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Estimating Density and Residency of Bottlenose Dolphins (Tursiops truncatus) in three estuarine sites in South Carolina

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Estimating density and residency of bottlenose dolphins (*Tursiops truncatus*) in three estuarine sites in South Carolina

By

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Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Coastal Marine and Wetland Studies in the School of the Coastal Environment Coastal Carolina University 2017

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Abstract

Of the three estuarine bottlenose dolphin stocks in South Carolina, two are considered data insufficient, with no minimum population estimate or assigned potential biological removal value. Additionally, the Northern Georgia Southern South Carolina Estuarine System (NGSSCES) stock’s boundaries are based on sighting data that do not extend to the full area encompassed by the boundary lines. In areas where stock boundaries are not clearly defined and data is insufficient for traditional methods of estimating abundance, density may provide insight into local distributions and serve as a proxy for actual abundance. Photo-identification surveys were conducted in three sites, representative of the two data insufficient estuarine stocks, between March 2012 and February 2013. Linear density (dolphins/km transect) was similar for all three sites (p=0.0773) and resident dolphins made up between 15.45% and 23.61% of total individuals within each site. Additionally, there was no movement of individuals between study areas, specifically between the two sites that make up the NGSSCES stock. These patterns provide evidence that estuarine bottlenose dolphins in South Carolina share similar characteristics regardless of stock designation, and that the NGSSCES stock might be comprised of smaller, independent communities or sub-populations. Current management approaches for estuarine bottlenose dolphin stocks in South Carolina are problematic due to the uncertainty of stock boundaries and abundance. If future studies continue to identify small groups of dolphins with strong site fidelity or small home ranges such as in this study, the traditional stock concept might need to be re-evaluated with management efforts shifting toward simple measures of linear density to determine relative abundance.
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Introduction


The MMPA was passed by Congress in response to declines in marine mammal populations due to human activity, as well as an inadequate knowledge of population dynamics of such species (MMPA, 16 U.S.C. §1361.2). The MMPA established new regulations and programs in an effort to increase research and ensure that populations do not diminish beyond their optimum sustainable population. Section 117 of the MMPA requires NMFS to prepare assessments for each marine mammal population within the jurisdiction of the United States. The purpose of these assessments is to evaluate and improve the understanding of their structure and dynamics, better assess the impacts of anthropogenic activity, and promote management policies to reduce incidental
take. Incidental take refers to the unintentional but not unexpected harassment, capture, collection, or kill of any marine mammal (MMPA, 16 U.S.C. §1363.3(13)).

Along the Atlantic U.S coast, bottlenose dolphins inhabit coastal waters and are subject to potential threats from both human activity and natural disturbances. As long lived, apex predators exposed to coastal pollution and the biomagnification of contaminants, dolphins are important sentinels of the health of coastal marine ecosystems (Wilson et al. 1997; Wells et al. 2004). Understanding the structure and dynamics of these populations is necessary to improve conservation management and policies that protect them (Pitchford et al. 2016).

Through examination of historical data from sightings, live captures, and strandings, NMFS has classified Atlantic bottlenose dolphins into two morphologically and genetically distinct morphotypes described as the offshore and coastal forms. The offshore morphotype is primarily distributed along the outer continental shelf and continental slope of the Atlantic Ocean. The coastal morphotype inhabits oceanic and estuarine waters inshore of the continental shelf and is genetically distinct from the larger, more robust offshore form (Waring et al. 2015).

Coastal dolphins can be further subcategorized into estuarine and nearshore coastal groups based upon multiple lines of evidence that support demographic separation between dolphins that reside solely within inshore systems such as bays, sounds and estuaries (BSE), and those with larger home ranges that occupy nearshore waters and often display seasonal migration patterns (Waring et al. 2015). Additional evidence supports genetic differentiation between nearshore coastal and estuarine bottlenose dolphin populations, but there is still uncertainty to the degree of spatial
overlap between the two (Rosel et al. 2011). Within BSE systems, both transient and resident individuals exist, forming unique and overlapping population structures (Wilson et al. 1997; Barco et al. 1999; Conn et al. 2011). Resident dolphins are those considered to be permanent members of an estuarine system, whereas transients are either coastal nearshore dolphins visiting the BSE system temporarily or members of an adjacent estuarine population where home ranges may overlap (Rosel et al. 2011). Geographic boundaries of the resident estuarine dolphin populations have been difficult to distinguish due to the potential overlap of adjacent populations, especially along the southeastern Atlantic coast. Some resident estuarine dolphins are known to display strong site fidelity (Gubbins, 2002b) and unique foraging behaviors associated with specific habitat requirements (Fox and Young, 2012). These factors make resident estuarine dolphins extremely susceptible to anthropogenic activities and habitat degradation.

Under the MMPA, bottlenose dolphin populations are classified into management units called stocks and each stock is evaluated annually, or when new data become available. When the MMPA was first established, a stock was defined as “a group of marine mammals of the same species in a common spatial arrangement that interbreed when mature” (16 USC § 1362(11)). This definition has since been updated to “a demographically independent population in which the internal processes of births and deaths are more important to the cohesiveness of the population than the external dynamics of immigration and emigration” (Rosel et al. 2011). This updated definition is more applicable when evaluating stock boundaries because of the spatial overlap between resident and transient groups within BSE systems (Conn et al. 2011).
NMFS produces stock assessment reports (SARs) for bottlenose dolphin stocks in U.S. waters as mandated by Section 117 of the MMPA. SARs are established to identify and evaluate the status of marine mammal populations, assess the impact of anthropogenic disturbances, calculate the authorized taking of marine mammals incidental to human activities, evaluate the progress of each fishery in reducing its incidental mortality, and design and implement appropriate conservation measures. Each SAR includes a description of the stock’s geographic range, current population trends and status, estimates of annual human caused mortality, productivity rates, a minimum population estimate, and potential biological removal (PBR) level.

