Strandings as indicators of marine mammal biodiversity and human interactions off the coast of North Carolina

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Abstract—The adjacency of 2 marine biogeographic regions off Cape Hatteras, North Carolina (NC), and the proximity of the Gulf Stream result in a high biodiversity of species from northern and southern provinces and from coastal and pelagic habitats. We examined spatiotemporal patterns of marine mammal strandings and evidence of human interaction for these strandings along NC shorelines and evaluated whether the spatiotemporal patterns and species diversity of the stranded animals reflected published records of populations in NC waters. During the period of 1997–2008, 1847 stranded animals were documented from 1777 reported events. These animals represented 9 families and 34 species that ranged from tropical delphinids to pagophilic seals. This biodiversity is higher than levels observed in other regions. Most strandings were of coastal bottlenose dolphins (*Tursiops truncatus*) (56%), harbor porpoises (*Phocoena phocoena*) (14%), and harbor seals (*Phoca vitulina*) (4%). Overall, strandings of northern species peaked in spring. Bottlenose dolphin strandings peaked in spring and fall. Almost half of the strandings, including southern delphinids, occurred north of Cape Hatteras, on only 30% of NC's coastline. Most stranded animals that were positive for human interaction showed evidence of having been entangled in fishing gear, particularly bottlenose dolphins, harbor porpoises, short-finned pilot whales (*Globicephala macrorhynchus*), harbor seals, and humpback whales (*Megaptera novaeangliae*). Spatiotemporal patterns of bottlenose dolphin strandings were similar to ocean gillnet fishing effort. Biodiversity of the animals stranded on the beaches reflected biodiversity in the waters off NC, albeit not always proportional to the relative abundance of species (e.g., *Kogia* species). Changes in the spatiotemporal patterns of strandings can serve as indicators of underlying changes due to anthropogenic or naturally occurring events in the source populations.

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Marine biogeographic boundaries are remarkable 1) for the diversity of species that occur as a result of the biogeographically distinct provinces on either side of the environmental or dispersal discontinuities (e.g., Ekman, 1953; Searles, 1984) and 2) for the long-term influences of these boundaries on phylogeography (e.g., Wares et al., 2001; Adams and Rosel, 2006). Several marine biogeographic boundaries occur along the continental United States, such as at Point Conception, California; Cape Canaveral, Florida; Cape Cod, Massachusetts; and Cape Hatteras, North Carolina (NC) (Briggs, 1974; Fautin et al., 2010). The faunal transition zone at Cape Hatteras results from the juxtaposition of warm waters from the northeast-flowing Gulf Stream and cool waters from the south-flowing Virginia Current and leads to the occurrence of both temperate and subtropical-tropical species of algae (Searles, 1984), invertebrates (Cerame-Vivas and Gray, 1966; Baker et al., 2008), ichthyoplankton (Grothues and Cowen, 1999), and fishes (Schwartz, 1989) along the NC coast. In addition to the biogeographic boundary at Cape Hatteras, the Cape is the closest point of land to the Gulf Stream along the mid-Atlantic coast (Briggs, 1974), concentrating pelagic fauna relatively close to shore. Many fish species occurring in NC waters are estuarine-dependent coastal migratory species from northern and southern biogeographic provinces (Ray et al., 1997), taking advantage of NC estuaries, the second largest estuary system in the continental United States (Paerl et al., 2001).

The conditions described previously create an environment conducive for productive commercial (Steve et al., 2001) and recreational fisheries

(NCDMF[1]). Commercial fishing gear, such as gill nets that entangle the endangered North Atlantic right whale (*Eubalaena glacialis*; hereafter 'right whale') (Kraus et al., 2005) and the common bottlenose dolphin (*Tursiops truncatus*; hereafter 'bottlenose dolphin') in NC waters (Byrd et al., 2008), and longlines that entangle pilot whales (*Globicephala* spp.) and Risso's dolphins (*Grampus griseus*) (Garrison, 2007) pose risks for marine mammals. These risks, along with 2 major shipping ports and an active boating and recreational fishing community, intersect with a presumed high diversity of marine mammals along the NC coast.

Documenting and monitoring the biogeographic stratification and biodiversity of marine mammals often requires large-scale aerial or shipboard surveys (e.g., Mullin and Fulling, 2003; Torres et al., 2005). Another mechanism for determining species presence, and potentially relative abundance, is the monitoring of stranded animals over time, especially when monitoring can be conducted in a systematic way (Evans and Hammond, 2004; Pyenson, 2011). Marine mammal strandings (hereafter 'strandings') provide researchers with rare access to protected species and serve as an invaluable source of information on their spatiotemporal distribution (e.g., Maldini et al., 2005; Nemiroff et al., 2010), and biology (e.g., Fernandez and Hohn, 1998; Thayer et al., 2003; Gannon and Waples, 2004). In addition, stranding investigations have been critical in documenting human-induced serious injuries and mortality, such as from vessel strikes (e.g., Campbell-Malone et al., 2008), fishery entanglements (e.g., Byrd et al., 2008; Cassoff et al., 2011), and sonar effects (e.g., Jepson et al., 2005). Changes in temporal or spatial patterns of strandings may serve as indicators of underlying changes in the source populations that were driven either by human causes (see previous references in this paragraph) or by naturally occurring events (e.g., Evans et al., 2005; Johnston et al., 2012; Peltier et al., 2013).

We examined spatiotemporal patterns of marine mammal strandings in NC over a 12-yr period when stranding response effort was relatively consistent and high and examined whether those observed patterns, and patterns of species diversity, reflected published records of marine mammal populations off the NC coast. While in waters off NC, marine mammals are at risk of interactions with commercial fisheries; therefore, patterns of human interactions evident from strandings were also evaluated. This study is the first comprehensive overview of NC stranding records.

Materials and methods

North Carolina geography

North Carolina's ocean coastline (~537 km) (Fig. 1) is a series of barrier islands separated from the mainland by various sounds and the Intracoastal Waterway. Several state and federal parks and reserves (>227 km) occur on the barrier islands, some of which are accessible only by boat. In addition, property at the U.S. Marine Corps base at Camp Lejeune is off-limits to unauthorized personnel—an area that includes the inshore (defined here as inside the International Regulations for Preventing Collisions at Sea [COLREGS] demarcation line[2]) coastline at the base, Brown's Island (~8 km long), and Onslow Beach (~18 km long). All inshore coastline poses significant challenges for detection of and responses to stranded animals; the expansive estuary system has many remote areas and much of the shoreline consists of cordgrass (*Spartina* spp.) where carcasses may not be detected.

Stranding response and data collection

Although responses to strandings occurred intermittently in NC as early as the mid-1970s (Mead[3]), coverage by an extensive stranding network has been most consistent since 1997. From February 1997 through February 1998, researchers at the National Marine Fisheries Service, Beaufort Laboratory in NC (hereafter 'NMFS-Beaufort') led a systematic, intensive, statewide effort to document strandings that may have resulted from interactions with fisheries. Surveys were conducted weekly by driving the same route along ocean-side beaches. During that year, the network was expanded and strengthened to ensure that reporting of strandings would continue after conclusion of the project. From 1998 through 2008 the network continued a collaborative stranding response with multiple agencies in the state. In 2008 the NC stranding network underwent reorganization; therefore, only data from

[1] NCDMF (North Carolina Division of Marine Fisheries). 2012. North Carolina License and Statistics Section summary statistics of License and Permit Program, Commercial Trip Ticket Program, NC Marine Recreational Information Program, Striped Bass Creel Survey in the Central and Southern Management Area, NC Recreational Saltwater Activity Mail Survey, 399 p. [Available from NCDMF, 3441 Arendell St., Morehead City, NC 28557 or http://portal.ncdenr.org/c/document_library/get_file?uuid=6cd202a9-45e6-4e42-bb83-418ead9db653&groupId=38337, accessed June 2013.]

[2] The line of demarcation delineating waters upon which mariners shall comply with the International Regulations for Preventing Collisions at Sea, 1972, and those waters upon which mariners must comply with the Inland Navigation Rules as described in 33 CFR part 80. [Available from http://www.gpo.gov/fdsys/pkg/CFR-2012-title33-vol1/pdf/CFR-2012-title33-vol1-part80.pdf, accessed November 2013.]

[3] Mead, J. G. 1979. An analysis of cetacean strandings along the eastern coast of the United States. *In* Biology of marine mammals: insights through strandings (J. B. Geraci and J. St. Aubin, eds.), p. 54–68. Final report to the U.S. Marine Mammal Commission in fulfillment of Contract MM7AC020. Report Number PB-293890. [Available from the U.S. Marine Mammal Commission, 1625 I St., NW, Washington, D.C. 20006.]

1997 through 2008 were examined here. During those years, the state was divided into 2 primary response areas with overlap as needed. Responders from NMFS-Beaufort covered mainly the area north of New River Inlet to the NC–Virginia (VA) border, whereas responders from the University of North Carolina Wilmington covered predominantly south of New River Inlet to the NC–South Carolina (SC) border (Fig. 1). Strandings were reported by means of a dedicated phone number or 24-hour pager, and came from a variety of sources, including the public, local municipalities, and state and federal agencies. Generally, public reporting was opportunistic. Some areas and seasons, however, had more systematic coverage. For example, participants of the NC Sea Turtle Project reported strandings observed during daily surveys of ocean beaches for sea turtle nests. These surveys occurred each year from May 1 through August 31 and were almost state-wide, including Onslow Beach. The only exceptions were 2 barrier islands accessible only by boat (totaling ~20 km) that were surveyed only twice per week and Brown's Island, which was not surveyed because of live-fire exercises conducted by the U.S. Marine Corps. Outside of the sea turtle nesting season, national and state park rangers conducted weekly surveys within state and federal parks.

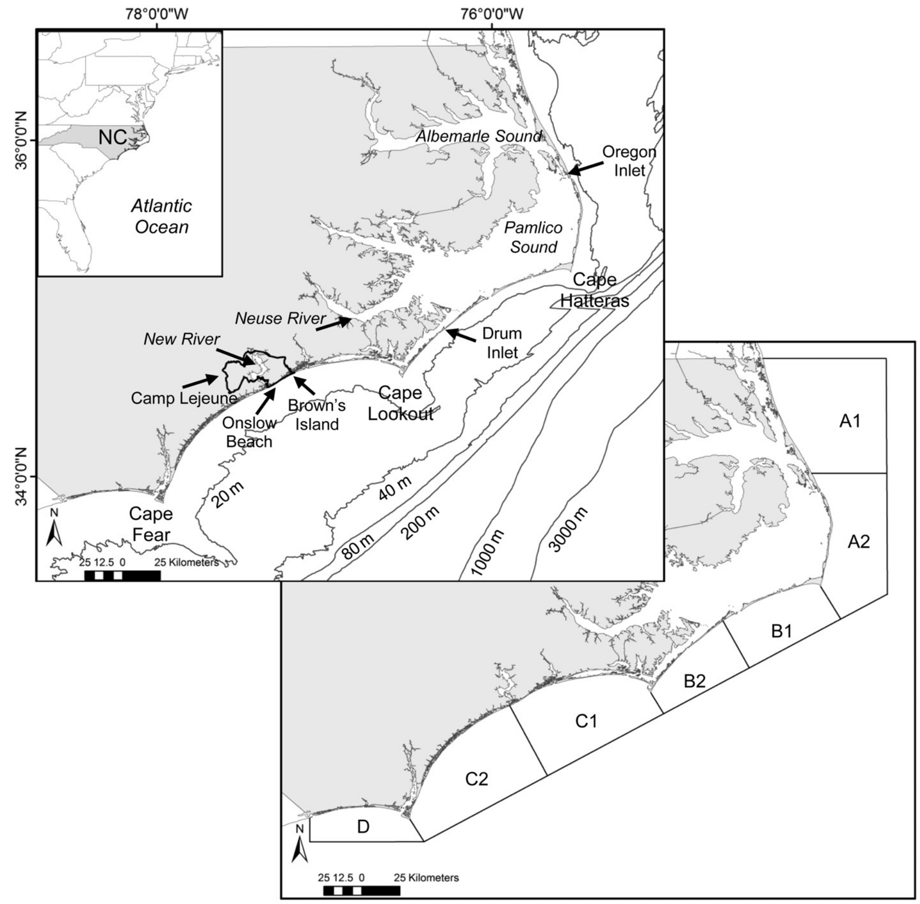

Figure 1

(**Upper left**) Coast of North Carolina (NC) showing major bodies of water, landmarks, and bathymetry. The black boundary line around New River represents Camp Lejeune, property of the United States Marine Corps. (**Lower right**) Stratification of coastal beaches for spatial analysis by segment from the Virginia–NC border south to the NC–South Carolina (SC) border: north of Cape Hatteras (A1–A2), Cape Hatteras to Cape Lookout (B1–B2), Cape Lookout to Cape Fear (C1–C2), and Cape Fear to SC (D).

