Abstract—The U.S. Marine Mammal Protection Act requires that the abundance of marine mammals in U.S. waters be assessed. Because this requirement had not been met for a large portion of the North Atlantic Ocean (U.S. waters south of Maryland), a ship-based, line-transect survey was conducted with a 68 m research ship between Maryland (38.00°N) and central Florida (28.00°N) from the 10-m isobath to the boundary of the U.S. Exclusive Economic Zone. The study area (573,000 km^2) was surveyed between 8 July and 17 August 1998. Minimum abundance estimates were based on 4163 km of effort and 217 sightings of at least 13 cetacean species and other taxonomic categories. The most commonly sighted species (number of groups) were bottlenose dolphins, *Tursiops truncatus* (38); sperm whales, *Physeter macrocephalus* (29); Atlantic spotted dolphins, *Stenella frontalis* (28); and Risso's dolphins, *Grampus griseus* (22). The most abundant species (abundance; coefficient of variation) were Atlantic spotted dolphins (14,438; 0.63); bottlenose dolphins (13,085; 0.40); pantropical spotted dolphins, *S. attenuata* (12,747; 0.56); striped dolphins, *S. coeruleoalba* (10,225; 0.91); and Risso's dolphins (9533; 0.50). The abundance estimate for the Clymene dolphin, *S. clymene* (6086; 0.93), is the first for the U.S. Atlantic Ocean. Sperm whales were the most abundant large whale (1181; 0.51). Abundances for other species or taxonomic categories ranged from 20 to 5109. There were an estimated 77,139 (0.23) cetaceans in the study area. Bottlenose dolphins and Atlantic spotted dolphins were encountered primarily in continental shelf (<200 m) and continental slope waters (200–2000 m). All other species were generally sighted in oceanic waters (>200 m). The distribution of some species varied north to south. Striped dolphins, Clymene dolphins, and sperm whales were sighted primarily in the northern part of the study area; whereas pantropical spotted dolphins were sighted primarily in the southern portion.

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Abundance of cetaceans in the southern U.S. North Atlantic Ocean during summer 1998

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The U.S. Marine Mammal Protection Act (MMPA) requires that stocks of marine mammal species in U.S. waters be maintained at or above their optimum sustainable population (OSP) level, defined as the number of animals that will result in maximum productivity. The MMPA, as amended in 1994, requires that the U.S. National Marine Fisheries Service (NMFS) determine the potential biological removal (PBR) of each stock for management purposes. PBR is an estimate of the maximum number of animals that may be removed from a stock due to human activities (e.g. fisheries bycatch) while allowing the stock to reach or maintain its OSP. The PBR is calculated by using the estimated minimum abundance of a stock, half its maximum net productivity rate (theoretical; or estimated), and a recovery factor (Barlow et al., 1995).

For the U.S. Exclusive Economic Zone (EEZ) adjacent to the Atlantic coast of the continental U.S., the NMFS currently defines 27 taxa of cetaceans as stocks (Waring et al., 2001). These stocks include 24 one-stock species, bottlenose dolphins (*Tursiops truncatus*) that are divided into two stocks, and one mesoplodont beaked whale stock. Abundance estimates are available for most of these stocks from U.S. waters north of the Virginia-Maryland border (38.00°N). In 1998, except for three stocks, abundance estimates were not available for Atlantic cetacean stocks from U.S. waters south of Maryland (Waring et al., 1997). Abundance estimates for these three stocks were based on a small amount of effort from a 1992 winter ship survey south of Cape Hatteras (Mullin and Ford[1]). Other cetacean abundance estimates from U.S. waters south of Maryland are for portions of the continental shelf or continental slope (Blaylock and Hoggard, 1994; Blaylock, 1995; CeTAP[2]; Fritts et al.[3]).

To estimate the abundance of cetaceans in U.S. Atlantic waters south of Maryland, a ship survey was conducted during summer 1998 and the results are reported in this study. Abundance estimates from this area are combined with abundance estimates from surveys of U.S. waters north of the Virginia-Maryland border conducted by the NMFS Northeast Fisheries Science Center to obtain overall abundance estimates for western North Atlantic cetacean stocks (e.g. Waring et al., 2001).

