Spatial and temporal trends of Tamanend's bottlenose dolphin (*Tursiops erebennus*) strandings in South Carolina, USA, 2006–2020

Megan M. Krzewinski[1], Wayne E. McFee[2] and Robert F. Young[3]

Contact email: megkrzewinski@gmail.com

ABSTRACT

Marine mammal strandings data contribute towards overall assessments of cetacean populations, including seasonal, annual and life-history trends which result from both natural and anthropogenic causes. We conducted spatial and temporal analyses of Tamanend's bottlenose dolphin (*Tursiops erebennus*) strandings in the waters of South Carolina, USA, over a 15-year period from 2006 to 2020, with the following objectives: (1) to determine spatial and temporal trends; (2) to analyse seasonal reproductive trends; (3) to determine life-history parameters, such as sex ratio and age class; (4) to determine the extent to which human interaction contributed to strandings; and (5) to compare stranding patterns with historical data from 1992–2005. A total of 837 strandings occurred over the study period, with a mean of 55.8 strandings per annum. The season with most strandings was Spring (April–June), while March and April had the highest number of strandings. A relatively equal number of male and females dolphins stranded, and mortality was highest in neonates, first-year calves and adults. Neonatal strandings comprised 22.1% of all strandings and were predominant in May. Ninety-five human-interaction (HI) cases were observed, representing 22.9% of strandings where HI or non-HI could be determined. Confirmed crab-pot buoy-line entanglements were the predominant HI category (n = 31). Density maps and hot spot analysis showed most strandings, including live and neonatal strandings and HI cases, occurred in defined areas of Charleston and Beaufort Counties. While many trends were similar to historical data, some new trends emerged, particularly an increase of strandings in March and April. Neonatal strandings decreased in November and the historical spike during this month has essentially disappeared. The results of this analysis serve as a tool to predict stranding rates and inform conservation and management decisions to better protect bottlenose dolphins.

KEYWORDS: TAMANEND'S BOTTLENOSE DOLPHIN; TURSIOPS EREBENNUS; STRANDINGS; TRENDS; ATLANTIC OCEAN; NORTH AMERICA

INTRODUCTION

The South Carolina Marine Mammal Stranding Network (SCMMSN) was founded in 1991 under the Marine Mammal Protection Act's Marine Mammal Health and Stranding Response Programme. The SCMMSN operates under a Stranding Agreement from the National Marine Fisheries Service (NMFS) and is a member of NMFS's Southeast Region Marine Mammal Stranding Network. Standardised stranding coverage across the State began in 1992. The South Carolina Department of Natural Resources first assumed responsibility as State Coordinator

[1] Lowcountry Marine Mammal Network, North Charleston, South Carolina, USA
[2] National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science, Charleston, South Carolina, USA
[3] Department of Marine Science, Coastal Carolina University, Conway, South Carolina, USA

of the SCMMSN from 1991 to 2005 (Sally Hopkins-Murphy, 1991–2004; Al Segars, 2004–05). The National Ocean Service's Centre for Coastal Environmental Health and Biomolecular Research assumed responsibility for stranding response from 2005–08. In 2008, Coastal Carolina University (Robert Young) accepted responsibility as State Coordinator through 2020.

Marine mammal strandings provide an opportunity to collect valuable information and tissue samples. Level A data are collected, which include species, sex, length, stranding date, stranding location and condition code (i.e., Code 1–5; Wilkinson, 1991). Evidence of human interaction (HI) is also evaluated and designated as 'Yes', 'No' or 'Could Not Be Determined (CBD)' (Moore & Barco, 2013). These data are used to monitor life-history trends, seasonal and annual trends, anthropogenic impacts and areas of conflict (McFee *et al*., 2006; McFee & Burdett, 2007; Moore & Barco, 2013). Furthermore, these data are especially important for conservation and management to provide baseline information, monitor the health and status of species and populations and help detect Unusual Mortality Events (UMEs) (McFee *et al*., 2006; McFee & Burdett, 2007).

Tamanend's bottlenose dolphins (*Tursiops erebennus*; hereafter referred to as bottlenose dolphins) are the most common marine mammal species to strand in South Carolina. Their stranding patterns have previously been analysed from 1992–2005 (McFee & Hopkins-Murphy, 2002; McFee *et al*., 2006; McFee & Burdett, 2007). Recently renamed (Costa *et al*., 2022), the species was referred to in the previous analyses as the common bottlenose dolphin (*Tursiops truncatus*). Despite this name change, the species is the same in both the current and previous studies. The offshore population of bottlenose dolphins is still considered *T. truncatus* (Costa *et al*., 2022), but strandings of offshore dolphins are excluded from the current and previous studies. This study extends the spatial and temporal analysis of bottlenose dolphin strandings in South Carolina waters from 2006–20, with the following objectives: (1) to determine spatial and temporal trends; (2) to analyse seasonal reproductive trends; (3) to determine life-history parameters, such as sex ratio and age class; (4) to determine the extent to which human interaction contributed to strandings; and (5) to compare stranding patterns to historical data from 1992–2005.

METHODS & MATERIALS

Data collection followed the same methods as described in McFee & Hopkins-Murphy (2002) and McFee *et al*. (2006). In short, Level A data were collected by SCMMSN personnel for each stranded bottlenose dolphin in South Carolina. Findings of HI were also evaluated (e.g., attached gear, line or rope wounds, propeller wounds) following the methods outlined in Moore & Barco (2013). When applicable, additional data generated from necropsies were included.

Statistical analyses

Stranding data were analysed using R 4.1.1 (R Core Team, 2021) with a significance level of 0.05. A chi-square test of equal proportions was used to test for a significant difference in the number of strandings annually and seasonally (as defined in McFee *et al*., 2006). To test for a significant difference in the observed number of strandings seasonally each year, a chi-square goodness-of-fit test was used. The proportion of strandings observed each season over the 15-year period was considered the 'average' proportion and used to calculate the expected number of strandings for each season annually. An ANOVA test was used to test for a significant difference in the mean number of strandings monthly followed by a Tukey-Kramer *post hoc* test to determine which months had a significantly different mean number of strandings. To determine if there was a significant difference in the number of males and females, a chi-square test of equal proportions was used. A chi-square goodness-of-fit test was used to test for a significant difference in the number of reproductively mature (≥ 220 cm) females seasonally. A chi-square test of equal proportions was used to test for a significant difference in the number of male and female neonates. The fit of monthly neonatal stranding distribution was tested to a circular uniform distribution using a Kuiper's test and to a von Mises distribution using a Watson's test (McFee *et al*., 2014). A linear regression model was used to test if there was a significant increase in %HI annually and %HI in Charleston County. The %HI was calculated by removing CBD animals and dividing total HI by total HI plus no HI.

Comparisons were made between historical (1992–2005) and study data (2006–20). A Wilcoxon rank-sum test was performed to compare the mean number of annual strandings between the time periods overall and excluding UME years (2011, 2013, 2014) after data were tested for normality using a Shapiro-Wilk test and F-test. A linear regression model was used to test if there was a significant increase in the number of strandings annually from 1992 to 2020. A chi-squared test of independence was performed to test for a significant difference in the number of strandings seasonally and monthly between the two timeframes. To test for a significant difference in the proportion of males, females, reproductively mature females (≥ 220 cm), neonates and HI cases between the two timeframes, a chi-square test of equal proportions was used.

Spatial analyses

Maps were created using ArcGIS Pro 2.9.0 (ESRI, 2021) to perform spatial analyses. Stranding point data were projected in decimal degrees from a CSV file in the NAD 1983 geographic coordinate system and NAD 1983 UTM Zone 17N projected coordinate system. A shapefile of the United States coastline was obtained from the United States Geological Survey (Miller *et al*., 2005). Stranding point data were used to display statewide, county, seasonal, sex, age class, live stranding, HI and condition code distributions. The kernel density tool in the spatial analyst extension was used to create a density map using a 6 km search radius and cell size of 400. Seasonal density maps were created with a 6 km search radius and cell size of 795. A density map for HI cases was created using a 6 km search radius and cell size of 400. Using a mask to shade out low or non-existent stranding values, the density maps were exported as rasters and re-projected to NAD 1983 for display. Optimised hot spot analysis was performed using a cell size of 5 km to identify hot and cold spots. Optimised hot spot analysis was also performed for neonatal strandings with a cell size of 5 km and HI cases with a cell size of 10 km.

