USE OF A GEOGRAPHIC INFORMATION SYSTEM (GIS) TO EXAMINE BOTTLENOSE DOLPHIN COMMUNITY STRUCTURE IN SOUTHEASTERN NORTH CAROLINA

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ABSTRACT

From June 1987 to April 1988 an epizootic of bottlenose dolphins (*Tursiops truncatus*) occurred along the eastern coast of the United States from New Jersey to Florida. As a result of this mortality, the mid-Atlantic "coastal migratory stock" of bottlenose dolphins was identified and estimated to have been reduced by more than 50%, which resulted in its classification as "depleted" under the U.S. Marine Mammal Protection Act. Since that time, researchers have documented the existence of multiple coastal stocks of Atlantic bottlenose dolphins, which are believed to include a complex mix of residents, seasonal inhabitants, and transient animals. One of these putative stocks occurs approximately between Beaufort, NC and Myrtle Beach, SC; 40 of the animals belonging to this stock were the focus of this study. Sighting histories for these 40 bottlenose dolphins have been compiled over the past nine years as part of an ongoing photo-identification study near Wilmington, NC.

Two hypotheses were tested for dolphins in the Wilmington, NC area: (1) a single community of dolphins exists and (2) dolphins exhibit no preference for specific locations within the study area. To account for survey effort, a weighted index was developed to standardize the data. To investigate dolphin community structure, a variety of area use methods were tested using a Geographic Information System (GIS). Most common in the literature are the adaptive kernel estimator (ADK) and the minimum convex polygon (MCP) methods, which have become standards in animal movement studies. Conversely, geographers and statisticians have developed point pattern and density estimation techniques. These approaches were compared, and the geographically-based interpolation methods were found to most accurately represent the dolphins' distributions. Based upon the area use results and dolphin association values (CoAs),

there appeared to be one core area and a strong preference for the Intracoastal Waterway portions of the study area.

ACKNOWLEDGEMENTS

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INTRODUCTION

From June 1987 to April 1988 an epizootic of bottlenose dolphins (*Tursiops truncatus*) occurred along the eastern coast of the United States from New Jersey to Florida. The event was likely caused by a morbillivirus, which has infected bottlenose dolphins in the western Atlantic and Gulf of Mexico since at least the early 1980s (Duignan et al. 1996). From the pattern of bottlenose dolphin strandings resulting from the 1987-88 epizootic event, Scott et al. (1988) proposed the existence of a single coastal migratory stock (CMS) of dolphins that migrates seasonally along the U.S. Atlantic coast. A total of 742 stranded dolphins was reported for the duration of the epizootic, which was a substantial increase from the 73.3 average yearly number of strandings from 1984 to 1986. As a result of this mortality, the mid-Atlantic coastal migratory stock of bottlenose dolphins was estimated to have been reduced by more than 50%, which resulted in its classification as depleted under the U.S. Marine Mammal Protection Act (Scott et al. 1988).

A recent study by McLellan et al. (2002) indicated that stranding patterns during the epizootic were not typical for mid-Atlantic bottlenose dolphins. By comparing stranding data from the epizootic (1987-88) to data before (1972-86) and after (1989-97) the event, McLellan et al. (2002) found that the distribution pattern of strandings during the epizootic was unique to those years. During the epizootic, mortality traveled north in the summer months and south in the winter months, suggesting a seasonal migration of the disease. The stranding distributions before and after the epizootic were similar to each other, but significantly different from that which occurred during the epizootic. Propagation of the disease along the Atlantic coast may have resulted from interactions between migratory animals and adjacent resident communities of bottlenose dolphins (Duignan et al. 1996; McLellan et al. 2002).

McLellan et al. (2002) and other studies (Hohn 1997; Waring et al. 1999) support the existence of multiple coastal stocks of Atlantic bottlenose dolphins, which are believed to include a complex mix of residents, seasonal inhabitants, and transient animals (Figure 1). One of these putative stocks, the southern NC management unit, occurs approximately between Beaufort, NC and Myrtle Beach, SC (Figure 2); a number of the animals belonging to this stock are the focus of the present study. One goal of this study is to examine whether fine scale community structure exists within this stock, using a Geographic Information System (GIS).

To date, only a few studies have used geographic positioning data to study the spatial and temporal distribution of bottlenose dolphins in North Carolina, such as Friedlaender et al. (2001). GISs are the collection of hardware, software, data, and procedures for the capture, storage, analysis, and display of spatially referenced data (Chang 2002). GISs, in conjunction with statistical techniques, have proven to be valuable tools for researching habitat suitability, home range, and protection of endangered species (Gerrard et al. 2001; Gurnell et al. 2002). These studies have taken place primarily in terrestrial environments, but as spatial analysis has become more prevalent in scientific research, GIS technology has also been applied to marine-based studies (Sauer et al. 1999; Stanbury and Starr 1999; Barber et al. 2001; Urian 2002). Appendix A contains a list of GIS terms and definitions.

Bottlenose Dolphins and Community Structure

Bottlenose dolphin populations are often referred to as open or closed, depending on the number of new animals sighted over time versus the number of recurring sightings of individual dolphins over time. Open populations have a high number of new animals sighted over time and a low number of resights, and are characterized by relatively high levels of immigration and

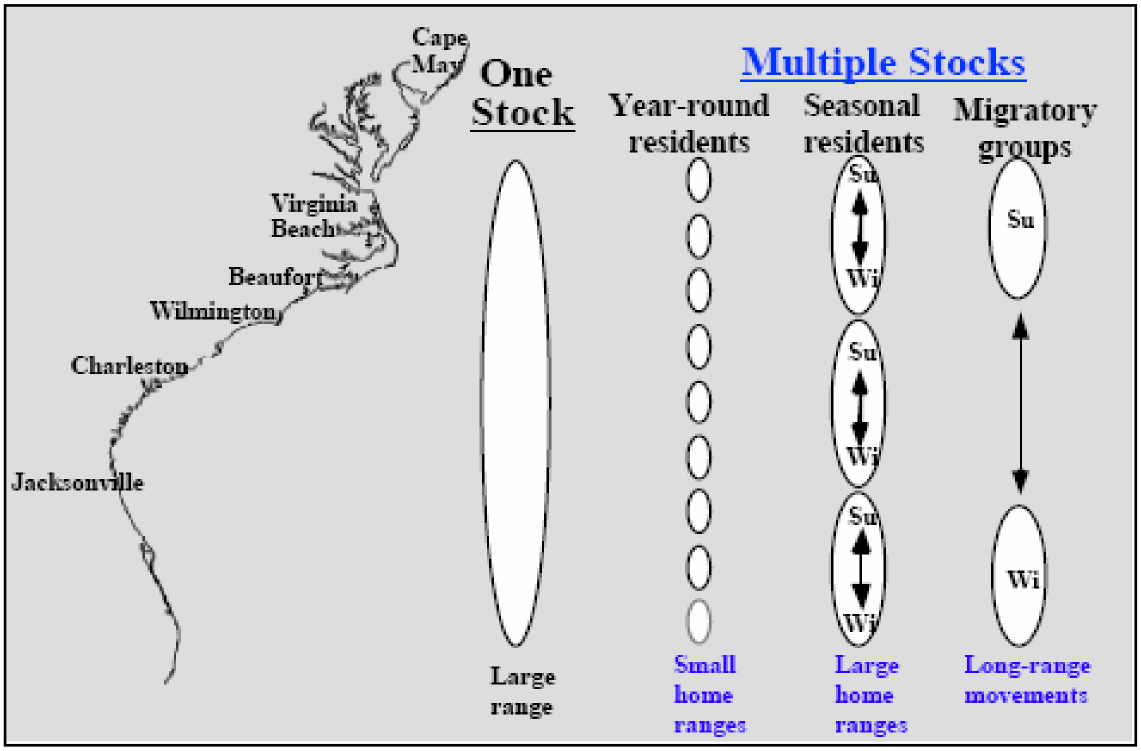


Figure 1. Hypotheses for the stock structure of Atlantic coastal bottlenose dolphins. One stock ranging from New Jersey to Florida, or multiple stocks which may include: 1) year-round residents; 2) seasonal residents; and 3) migratory groups (from Hohn 1997).

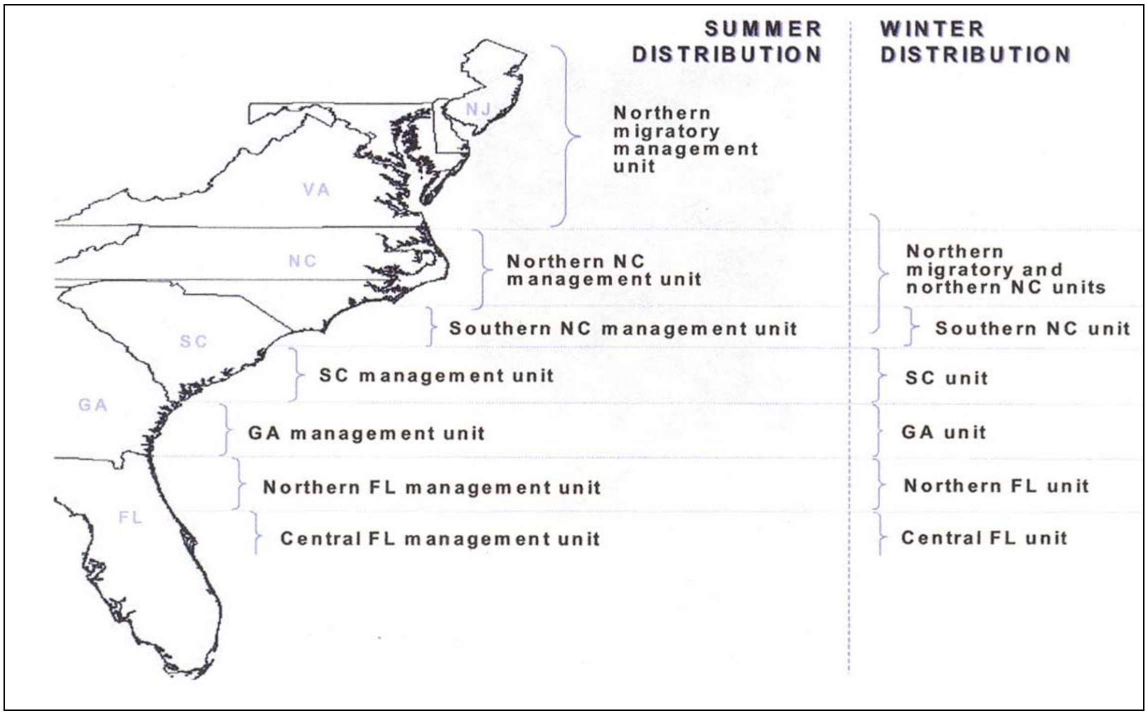


Figure 2. Putative stock distinctions for coastal bottlenose dolphins along the Atlantic coast of the U.S (from Waring et al. 2002).

emigration and by seasonal sighting patterns (Wells 1986a). Open populations of bottlenose dolphins have been documented in many locations, including Virginia Beach, VA (Barco et al. 1999), Lower Tampa Bay, FL (Weigle 1987), and Port Aransas, TX (Shane 1980). Conversely, in closed populations there is a leveling off of sightings of new animals over time and a high number of resights of individuals, resulting from a high degree of residency (Ballance 1990). Closed populations of bottlenose dolphins have also been documented in a variety of locations, including Sarasota, FL (Wells et al. 1987), the Adriatic Sea (Bearzi et al. 1997), Doubtful Sound, New Zealand (Williams et al. 1993), and the Moray Firth, Scotland (Wilson et al. 1997). However, some populations of dolphins are not easily classified as open or closed since they contain a mix of year-round residents, seasonal residents, and transitory animals. Such populations include those of Kino Bay, Mexico (Ballance 1990), San Diego, CA (Defran and Weller 1999), Golfo San José, Argentina (Wursig 1978), and Shark Bay, Western Australia (Smolker et al. 1992).

Closed populations of bottlenose dolphins are often subdivided into communities (Wells 1986a), which may be important for management purposes. Community members are defined as those that share an overall home range (Wells 1986a) and associate more with one another than with members of other communities (Urian 2002). Thus, ranging and association patterns of individual dolphins are key aspects of defining dolphin communities.

Home range is defined as the area that an animal regularly occupies while carrying out its habitual, everyday activities (Burt 1943). Several methods have been utilized to estimate home range size. The adaptive kernel estimator (ADK; Figure 3a) uses a bivariate probability distribution by fitting a kernel-shaped function around known locations of individual animals to estimate their home range (Worton 1989; Kie et al. 1996; Seamen and Powell 1996). Analysis with ADK incorporates probability contours (for example, 95%, 80%, and 65%) of home range use, thereby providing core area identification (i.e. zones of likelihood of use; Sauer et al. 1999). The minimum convex polygon (MCP; Figure 3b) method has also been used to estimate home range size. Outer sighting locations are connected to form a convex hull polygon, and then the area of the polygon is calculated (Mohr 1947; Wells et al. 1980; Selkirk and Bishop 2002; Urian 2002).

Two other methods used to estimate home range size are harmonic mean (Dixon and Chapman 1980; Figure 3c) and bivariate normal (Jennrich and Turner 1969; Figure 3d). Harmonic mean indicates the true center of an animal's home range by calculating the mean of the inverse distances from any data point to the remaining observations. The mean value is then inverted again to yield the final result. Due to the nature of the calculations, the value of the harmonic mean is inversely proportional to the amount of observations at any given location (Seaman and Powell 1996). The bivariate normal method places an ellipse around the observed data points at a percentage of 95, 90, or 50. Location points are statistically distributed along the major and minor axes of the ellipse and are assumed to be normally distributed (Jennrich and Turner 1969). While both the harmonic mean and bivariate normal methods are discussed in the earlier literature, other techniques, such as ADK, have been developed subsequently and are more widely used for estimations of home range size. In addition, the results of harmonic mean do not include a probability density and consequently are limited in their ability to aid in interpretation, and the bivariate normal method is known to depend too greatly on a bivariate normal distribution of data points and to overestimate the home range size (Don and Rennolls 1983). Therefore, harmonic mean and bivariate normal calculations will not be performed in this study.

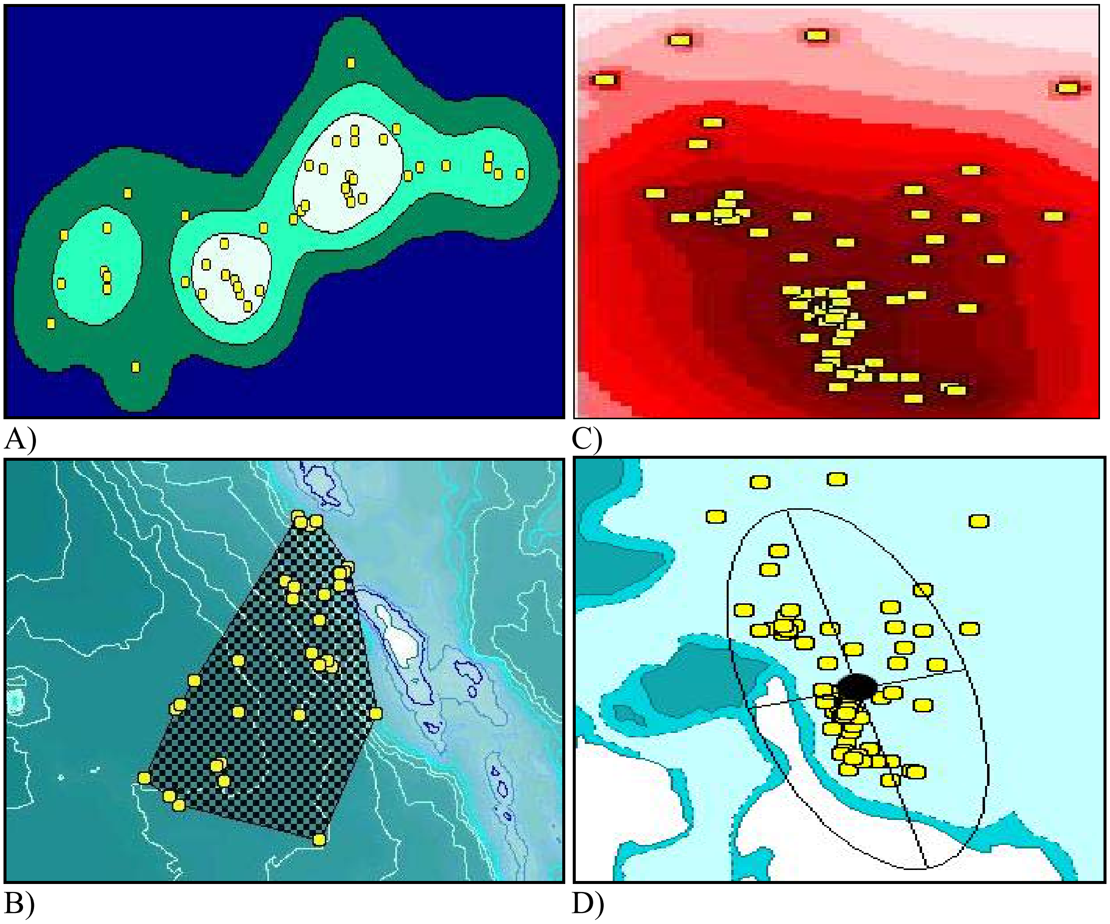


Figure 3. Output graphics from four area use methods calculated within a GIS using the Animal Movement Analysis extension (AMAE; Hooge and Eichenlaub 2000). Yellow circles represent data points. (A) ADK: 50% (white), 75% (light green), and 90% (dark green) probability contours represented. (B) MCP: the checkered area is the MCP polygon. (C) Harmonic mean: dark reds represent smaller probabilities (core areas); light pinks represent larger probabilities. (D) Bivariate normal: 95% ellipse shown with major and minor axes.

Geographic Information Systems (GISs) have been used for calculating home ranges for a variety of animals. Selkirk and Bishop (2002) examined the home ranges of four eastern Australian grey kangaroos (*Macropus giganteus*) and demonstrated the advantages of using a GIS for home range analysis. All relevant calculations, such as MCP and ADK, were calculated within the GIS, establishing GIS as a mechanism not only for display but for analysis as well. The Animal Movement Analysis Extension (AMAE) was used to calculate an ADK for each kangaroo and then all ADKs were displayed simultaneously (Hooge and Eichenlaub 2000). The concurrent display illustrated the ability of GIS to enhance comparisons of location data for more than one animal (Selkirk and Bishop 2002).

Bowyer et al. (1995) examined river otter (*Lutra canadensis*) home ranges in Alaska following the Exxon Valdez oil spill. Data were analyzed simply by measuring the length of the shoreline used by individual otters. Although this method gave a conservative estimate of the otters' home ranges, it did not provide a measure of probability or an indication of core areas. Sauer et al. (1999) studied the same river otter home ranges using the ADK method within a GIS. Probability contours of 100%, 95%, 80%, and 65% were estimated, and compared to the range estimates from the earlier study by Bowyer et al. (1995). Kernels of 100% and 95% density contours resulted in estimates larger than those of Bowyer et al. (1995); however, the 80% and 65% contours were not significantly different than the earlier estimates. Thus, the overall total ranges were greater when calculated with the ADK method within the GIS. The ADK method also identified potential core areas, in this case defined as the 65% contours (Sauer et al. 1999).

Stone et al. (1997) studied home ranges of the southern flying squirrel (*Glaucomys volans*) using a GIS. Previous studies of the squirrels' home range assumed the terrain to be flat and did not consider differences in topography (Madden 1974; Gilmore and Gates 1985; Bendel and Gates 1987; Fridell and Litvaitis 1991). However, since the slope, or topography, was found to change throughout the squirrels' habitat, Stone et al. (1997) determined the home ranges with and without topography, and compared the results. MCP was used to calculate the ranges without topography; the resulting polygons were overlaid on topographical representations within the GIS and an additional home range area was computed. The topographical home ranges of the squirrels were found to be significantly larger (8.5% ± 1.9%, on average) than the ranges computed without accounting for topography. By using GIS to incorporate topography, the surface areas of the ranges increased, and a more accurate representation of the home range was calculated (Stone et al. 1997).

Gubbins (2002a) examined home range boundaries and core use areas of 20 resident bottlenose dolphins near Hilton Head Island, South Carolina using ADK and MCP methods. The resident dolphins occurred exclusively in the inshore estuarine waters of the study area, showing strong site-fidelity and distinct patterns of core use within their ranges. Home range sizes resulting from the ADK method were 17.2 to 98.9 km^2, while range sizes from the MCP method were 14.7 to 65.8 km^2. Core use areas, defined by the 50% contour, were apparent for all 20 dolphins and ranged from 0.6 to 21.4 km^2. The relative size of the core areas varied from 3% to 36% of an individual's home range. The 95% contours were overlaid in a GIS to quantify relationships among individual range locations. Many of the ranges overlapped, creating two distinct hubs of home ranges.

The studies described thus far demonstrate the importance of calculating home range to analyze animal distributions. Two common tools used to calculate home range are the adaptive kernel estimator (ADK) and the minimum convex polygon (MCP) methods. GIS analyses typically yield more accurate representations of spatial distribution of data than do other methods. However, there are limitations when performing these analyses. Numerous studies have used their own study areas to define an animal's home range; in many cases this is not accurate, since the animal may be traveling beyond the reach of the surveys.

In addition to home range, association indices, or coefficients of association (CoA), are also useful for determining community membership (Wells et al. 1987; Ballance 1990; Weller 1991; Brager et al. 1994; Urian 2002); community members associate more with one another than with members of other communities (Urian 2002). CoA values are measures of how often an individual co-occurs with another individual. A value of 1.0 indicates that two animals were always sighted together, whereas a value of 0.0 indicates that two animals were never seen together.

Bräger et al. (1994) found relatively weak associations (mean = 0.18) among 35 dolphins in Galveston Bay, Texas. The authors suggested that the dolphins may have been simply passing through the area, rather than members of a discrete community. These findings are similar to those of other studies of associations among dolphins along the Pacific coast of California (mean = 0.21; Weller 1991) and in the Gulf of California (Ballance 1990). In contrast, relatively high coefficients of association were reported for 38 dolphins from a resident community of approximately 100 animals in Sarasota, Florida (Wells et al. 1987).

Rossbach and Herzing (1999) used home ranges and association indices to distinguish communities of bottlenose dolphins near Grand Bahama Island, Bahamas. Individual dolphins observed five or more times (n = 98) were found to exhibit fidelity to specific regions in the study area, and were clustered in four main groups according to their association patterns. Dolphins belonging to the same group shared similar ranges, which occasionally overlapped with the ranges of another group. Dolphins identified fifteen times or more (n = 28) were part of the two largest groups, characterized as either the inshore community or the offshore community. The two communities of dolphins showed long-term site fidelity, relatively high associations between members, and low associations with members of other communities. A total of 95% of possible interactions within communities was observed, while only 18% of possible interactions among communities were observed.

Gubbins (2002b), building upon previous research showing two distinct home range hubs (Gubbins 2002a), conducted cluster analysis of CoA values of dolphins with at least ten sightings, showing two distinct social groups of resident dolphins. A seasonal influx of transient dolphins was also documented, and associations did occur between transient and resident dolphins. However, residents were more likely to associate with other residents than with transients, and associations within a social group were more likely than associations between the two groups (Gubbins 2002b).

Urian (2002) examined dolphin community structure in Tampa Bay, Florida using sighting locations and association indices to determine if a single community was present. The author calculated CoA values and mean values for the latitudes and longitudes of sighting locations for 102 dolphins that had been sighted ten or more times. This number of sightings was chosen because most dolphins sighted in Tampa Bay had not been identified more than ten times. Each individual dolphin was assigned to one of five presumed communities, based upon classifications resulting from cluster analyses. These results are interesting since Tampa Bay is a relatively open expanse of water without any physiographic barriers to movement, yet distinct communities of dolphins were found within the bay. Mean locations of the five communities were compared using analysis of variance (ANOVA); all locations were significantly different.

Mean CoA values of dolphins were found to be significantly higher within a community than between communities. Finally, the ADK method was used to validate the results of the cluster analysis. A home range for each community was estimated; presence or absence of overlap among communities was determined using the AMAE in a GIS. Results indicated overlap among some communities, but not all (Urian 2002).

The Urian (2002) study has important management implications. Bottlenose dolphins are grouped together for management into stocks, which should ideally correspond to biological populations. The presence or absence of fine-scale community structure within stocks could affect the methods used to protect them. The dolphins in Tampa Bay are currently considered one discrete stock, which may not be appropriate given the existing community structure (Urian 2002).

Research Objectives and Hypotheses

There were three main objectives for this research project. The first objective was to develop a GIS to study bottlenose dolphins in the Wilmington, North Carolina area. The second objective was to establish whether or not discrete communities of dolphins exist throughout the study area. The third objective was to determine if dolphins show preferences for specific regions within the study area.

A GIS was developed to analyze the spatial distribution of dolphin sightings. Other researchers have documented many of the animals that were used in this study north and/or south of the Wilmington study area (Urian et al. 1999). Thus, the full extent of the home ranges was not quantified, and the term “home range” was not used in this study. Instead, each dolphin’s “local area use” (LAU) was estimated. LAU indicated which regions within the study area were used by dolphins. By quantifying the dolphins' local area use and association indices, I tested the null hypothesis that a single community of dolphins exists in the study area. Using data collected and incorporated into the GIS, I examined whether or not individual dolphins prefer certain regions of the study area (*i.e.* Cape Fear River, Intracoastal Waterway, inlets, or nearshore ocean). I tested the null hypothesis that dolphins exhibit no preference for any region of the study area.

