A GIS analysis of coastal development and trends in bottlenose dolphin strandings in Charleston, SC: implications for coastal marine spatial planning



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A GIS analysis of coastal development and trends in bottlenose dolphin strandings in Charleston, SC: implications for coastal marine spatial planning

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ABSTRACT

Bottlenose dolphins (*Tursiops truncatus*) inhabit estuarine waters near Charleston, South Carolina (SC) feeding, nursing and socializing. While in these waters, dolphins are exposed to multiple direct and indirect threats such as anthropogenic impacts (egs. harassment with boat traffic and entanglements in fishing gear) and environmental degradation. Bottlenose dolphins are protected under the Marine Mammal Protection Act of 1972.

Over the years, the percentage of strandings in the estuaries has increased in South Carolina and, specifically, recent stranding data shows an increase in strandings occurring in Charleston, SC near areas of residential development. During the same timeframe, Charleston experienced a shift in human population towards the coastline. These two trends, rise in estuarine dolphin strandings and shift in human population, have raised questions on whether the increase in strandings is a result of more detectable strandings being reported, or a true increase in stranding events. Using GIS, the trends in strandings were compared to residential growth, boat permits, fishing permits, and dock permits in Charleston County from 1994-2009. A simple linear regression analysis was performed to determine if there were any significant relationships between strandings, boat permits, commercial fishing permits, and crabpot permits.

The results of this analysis show the stranding trend moves toward Charleston Harbor and adjacent rivers over time which suggests the increase in strandings is related to the strandings becoming more detectable. The statistical analysis shows that the factors that cause human interaction strandings such as boats, commercial fishing, and crabpot line entanglements are not significantly related to strandings further supporting the hypothesis that the increase in strandings are due to increased observations on the water as human coastal population increases

and are not a natural phenomenon. This study has local and potentially regional marine spatial planning implications to protect coastal natural resources, such as the bottlenose dolphin, while balancing coastal development.

INTRODUCTION

Coastal marine spatial planning (CMSP) is not a new idea but recently has become one of 9 core areas outlined by the Interagency Ocean Policy Task Force (IOPTF; 2009). CMSP is an integrated, ecosystem-based process using the best technology and research available to determine the current and future uses of the coasts, oceans, and Great Lakes regions in order to minimize deleterious impacts and maintain sustainability (IOPTF 2009). A recent example of the benefits of MSP involved one of the most endangered whales, the North Atlantic right whale (*Eubalaena glacialis*), and the movement of a shipping lane in Massachusetts (MA). Past research on right whale distribution determined that these animals were sighted frequently in the shipping lane near Cape Cod, MA, increasing the risk of ship collisions. The movement of the shipping lane reduced ship collisions by 58%, while causing minimal delays to ship traffic (IOPTF 2009).

The CMSP can create opportunities and incentives on a local level that can apply to a broader, regional level of similar concerns. Like right whales, bottlenose dolphins (*Tursiops truncatus*) inhabit coastal waters and are subjected to human activities including contaminant runoff, development, boat traffic, fishery operations, and others.

Bottlenose dolphins are distributed throughout the world in temperate and tropical waters (Leatherwood and Reeves 1983). They can be found in harbors, estuaries, and river mouths among other habitats and have two distinct ecotypes, coastal and offshore (Gubbins 2002, Wilson et al. 1997). Some populations of dolphins have limited home ranges and others are migratory (Wilson et al. 1997). Along the east coast of the U.S. there is the coastal migratory stock (CMS) of bottlenose dolphins that range from the Florida Keys to Long Island, New York that comes through Charleston, SC (Zolman 2002). In addition to the CMS present in Charleston

there are also data showing the presence of a small community of year-round residents (Zolman 2002; Speakman et al. 2006). When located near shore, resident populations of dolphins are potentially subjected to anthropogenic habitat alterations and increased human contact (Allen and Read 2000).

Marine Mammals and Human Interaction

In coastal regions bottlenose dolphins are exposed to multiple direct and indirect threats. Threats of concern include: effects of anthropogenic chemicals (Hammond et al. 2008), reduced prey availability due to environmental degradation and overfishing, direct and indirect harassment caused from boat traffic, entanglements in fishery gear, and habitat destruction and degradation (Burdett et al. 2007, Hammond et al. 2008, Wells and Scott 1997).

Due to increased boat usage in coastal areas over the years, there has been growing concern that this will result in more collisions with bottlenose dolphins (Figure 1) (Read 2008, Wells and Scott 1997, Nowacek et al. 2001). During the summer months the threat of dolphins colliding with boats increases significantly. There are several factors that contribute to this trend. First, from late spring through early autumn dolphins tend to shift their daily ranges from deeper coastal waters to shallow inshore waters and narrow channels (Constantine et al. 2004, Wells 1993, Wells and Scott 1997). Second, tourism and major holidays during the summer greatly increase boat traffic (Wells and Scott 1997; Constantine et al. 2004). These factors make bottlenose dolphins more vulnerable to collisions with recreational boats (Wells and Scott 1997).

The increased presence of boats in coastal habitats also alters the bottlenose dolphin behavior by changing dive patterns and distribution (Nowacek et al. 2001; Hastie et al. 2003; Constantine et al. 2004; Lusseau 2005; Nowacek et al. 2007). In fact, Lusseau (2005) suggests that if a habitat becomes too populated with boats, dolphins will completely abandon the habitat

due to increased disturbance and harassment. It is in these waters where dolphins feed and rear calves. The increased presence of boats causes the shallow waters, once a safe haven, to be hazardous.

The threat of entanglement in fishing gear is another hazard to marine mammals, including the bottlenose dolphin. Marine mammals and fisheries (commercial and recreational) directly interact with each other, often occupying similar geographic locations and competing for the same target species (Northridge 1984; Fertl and Leatherwood 1997; Northridge and Hofman 1999; Friedlaender et al. 2001; Burdett et al. 2007). This can lead to marine mammal entanglement in fishing gear or ingestion of fishing gear (Mann et al. 1995; Knowlton and Kraus 2001; Noke and Odell 2002; Burdett and McFee 2004; Burdett et al. 2007) (Figures 2 and 3).

Other threats faced by bottlenose dolphin populations are the indirect threats caused by anthropogenic chemicals and environmental degradation (Hammond et al. 2008). A rise in the reporting of diseases in marine organisms has raised concerns that ocean health is deteriorating (Brouwer et al. 1989; Geraci et al. 1999; Harvell et al. 1999). There is a compelling body of evidence indicating that persistent organic pollutants can affect marine mammal immunity (DeSwart et al. 1994; Ross et al. 1995; Hammond et al. 2005). Schwacke et al. (2002) assessed reproductive risk in bottlenose dolphins and suggested that elevated PCB concentrations increased probabilities of first-born mortalities. Pathogens of terrestrial origin, such as *Toxoplasma gondii*, are causing disease in marine mammals and appear to originate in fresh water run-off (Miller et al. 2002, Stoddard et al. 2008). Thus anthropogenic effects on the ocean may cause an increase in disease outbreaks and deterioration of health in marine mammals (Gulland and Hall 2007).

Bioaccumulation of heavy metals through ingestion of food is also a great concern for the health of bottlenose dolphins (Beck et al. 1997). Metals such as mercury (Hg), cadmium (Cd), and lead (Pb) are toxic, with presence in the water being heavily influenced by anthropogenic run-off (Garcia and Millan 1998, Goyer 1991).

Trends in South Carolina

Prior research on trends in bottlenose dolphin strandings in South Carolina has focused on life history parameters, population distributions, and natural and human-induced mortality rates (McFee and Hopkins-Murphy 2002, McFee et al. 2006, McFee and Burdett 2007). From 1992-96, the mean number of strandings was 30.6/year; mean strandings per year increased to 43.1 during the years 1997-2003 (McFee and Hopkins-Murphy 2002, McFee et al. 2006, McFee and Burdett 2007). Seasonal trends remained consistent between the two data sets, with strandings occurring more often in the spring and less in the winter. Strandings with evidence of human interactions (HI) also increased between the two studies, from a total of 25 during 1992-96 to a total of 36 during 1997-2003. Both studies showed that HI strandings occurred most often during summer months and the main cause of death was fishing gear entanglements (McFee and Hopkins-Murphy 2002, McFee et al. 2006, McFee and Burdett 2007). In the 1992-96 study, 64% of HI cases and in the 1997-2003 study 44% of HI cases were a result of gear entanglements. It is during summer that recreational boating activities increase, thus increasing the likelihood of collisions, dolphin entanglement in fishing gear, and interaction with dolphin-watch tour boats.

Along the South Carolina coast there has been prior research focusing on bottlenose dolphin strandings associated with high tissue levels of contaminants. High levels of mercury have been found in livers of stranded dolphins in South Carolina (Beck et al. 1997). Mercury enters the environment through emissions from runoff, forest fires, and the burning of fossil fuels

and incineration of wastes (Goldwater 1971). High exposure to mercury for dolphins can cause death or lead to reproductive problems (Goldwater 1971). High levels of persistent organochlorines (POC), polybrominated diphenyl ethers (PBDE), perfluoralalkyl compounds (PFC), and other contaminants have been found in dolphins captured alive in the Charleston area (Hansen et al. 2004; Houde et al. 2006; Adams et al. 2008; Houde et al. 2009).

In South Carolina, and many other regions of the United States, there is ongoing research analyzing trends in human population growth. Historically, South Carolina has experienced little growth, but starting in the 1970s urbanization increased dramatically due to immigration (Brown and Wardwell 1980). Over the last two decades, particularly in coastal regions, this trend has accelerated. In the Charleston region from 1973 to 1994 urban land use grew by 256% while the population grew by 41% (BCD COG 1997). By 2030 the projected population growth change for Charleston is expected to be 52.65% with an annual growth rate of 1.46% (Table 1, Figure 4). In addition, the urban area growth change is projected to be 185.64% with an annual growth rate of 5.15% (Table 1, Figure 4).

Urban growth is considered necessary for a sustainable economy, but uncontrolled or sprawling urban growth can lead to consumption of precious land resources such as rural land and marshes (Allen and Lu 2003). The projected population and urban growth in Charleston, SC may lead to more people living near marsh and estuarine areas resulting in more strandings being reported. The increase in population growth may also lead to increased runoff and environmental contamination which can affect a dolphin's immune system (Beck et al. 1997, Allen and Lu 2003).

