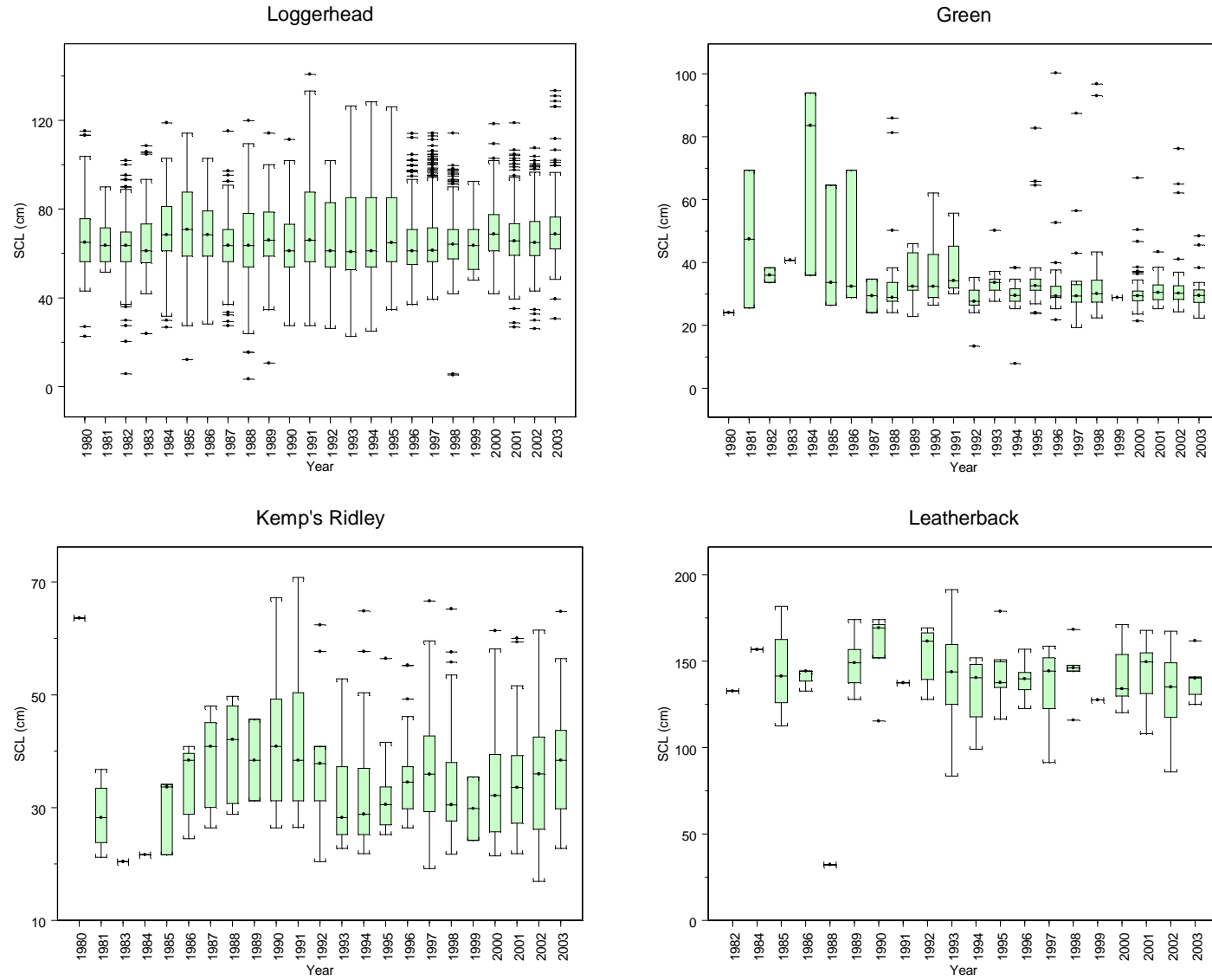


Figure 8 Boxplots of monthly mean SCL size by species.