The PBR is a parameter reflecting the maximum number of individuals not including natural mortalities that may be removed from a population without causing the total number of individuals to fall below the optimum sustainable population (Read et al. 2003; Conn et al. 2011; Rosel et al. 2011). In areas with heavy fishing or recreational activity, such as BSE systems, the risk of mortality due to boat strike or entanglement is increased, making PBR a critical calculation to ensure that dolphin populations are not declining due to human interaction (Waring et al. 2015). The PBR calculation relies heavily on accurately identified stock boundaries and requires abundance estimates that are less than 8 years old (Wade and Angliss 1997, Pitchford et al. 2016).

Estimates of abundance can also be used to directly assess the impact of mortality from a disturbance event by comparing pre- and post-event population indices, where the number of mortalities is a fraction of the total population (Wang et al. 1994). This method was used during the Atlantic bottlenose dolphin Unusual Mortality Event (UME) of 1987-88 in which more than 740 coastal bottlenose dolphins stranded dead along
eastern U.S. shores from New Jersey to Florida (Wang et al. 1994). The UME was likely caused by a strain of *Morbilivirus spp.*, which left the dolphins immunocompromised and susceptible to skin lesions, pneumonia, and brain infections (Lipscomb et al. 1996). Based on this event, Scott et al. (1988) hypothesized that a single coastal migratory stock, spanning the entire coast from New Jersey to Florida, suffered a greater than 50% reduction in size (Scott et al. 1988). However, upon re-analysis of the UME stranding data (McLellan et al. 2002) and subsequent photo-identification and genetic surveys (Litz, 2007), the concept of a single coastal migratory stock has been replaced by a more complex coastal stock structure including multiple coastal stocks that overlap geographically. All five of the currently recognized coastal stocks that make up the formerly proposed single Western North Atlantic Coastal stock are still considered “depleted,” or below their optimum sustainable population.

The estuarine (BSE) stocks along the southeastern U.S. coast were not officially recognized by NMFS as distinct management units until 2009 (Waring et al. 2011). As of 2017, five coastal stocks and 11 BSE stocks of bottlenose dolphins are recognized along the Atlantic U.S. coast (Waring et al. 2015, Fig. 1). BSE dolphins live in close proximity to humans and are therefore vulnerable to localized disturbances (Conn et al. 2011). The estimation of essential BSE stock parameters, such as stock abundance and range, are complicated by the geographic overlap of estuarine and adjacent coastal stocks, and in some cases, by poorly understood seasonal movement patterns.

There are many methods of estimating abundance of bottlenose dolphins, including line-transect visual surveys from aircraft and vessels (Waring et al. 2011), video surveys (Hastie et al. 2004), and mark-recapture models (Read et al. 2003; Conn et
In each of these methods, individual dolphins are distinguished by the unique combination of notches, shape, scars, and patterns of pigmentation on their dorsal fins (Wursig and Wursig 1977; Wilson et al. 1997; Read et al. 2003). Photo-identification techniques for bottlenose dolphins are well established and used to build catalogs of known individuals in specific locations during visual surveys (Rosel et al. 2011). Most often, data used for abundance estimates are collected from photo-identification surveys and then applied to various models and analyses.

Mark-recapture photo-identification techniques have previously been used to estimate abundance of bottlenose dolphins (Nicholson, 2012; Urian et al. 2014; Silva, 2016). Dolphins are photographically “captured” and immediately “released”. Subsequent photographs of the same dorsal fin during separate sampling events are considered to be recaptures. Mark-recapture techniques can be difficult to use to estimate abundance in BSE systems however, due to potential home range overlap of adjacent stocks, and fluctuations in seasonal distribution of dolphins.

Pollock’s robust design model (Pollock, 1982) has been used to estimate abundance of bottlenose dolphins (Speakman et al. 2010; Silva, 2016). This design follows a set of assumptions derived from both open and closed population models, such as Jolly-Seber and Lincoln Peterson models respectively, to allow for the effects of temporary emigration. These assumptions include: (1) all marks are unique and permanent; (2) survival is equal among all individuals between primary sampling periods; (3) each individual’s probability of capture and survival is independent of all others; (4) the population is closed within primary sampling periods; and (5) all
emigration between primary sampling periods is temporary (Kendall et al. 1999). Despite the advantages of the robust design, assumptions 2, 4, and 5 could be easily violated in BSE systems where bottlenose dolphin populations are known to experience frequent emigration and immigration as well as interaction with humans, which would result in an upward bias of abundance estimates (Speakman et al. 2010). Although mark-recapture models provide effective estimates of abundance in BSE systems, these methods require a significant survey effort, do not distinguish between residents and transients, and are difficult to employ across multiple seasons.

Relative abundance and trends over time can be tracked using simple measures of survey density (number of dolphins per distance or area surveyed) with relatively low survey effort (Pitchford et al. 2016). Density can also be used to investigate the influence of environmental factors such as water temperature and photoperiod on dolphin abundance. In areas where stock boundaries are not clearly defined, such as BSE systems, density can provide insight into local distribution and can be extrapolated to infer patterns in areas with limited data. While density does not differentiate between residents and transients, it does require much less survey effort than mark-recapture models and can be easily employed in BSE systems.