This study investigated the relationships between dolphin strandings, human population densities, and human interactions near Charleston, SC from 1994-2009. An increase in reported

strandings has occurred near areas of residential development during this time. It is not clear if the increase in strandings is a result of human population shifts toward the coast, resulting in more reported strandings, or if the increase represents a real increase in the number of strandings (eg. emerging diseases, increase in boat collisions, pollution impacts, etc.). This study may have implications for marine spatial planning efforts on a local scale that may be applied statewide or regionally.

METHODS

Stranding and Data Collection

Stranding data were collected by researchers at the National Oceanic and Atmospheric Administration (NOAA), Charleston, SC from 1994 to December 31, 2009. These data included: Species, Sex, Length, Location, Date, Season, Body Condition Code (1,2,3,4 or 5 with 1 being alive and 5 mummified), Human Interaction (Yes, No or Could Not Be Determined), Human Interaction Type (Crab pot, Gillnet, Boat Strike), Latitude, and Longitude. Stranded animals were also categorized as having been stranded in an estuary (estuarine) or on the front beach of barrier islands (beach). The GPS coordinates for each stranding were recorded in decimal degrees (DD). The time frame began in 1994 when stranding data were collected more thoroughly and on a consistent basis. Basic stranding demographics were initially divided into three sets: 1) mean strandings per year of all species that stranded in SC; 2) mean strandings per year of bottlenose dolphins in SC; 3) and mean strandings per year of bottlenose dolphins in Charleston County, SC. These means were used for two time frames: 1994 to 2001 and 2002 to 2009. The analysis was repeated for animals involved with a human interaction.

Boat registration data were collected through a Freedom of Information Act (FOIA) request to the South Carolina Department of Natural Resource (SCDNR). SCDNR was able to provide boat licensing data from 2002 to 2009 for Charleston County. The data included were year, county, and number of boat registrations.

Fishing license data were collected through a FOIA request to SCDNR. SCDNR was able to provide commercial (2002-2009) and recreational fishing licenses (2006-2009) for Charleston County. These data included year and number of commercial licenses and number of recreational licenses. Recreational fishing license data only went back to 2006 due to a recent purge in the SCDNR system under the SCDNR Document Retention Policy.

Dock permitting data were collected under a FOIA request to the Ocean and Coastal Resource Management (OCRM). These data were requested for GIS use and thus OCRM provided the data as a feature class for the years 1994 to 2009 for Charleston County. The data were a point feature class. Each point represented a residency that obtained a dock permit for a designated year between 1994 and 2009.

Residential data were collected from the Santee Cooper GIS Laboratory in downtown Charleston. These data were parcel data with a joined table. The table included a specific field for year built that allowed parcels to be shown by the year houses were built. The years ranged from 1994 to 2009 for Charleston County. These data were in polygon feature class form.

The time frame from 1994 to 2009 was divided into four year intervals: 1994-1997, 1998-2001, 2002-2005, and 2006-2009. This allowed trends to be observed at equal intervals and to be more noticeable.

GIS Mapping

All data for this project used ArcGIS Software 9.3 (ESRI, Redlands, CA, USA). In addition all data used for the maps used the geographic coordinate system set to North American Datum 1983 and their projected coordinate system set to NAD UTM Zone 17N. Both the stranding data and dock permitting data were divided into the four year intervals. Each four year interval was then added to ArcMap using their coordinates to plot the locations. Both stranding and dock permitting data were then exported out of ArcMap into a geodatabase as a point feature class.

The general stranding maps consist of a base map of the South Carolina shoreline, obtained from the United States Geological Survey (USGS), zoomed in on Charleston. The stranding data were converted to point density data using kernel density located in the spatial analyst tools in the ArcMap toolbox. The kernel density data were set showing the density of strandings per square meter with a 6 km search radius. The symbology for the kernel density layer for each four year interval was set to the minimum-maximum type and the background value was set to equal zero.

The dock permitting maps were created using a South Carolina base map obtained from NOAA's Center for Coastal Environmental Health and Biomolecular Research (CCEHBR). The dock permitting point data were converted to point density raster datasets using kernel density, and was set with density showing docks per square meter with a 6 km search radius. The symbology was set the same way as the stranding density datasets were set. The dock permit densities are set to show cumulative growth. Stranding point data for each year interval were then overlayed on top of the dock density datasets with corresponding year intervals.

There were two sets of residential growth maps. The first map used the South Carolina base map from USGS. The parcel data contains information on when homes were built and these data were used to show residential growth. However the data contains homes built ranging from 1690 to 2009. Only homes built from 1994-2009 are shown on the maps. Homes built outside the time frame shown on the maps were removed from the symbology tab under layer properties and the remaining years were grouped. The residential growth data show cumulative growth from 1994 to 2009. These data were then overlayed on top of the South Carolina base map and the stranding densities for the corresponding year interval were added. The second set of residential maps was created in case trends on the first set were not noticeable. The parcel data used for the first set were converted to points. These points were then converted to density rasters and then classified under the symbology tab. These data were then overlayed on top of the South Carolina base map and stranding densities for the corresponding year interval were added.

Statistical maps were created using the raster datasets for strandings, dock permits, and residential growth. The raster datasets were classified under the symbology tab to standard deviation. The classified raster datasets for dock permits and residential growth were each overlayed on top of the classified raster datasets for strandings. These data were then overlayed on top of the South Carolina base map.

Statistical Methods

The spatial statistics for strandings, dock permit growth and residential growth were created in ArcMap to show the standard deviations. Standard Deviation is a measure of dispersion of a set of data from its mean (Ramsey and Schafer 2002). The more spread apart the data, the higher the deviation. In order to map the spatial statistics for strandings, dock permit growth, and residential growth, to show the significance of the trends, only data greater than the

standard deviation were shown. This resulted in maps showing trends that were outside the normal occurrences making them more significant. When the most significant regions for each dataset intersect they create a dark purple color that shows the overall most significant region.

A Pearson correlation analysis was performed to determine if any of the factors that would be used in the regression analysis were strongly correlated with one another. If two factors were strongly correlated, then having both present for the regression analysis at the same time would give inaccurate results. The correlation analysis gives the Pearson correlation and the p-value for each comparison. The Pearson correlation ranges from -1 to 1 where a value of 1 implies a linear relationship, or strong correlation and a -1 implies an inverse linear relationship where the Y factor decreases as X increases (Ramsey and Schafer 2002). Having a Pearson correlation of 0 implies that there is no correlation between the two factors (Ramsey and Schafer 2002). A p-value less than 0.05 was considered significant.

A multiple linear regression model was then used for the analysis. Recreational fishing was left out of the statistical analysis because it only went as far back as 2006, whereas the boat data, commercial fishing data and crab pot permit data go back to 2002. If recreational fishing was included, the analysis could only go as far back as 2006 for all data (only four years), which is not enough data for a thorough statistical analysis. Including these data would impact the results of the analysis.

Another Pearson correlation analysis was performed to determine if there were any correlations between strandings, human interaction strandings (HI), boats, commercial fishing, recreational fishing and crabpot permits for Charleston County. A multiple linear regression model was then constructed to investigate the relationship between strandings, boats, commercial fishing, and crabpot permits for Charleston County from 2002-2009. A multiple linear regression

model was also constructed to examine the relationship between HI strandings, boats, commercial fishing, and crabpot permits in Charleston County from 2002-2009. A second correlation analysis was performed to see if there were any correlations between total strandings, total crabpots, and total HI strandings. A multiple linear regression model was then constructed to investigate the relationship between total strandings and total crabpot permits from 2002-2009. A fourth multiple linear regression model was constructed to examine the relationship between total HI strandings and total crabpot permits from 2002-2009. Total strandings, total crabpot permits and total HI strandings are referring to data that is state wide and not just in Charleston County.

Stranding Graphs

Basic stranding graphs were created to show trends in strandings, HI strandings, commercial fishing, crabpot permits, and boat licenses. These graphs show strandings in Charleston versus total strandings in the corresponding year intervals as well as annually; HI strandings in Charleston versus total HI strandings in the corresponding year intervals as well as annually; total crabpot permits versus total strandings annually from 2002 to 2009; crabpot permits versus strandings in Charleston annually from 2002 to 2009; trends in Charleston commercial fishing licenses from 2002 to 2009; and trends in Charleston boat licenses from 2002 to 2009.

RESULTS

GIS Analysis

The stranding analysis in Figure 5 shows that from 1994 to 1997 the area around Sullivan's Island (southeast of peninsula) had the most strandings. From 1998 to 2001 the

densest areas of strandings remained around Sullivan's Island, but also extended to the Isle of Palms (east of peninsula) area as well as near Seabrook Island (southwest of peninsula). From 2002 to 2005 the densest area of strandings moved towards Charleston Harbor and up into the Ashley (northwest of peninsula), Cooper, and Wando Rivers. There also was a high density near Kiawah Island (southwest of peninsula). From 2006 to 2009 high density continued to move into the Charleston Harbor. There also was a high density of strandings near Folly Beach (south of peninsula) (aka Stono River Estuary) and Seabrook Island.

The trends in dock permitting versus strandings in Figure 6 show that from 1994 to 1997 the densest areas for docks were located in the Wando River (northeast of peninsula), Charleston Harbor, Sullivan's Island and Isle of Palms. There was also a high density of docks in the Stono River Estuary near Folly Beach. From 1998 to 2001 the densest areas for docks remained in the Wando River and the Stono River Estuary near Folly Beach. There is an increased number of strandings occurring up the Cooper River (north of peninsula), the Stono River Estuary, and in the Charleston Harbor (Figures 5, 6). From 2002 to 2005 a high number of docks remained in the Wando River with the Stono River Estuary and Charleston Harbor increasing. From 2006 to 2009 high dock densities increased in the Charleston Harbor, as well as near Isle of Palms, Wadmalaw Island (west of peninsula), Stono River Estuary and up the Wando River.

The residential growth maps (Figures 7, 8) show that the greatest residential growth from 1994 to 1997 is located in the Mt. Pleasant area followed by James Island (south of peninsula) and the West Ashley area. The greatest residential growth from 1998 to 2001 remained in the Mt. Pleasant area followed by James Island and the West Ashley area. From 2002 to 2005 residential growth remained highest in Mt. Pleasant but was also high in West Ashley and James

Island. Residential growth also increased in the Goose Creek area (north of peninsula). From 2006 to 2009 residential growth remained highest in Mt. Pleasant, with Johns Island (southwest of the peninsula) showing growth as well. West Ashley and James Island also increased in residential growth.