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[1] Mullin, K. D., and R. Ford. 1992. Report of NOAA ship *Oregon II* cruise 92-01 (198) (a cetacean survey of U.S. Atlantic waters south of Cape Hatteras, winter 1992). Southeast Fisheries Science Center, P.O. Drawer 1207, Pascagoula, Mississippi 39568.

[2] 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 of the Cetacean and Turtle Assessment Program Bureau of Land Management, contract no. AA551-CT8-48, 450 p. U.S. Dep. Interior, Washington D.C.

[3] Fritts, T. H., A. B. Irvine, R. D. Jennings, L. A. Collum, W. Hoffman, and M. A. McGehee. 1983. Turtles, birds, and mammals in the northern Gulf of Mexico and nearby Atlantic waters. Rep. FWS/OBS-82/65, 455 p. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C.

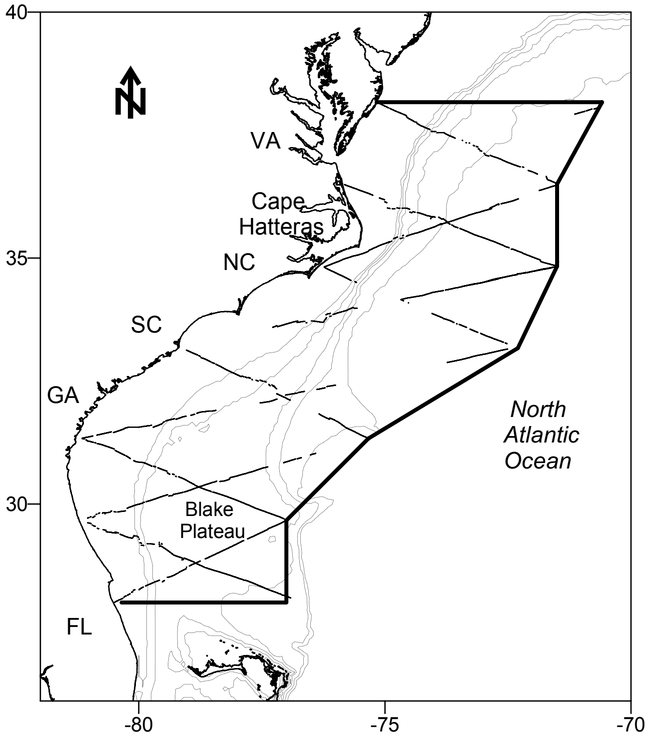

Figure 1

Survey effort (4163 km; thin lines) in Beaufort sea state ≤4 in the southern U.S. Atlantic study area (outlined by thick line) during summer 1998. Blank areas indicate Beaufort sea states >4 that were not included in the survey effort. The 200-, 500-, 1000-, 2000-, and 3000-m isobaths are shown.

Methods

Study area and survey design

The study area (573,000 km^2) was North Atlantic Ocean waters between central Florida (28.00°N) and Maryland (38.00°N) from the 10-m isobath to the boundary of the U.S. EEZ, generally 371 km (200 nmi) from the nearest U.S. point of land (Fig. 1). The study area has a diverse bottom topography and includes a very narrow continental shelf (<200 m) at Cape Hatteras which broadens to form the mid-Atlantic Bight to the north and the Florida-Hatteras Shelf to the south. Beyond the shelf, south of Cape Hatteras are found the following features: the Florida-Hatteras Slope, the Blake Plateau (700–1000 m deep), and the Blake Escarpment. North of the Blake Plateau, the continental slope from 200–2000 m deep is steep and most of the study area has water depths >2000 m. The Gulf Stream is the dominant oceanographic feature in the study area. From the south, the Gulf Stream Front generally follows the upper continental slope northward to Cape Hatteras, where it flows to the northeast. Seaward of the Gulf Stream are Sargasso Sea waters. North of Cape Hatteras and the Gulf Stream Front, cooler waters, which largely originate in the Labrador Sea, drift into the study area from the north and northeast.

Transects covered the study area uniformly in a sawtooth pattern from a random start at the southernmost inshore point and were surveyed from the 68-m NOAA ship *Relentless* (renamed *Gordon Gunter* in 1999) between 8 July and 17 August 1998 from south to north, and from north to south. Transects were placed to cross the bathymetry gradient. The narrow band of U.S. waters between central Florida and Key West, Florida, were partially surveyed but were not included in the present report.