Determination of residency can be complicated by the fact that it is difficult to define the geographic range of an estuarine stock without long-term survey effort (Rosel et al. 2011). Non-resident dolphins should not be included in abundance estimates of estuarine stocks because it may skew the data and overestimate the PBR. Generally, residency is determined by the number of times and during how many seasons within a year an individual dolphin has been sighted in a certain location (Gubbins, 2002b;
Zolman, 2002; Rosel et al. 2011). In a workshop to identify best practices for estimating abundance of estuarine bottlenose dolphins, a definition of a resident dolphin was agreed upon by participants as one who spends greater than 50% of its time in an estuary in a given year (Rosel et al. 2011). In practice this is very difficult to determine, and thus, the amount of survey effort and historical sighting data available for a particular area increases the accuracy of residency estimates.

Catalogs of known residents have been developed in various BSE systems in South Carolina through several years of survey effort (Gubbins, 2002b; Young and Phillips 2002; Zolman, 2002; Fox and Young 2012; Speakman et al. 2010; Brusa et al. 2016). Despite significant research effort on population dynamics along the Atlantic U.S. coast, abundance, seasonal distribution, and distinction between populations remains unclear, especially south of Cape Hatteras (Barco et al. 1999; Zolman 2002; Read et al. 2003; Torres et al. 2005; Rosel et al. 2011).

Three of the 11 bottlenose dolphin BSE stocks are located completely or primarily within South Carolina. South Carolina’s coastal plain is largely dominated by shallow, bar-built estuarine systems (Dame et al. 2000) with over 500,000 acres of coastal marsh, more than any other state along the Atlantic U.S. coast (SC Department of Natural Resources [SCDNR], 2014a). The three South Carolina BSE stocks are: the Northern South Carolina Estuarine System (NSCES), the Charleston Estuarine System (CES) and the Northern Georgia Southern South Carolina Estuarine System (NGSSCES; Waring et al. 2015; Figure 2), and the boundary lines established for those stocks collectively cover nearly all estuarine waters within the state.
The CES lies between the other two stocks and was the first to be recognized, with stock boundaries to the north and south based primarily on the geographic limit of surveys conducted in 2006. Those surveys produced a minimum population estimate and PBR value for the CES stock, but no estimates have been published for the NSCES and NGSSCES stocks (Waring et al. 2015). The NGSSES stock, in particular, has been sparsely studied, with most previous effort centered in the southern portion of the South Carolina coast, near Calibogue Sound and May River (Gubbins, 2002a; Fox and Young, 2012). The NGSSCES stock encompasses four large inshore systems (St. Helena, Port Royal, Calibogue, and Wassaw Sounds), and spans an area of over 5,000 km².

Gubbins (2002a) showed that many NGSSCES dolphins in the Calibogue Sound area have small home ranges and display strong site fidelity, and similar patterns were found for some NSCES dolphins in North Inlet (Brusa et al. 2016). Therefore it is unlikely that all dolphins within the South Carolina BES stocks have home ranges that extend to the full extent of their stock boundaries. It is possible that these stocks may have smaller, stable social communities within their described range which, if demographically and reproductively isolated from other groups, could be considered separate stocks. It is important to manage stocks separately and prevent their decline past the point of sustainability, especially because there is evidence of genetic differentiation between dolphins assigned to separate stocks. Genetic diversity in a local population increases its resiliency and ability to adapt to changes in the environment because it preserves various traits that could become important in the face of ecological changes. Alternatively, a continuous gradient of small, overlapping yet self-contained groups may confound the traditional stock concept completely.
Clearly, the current stock management approach for BSE dolphins in the large salt marsh systems of South Carolina and Georgia is problematic due to the uncertainty of stock boundaries and, therefore, stock abundance. Abundance estimates are required to ensure that BSE populations are not declining past the point where they are sustainable. Measures of relative abundance, such as survey density, may serve as useful proxies for actual abundance, if changes are tracked over time. Additionally, when home ranges and stock boundaries are unknown, density calculations can be useful for predicting the number of dolphins that may be sighted in a given area. Though a PBR cannot be calculated from relative abundance, survey densities can be used as an efficient way to monitor population changes over time or, if surveys reveal similar densities from different but similar sites, as an initial assessment relative to minimum density expectations.
Objectives and Hypotheses

The objective of this study is to investigate bottlenose dolphin stock structure and the implied effectiveness of current stock management practices for BSE stocks in South Carolina. Specifically, I will: (1) examine stock structure and substructure in the NGSSCES stock by estimating density, residency, and movements between two separate areas within the stock boundaries: the well-studied Bull Creek region, and the unstudied ACE Basin (Ashepoo, Combahee, and Edisto Rivers), and (2) compare dolphin density values in two different estuarine stocks in South Carolina, including surveys in the two previously mentioned sites in the NGSSCES and the Cape Romain estuary in the NSCES. I hypotheses that: (1) resident dolphins will be observed at both NGSSCES sites and that no movements will be observed between the two sites, suggesting that the currently recognized stock boundaries may be suspect, (2) that there will be no statistical difference in estuarine survey dolphin densities at all sites studied, regardless of stock designation, suggesting density is relatively stable in similar salt marsh habitats and that density as a measure of relative abundance may be broadly useful as a management tool, and (3) that dolphin density will vary seasonally, with the highest values in autumn and the lowest in winter, in accordance with previous studies in the region (Zolman, 2002; Speakman et al. 2010).
Methods

Survey Sites

Transect-based photo-identification surveys were conducted in three inshore, tidal salt marsh systems in South Carolina: Bull Creek, ACE Basin, and Cape Romain. Bull Creek and ACE Basin fall within the NGSSCES stock boundaries but are separated by approximately 57 km of continuous salt marsh systems, estuarine river mouths, and open sounds. Cape Romain falls within the NSCES stock boundary and is approximately 105 km north of ACE Basin. The CES stock lies between the NSCES and NGSSCES stocks. Each survey focused on tidal creeks as opposed to larger open bodies of water (bays and sounds), because most BSE bottlenose dolphin sightings occur in these areas (Wilson et al. 1997; Gubbins, 2002b; Torres et al. 2005), and it reduces the possibility of sighting coastal dolphins who may be found near inlets and bay mouths.