The maps comparing the significance between strandings and docks show that from 1994 to 1997 strong correlations exist in locations near Sullivan's Island, Isle of Palms and the Stono River Estuary near Folly Beach (Figure 9). From 1998 to 2001 the most significant regions for both docks and strandings were located near Sullivan's Island, Isle of Palms, the Stono River Estuary near Folly Beach, and near Seabrook Island. The most significant regions for both docks and strandings from 2002 to 2005 were located in the Charleston Harbor, Sullivan's Island, parts of the Stono River Estuary near Folly Beach, and near Seabrook Island. From 2006 to 2009 the most significant regions for both docks and strandings were in the Charleston Harbor, parts of the Stono River Estuary near Folly Beach, Isle of Palms, Sullivan's Island, and a small region near Seabrook Island.

The statistical maps comparing strandings and residential growth show that from 1994 to 1997 strong correlations exist in locations near Sullivan's Island, Isle of Palms, and the Stono River Estuary near Folly Beach (Figure 10). From 1998 to 2001 the most significant regions were located near the Stono River Estuary, Sullivan's Island and Isle of Palms. The most significant regions for strandings and residential growth from 2002 to 2005 were located on James Island, Mt. Pleasant, and Sullivan's Island. From 2006 to 2009 the most significant regions were located in the Charleston Harbor, Sullivan's Island, and James Island.

Spatial Statistical Analysis

The spatial statistics for strandings, dock permit growth and residential growth were mapped to show data greater than the standard deviation. The standard deviations for strandings are: 0.01867 for 1994-1997, 0.02399 for 1998-2001, 0.01934 for 2002-2005, and 0.01812 for 2006-2009 (Figure 9). The standard deviations for dock permits are: 0.37574 for 1994-1997, 0.83335 for 1998-2001, 1.46581 for 2002-2005, and 1.46581 for 2006-2009 (Figure 9). The standard deviations for residential growth are: 2.76541 for 1994-1997, 6.43772 for 1998-2001, 10.09907 for 2002-2005, and 11.12970 for 2006-2009 (Figure 10).

Pearson correlation analysis and associated p-values for multiple comparisons among strandings, HI strandings, boat licenses, commercial fishing licenses, recreational fishing licenses, and crab pot licenses for both Charleston County and South Carolina as a whole can be found in Table 2. There was no significant relationship between strandings and boat licenses ($p=0.689$), strandings and commercial fishing licenses ($p=0.672$), or strandings and crabpot permits ($p=0.411$). There was no significant relationship between HI strandings and boat licenses ($p=0.377$), HI strandings and commercial fishing ($p=0.407$), or HI strandings and crabpot permits ($p=0.226$). Likewise there was no significant relationship between total strandings and total crabpot permits ($p=0.624$) and total HI strandings and total crabpot permits ($p=0.147$).

Stranding Analysis

From 1994 to 2009, 638 bottlenose dolphin strandings were recorded in South Carolina. Of these, 332 were recorded in Charleston County. In Charleston County, from 1994 to 1997, 37.2% of the bottlenose dolphin strandings occurred in the estuaries and from 1998 to 2001, 38.0% occurred in the estuaries. Those percentages increased dramatically for the time periods of 2002 to 2005 (51.3%) and 2006 to 2009 (51.8%).

Total strandings in South Carolina and strandings in Charleston follow similar trends over the four year intervals (Figure 11). The lowest number of strandings occurs from 1994 to 1997 while the highest number occurs from 1998 to 2001. Annual trends of total strandings in South Carolina versus strandings in Charleston follow similar trends (Figure 12).

Figure 13 shows the total HI for South Carolina strandings versus HI strandings in Charleston divided into the four year intervals. The highest number of total HI strandings appears to be in both the 1998-2001 and the 2002-2005 intervals. The highest number of HI strandings in Charleston occurs in the 1998-2001 interval. The lowest number of total HI strandings occurs from 1994 to 1997 while for the HI strandings in Charleston the lowest occur from 2002 to 2005. Figure 14 shows the total HI strandings versus HI strandings in Charleston annually with the peak number of strandings for both being in 1997 and the lowest being in 2007.

Figure 15 shows the total crabpot permits versus total strandings from 2002 to 2009. The highest number of crabpot permits is in 2004 while the highest number of strandings is in 2007. The lowest number of crabpot permits is in 2008 while the lowest number of strandings is in 2002. Figure 16 shows the trends in crabpot permits in Charleston versus trends in strandings in Charleston from 2002 to 2009. The highest number of crabpot permits is in 2005 while the highest number of strandings is in 2009. The lowest number of crabpot permits is in 2008 while the lowest number of strandings is in 2005.

Figure 17 shows the trends in commercial fishing licenses in Charleston County from 2002 to 2009. The trend shows that there is a steady decline of commercial fishing licenses until 2008 where licenses begin to rise. The peak number of commercial fishing license is in 2002 while the lowest is in 2006.

Figure 18 shows the trends in boat licenses in Charleston County from 2002 to 2009. The trend shows a steady rise in boat licenses from 2002 to 2007 with the peak being in 2007. The trend makes a sharp decline for 2008 and rises again in 2009. The lowest number of boat licenses occurred in 2002.

DISCUSSION

While the total number of reported strandings in South Carolina has declined since 2001, recent stranding data (since 2001) shows an increase in strandings occurring near areas of increasing residential development in Charleston, SC. Reports of strandings in Charleston estuaries increased nearly 50% in the last eight years of this study. It is not clear if the increase in strandings in estuaries is a result of human population shifts toward the coast, resulting in more detectable strandings, or if the increase represents a real phenomenon. This project served as a tool to evaluate the trends in strandings in relation to changes in residential growth and dock permitting in Charleston County from 1994-2009. The results of this project will be useful in detecting shifts in strandings in relation to increased coastal development.

Stranding Trends

The stranding trends from 1994 to 2009 clearly show increased stranding density moving into the Charleston Harbor and the Stono River Estuary (Figure 5). This may suggest that the increase in strandings is due to an increase in people living on the coast and more chance for observations. Based on the trends in Figure 6, dock growth is focused up the Wando River, Charleston Harbor, and the Stono River Estuary near Folly Beach. The dock growth appears to grow in the Charleston Harbor over the four year intervals and in the 2006 to 2009 year interval the Charleston Harbor seems to be the densest in docks. At the same time the stranding trend

seems to gradually move into the Charleston Harbor and the Stono River Estuary. The number of people living in South Carolina estuaries has increased over the years due to land located in these areas being highly valued as sites for homes (Cofer-Schabica et al. 1999, Miller 1993). This increase in residence has also led to an increase number of requests for dock permits (NOAA 2001). An increase in docks present in these habitats can potentially lead to more people overlooking the waters and increase the chance of spotting a stranding that in the past would not have been seen.

An increase in docks can also provide easier boat access to the harbor, resulting in an increase in boat traffic and human interaction with dolphins. Two key elements in the CMSP process are to 1) engage stakeholders and the public during the CMSP process and 2) consult scientists and/or experts (IOPTF 2009). City planners should not only bring the stakeholders to the table when assessing dock needs and construction of new boat landings but also should bring scientists in on the process who are familiar with wildlife issues. For instance, the NOAA facility in Charleston has been conducting marine mammal stranding assessments since at least 1993 (McFee et al. 2006) and photo-identification/population assessments on bottlenose dolphins in the Charleston Estuary since 1994 (Speakman et al. 2006). This would ensure support and cooperation throughout the development, implementation, and evaluation phases of a coastal marine spatial plan so that a determination of how these estuaries can be sustainably used and protected in the future (IOPTF 2009).

The residential growth trends show that the Mt. Pleasant area remains fairly high in residential growth relative to other areas in Charleston County and appears to slowly grow from 1994 to 2009 (Figures 7,8). James Island and Johns Island also seems to have increased residential growth occurring from 1994 to 2009. Mt. Pleasant and James Island surround the

Charleston Harbor where the stranding density is moving. The increase in residential growth, specifically in marsh front acreage, suggests that there may be more opportunity to detect strandings, as well as the possible increase in human interaction with dolphins.

Statistical maps were created for docks and residential growth to see if the trends between them and strandings were significant (Figures 9, 10). The most significant regions for both docks and strandings are the Charleston Harbor and Stono River Estuary. The trend remained stagnant around the Stono River Estuary except during the 2002-2005 interval where dock permitting may have decreased. However the trends for both docks and strandings are increasing into the Harbor and up into the rivers surrounding Charleston. This suggests that the dock permitting trend and stranding trend correlate in the Charleston Harbor.

Residential growth and strandings trends move from the Stono River Estuary and Sullivan's Island areas towards the Harbor along the James Island side and Mt. Pleasant side. This suggests that both residential development and stranding density are gradually increasing in the Charleston Harbor.

Allen and Lu (2003) and Campbell et al. (2001) show projected population growth up to the year 2030 based on current population trends. Table 1 shows the projected population growth change from 1994 to 2030 to be 52.65% with an annual growth rate of 1.46%. The projected urban area growth change is expected to be 185.64% with an annual growth rate of 5.15%. These data show that Charleston is expected to continue growing in population density and urban development. With stranding density trends moving into the Charleston Harbor, the projected increase in population and development along the coast may lead to an increase in sightings thus causing strandings to show an overall increase.

The results of this study show that the stranding trend moves toward the Charleston Harbor over time and suggest that the increase in strandings is related to an increase in population and residential growth on the coast leading to strandings becoming more detectable. This suggests that more people are living in the areas where strandings occurred. The significance of docks can also suggest that boats have easier access to open waters which can increase the chance of human interaction. The factors that cause human interaction strandings such as boats, commercial fishing, and crab pot licenses are not significantly related to strandings, further supporting the hypothesis that the increase in strandings is due to increased opportunities for observations on the water and are not a natural phenomenon.

HI Significance

Boat strikes, crabpot line entanglements, and other fishing gear related interactions are some of the main causes of HI strandings (Burdett and McFee 2004, Burdett et al. 2007, Fertl and Leatherwood 1997, Friedlaender et al. 2001, Knowlton and Kraus 2001, Mann et al. 1995, Noke and Odell 2002, Northridge and Hoffman 1999, Read 2008, Wells et al. 1998). Neither the correlation analyses nor multiple regression analyses showed any significant relationships between boat, commercial fishing, and crabpot licenses with strandings and HI strandings. This non-linear relationship supports the conclusion that the stranding trends are not a natural phenomenon, nor due to increased HI deaths.