Marine mammals were considered stranded if they were dead (either on land or in the water) or alive and in need of human intervention (e.g., cetaceans stranded on land, marine mammals entangled in fishing gear, sick or injured seals, seals that were relocated to a more secluded location due to human and animal welfare concerns). For each stranding, standard data (level A) (e.g., species, geographic coordinates, length, sex) and additional data (e.g., extensive morphometrics, life history) were collected when possible according to protocols reviewed in Geraci and Lounsbury (2005). Common and species names were taken from the list published by the Society for Marine Mammalogy [http://www.marinemammalscience.org]. Various samples were collected systematically (e.g., for genetic analysis or *ad libitum* (e.g., for histological, toxicological analysis) for sample banks or for further biological studies.

Each stranding was assigned a human interaction (HI) category: yes, no, or could not be determined (CBD) (Read and Murray, 2000). Strandings were classified as HI-CBD if 1) the carcass was too decomposed to determine presence or absence of HI evidence, 2) the carcass was not examined for HI evidence, 3) the required information was not recorded, or 4) suspicious lesions could not be identified definitively as HI. A description of HI evidence was recorded for most HI-yes strandings, although recognizing that the interaction may not have caused the mortality. HI-yes strandings were further stratified by HI-FI (fishery interaction) (e.g., evidence of entanglement lesions, including healed lesions, or gear present) or HI-other (e.g., mutilations, propeller wounds, vessel strikes, gunshots, debris ingestion) (Byrd et al., 2008). Animals positive for FI with additional HI evidence were categorized as HI-FI with other evidence noted. Mutilation was distinguished from scavenger damage according to guidelines in Read and Murray (2000). In contrast to the consistent definitions of HI described above, the HI-other designation due to human harassment of live pinnipeds and cetaceans on the beach was applied inconsistently by stranding responders through the years because it is not clearly defined by the NMFS Marine Mammal Health and Stranding Response Program (MMHSRP), although such cases arguably fit the definition of harassment under the Marine Mammal Protection Act (MMPA; Title 16, U.S code [USC] 1361). Live seals are particularly vulnerable to harassment, especially in NC where their presence on the beach is relatively novel. As a result, each record of a live seal stranding was reviewed during the compilation of stranding data for this study. Seals not otherwise in need of medical attention (i.e., stranded) were considered stranded and classified as HI-other when a high level of harassment occurred (e.g., when they were touched by humans or relocated because of repeated disturbance), but not when seals were frightened back into the water. Live stranded cetaceans that the public pushed back into the water before notifying stranding responders were not generally classified as HI-other (i.e., harassed) according to the Southeast Regional MMHSRP policies.

Whenever possible, genetic analysis was conducted to verify or assign species identification for animals not identified to species in the field owing to advanced decomposition and for species hard to identify (e.g., *Kogia*, *Stenella* species). Genetic analysis also was used to assign the coastal or offshore morphotype (Rosel et al., 2009) for 185 samples from bottlenose dolphins. All other bottlenose dolphins were by default considered the coastal morphotype.

Stranding data and analyses

Stranding data from January 1997 through December 2008 were compiled from the comprehensive database maintained at NMFS-Beaufort. Level A stranding data from NC are also maintained in the MMHSRP database; however, the local database includes additional data such as detailed HI information. Analyses were conducted with SAS vers. 9.3, or SAS Enterprise, vers. 4.2[4] software (SAS Institute, Inc., Cary, NC).

For analyses, each stranding was considered a separate event, except for mass strandings and mother–calf pairs, where individual animals are not independent. For mother–calf pairs, maternity was either genetically determined or presumed on the basis of a combination of sex, age class, date, and proximity of an adult female to a calf. Mass strandings were defined as 2 or more individuals, excluding mother–calf pairs, of the same species at the same location (within 5 km from each other) on the same day. Two species were considered exceptions to this definition. Harbor porpoises (*Phocoena phocoena*) meeting these conditions were not considered a mass stranding because they do not travel in tight social groups (e.g., Raum-Suryan and Harvey, 1998) and, therefore, one animal beaching is unlikely to influence another animal beaching (Geraci and Lounsbury, 2005). Coastal bottlenose dolphins meeting the defined conditions also were not generally considered a mass stranding because of their high frequency of stranding and coastal abundance, except for one event where 3 animals stranded together alive.

For analyses of coastal bottlenose dolphins, stranding events were stratified by dolphin length and HI categories. There is a tendency for seasonal calving (Hohn, 1980; Thayer et al., 2003) and a concomitant high mortality of neonates (Fernandez and Hohn, 1998). The resulting preponderance of neonatal strandings can mask stranding patterns of older animals when all strandings are combined. Because documentation of neonatal characteristics (*see* Thayer et al., 2003) has not been consistent for all strandings, length was used as a proxy. In NC, Thayer et al. (2003) documented the maximum length of true neonates as 125 cm (mean=108.2 cm). Thus, all strandings <125 cm were categorized as perinates, although we recognize that this category could comprise most or all of the neonates, as well as some specimens up to 3 months of age (Fernandez and Hohn, 1998). Nonperinatal (≥125 cm) coastal bottlenose dolphin strandings were stratified into HI categories: HI-FI, HI-no, HI-CBD, and HI-other. For mother–calf pairs, the HI category of the mother was used. The sample size of the category HI-other was too small for analyses (n=26 events). Only 4 perinatal bottlenose dolphin strandings were positive for HI (HI-FI=2, HI-other=2); therefore, perinates were not stratified by HI category. Animals with an estimated or minimum length (such as that due to severed flukes) of <125 cm were excluded (91 individuals from 89 events).

Temporal patterns

Yearly and monthly patterns of stranding events were evaluated for taxonomic groups with sufficient sample sizes. When necessary to achieve adequate sample sizes, species with similar habitats were combined. Annual trends were assessed by using a simple linear regression (SAS PROC REG) for the following taxonomic groups: balaenopterids, pygmy sperm whales (*Kogia breviceps*); dwarf sperm whales (*Kogia sima*); harbor porpoises; harbor seals (*Phoca vitulina*); non-*Phoca* pinnipeds; non-*Kogia* pelagic odontocetes (delphinids except coastal bottlenose dolphins, ziphiids, and sperm whales [*Physeter macrocephalus*]), and the coastal bottlenose dolphin categories mentioned previously, including coastal and inshore strandings. For the simple regression only, data (plus 0.5 due to zeros) were natural log transformed. Monthly stranding patterns were

[4] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

evaluated by using a maximum likelihood generalized linear model (GLM) (SAS PROC GENMOD) with a log link function and a Poisson error distribution, with month as the categorical predictor variable and number of strandings as the response variable (McFee et al., 2006). For each model, the month with the lowest mean count was used as the reference group. The model was evaluated for over-dispersion and goodness of fit by examining the magnitude of the deviance and the Pearson chi-square statistic divided by its degrees of freedom and by computing the probability of obtaining the observed chi-square statistic for each test. If over-dispersion or lack of fit occurred with either criterion, the model was rerun with a negative binomial error distribution and the fit was similarly evaluated. The lowest Akaike information criterion (AIC) values were used to determine the best fit. Harbor porpoise and harbor seal strandings were highly seasonal, causing nonconvergence in the GLM analysis. As a result, their seasonal patterns were described qualitatively. Sample sizes were too small to test for month effects for balaenopterids, dwarf sperm whales, and non-*Phoca* pinnipeds.

For species represented by a preponderance of small individuals, each stranded animal was assigned a maturity state on the basis of length relative to published length estimates: humpback whales (*Megaptera novaeangliae*) (Rice, 1963), common minke whales (*Balaenoptera acutorostrata*; hereafter 'minke whales') (Boyd et al., 1999), harbor porpoises (Read and Gaskin, 1990; Lockyer, 1995), harbor seals (Boulva and McLaren, 1979), hooded seals (*Cystophora cristata*) (Reeves et al., 1992), gray seals (*Halichoerus grypus*) (Bonner, 1981), and harp seals (*Pagophilus groenlandicus*) (Reeves et al., 1992; Hammill et al., 1995).

Spatial patterns

Spatial patterns were evaluated after stratifying the data into strandings recovered ocean-side or inshore. Relatively few strandings were recovered inshore; therefore, only qualitative results were presented. For the ocean-side analysis, the coast was stratified into 4 segments (A–D) with boundaries at the VA–NC line, each cape (Hatteras, Lookout, and Fear), and at the NC–SC line (Fig. 1). The coastline length of each segment was calculated in ArcGIS 10 software (Esri, Redlands, CA). Within each taxonomic group, a chi-square analysis was used to compare the number of observed strandings with an expected value proportional to the segment length. When a significant difference (P=0.05) was found, standardized residuals were examined to determine which coastal segments had significantly more or fewer strandings (i.e., standardized residuals $>|1.96|$). Delphinid species included in the taxonomic group of non-*Kogia* pelagic odontocetes were further divided into groupings that could be plotted in ArcGIS to qualitatively examine patterns not testable due to small sample sizes: 1) pilot whales, 2) pelagic delphinids generally associated with cool northern waters, 3) pelagic delphinids generally associated with warm southern waters, and 4) pelagic delphinids with a more cosmopolitan distribution in areas north and south of NC. Species whose distribution in the western North Atlantic are not well defined were assigned to one of the aforementioned categories on the basis of what is generally known of their distribution (e.g., melon-headed whales [*Peponocephala electra*] are generally a tropical–subtropical species; Perryman et al., 1994).

Because coastal bottlenose dolphin strandings were numerous enough to be investigated in more detail, the coastline was divided into 7 segments by dividing segments A–C in half (A1, A2, B1, B2, C1, C2) (Fig. 1). Segment D was not divided because it was already less than half the length of segments A–C. As with the 4-segment analyses, a chi-square analysis was used to determine whether the number of observed strandings per segment was significantly different from an expected value proportional to the segment length (P=0.05); standardized residuals were examined when a significant difference was found in order to identify which segments had significantly more or fewer strandings (i.e., standardized residuals $>|1.96|$).

To visualize the distribution of all strandings on a finer scale, the NC coast was divided into 10-km sections by using ArcGIS; the last (most southern) section was 7.6 km. Strandings were assigned to one of these 54 sections with ArcGIS. The mean annual strandings per section were graphed for coastal bottlenose dolphins and all other species combined.