METHODS

Field Methods

The study area was located in the 330 km^2 coastal region between New Topsail Inlet and Bald Head Island Inlet, North Carolina (Figure 4). Boat-based photo-identification surveys of bottlenose dolphins were carried out year-round by researchers from Dr. Laela Sayigh's laboratory at the University of North Carolina Wilmington. These surveys were conducted in the Cape Fear River (CFR), Intracoastal Waterway (ICW), surrounding inlets, and in the nearshore (approximately three kilometers offshore) coastal ocean. Survey effort was spread throughout the study area based upon recent coverage and on weather conditions. Individual dolphins were identified by photographs of the unique patterns of nicks, notches, and scars on their dorsal fins (Wursig and Wursig 1977; Urian and Wells 1996). Once a dolphin or group of dolphins was spotted, a Nikon N 90s camera with a 70-300 mm telephoto lens was used to obtain photos of the dorsal fins. An attempt was made to photograph every dolphin in each sighting; however, this was not always possible. Sightings were terminated if the dolphins had not been seen for a period of at least 10 minutes, or if weather conditions became threatening. During each sighting, the latitudes and longitudes of the dolphins' locations were recorded using a Garmin 12XL

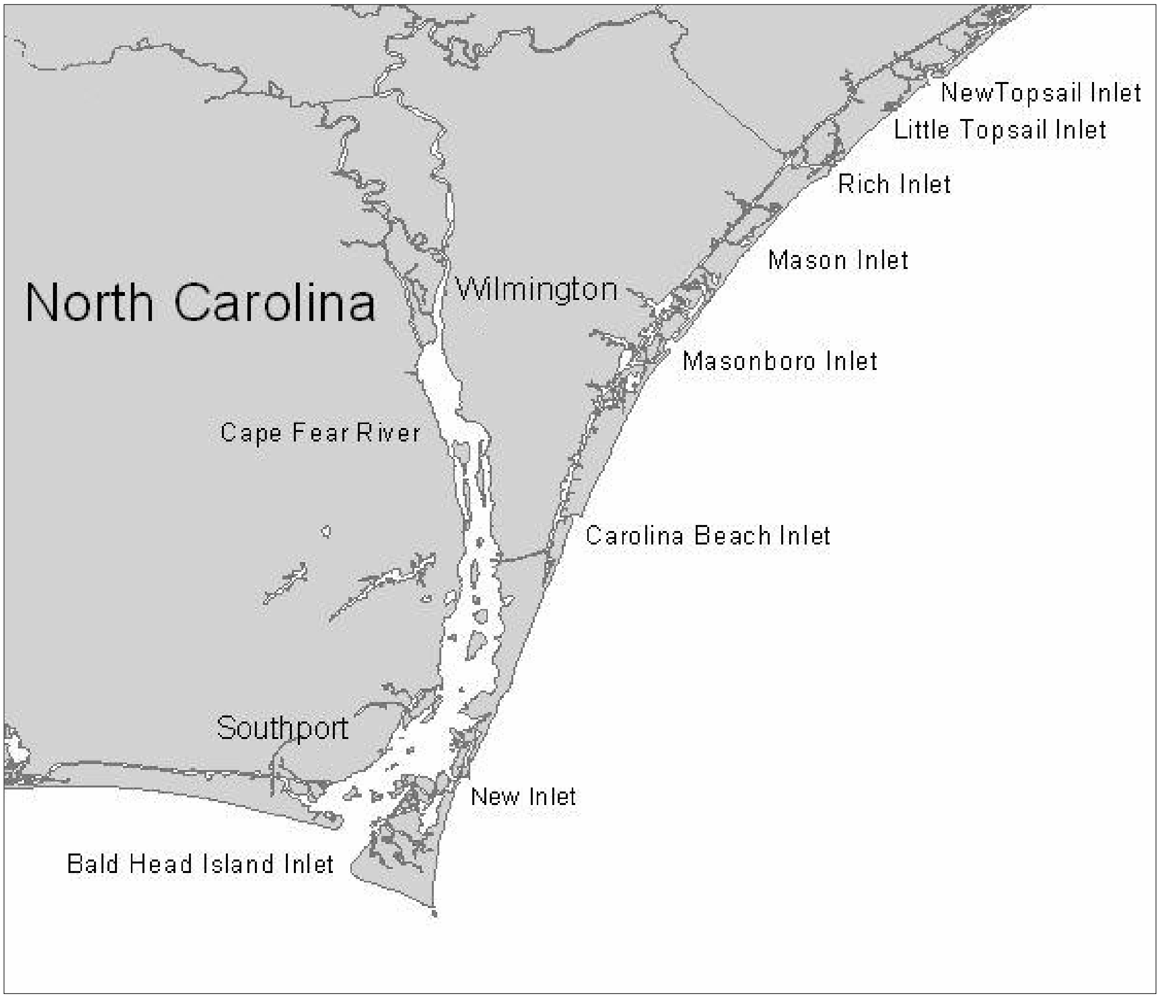


Figure 4. Wilmington, NC study area: New Topsail Inlet to Bald Head Island Inlet, North Carolina.

Global Positioning System (GPS). Additional data recorded at each sighting were tidal state, temperature, salinity, depth, and sighting conditions (wind speed, glare, Beaufort Sea State).

Database Development

The Wilmington dolphin GIS was developed using ESRI's ArcView version 3.3. The study area shapefiles initially existed in three separate files, which were merged together to create a single study area shapefile. The shapefile was then projected to Universal Transverse Mercator (UTM) coordinates in Zone 17 North using the ArcView Projection Utility Wizard. To quantify survey effort, the study area was divided into 194 separate sections, each approximately 1.8 km^2. This area was chosen since it roughly equals the size of one of the inlets, the smallest area of water within the study area. If the sections were any larger, unnecessary areas of land would have been included. The sections were drawn by hand on twelve paper maps that composed the study area and covered the CFR, ICW, surrounding inlets, and the nearshore ocean. These sections were digitized as a new polygon theme in ArcView, drawn using the study area maps for reference.

As stated previously, bottlenose dolphin populations are considered to be either open or closed. To address whether the Wilmington population was open or closed and the possible existence of one or more communities, the frequency of dolphin observations was analyzed. The Wilmington dolphin population appeared to consist of a combination of resident and transient individuals (Koster 2002). A total of 381 dolphins were identified and included in the Wilmington dolphin database from 1995-2002. Of the 381, 302 dolphins were seen less than five times, 35 were seen between 5 and 9 times, 10 were seen between 10 and 15 times, 12 were seen between 16 and 20 times, and 22 were seen more than 20 times (Figure 5). When these

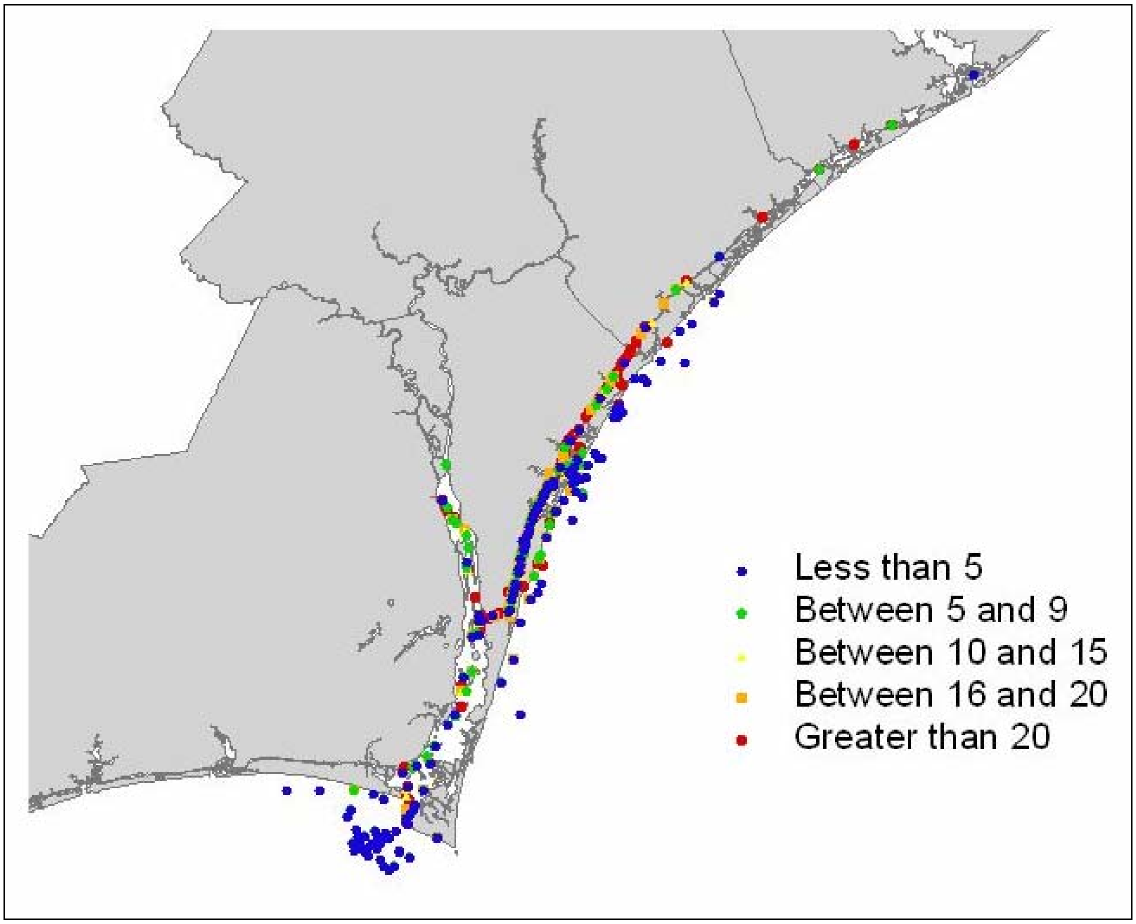


Figure 5. Sighting locations for all dolphins according to total number of sightings.

survey data were brought into ArcView, many of the sighting points were incorrect, plotting far offshore instead of within the study area. Discrepancies with the GPS unit used to collect the data points in the earliest years of the study were determined to be the cause of the error; points were obtained in degrees-minutes-seconds rather than decimal degrees. A conversion formula was applied, and all points were corrected.

As in Urian (2002), dolphins with ten or more sightings were used in the analyses. A high number of sightings was necessary in order to more accurately represent the dolphins' distributions. Only the beginning location of the first sighting on any given survey day was included in the dataset to assure independence of dolphin sightings. There were 44 dolphins sighted ten or more times; however, four of these 44 dropped below the ten-sighting cutoff after eliminating multiple sightings on the same survey day. Thus, a total of 40 dolphins identified between October 1995 and October 2002 were used in this study. The total number of first sightings for individual dolphins ranged from 10 to 48 (Table 1). For each sighting, the date, location (latitude and longitude), dolphin ID numbers, and other data had previously been entered into a Microsoft Access database.

A spreadsheet containing the complete dataset was created in Microsoft Excel. Organized by dolphin ID number, the complete dataset included fields for Unique ID, Date, ID Code, Sighting #, Lat, Long, Map #, Section, Depth, Temp, and Salinity. A unique ID was assigned to each sighting number on each date in the complete dataset. The "Map #" field identified on which paper map of the study area the sighting occurred. The "Section" field identified in which section of the study area the sighting occurred. All data were incorporated into ArcView GIS by converting from Excel files to DBF files, which are compatible with ArcView. Once the DBF files were in ArcView, they were converted to shapefiles. All

Table 1. Listing of dolphin ID codes and total number of first sightings.

Dolphin No.	Dolphin ID Code	Number of Sightings
1	10030	13
2	10040	17
3	10070	13
4	10140	11
5	10520	16
6	30020	21
7	60040	23
8	60060	35
9	60061	15
10	60070	12
11	60080	15
12	60630	34
13	60631	12
14	70160	35
15	70170	25
16	70240	13
17	70300	22
18	70310	28
19	70320	27
20	70330	23
21	70560	19
22	70610	27
23	70820	24
24	70990	27
25	71110	10
26	80100	11
27	80120	29
28	80140	32
29	80150	11
30	80290	25
31	80300	20
32	80310	29
33	90040	16
34	7071	17
35	7072	18
36	707	48
37	713	43
38	715	27
39	727	18
40	732	20

shapefiles were projected to UTM coordinates in Zone 17 North using the ArcView Projection Utility Wizard.

Seasonality Analysis

Chi-square tests were performed on seasonal data to determine if a relationship existed between the number of surveys carried out and the number of sightings documented in each season. The total numbers of surveys and sightings were tallied for fall (September-November), winter (December-February), spring (March-May), and summer (June-August), expected values were calculated (based upon survey effort), and a chi-square test was applied. In addition, chi-square tests were performed on an individual basis to determine if dolphins exhibited a preference for any particular season. Each dolphin's total number of sightings was tallied for each of the four seasons, expected values were calculated (based upon survey effort), and chi-square tests were applied.

Accounting for Survey Effort

The sightings for the 40 dolphins were weighted based on survey effort. Survey effort was calculated by counting the number of times each section of the study area was surveyed (possibly more than once in a day). The total number of times each of the 194 sections was surveyed ranged from 0 to 627. The total number of surveys for all 194 sections was 19,485. Survey frequency was calculated using the following formula:

frequency = (# of times each section was surveyed / total # of surveys)

Survey frequencies ranged from 0 to 0.032. The inverse of the survey frequency was chosen as the weighting factor to give points located in less frequently surveyed sections more weight than points located in more frequently surveyed sections (Figure 6). Inverse survey frequencies ranged from undefined to 19,485.00. Seven sections were never surveyed, and a value of undefined was returned for those. Sections that were surveyed only once returned a maximum value of 19,485.00; sections that were surveyed 627 times returned a minimum value of 31.08. The effort calculation provided a weight that was applied to the calculation of local area use. Adjusting for effort was important because field surveys were not uniform; surveys took place more in the ICW than in the other regions of the study area.

Local Area Use

To estimate the dolphins' local area use (or LAU), several different methods were used in ESRI's ArcView version 3.3, including ADK and MCP. Both methods were facilitated by the Animal Movement Analysis extension (AMAE; Hooge and Eichenlaub 2000). Using the AMAE, ADK contours were calculated from shapefiles of dolphin sighting points. The density contours were set to 95, 80, and 65% (as in Sauer et al. 1999; Selkirk and Bishop 2002; and Gubbins 2002a) and the smoothing parameters were kept at the original *ad hoc* values (based upon the Animal Movement documentation). MCPs were also calculated from the same shapefiles of dolphin sighting points using the AMAE in ArcView. The only output for MCP is 100% because it defines the outer boundaries for sightings.

One problem with using ADK and MCP is the inclusion of land in the creation of density contours. Therefore, a new technique was developed to remove land from the analysis area and to also account for survey effort. This new technique, termed spatial density calculation (or SDC), used functions within the Nearest Features (Jenness 2004) and Spatial Analyst extensions to ArcView. SDC is similar to ADK in that the outputs are polygons representing probability

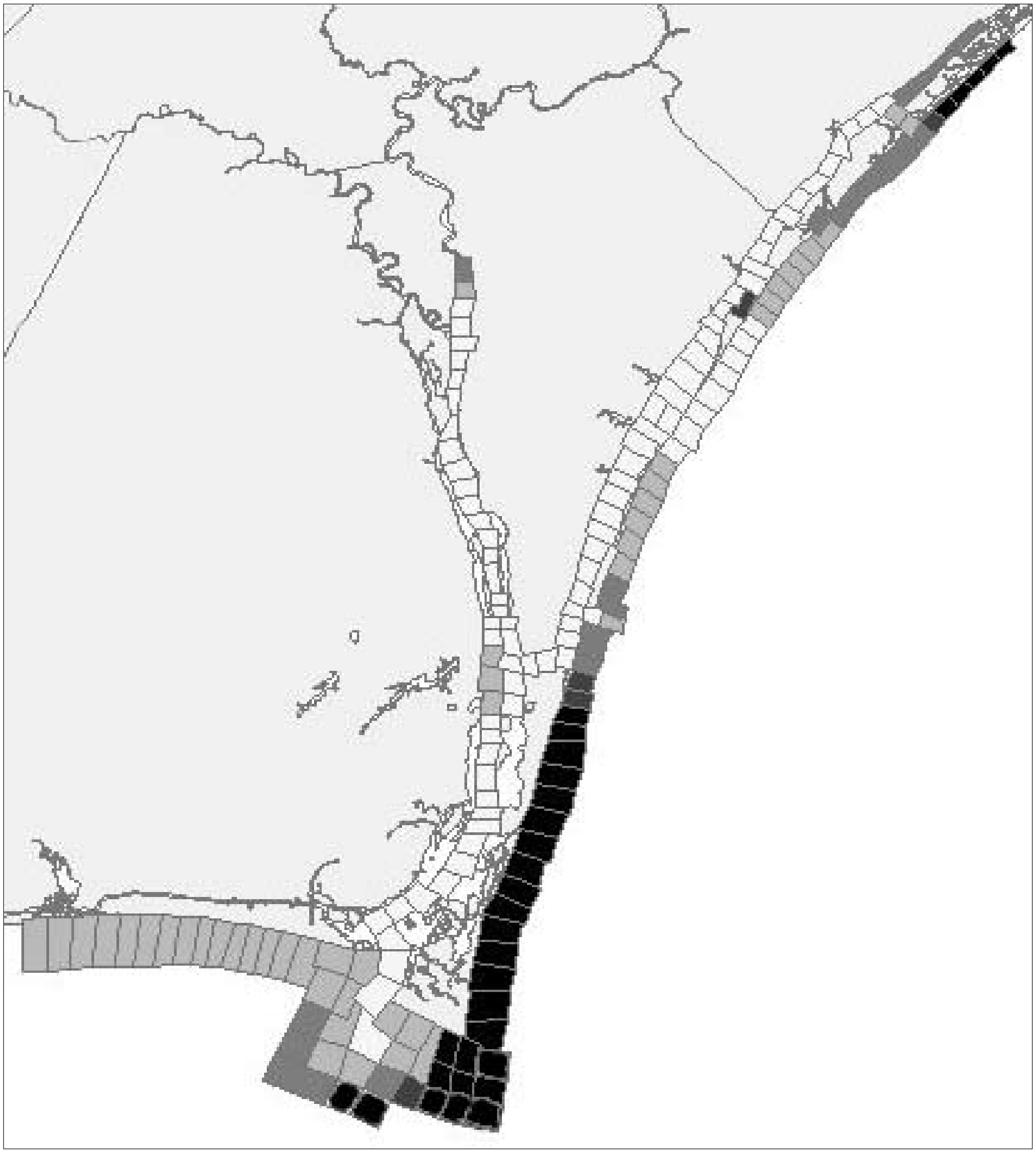


Figure 6. Effort polygons drawn according to inverse survey frequency values. Lighter polygons correspond to low values (high number of surveys); darker polygons correspond to high values (low number of surveys).

contours; however, when performing the actual calculations, the algorithm excludes land by creating a mask layer. SDC estimates were calculated from shapefiles of dolphin sighting points for the 95, 80, and 65% probability contours (as in Sauer et al. 1999; Selkirk and Bishop 2002; and Gubbins 2002a).

For estimates of SDC, the bandwidth size, or the search radius at which the analysis is performed, was selected using the Nearest Features extension to calculate the average distance between the k-nearest neighbors of five randomly chosen dolphin point themes, each with a different number of sightings (Williamson et al. 1998; McLafferty et al. 2000). Williamson et al. (1998; p.4) described the process as follows:

> "First, the distances between each point and every other point are calculated. Then, using a nested loop structure, the distances for each point are sorted, and the average distance of the k-nearest neighbors is calculated. Then, in another loop, the average of those distances is calculated. The result is the recommended bandwidth based on k."

Several values for k were tested, including three, four, and five nearest neighbors. After performing the area use calculations using the distances for $k = 3$, 4, and 5 for the five dolphins, the results showed little difference between the different values for k (Figure 7). Since the dataset being studied is relatively small, the distance for $k = 3$ was chosen so that the data would not be over-generalized. This procedure allowed each of the five dolphins' point distributions to be considered during the bandwidth selection, as opposed to concentrating on the size of the study area or the number of points in a given theme. A more thorough discussion of spatial point pattern analysis can be found in Bailey and Gatrell (1995).

Once the bandwidth size was determined for each dolphin theme, the Spatial Analyst extension was utilized for the calculation of SDC (see Appendix B). The extension allows the user to set an analysis mask, if desired. When this option is used, Spatial Analyst will only analyze the extent of the theme set as the mask. For this study, the land was excluded from any

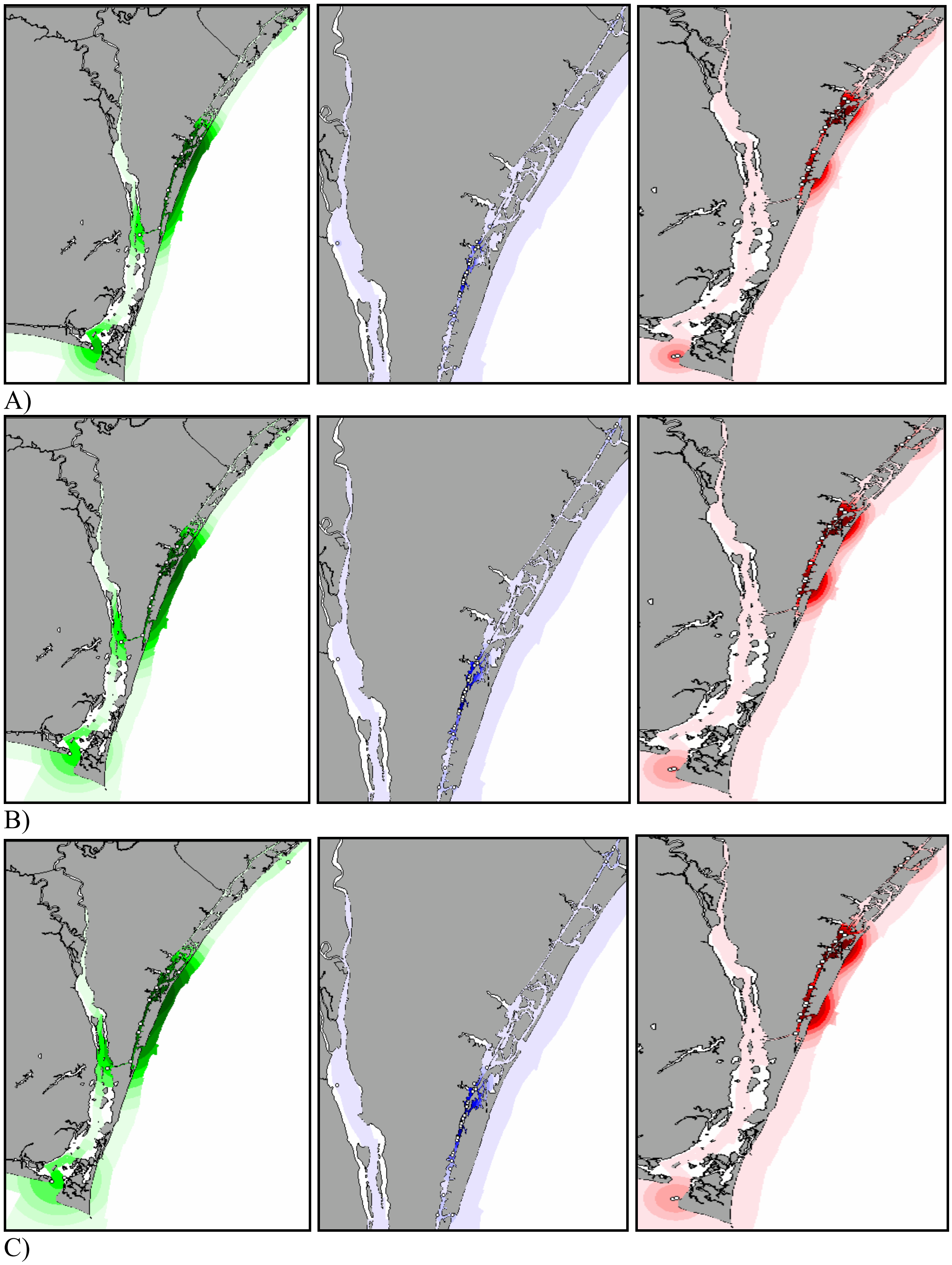


Figure 7. Results of bandwidth selection procedure using the Nearest Features extension on three dolphins' sighting shapefiles. Darker colors represent higher densities. Row A contains each dolphin's density output for k = 3; row B contains output for k = 4; row C contains output for k = 5.

SDC calculations. To create the mask, the study area shapefile was intersected with the effort polygons shapefile, resulting in a new theme. The query builder was used to select the land portions of the theme, and those selections were deleted. This process resulted in a grid theme containing only the water portions of the study area, which was then set as the analysis mask (Figure 8).

The "Calculate Density" option within the Spatial Analyst extension was used to calculate SDC for each dolphin. The calculation created a continuous surface grid that depicted the probability density based upon the distribution of dolphin sighting points. The density at each grid cell indicated the concentration of points in the surrounding area. Two methods for calculating density were available, simple and kernel; however, all area use calculations were performed using the kernel density type, which returned smoother results. The search radius, or bandwidth size, was chosen based upon the results of the neighborhood distance analysis with the Nearest Features extension described above.