In addition, Figures 11 and 12 show that strandings in Charleston are following a similar trend to strandings statewide. Figures 13 and 14 also show that HI strandings in Charleston are following a similar trend to HI strandings statewide. These graphs point out that any noticeable increase in strandings in the Charleston area may not be an isolated occurrence but may be a statewide trend. Population growth is expected to increase in Charleston and South Carolina's

population is expected to increase on average 40,000 a year through 2025 (EPA 2008). Knowing the stranding and population trends are similar on a local and statewide level can help determine the causes of increased strandings and improve the CMSP process and marine mammal management.

Figures 17 and 18 show the trends in Charleston commercial fishing licenses and Charleston boat licenses starting to increase in 2009. If this trend continues, it may lead to potential problems with increased strandings due to human interaction. However, based on our results, the increase in strandings in the estuaries may still be due to the increased coastal development and subsequent increase in human population density in coastal areas that will allow for more observations in the creeks, rivers, and embayments.

Marine Spatial Planning Implications

Bottlenose dolphins that live in a coastal habitat face disturbance from and interaction with human activities. This study showed that the detection of strandings in the estuaries increased as the human population and coastal development has increased in the Charleston Estuarine System (CES). We can project that at the current rate of coastal development in the estuaries more strandings will become detectable, thus increasing the pressure on stranding personnel to respond. This could be troublesome with dwindling budgets and reduced staff. Marine mammal strandings are high profile occurrences that generate public and media attention in South Carolina and other regions of the coastal U.S. Proper funding and appropriate staff levels will be necessary in the future to respond to the growing questions by the public and media on marine mammal mortality and to continue to use marine mammals as sentinels of our coastal oceans.

With increased development in the estuaries we are likely to see shifts in habitat preference due to increased siltation rates that may cause prey shifts and loss of habitat. This, in turn, could result in competition with humans for food resources as recreational fisheries (e.g., hook/line, crabpot) increase (Wells et al. 2008).

With increased development comes the need to pave roads in new subdivisions that add contaminants to the estuaries through stormwater runoff. Similarly, the increased use of fertilizers and pesticides for residential lawns and pests may increase in the estuaries. This increasing contaminant load into the system could affect growth and reproductive fecundity of resident bottlenose dolphins. Previous studies on captured dolphins in the CES were shown to contain high persistent organic pollutants (Schwacke et al. 2002; Houde et al. 2005a), polybrominated diphenyl ethers (Fair et al. 2007; Houde et al. 2009), triclosan (Fair et al. 2010), and polyfluoroalkyl compounds (Houde et al. 2005b). Some of these contaminants are known to affect immune function, growth, and reproduction.

While this study identifies the need to develop marine spatial planning mitigation strategies only in Charleston County, SC, the increased human population growth and development in other estuaries in SC, and in the southeastern U.S., will undoubtedly require mitigation strategies to protect our coastal natural resources.

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Tables

Table 1. Summary of predicted urban growth in the Charleston region from 1994 to 2030 (Allen and Lu 2003).

Items	BCD Region	Berkeley	Charleston	Dorchester
Population Growth				
Population 1994 (in person)	532,688	138,776	307,468	86,444
Population 2030 (in person)	795,879	200,000	469,346	126,533
Net Growth	263,211	161,224	161,878	40,089
Change	+49.41%	+44.12%	+52.65%	+46.38%
Annual Growth Rate	+1.37%	+1.23%	+1.46%	+1.29%
Urban Area Growth				
Urban Area 1994 ($mile^2$)	250.07	81.61	126.50	41.96
Urban Area 2030 ($mile^2$)	867.60	306.41	361.33	199.86
Net Growth	603.53	224.80	234.83	157.90
Change	+246.94%	+275.46%	+185.64%	+376.31%
Annual Growth Rate	+6.85%	+7.65	+5.15%	+10.45%
Population vs. Urban Area				
Population Density 1994 (person/ $mile^2$)	2030	1700	2431	2060
Population Density 2030 (person/ $mile^2$)	917	652	1299	633
Change	-54.83%	-61.65%	-46.57%	-69.27%
Per Capita Urban Area 1994 (acres)	0.30	0.38	0.26	0.31
Per Capita Urban Area 2030 (acres)	0.70	0.98	0.49	1.01
Change	+133.33%	+158.03%	+88.46%	+225.81%
Sprawl Index (growth ratio)	5:1	6.24:1	3.53:1	8.11:1

Table 2. Pearson correlations and associated p-values for strandings and various license data for Charleston County and South Carolina.

	Comparison	Pearson Correlation	p-value
Charleston County			
	Strandings vs. boat licenses	0.021	0.960
	Strandings vs. HI strandings	-0.216	0.607
	Strandings vs. commercial fishing licenses	-0.104	0.806
	Strandings vs. recreational fishing licenses	0.395	0.605
	Strandings vs. crab pot licenses	-0.376	0.358
	HI strandings vs. boat licenses	-0.137	0.746
	HI strandings vs. commercial fishing licenses	0.128	0.763
	HI strandings vs. recreational fishing licenses	-0.595	0.405
	HI strandings vs. crab pot licenses	0.431	0.287
	Boat licenses vs. commercial fishing licenses	-0.676	0.066
	Boat licenses vs. recreational fishing licenses	-0.711	0.289
	Boat licenses vs. crab pot licenses	0.069	0.810
	Commercial fishing licenses vs. recreational fishing licenses	0.671	0.329
	Commercial fishing licenses vs. crab pot licenses	0.473	0.237
	Recreational fishing licenses vs. crab pot licenses	-0.493	0.507
South Carolina			
	Strandings vs. crab pot licenses	-0.206	0.624
	HI strandings vs. crab pot licenses	0.562	0.147
	Strandings vs. HI strandings	0.007	0.988

Figures

Figure 1. Bottlenose dolphin showing propeller wounds after being struck by a boat.

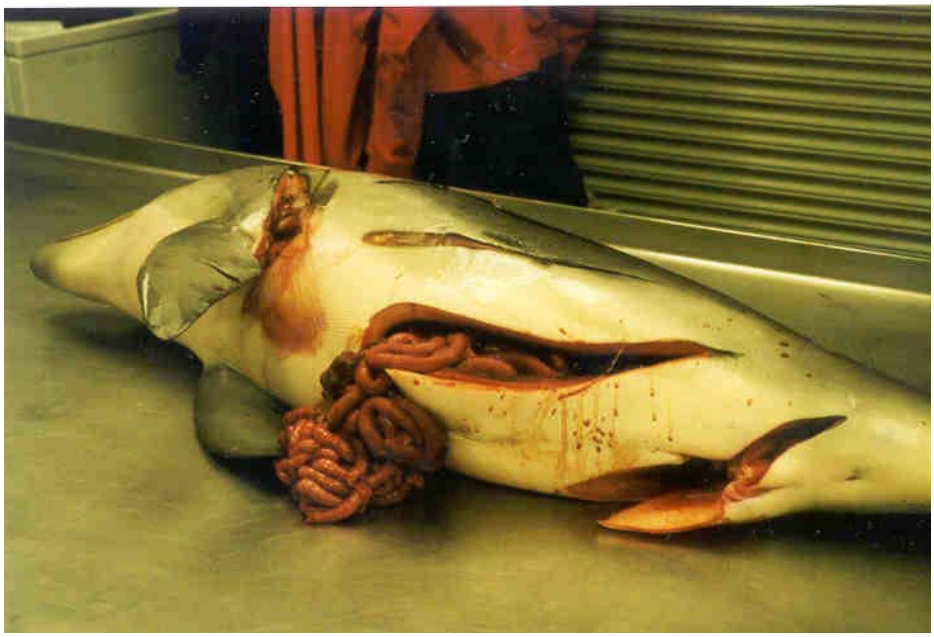


Figure 2. Bottlenose dolphin with evidence of fishing line entanglement around tail.



Figure 3. Beaked whale with hook and line in lower jaw.

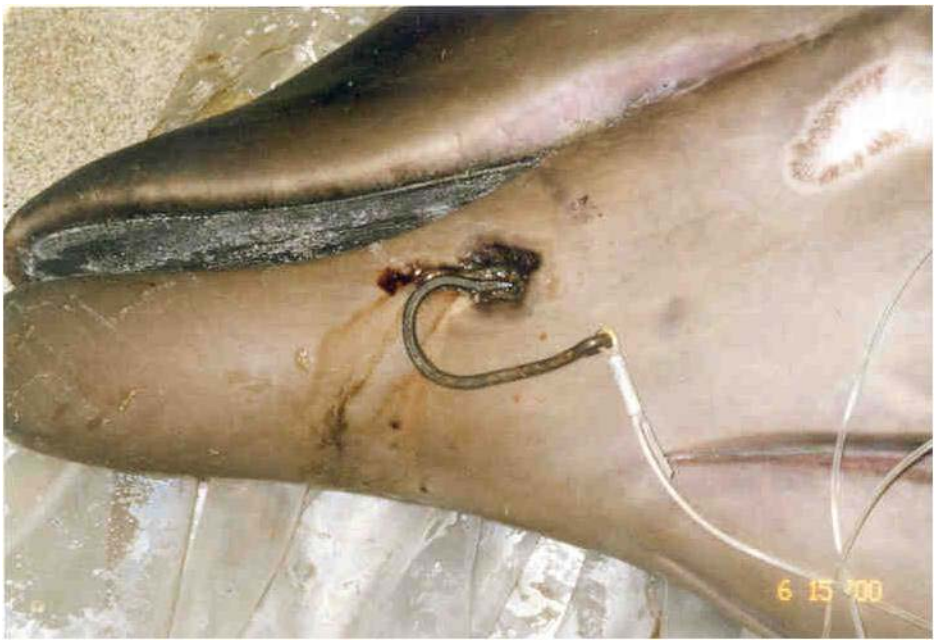


Figure 4. Projected population growth for Charleston, SC (Allen and Lu 2003).