Data collection

Data were collected by two teams of three observers from the ship's flying bridge, located 14.5 m above the surface of the water, during daylight hours, weather permitting (i.e. no rain, Beaufort sea state <6). Observers used standard line-transect survey methods for cetaceans that were similar to those used from ships in the Pacific Ocean and Gulf of Mexico (e.g., Barlow, 1995; Hansen et al.[4]). Each team had at least two members experienced in shipboard line-transect methods and in the identification of tropical and temperate cetaceans. Two observers searched for cetaceans using 25× binoculars and another observer searched using unaided eye or 7× hand-held binoculars and recorded data. These three observers constituted the "primary team." From 18 July to 17 August, a fourth observer was added to one team to act as a conditionally independent observer (CIO, see below). The area from 90° left and right of the ship's bow to the horizon was searched by the primary team. Observers changed position (including the CIO position) every 30–40 minutes, and each team alternated two-hour watches throughout daylight hours. The survey speed was usually 18 km/h but varied with sea conditions.

Data were recorded on a computer interfaced with a global positioning system (GPS) by a data acquisition program. Data collected for each cetacean sighting included time, position, bearing, and reticle (a measure of radial distance) of the sighting, species, group-size, behavior, bottom depth, sea surface temperature, and associated animals (e.g. seabirds, fish). The bearing and radial distance for sightings that were close to the ship were estimated. Survey effort data were automatically recorded every two minutes and included position, heading, effort status, observer position, and environmental conditions that could affect the observers' ability to sight animals (e.g. Beaufort sea state, position of the sun).

Typically, if a sighting was within a 5.5-km strip on either side of the ship, the ship was diverted from the transect line and approached the group so that observers could identify species and obtain group-size estimates. For each sighting, the final group-size was estimated by a consensus

[4] Hansen, L. J., K. D. Mullin, T. A. Jefferson, and G. P. Scott. 1996. Visual surveys aboard ships and aircraft. *In* Distribution and abundance of marine mammals in the north-central and western Gulf of Mexico: final report; vol. II: technical report (R.W. Davis and G. S. Fargion, eds.), p. 55–132. Outer Continental Shelf (OCS) Study MMS 96-0027. U.S. Dep. Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, LA.

Table 1

Number of on-effort cetacean group sightings of each species or other taxonomic category during 4163 km of survey effort in the southern U.S. Atlantic study area during summer 1998. Species are listed in categories pooled to estimate *f*(0) (see Table 2). The number of sightings used for line-transect and strip-transect abundance estimates are indicated for each species.

f(0) groupings and species	Line-transect	Strip-transect
Large whales		
Fin whale (*Balaenoptera physalus*)	1	0
Minke whale (*B. acutorostrata*)	1	0
Sperm whale (*Physeter macrocephalus*)	29	0
Unidentified large whale	6	0
Cryptic whales		
Dwarf and pygmy sperm whale (*Kogia* spp.)	9	0
Mesoplodon spp.	4	0
Unidentified Ziphiidae	3	0
Unidentified small whale	4	0
Unidentified odontocete	12	0
Small whales and large dolphins		
Pilot whale (*Globicephala* spp.)	10	0
Bottlenose dolphin (*Tursiops truncatus*)	35	3
Risso's dolphin (*Grampus griseus*)	22	0
"Coastal" Atlantic spotted dolphin (*Stenella frontalis*)	24	3
Unidentified *T. truncatus* or *S. frontalis*	7	1
Rough-toothed dolphin (*Steno bredanensis*)	1	0
Small dolphins		
Pantropical spotted dolphin (*Stenella attenuata*)	6	0
Striped dolphin (*Stenella coeruleoalba*)	5	0
Clymene dolphin (*Stenella clymene*)	2	1
"Offshore" Atlantic spotted dolphin (*Stenella frontalis*)	1	0
Unidentified dolphins		
Unidentified dolphins	26	0
Stenella spp.	1	0
Total	209	8

of the primary team. Mixed-species groups were uncommon (five of 217 sightings) and group-size estimates were made separately for each species.

