Determining the northern range of the NNCES stock of bottlenose dolphins (*Tursiops truncatus*) through photo-identification

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Date: 27 April 2018

Masters Project submitted in partial fulfillment of the requirements for the Masters of Environmental Management degree in the Nicholas School of the Environment, Duke University, May 2018
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ABSTRACT

The Roanoke Sound is an important summer habitat for coastal Atlantic bottlenose dolphins, including members of the Northern North Carolina Estuarine System (NNCES) stock. However, our understanding of the northern range of this stock is limited. It has been assumed that the stock occurs northward only as far as the NC/VA border, but there is considerable uncertainty in the location of this boundary. The objective of the present study was to better delineate this boundary by determining the northern range of individual dolphins sighted in Roanoke Sound. I matched individuals with high capture probabilities (n=59) in Roanoke Sound (NC-OBXCDR catalog) with individuals sighted in Norfolk, Virginia (VA-HDR catalog), the Potomac (MD-PCDP) catalog, and Cape May, NJ (NJ-CMWWRC catalog) through the MABDC. Five individuals, all likely females, were matched to VA-HDR, but none were matched to MD-PCP nor to NJ-CMWWRC. Four of the matched individuals were also sighted in the Pamlico Sound. The movements of these dolphins show some degree of seasonality, with sightings in the Roanoke Sound peaking in June but occurring from May to October, and in Virginia only in July and August. The results of my study indicate that the NC/VA border is not the northern boundary of the NNCES stock, but instead that the movement of these dolphins extends into the Chesapeake Bay. Thus, the management of this stock of dolphins should consider the threats, including by-catch, that may occur in this extended range.

INTRODUCTION

In the western north Atlantic, bottlenose dolphins (*Tursiops truncatus*) are distributed continuously from Florida to Long Island, NY. On both sides of the Atlantic, niche specialization through time has resulted in the identification of two distinct ecotypes, coastal and pelagic, with genetic divergence associated with social organization and foraging ecology (Louis et al. 2014). The coastal ecotype is composed of a series of stocks that occupy both coastal and estuarine systems. In North Carolina, Roanoke Sound provides an important summer habitat for members of the Northern North Carolina Estuarine System (NNCES) stock (Waring et al. 2015), where individuals are seasonally resident from April through November, with seasonal movement corresponding to a range of factors including, but not limited to, temperature,
resource availability, habitat suitability, predation, and other environmental and ecological parameters (Barco et al. 1999). Even within a population, site fidelity among individuals may vary (Defran et al. 1999). Survey effort in the Roanoke Sound is high and much is known about this stock’s behavior during the summer and fall, but knowledge of their movements is limited once they migrate out of the Roanoke Sound. During winter, this stock moves primarily into Pamlico Sound, and individuals are sighted as far south as Beaufort, NC. The southern range of these movements is well established, but it is still unclear exactly how far north their range extends during summer.

The NNCES, as defined by the National Marine Fisheries Service, is composed of an estimated 823 individuals, based on a photo-ID mark-recapture survey conducted in 2013 (Waring et al. 2015). It was originally believed that the range of this stock extended only as far north as the NC/VA border, but aerial survey data revealed that bottlenose dolphins in the NNCES stock occupy estuarine and coastal waters from the Pamlico Sound through southern VA and into the lower Chesapeake Bay (Fig 1), as reflected in the most recent stock assessment (Waring et al. 2015). However, we still do not have information on the movement of individual dolphins that demonstrates their movement beyond the NC/VA border. Reliable approximations of stocks involve the incorporation of movement and ranging patterns (Shane, Wells, and Würsig 1986), so it is important to ascertain the full geographic extent of NNCES to manage this stock.

Marine mammals in United States waters are granted federal protection under the Marine Mammal Protection Act (MMPA). This Act prohibits the take of marine mammals, including harm and harassment (16 U.S.C. § 31). Section 117 of the MMPA regulates the bycatch of marine mammals in commercial fisheries; fishermen must obtain a certification and record all incidental catch, which includes mortality as well as any injuries and entanglements in gear. The bycatch of marine mammals is monitored by fisheries observers and enforced at the federal level, as incidental catch has important potential implications for marine mammal demographics (Read et al., 2006).