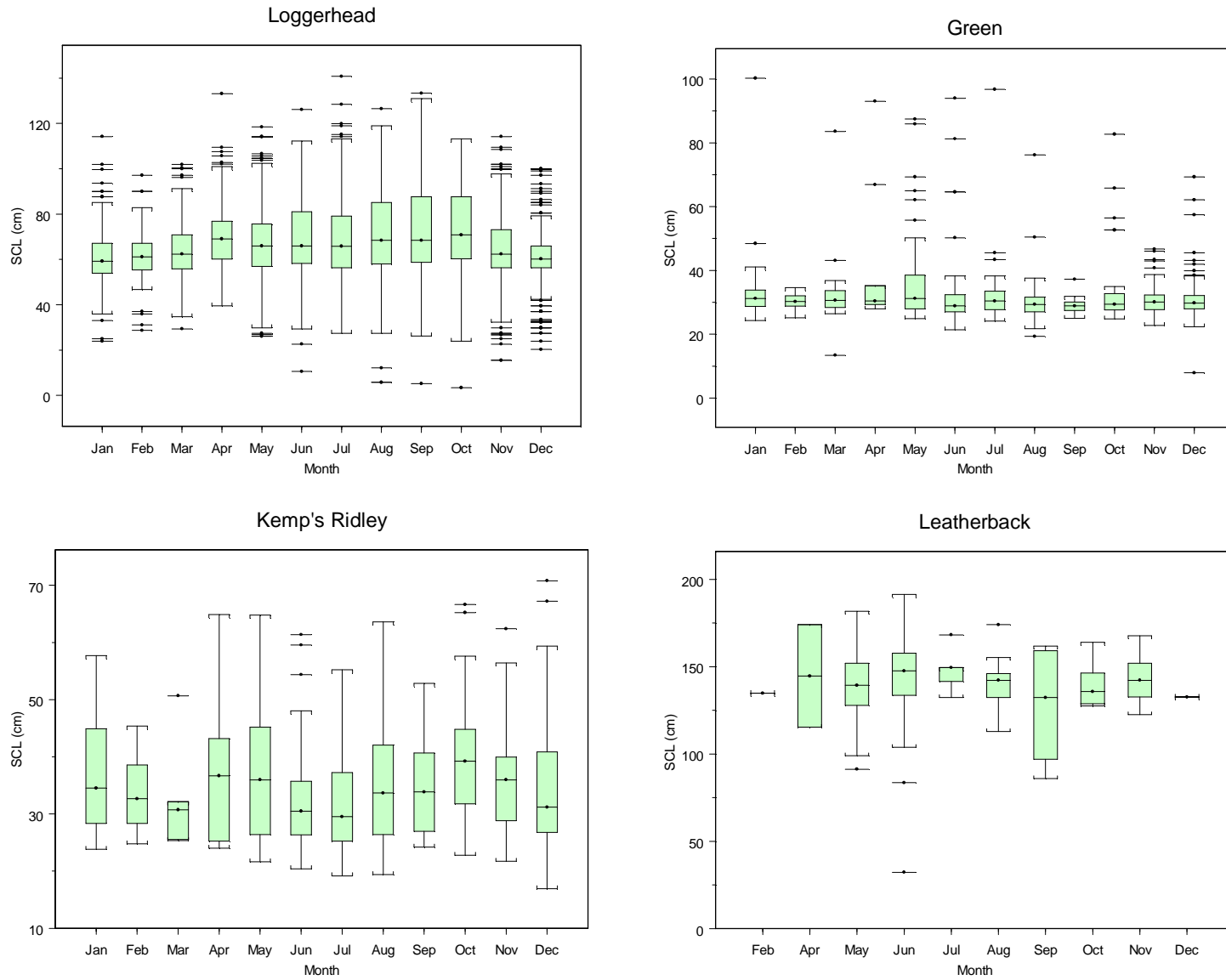


Table 2: Actual and Expected Internode Distances between Turtle Strandings. Actual Internode Distances are defined by the median interstranding distance. Strandings represents the number of stranding records attached to the nodes of the shoreline through the pointnode function. Expected Distance is the length of the coastline divided by the number of strandings.

Annual Interstranding Distances

	Median	Expected	Strandings
1995	0.90	2.05	261
1996	0.80	1.79	299
1997	1.09	2.15	249
1998	1.33	2.41	222
1999	0.80	1.58	340
2000	0.25	0.97	552
2001	1.70	2.64	203
2002	0.92	1.96	274
2003	0.80	1.73	309

Monthly Interstranding Distances

	Median	Expected	Strandings
January	2.63	8.38	64
February	9.30	26.8	20
March	2.16	9.40	57
April	0.54	2.43	221
May	0.20	0.71	751
June	0.50	1.00	537
July	0.80	2.02	266
August	1.50	2.69	199
September	1.20	3.39	158
October	1.32	2.96	181
November	1.20	3.17	169
December	2.60	6.23	86

Figure 9 Histogram of all strandings from 1995-2003 as a function of distance from the North Carolina/ Virginia border. The area above the thick dashed blue line represents hotspots. The area above the thin dotted and dashed line represents medium strandings. The grey bars reference to geographical features of the coast as seen in Figure 7.