Species identification

Cetaceans were identified to the lowest taxonomic level possible from descriptions in field guides and scientific literature (e.g. Leatherwood and Reeves, 1983; Jefferson et al., 1993; Carwardine, 1995) (Table 1). An observer's ability to make identifications depended on weather and animal behavior. The study area was potentially inhabited by short-finned pilot whales (*Globicephala macrorhynchus*), which are thought to occur within the study area from about Virginia south, and long-finned pilot whales (*G. melas*), thought to occur from near Cape Hatteras north (Payne and Heinemann, 1993). Because the two species cannot be reliably distinguished at sea, they were recorded simply as pilot whales. Two forms of the Atlantic spotted dolphin (*Stenella frontalis*) were tentatively identified: the larger, more coastal form, and the smaller offshore form (Perrin et al., 1994). Abundances were estimated for each form and for all Atlantic spotted dolphins combined because only one stock is currently designated for U.S. Atlantic waters. Coastal and offshore forms of bottlenose dolphins (Hersh and Duffield, 1990), which constitute the two stocks, were recorded, but most sightings could not be clearly categorized; therefore, all bottlenose dolphin sightings were pooled for one overall abundance estimate. Bottlenose and Atlantic spotted dolphins could not always be distinguished at large distances and a separate estimate was made for animals that could not be approached and were identified as "*Tursiops* or *S. frontalis*." Overall abundances for the genus *Kogia* and the genus *Mesoplodon* were estimated. Dwarf sperm whales (*K. sima*) and pygmy sperm whales (*K. breviceps*) were difficult to distinguish and stranding records of both species are numerous from U.S. Atlantic shores (Schmidly[5]). Based on

[5] Schmidly, D. J. 1981. Marine mammals of the southeastern United States and the Gulf of Mexico. U.S. Dep. Interior, U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-80/41, 165 p.

Table 2

Estimate of $f(0)$ for each species group (see Table 1). n = number of sightings used for the estimate of $f(0)$ before truncation (included in n is the number of sightings in parentheses that occurred while the ship was in transit in or near the study area). Truncation = the perpendicular distance, y, at which groups with a greater y were excluded from the analysis. ESW = effective strip width.

Species group	n	$f(0)$ (/km)	CV [$f(0)$]	Truncation (m)	ESW (m)
Large whales	38 (1)	0.300	0.12	5500	6666
Cryptic whales	33 (1)	0.561	0.13	3000	3565
Small whales and large dolphins	121 (22)	0.498	0.10	4000	4016
Small dolphins	20 (6)	0.398	0.11	4500	5025
Unidentified dolphin	27 (0)	0.496	0.10	4000	4032
Total	239 (30)				

stranding records of mesoplodont whales from U.S. Atlantic shores, sightings of *Mesoplodon* were probably True's (*M. mirus*), Gervais's (*M. europaeus*) or Blainville's (*M. densirostris*) beaked whales (Mead, 1989). In some cases cetaceans could only be identified as large whales (>7 m long), small whales (nondolphin, <7 m), dolphins, or odontocetes.

Analytical techniques

For each species or taxonomic category, abundance estimates (N) were made with line-transect methods by using the software program DISTANCE (Colorado Coop. Fish and Wildlife Research Unit, Colorado State Univ., Fort Collins, CO) (Buckland et al., 1993) with the equation

$$N = \frac{A\, n\, S\, f(0)}{2\, L\, g(0)},$$

where A = size of the study area;
n = number of on-effort group sightings;
S = mean group-size estimate;
$f(0)$ = sighting probability density function at perpendicular distance zero;
L = total length of transect line; and
$g(0)$ = probability of seeing a group on the transect line.

The log-normal 95% confidence interval was computed for each abundance estimate because it was a product of estimates and tends to have a skewed distribution. The variance of N was estimated as

$$\mathrm{var}(N) = N^2\left[\frac{\mathrm{var}(n)}{n^2} + \frac{\mathrm{var}(S)}{S^2} + \frac{\mathrm{var}[f(0)]}{f(0)^2} + \frac{\mathrm{var}[g(0)]}{f(0)^2}\right]$$

and the coefficient of variation (CV) was estimated as

$$CV(N) = \frac{\sqrt{\mathrm{var}(N)}}{N}.$$

The sampling unit was the length of the transect completed on-effort each day when the Beaufort sea state was <5. The formula used to estimate each component of the variance is given in Buckland et al. (1993). Var(n) was length-weighted and based on the variation in the number of on-effort group sightings between sampling units that ranged in length from 39 to 229 km/day.