RESULTS

Stranding patterns 2006–2020

A total of 837 coastal and inshore bottlenose dolphin strandings occurred between 2006–20, ranging from 32 in 2008 to 112 in 2013 (mean = 55.8; Fig. 1). Bottlenose dolphin strandings accounted for 85.8% of all strandings in the 15-year period (mean = 84.5% ± 7.8% SD). The total number of strandings was significantly different between years (χ^2 test of equal proportions; $\chi^2 = 118.63$, $p < 0.0001$). The majority of strandings occurred in Charleston County (n = 459, 55%), while the minority of strandings occurred in Jasper County (n = 6, 1%; Fig. 2). Density maps and hot spot analysis revealed most strandings occurred from Isle of Palms (IOP) to Edisto Island, throughout Charleston Harbor and its surrounding rivers (Wando, Ashley and Cooper Rivers), the Stono River

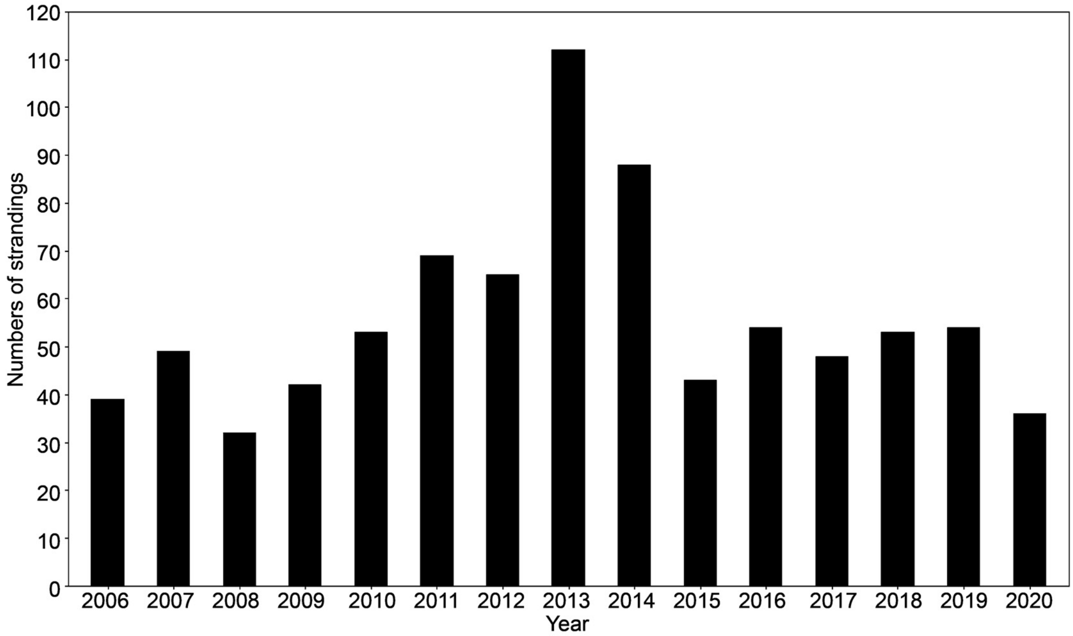

Figure 1. Number of bottlenose dolphin strandings per year in South Carolina, 2006–2020.

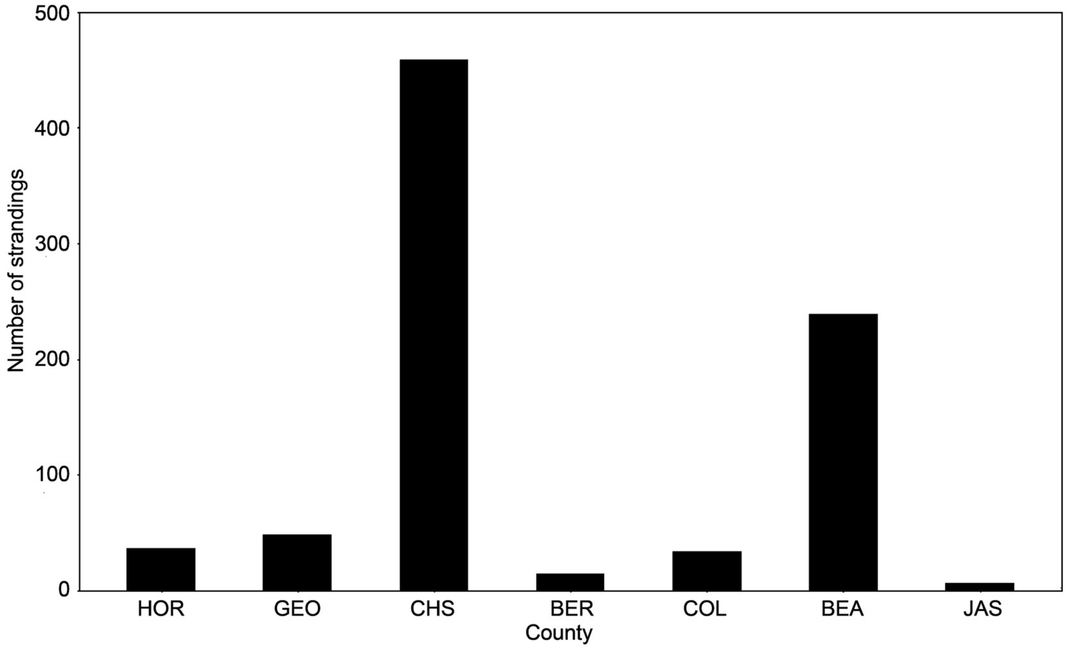

Figure 2. Number of bottlenose dolphin strandings per county, 2006–2020 (HOR = Horry; GEO = Georgetown; BER = Berkeley; CHS = Charleston; COL = Colleton; BEA = Beaufort; JAS = Jasper).

Estuary (SRE) and the southern portion of Hilton Head Island (HHI), including Calibogue Sound and the oceanfront southern beach (Fig. 3). No cold spots were identified.

Fifty-five live strandings occurred (6.6% of all strandings), ranging from one in 2009 and 2014 to seven in 2018 (mean = 3.67). Spatial analysis showed most live strandings occurred in Charleston Harbor, followed by the southern portion of HHI (Fig. 4).

The highest number of strandings occurred in spring (n = 262, 31.3%) and the lowest number in the fall (n = 182, 21.7%; Fig. 5). A significant difference in the number of strandings seasonally was found (χ^2 goodness-of-fit; $\chi^2 = 18.42$, $p < 0.001$). Only three of the years did not conform to the observed 15-year pattern of seasonal strandings: 2009, 2011 and 2013 (χ^2 goodness-of-fit; Table 1).

Seasonal density maps showed the majority of strandings in the northern portion of the state occurring in the fall and winter. For Charleston County, strandings in the fall and winter were more frequent along the oceanfront beaches of barrier islands, while strandings in the spring and summer were more frequent in Charleston Harbor, its surrounding rivers and the SRE. Strandings on HHI occurred more frequently around the southern portion of the island in the winter, shifting to the oceanfront northern beach in the spring and shifting back to the southern portion of the island in the summer. Strandings occurred around the entirety of HHI in the fall.

The greatest number of strandings occurred in the months of March (n = 105, 12.5%) and April (n = 102, 12.2%), while the lowest number of strandings occurred in October (n = 39, 4.7%) and January (n = 41, 4.9%; Fig. 6). A significant difference in the mean number of strandings per month was found (ANOVA; $F = 2.63$, $p < 0.001$). Months with a significantly different mean number of strandings were March and October (Tukey-Kramer post-hoc test; $p < 0.5$).

A total of 326 males, 287 females and 224 dolphins of unknown sex stranded over the 15-year period (1.1:1 M:F). There was no significant difference in the proportion of males and females that stranded (χ^2 test of equal proportions; $\chi^2 = 2.48$, $p = 0.12$).

Total length was determined for 654 dolphins (78.1%) over the 15-year period, including 20 foetuses (< 95 cm; 7 M, 10 F, 3 U) and four perinates (95–115 cm, death considered around the time of birth; 1 M, 3 F). Sex was unknown for 77 of the measured dolphins. The remaining 577 measured dolphins were stratified into five sexual maturity classes: neonates (defined as a newborn based on folded dorsal fin/flukes, umbilical

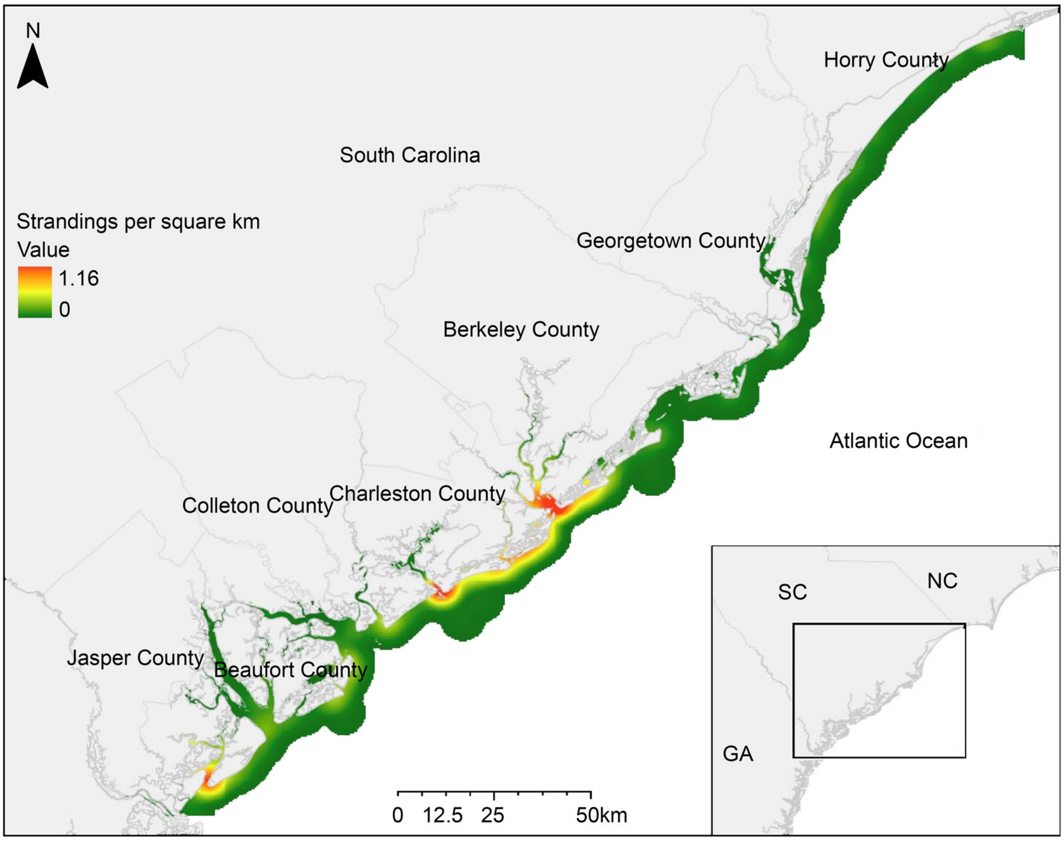

Figure 3. Density map displaying the number of bottlenose dolphin strandings per km^2 along the South Carolina coastline, 2006–2020.