Bottlenose dolphin stocks are managed by the National Marine Fisheries Service under the MMPA (Waring et al. 2015). Under Section 117 of the MMPA, stocks of marine mammals are considered either strategic or non-strategic, depending on their conservation status. Stocks are considered strategic if bycatch exceeds Potential Biological Removal (PBR) Strategic stocks are either depleted (below Optimum Sustainable Population) or declining, or likely to be or
already listed as threatened or endangered in the ESA. These stocks are assessed annually, and non-strategic stocks are assessed every three years or when new information becomes available (NMFS 2004). Stock delineation is a particularly difficult undertaking for coastal bottlenose dolphins which exhibit complex patterns of distribution, seasonal variation in occupancy, and overlap in some locations.

Figure 1. Boundaries of NNCES stock as designated in 2009 (A) and distribution of sightings of individuals in NNCES stock as of May 2015 (B). Individuals were identified by aerial surveys (triangles), photo-identification (squares), and satellite telemetry (circles). Filled symbols represent individuals that are part of the NNCES stock.

The NNCES stock is considered strategic because human-caused injury and mortality may exceed PBR, and its last assessment was in 2015 (Waring et al. 2015). This assessment acknowledged that the dolphins move north of the NC/VA border, which was supported by evidence from aerial surveys. However, this northern delineation of their range is still unclear, with no photo-identification evidence of movement past the state line referenced in the assessment. More research is necessary to elucidate the movement patterns of these dolphins.
Without proper knowledge of the range of this stock, assessments are prone to error and may not account for the full population.

Improper stock delineation can result in an inaccurate estimation of abundance. A stock’s PBR depends primarily on its abundance estimate. Human-induced mortality, primarily bycatch for estuarine dolphins, must be managed throughout the entire range of a stock. In a study to assess the accuracy of the 2002 stock assessment reports, it was revealed that 134 out of 165 stocks (81%) were insufficient, primarily due to a lack of information on abundance and stock identification (Moore and Merrick 2011). Defining the full extent of NNCES’ range is necessary to meet the requirements of stock assessment reports, as mandated by the MMPA.

Photo-identification is one of the most efficient techniques to monitor well-marked individuals in a defined area over long periods of time (Cheney et al. 2013). In terms of long-term management, it is the most practical method to collect and maintain knowledge of stock structure. The use of photo-identification data is vital in gaining more insight into the range of NNCES.

The Mid-Atlantic Bottlenose Dolphin Catalog (MABDC) was created in 1997 to compile photo-identification records of bottlenose dolphins along the U.S. east coast. It includes contributions from 19 individual catalogs of dorsal fin images, and allows for collaboration and matching to be made from New Jersey to Florida (Urian et al 1999). Individual sightings from each catalog are accessible through the MABDC OBIS-SEAMAP database. The Outer Banks Center for Dolphin Research (OBXCDR), established in 2008, is a nonprofit organization that is engaged in the long-term monitoring of bottlenose dolphins in the Roanoke Sound, performed through opportunistic and dedicated photo-identification surveys. OBXCDR contributes images and data to the MABDC to further understand the long-range movement patterns of the dolphins that occur in the sound.

The present study aims to determine the northern range of the individuals frequently sighted in the Roanoke Sound and better delineate the northern boundary of NNCES. In conjunction with OBXCDR, I matched dorsal fins photographed in Roanoke Sound (NC-OBXCDR catalog) with those from Norfolk, Virginia (VA-HDR catalog), the Potomac (MD-PCDP), and Cape May, NJ (NJ-CMWWRC) through the MABDC. By matching Roanoke Sound dolphins to all of the northern contributors to the MABDC, I hoped to determine whether any
NNCES individuals move into and beyond Virginia, and consider the implications of such movements for stock delineation.

METHODS

Catalogs

My study focused on making matches to the MABDC catalogs with sighting records north of North Carolina. By matching individuals sighted in the Roanoke Sound with these three catalogs (Table 1), I hoped to ascertain the northern range of this stock. All catalogs have different degrees of effort, and encompass sightings from a variety of years. Therefore, it is important to note that my analysis was, in part, limited by these sources of variation.