The southernmost track surveyed Bull Creek and adjacent tidal creeks located near Bluffton, SC (32°11’N, 80°51’W). The survey area was bordered on the north by the May River and on the south by the Calibogue Sound, with a transect length of 24.9 km (Figure 3). Numerous dolphin studies have been previously conducted in Bull Creek and surrounding areas (Petricig, 1995; Gubbins, 2002a; Gubbins, 2002b; Fox and Young 2012). The second and longest survey track was within ACE Basin, located near Bennett’s Point, SC (32°33’N, 80°27’W). The survey area was bordered on the north by the Ashepoo River and on the south by the St. Helena Sound, with a transect length of 38.4 km (Figure 4). The ACE Basin includes the Ashepoo, Combahee, and Edisto Rivers. It is one of the largest undeveloped estuaries on the eastern U.S coast and is home to the ACE Basin National Estuarine Research Reserve (SCDNR, 2014b). A
bottlenose dolphin dorsal fin catalog has not been previously established in this area or anywhere in the northern half of the NGSSCES. The third and northernmost survey was within the Cape Romain National Wildlife Refuge located near McClellanville, SC (33°04’N, 79°27’W). The survey included Five Fathom Creek and adjacent tidal creeks and was bordered on the north by the Intracoastal Waterway and on the south by Bulls Bay. The transect route was 20.6 km in length (Figure 5). The Cape Romain National Wildlife Refuge is a large, federally managed area located within the NSCES stock. Cape Romain is an extensive salt marsh system with heavy recreational and commercial fishing practices (USFWS, 2016).

*Survey Protocols*

Surveys were conducted under the NMFS General Authorization permit number 16104 between March 2012 and January 2013. Surveys were divided into multiple primary sampling periods in which each of the three sites was surveyed for two to four days at a time, depending on weather. Primary surveys took from three to eight weeks to complete, depending on conditions. Primary surveys were repeated on a rotating schedule throughout the year, ultimately resulting in a total of eight primary surveys per site covering all four seasons. Primary periods were frequent enough to capture potential dolphin movements between and within sites at a sub-season level, while the sampling periods within the primary periods were short enough to assume a closed population, while still long enough to run several complete transects and maximize the likelihood of sighting all dolphins in the area. Seasons were defined as: fall (October-December),
winter (January-March) spring (April-June), and summer (July-September), based on previous studies in South Carolina (Zolman, 2002; Speakman et al. 2010).

Two 18-foot aluminum skiffs, each equipped with a 60 hp Yamaha engine, were used interchangeably throughout the study. Surveys were staffed by two to four observers and followed a pre-defined transect route at each site maintaining a speed of 10-12 knots (18-22 km/hr) until a dolphin was sighted. Transects were short enough so that they were able to be repeated during one field day, in order to sample multiple tidal stages. Typical survey days lasted on average six hours and occurred between 0700 and 1900 hours. Surveys took place during every tidal phase and only when the Beaufort Sea State was a three or less.

Surveys were “on effort” when following the transect with observers actively looking for dolphins. In sections of the transect where the track overlapped in two directions, only the first pass was considered on effort, and similarly transect length only included the first pass. Creek widths were narrow enough so that dolphins could be readily sighted along either edge of the creek. When a dolphin was sighted, an event was started and effort was considered to be “off effort”. During an event, the vessel slowly followed the dolphin or group of dolphins parallel to their course while maintaining enough distance so that the boat did not influence movement or behavior. Photographs of dorsal fins were taken using a Canon EOS Rebel T2i equipped with a Canon Ultrasonic 100-400mm telephoto zoom lens. Events lasted until either the dolphin or group was lost to sight or until photographs of each dorsal fin were taken. During each event, minimum, maximum, and best estimates of group size were recorded as well as air and water temperatures, salinity, tidal phase, and the time and geographic location of the start and
end of the event. Geographic position was recorded using a Garmin GPSMap 76Cx. Age categories of dolphins (adult, calf or neonate) were estimated when possible. Neonates were classified based on the presence of fetal folds, a size less than half the length of the accompanying adult, the presence of a floppy dorsal fin, a dark color, extreme buoyancy, and close position in relation to the assumed mother (Barco et al. 1999; Thayer et al. 2003). Calf classification differed from neonates in that fetal folds were no longer present (Grellier et al. 2003), and they displayed more independent surfacing behavior. Gender was determined by proximity of neonates and calves to an assumed mother. After each event the boat returned to the point where it had previously gone off effort and resumed its “on effort” path along the transect.

Photographic Analysis

The best photographs for each dolphin from each event were assessed and scored based on quality and fin distinctiveness using methods proposed by Urian et al. (1999). Quality of the photo was based on clarity, contrast, angle of fin, and proportion of fin visible in the photo. Quality was given a score of 1-3 where 1 represents poor quality and 3 represents high quality. This study used the method performed by Read et al. (2003) for fin distinctiveness, with distinctiveness graded as: D-1 (very distinct), D-2 (average distinctiveness) and D-3 (not distinctive). A D-1 fin is identifiable even in a poor quality photo. A D-2 fin has one major distinctive feature or two obvious features. D-3 fins have no distinct features, or they have features so subtle that they can only be identified in a high quality photograph. Only high quality images (2 and 3) of D-1 and D-2 fins were used in the catalogs and residency analyses.
Photographs of unique individual dorsal fins were compiled into a fin catalog and assigned a unique identification number for each of the three sites. After each survey day, photographs were uploaded onto a computer and images from each event were analyzed. The best right and left images of each dolphin from each event were placed in a separate folder and were visually compared to existing dorsal fin images from each site’s catalog. If a dorsal fin could not be matched to a previously known dolphin, it was added as a new individual in that site’s catalog. Dorsal fin photographs from Bull Creek were also compared to a catalog of individuals previously established by Fox and Young (2012). If a dolphin fin image matched an individual from Fox’s catalog, the corresponding identification number from the original catalog was added to the end of the assigned identification number in this study, for reference.