Figure 4. Live bottlenose dolphin stranding locations along the South Carolina coastline, 2006–2020.

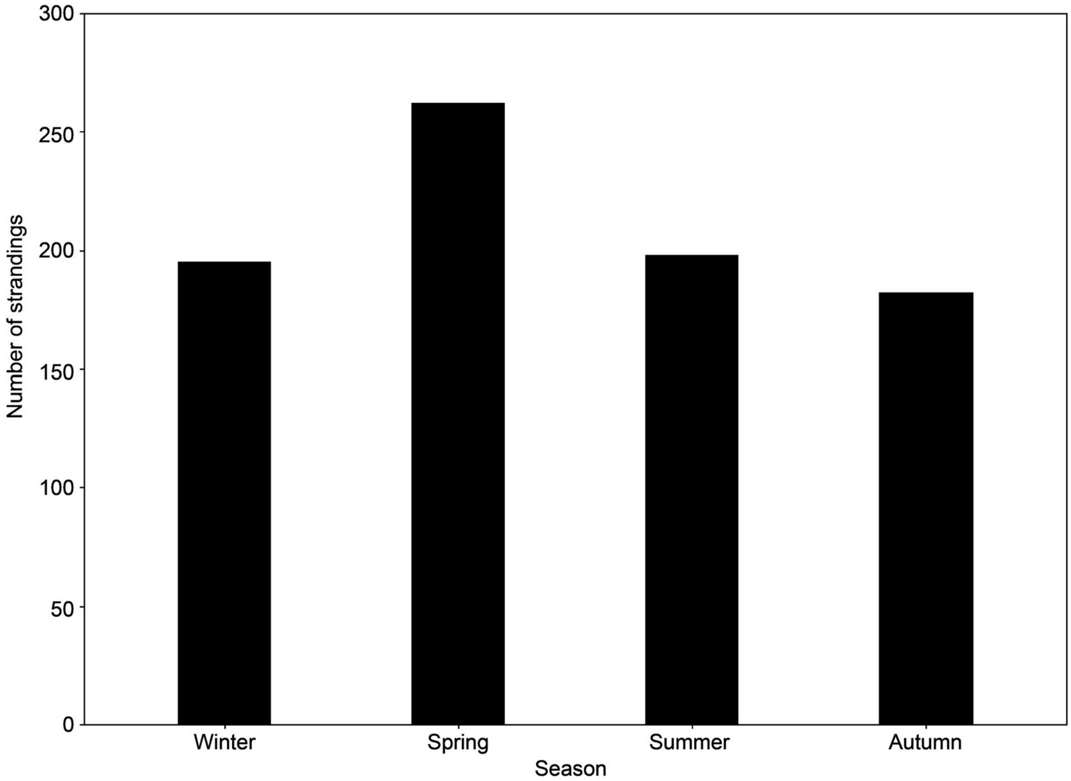

Figure 5. Number of bottlenose dolphin strandings per season, 2006–2020 (winter = January–March; spring = April–June; summer = July–September; winter = October–December).

Table 1

Chi-square goodness-of-fit test results (χ^2 and p values) from testing annual seasonal patterns (*indicates statistical significance ≤ 0.05)

Year	χ^2 value	p-value
2006	1.81	0.61
2007	5.52	0.14
2008	5.31	0.15
2009	12.56	*< 0.01
2010	4.46	0.22
2011	8.56	*< 0.05
2012	5.24	0.16
2013	79.56	*< 0.0001
2014	7.23	0.065
2015	7.51	0.057
2016	2.34	0.51
2017	7.78	0.051
2018	6.42	0.093
2019	4.09	0.25
2020	3.51	0.32

remnants, or both); young-of-the-year (< 160 cm); juveniles (160–200 cm); subadult (males: 201–239 cm; females: 201–219 cm); and adults (males: ≥ 240 cm; females: ≥ 220 cm). The sex ratio was relatively equal for neonates and juveniles (Fig. 7). Males were more prevalent among young-of-the-year (59.6%) and subadult (84.7%) age classes, while adult females (54.4%) were more prevalent in the adult class.

Reproductively mature females (≥ 220 cm) represented 43.0% (n = 116) of known sex and length females (n = 270). No significant difference in the number of reproductively mature females that stranded each season was found (χ^2 goodness-of-fit; χ^2 = 5.52, p = 0.14).

A total of 185 neonatal strandings (22.1%) occurred over the 15-year period, which included 68 males, 55 females and 62 dolphins of unknown sex (1.2:1 M:F). The difference between males and females was not

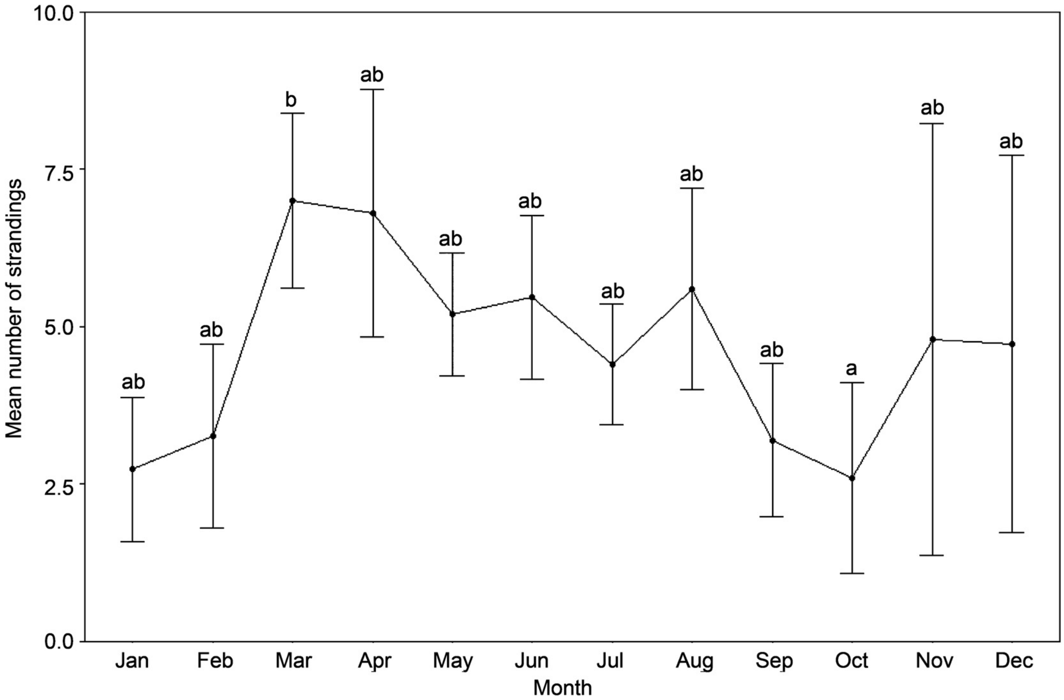

Figure 6. Mean number of bottlenose dolphin strandings (± 2 SE) per month, 2006–2020. Letters denote results of Tukey-Kramer post hoc test.

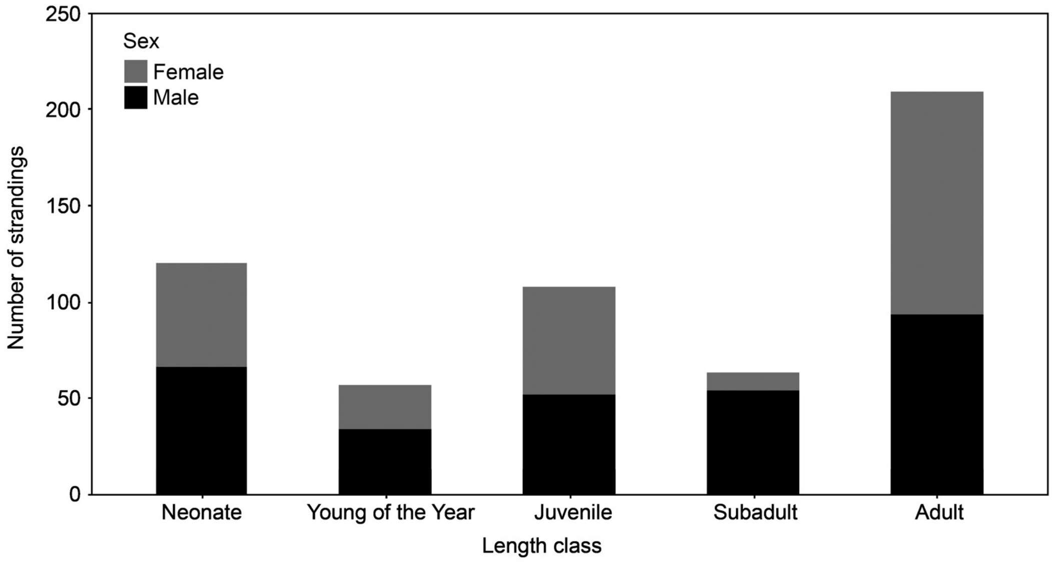

Figure 7. The number of male and female bottlenose dolphins stranded in South Carolina stratified by sexual maturity, 2006–2020 (neonates: defined as a newborn having a folded dorsal fin or flukes or with umbilical remnants [or with both physical features]); young-of-the-year: < 160 cm; juvenile: 160–200 cm; subadult:

statistically significant (χ^2 test of equal proportions; $\chi^2 = 1.37$, $p = 0.24$). Neonatal strandings were highest in the spring (n = 95, 51.4%) and lowest in the fall (n = 20, 10.8%; Table 2). Charleston County had the most neonatal strandings (n = 105, 56.8%), while Berkeley County had the least (n = 2, 1.1%). The monthly distribution of neonatal strandings (Fig. 8) was significantly different from both a circular uniform (Kuiper's test; V = 8.44, $p < 0.01$) and von Mises distribution (Watson's test; V = 0.54, $p < 0.01$). May had the most neonatal strandings (n = 39, 21.1%), while February had the least (n = 2, 1.1%).