Estimation of *f*(0)

The perpendicular distance, y, was estimated by using bearing and reticle measurements. The reticle readings were converted to radial sighting distances (R) by the method of Lerczak and Hobbs (1998), and the formula $y = R \sin(b)$, where b = angle between the sighting and the transect line. Estimates of $f(0)$ were made by using a hazard-rate, uniform, or half-normal model with exact perpendicular sighting distances. For each species group, outlying values of y were truncated to improve the fit of the model (Table 2). Model selection was determined by using Akaike's information criterion (AIC; Buckland et al., 1993).

The number of groups sighted of most species was insufficient to obtain an estimate of $f(0)$. Therefore, sightings of species with similar sighting characteristics (i.e. body size, group-size, surface behavior, blow visibility) were pooled to estimate $f(0)$ for five categories (Table 1). The abundance for each species was estimated by using the pooled $f(0)$ and var[$f(0)$] for its category. The var[$f(0)$] was assumed to be zero for the strip-transect estimates explained below. If the individual detection functions of all species within a category are indeed very similar, by pooling, the variance, *CV,* and confidence interval of each abundance estimate was probably underestimated because the variance of $f(0)$ was based on an artificially high sample size. On the other hand, if the true detection functions of the species within a category are highly variable, the variance of $f(0)$ for an individual species may be overestimated.

During the study, effort was sometimes maintained while in transit to and from ports or along the border of the study area, but it usually occurred in a small range of water depths (e.g. parallel to shore) and was excluded because it could have biased abundance estimates. However, due to the small number of sightings for the survey, y from the "transit" sightings were pooled with the on-effort sightings for estimates of $f(0)$ (Table 2).

Estimation of mean group-size

The group-sizes for most species tended to be related to y, because in many cases larger groups are easier to see than small groups with increasing y. In general, the arithmetic mean of group-size may be an overestimate of the true mean group-size and could lead to positively biased abundance estimates. Therefore, a regression of group-size by y was used to estimate an "expected mean group-size" (program DISTANCE). The expected mean group-size was used in the abundance estimate if it was smaller than the arithmetic mean group-size. For estimates based on a small number of sightings, the expected mean group-size was sometimes greater than the arithmetic mean. Because group-size estimates were usually made after the ship approached the group, this was assumed to be an artifact of the small sample size, and the arithmetic mean was used in these cases. Var(S) was the analytical variance for mean group-sizes based on arithmetic means or was estimated as in Buckland et al. (1993:79) for expected mean group-sizes.

Strip-transect estimates

One requirement for unbiased line-transect estimates of abundance is that the cetacean group should not move in response to the ship before it is sighted (Buckland et al., 1993). If cetaceans are not sighted before they respond to the ship, in cases of attraction to the ship, $f(0)$ and abundance will be overestimated. In the Gulf of Mexico, five species appear to be consistently attracted to ships to ride the bow waves (i.e. bottlenose, Atlantic spotted, spinner [*S. longirostris*], Clymene [*S. clymene*], and pantropical spotted dolphins [*S. attenuata*]) (Würsig et al., 1998). All sightings made with 25× binoculars had radial distances >665 m and were assumed to be made before these species were attracted to the ship. If sightings of these species were made at radial distances <665 m, because of the possibility of attraction, they were not included in the line-transect abundance estimate, and a separate strip-transect abundance estimate was made with these sightings. For each species, the width of the strip for strip-transect estimates was set at the line-transect strip width ($1/2f(0)$) for that species (Tables 1 and 2). This procedure yields the same result as the formula given above with $f(0)$ for the species-group category. However, $f(0)$ for small dolphins and for small whales and large dolphins combined was not positively biased by including sightings of groups that were probably attracted to the transect line. For each species, the line- and strip-transect estimates were summed for one overall abundance estimate.