Table 1. MABDC catalogs used in the present analysis

<table>
<thead>
<tr>
<th>Catalog</th>
<th>Contact</th>
<th>Study Area</th>
<th>Study Period</th>
<th>Catalog Size</th>
<th>Percent matched to MABDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC-OBXCDR</td>
<td>Jessica Taylor, OBXCDR</td>
<td>Roanoke Sound, NC</td>
<td>2007-2014</td>
<td>765</td>
<td>7.7%</td>
</tr>
<tr>
<td>VA-HDR</td>
<td>Amy Engelhaupt, HDR Inc.</td>
<td>Norfolk, VA</td>
<td>2012-2013</td>
<td>442</td>
<td>4.5%</td>
</tr>
<tr>
<td>MD-PCDP</td>
<td>Eric Patterson, Georgetown University</td>
<td>Potomac/Chesapeake</td>
<td>2014-2015</td>
<td>193</td>
<td>1.6%</td>
</tr>
<tr>
<td>NJ-CMWWRC</td>
<td>Melissa Laurino, Cape May Whale Watch</td>
<td>Cape May, NJ</td>
<td>2011-2016</td>
<td>242</td>
<td>0%</td>
</tr>
</tbody>
</table>
Study Areas

**Roanoke Sound (NC-OBXCDR)**-The Roanoke Sound is a small body of water that lies between Roanoke Island and Nags Head inside the Outer Banks of North Carolina (Fig 2). The Sound is part of the Albemarle-Pamlico estuarine system (APES), which is the second largest estuarine system in the United States. APES encompasses 77700 square kilometers, with multiple inlets leading to the Atlantic Ocean and input from five major rivers in North Carolina and Virginia; this creates a brackish-water environment (Steel 1991). Several dozen inlets have opened and closed along this system, with some remaining more permanent than others (Eulie et al. 2017). These inlets not only enable the movement of water in and out of the sound, but also allow the migration of fish and mammals between the estuarine system and the ocean. The Roanoke Sound is shallow, with an average depth of ~1m; this provides a key habitat for soniferous fish that make up the diet of bottlenose dolphins (Gannon and Waples 2004), and thus serves as an important feeding area. Deeper channels are maintained through dredging to provide passage for large vessels. The Roanoke Sound is also a key nursery area for the bottlenose dolphins, and newborns are frequently sighted throughout the spring and summer.

**Chesapeake Bay watershed (VA-HDR, MD-PCP)**-The Chesapeake Bay watershed covers over 64,000 square miles and parts of Virginia, Maryland, New York, Pennsylvania, West Virginia, Delaware, and Washington DC. Many rivers and tributaries flow into the Chesapeake, including the Potomac, the Susquehanna, Rappahannock, James, and York Rivers (Fig 3). This is the largest estuary in the United States. Dolphins are present only in warmer months, and are assumed to migrate out of the Bay in the winter. Bottlenose dolphins sighted in this watershed are assumed to be members of the Northern Migratory, Southern Migratory, and possibly the South Carolina-Georgia coastal stock (Waring et al. 2015).

**Delaware Bay (NJ-CMWWRC)**-The Delaware Bay is the largest estuary in New Jersey. It is a coastal plain estuary with an average depth of around 8m; it is composed of freshwater influences from the Delaware River and seawater from the Atlantic Ocean. The estuary is shallow with a deep central channel that is dredged for shipping (Aristizábal and Chant 2014). The Delaware Bay is an important shipping port and also serves as an important migration area.
for a variety of species, so it is a site where human use and wildlife may interact. By definition, the dolphins here form part of the Northern Migratory stock. In the winter, no bottlenose dolphins occur north of the Chesapeake Bay (Waring et al. 2015).