Neonatal strandings in Charleston County were more frequent on oceanfront beaches in the fall and winter before moving into the harbour and surrounding rivers in the spring and summer. In Beaufort County, neonatal

Table 2
Neonatal bottlenose dolphin strandings by season and county in South Carolina, 2006–2020

	Winter	Spring	Summer	Fall	Total
Horry	0	2	3	0	5
Georgetown	1	3	7	1	12
Charleston	11	60	21	13	105
Berkeley	0	2	0	0	2
Colleton	1	4	0	1	6
Beaufort	13	24	13	5	55
Total	26	95	44	20	185

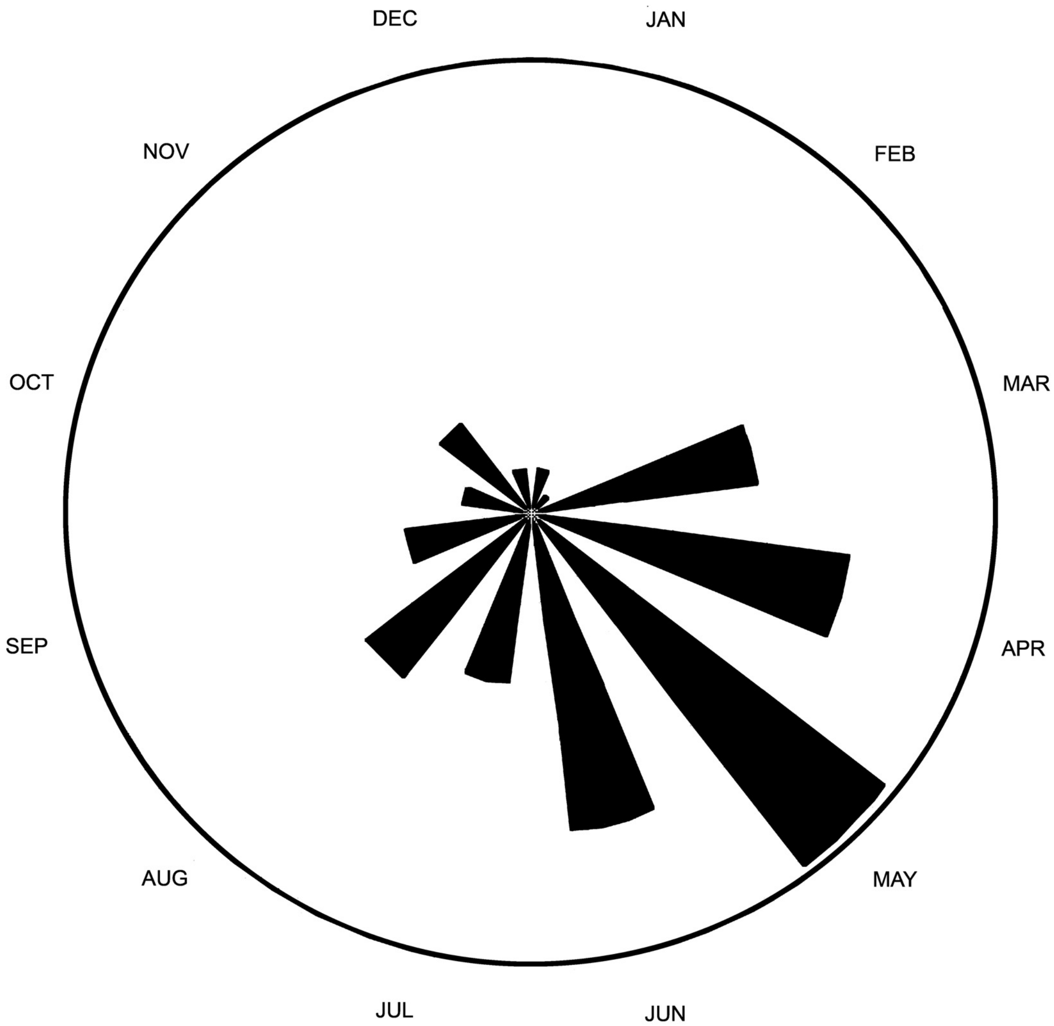

Figure 8. Rose plot showing the monthly distribution of neonate strandings, 2006–2020.

strandings primarily occurred around HHI and further inland in the May River during all seasons. Neonatal strandings in the northern portion of the state were most frequent in the summer. Hot spots for neonatal strandings were identified surrounding Sullivan's, Morris and Folly Islands, Charleston Harbor, the SRE and on the oceanfront northern beach of Kiawah Island (Fig. 9). No cold spots were identified.

A total of 95 HI cases (22.9 %HI) occurred over the 15-year period (Table 3; Fig. 10). The %HI was greatest in 2018 (48.0%) and lowest in 2007 (4.2%). The number of HI cases was highest in Charleston County (n = 53) and lowest in Horry County (n = 0; Fig. 11). Confirmed crab-pot buoy-line entanglements were the most prevalent HI category (n = 31). Though there was a slight positive trend in %HI annually, the increase was not statistically significant ($R^2 = 0.12$, $p = 0.11$; Fig. 12). This trend was also examined for Charleston County alone, but again, the positive trend was not significant ($R^2 = 0.14$, $p = 0.091$). Density maps showed the greatest number of HI cases

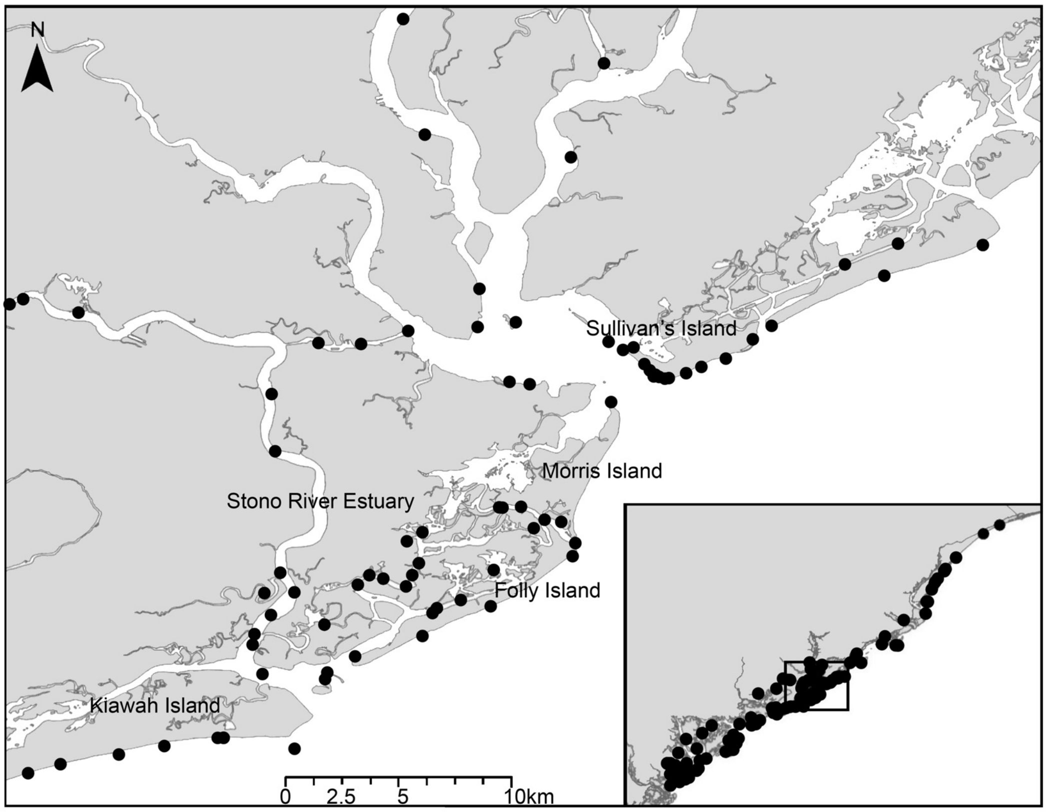

Figure 9. Stranding location of neonatal bottlenose dolphins in Charleston County and along the South Carolina coastline (inset), 2006–2020.