Human interactions

Stranding data were stratified into the HI categories mentioned previously. The evidence for HI was reviewed for strandings categorized as HI-FI and HI-other. Unless FI lesions were noted as healed, they were assumed to be fresh. For HI-FI animals recovered with attached gear, totals were produced by gear type.

Results

During 1997 through 2008, 1847 individual marine mammal strandings were reported for 1777 events comprising 9 families and 34 species (Table 1). Species could not be determined for 67 strandings. The majority of individual strandings were coastal bottlenose dolphins (56%), harbor porpoises (13%), and harbor seals (4%) (Fig. 2). Nineteen of 185 bottlenose dolphins tested were confirmed genetically as being the offshore morphotype. *Kogia* spp. represented 5% of strandings; of those, pygmy sperm whales were found to be more common than dwarf sperm whales. There were 19 group stranding events, primarily those of *Kogia* spp. and coastal bottlenose dolphins, and mostly mother–calf pairs (Table 2). For 3 of the 9 mother–calf pairs of

Table 1

Annual totals of individual (inds.) marine mammal strandings (n=1847; 34 species) recovered from 1777 reported events (evts.) in North Carolina during 1997–2008.

Species by family	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	All inds.	All evts.
Balaenidae														
Eubalaena glacialis						1	1	1			1	1	5	5
Balaenopteridae														
Balaenoptera acutorostrata			2	1		2			2			1	8	8
Balaenoptera borealis								1					1	1
Balaenoptera edeni							1						1	1
Balaenoptera physalus		1					2						3	3
Megaptera novaeangliae	2	2		3	5	3	1	1		2	2	2	23	23
Unidentified balaenopterid	1	1										1	3	3
Delphinidae														
Delphinus delphis	2	2		6	16	4	8	4	1	2		1	46	40
Feresa attenuata		1										1	2	2
Globicephala macrorhynchus		1		1	1		1	1	37			3	45	13
Globicephala melas			2				2	1	1				6	6
Globicephala species							1		2	1		1	5	5
Grampus griseus	1	2	1		3	2	2	3	2	1		1	18	18
Lagenorhynchus acutus			1		1		1	2	4	1	1	3	14	14
Peponocephala electra										1		1	2	2
Pseudorca crassidens						1							1	1
Stenella attenuata						2	1						3	3
Stenella clymene			2	1				1					4	4
Stenella coeruleoalba	6	1		1	3	3	5	1	13	1	3	2	39	28
Stenella frontalis	1	2		3	2	2	3		2	1	2	1	19	18
Stenella longirostris	1				2								3	3
Stenella species	1	1											2	2
Steno bredanensis				1						2			3	3
Tursiops truncatus coastal	127	103	95	102	88	92	68	84	75	64	75	66	1039	1034
Tursiops truncatus offshore			1	1		2	3	6	3	2		1	19	19
Unidentified delphinid	1	2	1	2	4		2	1	3	2	1	4	23	23
Kogiidae														
Kogia breviceps	3	5	1	3	2	5	6	5	6	8	5	4	53	47
Kogia sima	1		6	4	1		2	2	4	7	7	1	35	27
Kogia species		1										1	2	2
Phocidae														
Cystophora cristata			1	1	5					4			11	11
Halichoerus grypus	1			1		1		2	2	2	2	1	12	12
Pagophilus groenlandicus	1		1			1	1	1	1	1			7	7
Phoca vitulina	1	11	2	8	4	3	15	4	12	5	2	6	73	73
Unidentified phocid				1					1	1		2	5	5
Phocoenidae														
Phocoena phocoena	25	4	59	6	21	5	38	15	43	6	20	7	249	249
Physeteridae														
Physeter macrocephalus		1	1	1		1	1	1		1		1	8	8
Trichechidae														
Trichechus manatus		2			1			1				1	5	5
Ziphiidae														
Mesoplodon densirostris					2			1	1	1	1	1	7	6
Mesoplodon europaeus		5	1		2	1	2		2				13	13
Mesoplodon mirus							1						1	1
Mesoplodon species		1									1		2	2
Ziphius cavirostris		1		1									2	2
Unidentified ziphiid		1			1								2	2
Unknown	3	1	2	1	1	2	3		4	1		5	23	23
Total	178	152	179	149	165	133	171	139	221	117	123	120	1847	1777

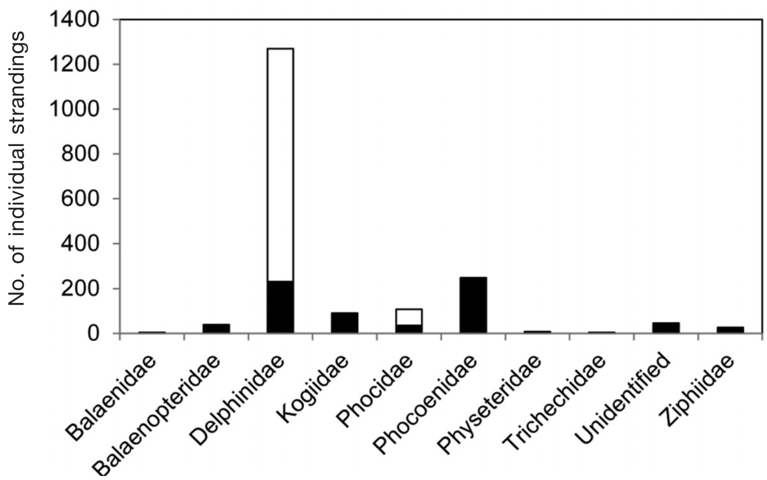

Figure 2

Number of marine mammal strandings (n=1847) reported in North Carolina during 1997–2008 by family. The families Delphinidae and Phocidae are subdivided to show the large contribution of a single species (white bars: coastal bottlenose dolphin [*Tursiops truncatus*] and harbor seal [*Phoca vitulina*] respectively) to other species in each family (black bars).

Kogia spp., the pair stranded with an adult male. Total length was measured (i.e., not estimated) for 570 females and 679 males identified to species (Table 3). The average length of the coastal bottlenose dolphins classified as perinates (n=179) was 105.8 cm (standard deviation [SD]=9.6). Of those dolphins, 28 were <95 cm, the size of the smallest measured neonate in NC during 1992–99 (Thayer et al., 2003).

Live strandings accounted for 15% of all strandings; more than 41% of pelagic odontocetes (40% of delphinids, 52% of *Kogia* spp., 15% of ziphiids, and 75% sperm whales) and 60% of pinnipeds were found alive. Of the 282 live strandings (233 cetaceans, 65 seals), 41% died on their own, 29% were euthanized, 15% were transferred to a rehabilitation facility (36 seals, 7 cetaceans), and 13% were immediately released or relocated. The fate was unknown for the remaining 2 animals, both dwarf sperm whales: 1) one animal was attacked by a shark at the time of the stranding, and 2) a calf was reported but gone when the

Table 2

Marine mammal stranding group events (mother–calf pairs, mass strandings) (n=19) during 1997–2008 in North Carolina.

Year	Month	Day	Species	Mother–calf pair	Mass stranding	No. of animals	Habitat
1997	Jan	6	*Tursiops truncatus* coastal	yes	no	2	Ocean
1998	Sep	13	*Kogia breviceps*	yes	no	2	Ocean
1999	Nov	11	*Kogia sima*	yes	no	2	Ocean
1999	Nov	29	*Kogia sima*	yes	no	2	Ocean
2000	Feb	9	*Stenella frontalis*	no	yes	2	Ocean
2000	Sep	15	*Kogia sima*	yes	no	2	Ocean
2001	Feb	1	*Delphinus delphis*	no	yes	7	Ocean
2001	Sep	21	*Mesoplodon densirostris*	yes	no	2	Ocean
2003	Apr	1	*Tursiops truncatus* coastal	yes	no	2	Ocean
2003	Nov	23	*Kogia breviceps*	yes	no	2	Ocean
2004	May	27	*Tursiops truncatus* coastal	yes	yes	3	Inshore
2005	Jan	15	*Globicephala macrorhynchus*	yes	yes	33	Ocean
2005	Jan	16*	*Kogia sima*	yes	yes	3	Ocean
2005	Aug	22	*Stenella coeruleoalba*	no	yes	12	Ocean
2006	Feb	17	*Kogia sima*	yes	yes	3	Ocean
2006	Sep	2	*Kogia breviceps*	no	yes	3	Ocean
2006	Oct	17	*Tursiops truncatus* coastal	yes	no	2	Ocean
2007	Feb	5	*Kogia sima*	yes	no	2	Ocean
2007	Jul	28	*Kogia breviceps*	yes	yes	3	Inshore

* Genetically confirmed calf recovered 19 January 2005.

Table 3

Measured lengths (cm) for marine mammal strandings identified to species and sex in North Carolina during 1997–2008. SD=standard deviation (SD). Min=minimum. Max=maximum.

	Female					Male				
Species by family	Mean	SD	Min	Max	*n*	Mean	SD	Min	Max	*n*
Balaenidae										
Eubalaena glacialis	1490.0				1	633.5	195.9	495	772	2
Balaenopteridae										
Balaenoptera acutorostrata	466.5	14.8	456	477	2	288.5	6.4	284	293	2
Balaenoptera borealis						1402.0				1
Balaenoptera edeni						1105.0				1
Balaenoptera physalus	1690.0				1	1720.0				1
Megaptera novaeangliae	831.7	76.5	745	890	3	889.1	91.0	763	1065	9
Delphinidae										
Delphinus delphis	201.1	8.2	182	211	17	210.8	24.2	121	229	20
Feresa attenuata						210.0	7.1	205	215	2
Globicephala macrorhynchus	336.0	48.4	210	387	26	309.5	122.3	156	506	12
Globicephala melas	350.0				1	342.0	181.0	214	470	2
Grampus griseus	240.6	30.7	187	261	5	242.8	50.2	164	321	10
Lagenorhynchus acutus	166.5	2.1	165	168	2	202.0	51.0	152	281	9
Peponocephala electra						247.0	1.4	246	248	2
Pseudorca crassidens	455.0				1					
Stenella attenuata	191.0				1					
Stenella clymene	189.0				1	174.3	35.0	135	202	3
Stenella coeruleoalba	195.8	26.4	156	217	5	214.2	27.0	152	241	30
Stenella frontalis	170.2	32.0	118	212	9	195.6	27.5	150	221	8
Stenella longirostris						230.0	2.8	228	232	2
Steno bredanensis	235.0				1	191.0				1
Tursiops truncatus coastal	199.3	58.7	85	285	334	196.5	59.3	88	334	377
Tursiops truncatus offshore	276.5	17.8	245	298	6	261.4	36.5	180	291	12
Kogiidae										
Kogia breviceps	241.1	59.1	117	312	16	276.1	43.7	154	346	31
Kogia sima	200.7	33.8	123	242	15	207.1	30.9	133	243	15
Phocidae										
Cystophora cristata	109.0	11.8	96	119	3	112.4	10.1	94	125	6
Halichoerus grypus	92.0	9.7	78	99	4	124.2	14.4	108	136	3
Pagophilus groenlandicus	114.0				1	103.0	17.0	91	115	2
Phoca vitulina	103.6	19.6	76	135	17	104.3	21.8	83	172	21
Phocoenidae										
Phocoena phocoena	117.9	13.6	84	169	80	115.4	9.0	99	154	79
Physeteridae										
Physeter macrocephalus	677.7	321.9	381	1020	3	872.3	407.5	416	1200	3
Trichechidae										
Trichechus manatus						298.5	9.9	288	310	4
Ziphiidae										
Mesoplodon densirostris	383.6	105.1	196	439	5	415.0	11.3	407	423	2
Mesoplodon europaeus	384.8	89.1	202	463	7	407.8	56.4	295	444	6
Mesoplodon mirus	478.0				1					
Ziphius cavirostris	484.5	55.9	445	524	2					

response team arrived. Attempted rehabilitation was chosen for a greater percentage of seals (55%) than for cetaceans (3%). The majority of seals (72%) and minority of cetaceans (2 of 7: 29%) were released after rehabilitation.