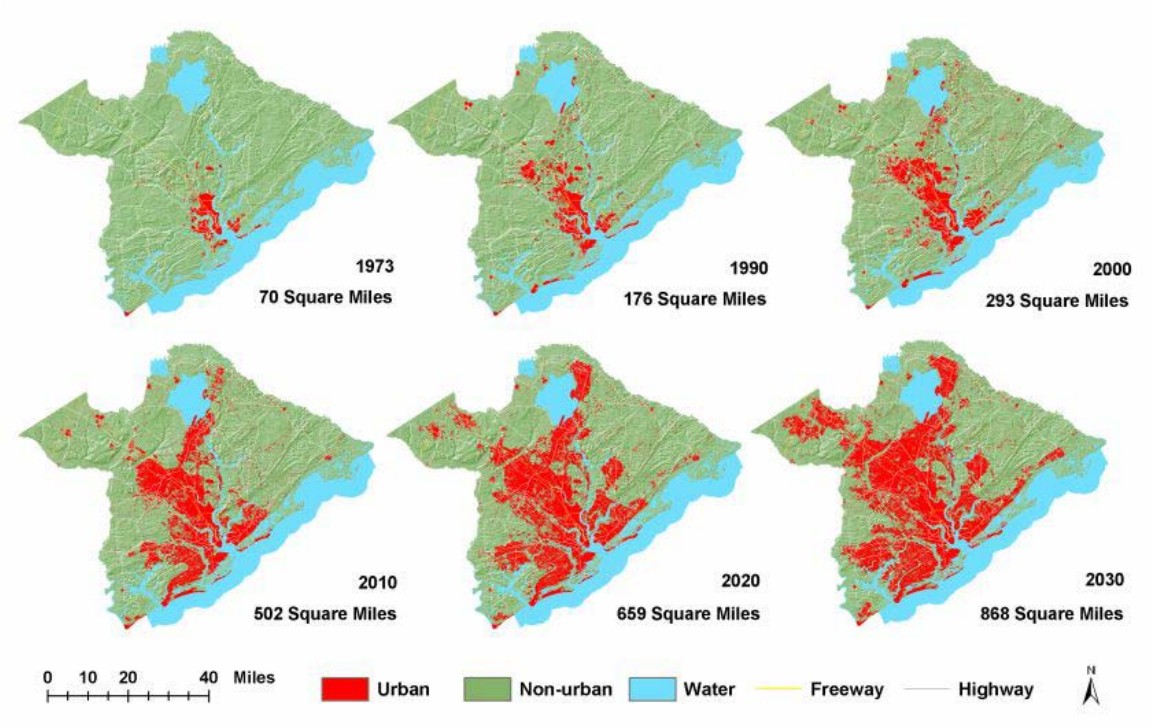


Figure 5. Trends in stranding density in Charleston County divided into four year intervals from 1994-2009.

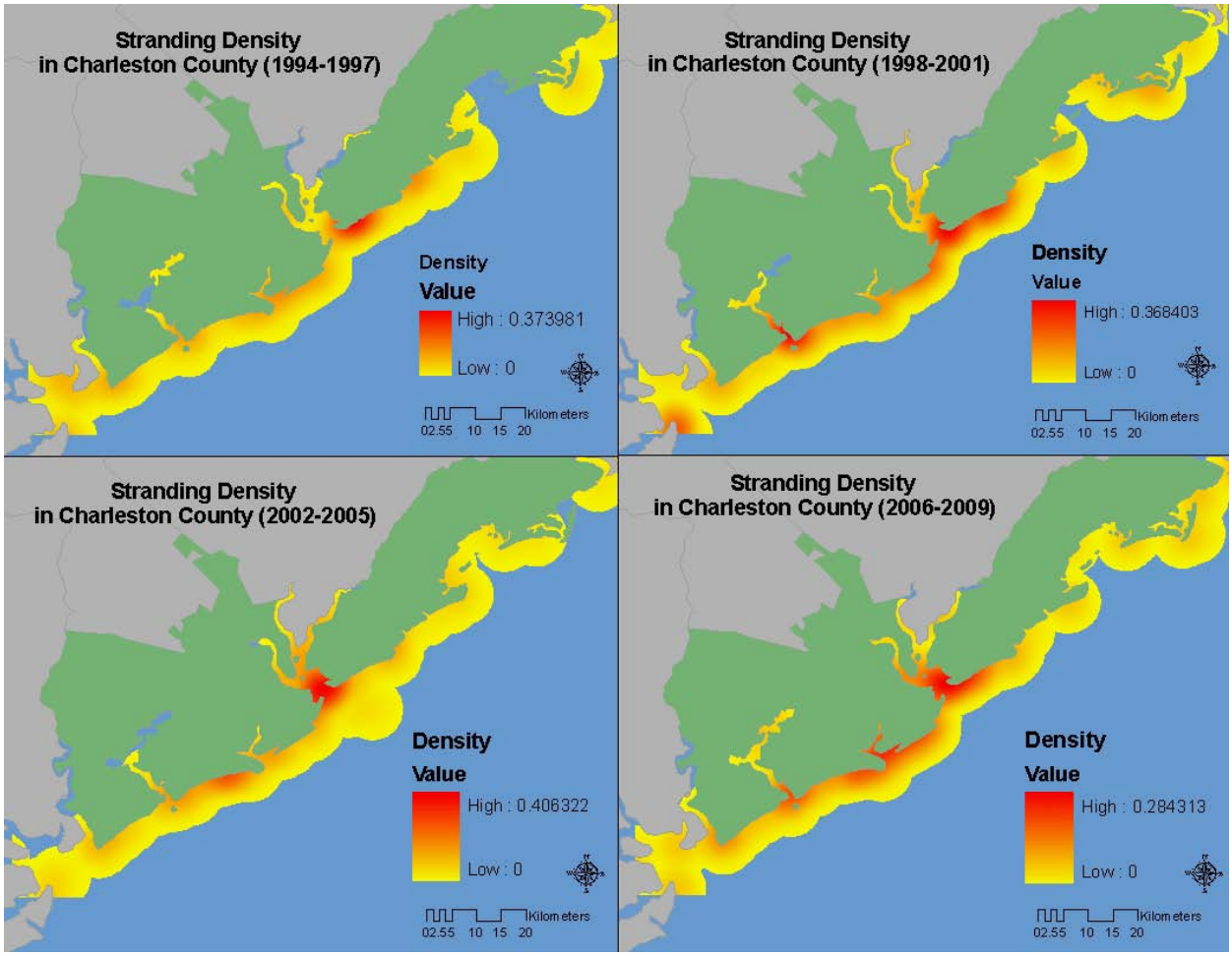


Figure 6. The trends between dock permit density and bottlenose dolphin strandings in Charleston County divided into four year intervals from 1994-2009.

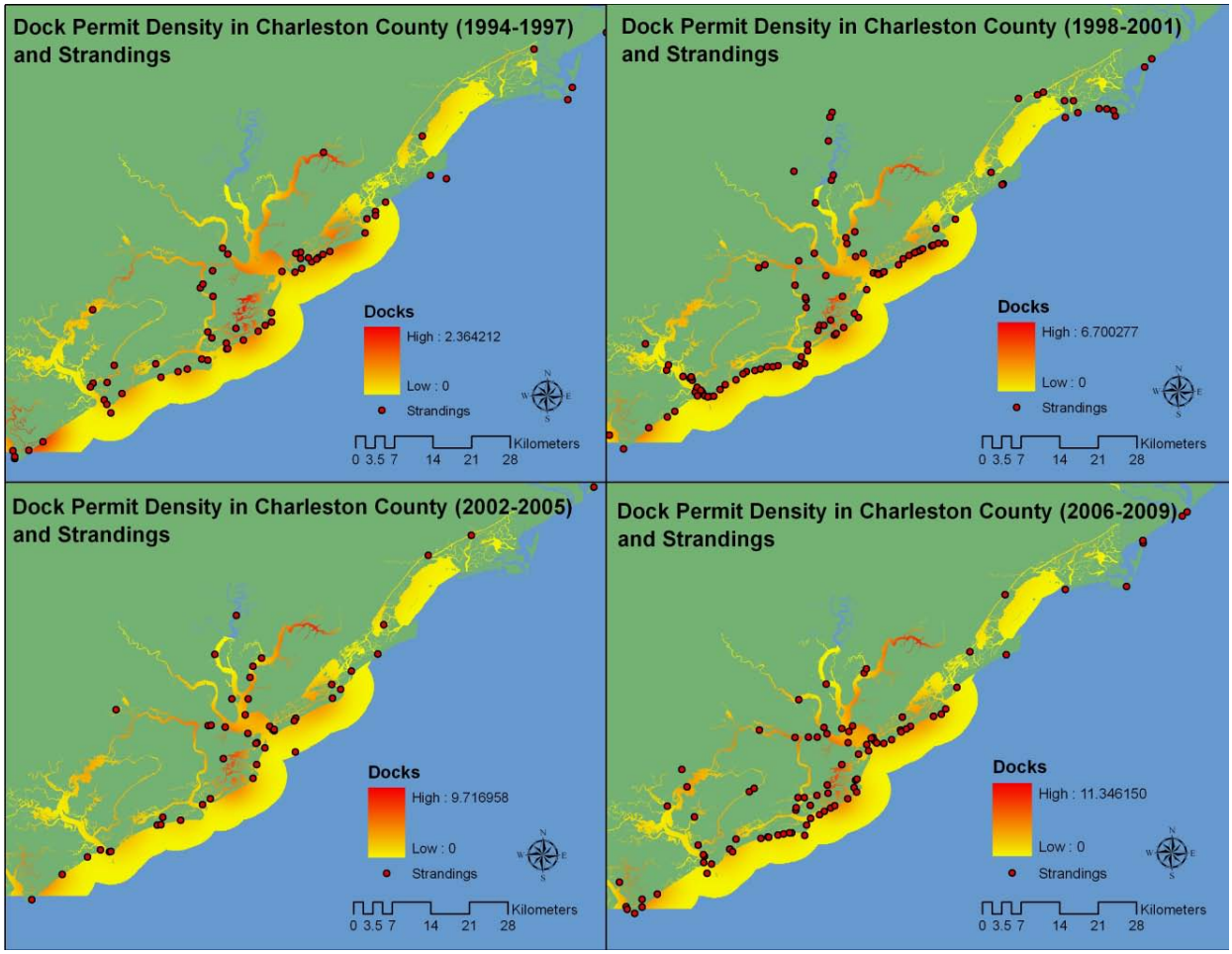


Figure 7. Trends in residential growth (in polygon form) and trends in bottlenose dolphin stranding density in Charleston County divided into four year intervals from 1994-2009.