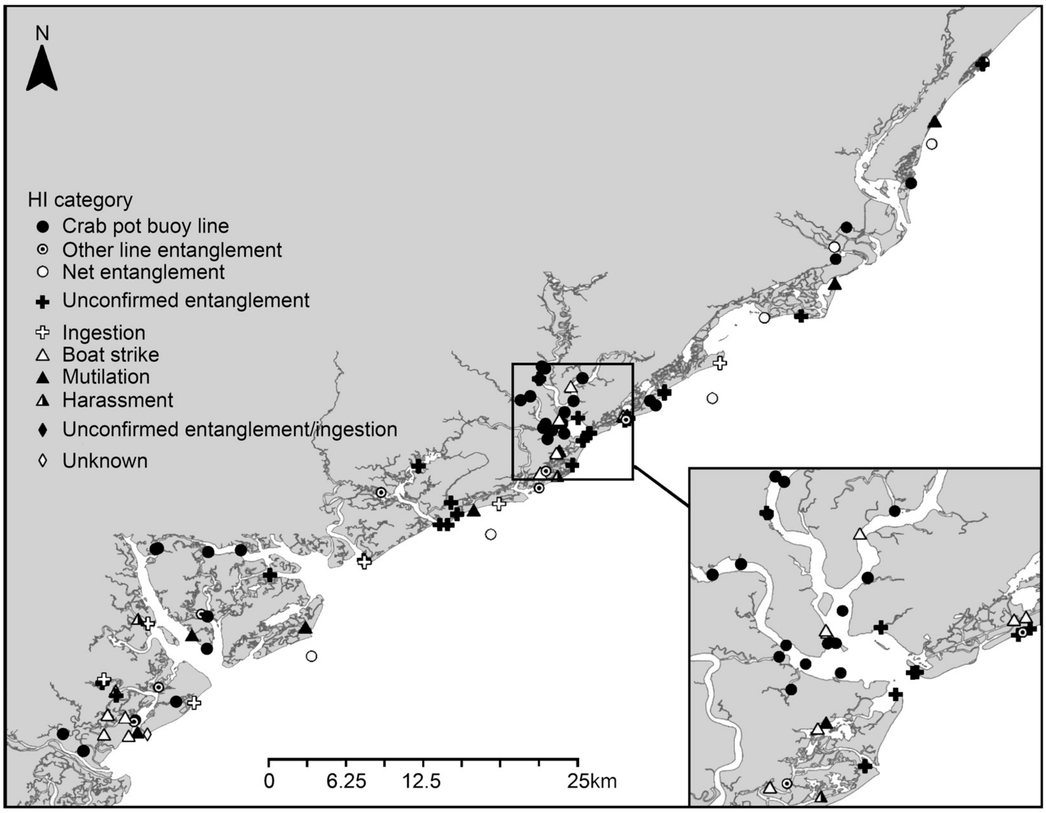

Figure 10. Stranding location and category of HI cases for bottlenose dolphins along the South Carolina coastline and Charleston County (inset), 2006–2020. Other line entanglement includes monofilament and rope unknown origin; net entanglement includes SEAMAP trawl, trammel/gill net, trawl/shrimp industry, and shad net; unconfirmed entanglement includes rope (line) wounds and monofilament wounds; ingestion includes marine debris and hook/line.

Table 3

Human interaction (HI) cases for bottlenose dolphins in South Carolina, 2006–2020. Percent (%) HI was calculated by removing the Could Not be Determined (CBD) animals and dividing Total HI by Total HI plus No HI. $^{+}$ denotes one dolphin with marks consistent with either a boat strike or fishery interaction. * denotes one dolphin with rope (line) wounds and ingested marine debris.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	**Total**
Total Tt	39	49	32	42	53	69	65	112	88	43	54	48	53	54	36	837
Confirmed entanglements																
Crab pot buoy line	3	0	0	1	1	2	1	0	1	2	3	4	7	3	3	31
Monofilament	0	0	0	0	1	0	0	0	0	0	0	2	0	0	1	4
Rope unknown origin	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	3
SEAMAP trawl	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	3
Trammel/gill net	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	2
Trawl/shrimp industry	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Shad net	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Unconfirmed entanglements																
Rope (line) wounds	2	0	0	2	2	1	0	0	2^{*}	1	2	2	2	1	1	18
Monofilament wounds	0	0	0	1	0	0	0	1	1	0	0	0	0	0	1	4
Ingestion																
Marine debris	0	0	0	0	1	1	1	0	1^{*}	0	1	0	0	0	0	5
Hook/line	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	2
Boat strike	1	0	0	0	1	1	3	3	0	0	0	1	0	1	1	12
Mutilation	0	1	1	1	0	2	0	0	0	0	0	1	0	1	0	7
Other	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2
Unknown	0	0	0	1^{+}	0	0	0	0	0	0	0	0	0	0	0	1
Total HI	7	1	2	6	7	8	7	6	4	4	7	10	12	7	7	95
No HI	11	23	9	18	35	27	25	38	25	11	26	23	13	25	10	319
CBD	21	25	21	18	11	34	33	68	59	28	21	15	28	22	19	423
%HI (–CBD)	38.9	4.2	18.2	25.0	16.7	22.9	21.9	13.6	13.8	26.7	21.2	30.3	48.0	21.9	41.2	22.9

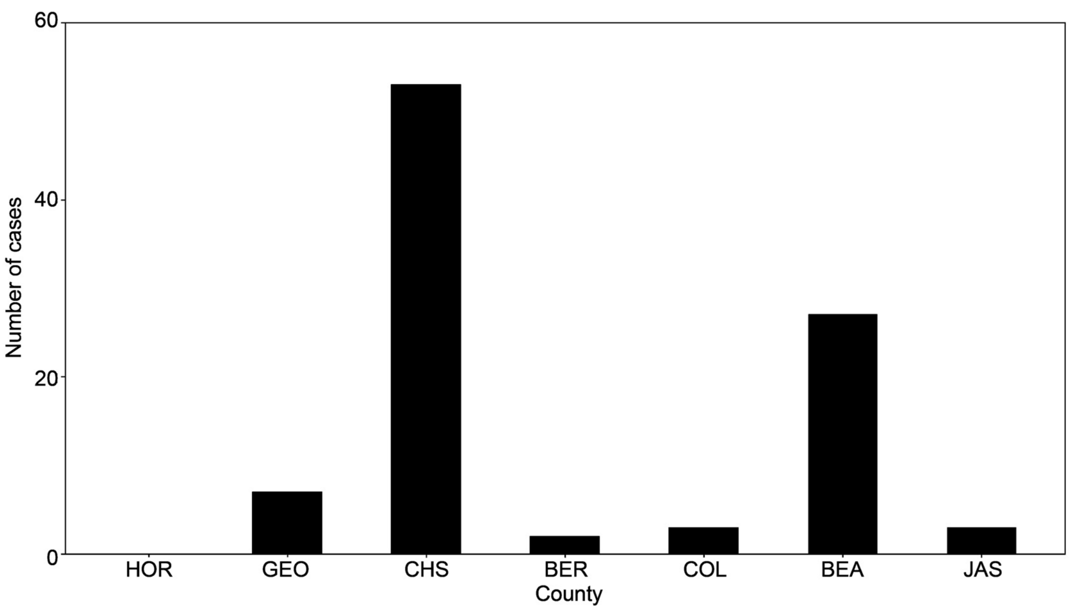

Figure 11. Number of bottlenose dolphin HI cases per county in South Carolina, 2006–2020 (HOR = Horry; GEO = Georgetown; CHS = Charleston; BER = Berkeley; COL = Colleton; BEA = Beaufort; JAS = Jasper).

in Charleston Harbor and surrounding rivers, and around IOP, Dewees Island and the southern portion of HHI. Hot spots were identified in Charleston Harbor and the surrounding rivers, the SRE and around IOP. No cold spots were identified.

Historical comparisons

Historical data from 1992 to 2005 were summarised in McFee & Hopkins-Murphy (2001), McFee *et al.* (2006) and McFee & Burdett (2007), but discrepancies in total number of strandings annually and overall were found,

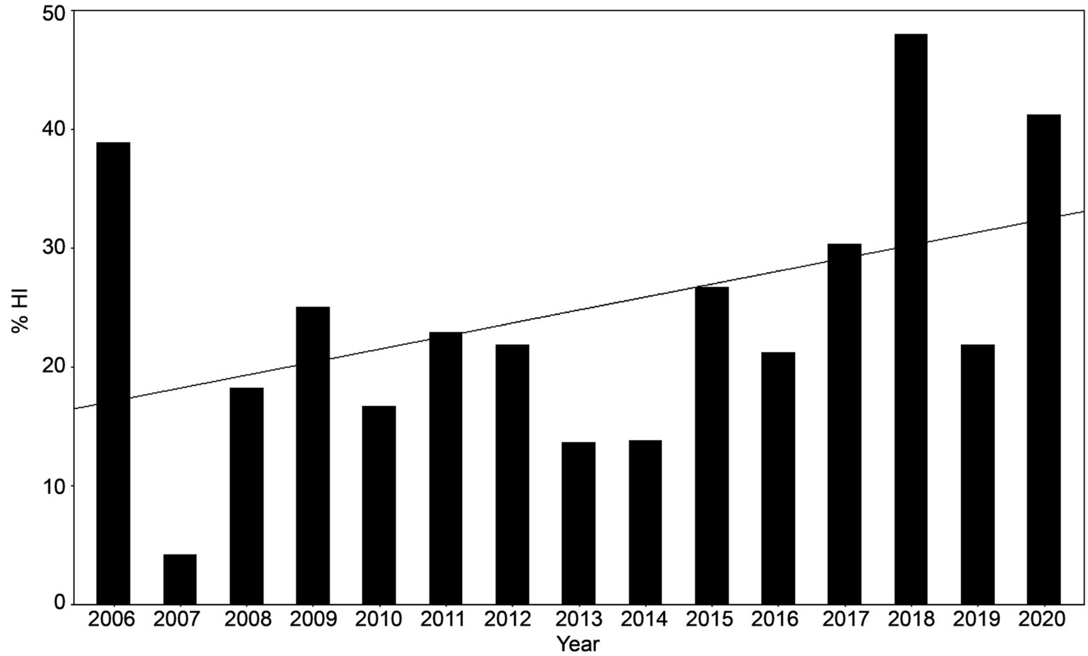

Figure 12. %HI per year for bottlenose dolphin strandings in South Carolina, 2006–2020, with trendline (R^2 = 0.12).