Temporal patterns

An average of 154 individual strandings (SD=30.6) or 148.1 stranding events (SD=23.8) were reported annually. The highest annual number of individuals was recorded in 2005 (*n*=221) and the lowest in 2006 (*n*=117) (Table 1). Annual totals of individual strandings were influenced by mass strandings and unusual mortality events (UMEs) (MMPA 16 USC 1361; Gulland, 2006). Two of the mass strandings occurred on consecutive days in January 2005 and were designated part of the same UME (Table 2) (Hohn et al., 2006). Also in 2005 was an UME of harbor porpoises (*n*=43) (Hohn et al., 2013) in the spring and a mass stranding of striped dolphins (*n*=12) in late summer. Although the number of strandings in 2004 was not high, there was an UME of pelagic small cetaceans (primarily pygmy sperm whales and offshore bottlenose dolphins) along the mid-Atlantic from July to September 2004 that included 13 strandings in NC.

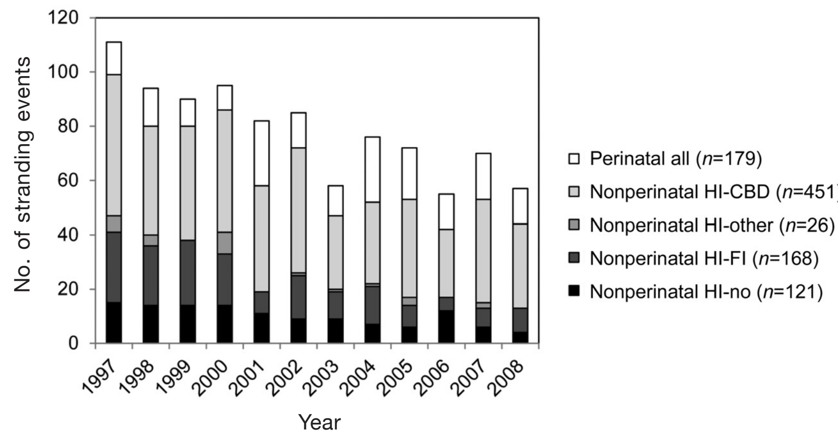

Figure 3

Number of annual stranding events for perinatal (<125 cm) and nonperinatal (≥125 cm) coastal bottlenose dolphins (*Tursiops truncatus)* in North Carolina. Nonperinatal strandings are divided into human interaction (HI) categories: HI-CBD (could not be determined), HI-other (e.g., mutilation, vessel strike), HI-FI (fishery interaction), and HI-no (no evidence of HI).

Annual trends were detected only for coastal bottlenose dolphins. The average annual number of coastal bottlenose dolphin strandings was 86.6 (SD=18.6) (Table 1), of which the average for perinates was 14.3 (SD=5.2; range: 9 [1999 and 2000] to 24 [2001 and 2004]). A significant negative annual trend was detected for all tested categories of nonperinatal bottlenose dolphin stranding events (HI-FI, *n*=168, *P*<0.001; HI-no, *n*=121, *P*=0.002; HI-CBD, *n*=451, *P*=0.05). No trend was detected for perinates (*n*=179, *P*=0.75) (Fig. 3) or for the second and third most numerous species, harbor porpoises (*n*=249, *P*=0.59) and harbor seals (*n*=73, *P*=0.86), both of which fluctuated greatly among years (Table 1). In addition, no annual trend was detected for balaenopterids, pygmy sperm whales, dwarf sperm whales, non-*Kogia* pelagic odontocetes, or non-*Phoca* pinnipeds. Strandings of baleen whales occurred at low levels, but there were never fewer than 2 per year. All 5 right whales stranded during or after 2002.

Significant month effects (GLM, all *P*<0.0001) were found for non-*Kogia* pelagic odontocetes and all tested categories of coastal bottlenose dolphin events except HI-no (*P*=0.69), and no month effect for the other groups or species. For many species, strandings peaked in the spring (Table 4, Fig. 4). HI-FI and HI-CBD bottlenose dolphins had a second peak in the fall.

Other species or species groups showed general seasonal patterns (Table 4). Although there were relatively few sperm whale strandings (*n*=8), all occurred between December and June. Baleen whales also were notably absent during summer months (June–August) (Fig. 4). Minke whales and humpback whales were all immature according to their length (Table 3). Of the 8 minke whale strandings, 2 were likely newly weaned and 2 were dependent calves. Harbor porpoises occurred exclusively from January through May, with 78% of the strandings during March and April (Fig. 4). Of the 184 measured harbor porpoises, 96% (*n*=177) were immature on the basis of length and 70% (*n*=128) were approximately 1 year old or less. Harbor seals occurred in every month, except August, although 86% stranded between January and April (Fig. 4). Eleven of 12 gray seals stranded from February through May (Table 4). In contrast, 73% of hooded seals stranded during July–September. Hooded and gray seals were all immature on the basis of length, whereas 85% of harbor seals and 86% of harp seals were immature.

Spatial patterns

Strandings were not uniformly distributed. Of the 1847 strandings documented, 88% (*n*=1624) occurred ocean-side and included 1557 events (0.24 events per km of ocean coastline). Of the ocean-side stranding events, 46% occurred north of Cape Hatteras (160 km or 30% of coast), and 76% occurred north of Cape Lookout (>280 km or 52% of coast) (Figs. 5 and 6). For all tested categories of coastal bottlenose dolphins except HI-no (χ^2=3.9, *n*=101, *P*=0.69), there was a segment effect (7 ocean-side segments, A1–D) (perinatal, χ^2=26.2, *n*=161, *P*=0.0002; nonperinatal HI-FI, χ^2=26.8, *n*=145, *P*=0.0002; nonperinatal HI-CBD, χ^2=62.9, *n*=357, *P*<0.0001) (Fig. 7). On the basis of standardized residuals (>|1.96|), segment B1 had significantly more strandings than expected for these 3 significant categories. For all other significant segments, observed strandings were less than expected

Table 4

Monthly totals of individual (inds.) marine mammal strandings (n=1847) recovered from 1777 reported events (evts.) in North Carolina during 1997–2008.

Species by family	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All inds.	All evts.
Balaenidae														
Eubalaena glacialis			1	1					1		1	1	5	5
Balaenopteridae														
Balaenoptera acutorostrata	1	1	1	2	1					1	1		8	8
Balaenoptera borealis		1											1	1
Balaenoptera edeni			1										1	1
Balaenoptera physalus		1	1		1								3	3
Megaptera novaeangliae	1	2	4	4					1		2	9	23	23
Unknown balaenopterid	1	1	1										3	3
Delphinidae														
Delphinus delphis	1	12	11	9	6				1		1	5	46	40
Feresa attenuata					1			1					2	2
Globicephala macrorhynchus	33	3	1	1	1		2		2	1		1	45	13
Globicephala melas		1	1	1	2						1		6	6
Globicephala species				3	1					1			5	5
Grampus griseus	1		1	3	2	3		2	2	2	2		18	18
Lagenorhynchus acutus		1	5	8									14	14
Peponocephala electra					1		1						2	2
Pseudorca crassidens					1								1	1
Stenella attenuata			1	2									3	3
Stenella clymene		1			1			1			1		4	4
Stenella coeruleoalba	2	6	1	6	2	1		14	1	1	2	3	39	28
Stenella frontalis		4	3	1	2	1	1	3	1	1		2	19	18
Stenella longirostris			3										3	3
Stenella species								1		1			2	2
Steno bredanensis	2							1					3	3
Tursiops truncatus coastal	73	78	105	200	172	61	33	49	31	92	94	51	1039	1034
Tursiops truncatus offshore		2	2	1		1	6	5		1	1		19	19
Unidentified delphinid	2	1	3	5	5	2			2	2		1	23	23
Kogiidae														
Kogia breviceps	3	4	3	10	1	4	6	4	9	2	6	1	53	47
Kogia sima	7	9	1	2	3	1	2	1	2		5	2	35	27
Kogia species		1			1								2	2
Phocidae														
Cystophora cristata			2		1		2	4	2				11	11
Halichoerus grypus		2	4	3	2			1					12	12
Pagophilus groenlandicus	2	2		2					1				7	7
Phoca vitulina	12	18	25	8	1	1	1		2	1	2	2	73	73
Unidentified phocid			1	3	1								5	5
Phocoenidae														
Phocoena phocoena	2	39	139	55	14								249	249
Physeteridae														
Physeter macrocephalus	1		2	2		2						1	8	8
Trichechidae														
Trichechus manatus	1						1	1				2	5	5
Ziphiidae														
Mesoplodon densirostris	1		1			1			3		1		7	6
Mesoplodon europaeus	1		1	1	1	3	1	4	1				13	13
Mesoplodon mirus										1			1	1
Mesoplodon species				1								1	2	2
Ziphius cavirostris					1	1							2	2
Unidentified ziphiid					1	1							2	2
Unknown	1	1	2	3	3	3	2	0	3	3	1	1	23	23
Total	148	191	327	337	229	86	58	92	65	110	121	83	1847	1777

(segments C2 and D for HI-CBD, segments B2 and C2 for HI-FI, and segment C2 for perinatal strandings).

There was a significant difference in number of ocean-side stranding events among the 4 segments (A–D) for harbor porpoises (χ^2=176.1; P<0.0001, n=247), non-*Kogia* pelagic odontocetes (χ^2=55.1; n=206, P<0.0001), harbor seals (χ^2=17.8; n=67, P=0.0005), and non-*Phoca* pinnipeds (χ^2=11.4; n=34, P<0.0096) (Fig. 7), and no segment effect for the other groups or species. Segment A had significantly more events than expected and segment C less than expected for all 4 taxonomic groups. In addition there were significantly fewer than expected harbor porpoises, harbor seals, and non-*Kogia* pelagic odontocetes in segment D and fewer than expected harbor porpoises in segment B. The spatial patterns of non-*Kogia* pelagic odontocetes were driven by the pelagic delphinids, which represented the majority of this taxonomic group. Generally, all 4 subcategories of pelagic delphinids, including southern species, stranded primarily north of Cape Hatteras (Fig. 6). For pilot whales, the more southerly short-finned pilot whale occurred in all 4 segments, whereas the more northerly long-finned species (*Globicephalus melas*) was never recovered south of Cape Hatteras. More northern pelagic delphinid individuals (n=99) were recovered than southern delphinid individuals (n=17); no stranding within either group was recovered in segment D (Fig. 6). Cosmopolitan pelagic delphinids (n=57) were recovered in all segments. Although samples sizes of the individual species did not allow for statistical analysis, the overall spatial distribution of strandings demonstrated the preponderance of strandings in coastal segment A and a clustering of strandings just south of Cape Hatteras and Cape Lookout. Harbor seals and other seals showed the same patterns of differences among segments; however, a map of sightings shows that although harbor seals were recovered from the VA line to southwest of Cape Fear (segment D), the other seals were never recovered very far south of Cape Lookout.

The spatial pattern of balaenopterids was pronounced despite no statistical difference (P=0.39) among the 4 coastal segments. Of the 36 ocean-side strandings, 42% occurred north of Cape Hatteras (segment A) and 69% occurred north of Cape Lookout (segments A and B). Seven of the 10 whales within segment C were recovered in the northern 30 km (Fig. 6). Interestingly, 3 of the 8 minke whales stranded in segment C, just inside the bight at Cape Lookout, and another minke whale stranded inshore of the bight about 10 km into the sound.