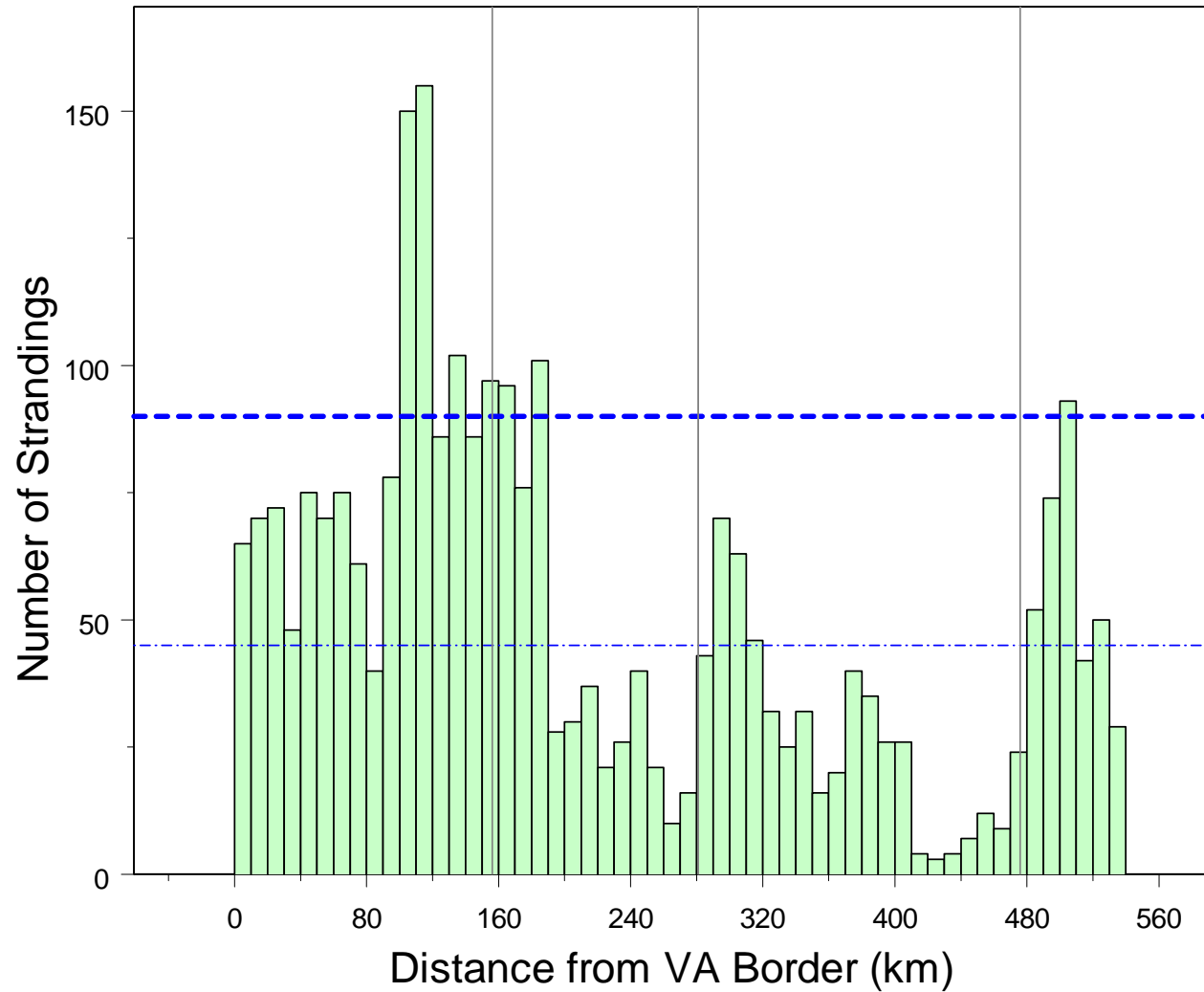
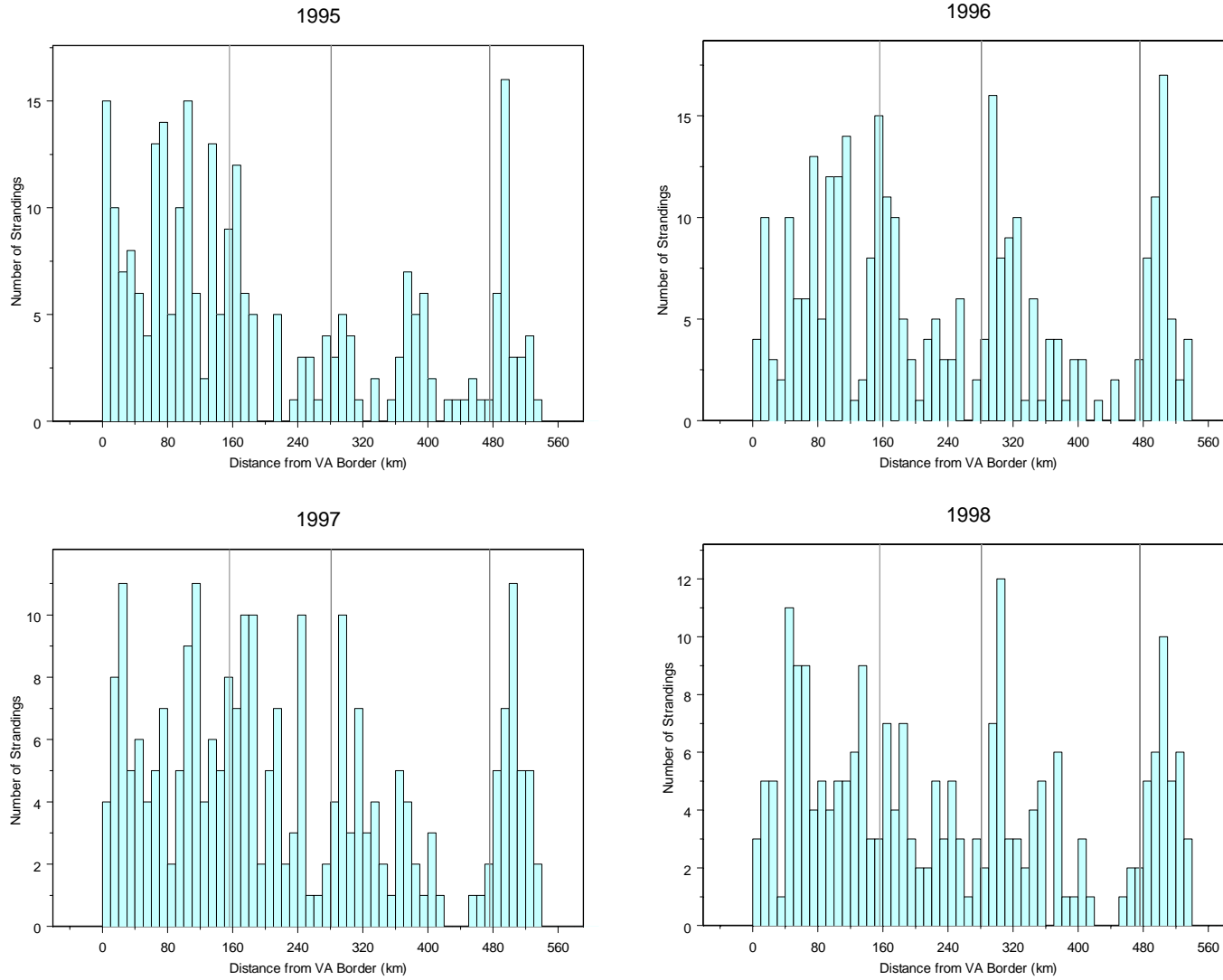
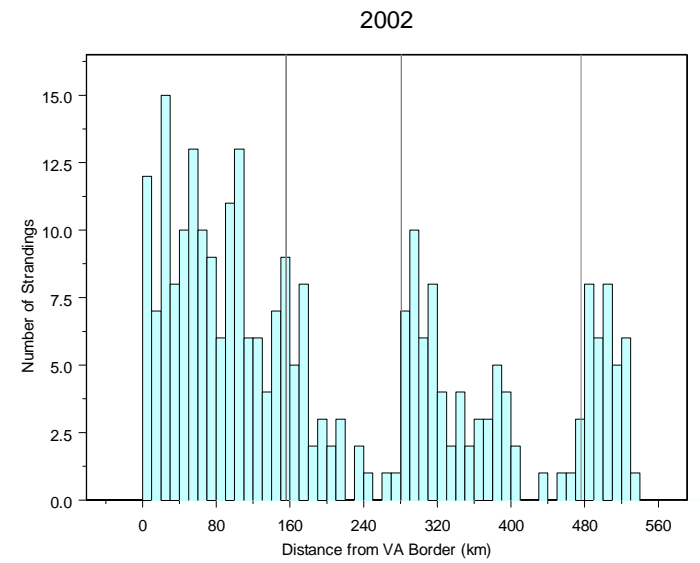