which were not resolved. The analysis for the present study found that both 1994 (n = 30) and 2004 (n = 45) had one less stranding, while 1996 (n = 30) had one more stranding, resulting in one less stranding from 1992 to 2005 than previously described. All historical data were based on the total number of strandings (n = 538) calculated for this study.

The historical mean number of annual bottlenose dolphin strandings (mean = 38.4) was significantly less than the mean from this study (mean = 55.8; Wilcoxon rank sum test; Z = 2.95, $p < 0.01$). When UME years were excluded (2011, 2013, 2014), the historical mean was still significantly less than the mean from this study (mean = 47.3; Wilcoxon rank sum test; Z = 2.40, $p < 0.05$). A significant increase in the number of strandings annually was found (Fig. 13; R^2 = 0.21, $p < 0.01$). Proportions in this study did not significantly differ from historical

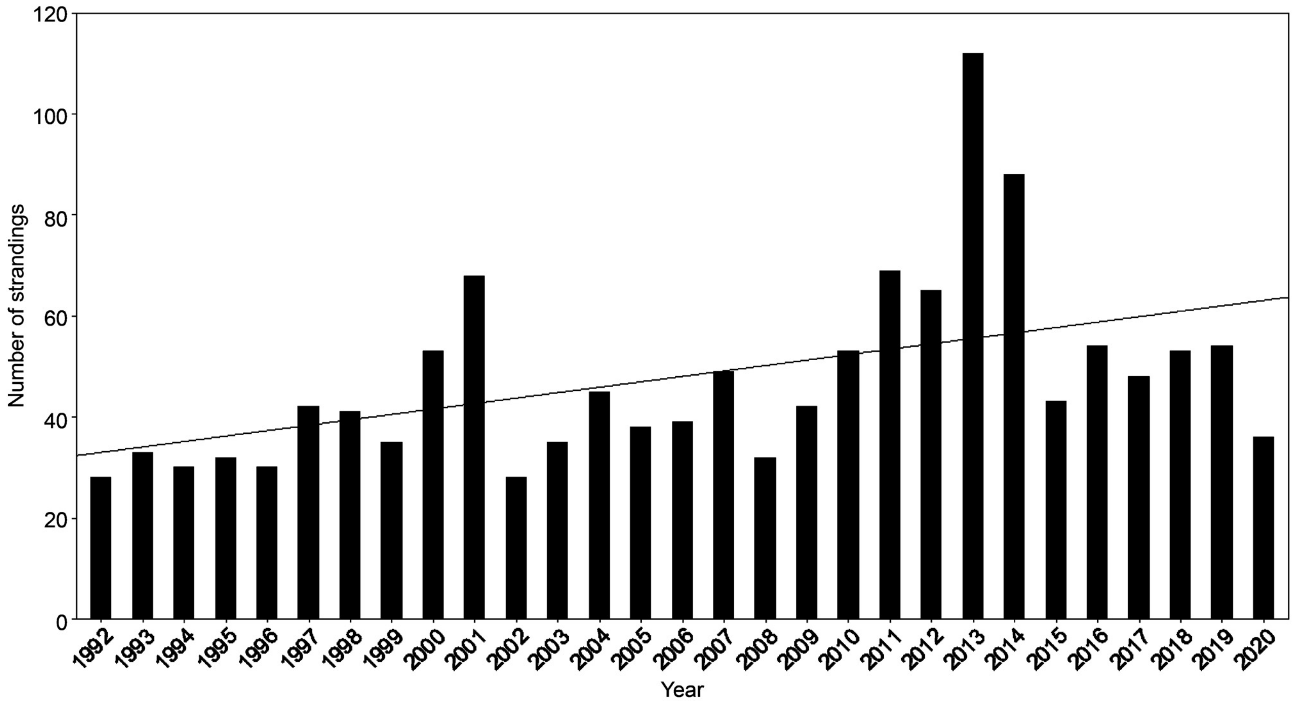

Figure 13. Number of bottlenose dolphin strandings in South Carolina per year, 1992–2020, with trendline (R^2 = 0.21).

proportions for males, reproductively mature females, neonates and HI cases (χ^2 test of equal proportions; Table 4). The seasonal distribution of strandings was not significantly different between the two timeframes (χ^2 test of independence; $\chi^2 = 5.06$, $p = 0.17$), with the highest number of strandings in the spring (Fig. 14). Monthly stranding patterns were not significantly different between the two timeframes (χ^2 test of independence; $\chi^2 = 19.01$, $p = 0.061$), although the number of strandings each month was greater during this study period compared with the historical data (Figs. 15 and 16). The monthly distribution of neonatal strandings was similar between the two time periods, except for a large peak in November in historic data that was absent from the current study data (Fig. 17). The monthly number of neonatal strandings was significantly different between the two time periods (χ^2 test of independence; $\chi^2 = 29.41$, $p < 0.01$).

DISCUSSION

This study analysed spatial and temporal patterns of bottlenose dolphins stranded in South Carolina waters over a 15-year period between 2006–20, building on previous analyses dating back to 1992. In summary, while many historical spatiotemporal trends were reinforced by this analysis, some new trends emerged. The majority of strandings, including live and neonatal strandings and HI cases, occurred in Charleston County. Of the four seasons, spring (April–June) had the most strandings, with March and April having the highest monthly strandings. The cause of these patterns will be further discussed, but the peaks correspond with the start of the calving season and increased neonatal strandings for resident estuarine stocks in Charleston County (McFee *et al.*, 2014),

Table 4

Comparison of historic (1992–2005) and current study (2006–2020) stranding percentages for various categories with chi-square test of equal proportion results (χ^2 and p values) (*indicated statistical significance ≤ 0.05)

	1992–2005		2006–2020			
	Proportion	n	Proportion	n	χ^2	p-value
Sex ratio (proportion male)	0.50	410	0.53	613	0.18	0.67
Reproductively mature females	0.48	98	0.43	116	0.83	0.36
Neonates	0.19	101	0.22	185	2.01	0.16
HI	0.24	73	0.23	95	0.086	0.77

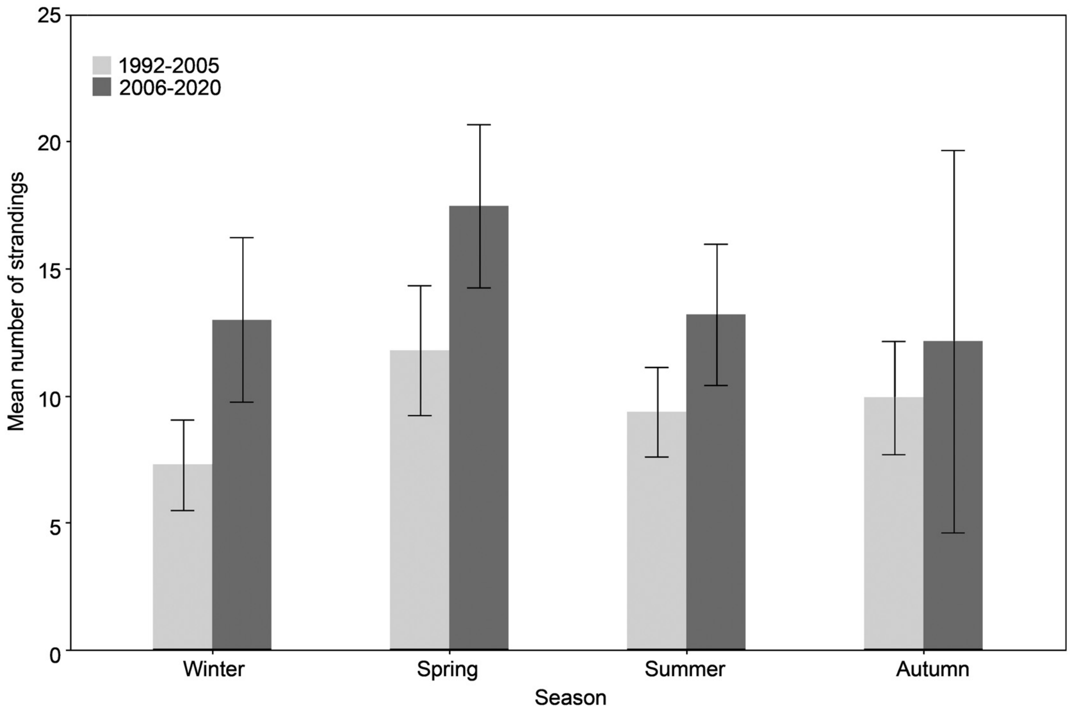

Figure 14. Mean number of bottlenose dolphin strandings (± 2 SE) per season in South Carolina grouped as historical (1992–2005) and the present study (2006–2020) data.