Conditionally independent observer

The central assumption for estimating abundance with line-transect methods is that cetacean groups on the transect line are detected with certainty (i.e. $g(0) = 1$; Buckland et al., 1993). However, this assumption is usually not met during cetacean surveys because of availability and perception bias (i.e. $g(0) < 1$) (Marsh and Sinclair, 1989). Some groups on the transect line are missed because they may not be at the surface during the time the ship is in the area and are not available to be seen, whereas other groups at the surface are missed by observers (i.e. not perceived) because of factors such as observer experience, sea state, and animal behavior, among others.

An attempt was made to estimate $g(0)$ due to perception bias with a conditionally independent observer (CIO) by using methods based on Barlow (1995). The CIO was used when the 4-observer team was on duty and was stationed at 25× binoculars located on a bridge-wing 2.7 m below the primary team. One individual switched teams each day; therefore all seven observers on the ship acted as the CIO at different times. The CIO searched for cetaceans near the transect line (from 30° left to 30° right of the bow) when the primary observers were on-effort. The CIO and the primary team could not see or hear each other. Whenever the primary team made a sighting, the data recorder relayed its bearing and reticle to the CIO. When the CIO made a sighting, the time, bearing and reticle were noted by the CIO, and the sighting was monitored until it was sighted by the primary team or, theoretically, passed abeam, at which time the CIO was to notify the primary team to divert the ship to identify the species and estimate group-size.

Results

Abundance estimates were based on 4163 km of effort in Beaufort sea states ≤4 and 217 on-effort sightings of cetacean species or other taxonomic categories (Fig. 1 and Table 1). At least 13 cetacean species were sighted. The most commonly sighted species (number of sightings) were bottlenose dolphins (38), sperm whales (*Physeter macrocephalus*) (29), Atlantic spotted dolphins (28), and Risso's dolphins (*Grampus griseus*) (22). Thirty sightings occurred during transit in Beaufort sea states ≤4 (861 km) and were used to estimate $f(0)$. Estimates of $f(0)$ ranged from 0.300/km for large whales to 0.561/km for cryptic whales (Table 2).

Conditionally independent observer

The CIO achieved 1775 km of effort (35% of effort, including transit, with Beaufort sea state ≤4) and sighted 21 cetacean groups. Of these, six groups ranging in size from 1 to 10 animals were missed by the primary team and included three unidentified dolphin groups, two unidentified odontocete groups, and one *Mesoplodon* sp. Each of these sightings was observed briefly by the CIO but could not be tracked until they passed the beam of the ship; however, in each of the six cases no sightings were made by the primary team during the time frame it would have been possible to sight them. To estimate $g(0)$ following the analytical methods described by Barlow (1995), a separate estimate of $f(0)$ is therefore required for CIO sightings missed by the primary team. Because there were only six of these, $g(0)$ could not be estimated for any $f(0)$ category, and $g(0) = 1$ and var[$g(0)$] = 0 was used in each abundance estimate.