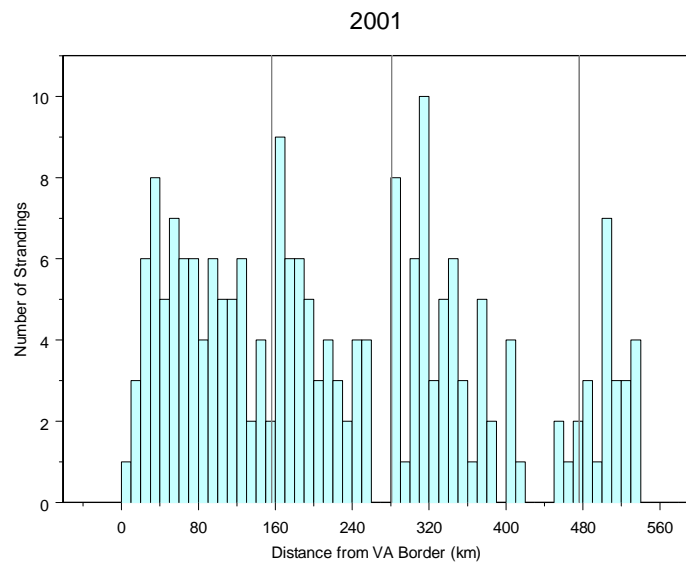
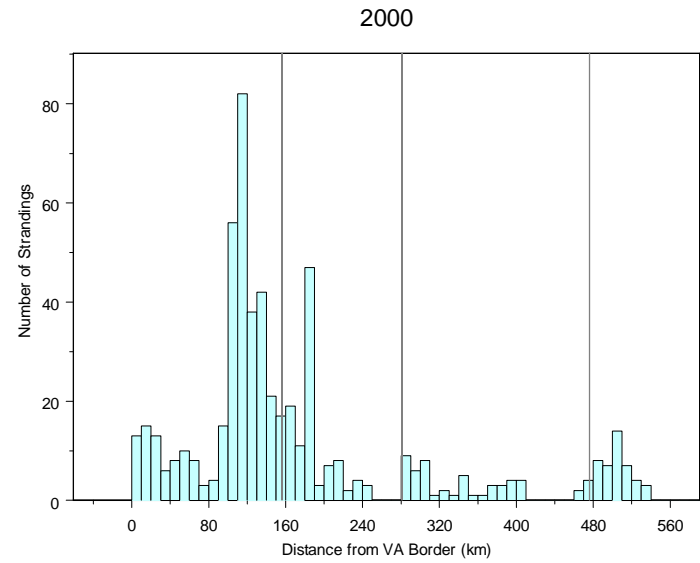
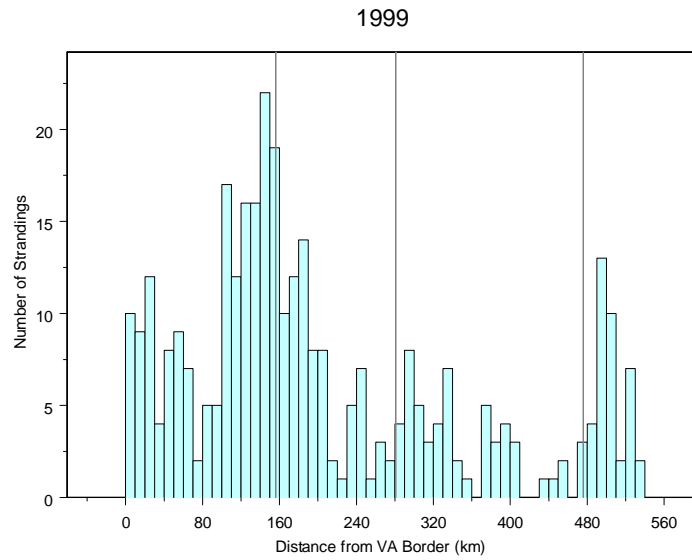