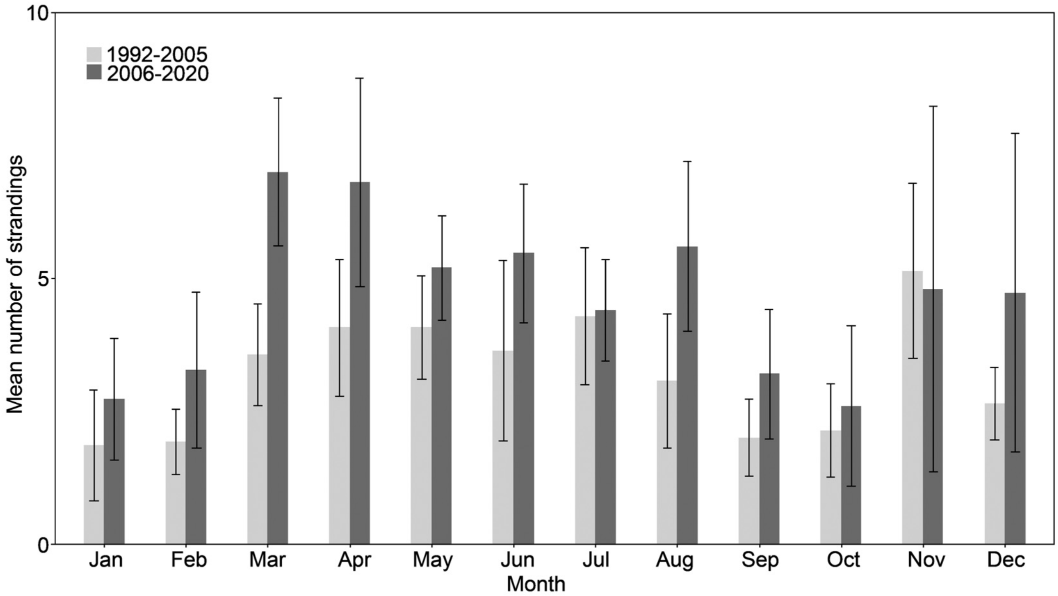

Figure 15. Mean number of bottlenose dolphin strandings (± 2 SE) per month in South Carolina grouped as historical (1992–2005) and the present study (2006–2020) data.

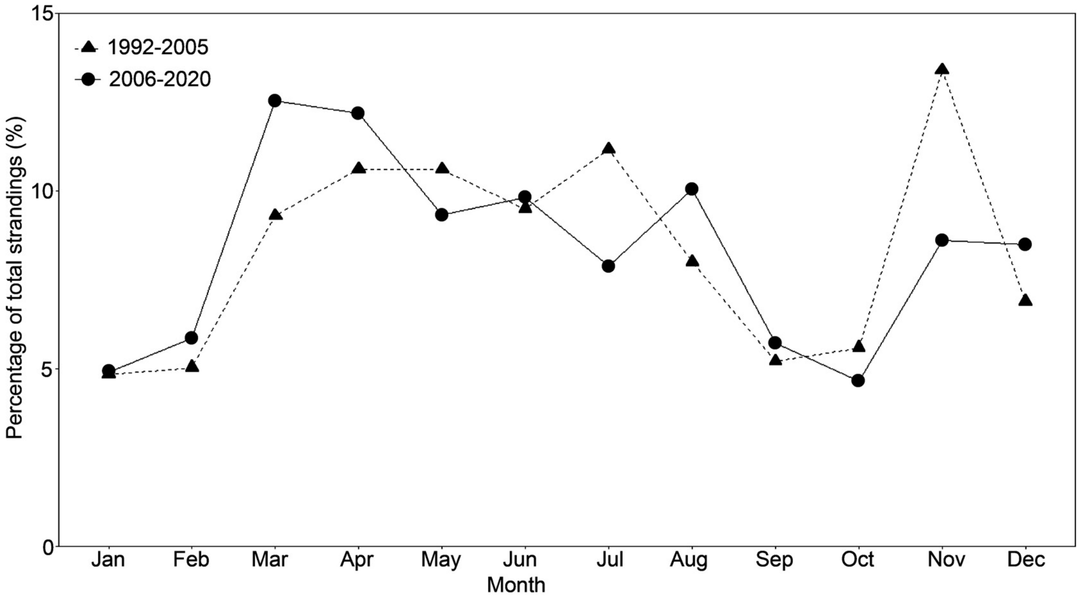

Figure 16. Monthly percentage of strandings in South Carolina grouped as historical (1992–2005) and the present study data (2006–2020).

and may also be related to changes in the migratory patterns of coastal stocks. Bottlenose dolphin mortality (minus HI cases) followed typical patterns of natural mortality, with high neonatal, first-year and adult mortality, and a relatively even distribution of male and female mortality (Ralls *et al*., 1980). Compared with historical monthly patterns, strandings rates increased in March and April relative to other months. Neonatal strandings were predominant in the spring in both the current and previous studies, but the historically significant November peak in neonatal strandings has disappeared from the patterns of the last 15 years. Percent HI did not significantly increase annually or in comparison with historical data, but crab-pot buoy-line entanglements have become more prevalent.

The mean number of strandings differed annually during the study period, which was expected due to the high number of strandings in 2013 and 2014, attributed to the Mid-Atlantic Bottlenose Dolphin UME, and in 2011, attributed to the South Carolina Bottlenose Dolphin UME. The number of strandings increased over time

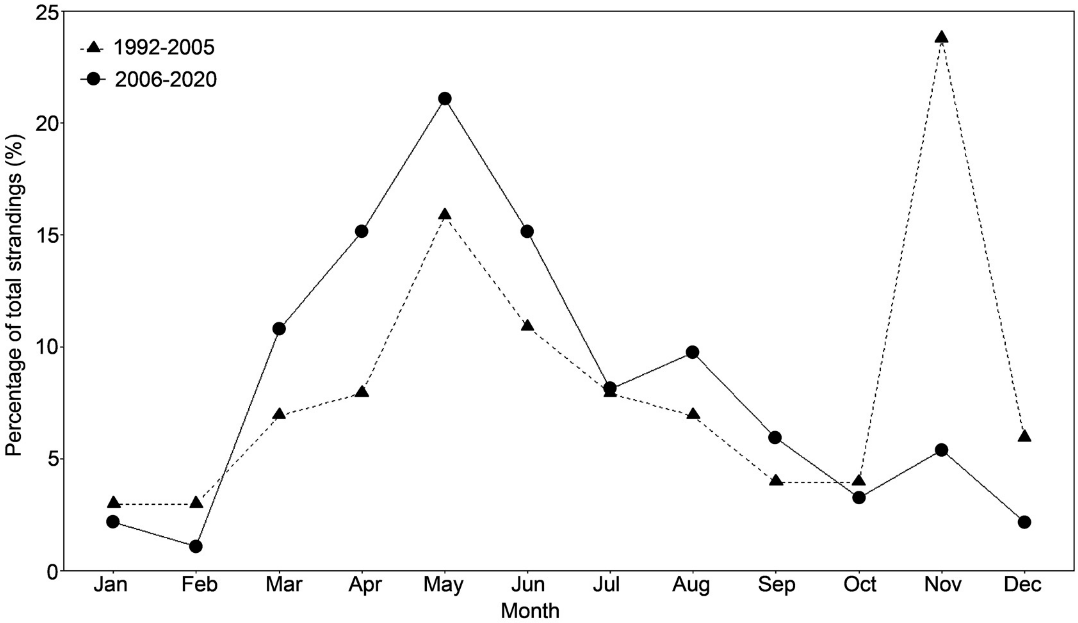

Figure 17. Monthly percentage of neonatal strandings in South Carolina grouped as historical (1992–2005) and the present study data (2006–2020).

when incorporating historical data. While effort from the SCMMSN has stayed relatively consistent across years, public awareness and real-time communications (i.e., smart phones) have improved, possibly resulting in increased reporting. It is also possible that stranding occurrences are becoming more detectable, especially in coastal areas around Charleston County where human population and development has dramatically increased along the coastline (Green *et al*., 2010). Conversely, those same population and development increases expose dolphins to increasing anthropogenic threats in South Carolina waters, including vessel traffic, contaminants and microplastics, which may be contributing to an increase in strandings (Green *et al*., 2010; Kucklick *et al*., 2011; Battaglia *et al*., 2020). Other natural factors, such as prey availability and disease outbreaks, may also contribute to increased strandings.

The majority of strandings occurred in Charleston and Beaufort Counties, particularly in Charleston Harbor and its surrounding waterways, nearby barrier islands and around HHI, which was corroborated by historical data (McFee & Hopkins-Murphy, 2002; McFee *et al*., 2006; McFee & Burdett, 2007). These are high-use areas inhabited year-round by resident dolphin stocks that inhabit both estuarine and coastal waters, which means more strandings are expected to occur in these areas (Gubbins, 2002; Speakman *et al*., 2006; Laska *et al*., 2011; Waring *et al*., 2016). Stranded dolphins in South Carolina waters could be from a number of stocks, including the Northern South Carolina Estuarine System (NSCES), Charleston Estuarine System (CES), Northern Georgia/Southern South Carolina Estuarine System (NGSSCES), South Carolina/Georgia Coastal (SCGAC) and Southern Migratory Coastal (SMC) stocks.