Two SDC analyses were performed, non-weighted and weighted. The population field in the "Calculate Density" dialog box was used to allocate weight to the sighting points. In the non-weighted calculations, the population field was set to "None," thereby assigning each sighting point an equal value of 1. In the weighted calculations, the population field was set to an attribute that represented the survey effort for each section of the study area. For each dolphin, sighting points were intersected with the study area sections. This assigned each sighting point the inverse survey frequency value of the section in which the point appeared. Next, because the range of values for inverse survey frequency was so large, the values for each of the 40 dolphins were separated into three natural break classes and assigned a value of 1, 2, or 3. This resulted in a different range of values for each dolphin. Values of 1 assigned dolphin

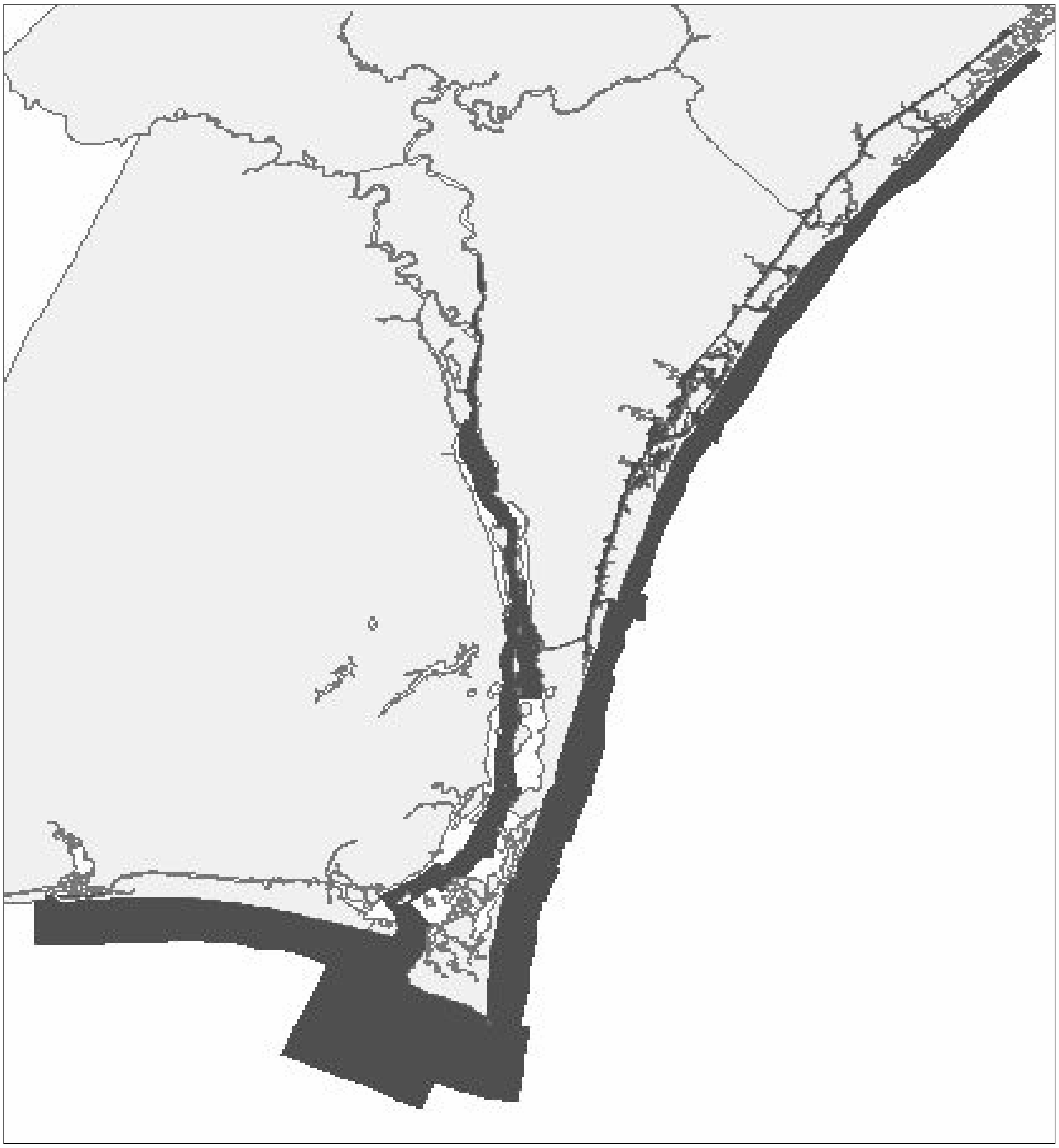


Figure 8. Results of analysis mask creation. Dark grey areas represent the water portions of the study area.

sighting points a small weight, values of 2 assigned a moderate weight, and values of 3 assigned a large weight. Figure 9 illustrates the weights assigned to three dolphins' sighting records.

The outputs of all SDC calculations were grid themes (Figure 10). To calculate the probability contours, the density values were divided by the maximum value within the grid using the Map Calculator in ArcView. These probability grid themes were queried three times to select the 95, 80, and 65% contours. The selected areas were then converted to new shapefiles. Next, an area field was added to the attribute tables. A shapefile containing all dolphins for each scenario (three probabilities and weighted/non-weighted) was created from each individual file. This resulted in the final SDC shapefiles.

The results from the four different LAU methods (ADK, MCP, SDC non- weighted, and SDC weighted) were tested for significant differences using the non-parametric Wilcoxon / Kruskal-Wallis test in the statistical software program JMP IN, version 5.1 (SAS 2003). Using the "Fit Y by X" command, the distribution of area values was plotted against the method employed to obtain the values, and the test was applied.

Nearest Neighbor Analysis

A measure of each dolphin's spatial distribution was calculated using the Nearest Neighbor tool from the Spatial Statistics ArcView extension (Monk 2001). This technique enabled an overall spatial analysis of each dolphin's point data. Nearest neighbor analysis is used to determine if a point pattern is clustered, uniform, or random. The observed mean distances between adjacent points are compared to expected mean distances of a theoretical random pattern. If the observed distances are greater than the expected distances, then the distribution is considered more uniform. If the observed distances are less than the expected

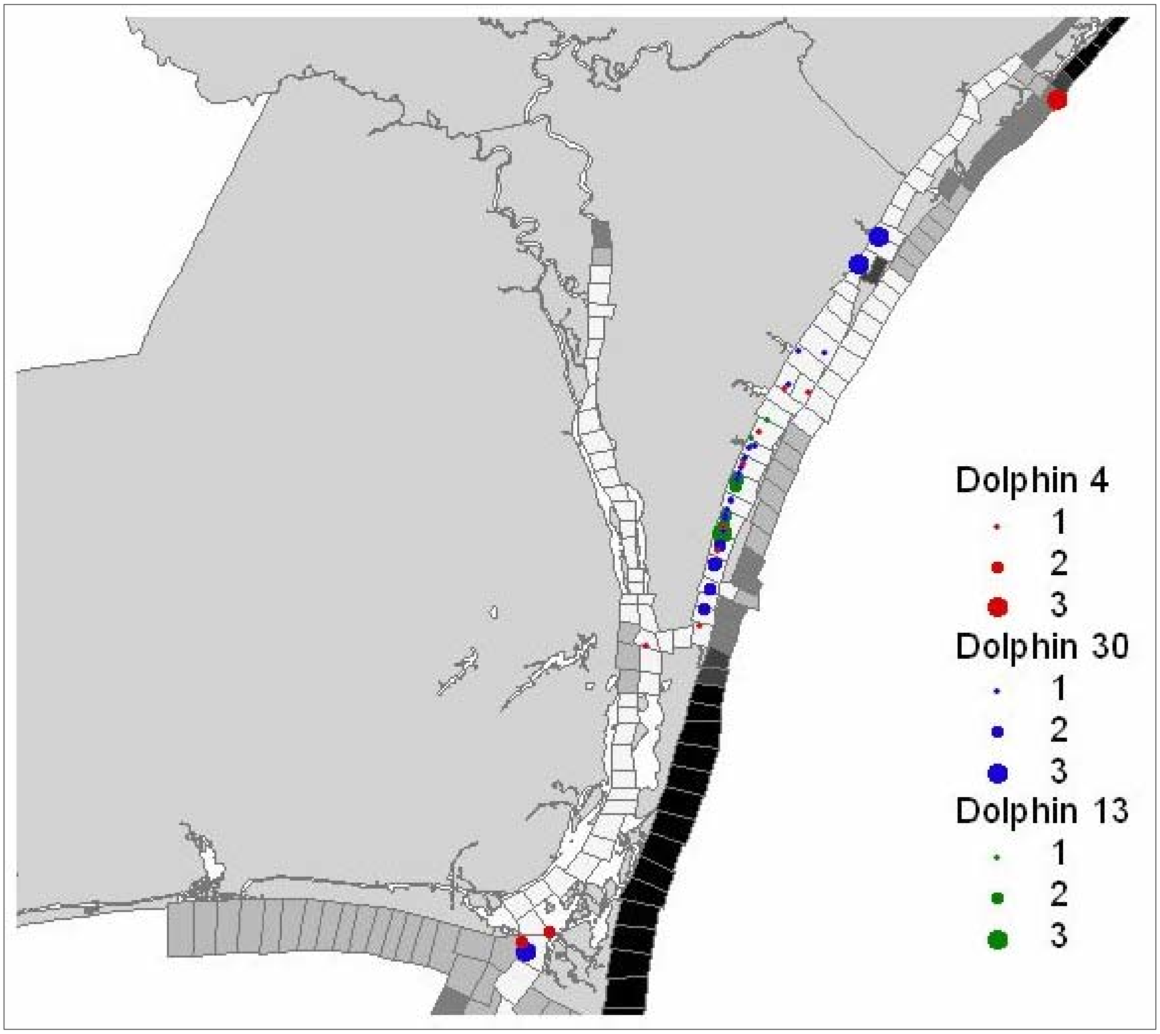
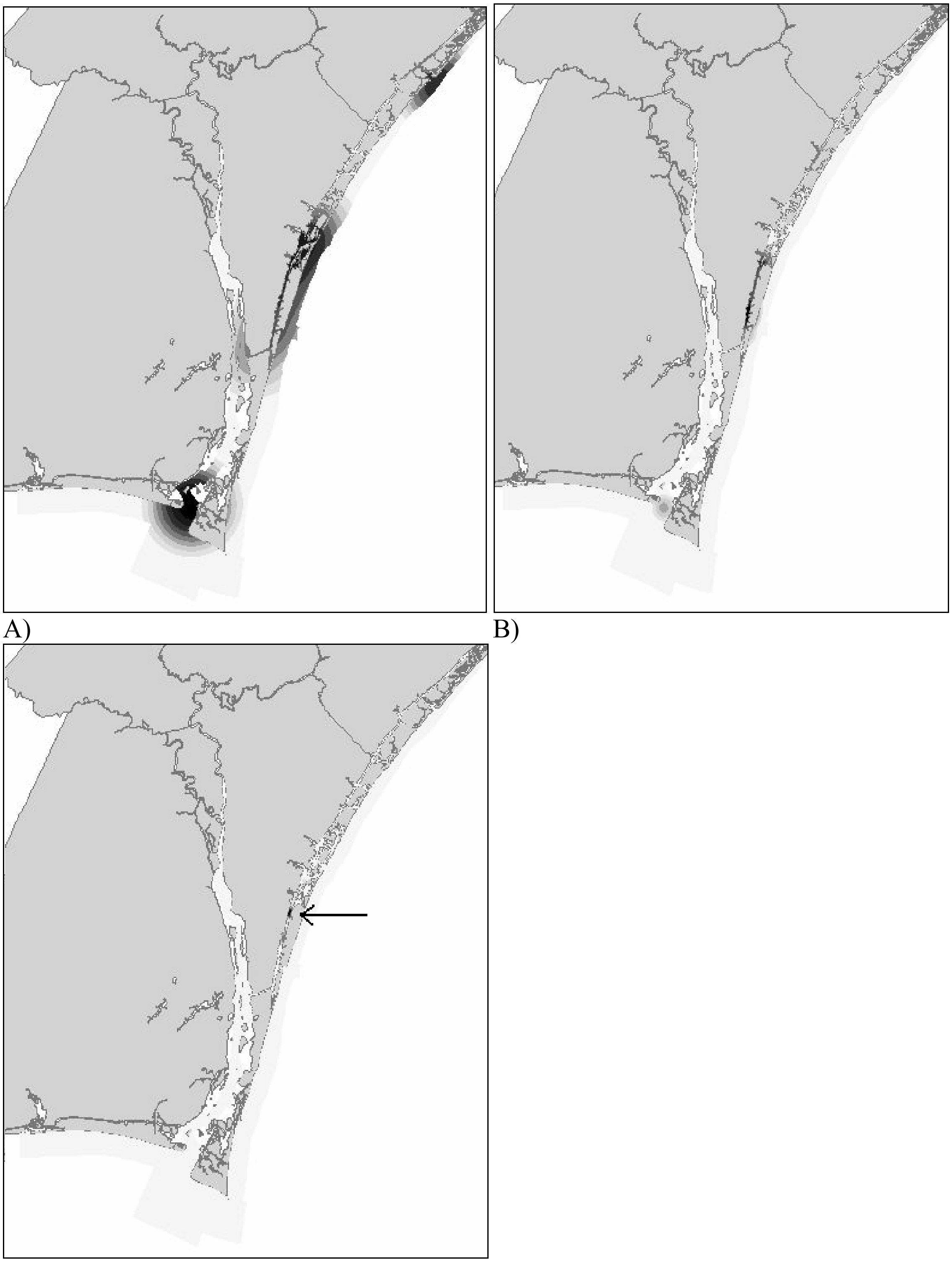


Figure 9. Depiction of three dolphins' sighting records, weighted according to survey effort values in the study area sections. Small points represent a value of 1 (small weight); medium points represent a value of 2 (medium weight); large points represent a value of 3 (large weight). Effort polygons are drawn according to the calculated survey effort values (as in Figure 6).



A) B)

C)

Figure 10. SDC output grid themes for dolphins 4, 30, and 13. Darker colors represent higher densities. A) Dolphin 4, illustrating a large SDC area with three core areas visible; B) Dolphin 30, illustrating a moderate SDC area with two core areas visible; C) Dolphin 13, illustrating a single small SDC area (indicated by the black arrow).

distances, then the distribution is considered more clustered. The output of the nearest neighbor analysis is a descriptive statistic, R, which ranges in value from 0 to 2.15. A value close to 0 indicates a clustered pattern, a value close to 2.15 indicates a uniform pattern, and a value close to 1 indicates a random pattern.

Coefficients of Association

Coefficients of association (CoAs) were computed using the computer software program SOCPROG (Whitehead 1999). The Half-Weight Index was used:

$$\frac{x}{0.5(n_a + n_b)}$$

where x is the number of times animals A and B were seen together, n_a is the number of times animal A was seen, and n_b is the number of times animal B was seen (Ginsberg and Young 1992). A matrix of CoA values was created by SOCPROG for all dolphins in the dataset. Dolphin pairs with a value greater than 0.2 were considered highly associated based upon the upper quartile of the data's distribution. The results were broken up into 6 classes: 0, 0.01 - 0.2, 0.21 - 0.4, 0.41 - 0.6, 0.61 - 0.8, and 0.81 - 1.0, and the total number of values in each class was determined.

Community Structure

Data on LAU and CoA patterns of individuals were analyzed to determine whether or not multiple dolphin communities exist within the study area. A percentage of overlap was calculated between each dolphin and the other 39 dolphins for each of the three density contours (95, 80, and 65%). The shapefiles containing the total SDC polygons for all 40 dolphins were queried for each dolphin pair and the total area was compared to the amount of shared (overlapped) area. Shared area values were divided by total area values and then multiplied by 100 to obtain the percentage of overlap for each pair and for each probability contour (95, 80, and 65%). These values were then compared to each pair's CoA value to provide insights into the possible existence of communities.

Each dolphin pair for each probability was assigned to one of six groups: HH, MH, LL, HL, ML, or LH. A high or moderate amount of overlap and a high CoA value (HH and MH) indicated that the animals used the same area and were often seen together. A low amount of overlap and a low CoA value (LL) indicated that the animals did not use the same area and were not often seen together. A high or moderate amount of overlap and a low CoA value (HL and ML) indicated that the animals used the same area but were not often seen together. A low amount of overlap and a high CoA value (LH) indicated that the animals did not use the same area but were often seen together. Degree of overlap was determined to be high, moderate, or low based upon the distribution of data for each probability. Percent overlap values above the third quartile (75%) were considered high, values below the first quartile (25%) were considered low, and values in between the first and third quartiles were considered moderate. A correlation test was performed in Excel to statistically determine if a relationship existed between each pair's CoA value and the percentage of overlap for each density contour.

Regional Analysis

Chi-square tests were performed on generalized regional (ICW, CFR, ocean, and inlets) data to determine if a relationship existed between the number of surveys carried out and the number of sightings documented in each region. The total numbers of surveys and sightings were tallied for the ICW, inlets, Cape Fear River, and nearshore ocean, expected values were calculated (based upon survey effort), and a chi-square test was performed. In addition, chi-square tests were performed to determine if individual dolphins exhibited a preference for any particular region. Each dolphin's total number of sightings was tallied for each of the four regions, expected values were calculated (based upon survey effort), and the chi-square test was applied.

To examine regional preference in more detail, further analysis was conducted using the SDC results for each dolphin. First, the survey effort sections were assigned an attribute based on the region in which they occurred: ICW = 1, inlets = 2, Cape Fear River = 3, and ocean = 4. Next, a shapefile containing each region was created, resulting in the collective areas of the four regions throughout the study area (Figure 11). Then, each dolphin's SDC shapefile for each of the three probabilities (*i.e.* 65, 80, and 95%) was intersected with the regional shapefile, which assigned each portion of the SDC polygon an attribute based on region (1, 2, 3, or 4). Observed region percentage values were calculated for each dolphin by dividing the total area for each region by the total area of all regions. Expected values were assigned based upon each region's percentage of the study area. Total percentages of preference for each region were calculated using a tally of each dolphin's preferred region. Chi-square tests were performed on each dolphin's percentage results and on the total percentage results for each region to determine if there were significant differences for any of the three probabilities.

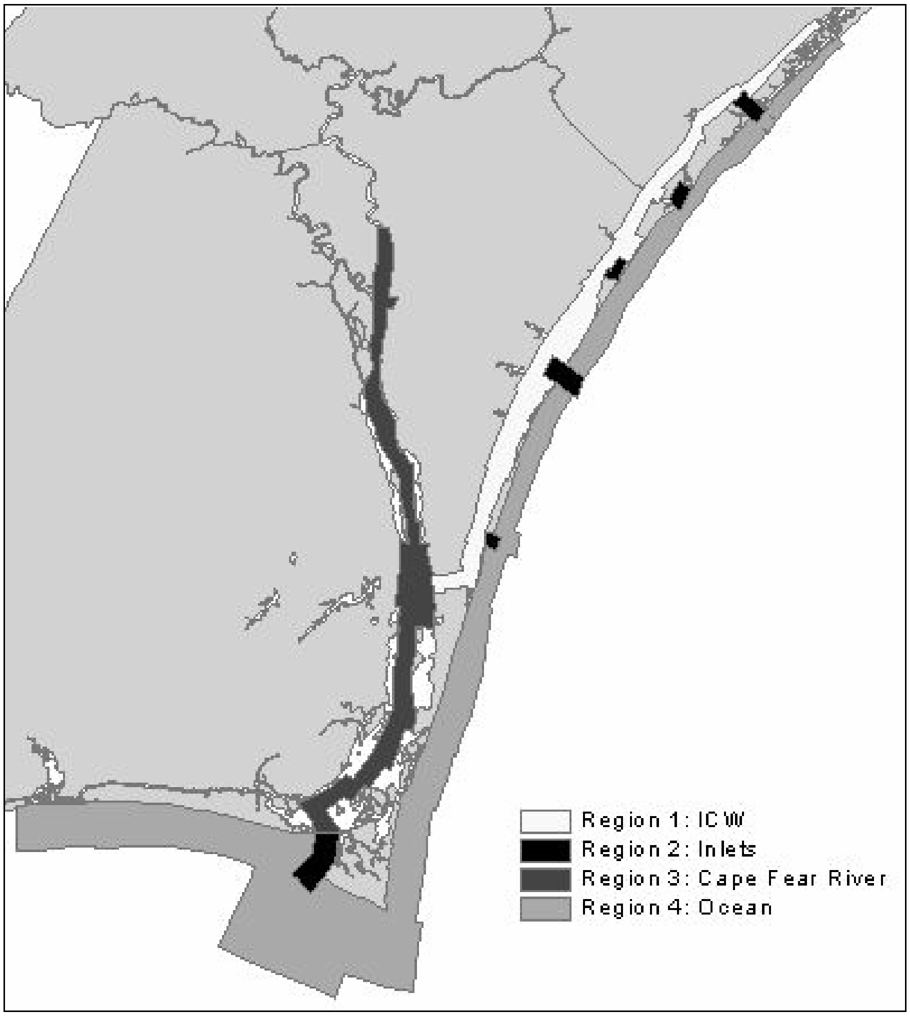


Figure 11. Study area defined by four distinct regions for use in regional preference analysis.

RESULTS

Seasonality Analysis

Dolphin sighting records for each season are illustrated in Figure 12. There was no significant difference in the number of sightings in different seasons after adjusting for survey effort ($\chi^2 = 1.3$, $p = 0.7$, Table 2). However, the sightings of 22 of the 40 dolphins (55%) varied significantly with season (Table 3). Of these 22 dolphins, 10 favored the study area in the fall, 8 in the winter, 2 in the spring, and 2 in the summer. Twenty-five (62.5%) dolphins were seen year-round, in all four seasons.

Local Area Use

ADK area results ranged from 21.7 to 1162.6 km^2 for the 95% contour, 12.5 to 568.5 km^2 for the 80% contour, and 6.8 to 341.9 km^2 for the 65% contour (Table 4). Many of the contours included land, and the area of land was not subtracted (Figure 13). MCP area results were somewhat similar and ranged from 2.3 to 333.1 km^2 (Table 5). Many of the results included land, and the area of land again was not subtracted from the analysis (Figure 14). SDC area results had smaller sizes and are summarized in Table 6. None of the contours included land given that a mask was applied (Figure 15).

The Wilcoxon / Kruskal-Wallis test on the four LAU methods returned significant p-values (<0.001) for all three probability contours. Results from the two SDC methods (weighted and non-weighted) were very similar for all three contours; however, results from the ADK and MCP methods were significantly higher than the SDC results for all three probability contours. This indicated that SDC was preferable for calculating the dolphins' local area use. Of the two SDC methods used, the results with the weighted technique were chosen for more detailed

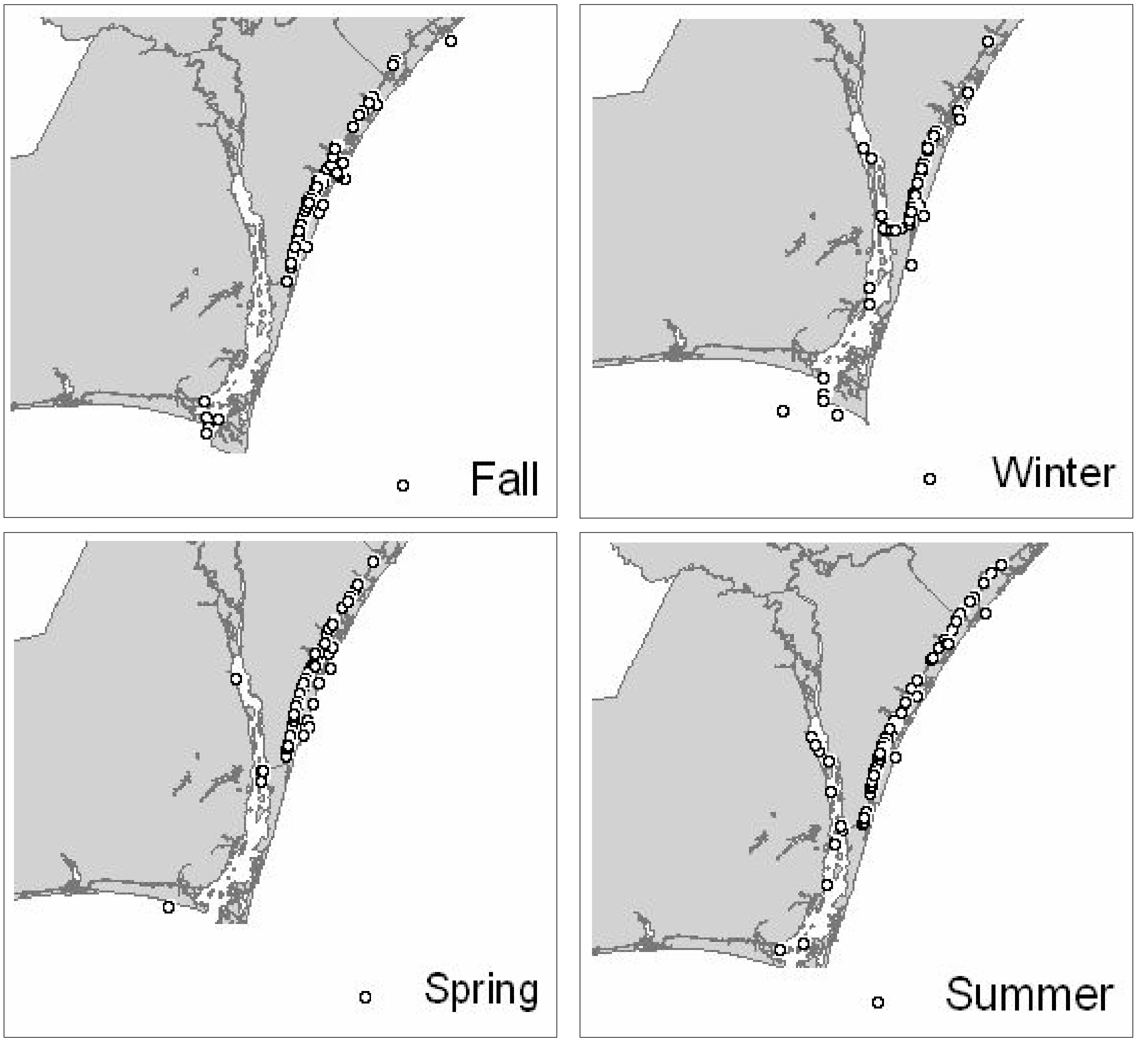


Figure 12. Sighting locations for the 40 dolphins according to season.