Figure 2. Roanoke Sound study area.
Data Collection

The Outer Banks Center for Dolphin Research regularly conducts photo-identification surveys of bottlenose dolphins in the Roanoke Sound. OBXCDR first conducted a dedicated exploratory survey of the southernmost portion of the study site in October 2007, and then conducted dedicated exploratory surveys of the entire Roanoke Sound from June-August 2008, February 2009, May-October 2009, May-October 2010, and May-October 2011. Following these exploratory surveys, the OBXCDR created a standardized transect route to cover the study area. This transect route was developed on MapSource and transferred to a handheld GPS unit for use in the field. Dedicated transect surveys were conducted from a 16’ or 17’ outboard-powered vessel, once in November 2011 and then at least once per month from April-November 2012 and 2013, except for May and July 2013 due to weather and boat issues. At each dolphin sighting in the dedicated survey, the transect location was marked on the GPS, and the group of dolphins was approached slowly for photographs to minimize impact on their behavior. Photo-
identification was conducted following standard procedures (Urian et al. 2015). The location, date, time, number of dolphins sighted, observed behaviors, salinity, water temperature, visibility, sightability, cloud cover, and Beaufort Sea State (BSS) were also recorded at each sighting. Sightings ended when: (1) dolphins exhibited avoidance behavior; (2) contact with dolphins was lost; (3) an hour passed, in accordance with the General Authorization under which the surveys were conducted; or (4) all dorsal fins were photographed. Following the conclusion of each sighting, the vessel returned to the transect location where the sighting began and continued along the transect route until either another group of dolphins were sighted or the transect route was completed.

Opportunistic data were also collected multiple times daily between May and October 2008-2013 aboard the Nags Head Dolphin Watch. Data collection and survey methodology was similar to that collected on the dedicated surveys, but rather than following a set transect, the vessel moved freely around the Roanoke Sound. Additionally, groups of dolphins were approached at greater distances, and each sighting was limited to a half hour as outlined by the NMFS Recommended Viewing Guidelines for bottlenose dolphins in the southeast region.

Analysis

All images taken from dedicated and opportunistic surveys were sorted and graded for photo quality using FinBase (Adams et al. 2006). Here, images were scored as either very distinct, moderately distinct, or not distinct. Additionally, photo quality was evaluated in regard to focus, angle, contrast, distance, and degree of obstruction. These multi-factor designations are converted by FinBase into a value for distinctiveness (1-3, with 3 being the most distinct) and photo quality (1-3, 3 being the highest quality). Once images were scored, they were matched to the NC-OBXCDR catalog, using distinctive features like nicks, scars, and fin shape. If no match could be made, the image was assumed to be a new fin and entered as a new entry in the catalog. Sighting data was also entered into FinBase and linked to the corresponding fin images. All matched fins were verified by a second experienced researcher. Once verified, matches were then sent to Kim Urian at the Duke University Marine Lab to be entered into the MABDC. Poor quality images or fins with low/no distinctiveness were excluded from analysis.
Good quality images scored with high or average distinctiveness were sorted into clusters using a Bayesian mark-recapture approach (Fearnbach et al. 2012; Durban et al. 2010) to identify groups of individuals with different patterns of capture probability over time. Clusters 2 and 3 were identified as having high capture probability in the Roanoke Sound, meaning that they showed high site fidelity. I expected NNCES members to have high site fidelity to the Roanoke Sound because they are seasonal residents, so cluster 1 individuals with low site fidelity (likely transient dolphins) were excluded from further analysis. Cluster 2 and 3 individuals, with high site fidelity to the Roanoke Sound, and therefore likely members of NNCES, were then matched to individuals from VA-HDR, MD-PCP, and NJ-CMWWRC through the MABDC (n=59). Upon submitting a match, both catalog contributors and the curator (Kim Urian) were notified and either consented to or rejected the match. Following consensus from all three individuals, the match was confirmed and entered into the MABDC. Sometimes consensus was difficult to reach, because the quality or distinctiveness of the individual was insufficient to make a match. This system attempts to eliminate false positives so that false rejections are much more common than false matches (Urian et al. 2014). This means that true matches can be missed, but any matches made can be confidently affirmed.

Spatial data recorded in the MABDC along with the sightings was translated and then imported into ArcMap10.5.1 for analysis. To determine patterns of associations between matched individuals, coefficients of association (COA) were calculated using the following equation (Rogers et al. 2004):

$$\frac{2N}{N_A + N_B}$$

where $N$ represents the number of times dolphins A and B were sighted together, $N_A$ is the number of times dolphin A was sighted without dolphin B, and $N_B$ is the number of times dolphin B was seen without dolphin A. COA values range from 0 to 1, 0 meaning dolphin A and B are never sighted together, and 1 that dolphin A and B are always sighted together. Traditionally, COAs are divided into three categories: high (>0.80), moderate (0.4-0.79) and low (<0.4).
RESULTS

A total of 59 individuals with high site fidelity in the Roanoke Sound were used in the present analysis. Five individuals (8.5%) were matched to the VA-HDR catalog, but none were matched to either MD-PCP or NJ-CMWWRC. It is important to note that due to this small sample size, any conclusions drawn in this paper are limited. The conclusions drawn here would be better supported with more robust data, but this sample is representative of the population and therefore insights drawn from these individuals help us to understand the spatial boundaries of the NNCES stock. The MABDC process ensures that the five matches were accurate, and the cluster analysis supports that these individuals are members of NNCES. It would be inappropriate to draw conclusions for the entire stock based on these five individuals alone, but the movement patterns of these individuals can help to delineate the northern range for this stock.