**Estimating Density**

An average transect density of bottlenose dolphins was calculated for each site. Density was estimated in two ways: linear density and areal density. Linear density was calculated for each transect by dividing the number of dolphins per transect by the length of the transect in kilometers, as determined by the GPS track. Areal density was calculated by dividing the number of dolphins per transect by the total aquatic surface area surveyed in square kilometers. ArcMap 9.0 was used to digitize transect maps and to calculate total creek surface area associated with each survey track. The surveyed area extended to the creek shoreline on either side of the track, except in one open water section of the ACE Basin track, where the survey boundary was set at a distance of 200 meters from the track line, and in one section in the Cape Romain track where the width
of Five Fathom Creek exceeded 0.5 km and a separate track was run on each side of the creek, with on-effort sightings restricted to the area from the bank to the center of the creek. Densities were calculated for each transect and compared between sites using a one-way ANOVA with a Tukey’s post-hoc test.

Total linear density for all sites was also compared seasonally, because not all seasons were equally represented between sites. Linear density of each transect for all sites was compared between seasons using a one-way ANOVA with a Tukey’s post-hoc test.

**Estimating Residency**

Residency was determined using a modified version of Rosel *et al.* (2011)’s suggested definition, in which residents are individuals who spend greater than 50% of their time in an estuary in a given year. In this study, residents were defined as individuals who were sighted in at least 50% of the sampling periods during the survey year or were sighted in more than 50% of seasons (three or more of the four season).

Data and dorsal fin images from Fox and Young (2012) were compared to this study as an additional determinant of residency for the Bull Creek site. If an individual dolphin was identified during both survey years (2009 and 2010) in the Fox and Young study as well as in this study, regardless of season, it was considered a resident. For these estimates there is no distinction between year-round and seasonal residency because Fox and Young (2012) only surveyed the area in the spring and summer months. This additional residency estimate for Bull Creek was not used in the statistical comparisons between sites.
Results

Photo Identification Surveys

Surveys were conducted from March 2012 through February 2013, during which eight survey periods were completed for each of the three sites (Table 1). Survey periods were between two and four days each, dependent upon weather conditions, and totaled between 22 and 27 days per site. Each season was represented at least once per site, with the exception of Cape Romain, where windy conditions interfered with winter surveys. The interval between survey periods at each site ranged from 16 to 74 days, with the exception of surveys 6 and 7 in Bull Creek, which had an interval of 123 days (Table 1). For all sites combined, a total of 135 transects were run with over 297 hours on the water (Table 2).

Water temperature varied seasonally, ranging from 10.8°C in the winter to 30.8°C in the summer. All three sites showed a similar pattern of water temperature throughout the survey year, with peak temperatures occurring during July and August, 2012 (Figure 6). Salinity varied seasonally and between sites, with an overall range between 15 and 39 ppt. Bull Creek had the overall highest average salinity and ACE Basin had the lowest (Table 3). Portions of the ACE Basin transect are within the Ashepoo River, a fresh water input into the St. Helena Sound, which accounts for the low salinity values.

A total of 382 unique individuals were catalogued from all sites (Cape Romain=115, ACE Basin=123, Bull Creek=144), and 7,197 high quality photos were used in photographic analysis. Individuals in Cape Romain were sighted one to 16 times, with the highest number of dolphins sighted only once (n=45; Figure 7). Dolphins in ACE Basin were sighted one to 14 times with the highest number of individuals sighted
twice (n=47; Figure 8). The frequency of sightings in Bull Creek ranged from one to 18, with the highest number of dolphins sighted once (n=45; Figure 9).

The rate of discovery of new fins identified per day for each site were fitted with a logarithmic trendline. In each site the number of newly identified dorsal fins starts to approach zero as survey days continue (Figures 10, 11, 12). In Bull Creek in particular, there were no new sightings in the last three survey days (Figure 12), suggesting that nearly all dolphins in the area had been identified.

Group sizes of bottlenose dolphins ranged from one to 21 individuals, but with an average group size of only 2.89 to 3.34 individuals for all sites (Table 4). Cape Romain had the highest maximum group size of 21, and the highest average group size of 3.34 dolphins. Bull Creek had both the lowest maximum group size of 14 individuals and lowest average group size of 2.89 individuals. Neonates and calves were found in all three sites. The number of individual mother/calf pairs ranged from 7 to 19, with Bull Creek being the highest and Cape Romain being the lowest. Mother/calf pairs made up between 6.1% and 13.2% of total individuals identified in each site. The highest number of neonates were sighted in ACE Basin (n=5) and the lowest number were sighted in Cape Romain (n=3; Table 4). The first sightings of new neonates were more frequent in spring, with the majority of first sightings in the month of June (Figure 13). One new neonate was sighted in both summer and fall, and no neonates were first sighted in winter.

Catalogs of distinct individuals from each site were compared to each other using the best left and right dorsal fin images, and there were no matches between sites. Thus, no individual dolphins were found in multiple sites.
Density Estimates

Linear density was similar for all three sites, with no significant statistical difference between sites ($n=121$, $df = 120$, $p = 0.077$). Bull Creek and Cape Romain had the same average linear density (0.440 dolphins/km) and ACE Basin had the lowest (0.296 dolphins/km, Figure 14). In contrast, the average areal density was significantly different for at least one site ($n=121$, $df = 120$, $p < 0.001$), with the areal density for Cape Romain significantly higher than each of the other two sites (Tukey’s post hoc, $p<0.01$) but no significant difference between ACE Basin and Bull Creek (Figure 15).