The majority (83%) of inshore strandings were those of coastal bottlenose dolphins (183 of 223). All manatees (n=5) were recovered inshore. There were 2 harbor porpoises recovered far inshore, both in 2005 and both found alive. Some nonestuarine species (e.g., humpback whale, sperm whale, offshore bottlenose dolphin) were also recovered inshore, but generally near inlets (Fig. 6).

Human interactions

Most strandings (60%; n=1096) were HI-CBD (Table 5). Human interactions (HI) were reported for 299 (16%) strandings, including 18 of the 34 species examined, as well as 5 carcasses unidentified to species (Table 5). The HI-yes category represented about 40% of those for which it was possible to determine whether an interaction occurred (excludes HI-CBD). Overall, most (80%) of the HI-yes strandings were HI-FI. For 5 species, there were 10 or more HI strandings: coastal bottlenose dolphins, harbor porpoises, short-finned pilot whales, harbor seals, and humpback whales. The percentage of HI was particularly high for humpback whales and coastal bottlenose dolphins (Table 5). The incidence of HI-FI of those for which it was possible to determine whether an interaction occurred was similar for coastal bottlenose dolphins recovered inshore (28 out of 60; 47%) and ocean-side (153 out of 331; 46%). Healed FI lesions were noted on 20 strandings: pilot whales (n=10), a common dolphin (n=1), striped dolphins (n=2), a coastal bottlenose dolphin (n=1), a Risso's dolphin (n=1), and humpback whales (n=5). All of the pilot whales with healed lesions were part of the 2005 mass stranding, and had no other evidence of HI. The Risso's dolphin also had fresh FI lesions. Of the humpback whales with healed FI lesions, one was caught in a gill net and died and one stranded dead with trauma consistent with a vessel strike. Two harbor porpoises and 24 coastal bottlenose dolphins classified as HI-FI were also mutilated; they had missing appendages or cuts into the abdomen, or both. Harbor porpoise strandings classified as HI-FI occurred in February (n=3), March (n=3) and April (n=5).

Of the 44 animals entangled in fishing gear (active or free-floating gear) or with ingested fishing gear, gill net, hook-and-line, and trap or pot line gears were the most prevalent (Table 6). Seven animals were released alive. In addition to these strandings, the network documented a humpback whale in February 2001 with a gill net caught on barnacles on its flukes. It was not considered stranded because it freed itself.

Evidence for HI-other (n=62) took several forms with mutilation being the most common (60%) (Table 5). In 3 cases, mutilation was known to have occurred after the stranding had been reported. Most of the mutilated coastal bottlenose dolphins, except for the one mutilated after it had stranded, and all of the harbor porpoises were CBD for FI. The mutilation for 20 of the 25 the dolphins and 7 of the 8 harbor porpoises was similar to that seen in HI-FI strandings with mutilation: clean cuts where fins or flukes were removed, ventral body slits, or both. The debris (e.g., "parachute cord" and thick rope) found entangled on 2 coastal bottlenose dolphins could not be confirmed as fishery-related. Harassment was recorded for 2 cetaceans: a pygmy sperm whale that was pushed back into the water 10 times before stranding responders

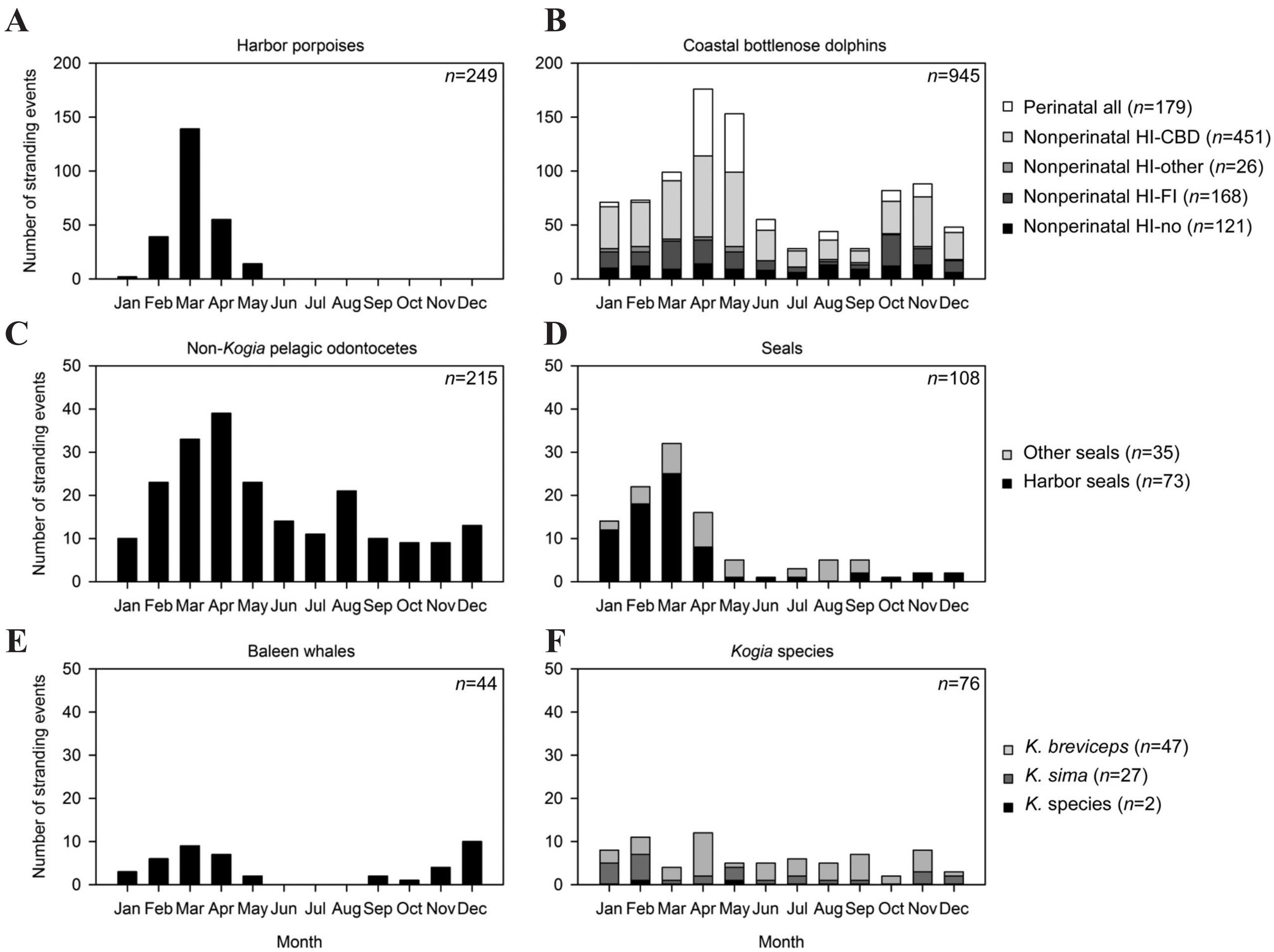

Figure 4

Monthly stranding events in North Carolina during 1997–2008 for (**A**) harbor porpoises (*Phocoena phocoena*), (**B**) perinatal (<125 cm) and nonperinatal (≥125 cm) coastal bottlenose dolphins (*Tursiops truncatus)*, (**C**) non-*Kogia* pelagic odontocetes, (**D**) seals, (**E**) baleen whales, and (**F**) *Kogia* species. Nonperinatal bottlenose dolphins strandings are divided into human interaction (HI) categories: HI-CBD (could not be determined), HI-other (e.g., mutilation, vessel strike), HI-FI (fishery interaction), and HI-no (no evidence of HI). Seals are divided into harbor seals (*Phoca vitulina*) and other seals. *Kogia* species are divided into pygmy sperm whales (*K. breviceps*), dwarf sperm whales (*K. sima*), and *Kogia* whose species were not identified. Note that *y*-axes in the top graphs are at a different scale than that of the other graphs.

arrived and a Risso's dolphin that the public tried to move when they heard it was going to be euthanized. Although cetaceans pushed off the beach were not generally classified as HI-other, these 2 animals were classified as HI-other because of excessive harassment. Harassment was more common for seals and included instances of the public trying to move or pick up the animal (n=4), resulting in one person being bitten, and instances where relocation was necessary because of persistent disturbance (n=2). Most of these seals were healthy, exhibiting normal haul-out behavior, and would not otherwise have met the definition of stranded.

Discussion

Biodiversity

A diverse array of marine mammal species strand in NC, reflecting the rich biodiversity of cetacean and pinniped fauna in nearby waters. Along a coastline of 537 km (<3 degrees of latitude), strandings included 9 families and 34 species (29 cetaceans; 4 pinnipeds; 1 manatee), ranging from tropical delphinids to pagophilic (ice-obligate) seals. This diversity is higher than that of other areas such as northwest Spain (15 marine mammal species along 1195 km, López et al., 2002), Hawaii

(16 odontocete species; Maldini et al., 2005), San Diego, California (24 cetacean species along 125 km, Danil et al., 2010), southeastern Canada (19 cetacean species, Nemiroff et al., 2010), and Cape Cod-southeastern Massachusetts (16 marine mammal species along 1126 km, Bogomolni et al., 2010). An exception is Western Australia where 34 cetacean species were found, but the study encompassed 12,889 km of coastline and roughly 20 degrees of latitude (Groom and Coughran, 2012). The high diversity found in NC emanates from multiple oceanographic features and the resulting 2 converging biogeographic zones off the coast. These findings may also reflect shifting distribution patterns over time that are indicative of climate change (e.g., MacLeod et al., 2005, Johnston et al., 2012).

A comparison of strandings to published records of live animals indicates that generally the most numerous stranded species inhabit nearshore waters, are very abundant, or both. Coastal bottlenose dolphins are the most abundant species nearshore, although their abundance varies seasonally (~1000–13,000 animals; Waring et al., 2010). Harbor porpoises and harbor seals generally inhabit coastal waters during at least part of the year (Bigg, 1981; Palka et al., 1996), although they are only seasonally present off NC and their local abundances and distribution are unknown. Relative stranding frequencies of pelagic delphinids generally reflect relative abundance during aerial and shipboard surveys (Waring et al., 2007). This is particularly interesting for species for which NC is their southern distribution (e.g., common dolphins, striped dolphins, Atlantic white-sided dolphins) (Waring et al., 2007). During summer surveys outside of the 10-m isobath along the mid-Atlantic coast of the United States, the most commonly sighted species were offshore bottlenose dolphins, sperm whales, Atlantic spotted dolphins and Risso's dolphins (Mullin and Fulling, 2003), and all of these species, except sperm whales, were quite often found stranded. In contrast, the prevalence of *Kogia* strandings is disproportionate to their relatively low population size estimate (pygmy sperm whales, *n*=741; dwarf sperm whales, *n*=1042) and pelagic distribution (Waring et al., 2013). This incongruity between stranding levels and population sizes for kogiids has been reported elsewhere (Maldini et al., 2005), and is likely due, in part, to population estimates that are underestimated owing to availability and perception bias during surveys (Barlow, 1999). Gervais' beaked whales (*Mesoplodon europaeus*) were also commonly stranded in this study, consistent with previous reports of this species stranding along the U.S. Atlantic coast (Waring et al., 2009a). As with *Kogia* species, the number of strandings is disproportionate to the low abundance estimate (*Mesoplodon* spp. and *Ziphius* spp. combined; *n*=3513; CV=0.63) (Waring et al., 2009a), and the species are also subject to the same detection biases during surveys. Some species (e.g., melon-headed whales, pygmy killer whales, false killer whales) that are rarely seen in the western North Atlantic (Mullin and Fulling, 2003; Waring et al., 2007) were also uncommon in the stranding record.