Matched Individuals

The individuals matched to VA-HDR are listed in Table 2. Four of the five matched dolphins were matched to other NC catalogs, with sighting records extending as far south as Beaufort, NC. Therefore, most of the NNCES individuals sighted in Virginia also travel to the southern extent of the range of the NNCES stock. Matched individuals were sighted throughout the northern and southern portions of the Roanoke Sound (Figs 4 and 5). The 2015 NMFS stock assessment features sightings only along the southern coastline of VA, but the present study confirms the movement of NNCES individuals into Chesapeake Bay. The lack of matches to both MD-PCP and NJ-CMWWRC may indicate that the stock does not move north of Virginia or into the Potomac, but failure to match to these catalogs may be due to the inability of photo-id to reveal the true movements of all individuals. Two individuals were matched to another VA catalog (VA-SB), which is no longer available on the MABDC, so it was not used in this analysis. These two individuals were also matched to other NC catalogs. This supports the conclusion that the movement of NNCES dolphins extend both northward and southward from Roanoke Sound. One of the matched individuals did not match to any other catalogs.
Table 2. Summary of individuals matched to the VA-HDR catalog.

<table>
<thead>
<tr>
<th>NC-OBXCDR ID</th>
<th>Alias</th>
<th>VA-HDR ID</th>
<th>Sex</th>
<th>Cluster</th>
<th>Other NC Matches</th>
<th>Other Non-NC Matches</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Knobby Top</td>
<td>316</td>
<td>F</td>
<td>2</td>
<td>NC-NCMM 2015; NC-DUML-UNCW, NC-RMD, NC-NCMM</td>
<td>-</td>
</tr>
<tr>
<td>33</td>
<td>FB717</td>
<td>274</td>
<td>F</td>
<td>2</td>
<td>NC-NCMM 2015; NC-DUML-UNCW, NC-RMD, NC-NCMM</td>
<td>VA-SB</td>
</tr>
<tr>
<td>242</td>
<td>Jess Squared</td>
<td>276</td>
<td>F</td>
<td>2</td>
<td>NC-RMD, NC-NCMM</td>
<td>VA-SB</td>
</tr>
<tr>
<td>246</td>
<td>Rocky</td>
<td>317</td>
<td>F</td>
<td>3</td>
<td>NC-RMD</td>
<td>-</td>
</tr>
<tr>
<td>818</td>
<td>-</td>
<td>318</td>
<td>U</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 4. Locations of MABDC sightings for all matched individuals. Due to clustering of points, not all sightings are visible.
Figure 5. Breakdown of MABDC sightings for each matched individual.
All of the matched individuals (with the exception of 818) were recorded as female in the MABDC, because they had been photographed with a calf. While 818 is listed as unknown (U) in the MABDC, recent sightings with a calf suggest that this individual is also a female.

**Number of Sightings**

Table 3 shows the number of sightings for matched individuals in each catalog. The mean number of sightings was 15.4 in OBXCDR and 1.8 in VA-HDR. Most matched individuals were seen 10-20 times in the OBXCDR catalog (Fig 6). There were far fewer sightings for matched individuals in the VA-HDR catalog, with a maximum of three sightings per individual (Fig 7).

**Associations**

COAs for matched individuals in the Roanoke Sound are shown in Figure 8. The COA between 33 and 818 was in the moderate range, but it was low for all other individual pairs. Three matched individuals were never sighted together in the Roanoke Sound.

All matched dolphins were sighted on the same day as another matched individual in the Roanoke Sound (Table 5). While 15, 33, 246, and 818 were all seen on August 13, 2013, 33 and 242 were sighted on July 24, 2013. 33 was also sighted on August 31, 2013; it is possible that the other dolphins left the Chesapeake by this date, or that they were just not sighted.