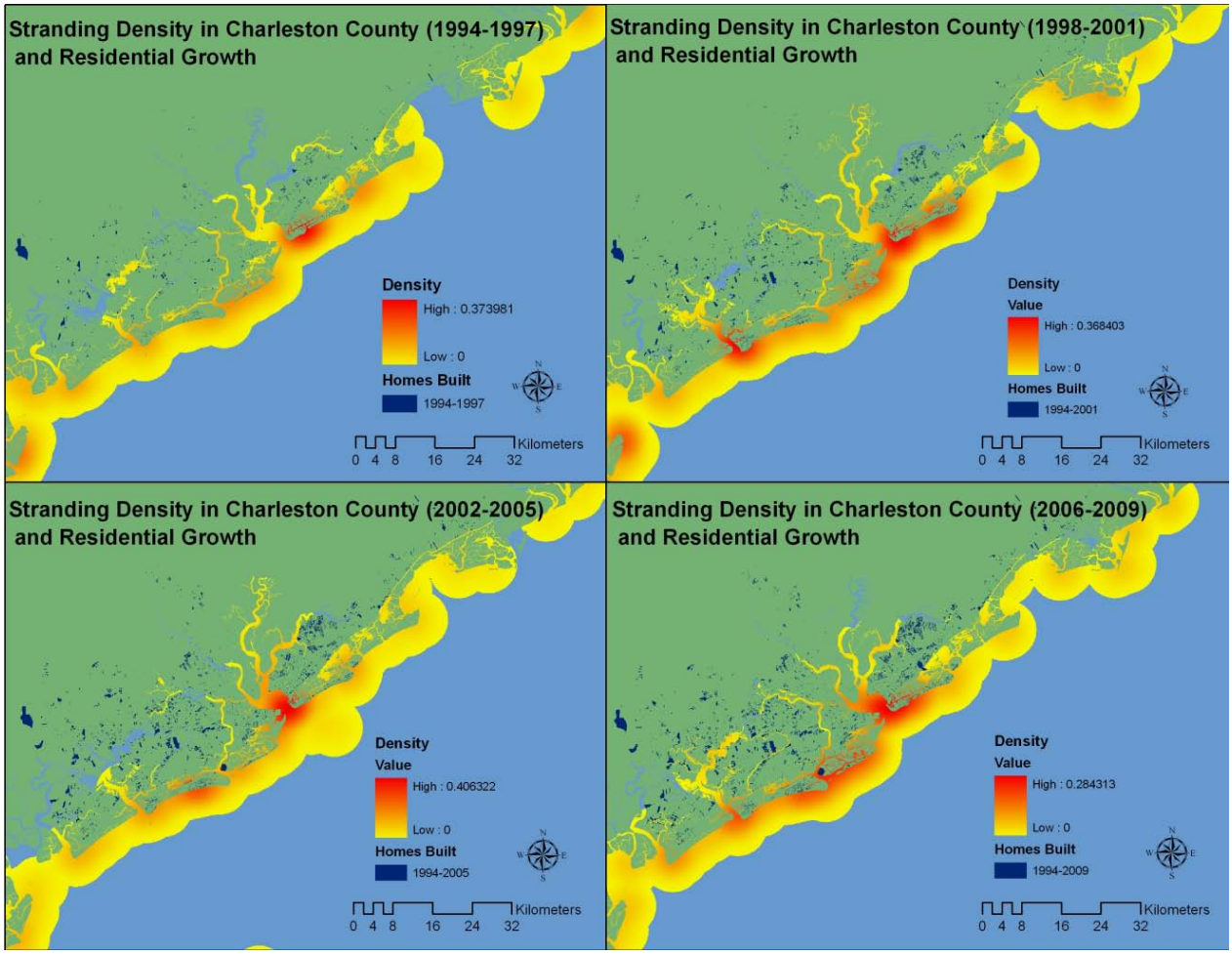


Figure 8. Trends in residential growth (after conversion to points) and trends in bottlenose dolphin stranding density in Charleston County divided into four year intervals from 1994-2009.

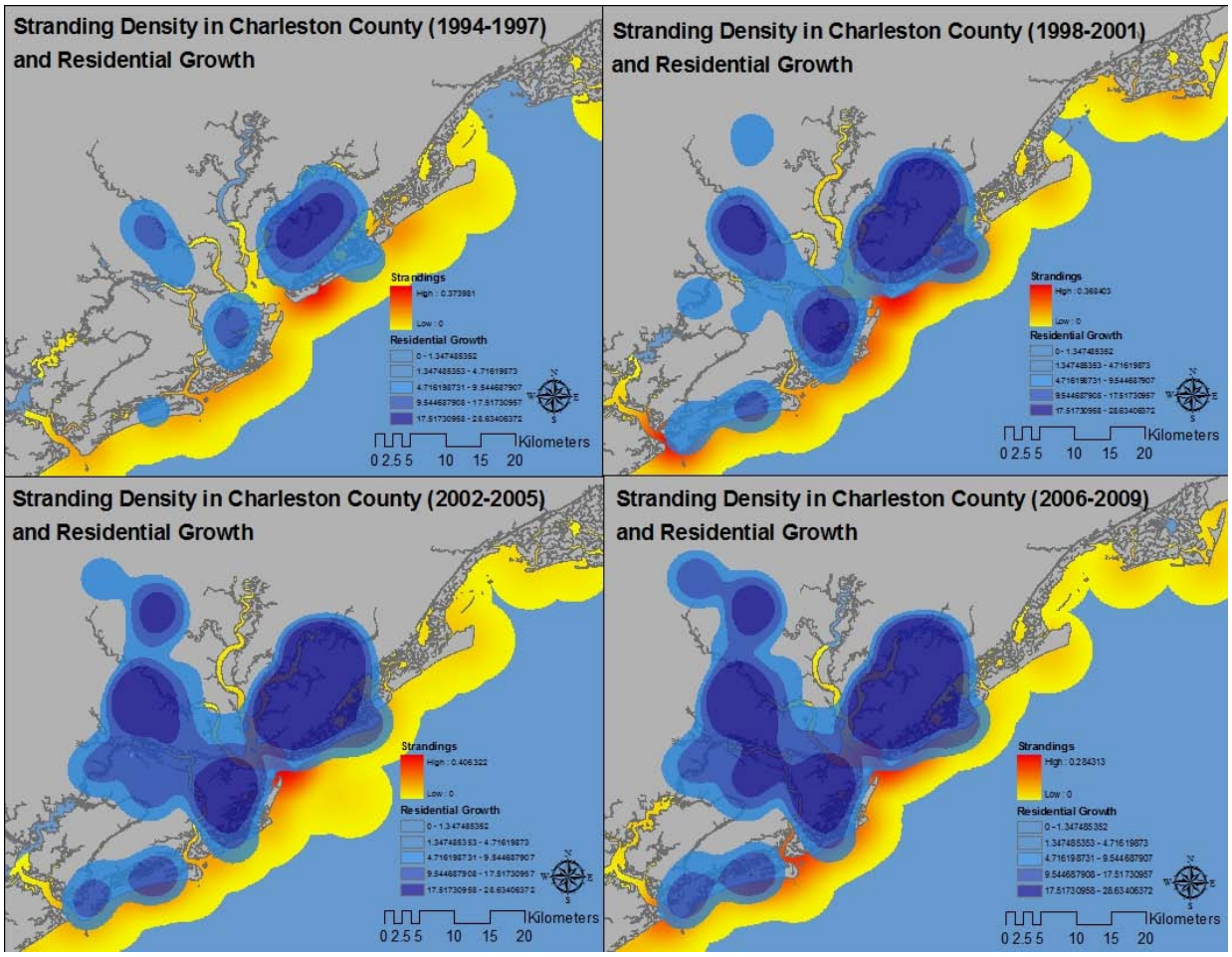


Figure 9. Statistical significance between the trends in docks and bottlenose dolphin strandings in Charleston County divided into four year intervals from 1994-2009.

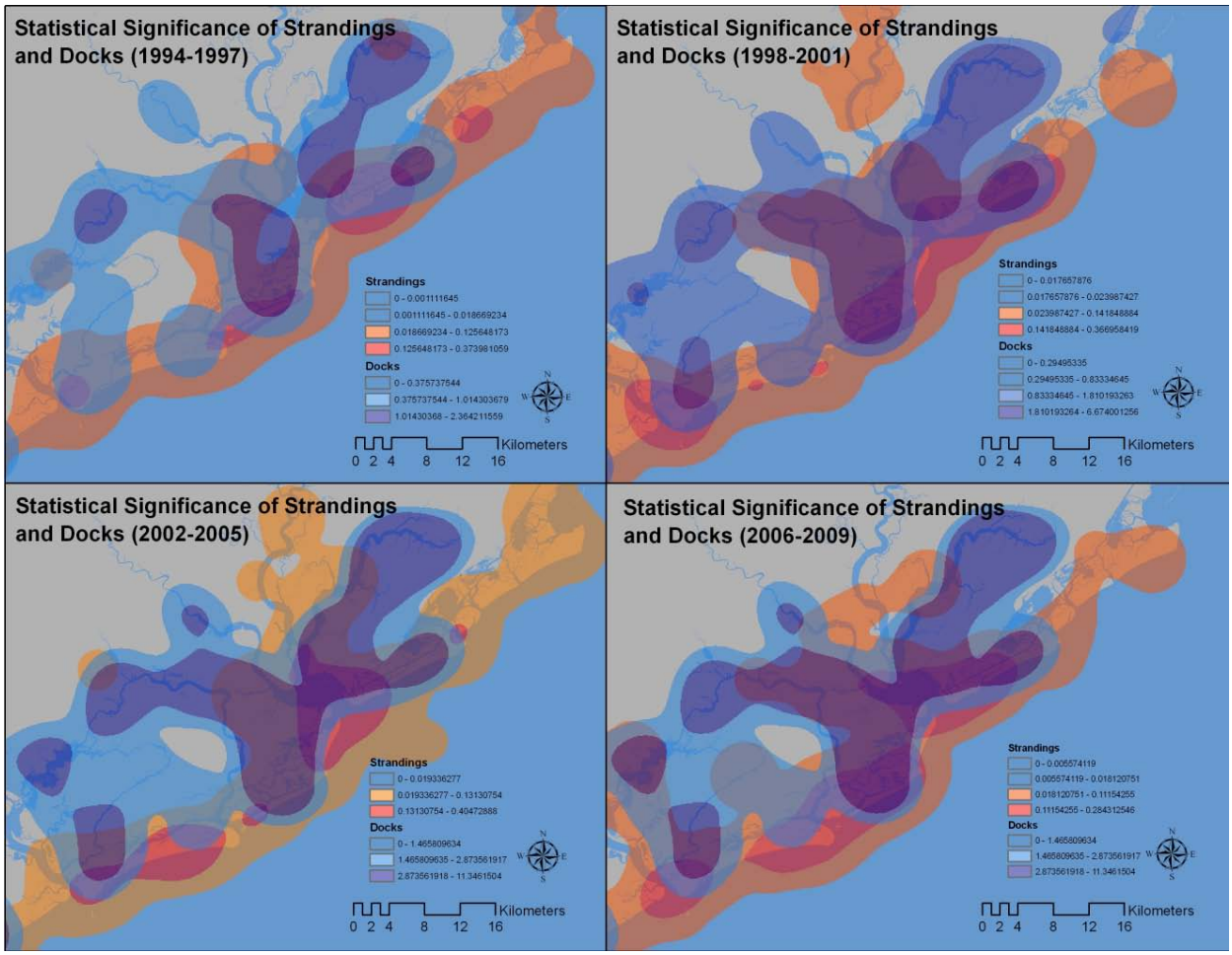


Figure 10. Statistical significance between trends in residential growth and bottlenose dolphin strandings in Charleston County divided into four year intervals from 1994-2009.