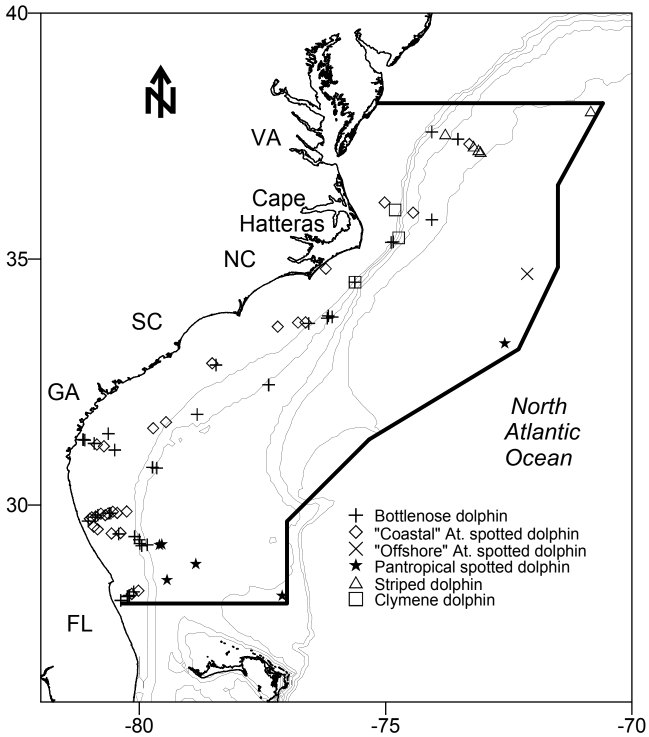

Figure 2

Locations of on-effort sightings of bottlenose dolphins (n=38), "coastal" (n=27) and "offshore" (n=1) Atlantic spotted dolphins, pantropical spotted dolphins (n=6), striped dolphins (n=5), and Clymene dolphins (n=2). The 200-, 500-, 1000-, 2000-, and 3000-m isobaths are shown.

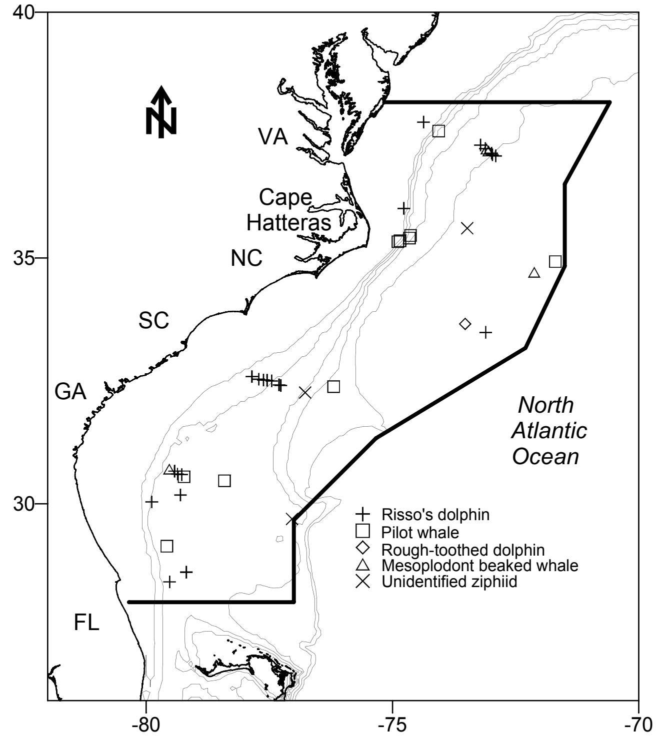

Figure 3

Locations of on-effort sightings of Risso's dolphins (n=22), pilot whales (n=10), rough-toothed dolphins (n=1), *Mesoplodon* spp.(n=4), and unidentified beaked whales (n=3). The 200-, 500-, 1000-, 2000-, and 3000-m isobaths are shown.

Abundance

The following were the most abundant species (abundance; coefficient of variation) observed in our study: Atlantic spotted dolphins (14,438; 0.63); bottlenose dolphins (13,085; 0.40); pantropical spotted dolphins (12,747; 0.56); and striped dolphins (*S. coeruleoalba*) (10,225; 0.91); and Risso's dolphins (9533; 0.50). Sperm whales were the most abundant large whale (1181; 0.51). Abundances for other species or taxonomic categories ranged from 20 to 6086. There were an estimated 77,139 (0.23) cetaceans in the study area.

Group sizes

Mean group sizes for balaenopterids, physeterids, and ziphiids were less than three animals per group. Bottlenose dolphins, pilot whales, Risso's dolphins, and "coastal" Atlantic spotted dolphins were in groups that averaged 12–18 animals. The average group sizes of pantropical spotted, Clymene, and striped dolphins ranged from 75 to 110 individuals (Table 3).

Distribution

Cetaceans were distributed throughout the study area, but few sightings occurred on the eastern Blake Plateau (Fig. 1). The distribution of species varied regionally and by water depth (Fig. 2–4, Table 4). Bottlenose dolphins and "coastal" Atlantic spotted dolphins were sighted throughout the study area but primarily in or near continental shelf waters. Pilot whales and Risso's dolphins were widely distributed seaward of the continental shelf. Sperm whales, unidentified large whales, "offshore" Atlantic spotted dolphins, striped dolphins, and Clymene dolphins occurred almost exclusively in oceanic waters (>200 m) from Cape Hatteras northward. Most pantropical spotted dolphin sightings were in the southern part of the study area.