Overall linear density was highest in the spring (April-June) and lowest in fall (October-December; Figure 16). There was a significant statistical difference between spring density and fall density (Tukey’s post hoc, $p = 0.010$), but no significance was detected between the other season’s values.

Residency Estimates

Resident bottlenose dolphins were found in all three sites. Bull Creek had the highest number of residents ($n=34$), followed by Cape Romain ($n=22$) and ACE Basin ($n=19$; Figure 17). Resident dolphins made up between 15.45% and 23.61% of total individuals, with Bull Creek having the highest proportion and ACE Basin having the lowest (Table 5). Additionally, 29 individuals from Bull Creek were matched to Fox and Young’s (2012) catalog in both his 2009 and 2010 survey seasons, further confirming residency and long term site fidelity in this area. Dolphins were sighted across the full extent of area covered by the transect, and many individuals were re-sighted within the
whole range of the survey tracks. For example, resident Dolphin 009 “Corsair” in Bull Creek was sighted at the upper end of the transect in May River and at the lower end of Bull Creek, spanning a linear distance of 6.21km. Another resident in ACE Basin, Dolphin 007 “Banana”, was sighted multiple times across a linear distance of 6.35km, representing the far north and far south end of the transect.
Discussion

Dorsal fin catalogs of unique individuals were established for three survey sites in South Carolina, representing two BSE stocks. As predicted, no matches were found within the two sites of the NGSSCES stock, suggesting that the NGSSCES may not be a single, interactive stock. In addition, linear survey density did not differ between three distinct salt marsh estuary habitat sites, representing at least two different stocks.

Similarities between sites also existed in the frequency of sightings, residency, and seasonal trends. These patterns provide evidence that estuarine bottlenose dolphins in South Carolina share similar characteristics regardless of stock designation and that measures of relative abundance, such as survey density, may be useful and widely applicable for the management of dolphins in large, contiguous salt marsh estuary systems.

Discovery curves for all three sites show a decline in the number of new fins identified per day toward the end of the survey period, indicating that most individuals who inhabit the area were accounted for. The Bull Creek survey area makes up less than 10% of the total potential dolphin habitat encompassed by the NGSSCES stock, yet the discovery curve suggests that most of the individuals that use the area were identified during this study. If members of the NGSSCES stock had home ranges that extended to the full area of the stock boundary, it would be expected that the discovery curve would continue to increase, however in this case new sightings approached zero toward the end of the survey.

The frequency of individual sightings in each of the three sites ranged from one to 18, though about half of the dolphins in each site were only sighted once or twice. The
individuals with low sighting frequencies likely have home ranges that are either larger than the survey area or only slightly overlap with the survey area. Several individuals were sighted across the full extent of the area covered by transect, so it is likely that those dolphins have home ranges that are larger than the areas surveyed in this study. More survey effort in the waters surrounding these defined study areas would provide more insight to whether these dolphins are residents, transients, or members of an adjacent estuarine stock where home ranges overlap.

Basic measures of social structure were similar in all sites and consistent with estuarine dolphin stocks. Group sizes of dolphins varied between one and 21 individuals, but average group size for all three sites was only about three dolphins. In coastal stocks of this region, group sizes are much larger, reaching up to 150 individuals (Silva, 2016), but the group sizes in this study are consistent with other reported estuarine group sizes in the region (Sloan, 2006; Fox and Young, 2012). Mother/calf pairings were also found in each site, and the timing of neonate appearances were similar in each site. The highest number of new neonate appearances occurred in late spring (June), which is consistent with the primary season of reproduction reported for the CES stock (McFee et al. 2014). Reproductive seasonality appears to be similar for most inshore bottlenose dolphins in the state of South Carolina.

No dolphins were sighted in more than one study area, suggesting that dolphins within the NGSSCES stock are not using the full area encompassed by the stock boundary. This is in contrast to studies of the Southern and Northern North Carolina Estuarine System stocks, in which individual dolphins were observed to move widely within the stock range, both within and between seasons (Read et al. 2003). The lack of
movement between areas within the stock, in addition to the presence of site fidelity, supports the idea that there might be smaller stocks located within the NGSSCES stock. Additional surveys and catalog comparisons in adjacent systems would strengthen the understanding of home range size for BSE dolphins.

Resident dolphins were found in all three study areas. Residents made up on average 19.4% of the total number of individuals in each site, similar to the 19% reported for the Charleston area (Zolman, 2002), and 18% reported in Cape Romain (Sloan, 2006). The discovery of residency in two sites within the NGSSCES stock supports the idea that there might be multiple stocks within the boundary, or at least smaller communities that do not mix with each other, especially since these two sites are separated by the Port Royal Sound.

Residency was calculated by the presence of dolphins in multiple seasons and survey periods, however, the definition of residency and its application are not consistent throughout bottlenose dolphin studies. Rosel et al. (2011)’s definition of a resident as a dolphin who spends greater than 50% of its time in an estuary in a given year is well accepted and useful in theory but is difficult to employ in the field because it requires knowledge of a dolphin’s location at all times. In this study, if a dolphin was sighted in consecutive survey periods or seasons, it was assumed that in between those sightings it remained in the same area. However, because the interval between survey periods ranged from 16 to 123 days, it is possible that individuals were moving out of the area during those times. It would be beneficial to have a standardized definition for residency that can be used in studies with varying amounts of survey effort, especially so that residency can be compared amongst several studies. Access to long term sighting data on bottlenose
dolphins is the most accurate way to understand their internal population structure, dynamics, and to monitor the effect of disturbances. Having a consistent definition for residency and a standardized way to translate that definition into an experimental design would be useful for comparing future studies and adding data to the amount of historical sighting information already available.