Figure 10 Strandings as a function of distance from the NC/VA border by year





2003

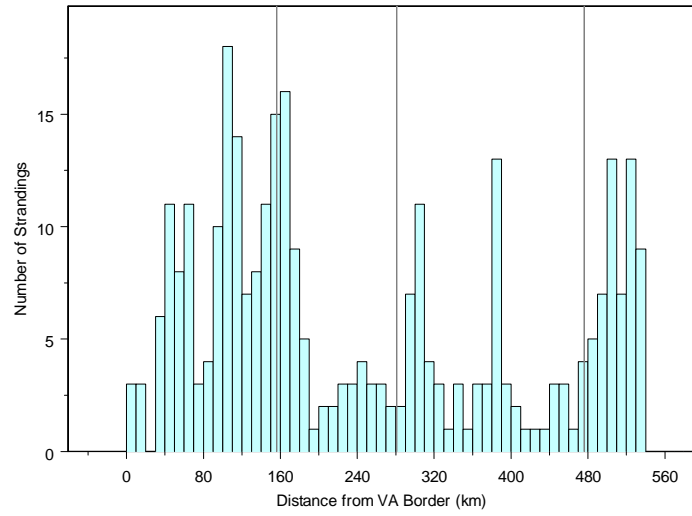
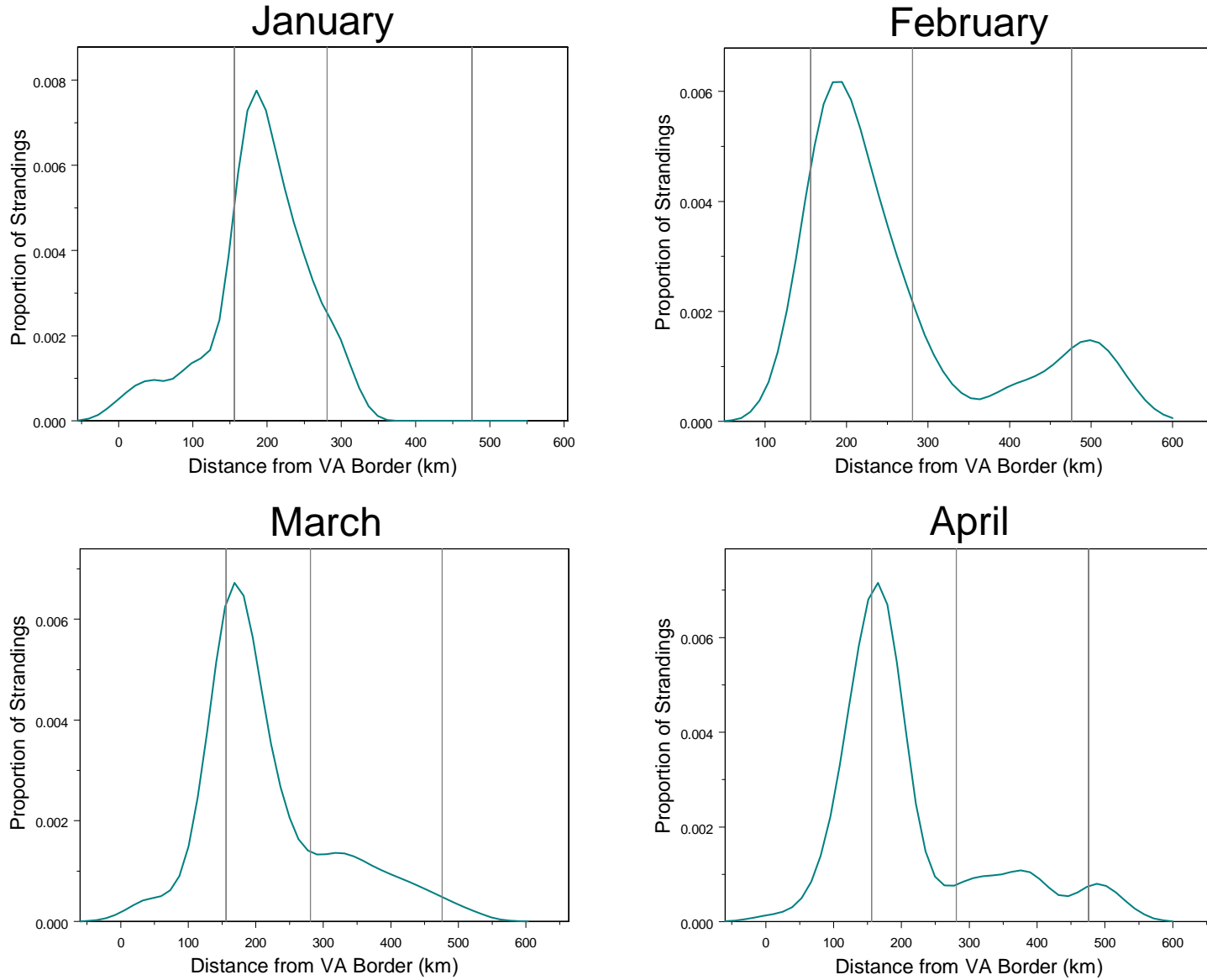
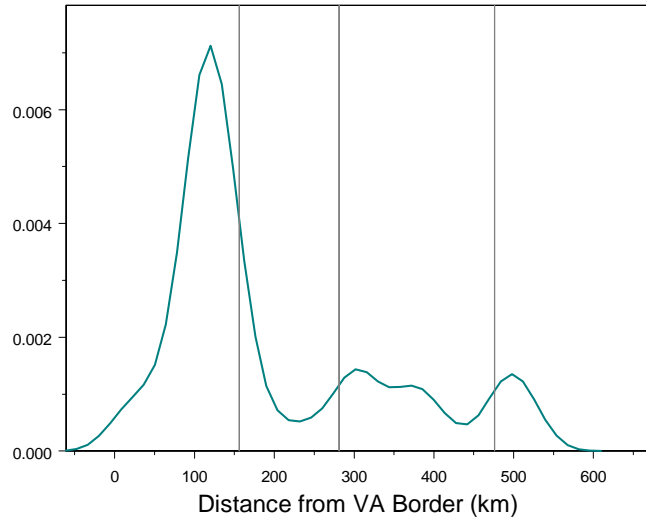