The spring had the most strandings in comparison with other seasons, which coincides with an increase in neonatal strandings as calving season begins (McFee *et al*., 2014). Three years did not conform to the expected seasonal pattern. In 2009, there were more strandings in the summer and less in the fall than expected. Almost half of the strandings in 2009 were comprised of neonates (47.6%), which is more than typically observed annually. Although the exact reason for this spike in neonatal strandings is unknown, it is possible there was a disease outbreak, such as *Brucella ceti*, a bacterial disease that could have impacted increased neonatal mortality during 2012 in the southeastern US, but was not analysed in 2009 (McFee *et al*., 2020). Fewer strandings occurred in the fall than expected in 2011. Despite the high number of strandings in the winter and spring during the 2011 South Carolina Bottlenose Dolphin UME from February to May, these two seasons did not significantly deviate from the expected pattern. While the exact cause of this UME remains undetermined, this UME coincided with unusually cold water-temperatures and subsequent prey die-offs (McFee & Arnott, 2011). A higher number of strandings occurred in the fall of 2013 than expected, which coincided with the Mid-Atlantic Bottlenose Dolphin UME attributed to morbillivirus.

Seasonal stranding patterns were spatially comparable with historical data (McFee & Burdett, 2007). Most strandings occurred in the northern portion of the state in the fall and winter, which coincides with the southern migration of the SMC stock (Young & Peace, 1999; Silva, 2016; Garrison *et al*., 2017). In Charleston County, strandings are concentrated on the oceanfront beaches in the fall and winter, likely comprised of dolphins from the SCGAC stock, the SMC stock and the increased use of coastal waters in winter by resident estuarine dolphins (CES) (Speakman *et al*., 2010). The waters around HHI exhibit the opposite pattern of strandings occurring on oceanfront northern beaches in the spring and occurring in Calibogue Sound and the oceanfront southern beaches in the winter and summer. While the exact reasons for this shift are unclear, prey distribution may impact this shift for the NGSSCES stock. Montie *et al*. (2015) found that sound production of soniferous fishes, many of which are known prey items of dolphins (Pate & McFee, 2012), around the mouth of the May River began in February and ended in September. Marian *et al*. (2021) found the highest acoustic detections of dolphins at the mouth of the May River in the months of November, December and January. It is plausible that estuarine dolphins follow these soniferous fishes during the winter and summer months into Calibogue Sound and around the southern portion of HHI, which is more accessible to Calibogue Sound. The two coastal stocks present in the waters surrounding HHI are likely contributing to strandings on the oceanfront beaches. The SCGAC stock is present year-round, while the SMC stock is present in the winter and early spring. The spring pattern on the oceanfront northern beaches may coincide with the SMC stock beginning its northward migration.

Monthly stranding patterns differed from historical data. This study found that the months of March and April had the most strandings, while the lowest number of strandings occurred in January and October. Historical data from 1992–96 found that the most strandings occurred in July and the least occurred in January and October, while data from 1997–2003 found the most in November and least in February and September (McFee & Hopkins-Murphy, 2002; McFee *et al*., 2006). The months of March and April coincide with the start of calving season, particularly for the CES stock (McFee *et al*., 2014). Another reason strandings may have increased in March and April is due to a change in the migration of the SMC stock. North of Winyah Bay and North Inlet, the South Carolina coast has few estuarine systems, and dolphin stranding patterns are primarily impacted by the activities of coastal stocks. In the mid-to-late 1990s, dolphin surveys conducted by Young & Peace (1999) documented an increase in the coastal dolphin abundance along the northern SC coastline of greater than an order of magnitude between mid-October and mid-November, attributed to a migratory pulse by the SMC stock. Silva (2016) conducted the most recent fall survey of these waters in 2014 and also documented this migratory pulse during the same time period. This increase in strandings in the fall was largely attributed to the southern migration of the SMC stock, which may be beginning its southern migration later in the year and beginning its northern migration earlier in the year, resulting in an increase of strandings in March and April. It is possible that increasing ocean temperatures contribute to this shift in migration patterns, signalling a shift in the both the timing and duration of the migration (Ramp *et al*., 2015; van Weelden *et al*., 2021). A change in timing and duration of migration has been documented in other cetacean species, specifically the fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeangliae*) in the Gulf of Saint Lawrence, Canada, to coincide with peak primary productivity for feeding (Ramp *et al*., 2015). More data are needed to explore a change in the timing or extent of the SMC stock migration. The monthly variations in this study highlight the importance of continued stranding response and analysis to attempt to understand the patterns.

In addition to a change in monthly distribution of strandings, neonatal strandings also changed their monthly distribution. Neonatal strandings may be influenced by a variety of factors, such as the experience of the mother, variation in threats (i.e., fishing efforts, disease) and shifting prey availability. The results of this study showed neonatal strandings are highest in the spring, specifically in the month of May. Historical data showed a bimodal reproductive strategy in South Carolina waters in the spring and fall, with the months of May and November having the highest number of neonatal strandings (McFee & Hopkins-Murphy, 2002; McFee *et al*., 2006; McFee & Burdett, 2007; McFee *et al*., 2014). Previous studies, in addition to a study in the adjacent waters of southern North Carolina, noted an increase in strandings in November, particularly neonatal strandings in the northern portion of the state, which was attributed to the southern migratory pulse of the SMC stock (McFee & Hopkins-Murphy, 2002; Thayer *et al*., 2003; McFee *et al*., 2006; Waring *et al*., 2016). However, the November increase in neonatal strandings along the northern coast has essentially disappeared. Only one neonatal stranding occurred in the north in the fall over the duration of the present study. The SMC Stock historically begins its southern migration from North Carolina in the fall and is seen in the Grand Strand in October and November, but this migration may now be later than previously occurred, thus neonatal strandings are not occurring in South Carolina waters in the fall (Garrison *et al*., 2017). Since this stock was heavily impacted by the 2013 UME, it is possible that reproduction was also impacted, either through a decrease in reproductive efforts or change in timing, also contributing to less detection of neonatal strandings in South Carolina waters in November.

Percent HI was not significantly different compared with historical data. Atlantic blue crab (*Callinectes sapidus*) pot buoy-line entanglements remained the most prevalent HI category, reconfirming the Atlantic blue crab fishery as the largest contributor to fishery-related marine mammal mortality in South Carolina waters (Burdett & McFee, 2004; McFee & Burdett, 2007). However, the number of confirmed crab-pot buoy-line entanglements increased during this study period, representing nearly one-third of all HI cases. This increase was especially notable between 2015–20. Dolphin entanglements correlated with moderate-to-severe wet seasons, likely due to an increase in turbidity impacting visibility, making entanglements more likely (McGhaw *et al*., 2022). With the potential for increased severe precipitation events due to future climate change, entanglements in this fishery could continue to rise. The Atlantic blue crab fishery remains a Category II fishery, where annual mortality and injury is greater than 1% and less than 50% of the stock's Potential Biological Removal (PBR) (NMFS, 2021). Based on density maps and hot spot analysis, the CES and NGSSCES stocks are likely interacting most frequently with this fishery; however, the PBR for both stocks are unknown (Waring *et al*., 2016). In order to better assess whether the Atlantic blue crab fishery is significantly impacting these stocks, the PBR for both stocks should be determined. New HI categories were documented over the duration of this study, such as ingestion of man-made material, which suggests that dolphins are exposed to increasing anthropogenic threats in South Carolina waters.

Density maps and hot spot analysis revealed important areas for conservation and management. Since most strandings occurred in Charleston and Beaufort Counties, these represent critical areas for the SCMMSN and its volunteer network. Live strandings consisted of a relatively equal number of beached dolphins and entangled dolphins across the coastline, but there was a large number of entangled dolphins reported in the Charleston Harbor and its surrounding rivers. Neonatal strandings were concentrated surrounding Sullivan's, Morris and Folly Islands, Charleston Harbor and the SRE. McFee *et al*. (2014) found similar areas of high neonatal sighting and stranding densities, particularly around Morris Island, the mouth of the SRE, the mouth of Charleston Harbor and the Folly River. These high-use nursery areas are important to preserve, especially from human development and habitat degradation (McFee *et al*., 2014). HI cases occurred in similar areas when compared with historical data, such as Charleston Harbor and its rivers and Calibogue Sound, highlighting areas of conflict where further management may be warranted (McFee & Burdett, 2007). These identified areas should be closely monitored in the future, particularly for any changes in trends, in order to provide protection for dolphins in South Carolina waters.

This study highlights the importance of a long-term dataset for monitoring and identifying changes in stranding rates for bottlenose dolphins in South Carolina waters. More information is needed to understand the seasonal stranding patterns in Beaufort County, timing and extent of the seasonal migration of the SMC stock, and the changes to neonatal stranding rates in November. The close monitoring of HI cases should continue as anthropogenic threats increase and diversify. Future spatial and temporal stranding analyses should be conducted at minimum every five years to detect fine-scale changes and can be expanded to other cetacean species that strand in South Carolina waters. This analysis can be used to predict strandings and is therefore important for conservation and management efforts to protect all bottlenose dolphin stocks that inhabit South Carolina waters.

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