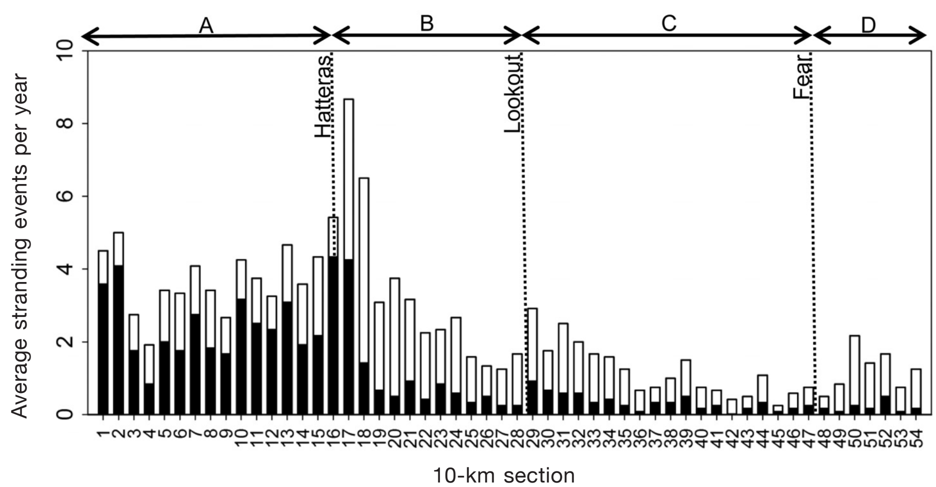

Figure 5

Mean annual stranding events by 10-km section within coastal segments (A–D) from the Virginia/North Carolina (NC) border (section 1) to the NC/South Carolina border (section 54; section=7.6 km) during 1997–2008. Graph shows coastal bottlenose dolphin (*Tursiops truncatus*) (white bars; *n*=855) separate from all other species (black bars; *n*=702). Vertical dotted lines indicate the areas of the 3 NC capes (Hatteras, Lookout, Fear) and divide the coastline into 4 segments: A, B, C, D.

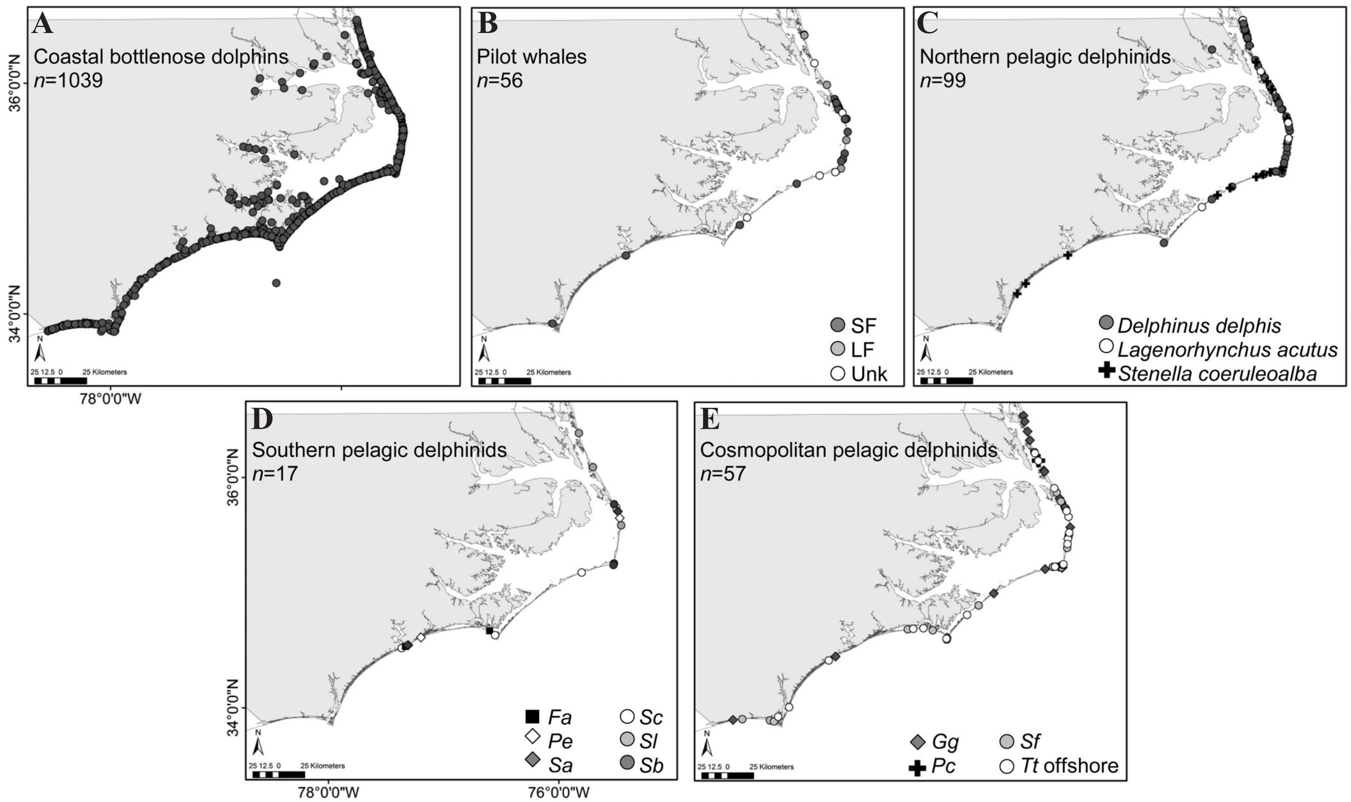

Figure 6

Locations of strandings in North Carolina during 1997–2008 by species or taxonomic group. (**A**) The ocean coastline is divided into 7 segments for coastal bottlenose dolphins (*Tursiops truncatus*) (from north to south: A1, A2, B1, B2, C1, C2, D) and (**B–K**) the ocean coastline is divided into 4 segments for all other taxonomic groups (from north to south: A, B, C, D). Map B: SF=short-finned pilot whales (*Globicephala macrorhynchus*), LF=long-finned pilot whales (*G. melas*), and Unk=unknown. Map D: southern pelagic delphinids—*Fa* (*Feresa attenuata*), *Pe* (*Peponocephala electra*), *Sa* (*Stenella attenuata*), *Sc* (*Stenella clymene*), *Sl* (*Stenella longirostris*), and *Sb* (*Steno bredanensis*). Map E: cosmopolitan pelagic delphinids—*Gg* (*Grampus griseus*), *Pc* (*Pseudorca crassidens*), *Sf* (*Stenella frontalis*), and *Tt* (*Tursiops truncatus*) offshore.

Spatiotemporal patterns

Seals In the western North Atlantic, seals generally occur at higher latitudes than those of NC. New Jersey is considered the prevalent southern distribution for harbor seals (Burns, 2009) and southeastern Canada for hooded and harp seals (McAlpine and Walker, 1990, McAlpine et al., 1999). Extralimital records exist from sightings but strandings are also an indicator of such extralimital movements. For example, juvenile harp seals have been reported as far south as Cape Henry, Virginia, (McAlpine and Walker, 1990), as well as having been stranded in NC. In contrast, although gray seals breed as far south as Massachusetts, their reported occurrence south of New Jersey is known only from strandings (Waring et al., 2013). Although the occurrence of extralimital records of hooded and harp seals has increased since the early 1990s (McAlpine and Walker, 1990; McAlpine et al., 1999), neither species was abundant in the current data set, despite stranding in most years. Extralimital sightings of hooded seals may be more common than those of harp seals overall; they are certainly more wide ranging, with reports as far south as Puerto Rico and the U.S. Virgin Islands (Mignucci-Giannoni and Odell, 2001). Nonetheless, in NC, harbor seals were recovered much farther south than hooded seals.

Although seal strandings occurred in every month and in all coastal segments, their occurrence primarily in winter and north of Cape Hatteras is consistent with general patterns of seal migration. Hooded seals were an exception with most strandings in the summer, including the southernmost records (McAlpine et al., 1999; Mignucci-Giannoni and Odell, 2001). In addition, the strandings of predominantly immature seals in NC may be indicative of age-segregated migration in which juveniles may be more likely to travel this far south or may be more likely to stay closer to shore than adults during winter, or may be indicative of greater mortality of immature animals while off NC.

For seals, human interactions were predominately a result of bycatch or harassment of live seals on the beach. The presence of these seals on the beach elicited great public interest because they are infrequent

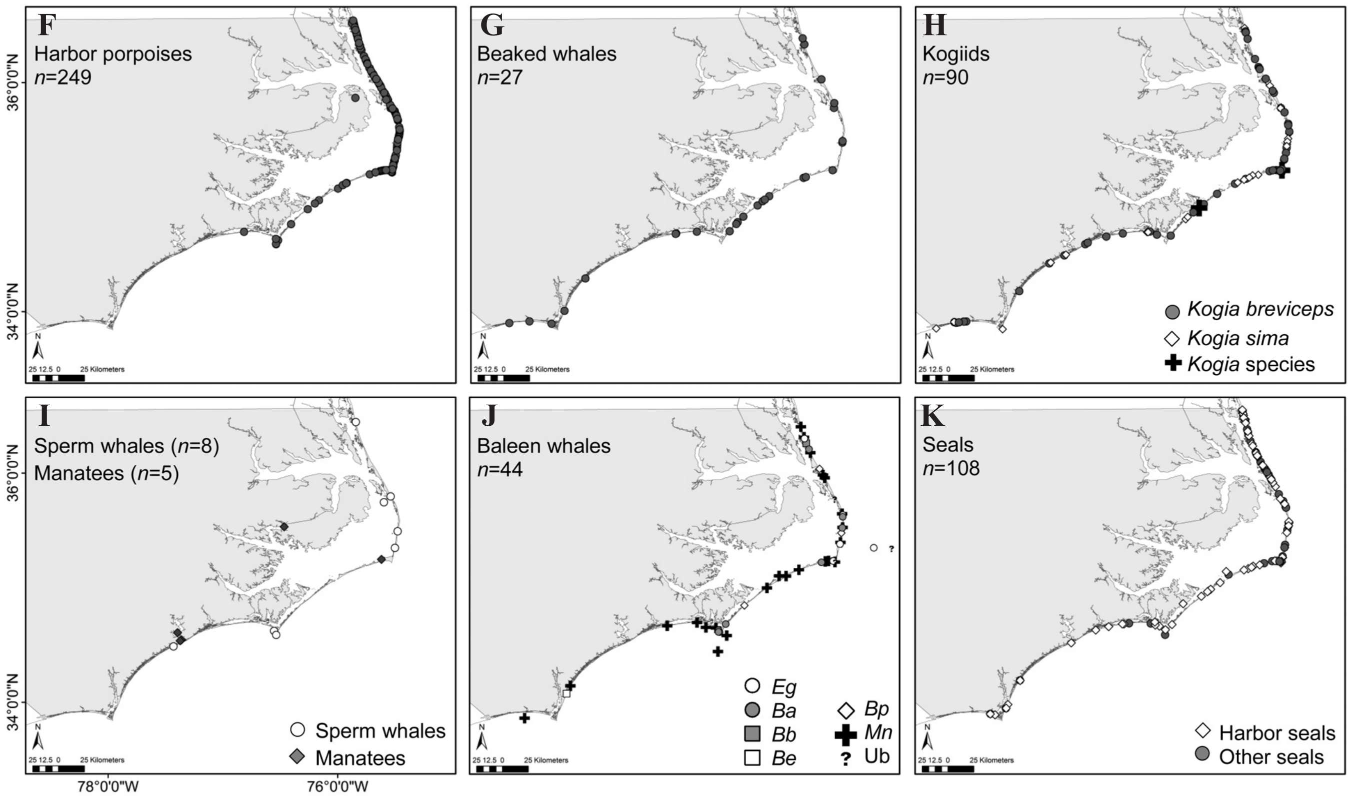

Figure 6 (*continued*)

Map J: baleen whales—*Eg* (*Eubalaena glacialis*), *Ba* (*Balaenoptera acutorostrata*), *Bb* (*Balaenoptera borealis*), *Be* (*Balaenoptera edeni*), *Bp* (*Balaenoptera physalus*), *Mn* (*Megaptera novaeangliae*), and Ub (Unknown balaenopterid). The baleen whales far from shore were found floating and towed to shore for necropsy when possible.

visitors and, at times, it was a challenge to maintain the safety of both seals and humans. The NC stranding network has increased outreach efforts to educate the public on the needs and dangers of hauled-out seals and on the legal mandates to protect seals from harassment (MMPA, 16 USC 1361).