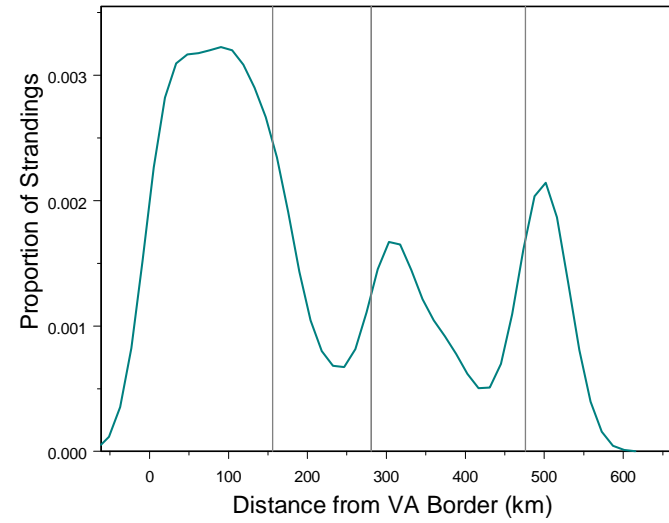
Figure 11 Monthly strandings (1995-2003) as a function of distance from the NC/VA border



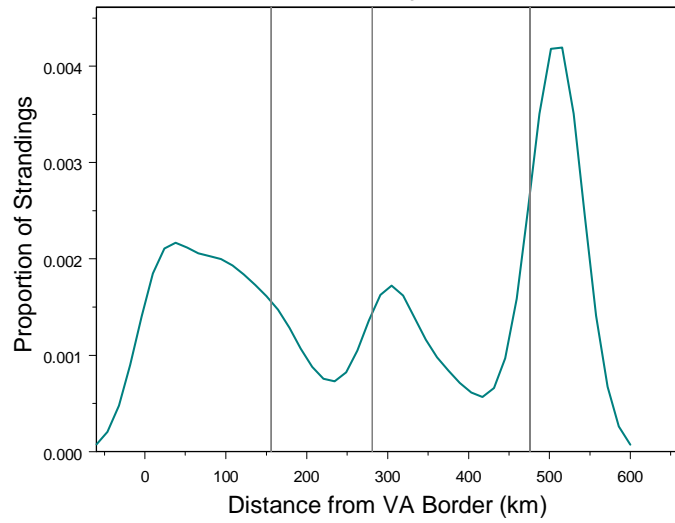
May



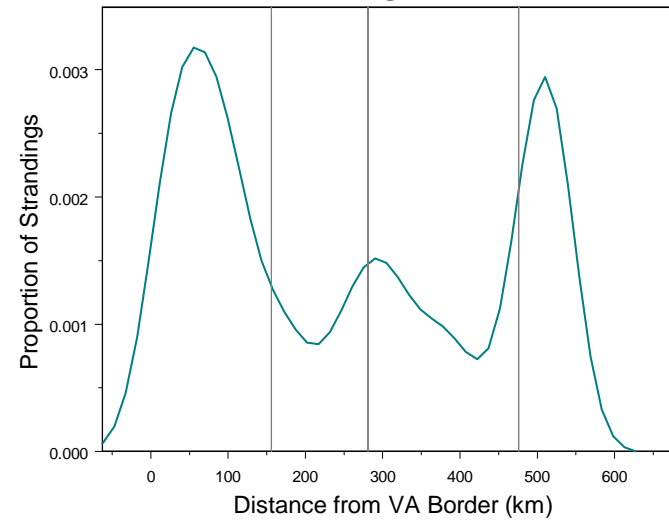
June



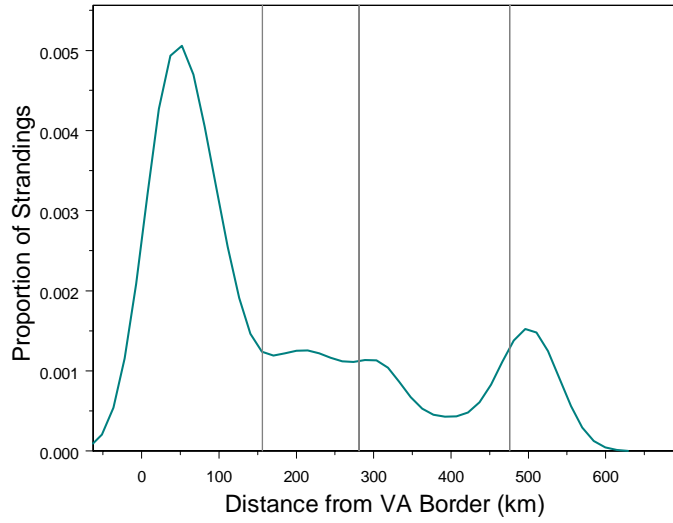
July



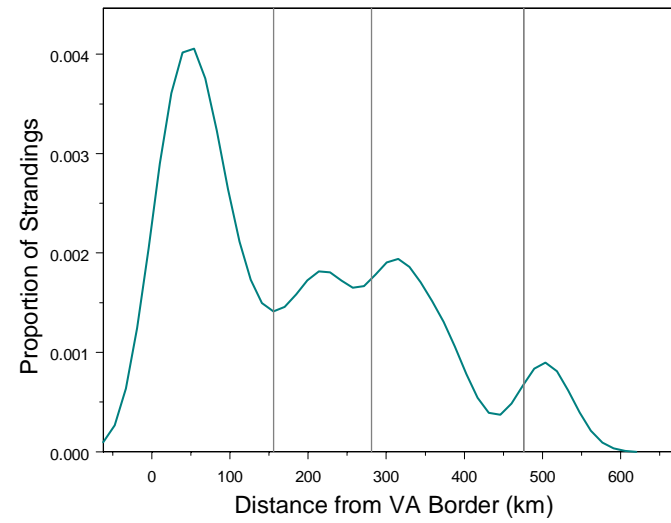
August



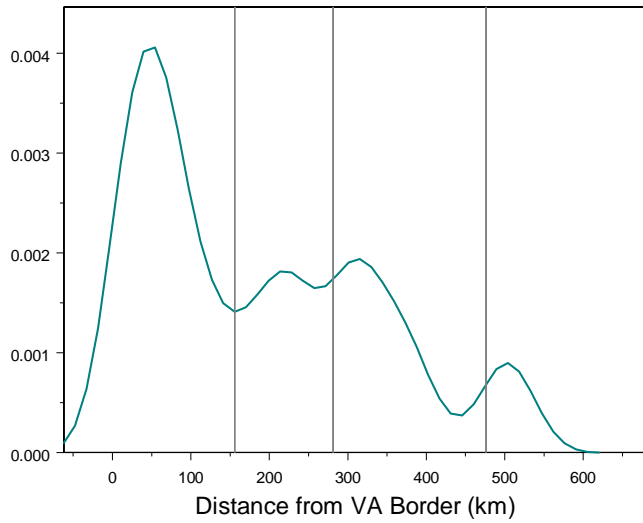
September



October



November



December

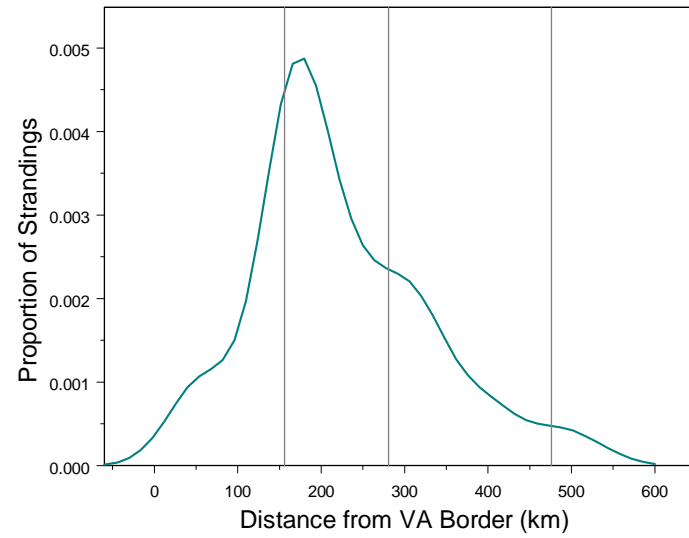