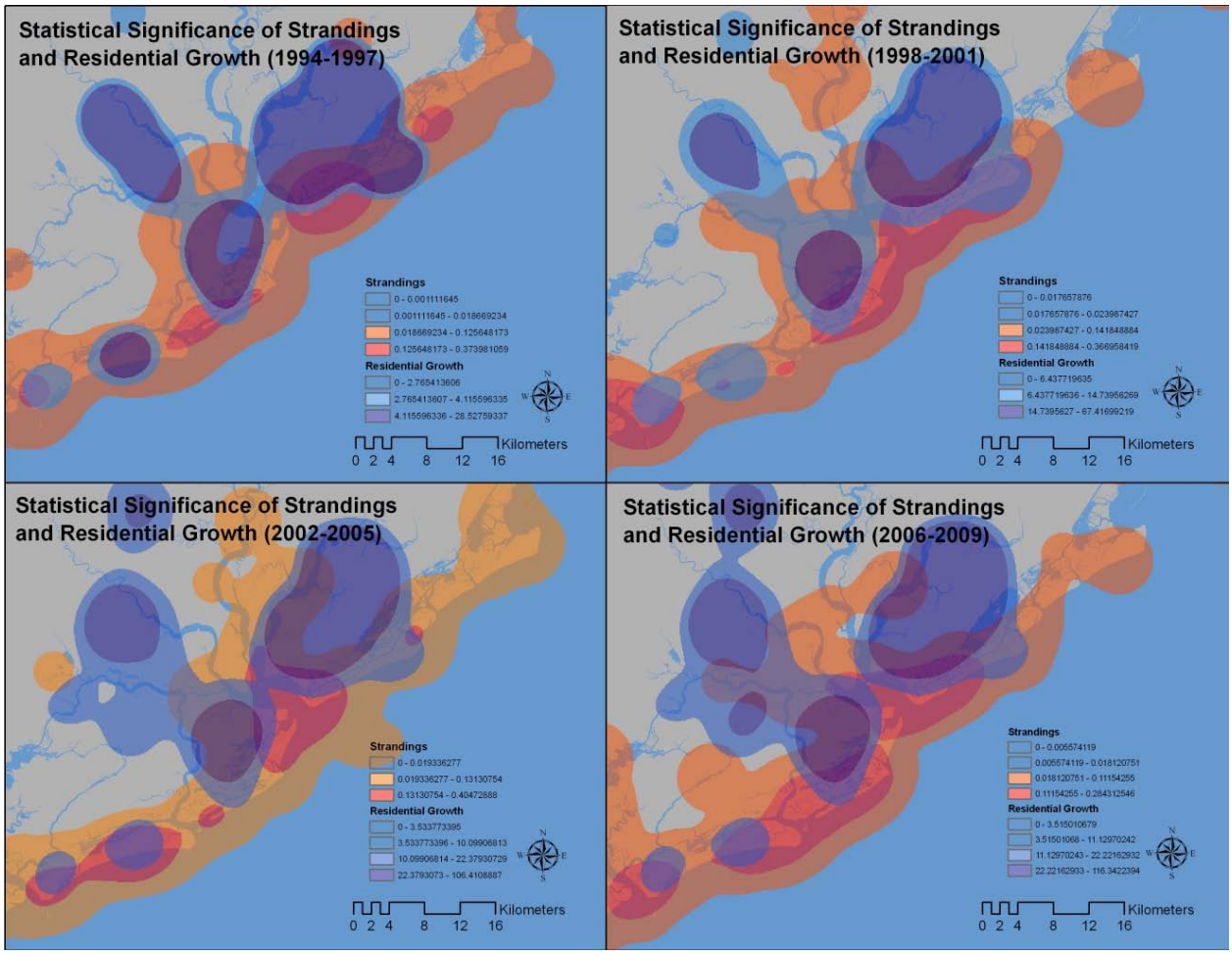


Figure 11. Total bottlenose dolphin strandings in South Carolina (black bars) plotted with the number of bottlenose dolphin strandings in Charleston County (open bars).

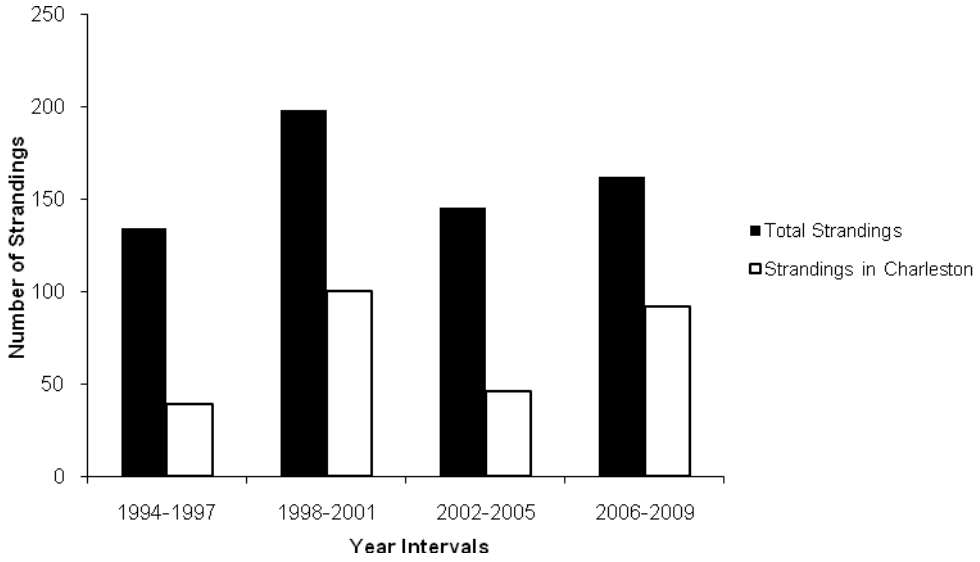


Figure 12. Total annual bottlenose dolphin strandings in South Carolina (black bars) plotted with annual bottlenose dolphin strandings in Charleston County (open bars), 1994-2009.

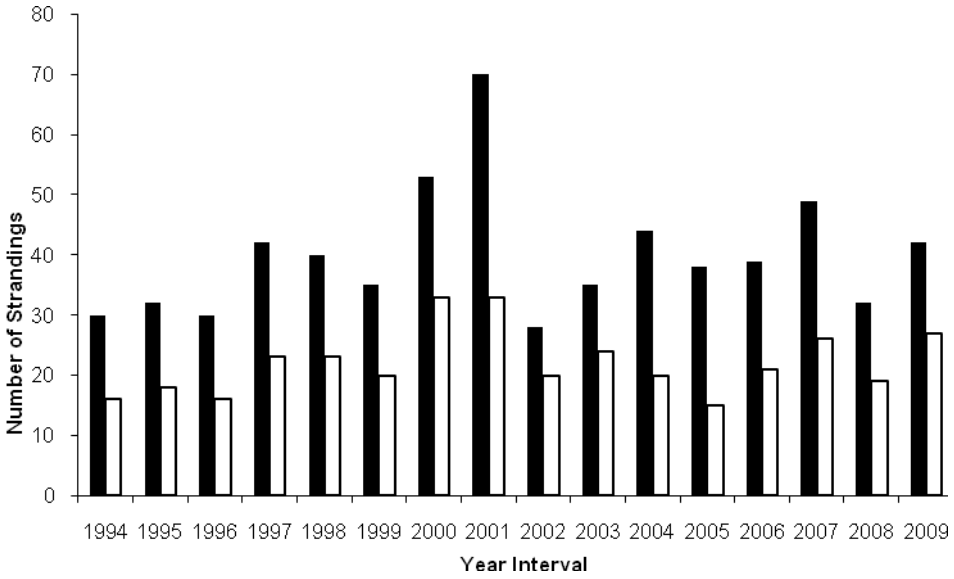


Figure 13. Total number of bottlenose dolphins with human interaction in South Carolina (black bars) plotted with bottlenose dolphins with human interaction in Charleston County (open bars).

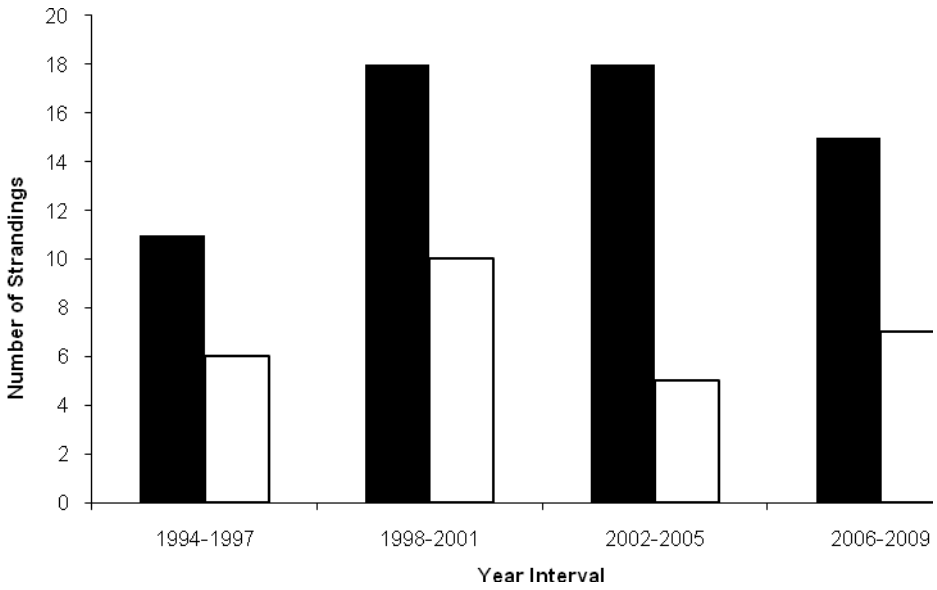


Figure 14. Annual number of bottlenose dolphin strandings with human interaction in South Carolina (black bars) plotted with annual number of bottlenose dolphin strandings in Charleston County (open bars).