Table 2. Values used to calculate chi-square test for season.

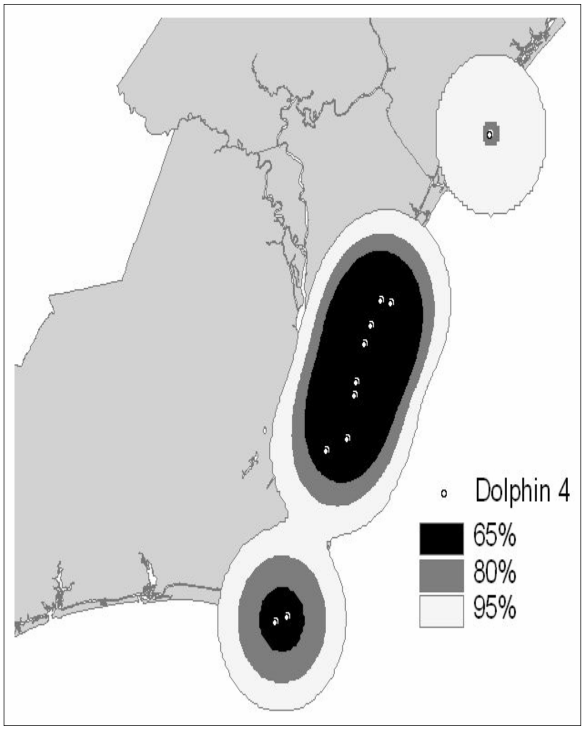
	Fall	Winter	Spring	Summer	Total
# of Sightings (observed)	103	69	76	119	367
# of Surveys	87	56	73	107	323
# of Sightings (expected)	98.9	63.6	82.9	121.6	

Table 3. Season chi-square results and P values for individual dolphins.

Dolphin No.	Chi-square	P value	Preferred Season	No. Seasons Observed
1	3.7	0.3	none	4
2	10	0.01	winter	3
3	2.8	0.4	none	4
4	3.7	0.3	none	4
5	10	0.01	spring	3
6	8.7	0.03	fall	4
7	34.5	1.50E-07	winter	3
8	9.7	0.02	fall	3
9	9.4	0.02	summer	3
10	2.9	0.4	none	4
11	10.7	0.01	fall	2
12	12.6	0.005	fall	4
13	9.4	0.02	fall	2
14	11.8	0.008	winter	4
15	3.8	0.3	none	4
16	10.6	0.01	winter	3
17	8.6	0.04	fall	4
18	26.8	6.50E-06	winter	4
19	2.7	0.4	none	4
20	27.2	5.40E-06	fall	3
21	1.9	0.6	none	4
22	8.5	0.04	winter	4
23	16.5	0.0009	summer	3
24	18.1	0.0004	winter	4
25	4.1	0.3	none	3
26	2.5	0.5	none	3
27	2.3	0.5	none	4
28	6.3	0.1	none	4
29	8	0.05	fall	2
30	2.4	0.5	none	4
31	14.7	0.002	fall	2
32	0.3	0.9	none	4
33	3.6	0.3	none	4
34	7.3	0.06	none	3
35	14.3	0.002	spring	4
36	6.7	0.08	none	4
37	11.6	0.009	fall	4
38	3.8	0.3	none	4
39	3.7	0.3	none	4
40	11.2	0.01	winter	4

Table 4. Area values resulting from the ADK method, given in square kilometers.

Dolphin No.	65% Contour	80% Contour	95% Contour
1	209.7	399.2	725.0
2	35.6	64.8	149.3
3	39.5	102.7	237.4
4	341.9	568.5	1162.6
5	55.0	86.8	185.5
6	115.6	162.3	368.4
7	88.1	133.3	263.7
8	39.8	68.2	142.5
9	32.5	57.9	142.6
10	280.9	475.9	726.5
11	119.3	241.7	555.8
12	31.4	48.1	117.8
13	6.9	12.5	21.7
14	121.8	183.4	269.1
15	223.5	354.4	648.2
16	111.8	156.7	336.7
17	143.5	214.7	535.4
18	102.4	152.0	385.7
19	136.3	217.2	606.6
20	39.9	72.8	173.0
21	144.3	229.6	476.5
22	144.3	292.0	624.6
23	83.1	114.8	240.2
24	128.6	201.2	518.3
25	102.1	143.9	297.6
26	81.2	118.7	283.0
27	131.8	201.6	538.2
28	62.2	100.6	213.7
29	12.7	22.4	39.5
30	62.9	100.9	241.1
31	40.9	65.9	122.8
32	190.6	331.9	692.3
33	108.6	154.0	341.1
34	63.4	101.5	190.3
35	35.9	65.4	121.3
36	50.4	70.7	135.2
37	60.5	94.3	182.2
38	63.5	99.6	193.3
39	103.0	149.9	287.3
40	91.9	135.2	263.5



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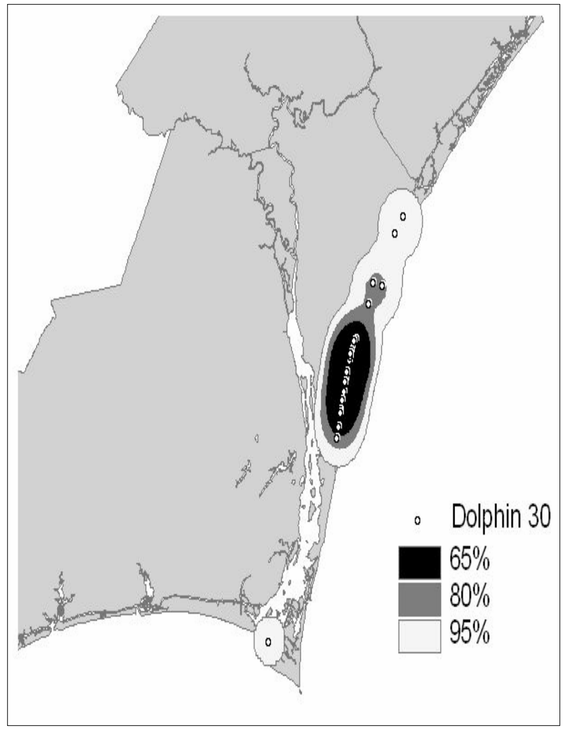

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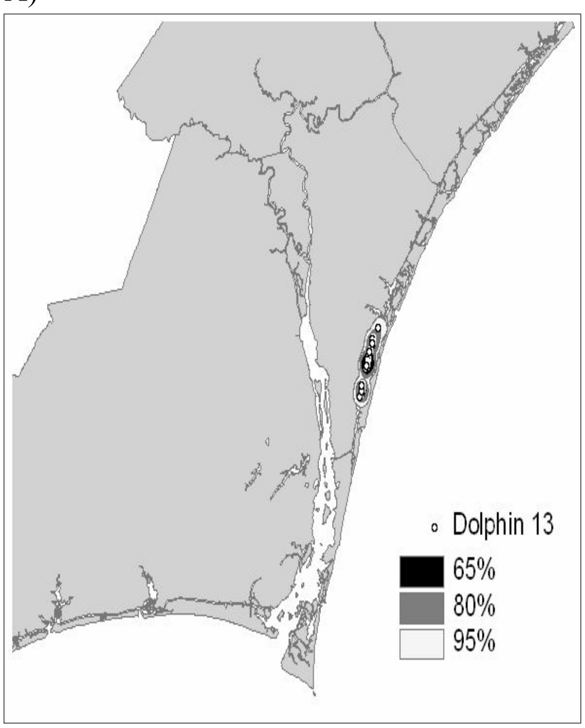
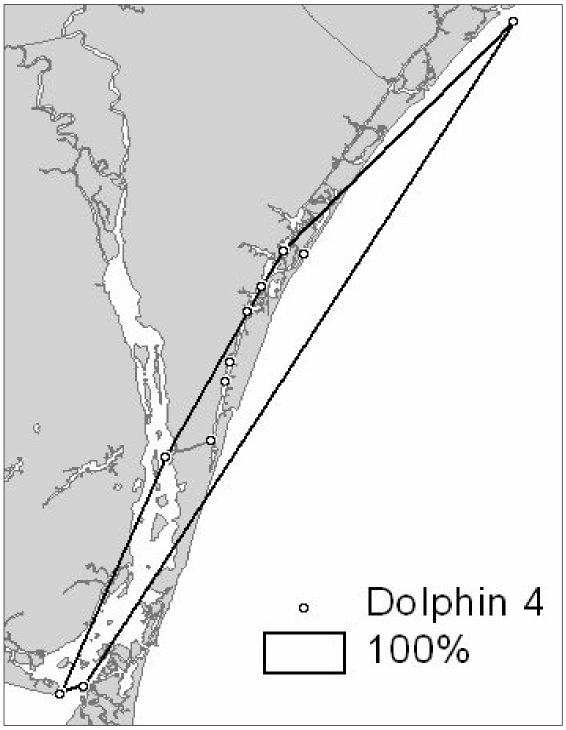


C)

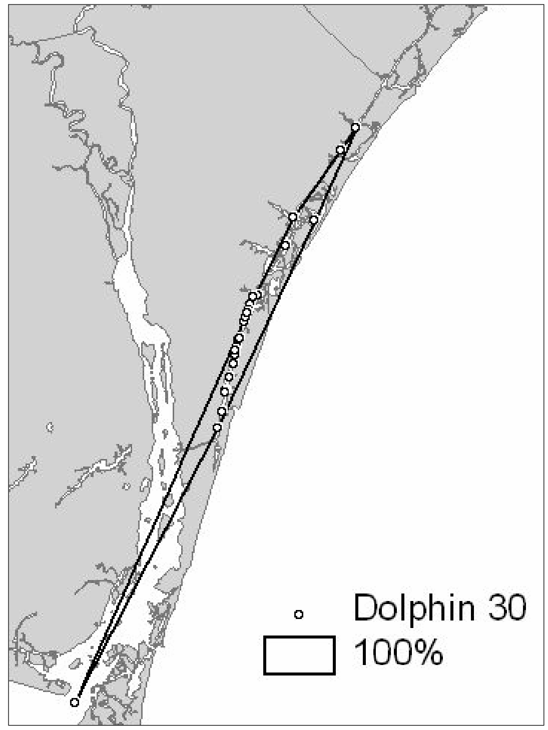
Figure 13. Results of local area use calculations with the ADK method for A) dolphin 4, B) dolphin 30, and C) dolphin 13. These examples illustrate the range in local area use estimates.

Table 5. Area values resulting from the MCP method, given in square kilometers.

Dolphin No.	100% Contour
1	149.3
2	97.2
3	103.7
4	189.9
5	136.8
6	46.1
7	99.9
8	62.9
9	40.8
10	129.9
11	197.6
12	167.1
13	2.3
14	58.6
15	201.7
16	146.0
17	176.7
18	137.4
19	218.5
20	58.8
21	52.3
22	145.6
23	184.0
24	143.9
25	18.0
26	47.7
27	229.3
28	296.7
29	8.7
30	50.0
31	41.1
32	333.1
33	85.9
34	60.0
35	19.3
36	116.1
37	59.6
38	64.3
39	93.2
40	89.3



A)



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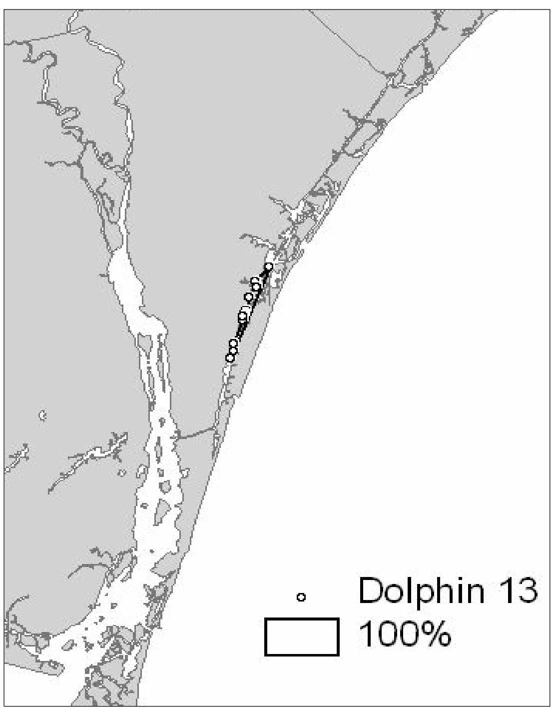
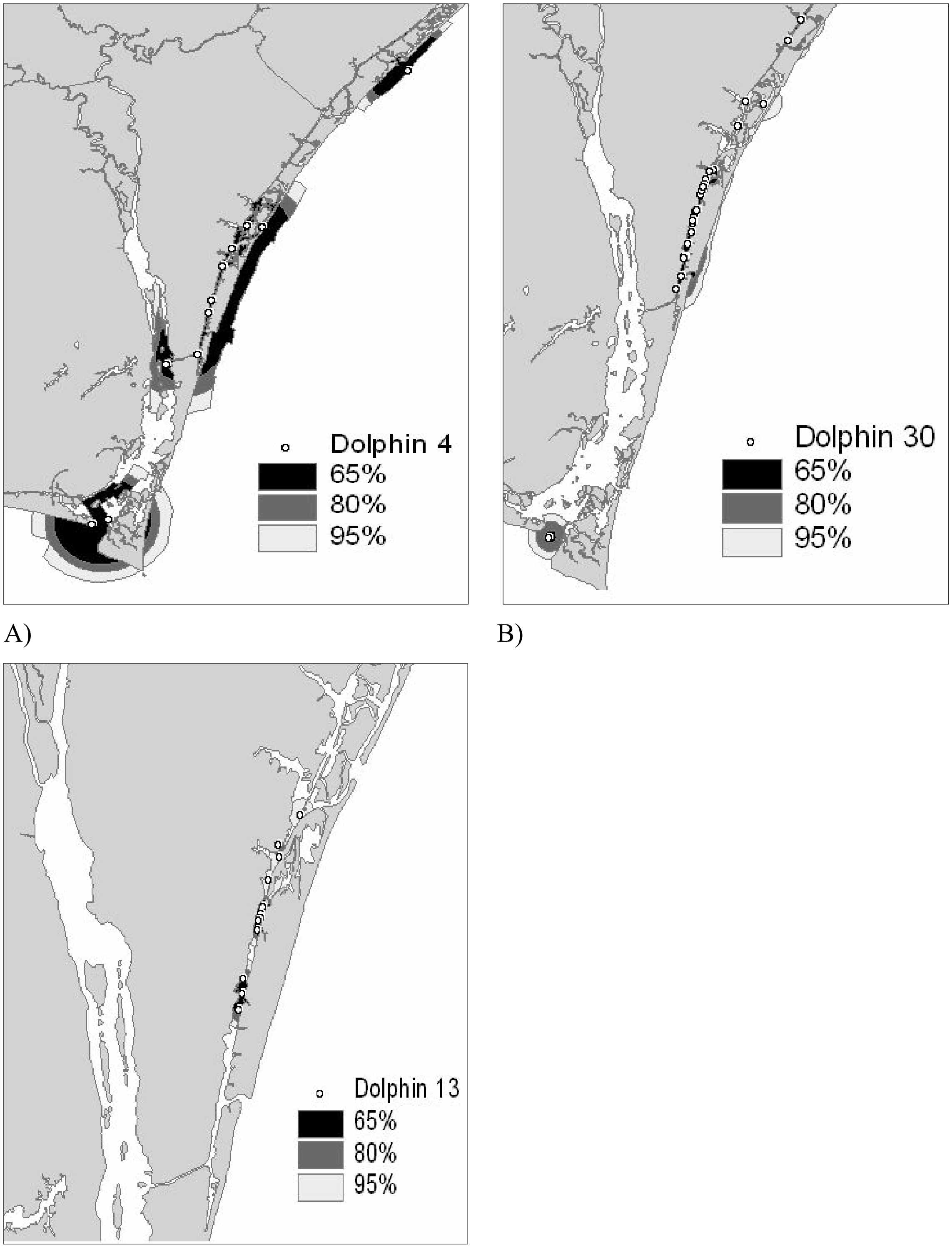


C)

Figure 14. Results of local area use calculations with the MCP method for A) dolphin 4, B) dolphin 30, and C) dolphin 13. These examples illustrate the range in local area use estimates.

Table 6. Area values resulting from the SDC method, given in square kilometers.

Dolphin No.	65% SDC, non-weighted	65% SDC, weighted	80% SDC, non-weighted	80% SDC, weighted	95% SDC, non-weighted	95% SDC, weighted
1	32.6	37.5	63.8	63.6	93.1	94.8
2	2.7	6.9	5.7	15.5	23.0	25.3
3	10.1	19.2	27.9	32.9	57.7	58.4
4	70.4	87.9	102.5	120.3	155.3	165.1
5	6.6	8.7	15.1	16.0	28.9	27.9
6	5.4	11.9	11.6	22.1	34.4	39.2
7	4.4	8.2	8.9	17.2	32.1	35.2
8	1.6	2.4	2.9	6.0	5.8	11.8
9	2.4	7.4	4.6	11.8	17.8	21.0
10	19.8	27.3	36.3	41.6	62.6	65.0
11	14.8	26.9	39.9	55.5	92.4	96.5
12	1.1	1.8	2.0	4.0	5.6	6.6
13	0.8	0.8	1.7	1.1	3.0	2.7
14	5.6	8.1	10.6	13.1	16.9	17.9
15	8.7	12.7	21.0	24.6	46.5	47.1
16	11.2	21.3	21.7	39.6	50.7	53.9
17	11.2	23.7	27.9	44.3	75.8	82.2
18	5.7	5.7	17.1	17.1	51.6	51.6
19	8.4	18.5	18.3	30.5	49.6	54.4
20	3.9	10.1	8.4	18.5	28.4	31.7
21	11.7	20.8	25.2	32.5	50.5	54.7
22	9.9	24.2	21.1	34.2	44.6	49.4
23	4.3	9.4	6.7	16.1	23.9	27.7
24	7.8	21.8	15.9	33.3	52.0	57.4
25	9.5	8.4	14.8	21.1	37.3	43.8
26	13.4	13.7	19.6	17.7	35.6	34.4
27	9.4	19.9	20.5	32.7	58.4	63.3
28	5.1	5.8	8.5	16.3	34.2	41.4
29	2.6	4.0	4.5	5.5	6.7	7.2
30	3.9	5.6	7.7	12.0	26.4	27.7
31	2.3	4.7	3.9	8.2	12.1	13.9
32	17.5	17.7	38.6	44.9	72.5	72.9
33	20.2	20.1	24.6	31.0	53.5	58.0
34	3.9	3.9	10.7	10.7	24.0	24.0
35	2.9	2.6	4.4	4.2	6.9	6.7
36	2.7	3.6	4.6	6.2	11.7	12.7
37	1.7	1.4	2.5	3.7	9.8	10.3
38	4.8	11.6	10.6	18.5	23.9	25.3
39	13.9	22.8	28.7	37.0	46.5	47.8
40	7.6	11.8	20.1	24.9	39.2	40.2



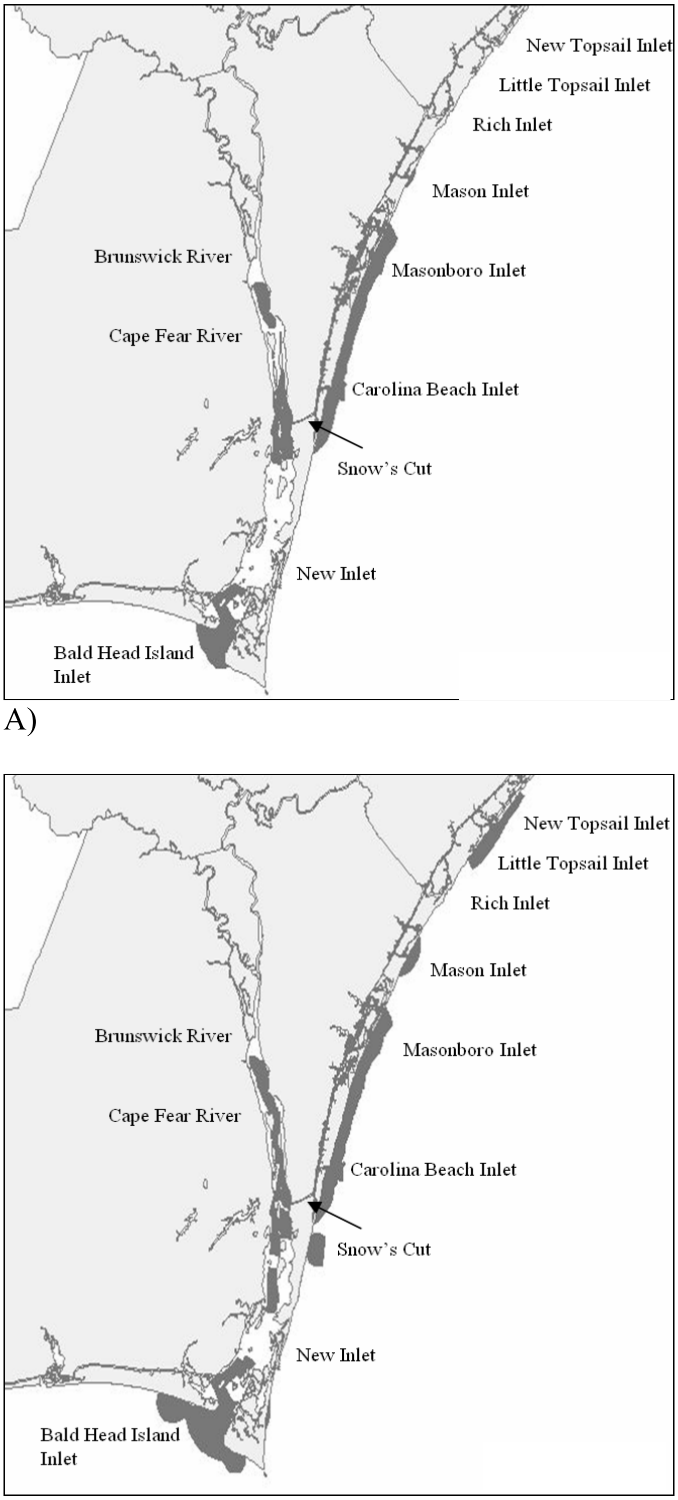
A) B) C)

Figure 15. Results of local area use calculations with the SDC method for A) dolphin 4, B) dolphin 30, and C) dolphin 13. The examples illustrate the range in local area use estimates.

analysis, since the weighting accounted for variations in survey effort.

By combining the SDC results for all 40 dolphins, several places in the study area appeared to be heavily used. The non-weighted results for the three probability contours are included with the figures of the weighted results for comparison; however, the non-weighted results are not specifically discussed since no further analysis was conducted on them. The weighted 65% results included a total of 137 square kilometers (Figure 16). With the exception of a few small sections between New Topsail Inlet and Masonboro Inlet, the results covered the entire ICW from New Topsail Inlet to Snow's Cut. The results also incorporated the entire stretch of ocean between Masonboro and Carolina Beach inlets, the areas surrounding New Topsail, Little Topsail, and Mason inlets on the ocean side, as well as a small circular section of ocean water south of Carolina Beach Inlet and a small elongated section of ocean water just south of New Inlet. In addition, the weighted 65% results encompassed much of the Cape Fear River, with only the area north of the Brunswick River, a small section in the middle of the river, and a larger stretch slightly farther south excluded. The southernmost area of the results included portions of ocean water to the east and the west of the inlet near Bald Head Island, as well as the inlet itself.

The weighted 80% results contained all of the areas within the weighted 65% results plus an additional 37 square kilometers (Figure 17). Area extent was slightly larger around the ocean sides of New Topsail, Little Topsail, Mason, New, and the Bald Head Island inlets. The Cape Fear River was almost entirely included, with the exception of the area north of the Brunswick River and a small area north of New Inlet, part of the same region excluded in the weighted 65% results.



A)

B)

Figure 16. Unioned SDC polygon shapefiles for A) 65% non-weighted and B) 65% weighted.