Anecdotal evidence suggests that there has been an increase in the number of seals overall on NC and VA beaches (S. Barco, personal observ.). No trend was detected through the years of data included in this study, although there was interannual variability with notably high strandings in 2003 and 2005. Although the populations of some species are increasing (Waring et al., 2013), the drivers affecting an associated expansion of movements may not result in regular and increased movements to NC. Strandings, however, do not reflect the number of seals on the beach because they do not include healthy seals unless they were harassed. In addition, a standardized mechanism for reporting and tracking sightings, which is needed to test any hypothesized increase, has been lacking.

Harbor porpoise Interannual variability was the prevalent annual pattern for harbor porpoise strandings. Although harbor porpoises are known to be caught in gill nets (Orphanides, 2009), the number of HI-FI strandings was not high enough to explain increased strandings during some years (Hohn et al., 2013). Because harbor seals and porpoises occur in NC during a similar time of year and originate from northern waters, their marked increases during the same years may be a result of the same processes.

The temporal occurrence of harbor porpoise strandings in NC is consistent with the migration of porpoises out of northern areas as water temperatures decrease (Gaskin, 1992). The wintering grounds and migration patterns of harbor porpoises migrating south to the mid-Atlantic are poorly understood, but there is evidence that some porpoises may occur in offshore waters (*see* Palka et al., 1996). Although Cape Hatteras has been the presumed southerly limit (*see* Palka et al., 1996), 13% of strandings occurred between Cape Hatteras and Cape Lookout, owing either to drifting carcasses or to porpoises swimming south of Cape Hatteras at least occasionally. Interestingly, as with strandings of harbor seals, most harbor porpoise strandings were of sexually immature individuals (*see* also Hohn et al., 2013), the drivers for which may also be age-segregated migration and age-specific mortality patterns.

Harbor porpoises migrating along the western North Atlantic coast are susceptible to entanglement in fishing gear. Indeed in NC stranded harbor porpoises were

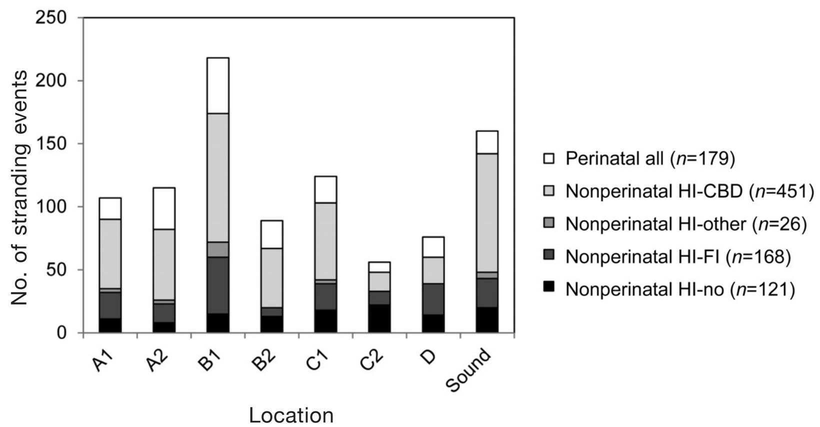

Figure 7

Spatial distribution of perinatal (<125 cm) and nonperinatal (≥125 cm) coastal bottlenose dolphins (*Tursiops truncatus*) stranding events by coastal segments (A1–D) and inshore in North Carolina during 1997–2008. Nonperinatal strandings are divided into human interaction (HI) categories: HI-CBD (could not be determined), HI-other (e.g., mutilation, vessel strike), HI-FI (fishery interaction), and HI-no (no evidence of HI).

found with fresh entanglement lesions that indicated that the entanglement occurred nearby. In addition, mutilation in the form of missing appendages, slit abdomens (or both) was noted on harbor porpoises that were HI-FI and on carcasses that were HI-other but CBD for FI. These types of mutilations are thought to be a result of fishermen's attempts to remove bycaught animals from gear, or to increase the possibility that the carcass would sink and not be recovered (or both) (Kuiken et al., 1994; Read and Murray, 2000). Most bycatch has been documented from New Jersey and north (Orphanides, 2009). However, data for the latest bycatch estimate were collected in February and March (Orphanides[5]), whereas more harbor porpoise strandings in NC were recovered in April than in February and many of those strandings were positive for FI. Observed trips and associated data used to calculate bycatch estimates of harbor porpoises off NC should therefore be expanded to April to ensure representative coverage of fisheries during months when harbor porpoises are present.

Pelagic odontocetes The distribution of pelagic odontocete strandings is likely influenced by the narrow shelf and proximity of the Gulf Stream to the coast (Cione et al., 1993) because habitat for many of these species is near the shelf break and at Gulf Stream fronts (Kenney and Winn, 1986; Hamazaki, 2002). Even southern species occurred north of Cape Hatteras; those species with oceanic distributions likely are associated with the Gulf Stream, as it approaches Cape Hatteras and remains close to shore north of the Cape before it meanders east, or with warm-water eddies (Gray and Cerame-Vivas, 1963) that can move shoreward.

Although pelagic odontocetes are a diverse group, across species they were often found alive or with evidence of having stranded alive, such as sand in the blowhole and abrasions or bruising on the ventrum and ventral flukes. Most live cetaceans died on their own before or shortly after stranding responders arrived. Animals recovered freshly dead (Geraci and Lounsbury, 2005) likely traveled nearshore and died shortly before or after stranding, but before the animal was discovered (Mead[3]). Individuals that died in their normal habitat far from shore would be less likely to be pushed by wind and currents and be deposited on the beach (Peltier et al., 2012). In some cases, the public pushed live animals back into the water—an action rarely chosen by stranding responders. The fates of animals pushed back are unknown except for a few instances where presumably the same animal restranded nearby. Decisions on the best course of action for other live strandings were made after responders consulted with veterinarians and the regional stranding coordinator. Euthanasia was chosen as the most humane treatment for most cetaceans (see Moore et al., 2007), in contrast to rehabilitation being a more suitable option for most seals.

Non-*Kogia* pelagic odontocetes generally stranded from February to May north of the zoogeographical and oceanographic boundary at Cape Hatteras. This trend was driven by species with the most stranding events: common dolphins and striped dolphins. Common dolphins and striped dolphins are generally northern species and occur most commonly off NC in winter (CeTAP[6]); this spatiotemporal distribution is similar to that found for harbor seals and harbor porpoises. Southern pelagic delphinids were less common, and despite their primarily southern distribution, generally showed the same spatiotem-

[5] Orphanides, C. D. 2011. Estimates of cetacean and pinniped bycatch in the 2009 northeast sink gillnet and mid-Atlantic gillnet fisheries. U.S. Dep. Commer. Northeast Fish. Sci. Cent. Ref. Doc. 11-08, 28 p. [Available from Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543-1026 or http://docs.lib.noaa.gov/noaa_documents/NMFS/NEFSC/NEFSC_reference_documnet/NEFSC_RD_11_08.pdf , accessed January 2013.]

[6] CeTAP (Cetacean and Turtle Assessment Program). 1982. A characterization of marine mammals and turtles in the mid- and north Atlantic areas of the U.S. outer continental shelf. Final Report, Contract AA51-C78-48, 538 p. Bureau of Land Management, Washington, D.C.

Table 5

Categories of human interaction (HI) for marine mammal strandings in North Carolina during 1997–2008: HI-FI (fishery interaction), HI-other (other HI evidence), HI-no (no evidence of HI), and HI-CBD (could not be determined). HI-other types are: mutil. (mutilation), vessel strike, ingest. plastic (ingested plastics), entangl. debris (entanglement in debris), gunshot (gunshot injury), and harass. (harassment). Each species or other taxonomic category with at least one record positive for (HI) is listed separately from "Other species".

		HI-other								
Species by family	HI -FI	Mutil.	Vessel strike	Ingest. plastic	Entangl. debris	Gun shot	Harass.	HI-no	HI-CBD	Total
Balaenidae										
Eubalaena glacialis	1		1					1	2	5
Balaenopteridae										
Balaenoptera acutorostrata	2							1	5	8
Balaenoptera edeni	1									1
Balaenoptera physalus			1						2	3
Megaptera novaeangliae	10		1					1	11	23
Unidentified balaenopterid	1								2	3
Delphinidae										
Delphinus delphis	2							22	22	46
Globicephala macrorhynchus	11	2		1				14	17	45
Grampus griseus	1						1	9	7	18
Stenella coeruleoalba	2							29	8	39
Tursiops truncatus coastal	181	25	3	1	2			179	648	1039
Tursiops truncatus offshore	2							15	2	19
Unidentified delphinid	2								21	23
Kogiidae										
Kogia breviceps							1	32	20	53
Phocidae										
Cystophora cristata							1	6	4	11
Halichoerus grypus							1	5	6	12
Phoca vitulina	9		1			2	4	24	33	73
Phocoenidae										
Phocoena phocoena	11	8						33	197	249
Physeteridae										
Physeter macrocephalus				1				3	4	8
Ziphiidae										
Mesoplodon densirostris				1				3	3	7
Mesoplodon europaeus				2				7	4	13
Other										
Unknown marine mammal	1	2							20	23
Other species								68	58	126
Total	237	37	7	6	2	2	8	452	1096	1847

poral stranding pattern as that of northern species. Those species with a more cosmopolitan distribution also were found most often north or just south of Cape Hatteras, but in contrast to the more northern or southern species, they, along with beaked whales, also stranded southwest of Cape Fear. Strandings of beaked whales were too few to detect trends, although the 2 months with the greatest number of Gervais' beaked whales were during summer.

Spatially, strandings of *Kogia* were similar to those of the cosmopolitan non-*Kogia* pelagic odontocetes. Although dwarf sperm whales have more tropical distribution than pygmy sperm whales (Chivers et al., 2005), the 2 species showed no obvious difference in their stranding distribution. Temporally, in contrast to the non-*Kogia* pelagic odontocetes, neither *Kogia* species showed a significant monthly pattern, which may be due to small sample sizes or presence offshore throughout the year.

The majority of fishery interactions among pelagic odontocetes were evident by healed lesions. Pilot whales and Risso's dolphins commonly interact with the pelagic longline fishery which operates throughout the western North Atlantic and elsewhere (Garrison, 2007). The presence of healed FI lesions on strandings indicates that some hooked animals survive. On the other hand, animals killed in the longline fishery with resulting fresh lesions are far from shore and unlikely to strand.