Density was calculated for each of the three sites using both surface area covered by transect and linear distance of transect. The hypothesis that linear density would not be statistically different was supported. There was a significant difference between sites for areal density but not linear, which could mean that dolphin distribution may be determined more by the linear distance of a waterway than by its width. Dolphins in BSE systems appear to be using their habitat linearly, for example preferring the edges of a creek instead of responding to increases in overall surface area or volume. Dolphin density could be influenced by the total volume of water they inhabit, if the amount of available prey increases with increasing volume. However, if prey abundance increases with increasing volume, the density of prey would, at best, remain relatively unchanged, therefore the capture of prey is no more likely to be successful. Additionally, detailed bathymetry data is not easily available for all BSE systems, so dolphin density per volume is a less practical measurement of abundance. Linear density is a simple measurement of dolphin abundance that could be a valuable tool for the management of BSE dolphins, especially since it appears consistent throughout the large salt marsh estuary systems investigated in this study. Linear density averaged between 0.2963 and 0.4401 dolphins/km transect in each site, but varied seasonally. There was not enough data to carry out statistical tests comparing seasonal variations of linear density in each
site, so density values per transect were combined for all sites and compared. The highest linear density of bottlenose dolphins was in spring, and the lowest in fall. In previous studies within the CES stock, density and abundance were greatest in the summer and fall, presumably due to an influx of coastal transients, and lowest in winter (Zolman, 2002; Speakman et al. 2010). The inconsistency between this study and previous studies in the region could be due to low survey effort in the fall and winter months, since the number of fall and winter sampling days only accounted for 30% of the total survey days. Variations could also be explained by shifts in water temperature over the last decade, or possibly shifts in prey distribution. Multiple years of survey effort would allow for a better understanding of how seasons influence dolphin abundance and distribution.

Regardless of seasonal variation, dolphins in all three sites had similar average linear densities, which could be a useful tool for managing bottlenose dolphins in areas with low survey effort. For example, density values could be extrapolated to encompass expected stock boundaries in order to provide a local abundance estimate and PBR calculation in areas that are considered data deficient, like the NGSSCES stock. If density values correlate with abundance estimates, they can be used to fill in the gaps where survey effort is low, providing important information for a specific stock and its assessment. Comparing local abundance estimates from mark recapture studies to linear density estimates could also be useful in identifying patterns and inferring the health of the population. For example, mark recapture abundance estimates that are higher than those derived from linear density in the same area could indicate that dolphin home ranges are larger than the area encompassed by the survey, or that the area experiences frequent immigration from adjacent stocks.
In areas such as Bull Creek where stock boundaries are unclear or insufficient, linear density may be used as a proxy for monitoring changes in a local population. Linear density estimates did not differ significantly between sites, suggesting a general pattern for the large salt marsh systems of South Carolina. If measured density is lower than expected in a certain area, it could indicate a negative disturbance to the population or ecosystem in general. The use of linear density as a management tool for bottlenose dolphins requires less time and effort than traditional mark-recapture abundance estimates and does not rely on the distinction between residents and transients. For BSE stocks like NGSSCES where there is no minimum population estimate, PBR value, or understanding of home range sizes, changes in density over time can be used to monitor the impacts of natural and anthropogenic disturbances on local populations.

This study provides the first bottlenose dolphin dorsal fin catalog for the ACE Basin site. ACE Basin is part of a large estuarine system with no previous data on bottlenose dolphin population dynamics. Despite the highest amount of area covered by transect, the ACE Basin site had the lowest number of residents. This section of ACE Basin may be smaller than the home ranges of its resident dolphins, which would explain the low calculated residency. More survey effort in the areas immediately adjacent to this site is needed to investigate this idea.

Dolphins in Bull Creek had the highest residency of the three sites. This strong site fidelity may be due to behaviors that limit them to a certain type of habitat. For example, the small group of dolphins that use strand-feeding as a foraging technique in Bull Creek only perform this strategy at low tide in a limited number of preferred sites (Petricig, 1995; Fox and Young 2012). The unique behavior of these dolphins makes
them susceptible to environmental changes such as sea level rise. Though not part of this study, the area just south of Savannah, Georgia, in the lower portion of the NGSSCES stock, also has strong site fidelity, with some of the highest rates of begging behavior demonstrated by bottlenose dolphins worldwide, further increasing their risk of mortality by boat strike or entanglement (Hazelkorn, 2016). The strong site fidelity and unique niche of strand-feeders in Bull Creek and beggars near Savannah illustrate the existence of unique sub-communities that may not be appropriate for management as part of the larger NGSSCES stock. Although the NGSSCES stock has no current PBR value due to insufficient data, a PBR for the entire stock’s population might not accurately reflect potential damages to those local sub-communities of dolphins. It would be beneficial to re-evaluate not only the structure of the NGSSCES stock, but the way that BSE dolphin populations are managed so that the small, high risk communities are assessed independently.
Conclusion

Current management practices for BSE stocks in South Carolina may not be effective due to limited data, especially in the southern portion of the state. The NGSSCES stock is large and data deficient, but there is evidence that there may be smaller stocks or local populations within it, that do not mix. If this is the case, management of this entire stock using one PBR value could potentially result in local populations becoming depleted despite incidental takes being within range of the PBR. Until more data become available for all areas encompassed by the boundary of BSE stocks, alternative management approaches should be discussed.

Designating stocks implies that all inhabitants are residents and that they are reproductively interactive with one another. However, unless there is significant survey effort and continuous sighting data available for the full extent of the stock area, it is difficult to distinguish residents from transients, or understand the internal processes of reproduction and ranging. PBR is a useful tool to monitor impacts on a population, but it requires an abundance estimate and relies on accurate stock boundaries. The NGSSCES and NSCES stocks are both data deficient and therefore have no assigned PBR values.