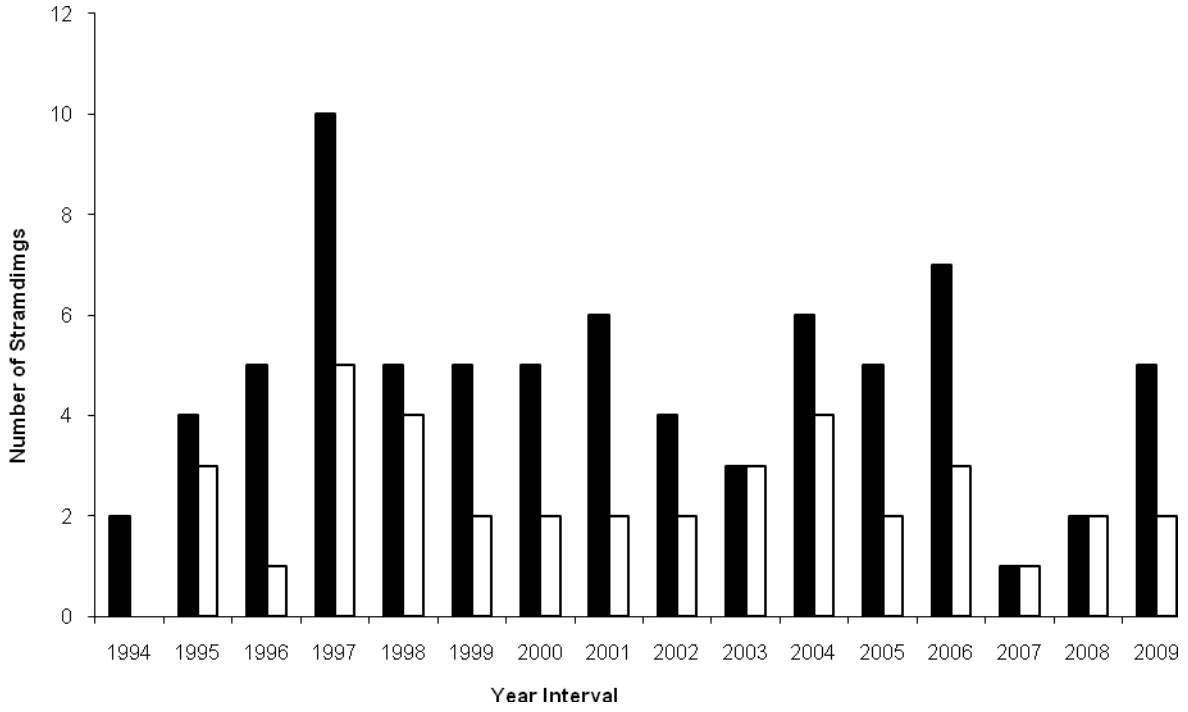


Figure 15. Annual number of crabpot fishery permits (black bars) in South Carolina plotted with annual bottlenose dolphin strandings in South Carolina (open bars), 2002-2009.

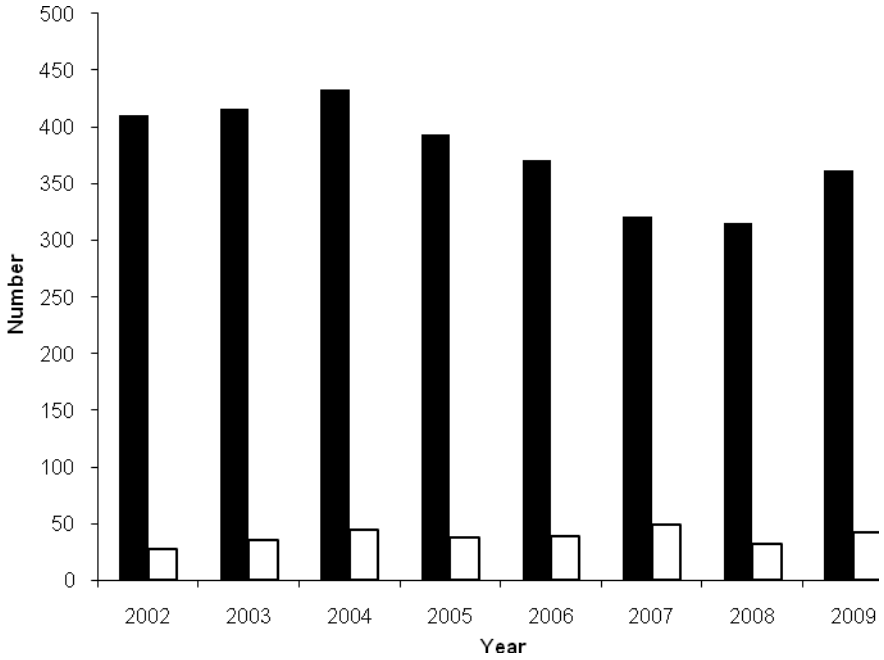


Figure 16. Annual number of crabpot fishery permits (black bars) in Charleston County plotted with annual bottlenose dolphin strandings in Charleston County (open bars), 2002-2009.

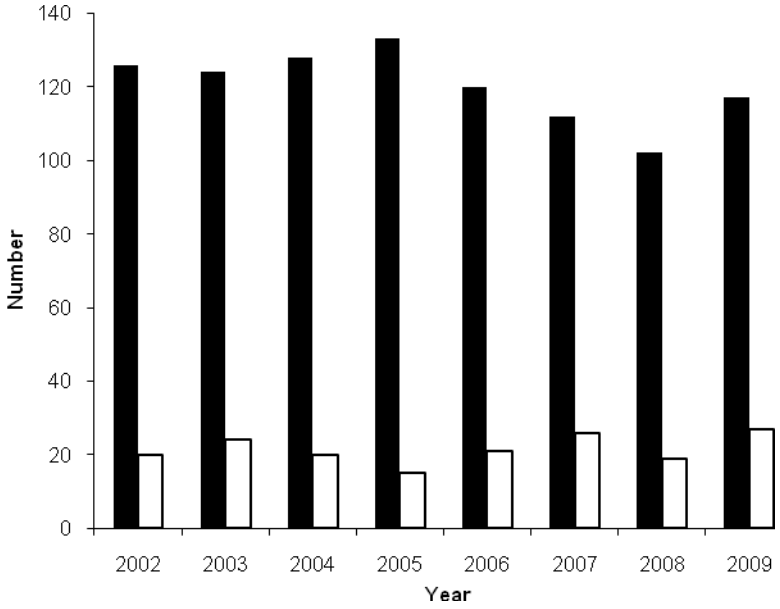


Figure 17. Trends in commercial fishing licenses in Charleston County from 2002 to 2009.

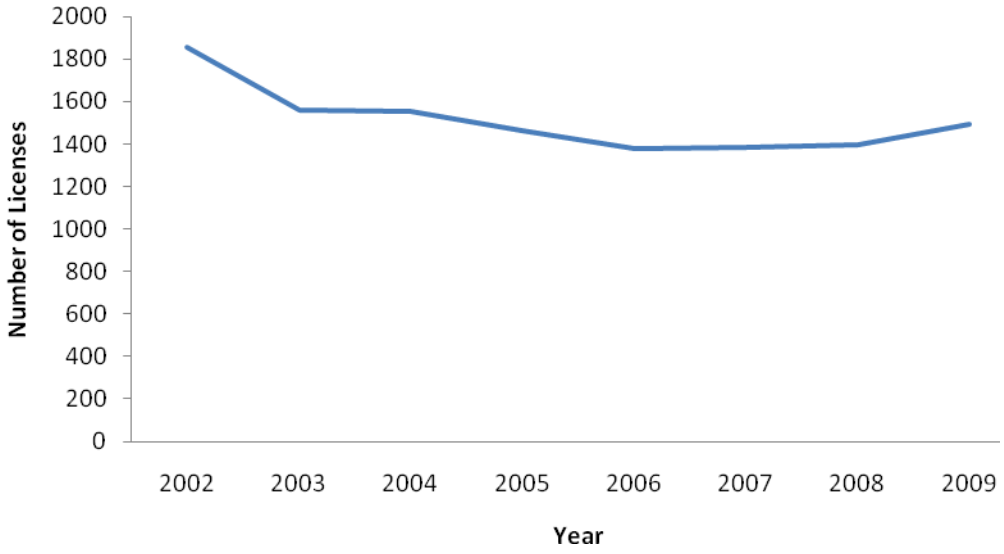
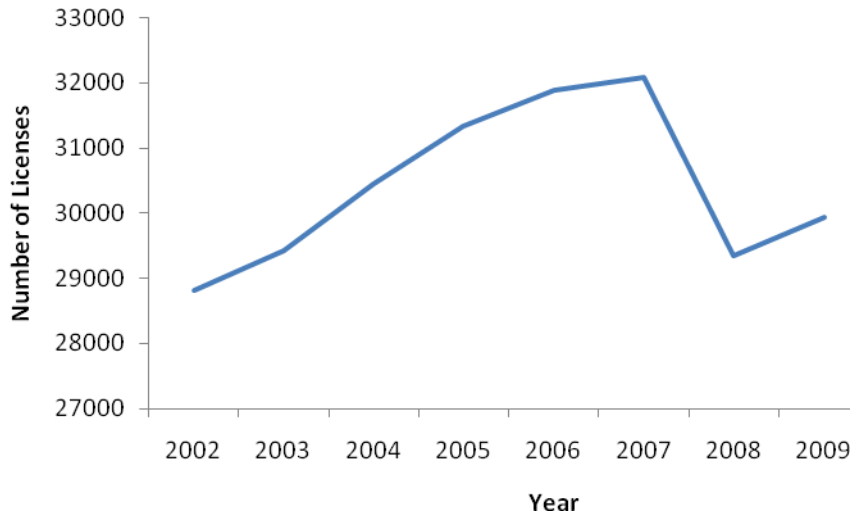


Figure 18. Trends in issued boat licenses in Charleston County from 2002 to 2009.



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