Figure 12 Strandings per km by number of surveys every 14 days for each monitoring group during 2003. Monitoring groups with no formal surveys were given an effort value of 0 and areas of the beach not covered by monitoring groups were labeled “no effort”. Each point represents average number of strandings reported by monitoring group related to number of surveys each group conducts every 2 weeks.

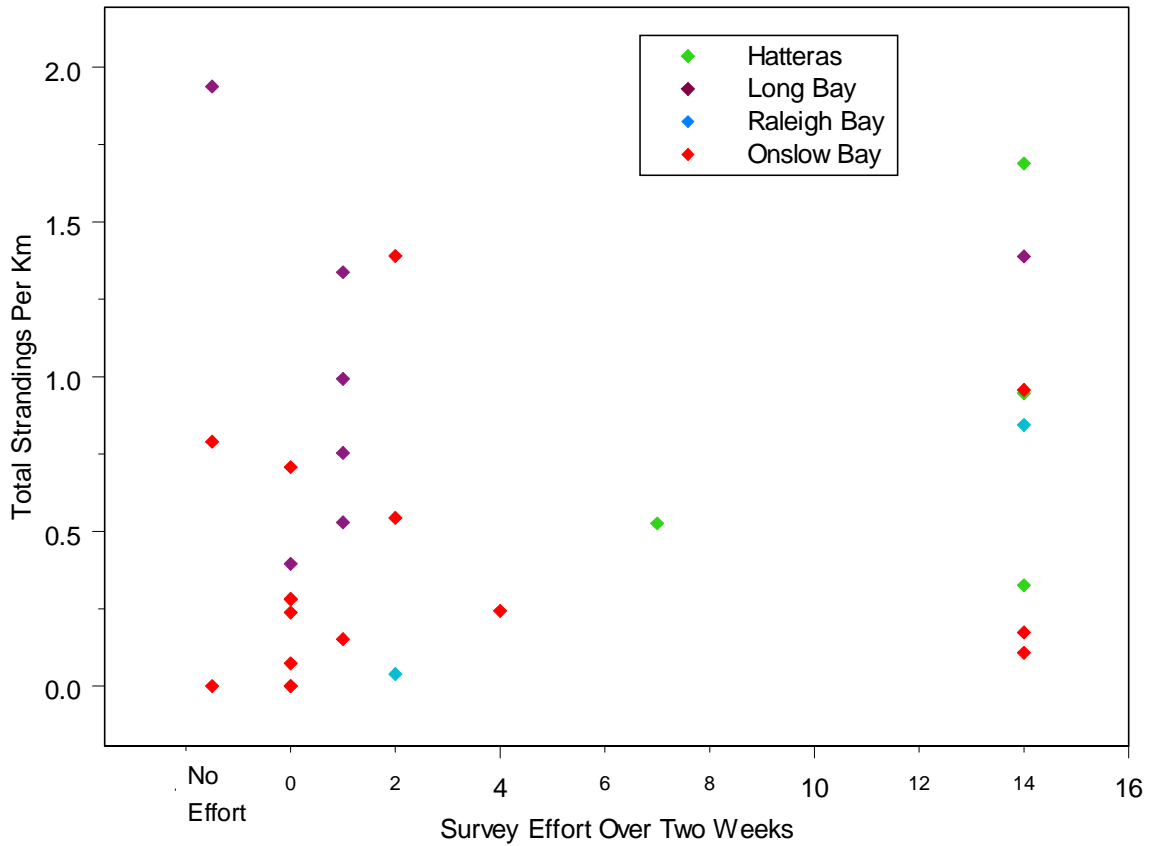


Figure 13 Stranding trends in North Carolina and national nesting trends for loggerheads (TEWG 2000)