**Table 3. Number of sightings for matched individuals.**

<table>
<thead>
<tr>
<th>NC-OBXCDR ID</th>
<th>Alias</th>
<th>VA-HDR ID</th>
<th>Number of Sightings (Roanoke Sound, NC)</th>
<th>Number of Sightings (Norfolk, VA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Knobby Top</td>
<td>316</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>33</td>
<td>FB717</td>
<td>274</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>242</td>
<td>Jess Squared</td>
<td>276</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>246</td>
<td>Rocky</td>
<td>317</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>818</td>
<td>-</td>
<td>318</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 6. Number of sightings for matched individuals in the OBXCDR catalog.

Figure 7. Number of sightings for matched individuals in the VA-HDR catalog.
Figure 8. COA values for matched individuals. Pairs with low COAs are in grey, and medium in black.

Table 5. Dates of sightings for matched individuals in VA-HDR

<table>
<thead>
<tr>
<th>Individual</th>
<th>Sighting Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>8/13/13</td>
</tr>
<tr>
<td>33</td>
<td>7/24/2013, 8/13/13, 8/31/13</td>
</tr>
<tr>
<td>242</td>
<td>7/24/13</td>
</tr>
<tr>
<td>246</td>
<td>8/13/13</td>
</tr>
<tr>
<td>818</td>
<td>8/13/13</td>
</tr>
</tbody>
</table>

Clusters

Most matches were cluster 2 individuals (Fig 9), which have a lower sighting probability in the Roanoke Sound than cluster 3. Of all individuals in the sample (n=59), 4 cluster 2 individuals (n=28) were matched to the VA-HDR catalog, while only 1 cluster 3 individual (n=31) was matched (Fig 10).
Figure 9. Breakdown of matched OBXCDR individuals by cluster.

Figure 10. Percent of individuals from each cluster matched.
Seasonality

Sightings in the OBXCDR catalog occurred only from April to October, but the VA-HDR catalog contains sightings made from January-November, although there were no sightings in March, May, or June. Sightings in the Roanoke Sound begin to rise in May, peak in June and July, and then start to decrease in August. Sightings in Virginia peak in July and August, then begin to decline through October and rise again in November and January (Fig 11). Sightings for matched individuals in the Roanoke sound peaked in June, but ranged from May-October. In Virginia, matched individuals were only sighted in July and August (Fig 12). Matched individuals exhibit monthly differences in peak sightings, with 15, 242, and 246 sighted most often in June, 818 in July, and 33 in August (Fig 13). Two matched individuals were not seen in the Sound until after May. Sightings for all matched individuals in the sound begin to drop after August, and only two were still present after September.

Plotting the latitudinal location of each sighting for matched individuals over time gives a clear picture of their movement patterns (Fig 14A-E). There was a regular movement between the Roanoke and Pamlico Sounds from summer to winter each year. This is most apparent in individuals with the most sightings, notably Knobby Top (15) and FB717 (33) (Fig 14A and B). Movement was difficult to ascertain for Jess Squared (242) since her sightings in Beaufort, the Roanoke Sound, and Norfolk were separated over time (Fig 14C). Knobby Top (246) and 818 did not have any coordinate data for their sightings in Beaufort, so this seasonal movement is not visible in the plots (Fig 14D and E). Movement into Virginia was less apparent than movement in and out of Beaufort, NC because there were no comparable historical sighting data in this area and a limited number of sightings.
Figure 11. Seasonality of sightings for all NC-OBXCDR and VA-HDR individuals catalogued in the MABDC
Figure 12. Seasonality of sightings for all matched individuals. Months with no sightings in each catalog (Nov-April) excluded.
Figure 13. Number of sightings of matched individuals in the Roanoke Sound (NC-OBXCDR) by month. Months with no sightings in OBXCDR excluded.
Figure 14A. Latitudinal (north/south) movement of Knobby Top (15) over sighting history. High latitudes indicate sightings in the north of their range (Norfolk, VA), low latitudes indicate the southern part of their range (Beaufort, NC) and mid latitudes indicate the middle of their range (Roanoke Sound, NC)
Figure 14B. Latitudinal (north/south) movement of FB717 (33) over sighting history. High latitudes indicate sightings in the north of their range (Norfolk, VA), low latitudes indicate the southern part of their range (Beaufort, NC) and mid latitudes indicate the middle of their range (Roanoke Sound, NC)
Figure 14C. Latitudinal (north/south) movement of Jess Squared (242) over sighting history. High latitudes indicate sightings in the north of their range (Norfolk, VA), low latitudes indicate the southern part of their range (Beaufort, NC) and mid latitudes indicate the middle of their range (Roanoke Sound, NC)
Figure 14D. Latitudinal (north/south) movement of Rocky (246) over sighting history. Since this individual does not have sighting data in the southern extent of NNCES range, high latitudes indicate sightings in the north of their range (Norfolk, VA), low latitudes indicate the middle of their range (Roanoke Sound, NC).
Figure 14E. Latitudinal (north/south) movement of 818 over sighting history. Since this individual does not have sighting data in the southern extent of NNCES range, here high latitudes indicate sightings in the north of their range (Norfolk, VA), low latitudes indicate the the middle of their range (Roanoke Sound, NC)
DISCUSSION