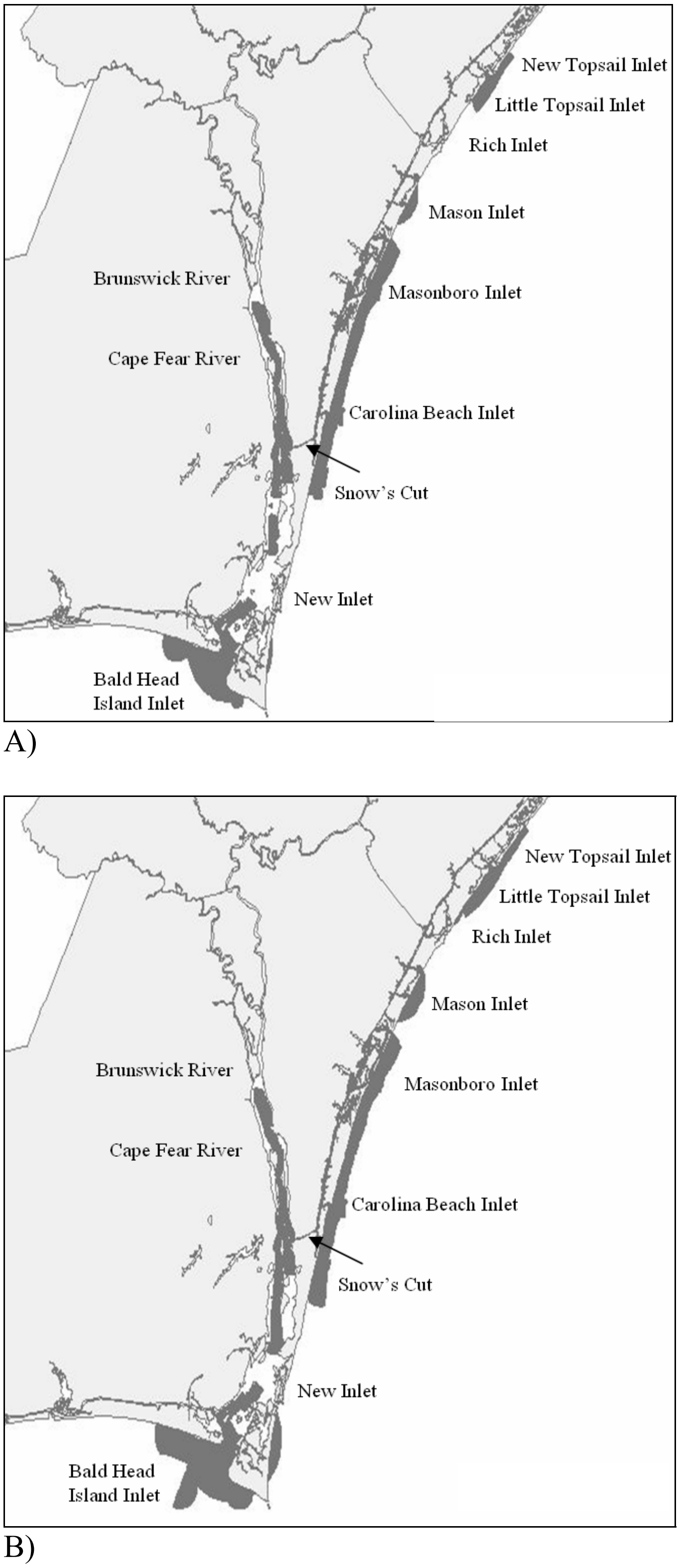
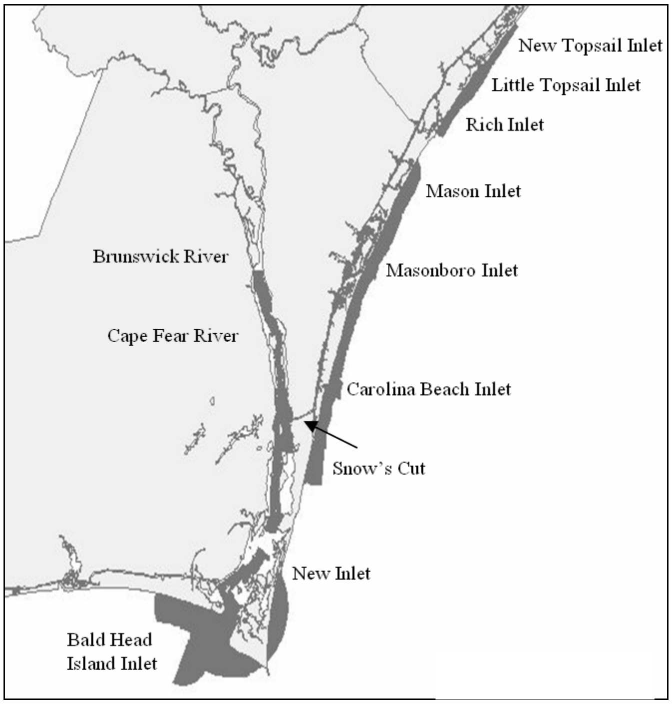


Figure 17. Unioned SDC polygon shapefiles for A) 80% non-weighted and B) 80% weighted.

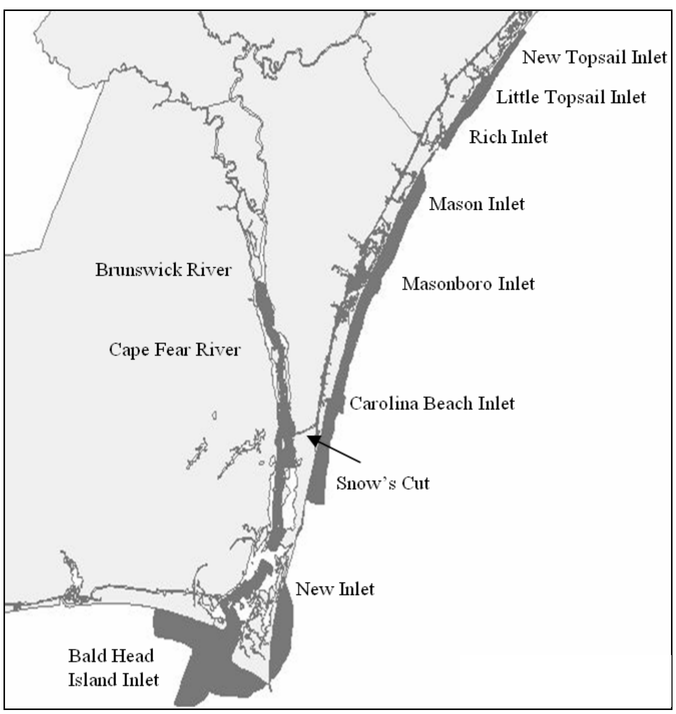
The weighted 95% results contained all of the areas within the weighted 80% results plus an additional 64 square kilometers (Figure 18). The entire ICW was included, as well as most of the Cape Fear River, with the exception of the area north of the Brunswick River and a small area just north of New Inlet, part of the same region excluded in the weighted 80% results. The ocean portions of the output expanded around New Topsail, Little Topsail, Mason, Masonboro, Carolina Beach, New, and the Bald Head Island inlets, with only a small area between Rich and Mason inlets and a slightly larger area to the north of New Inlet excluded.

Nearest Neighbor Analysis

Nearest neighbor R values ranged from 0.19 to 1.74 (Table 7). R values were separated into 8 classes: 1) 0.00-0.20, 2) 0.21-0.40, 3) 0.41-0.60, 4) 0.61-0.80, 5) 0.81-1.00, 6)1.01-1.20, 7) 1.21-1.40, and 8) 1.41-1.80. Classes 1 through 3 were considered “clustered” (13 dolphins); class 4 was considered “clustered / random” (10 dolphins); classes 5 and 6 were considered “random” (12 dolphins); class 7 was considered “random / uniform” (3 dolphins); and class 8 was considered “uniform” (2 dolphins). To visualize the nearest neighbor results, the SDC polygons for each dolphin were mapped by the R-value classes. This is illustrated in Figure 19 with the 65% SDC contours for all 40 dolphins. Results indicated that the nearest neighbor statistic, although designed to quantify point distributions in space, did not accurately illustrate distinct differences in the spatial distributions of the 40 dolphins. Nearest neighbor works best in areas that are as wide as they are long. The shape of the study area is long and linear with a small width and therefore does not provide the ideal area in which the statistic should be performed.



A)



B)

Figure 18. Unioned SDC polygon shapefiles for A) 95% non-weighted and B) 95% weighted.

Table 7. Results of nearest neighbor analysis.

Dolphin No.	R-value	Distribution	Class
1	0.4532	cluster	3
2	0.6683	cluster / random	4
3	0.9181	random	5
4	1.4481	uniform	8
5	0.7140	cluster / random	4
6	0.5144	cluster	3
7	0.8849	random	5
8	0.3765	cluster	2
9	0.6303	cluster / random	4
10	0.7157	cluster / random	4
11	1.1226	random	6
12	0.3966	cluster	2
13	0.1901	cluster	1
14	0.4722	cluster	3
15	0.8714	random	5
16	1.2503	random / uniform	7
17	1.1383	random	6
18	0.6710	cluster / random	4
19	0.6590	cluster / random	4
20	0.7820	cluster / random	4
21	0.3134	cluster	2
22	0.6482	cluster / random	4
23	0.9421	random	5
24	0.6919	cluster / random	4
25	1.3488	random / uniform	7
26	1.1204	random	6
27	0.7477	cluster / random	4
28	1.2745	random / uniform	7
29	0.2017	cluster	1
30	0.8898	random	5
31	0.4323	cluster	3
32	1.0995	random	6
33	1.7414	uniform	8
34	0.8406	random	5
35	0.2140	cluster	2
36	0.5533	cluster	3
37	0.4954	cluster	3
38	0.4627	cluster	3
39	1.0534	random	6
40	0.9276	random	5

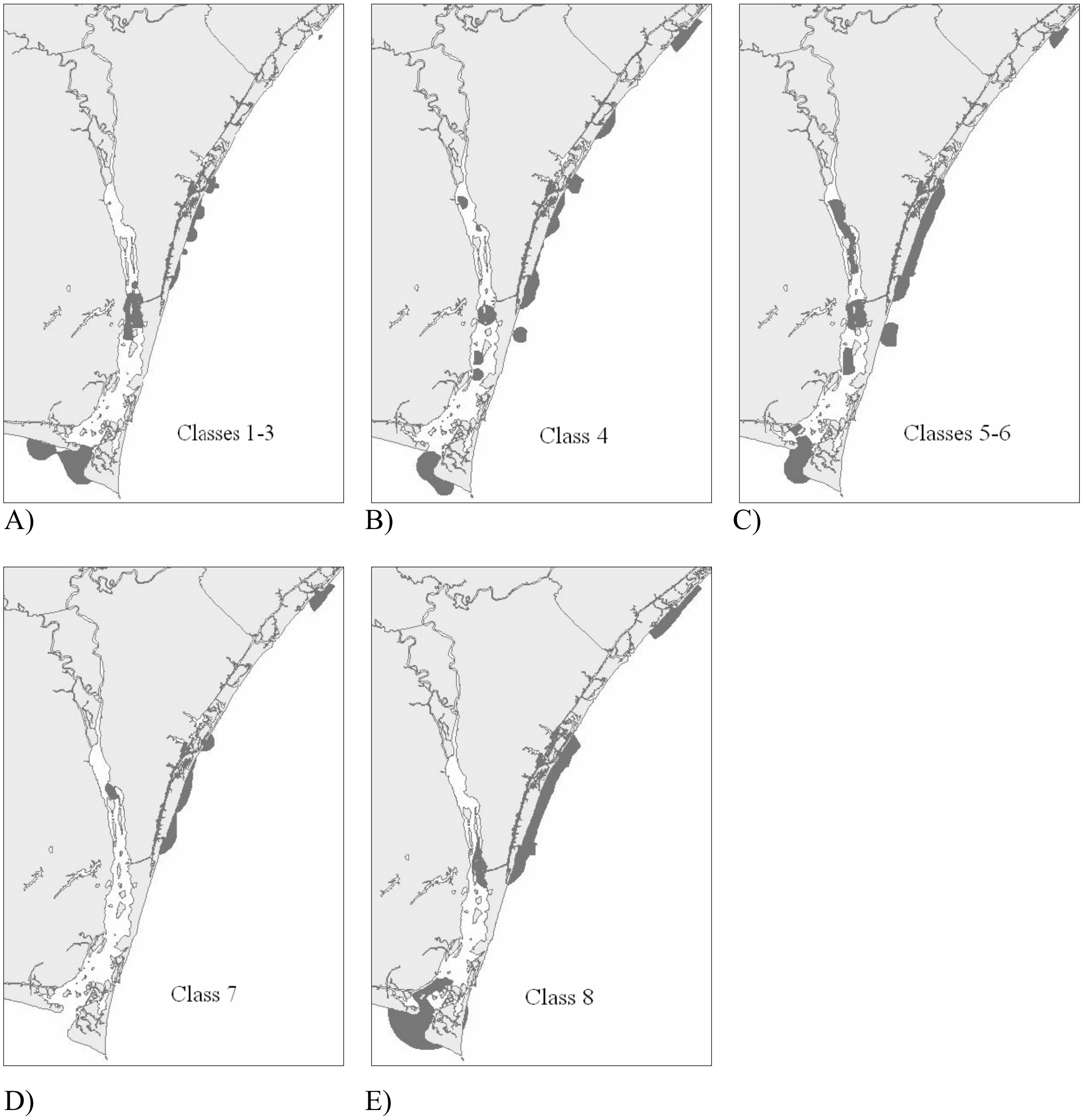


Figure 19. Nearest neighbor distribution maps drawn with weighted SDC polygons, 65% contour. A) Classes 1, 2, and 3 (cluster); B) Class 4 (cluster / random); C) Classes 5 and 6 (random); D) Class 7 (random / uniform); and E) Class 8 (uniform).

Coefficients of Association

A matrix of CoA values was created by SOCPROG for all dolphins in the dataset. Values ranged from 0 to 0.93. Out of a possible 780 associations, 52.9 % (413) of the values equaled 0; 38.7% (302) of the values were between 0.01 and 0.20; 6.1% (48) were between 0.21 and 0.40; 1.5% (12) were between 0.41 and 0.60; 0.3% (2) were between 0.61 and 0.80; and 0.4% (3) were between 0.81 and 1.0 (Figure 20). There were 64 dolphin pairs considered highly associated (>0.2).

Community Structure

Shared area, total area, and percent overlap values are summarized in Table 8. Percent overlap quartiles and medians for the three probabilities are given in Table 9. The distribution of dolphin pairs belonging to each percent overlap / CoA group for each probability contour is illustrated in Figure 21. Ninety-two percent of the dolphin pairs had low CoA values, while only 8% had high CoA values. However, regardless of CoA value, only 193 dolphin pairs had a low percentage of overlap, with the remaining 587 pairs exhibiting a high or moderate percentage of overlap.

Figures 22 through 25 depict four examples each for the LH (low overlap and high CoA), HH (high overlap and high CoA), LL (low overlap and low CoA), and HL (high overlap and low CoA) groups. Only the 65% probability contour is represented in each case, and the specific data associated with the examples are found in Table 10. Correlation test results were 0.4 for the 65% contour, 0.4 for the 80% contour, and 0.3 for the 95% contour, which indicated a weak association between percent overlap and CoA values. The total SDC polygons for each probability were analyzed to determine locations where all 40 dolphins occurred, with the results

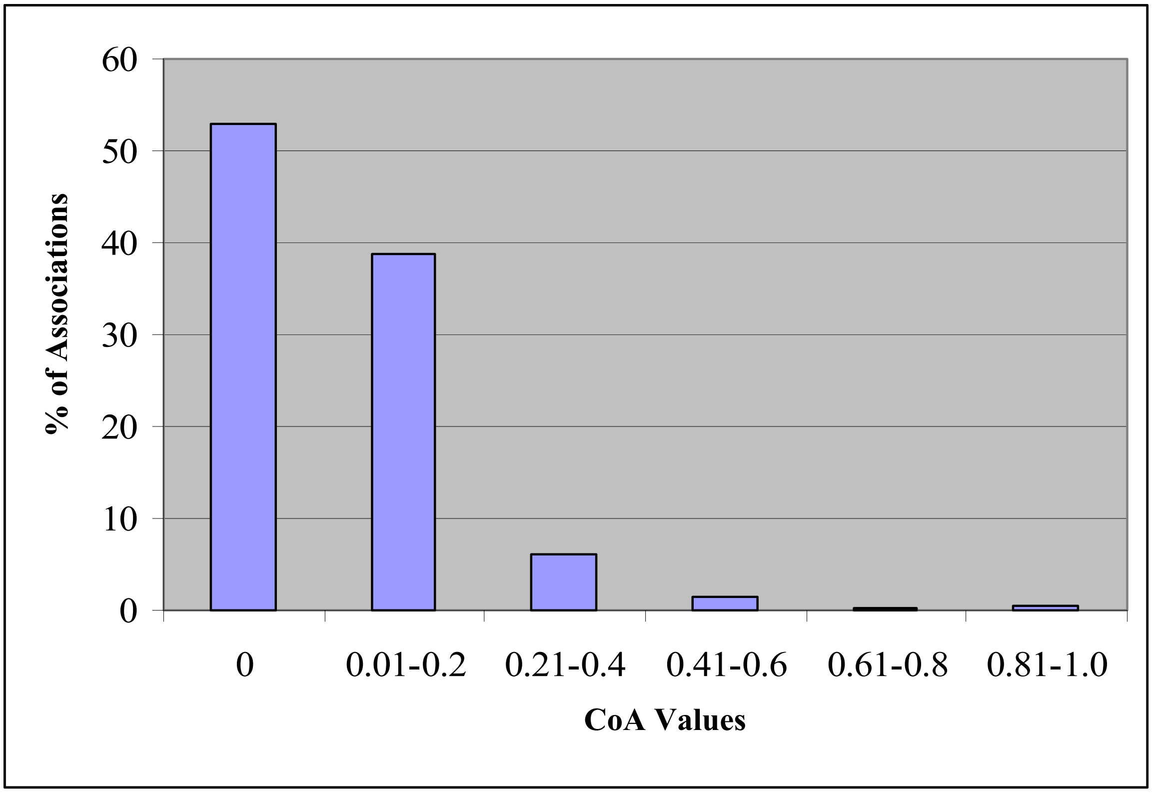


Figure 20. CoA value distribution by class.

Table 8. Summary statistics for shared area values, total area values, and percent overlap results. A) 65% contour; B) 80% contour; C) 95% contour.

	Minimum Value	Mean Value	Maximum Value
Shared Area (km^2)	0.0	4.2	25.1
Total Area (km^2)	25.6	32.1	1292.6
Percent Overlap (%)	0.0	13.1	44.4

A)

	Minimum Value	Mean Value	Maximum Value
Shared Area (km^2)	0.5	8.9	54.8
Total Area (km^2)	48.2	52.6	1875.3
Percent Overlap (%)	0.9	16.4	45.0

B)

	Minimum Value	Mean Value	Maximum Value
Shared Area (km^2)	2.2	23.9	99.7
Total Area (km^2)	128.9	103.5	2869.9
Percent Overlap (%)	2.3	22.1	46.1

C)

Table 9. Percent overlap quartile and median values for the three probabilities. Percent overlap values above the third quartile (75%) were considered to be high; values below the first quartile (25%) were considered to be low; values in between the first and third quartiles were considered to be moderate.

Probability	First Quartile	Median	Third Quartile
65	8	12.1	17.5
80	10.9	15.7	21.5
95	17.1	22.6	27.4

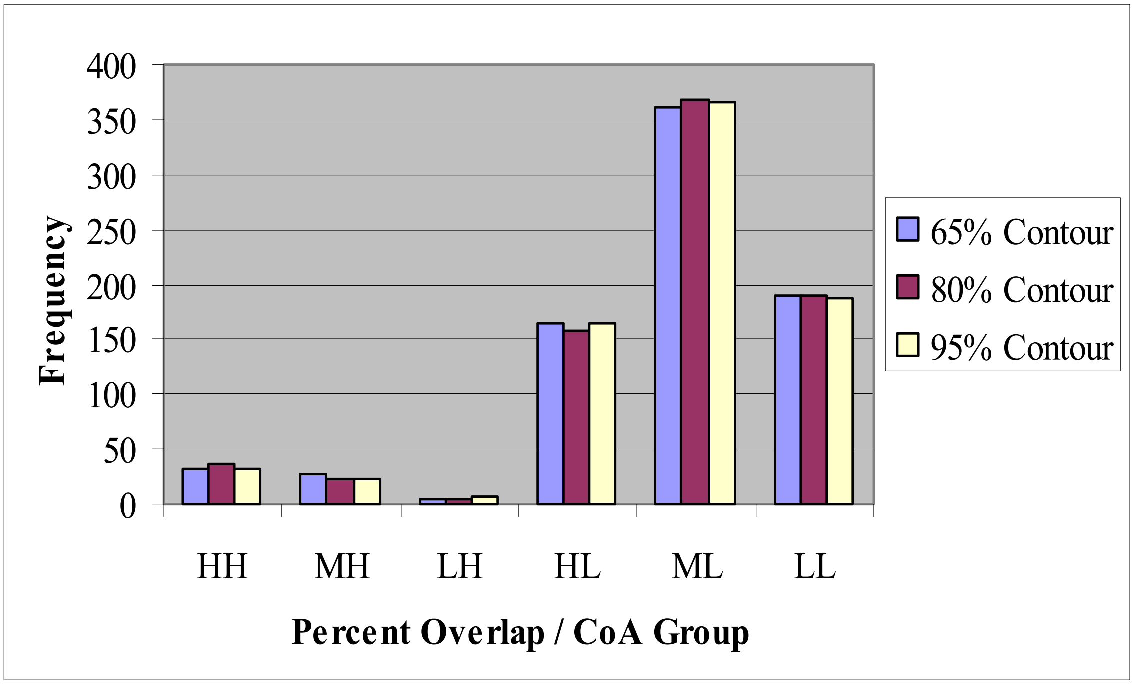
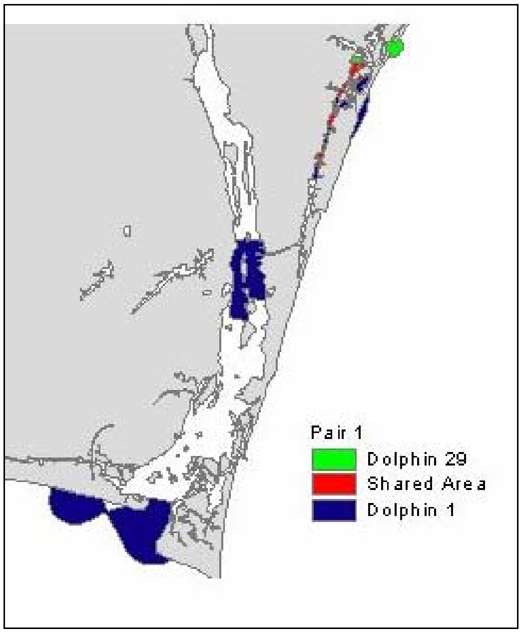
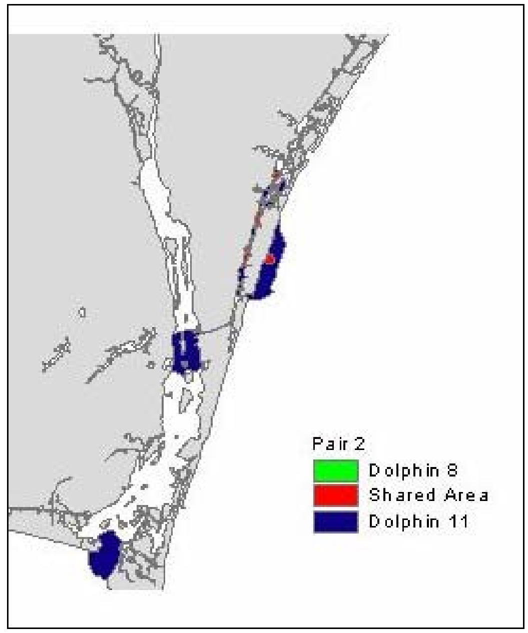


Figure 21. Distribution of percent overlap / CoA groups for each probability contour. Six groups are represented: HH (high overlap and high CoA), MH (moderate overlap and high CoA), LH (low overlap and high CoA), HL (high overlap and low CoA), ML (moderate overlap and low CoA), and LL (low overlap and low CoA).