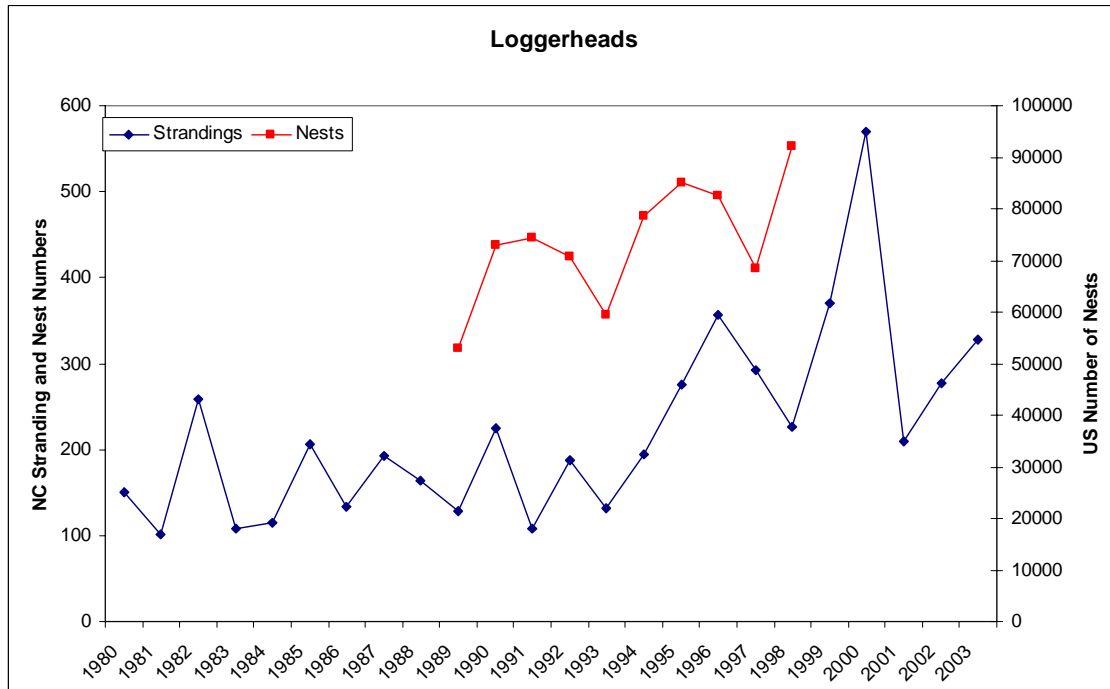
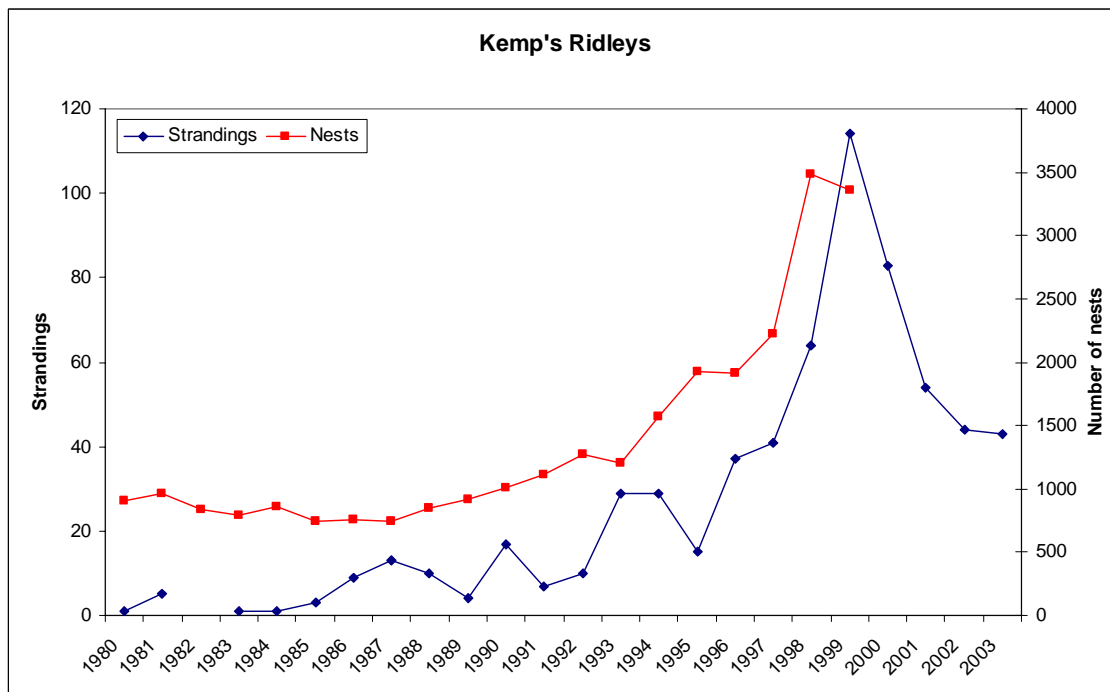


Figure 14 Stranding trends in North Carolina and national nesting trends for Kemp's ridleys (TEWG 2000)



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