The primary objective of this study was to delineate the northern range of the bottlenose dolphins seasonally resident to the Roanoke Sound. There were 59 cluster 2 and 3 individuals identified in Roanoke Sound and five of these dolphins were matched to the VA-HDR catalog from Norfolk, VA. The location of matched individuals confirms their movement into VA and into the mouth of the Chesapeake Bay (Figs 4 and 5). This is the first photo-id evidence of movement into Virginia (Fig 2) and the first of any survey to demonstrate movement into the mouth of the Chesapeake. No matches were made in MD or NJ, but this does not eliminate the possibility that NNCES individuals move north of Virginia; it only confirms movement past the NC/VA border and into the Chesapeake. More studies are needed to rule out movement north of VA. The results of the present study confirm and bolster previous findings that suggest movement of NNCES dolphins into the Chesapeake, and reveals the stock’s regular movement into the mouth of the Chesapeake Bay.

Most matched individuals (n=3) were not been matched to other VA catalogs, but have been sighted near Beaufort, NC (n=4), as detailed in Table 3. This indicates that individuals that move northward into VA also move into the southernmost range of NNCES. It is also interesting to note that all matched individuals were likely females (Table 2); males are expected to range further than females, but no cluster 2 or 3 males were sighted in VA-HDR. Nursery groups, then, might be moving into the Chesapeake to raise young or give birth, as an alternative to the estuarine environment in the Roanoke Sound. However, a study on estuarine dolphins in South Carolina found that while female range sizes are typically larger than males, there is no significant difference in the mean range size between males and females (Gubbins 2002). Again, more robust data would better support this conclusion.

In comparing the size of each catalog (Table 1), it can be noted that NC-OBXCDR (n=765) is much larger than the others used in this analysis, with almost double the number of sightings than VA-HDR (n=442) and nearly four times that of MD-PCP (n=193) and NJ-CMWWRC (n=242). VA-HDR was the second most robust catalogs, and 4.5% of its individuals have been matched to other MABDC catalogs. The large size of this catalog may explain why the probably of matching to it was higher than to the other catalogs. With equal efforts in all study areas, it would be possible to draw stronger conclusions. There are many more sightings for matched
individuals in the NC-OBXCDR catalog than VA-HDR (Table 3, Figs 6 and 7), which corresponds to the total number of sightings in each catalog.

The frequency of associations between matched individuals can provide insight into why these dolphins are moving from Roanoke Sound into VA. Most matched dolphins were very weakly associated (Fig 8), but Table 5 shows that most of these dolphins were sighted on the same date in VA. This means they may have travelled together as a social group and were thus associated, even if that bond is not maintained in Roanoke Sound. It is possible that other individuals in their social group accompanied them into VA, and more research into these associations would help draw more robust conclusions.

Four out of five individuals matched were in cluster 2, with only one match from cluster 3 (Fig 9), and a higher proportion of cluster 2 individuals were matched than cluster 3 (Fig 10). These results may indicate that individuals with higher site fidelity are less likely to move far from Roanoke Sound. A next step would be to match cluster 1 individuals, which have the lowest sighting probability and therefore lowest site fidelity. It is likely that these individuals will move further northward than cluster 2 or 3 individuals, but these individuals may not be members of NNCES, so their movements would not help to define the NNCES northern boundary.