A)



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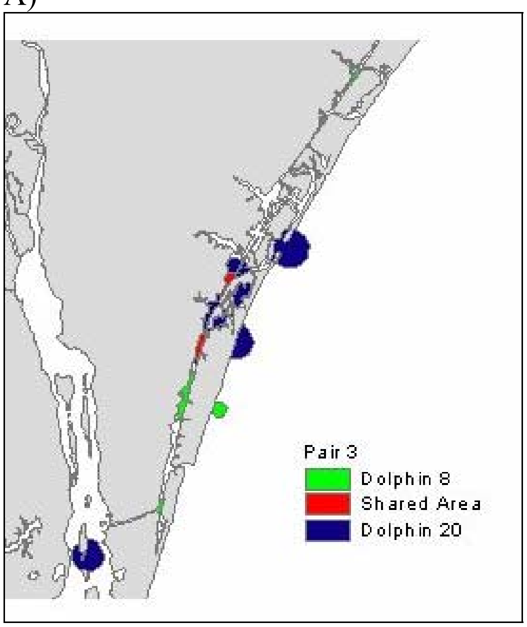

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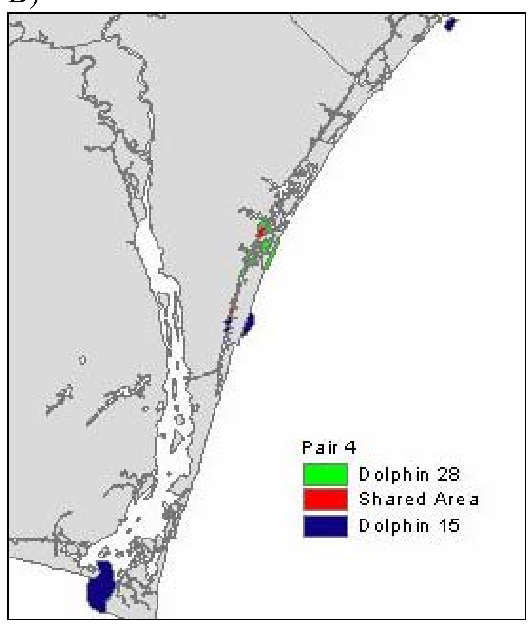

D)

Figure 22. Four dolphin pairs from the LH percent overlap / CoA group. A) through D) each illustrate the 65% SDC polygons of two dolphins with a low amount of overlap and a high CoA value. Green represents one dolphin, blue the other, and red their shared area.

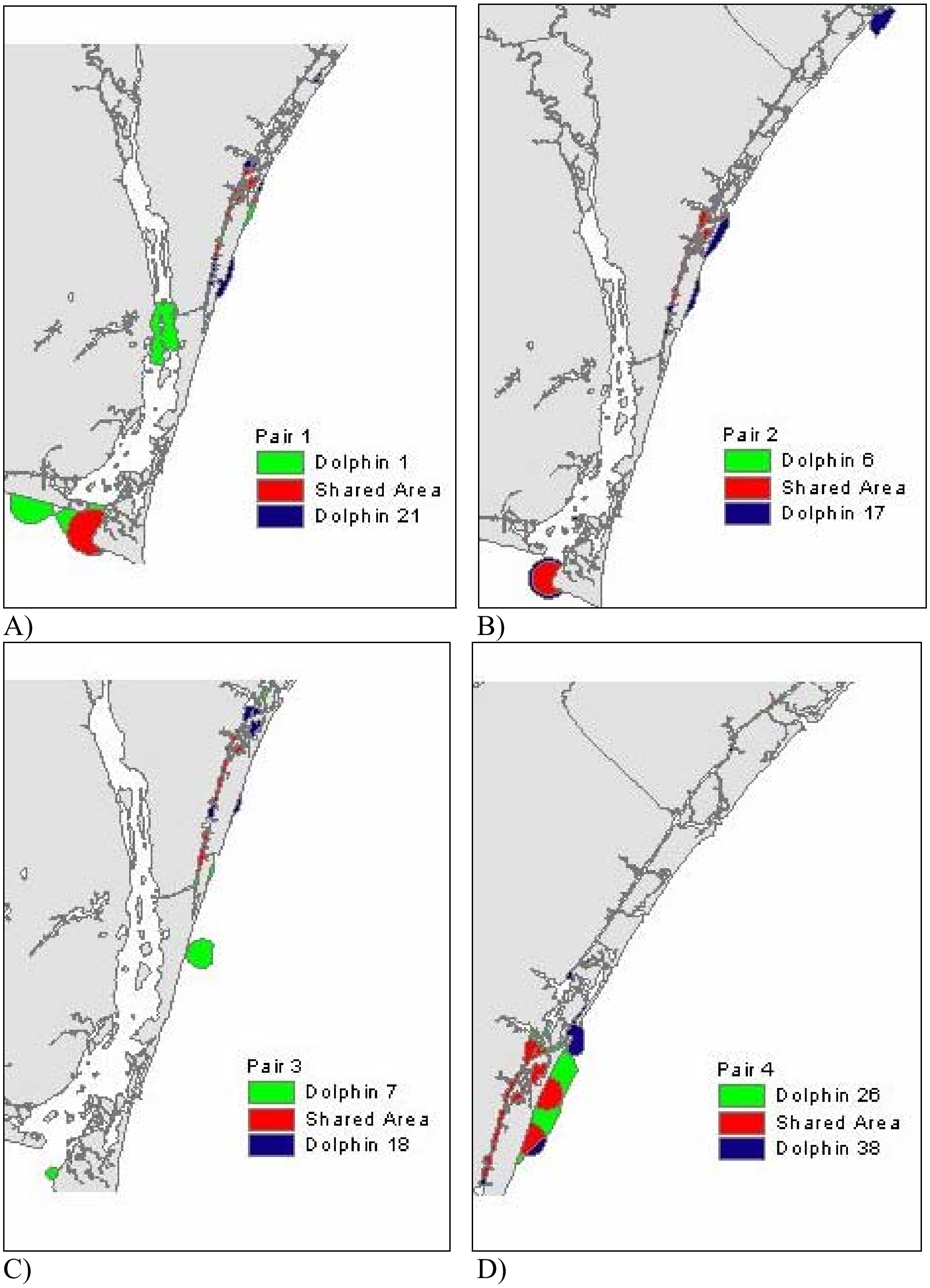

Figure 23. Four dolphin pairs from the HH percent overlap / CoA group. A) through D) each illustrate the 65% SDC polygons of two dolphins with a high amount of overlap and a high CoA value. Green represents one dolphin, blue the other, and red their shared area.

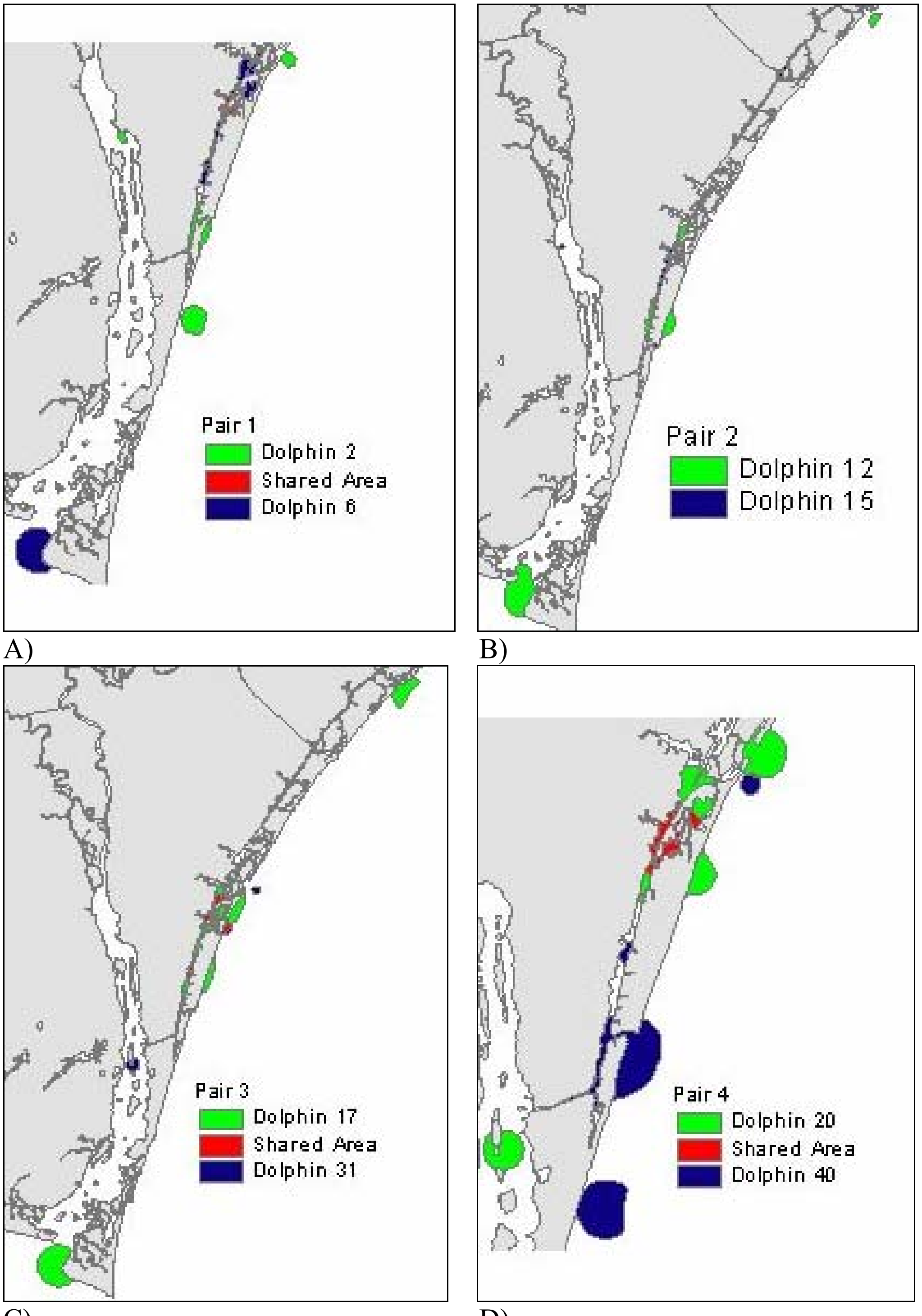

Figure 24. Four dolphin pairs from the LL percent overlap / CoA group. A) through D) each illustrate the 65% SDC polygons of two dolphins with a low amount of overlap and a low CoA value. Green represents one dolphin, blue the other, and red their shared area. Notice in B) there is no shared area for dolphins 12 and 15.

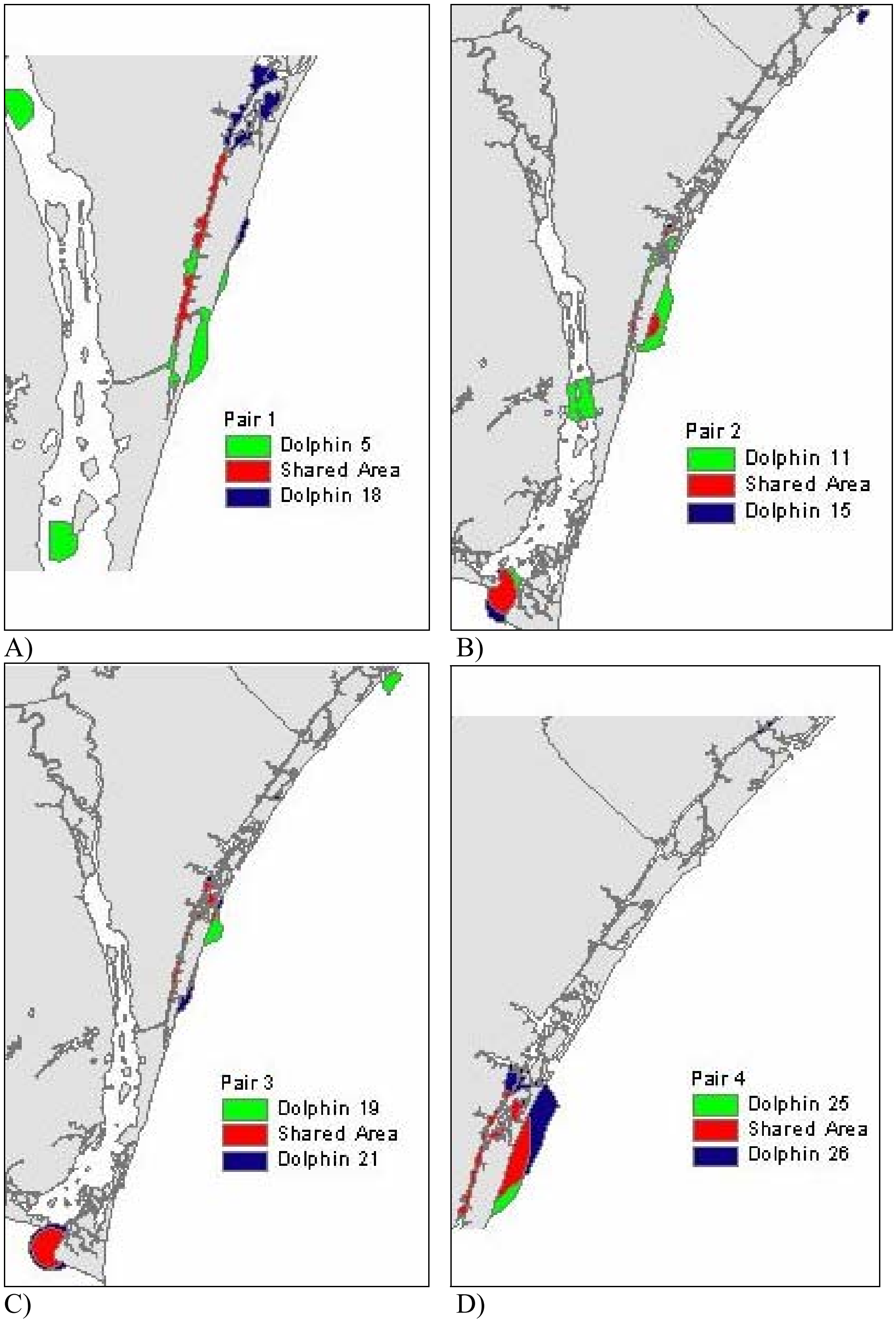

Figure 25. Four dolphin pairs from the HL percent overlap / CoA group. A) through D) each illustrate the 65% SDC polygons of two dolphins with a high amount of overlap and a high CoA value. Green represents one dolphin, blue the other, and red their shared area.

Table 10. Values used to examine community structure for four dolphin pairs categorized as A) LH, B) HH, C) LL, and D) HL.

	ID 1	ID 2	ID 1 65% Area (km^2)	ID 2 65% Area (km^2)	Shared Area	CoA Value	Percent Overlap
1	10030	80150	378.86	39.26	2.16	0.26	5.16
2	60060	60080	27.24	290.72	2.35	0.32	7.40
3	60060	70330	27.24	98.97	0.59	0.27	4.65
4	70170	80140	146.01	55.74	0.95	0.20	4.70

A)

	ID 1	ID 2	ID 1 65% Area (km^2)	ID 2 65% Area (km^2)	Shared Area	CoA Value	Percent Overlap
1	10030	70560	378.86	206.43	14.48	0.25	24.74
2	30020	70300	125.64	252.31	11.68	0.93	30.89
3	60040	70310	106.73	84.64	5.42	0.78	28.35
4	80100	715	135.46	116.83	8.16	0.58	32.35

B)

	ID 1	ID 2	ID 1 65% Area (km^2)	ID 2 65% Area (km^2)	Shared Area	CoA Value	Percent Overlap
1	10040	30020	87.99	125.64	0.87	0.05	4.07
2	60630	70170	20.64	146.01	0.00	0.00	0.00
3	70300	80300	252.31	46.99	2.28	0.19	7.62
4	70330	732	98.97	135.52	1.87	0.00	7.98

C)

	ID 1	ID 2	ID 1 65% Area (km^2)	ID 2 65% Area (km^2)	Shared Area	CoA Value	Percent Overlap
1	10520	70310	119.86	84.64	5.12	0.00	25.02
2	60080	70170	290.72	146.01	11.62	0.20	26.61
3	70320	70560	182.10	206.43	13.07	0.13	33.64
4	71110	80100	82.72	135.46	6.96	0.00	31.89

D)

representing shared use areas. There was one shared use area in the Wilmington study area (Figure 26), which is defined as the area used by all 40 dolphins.

Regional Analysis

The results of the general chi-square test for regional preference indicated that dolphins were sighted significantly more often than expected in the ICW and less often than expected in the other three regions of the study area (ocean, inlets, Cape Fear River; $\chi^2 = 261.5$, p = 2.1E-56, Table 11). Sightings of 33 of the 40 dolphins (82.5%) varied significantly with location in the general regional analysis (Table 12); all 33 favored the ICW over other regions in the study area. However, the results of the regional analysis with the dolphins' SDC polygons differed from the results with their sighting locations.

Observed and expected values for SDC percentages for each region were significantly different for all three probabilities (*i.e.* 65, 80, and 95%). On the individual level, all dolphins exhibited a significant preference for one of the four regions for each of the three probabilities (Tables 13, 14, and 15). The ICW and ocean regions were preferred by most individuals. The total percentage results were similar, but an interesting trend was detected (Table 16). Results indicated an inverse relationship between the ICW and ocean regions as SDC probability increased. The preference for the ICW region decreased with increasing SDC probability, whereas the preference for the ocean region increased with increasing SDC probability (Figure 27).

The number of observed sightings was the same in both season and region general analyses; however, the total number of surveys differed (Tables 2 and 11). Every survey day began in the ICW but the other three regions (ocean, inlets, Cape Fear River) were not always

Figure 26. Wilmington dolphin shared use area. Black areas represent the area of the 65% contour, dark grey areas represent the area of the 80% contour, and light grey areas represent the area of the 95% contour where all 40 dolphins were found.

Table 11. Values used to calculate general chi-square test for region.

	ICW	CFR	OC	IN	Total
# of Sightings (observed)	304	28	18	17	367
# of Surveys	323	182	86	189	780
# of Sightings (expected)	152.0	85.6	40.5	88.9	

Table 12. General regional chi-square results and P values for individual dolphins.

Dolphin No.	Chi-square	P value	Preferred Region	No. Regions Observed
1	0.9	0.8	none	3
2	11.9	0.008	ICW	3
3	7.1	0.07	none	2
4	0.8	0.9	none	4
5	14.7	0.002	ICW	2
6	14.2	0.003	ICW	3
7	20.1	0.0002	ICW	2
8	36.2	6.90E-08	ICW	4
9	16.8	0.0008	ICW	2
10	13.1	0.004	ICW	2
11	3.5	0.3	none	4
12	39	1.80E-08	ICW	3
13	17	0.0007	ICW	1
14	22.5	5.10E-05	ICW	4
15	3.9	0.3	none	4
16	6.9	0.07	none	4
17	9	0.03	ICW	4
18	18	0.0004	ICW	3
19	19	0.0003	ICW	3
20	12.9	0.005	ICW	4
21	18.6	0.0003	ICW	2
22	14.8	0.002	ICW	4
23	22	6.60E-05	ICW	2
24	14.8	0.002	ICW	4
25	10.5	0.01	ICW	2
26	11.8	0.008	ICW	2
27	17.7	0.0005	ICW	4
28	25.4	1.30E-05	ICW	3
29	11.3	0.01	ICW	2
30	30.8	9.40E-07	ICW	2
31	15.8	0.001	ICW	4
32	5.9	0.1	none	4
33	12	0.007	ICW	3
34	12.3	0.006	ICW	3
35	25.5	1.20E-05	ICW	1
36	50.5	6.30E-11	ICW	3
37	44.4	1.20E-09	ICW	3
38	22.3	5.70E-05	ICW	3
39	14.1	0.003	ICW	3
40	15.2	0.002	ICW	3

Table 13. 65% SDC regional chi-square results and P values for individual dolphins.

Dolphin No.	Chi-square	P value	Region Preferred	No. Regions Observed
1	89.2	3.30E-19	OC	3
2	155.3	1.9E-33	OC	3
3	266.5	1.8E-33	CFR	2
4	39.0	1.7E-08	OC	4
5	295.9	7.8E-64	CFR	2
6	726.8	3.2E-157	ICW	3
7	418.9	1.8E-90	ICW	2
8	1157.1	1.5E-250	ICW	4
9	591.7	6.2E-128	ICW	2
10	135.7	3.3E-29	OC	2
11	137.0	1.70E-29	CFR	4
12	1379.0	1.1E-298	ICW	3
13	1900.0	0	ICW	1
14	642.5	6.1E-139	ICW	4
15	478.1	2.7E-103	IN	4
16	129.0	8.8E-28	OC	4
17	247.7	2.0E-53	OC	4
18	1579.0	0	ICW	3
19	315.0	5.7E-68	OC	3
20	351.9	5.70E-76	ICW	4
21	431.2	3.8E-93	IN	2
22	290.3	1.20E-62	ICW	4
23	656.6	5.3E-142	ICW	2
24	207.1	1.2E-44	OC	4
25	297.1	4.3E-64	OC	2
26	282.9	5.0E-61	OC	2
27	310.3	5.8E-67	OC	4
28	1327.9	1.3E-287	ICW	3
29	1063.7	2.7E-230	ICW	2
30	1226.6	1.2E-265	ICW	2
31	468.6	3.1E-101	ICW	4
32	251.4	3.20E-54	CFR	4
33	157.4	6.8E-34	OC	3
34	1535.7	0	ICW	3
35	1617.5	0	ICW	1
36	1096.8	1.8E-237	ICW	3
37	1900.0	0	ICW	3
38	430.1	6.7E-93	ICW	3
39	81.5	1.5E-17	OC	3
40	101.4	7.8E-22	OC	3

Table 14. 80% SDC regional chi-square results and P values for individual dolphins.

Dolphin No.	Chi-square	P value	Region Preferred	No. Regions Observed
1	31.8	5.7E-07	OC	3
2	178.9	1.50E-38	OC	3
3	234.0	1.9E-50	CFR	2
4	18.4	3.6E-04	OC	4
5	213.0	6.7E-46	CFR	2
6	408.9	2.60E-88	ICW	3
7	375.3	5.1E-81	ICW	2
8	648.2	3.6E-140	ICW	4
9	399.1	3.5E-86	ICW	2
10	87.5	7.4E-19	OC	2
11	119.0	1.3E-25	CFR	4
12	1130.0	1.1E-244	ICW	3
13	1900.0	0	ICW	1
14	685.7	2.6E-148	ICW	4
15	256.0	3.4E-55	OC	4
16	77.4	1.1E-16	OC	4
17	109.1	1.7E-23	OC	4
18	392.4	9.8E-85	ICW	3
19	211.5	1.4E-45	OC	3
20	205.8	2.30E-44	CFR	4
21	213.3	5.6E-46	OC	2
22	206.4	1.7E-44	OC	4
23	404.3	2.6E-87	CFR	2
24	141.1	2.20E-30	OC	4
25	90.4	1.8E-19	OC	2
26	252.1	2.3E-54	OC	2
27	187.3	2.4E-40	OC	4
28	340.4	1.8E-73	ICW	3
29	1045.6	2.3E-226	ICW	2
30	645.5	1.4E-139	ICW	2
31	400.9	1.40E-86	ICW	4
32	197.6	1.40E-42	CFR	4
33	154.0	3.7E-33	OC	3
34	859.0	6.8E-186	ICW	3
35	1532.4	0	ICW	1
36	943.9	2.7E-204	ICW	3
37	827.1	5.8E-179	ICW	3
38	344.5	2.3E-74	OC	3
39	89.7	2.6E-19	OC	3
40	73.6	7.4E-16	OC	3

Table 15. 95% SDC regional chi-square results and P values for individual dolphins.

Dolphin No.	Chi-square	P value	Region Preferred	No. Regions Observed
1	22.5	5.3E-05	OC	3
2	167.8	3.9E-36	OC	3
3	134.7	5.3E-29	CFR	2
4	6.3	9.0E-02	OC	4
5	154.3	3.1E-33	CFR	2
6	181.0	5.50E-39	OC	3
7	238.8	1.7E-51	OC	2
8	486.0	5.1E-105	ICW	4
9	252.3	2.1E-54	OC	2
10	54.3	9.7E-12	OC	2
11	33.2	2.9E-07	OC	4
12	1002.3	5.7E-217	ICW	3
13	1900.0	0	ICW	1
14	608.2	1.7E-131	ICW	4
15	145.2	2.9E-31	OC	4
16	54.3	9.8E-12	OC	4
17	41.8	4.5E-09	OC	4
18	152.1	9.3E-33	OC	3
19	120.9	4.9E-26	OC	3
20	149.9	2.70E-32	CFR	4
21	82.6	8.5E-18	OC	2
22	114.7	9.7E-25	OC	4
23	301.3	5.2E-65	CFR	2
24	87.5	7.70E-19	OC	4
25	39.2	1.6E-08	OC	2
26	186.2	4.1E-40	OC	2
27	79.4	4.1E-17	OC	4
28	105.4	1.1E-22	OC	3
29	994.2	3.3E-215	ICW	2
30	340.8	1.5E-73	ICW	2
31	361.0	6.10E-78	ICW	4
32	120.9	5.00E-26	CFR	4
33	89.3	3.1E-19	OC	3
34	236.1	6.7E-51	OC	3
35	1453.4	0	ICW	1
36	699.2	3.1E-151	ICW	3
37	512.2	1.1E-110	ICW	3
38	300.3	8.5E-65	OC	3
39	85.5	2.1E-18	OC	3
40	99.4	2.1E-21	OC	3

Table 16. Observed and expected total values for SDC polygon area percentages for each region and resulting chi-square and P values for A) 65%, B) 80%, and C) 95% probabilities.