Density and residency characteristics of estuarine bottlenose dolphins in South Carolina appear to be consistent, regardless of stock designation. Three sites representing two separate BSE stocks both have similar densities, and residents that appear to have small home ranges. Density may be used as a management tool for these areas where additional data are unavailable. It can be used to examine relative abundance and observe changes in the population without needing accurate stock boundaries or a large amount of survey effort. If future studies continue to identify small groups of dolphins with strong
site fidelity and small home ranges, the traditional stock concept might need to be re-evaluated with management efforts shifting toward simple measures of linear density and relative abundance.
Literature Cited


Table 1. Summary of survey dates for each site during the 2012-2013 survey period.

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Table 3. Low, high, and average salinity measurements for each survey period per site. Salinity was measured in parts per thousand (ppt) using a refractometer during each sighting event.

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<th>Survey Period</th>
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<th>Bull Creek</th>
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Table 4. Summary of mom/calf pair sightings and dolphin group sizes for each site.

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Table 5. Number of unique individuals, residents and proportion of total individuals per site. Note the residency value in parentheses reflects the number of matches from this survey to Fox’s (2010) catalog during both study years (2009-2010).

<table>
<thead>
<tr>
<th>Site</th>
<th>No. Individuals</th>
<th>Residents</th>
<th>Prop. of Total Individuals</th>
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Figure 1. Bottlenose dolphin stocks recognized by the National Marine Fisheries Service (NMFS) along the Atlantic U.S. coast. Red squares indicate the boundaries of the 11 bay, sound, and estuary (BSE) stocks and bars indicate the latitudinal range of the five nearshore, coastal stocks. Bars a and b represent the two seasonal migratory coastal stocks that overlap latitudinally. BSE stocks shown are: Northern North Carolina Estuarine System (1), Southern North Carolina Estuarine System (2), Northern South Carolina Estuarine System (3), Charleston Estuarine System (4), Northern North Carolina/Southern South Carolina Estuarine System (5), Central Georgia Estuarine System (6), Southern Georgia Estuarine System (7), Jacksonville Estuarine System (8), Indian River Lagoon Estuarine System (9), Biscayne Bay (10), and Florida Bay (11). Coastal stocks shown are: W.N. Atlantic Northern Migratory Coastal (a), W.N. Atlantic Southern Migratory Coastal (b), South Carolina/Georgia Coastal (c), W.N. Atlantic Northern Florida Coastal (d), and W.N. Atlantic Central Florida (e).
Figure 2. Maps of the three South Carolina BSE stock boundaries. The Northern South Carolina Estuarine System (NSCES; A) is bounded on the north by Murrells Inlet and on the south by Price Inlet. The Charleston Estuarine System (CES; B) is bounded on the north by the southern border of the NSCES stock on the south by the North Edisto River. The Northern Georgia/Southern South Carolina Estuarine System (NGSSCES; C) is bounded on the north by the southern border of the CES stock and continues southwestward across the South Carolina/Georgia border to the northern extent of the Ossabaw Sound.
Figure 3. Map of Bull Creek survey site. Transects were surveyed along a predefined route (red line). Transects started at the black star and ended at the yellow star. Total transect length was 24.9 km.
Figure 4. Map of ACE Basin survey site. Transects were surveyed along a predefined route (red line). Transects started and ended at the black star. Total transect length was 38.4 km.
Figure 5. Map of Cape Romain survey site. Transects were surveyed along a predefined route (red line). Transects started and ended at the black star. Total transect length was 20.6 km.
Figure 6. Mean water temperature per survey period per site. Error bars represent one standard deviation.
Figure 7. Sighting frequency of marked individual dolphins photographed in Cape Romain.
Figure 8. Sighting frequency of marked individual dolphins photographed in ACE Basin.
Figure 9. Sighting frequency of marked individual dolphins photographed in Bull Creek.
Figure 10. Discovery curve of new marked dolphins sighted per survey day in Cape Romain. Plot fitted with a logarithmic trendline.

\[ y = -3.948\ln(x) + 13.685 \]

\[ R^2 = 0.2421 \]
Figure 11. Discovery curve of new marked dolphins sighted per survey day in ACE Basin. Plot fitted with a logarithmic trendline.

\[ y = -4.142\ln(x) + 14.716 \]
\[ R^2 = 0.4956 \]
Figure 12. Discovery curve of new marked dolphins sighted per survey day in Bull Creek. Plot fitted with a logarithmic trendline.
Figure 13. First sightings of neonates for all sites by season. Note most neonates were first sighted in spring (n=10), with the majority of sightings in the month of June (n=6).
Figure 14. Linear density of bottlenose dolphins per site with plus or minus one standard deviation. Density was calculated by dividing the number of dolphins per transect by transect length. Data displayed shows average density from all transects; however statistics were run on density estimates per transect (n=121). There was no significant difference between sites (p = 0.0773).
Figure 15. Areal density of bottlenose dolphins per site with standard error bars. Density was calculated by dividing the number of dolphins per transect by surface area of the transect. Data displayed shows average density from all transects; however statistics were run on density estimates per transect (n=121). There was a significant difference in density between sites (p<0.05).
Figure 16. Total linear density of all sites per season with standard error bars. Dolphin density was highest in the spring (Apr-Jun) and lowest in the fall (Oct-Dec). Density for spring was significantly different than fall density, as indicated by asterisks (p=0.010).
Figure 17. Comparison of residency for each site. Residency was determined if individuals were sighted in at least 50% of survey periods, or in at least three of the four seasons.