Table 6

Gear types found attached to or ingested by marine mammal strandings classified as HI-FI (human interaction evidence type is fishery interaction) (n=44) in North Carolina during 1997–2008. Seven animals were released alive. Research gear was set by the North Carolina Division of Marine Fisheries (NCDMF).

Species	Gear type	Ocean-side	In-shore	Live release
Balaenoptera edeni	line, trap or pot	1		
Megaptera novaeangliae	gill net	2		
Phoca vitulina	fishhook	1		
	gill net	3		1
Tursiops truncatus coastal	beach seine, multifilament research gear	1		
	beach seine, twine type unknown	1		1
	fishhook (ingested)	1		
	gill net	10	1	2
	gill net, beach-anchored	5		
	Gill net, research		1	
	line, monofilament and large hook	1		
	line, monofilament		2	
	line, monofilament-mixed	1		
	line, nylon with clear jug attached		1	1
	line, trap or pot		3	1
	line, thick multifilament—unknown source[1]		1	
	pound net		1	
	stop net	1		
	trawler, noncommercial	1		
Tursiops truncatus offshore	line, monofilament	1		
Unidentified balaenopterid	mixed-mutifilament webbing, rope, monofilament line, plastic bags	1		
Unidentified delphinid	line, polypropylene	1		
	line, trap or pot		1[2]	1
Unidentified odontocete	line, monofilament	1		
Total		33	11	7

[1] Line not recovered and source unknown, but animal had entanglement lesions consistent with webbing.
[2] Likely *Tursiops truncatus* coastal because occurrence was inshore.

All the pilot whales recovered with healed FI lesions occurred during a single stranding event and, thus, theoretically were from a single pod. Perhaps depredation of longline gear is a learned behavior that is confined within particular pods (Whitehead et al., 2004).

Baleen whales The overall presence of baleen whales primarily from winter through spring and their near absence during summer (May–September) align with known migration patterns (Rice, 1998). The most commonly stranded baleen whales were humpback and minke whales; these species may be more common in the stranding record because of their relative population abundance compared with that of other species of baleen whales, or they may be more common because of their distribution closer to shore (Waring et al., 2009b), or for both reasons. Humpback and minke whales were entirely represented by immature individuals, consistent with prior reports from New Jersey through Florida (Wiley et al., 1995). Wiley et al. (1995) suggested that some juvenile humpback whales may not migrate as far south as adults, but instead spend time feeding at mid-latitudes.

Along with vessel strikes, entanglement in fishing gear is a serious problem for large whales (Wiley et al., 1995; Kraus et al., 2005). The high rate of HI-FI strandings for humpback whales (10 of 23 or 43%) was higher than that reported during 1985–92 from New Jersey to Florida (5 of 20 or 25%) (Wiley et al., 1995). Humpback whales stranded in NC with fresh FI lesions were not necessarily entangled in gear set in NC because some whales carry entangling gear for an extended period of time before the entanglement potentially leads to the animal's death (Knowlton et al., 2012). Entanglement of whales has occurred, however, in gill nets set off NC. In one of these cases the whale died and later stranded. In the other case, the animal never stranded but instead breached, shook the net free, and was seen swimming without any gear attached. Two of the stranded humpback whales showed evidence consistent with vessel strikes; one of these also had healed FI lesions (scars).

Coastal bottlenose dolphins Within the diversity of strandings, the most common species by far was the coastal bottlenose dolphin, which resides in coastal and inshore waters and is present all year. Interpretation of spatiotemporal patterns is complicated, however, because multiple stocks occur in NC waters, including at least 2 migratory coastal stocks and 2 resident estuarine stocks (Waring et al., 2010). These multiple stocks add to the regional biodiversity and influence seasonal local abundance. All 4 stocks are susceptible to incidental mortality in the myriad and seasonally changing commercial fisheries (Steve et al., 2001).

Stranding patterns tended to echo the spatiotemporal occurrence of commercial gillnet fisheries, the principal source of known fisheries bycatch for coastal bottlenose dolphins off NC (Waring et al., 2010). The annual decline in nonperinatal HI-FI bottlenose dolphin strandings likely represents a real decrease in bycatch due, in part, to a series of regulations on gillnet fisheries since 2000 (Federal Register, 2006; Byrd et al., 2008). The monthly patterns of HI-FI strandings were similar to those of effort in the gillnet fishery, which is greatest in spring and fall and lowest in summer (Steve et al., 2001). Although gill nets are used state-wide, the ocean fishery operates primarily from Oregon Inlet to Drum Inlet on the coast (from approximately ocean segments A2 to B1) (NCDMF[7]) and nearshore (0–5.6 km) (Palka and Rossman[8]). The concentration of strandings just south of Cape Hatteras may indicate higher bycatch rates in that area due to either higher local abundance of dolphins (Torres et al., 2005), greater concentrations of gillnet effort, or both. In some cases, carcasses from north of Cape Hatteras may be entrained in waters that are driven south around the cape during strong northeast winds, which are more typical during winter months than other seasons (Gray and Cerame-Vivas, 1963). Although overall seasonal effort in the inshore gillnet fishery is similar to that of the coastal fishery (Steve et al., 2001), the number of inshore strandings was too low to evaluate spatial effects.

The close alignment of the patterns of HI-CBD with HI-FI strandings among years, months, and coastal segments, and the absence of similar patterns for HI-no strandings, provides further evidence that a substantial portion of HI-CBD strandings may indeed be HI-FI. More evidence comes from animals that were CBD for FI, but were mutilated similarly to those known to be positive for FI. In addition, physical processes, such as winds and currents, that resulted in the deposition of HI-FI or HI-CBD animals should have the same effect on HI-no strandings; therefore, those processes are not likely to be causing the difference between HI-no and HI-CBD stranding patterns.

Although there was an annual decline in HI-no strandings, there were no month or spatial effects. A similar negative annual trend during 1992–2003 was not found in SC, an area that shares at least one bottlenose dolphin stock with NC (McFee and Hopkins-Murphy, 2002; McFee et al., 2006). Causes for the annual decline detected in this study are unknown. The lack of coastal segment or month effects was curious given the high seasonal variability in local abundance of coastal bottlenose dolphins along the NC coast, with more dolphins just south of Cape Hatteras in all seasons except summer (Torres et al., 2005; Waring et al., 2010). Changes in abundance, habitat shifts, or survivorship rates could have resulted in these patterns, but data do not exist to test these hypotheses.

Perinatal bottlenose dolphins were recovered in every month, although they were primarily bimodal with the spring mode more pronounced than the fall mode. This pattern is consistent with previous reports of neonate strandings in NC (Thayer et al., 2003) and SC (McFee et al., 2006). However, care should be taken when interpreting reproductive seasonality from stranded perinatal animals. On the basis of size alone, coastal bottlenose dolphins <125 cm could include calves up to 3 months of age (Fernandez and Hohn, 1998). Unfortunately, a standardized data collection to assess whether a small dolphin was a true neonate (*see* Thayer et al., 2003) has not been consistent. As a result, the presence of perinatal strandings in January, for example, does not necessarily mean that the dolphins were born in January. Also, it is possible that some of the smallest perinates were late-term aborted fetuses and their occurrence in the stranding record would influence interpretations of seasonality. Spatial patterns of perinatal strandings may result from differences in local abundance along the coast during calving season; however, fine-scale abundance or density estimates are not available.

Caveats on the use of stranding data as indicators of biodiversity and distribution

Marine mammal strandings can serve as indicators of biodiversity and spatiotemporal presence of live animals in nearby waters. Stranding data may also indicate changes in distribution, phenology, or mortality—some times before changes are detectable in source populations (Gulland, 2006). It is critical, therefore, to recognize the combination of stochastic and deterministic effects on the occurrence and discovery of stranded

[7] NCDMF (North Carolina Division of Marine Fisheries). 2007. Assessment of North Carolina commercial finfisheries, 2004–2007. Final performance report for NMFS award number NA 04 NMF4070216, 380 p. [Available from NCDMF, 3441 Arendell Street, Morehead City, NC 28557.]

[8] Palka, D. L., and M. C. Rossman. 2001. Bycatch estimates of coastal bottlenose dolphin *(Tursiops truncatus)* in U.S. mid-Atlantic gillnet fisheries for 1996–2000. U.S. Dep. of Commer., Northeast Fish. Sci. Cent. Ref. Doc. 01-15, 77 p. [Available from 166 Water Street, Woods Hole, MA 02543-1026 or http://nefsc.noaa.gov/nefsc/publications/crd/crd0115/0115.pdf, accessed June 2012.]

marine mammals in order for stranding data to serve as reliable proxies of those source populations.

Some degree of variability in the number of strandings is expected among years, months, and locations owing to the variety of factors that can affect the likelihood that an animal dying is beach-cast, or that carcasses persist on shore (without being washed out or buried by wave action) long enough to be observed, reported, and recovered. Winds and currents affect stranding rates (Peltier et al., 2012) and it would be interesting to investigate their influences on the patterns documented here. For example, southern NC had relatively few strandings, particularly of species other than coastal bottlenose dolphins. It is also farthest from the Gulf Stream and has a large estuary plume outflowing from the Cape Fear River (Xia et al., 2007), both of which likely impact stranding rates.

Increased mortality due to human interactions also affects stranding patterns. These effects are not always discernible because the ability to detect HI varies across the nature of the interaction. Evidence of fishery interactions, mutilation, vessel strikes, and gunshot wounds are relatively obvious to trained responders. In contrast, the detection of sonar effects on the presence and health of stranded marine mammals is challenging and requires a much more sophisticated sampling protocol than can be implemented for most strandings recovered in NC. The sampling protocol requires fresh carcasses, expertise of the responders, and availability of resources for histopathology analysis and computerized tomography (CT scanning) (*see* Cox et al., 2006). Insufficient data exist to comment on the prevalence of sonar exposure as a cause of strandings for the current study. Strandings positive for HI provide much needed information about the nature, timing, and frequency of interactions, especially in light of the limitations of fisheries observer programs to sufficiently cover all fisheries (Byrd et al., 2008). Although human interactions were detected in more than half of all species recovered (18 of 34), the number of strandings positive for HI was likely underestimated because of the relatively large number of strandings assigned to HI-CBD as result of decomposition, scavenger damage, and a conservative approach to assigning HI status. HI-no is the most difficult assignment to make. For example, strandings with questionable lesions would be assigned by default to HI-CBD.

Maintaining the quality and consistency of stranding data is not a simple task. The stranding network in NC, with its extensive coastline, relies heavily on public reporting and therefore ties to state, federal, and local municipalities have been key to receiving reports of, and in some cases gaining access to, strandings. The availability of trained participants to respond to stranding reports has also been vital to the collection of irreplaceable data and samples.

Conclusions

Marine mammal strandings in NC from 1997 to 2008 reflected the rich biodiversity occurring in waters off this unique location, where ‘northern' and ‘southern' species as well as coastal and pelagic species intersect. Therefore the spatial and temporal patterns detected from strandings can provide clues to the presence of living animals occurring off the NC coast. In some cases, those patterns reflect what is known from published records of aerial and shipboard surveys. For other species, little is known and stranding data serve as a proxy for live animal distribution. In addition, the detection of HI, particularly FI, provides crucial information on the spatiotemporal patterns and relative mortality levels from these interactions with marine mammals which are otherwise difficult to obtain *in situ* (Friedlaender et al., 2001; Byrd et al., 2008). Moreover, changes in stranding patterns can serve as indicators of underlying change in source populations due to anthropogenic or naturally occurring events.

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