	ICW	IN	CFR	OC
Observed	50.00	5.00	10.00	35.00
Expected	5.00	4.00	15.00	76.00

Chi-square: 429.04 P value: 1.1E-92

A)

	ICW	IN	CFR	OC
Observed	40.00	0.0	15.00	45.00
Expected	5.00	4.00	15.00	76.00

Chi-square: 261.64 P value: 2.0E-56

B)

	ICW	IN	CFR	OC
Observed	25.00	0.0	12.5	62.5
Expected	5.00	4.00	15.00	76.00

Chi-square: 86.81 P value: 1.1E-18

C)

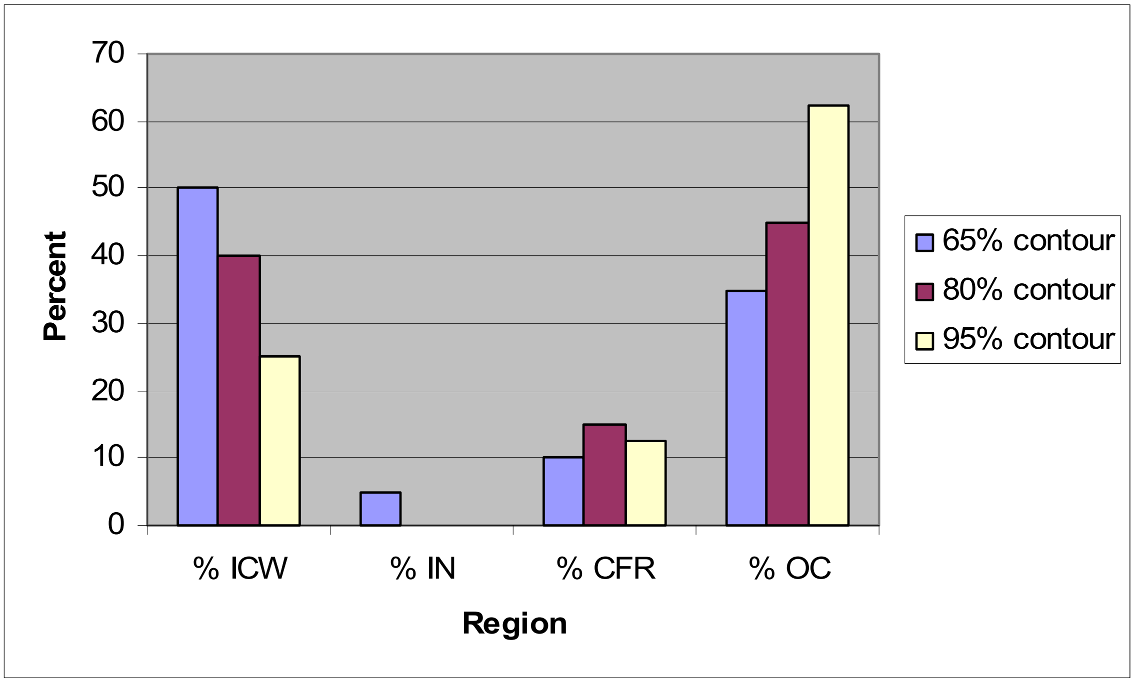

Figure 27. Regional preference percentage results using SDC polygon data. Overall percentages of dolphins showing preferences for each region are shown for each of the three probabilities (*i.e.* 65, 80, and 95%).

covered. However, the number of regions covered per survey could have been more than one, while the number of seasons per survey day could only be one. Thus, the survey totals for season are less than the totals for region.

DISCUSSION

There were two main goals of this study. The first goal was to determine if multiple communities of dolphins existed throughout the Wilmington study area. To achieve the first goal, four techniques to calculate area use were assessed. The second goal was to determine if Wilmington dolphins showed preferences for certain regions of the study area.

Although the 40 dolphins in this study showed a variety of different local area use patterns, all were found to occur in a large part of the ICW, as well as minimally into the ocean, between Masonboro Inlet and Snow's Cut. Thus, it may appear at first glance that the Wilmington study area is host to one core community. However, a community was previously defined as those dolphins that share an overall home range (Wells 1986a) and associate more with one another than with members of other communities (Urian 2002). Although the Wilmington dolphins used many of the same areas, the majority of associations between dolphins was low, so the definition of a community was not upheld. The area of shared use appears to be a corridor that connects different portions of the study area, such as sections of the Cape Fear River and the area near Bald Head Island inlet, both of which were also important areas for some dolphins.

The calculation of local area use (LAU) produced a range of results, from very small geographic distributions to very large areas (Figures 13, 14, and 15). Dolphin 4 had the largest SDC results (87.9 km^2 for the 65% probability; Figure 15A), with three distinct areas spread throughout all four regions of the study area. One high use area was located at New Topsail and Little Topsail inlets on the ICW and ocean sides, another in the area between Masonboro Inlet and Snow's Cut on the ICW and ocean sides and the middle portion of the Cape Fear River, and the last in the southern portion of the Cape Fear River, the Bald Head Island inlet, and the ocean areas near New Inlet. Conversely, dolphin 13 had the smallest SDC results (0.8 km^2 for the 65% probability; Figure 15C), occupying only a small area of the ICW between the Masonboro and Carolina Beach inlets. Seasonality could serve as an explanation for the difference in these LAU sizes. Dolphin 4 was sighted in all four seasons with no seasonal preference, while dolphin 13 was only sighted in two seasons and preferred the fall months. Thus, dolphin 4 may be a true year-round resident of the Wilmington area, whereas dolphin 13 may be passing through seasonally, using the ICW as a corridor to travel between other parts of its range.

Many of the dolphins' area use polygons overlapped, resulting in a shared use area for the Wilmington dolphins. These results are similar to the findings of Gubbins (2002a), who examined home range boundaries and core use areas for 20 resident dolphins in South Carolina. However, the range of area use values was larger for the Wilmington dolphins than for the South Carolina dolphins. This was due to the Wilmington study area occupying a larger portion of the coastline (330 km^2 versus 100 km^2); therefore, the Wilmington dolphins' ranges were expected to be larger.

In general, mean values of percent overlap of the weighted SDC polygons (for all three probability contours) increased as the CoA value increased, supporting the idea that dolphins who associate together more often share a greater proportion of area use. Only a small percentage of dolphin pairs (7% for all three contours) was placed into the HH or MH group, because only a small percentage of dolphin pairs had high CoA's, as discussed further below.

Surprisingly, 1% of dolphin pairs were placed into the LH group, which indicates that these animals associated together at a high level but were not sighted in the same area. However, the small number of dolphin pairs belonging to the LH group had CoA values close to the cutoff of 0.20 and not exceeding a value of 0.32. In addition, as can be seen from Figure 22 and Table 10, there is a larger discrepancy in area use sizes between dolphin pairs in the LH category than in other categories, ranging from approximately three to ten-fold. Thus, the high percent overlap seen in this category of dolphins is largely an artifact of the disparity in area use size.

The majority of dolphin pairs (92% for all three contours) belonged to one of the three percent overlap categories with a low CoA value (i.e. HL, ML, or LL). Several other studies of dolphin associations (Brager et al. 1994; Ballance 1990; Weller 1991; Koster 2002) found similarly low levels of CoAs, supporting the fission-fusion nature of bottlenose dolphin societies. Fission-fusion societies are characterized by small group associations that change in composition on a daily or even hourly basis (Wursig and Wursig 1977; Wells et al. 1987; Smolker et al. 1992). However, male-male pairs have been known to exhibit strong and stable bonds; some of the higher level associations in the Wilmington area could potentially be such pairs. Further analysis could not be performed because gender data were not available in this study.

Variations in seasonal sighting patterns may also contribute to the observed low CoAs. According to Shane et al. (1986), seasonal variations in habitat use are common for bottlenose dolphins; therefore, Wilmington dolphin pairs that have high or moderate amounts of overlap but low CoA values could potentially be using the same areas in different seasons. Seasonal changes in water temperature or prey availability could serve as an explanation for this behavior (Irvine et al. 1981; Wells et al. 1980; Shane et al. 1986; Barco et al. 1999; Fleming 2004). Some bottlenose dolphins in the Wilmington area are known to occur more often in the area near the

Bald Head Island inlet during the shrimp trawling season (summer and fall; Fleming 2004).

In general, the majority of Wilmington dolphins (83%) was found to prefer the ICW portions of the study area. The ICW is a relatively enclosed area of water, offering a certain amount of protection from potential predators that are more likely to occur in the open ocean (Shane et al. 1986). However, the preference could be at least partly due to methodological factors. Dolphins are sighted with greater ease in the ICW because the expanse of water is much smaller than in the Cape Fear River or the ocean. In addition, surveys are not systematic transects; therefore, a number of sightings in the river or the ocean could have been missed. Another factor is that more surveys were conducted in the ICW than in other regions of the study area. However, this study did account for survey effort in calculating local area use, something that is not done in many studies of animal movement. In this study, applying a weight to the SDC calculations reduced the effect of variations in survey effort across different regions on area use values.

Conducting a more detailed analysis of regional preference using the SDC data revealed that dolphins favored the ICW and ocean portions of the study area. The ICW region dominated for the 65 and 80% probabilities; however, the ocean region had an overall higher percentage of preference than the ICW (62% versus 25%) for the 95% probability. This result could be due to the weighting of the data and how SDC is calculated. Since surveys were mostly conducted within the ICW, sightings occurring in the ocean were assigned a large weight, which resulted in larger oceanic SDC areas, especially for the largest probability. In addition, the higher percent preference for the ocean in the 95% probability contour was still lower than the calculated expected value (76%), based upon the overall area of the ocean region.

The 40 dolphins analyzed represent a small fraction of the total number of animals observed throughout the Wilmington area during the study period (1995-2002). Based upon the SDC and CoA results, these 40 dolphins may be characterized as a mix of resident and seasonal. Additional residents are possible, as some may have been sighted less frequently and thus not included in this study. Sightings of less frequently observed dolphins are illustrated in Figure 28. Many of the sightings (58%) occurred within the shared use area. Future studies should investigate in-depth the transient, resident, and seasonal aspects of dolphins with a lower number of sightings in the Wilmington area.

One focus of this study was to test different ways of estimating area use within a GIS. The ADK and MCP methods were assessed largely because the majority of related literature employed one or more of those techniques in their studies of animal movement (Sauer et al. 1999; Urian 2002; Selkirk and Bishop 2002; Wells et al. 1980; Stone et al. 1997; Gubbins 2002a). However, both of these methods were proven inadequate for this study. Since there was no option to apply an analysis mask before running the calculations, the output polygons included large amounts of land. As a result, the returned area values were invalid.

Since the Spatial Analyst extension allowed for the application of an analysis mask, the SDC method proved to be the best choice for spatial analysis of this dataset. Applying a mask was important since most of the water portions of the study area are surrounded by land on one or more sides. In addition to applying a mask, selecting an appropriate bandwidth size at which to run the calculations is essential. If the selected bandwidth is extremely small, the resulting output appears too spiky. Conversely, if the selected bandwidth is extremely large, the resulting output appears too smooth. The default bandwidth size, or *ad hoc* value, in ArcView is determined using an arbitrary method that appears to have no statistical basis. The smaller

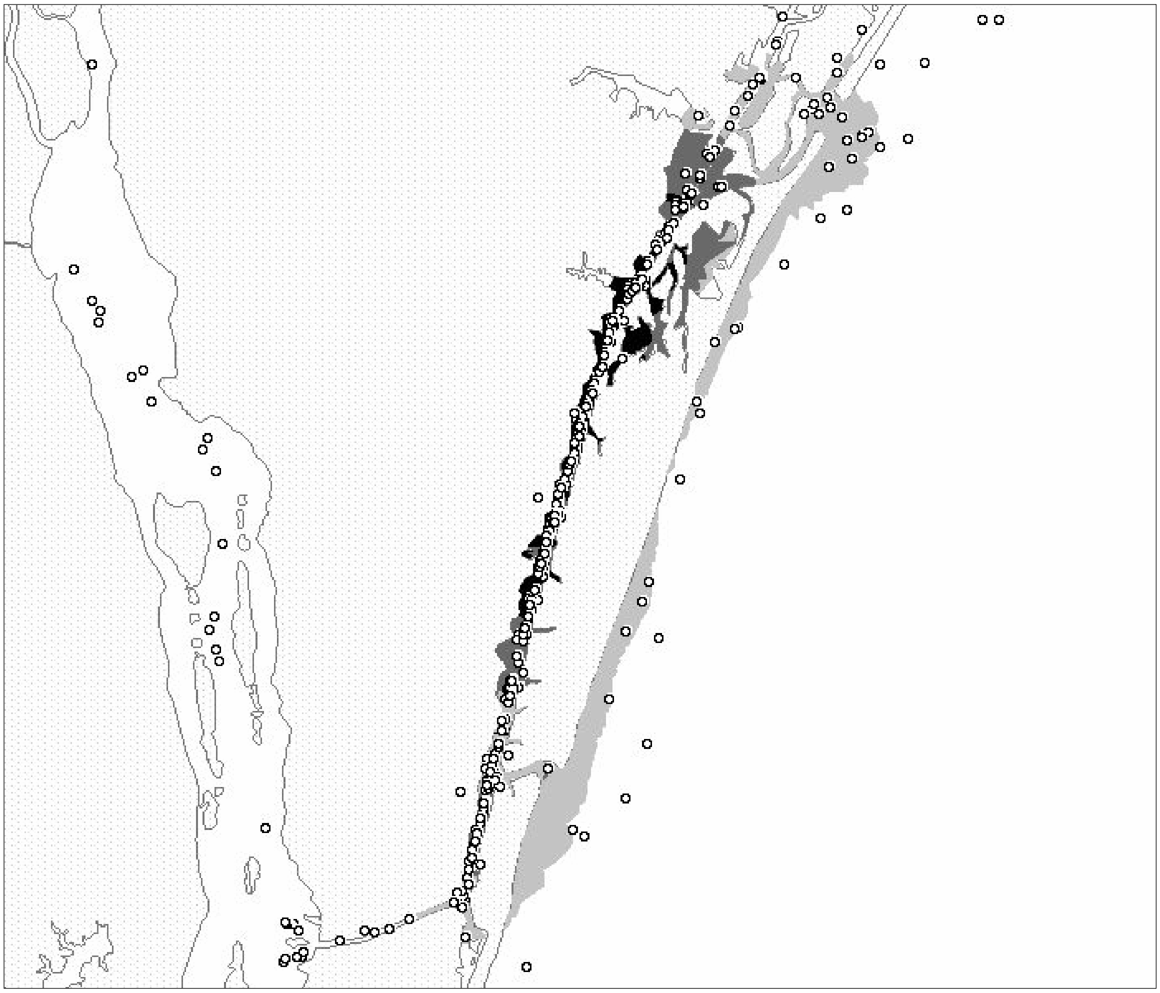

Figure 28. Shared use area for the 40 dolphins overlaid with less frequently observed Wilmington dolphin sightings. White circles represent sighting points. Black areas represent the area of the 65% contour, dark grey areas represent the area of the 80% contour, and light grey areas represent the area of the 95% contour where all 40 dolphins were found. Fifty-eight percent of these dolphins' sightings occur within the shared use area.

distance (width or length) of the extent of the point theme being analyzed is divided by 30, and the result is the bandwidth size. However, this technique fails to take into account the spatial distribution of the point theme. Therefore, choosing a sufficient bandwidth value is to some extent subjective, depending upon the desired outcome (Williamson et al. 1998; McLafferty et al. 2000).

This study has shown that a GIS can be used to successfully analyze dolphin spatial distributions. GIS techniques have been utilized for a wide variety of scientific studies of animal movements (Stone et al. 1997; Gerrard et al. 2001; Gurnell et al. 2002) but have only recently begun to appear in similar studies taking place in marine environments (Sauer et al. 1999; Stanbury and Starr 1999; Barber et al. 2001; Urian 2002). The findings of Stone et al. (1997) and Sauer et al. (1999) demonstrate the advantages of using GIS for specific calculations of area use; this study further develops the application of GIS in area use studies in a marine setting. Tools developed in this study, including the masking of land and weighting data according to survey effort, may prove valuable to other marine studies.

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Appendix A. Glossary of terms and definitions (taken from ESRI 2004).

Analysis extent: a tool to set geographic limitations on the results of a spatial analysis by defining the x,y coordinates for the bottom-left and top-right corners of the view.

Analysis mask: in the Spatial Analyst extension, a means of performing spatial analysis on a selected set of cells in a raster dataset. Cells of interest are given a value, while all other cells are characterized as NoData. Processing only occurs on cells assigned values.

Spatial Analyst: an ArcView extension that provides spatial modeling and analysis features. It allows the creation, querying, mapping, and analysis of cell-based raster data and integrated vector-raster analysis.

Area: a fundamental spatial unit consisting of a closed, two-dimensional shape defined by its boundary. Its extent is usually defined in terms of an external polygon or by a contiguous set of grid cells. The area of a polygon can be calculated in ArcView using the command "[Shape].returnarea."

Attribute: information about a geographic feature in a GIS, usually stored in a table and linked to the feature by a unique identifier. For example, attributes of a river might include its name, length, and average depth.

Attribute table: a database or tabular file containing information about a set of geographic features, usually arranged so that each row represents a feature and each column represents one feature attribute. In raster datasets, each row of an attribute table corresponds to a certain region of cells having the same value. In a GIS, attribute tables are often joined or related to spatial data layers, and the attribute values they contain can be used to find, query, and symbolize features or raster cells.

Bandwidth size: See "Search radius."

Cartography: the art and science of expressing graphically, usually through maps, the natural and social features of the earth.

Cell: the smallest unit of information in an image, raster, or grid. In a map, each cell represents a portion of the earth, such as a square meter or square mile, and usually has an attribute value associated with it, such as soil type or vegetation class. Cells are usually square or rectangular in shape, although hexagonal and circular areas have also been used.

Cell size: the area on the ground covered by a single cell in an image, measured in map units.

Chi-squared statistic: a statistic used to assess how well a model fits the data. It compares categorized data and a multinomial model that predicts the relative frequency of outcomes in each category to see to what extent they agree.

Coordinate system: a reference system used to locate geographic features on a two- or three-dimensional surface. A coordinate system is comprised of a spheroid, datum, projection, and units.

Coordinates: values represented by x, y, and possibly z, that define a position in terms of a spatial reference framework. Coordinates are used to represent locations on the earth's surface relative to other locations.

Correlation: a relation existing between mathematical or statistical variables which tend to vary, be associated, or occur together in a way not expected on the basis of chance alone.

Datum: in the most general sense, any set of numeric or geometric constants from which other quantities, such as coordinate systems, can be defined. A datum defines a reference surface. There are many types of datums, but most fall into two categories: horizontal and vertical.

Density: in Spatial Analyst, a function that distributes the quantity or magnitude of point or line observations over a unit of area to create a continuous raster – for example, population per square kilometer.

Extension: an optional software module that adds specialized tools and functionality to ArcView.

Field: a column in a table that stores the values for a single attribute.

Generalization: in cartography, any reduction of information so that a map is clear and uncluttered when its scale is reduced.

Geoprocessing: a GIS operation used to manipulate data stored in a GIS workspace. A typical geoprocessing operation takes an input dataset, performs an operation on that dataset, and returns the result of the operation as an output dataset.

Grid: a data format for storing raster data that defines geographic space as an array of equally sized square cells arranged in rows and columns. Each cell stores a numeric value that represents a geographic attribute (such as elevation) for that unit of space. When the grid is drawn as a map, cells are assigned colors according to their numeric values. Each grid cell is referenced by its x,y coordinate location.

Histogram: a graph showing the distribution of values in a set of data. Individual values are displayed along a horizontal axis, and the frequency of their occurrence is displayed along a vertical axis.

Latitude: the angular distance, usually measured in degrees, along a meridian north or south of the equator. Lines of latitude are also referred to as parallels.

Longitude: the angular distance, expressed in degrees, minutes, and seconds, of a point on the earth's surface east or west of an arbitrarily defined meridian (usually the Greenwich prime meridian). All lines of longitude are great circles that intersect the equator and pass through the north and south poles.

Nearest neighbor statistic: a focal function that computes an output grid in which the value at each location is a function of the input cells within a specified neighborhood of the location.

Point: a zero-dimensional abstraction of an object; a single x,y coordinate pair that represents a geographic feature too small to be displayed as a line or area at that scale.

Polygon: a digital representation of a place or thing that has area at a particular scale, such as a country on a world map or a land parcel on a parcel map.

Projection: a method by which the curved surface of the earth is portrayed on a flat surface. This generally requires a systematic mathematical transformation of the earth's graticule of lines of longitude and latitude onto a plane.

Query: a request that selects features or records from a database. A query is often written as a statement or logical expression.

Raster: a spatial data model that defines space as an array of equally sized cells arranged in rows and columns. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. Groups of cells that share the same value represent geographic features.

Search radius: the maximum distance in coverage units a feature can be from the current point for consideration as the closest feature.

Shapefile: a vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class.

Spatial analysis: the study of the locations and shapes of geographic features and the relationships between them. Spatial analysis is useful when evaluating suitability, when making predictions, and for gaining a better understanding of how geographic features and phenomena are located and distributed.

Spatial data: information about the locations and shapes of geographic features and the relationships between them, usually stored as coordinates and topology.

Spheroid: when used to represent the earth, the three-dimensional shape obtained by rotating an ellipse about its minor axis.

Theme: a set of related geographic features such as streets, parcels, or rivers, along with their attributes. All features in a theme share the same coordinate system, are located within a common geographic extent, and have the same attributes.

Union: a topological overlay of two or more polygon spatial datasets that preserves features that fall within the spatial extent of either input dataset; that is, all features from both datasets are retained and extracted into a new polygon dataset.

Universal transverse Mercator (UTM): a projected coordinate system that divides the world into 60 north and south zones, six degrees wide.

Vector: a coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each feature, as opposed to a raster data model, which associates attributes with grid cells.

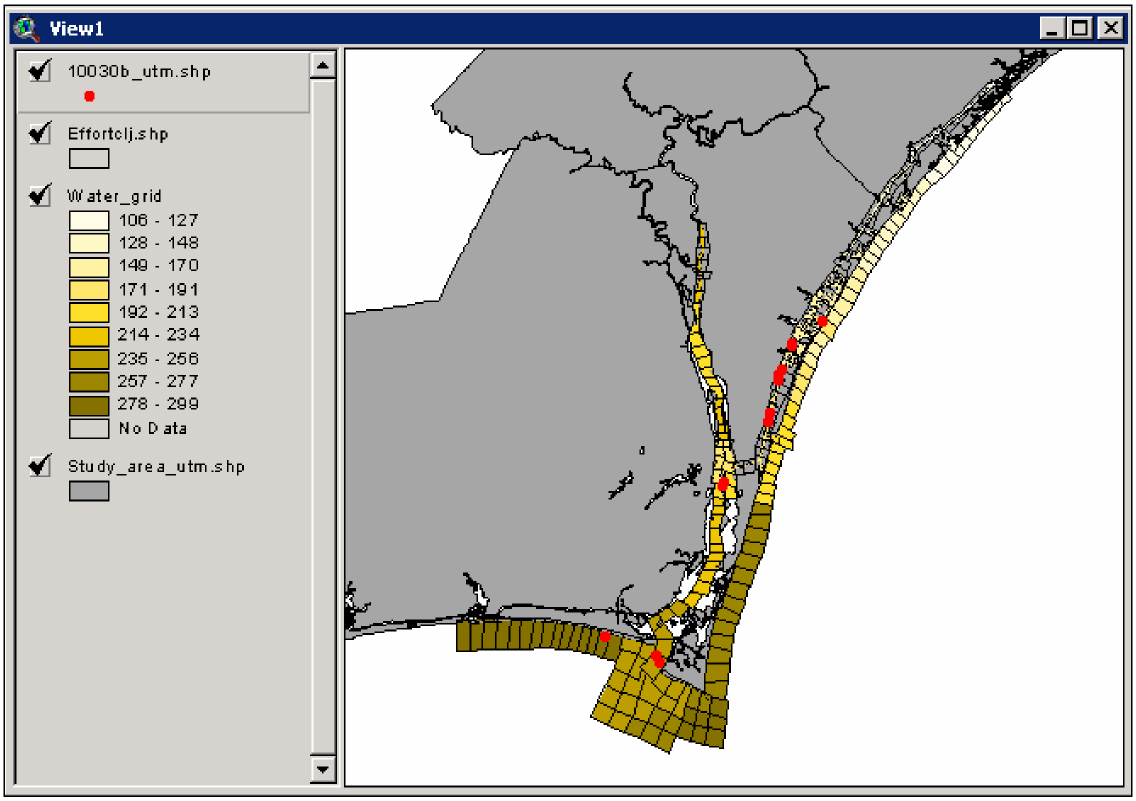
Weight: a number that tells how important a variable is for a particular calculation. The larger the weight assigned to the variable, the more that variable will influence the outcome of the operation.

Appendix B. Spatial Density Calculation method (with 95, 80, and 65% probability).

1. Launch ArcView and load the Spatial Analyst extension. Specify the map and distance units as meters under the view properties menu.