The seasonality of movements between NC and VA remains uncertain. Most matched individuals were present in the Roanoke Sound between May and October, but they were only sighted in VA in July and August (Figs 11 and 12). This suggests a seasonality to the movement of individuals into Virginia, but more sightings are required to confirm this finding. The movement of matched individuals into and out of the Roanoke Sound did not show any evident patterns (Fig 13). Peak sighting months varied among individuals, and presence vs. absence was similarly not uniform. Sightings of matched individuals in VA-HDR only occur in July and August, which means that either there is some overall seasonality to their movement or that effort is higher during these months.

Figure 14 incorporates temporality and location of sightings for each matched individual to provide a clearer picture of seasonal patterns in movement. There was clear seasonal movement between the Roanoke and Pamlico Sounds. This is most apparent in individuals with the greatest number of sightings, particularly dolphins 15 and 33. Temporality of movement into Virginia is less apparent because of data limitations, but it is possible that dolphins may move
through the Roanoke Sound on their way to Virginia in mid-summer. It is also possible that they pass back through the Roanoke Sound again before entering into Pamlico Sound for the winter, using the estuarine system as a pathway rather than moving along the coastline.

Limitations

It is important to acknowledge some of the assumptions that underpin this study.

(1) **Mark-recapture should provide an accurate picture of the population.** This holds true for populations with distinct boundaries and minimal movement. However, for highly migratory species like bottlenose dolphins, with overlapping ranges between stocks and high levels of seasonal movement, mark-recapture surveys may fail to sample a substantial portion of the population, and can over-sample some individuals.

(2) **Non-distinctive fins cannot be analyzed.** Dorsal fins without distinctive markings (and poor quality photographs of distinctive fins) were excluded from this analysis. It is necessary to exclude poor quality photos, but some individuals only had one sighting in the MABDC, so the exclusion of poor quality single sightings might result in an underestimation of the number matches. Non-distinctive fins are difficult to match and can lead to matching errors.

(3) **Effort is comparable between catalogs.** In this analysis, I assumed that it was equally likely to sight an individual in each catalog, but some catalogs are more recent and thus have less data. Thus, matches were more likely to be made to catalogs with more data.

Recommendations and Future Research

I encourage further information sharing among catalogs to better understand the movement of dolphins along the Atlantic coast. Most of the uncertainty in NNCES stock delineation is due to a lack of information. The MABDC facilitates information sharing, but catalogs vary in effort and seasonality. Ensuring the continuity of data collection on an annual (even if seasonal) basis could ensure that data availability is not a limiting factor, although this may not be possible due to resource constraints. Matching individuals from newer and smaller catalogs, where there are fewer photographs and sightings per individual, can create bias. Increasing effort could, therefore, eliminate this problem. Looking back into historical records can also provide insight
into whether this stock has recently extended into VA, or if individuals have always been there and have just not been assessed as part of the stock.

I further recommend that other researchers explore the geographical boundaries of the NNCES stock. It is vital that catalog contributors encourage research projects to better answer the complex questions of bottlenose dolphin movements. In directing projects towards this type of research, more information can be obtained and knowledge of the northern NNCES stock boundary can be more certain.

In addition to more information sharing and photo-identification effort, the use of satellite tags can provide more reliable and accurate data on the NNCES boundary. Satellite telemetry can provide fine-scale location data at relatively low cost, and can identify an individual’s ranging patterns across a greater distance from the study area. However, photo-identification is extremely effective for long-term management studies, which is common when defining and monitoring dolphin stocks. It can also offer more than just positional data, as a researcher can note behavior or other identifiers (Balmer et al. 2014). Future directions to assess dolphin stocks must look towards integrating multiple methods and refining technology to minimize harm to study animals. However, it is important that not all research moves to rely on telemetry just because of cheaper and more effective technology, and instead uses photo identification when it is more appropriate.

This study offers photographic evidence of the northernmost movement of NNCES individuals. Definition of the true northern range of NNCES is needed to assess threats to the stock throughout its range. The stock delineation of these individuals is difficult, but photo-identification is a vital tool in stock management. Increased effort and information sharing, as well as the integration of new technology, can strengthen these conclusions and offer additional information on the northern range of NNCES.
LITERATURE CITED