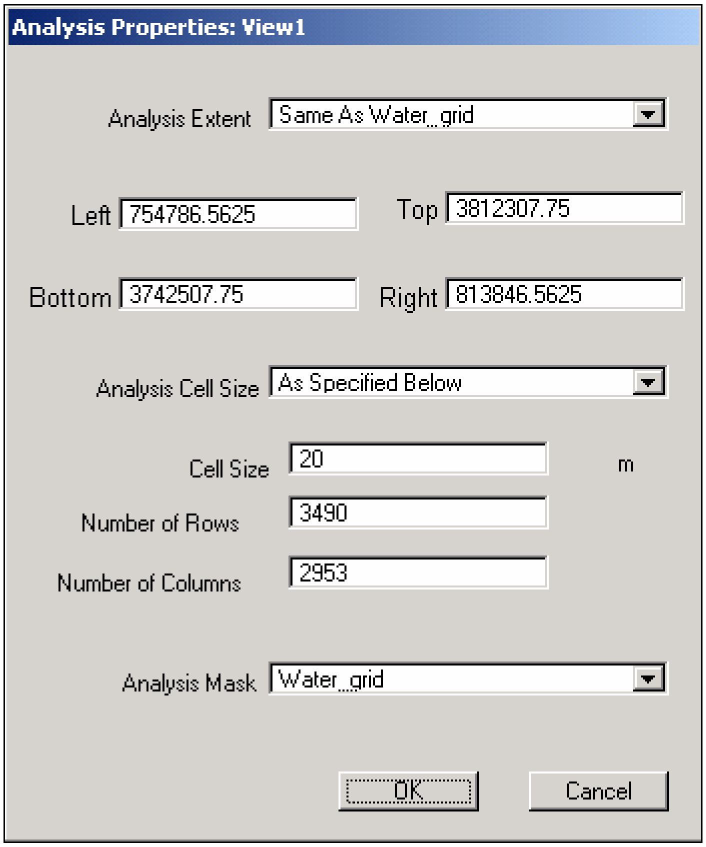
2. Add the study area, water grid, and effort polygons themes.

3. Add an individual dolphin sighting shapefile to analyze.

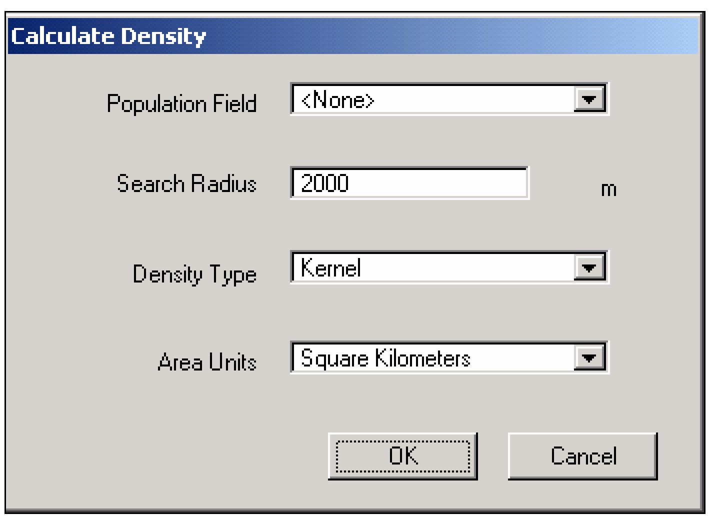


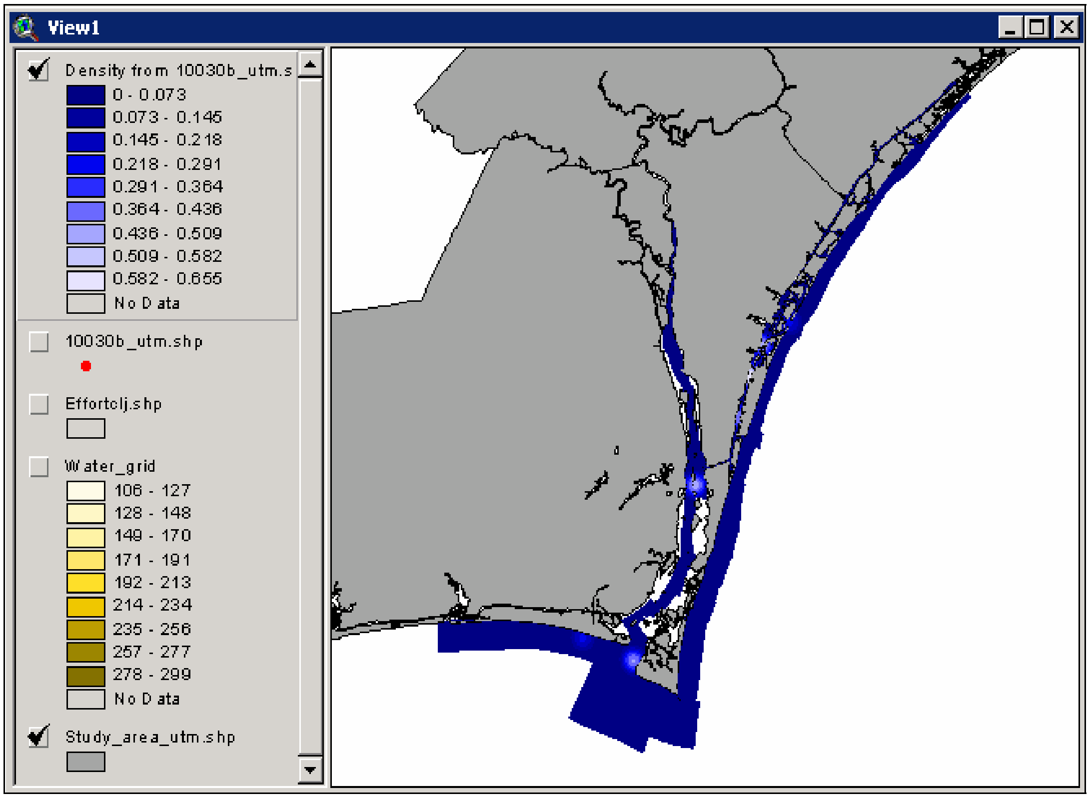
4. Set the analysis properties.

Extent: same as water grid
Cell size: as specified below, 20 meters
Mask: water grid
**Number of rows and columns will automatically fill in.



5. Make the point theme active, and then select "Calculate Density" from the Analysis menu. Set the population field to none, the search radius to the appropriate value, the density type to kernel, and the area units to square kilometers.

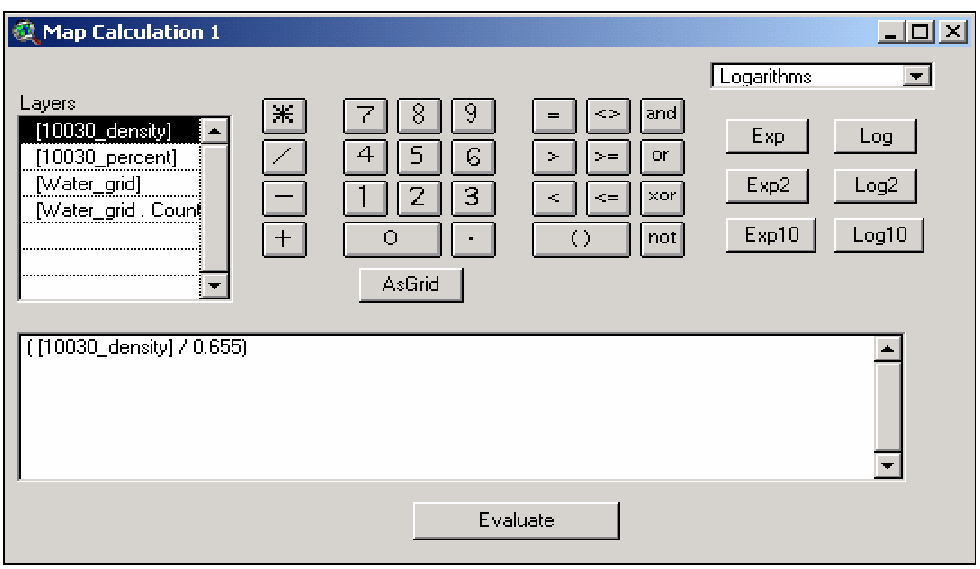


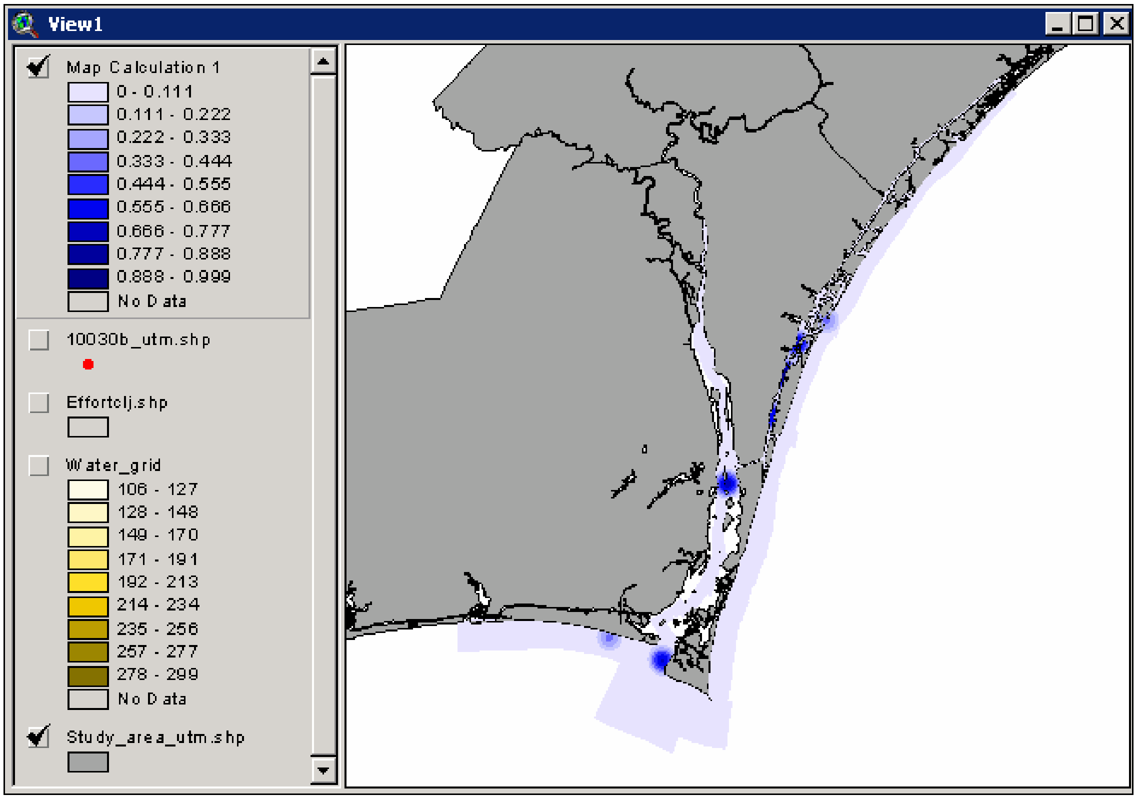


6. Make the resulting density output active, and then convert to a grid. This file is the density for the point theme.

7. Make the density grid active, and then select "Map Calculator" from the Analysis menu. Compose the following expression and click "Evaluate."

([Density grid]/ [maximum value])

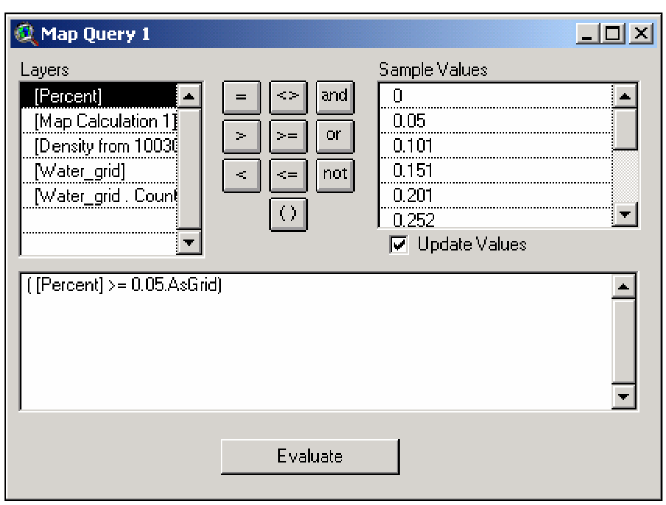


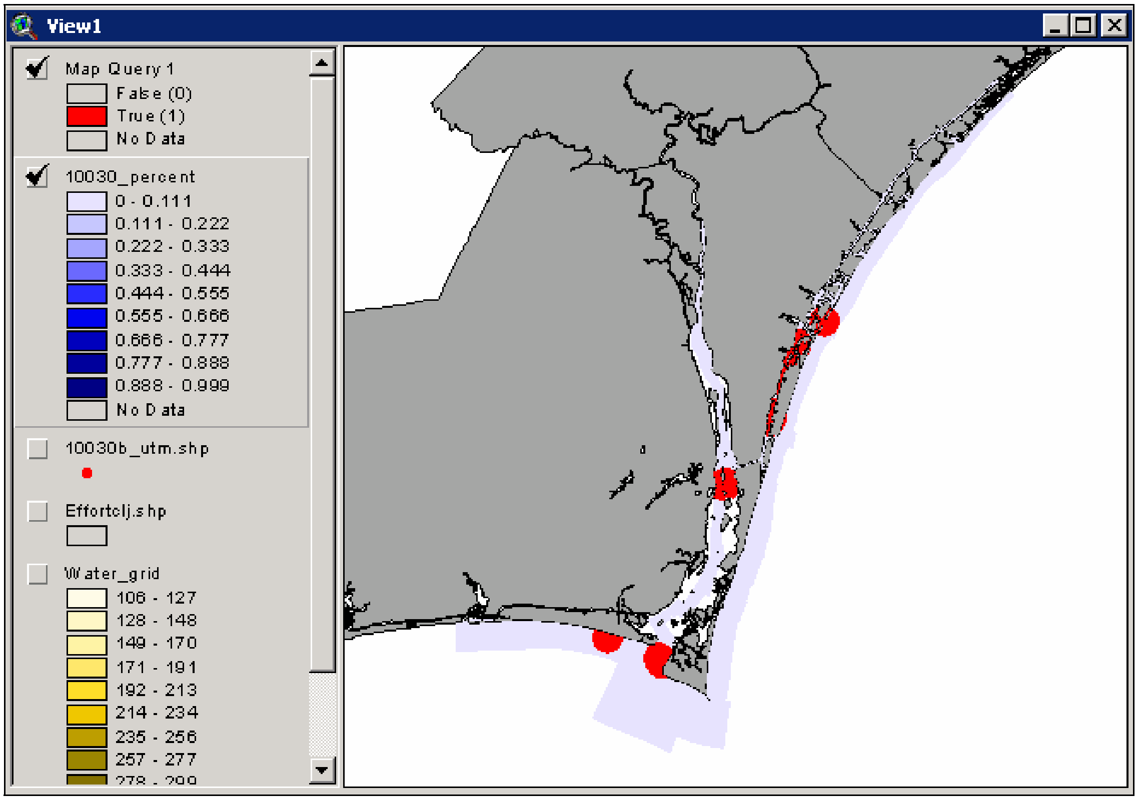


8. Make the resulting map calculation output active, and then convert to a grid. This file is the probability percentages for the point theme.

9. Make the probability percentages grid active, and select "Map Query" from the Analysis menu. Compose the following expression and click "Evaluate." This expression will create a new shapefile that contains the 95% probability area in which that particular dolphin will be found.

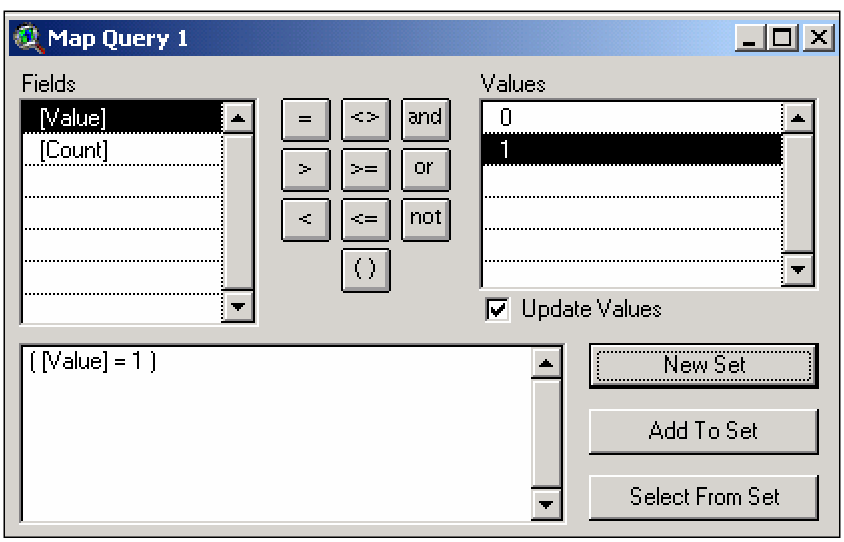
([Percent] >= 0.05.AsGrid)

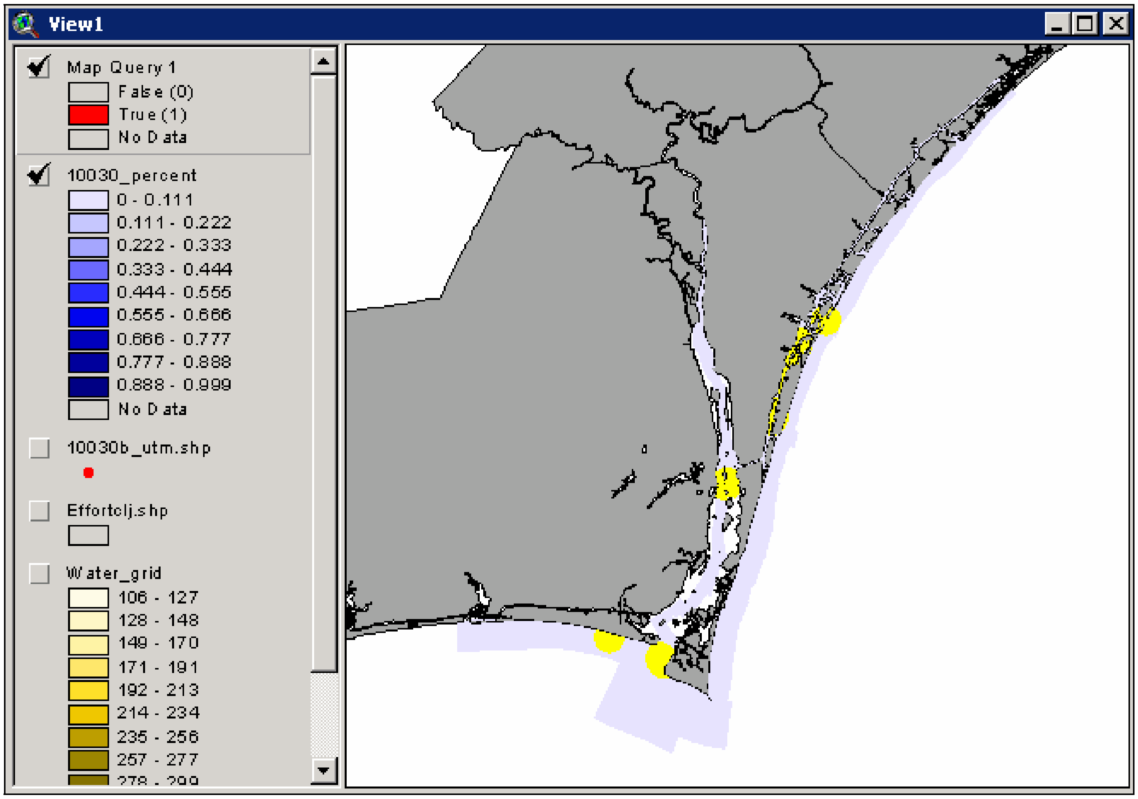




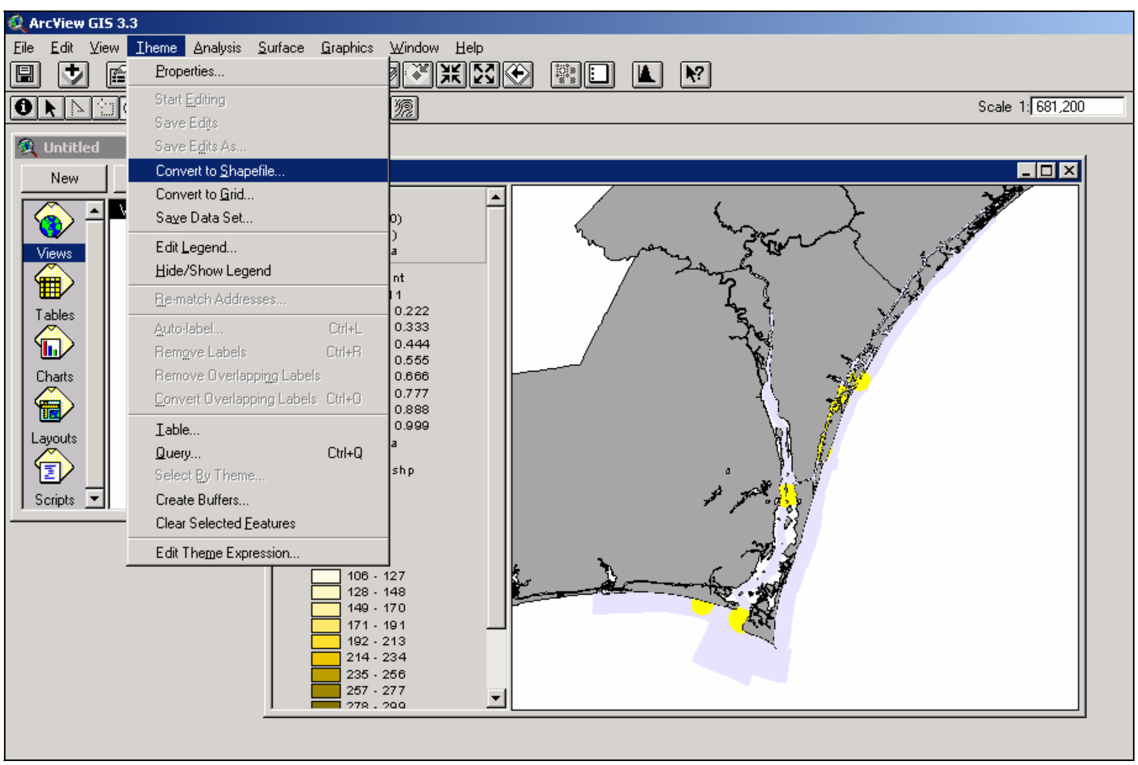
10. Make the map query output active, and select the Query Builder. Compose the following expression and click "New Set."

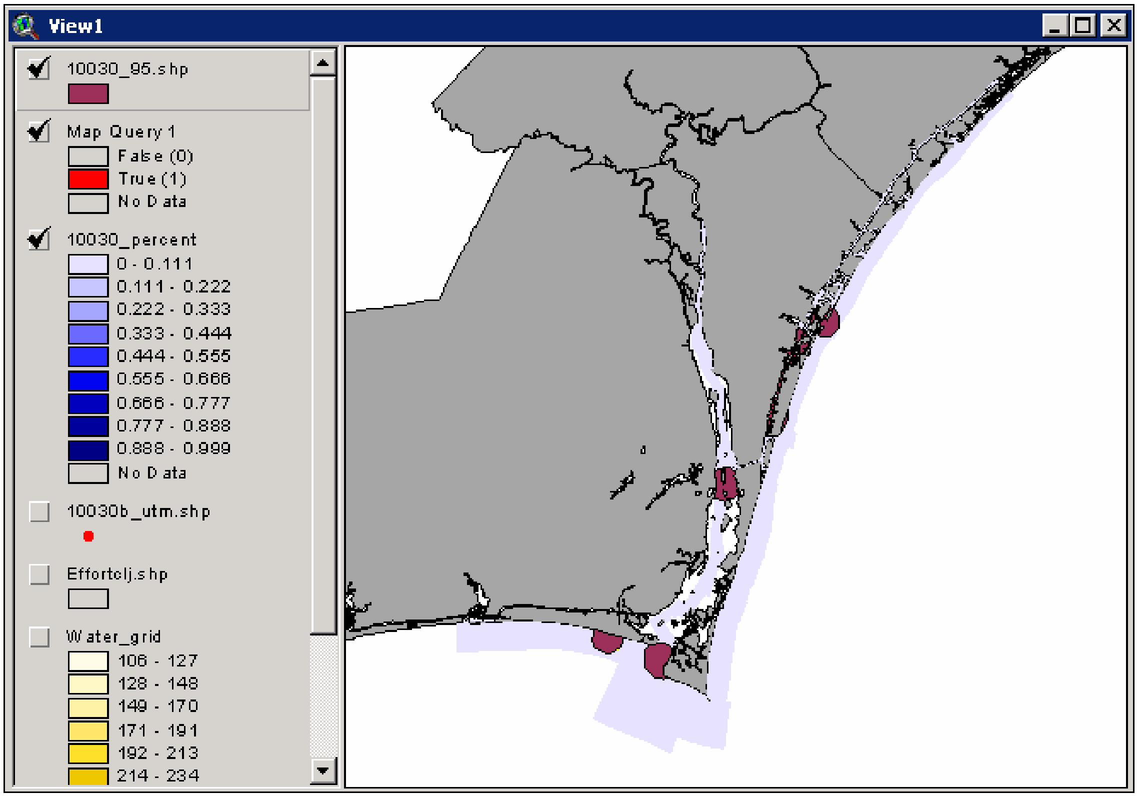
([Value] = 1)





11. Convert the selected data (in yellow) to a new shapefile.





12. Repeat steps 10-12 for 80% (0.2) and 65% (0.35) probabilities.