Discussion

Abundance

Cetacean abundances for the entire study area have not been estimated previously. Based on stranding records and previous surveys within or near the study area, all the species encountered were expected to be sighted. Previous abundance estimates for the western North Atlantic stocks of short-finned pilot whales and of dwarf and pygmy sperm whales, 749 (0.64) and 420 (0.60), respectively, were based on a winter 1992 ship survey in U.S. oceanic waters (>200 m) south of Cape Hatteras (Waring et al., 1997). The 1992 dwarf and pygmy sperm whale estimate is similar to our estimate (580; 0.57); although the 1998 study area was

Table 3

Group size, density and abundance estimates of cetaceans in the southern U.S. Atlantic Ocean during summer 1998 (n = number of on-effort group sightings after truncation, S = mean group-size estimate, D = animals/100 km^2, N = abundance estimate, CV = coefficient of variation, LCI and UCI = lower and upper limits of a log-normal 95% confidence interval).

Species	n	S	CV(S)	D	N	CV(N)	LCI	UCI
Fin whale	1	2.0	—	0.007	41	1.15	6	270
Minke whale	1	1.0	—	0.004	20	1.29	3	156
Sperm whale	28	2.1	0.12	0.206	1181	0.51	445	3136
Dwarf/pygmy sperm whale	8	1.9	0.16	0.101	580	0.57	197	1708
Mesoplodon spp.	4	2.3	0.28	0.061	348	0.76	88	1376
Unidentified Ziphiidae	3	1.7	0.40	0.034	193	0.71	49	755
Pilot whale	9	16.6	0.19	0.892	5109	0.41	2302	11,341
Bottlenose dolphin								
line-transect	31	11.8	0.29	2.194	12,571	0.42	5600	28,222
strip-transect	3	5.0	0.12	0.090	514	0.82	118	2249
sum				2.284	13,085	0.40	6098	28,077
Risso's dolphin	18	15.4	0.26	1.664	9533	0.50	3684	24,671
Atlantic spotted dolphin								
"coastal"								
line-transect	21	17.6	0.25	2.211	12,670	0.71	3471	46,244
strip-transect	3	7.3	0.39	0.132	754	0.64	211	2696
sum				2.343				
"offshore"								
line-transect	1	37.0	—	0.177	1014	0.85	223	4618
strip-transect	0							
sum (coastal and offshore)				2.520	14,438	0.63	4672	44,618
Unid. *T. truncatus* or *S. frontalis*								
line-transect	7	3.9	0.27	0.162	926	0.73	246	3480
strip-transect	1	1.0	—	0.006	34	0.99	6	189
sum				0.168	960	0.71	276	3334
Rough-toothed dolphin	1	8.0	—	0.048	274	1.03	47	1584
Pantropical spotted dolphin	6	77.5	0.25	2.225	12,747	0.56	4420	36,763
Striped dolphin	5	74.6	0.21	1.785	10,225	0.91	2072	50,449
Clymene dolphin								
line-transect	2	110.0	0.37	1.053	6031	0.94	1138	31,963
strip-transect	1	2.0	—	0.010	55	1.15	8	361
sum				1.063	6086	0.93	1293	28,652
Stenella spp.	1	15.0	—	0.089	512	1.15	77	3392
Unidentified large whale	6	1.2	0.14	0.025	143	0.58	48	426
Unidentified small whale	3	2.7	0.63	0.054	309	0.86	53	1796
Unidentified odontocete	11	1.4	0.14	0.101	580	0.36	284	1181
Unidentified dolphin	20	1.2	0.13	0.113	775	0.51	291	2066
Sum (all cetaceans)				13.462	77,139	0.23	49,649	119,850

much larger and many sightings occurred north of Cape Hatteras (Fig.4).

Abundances have also been estimated for small portions of the study area, but direct comparisons to our estimates are difficult. Seasonal abundances were estimated for about 26 cetacean species or genera encountered in U.S. continental shelf and slope waters between Cape Hatteras and Canada during aerial surveys conducted from 1978 to 1982 (CeTAP[2]), including at least 11 species or genera sighted during our survey. Fritts et al.[3] sighted 12 cetacean species during seasonal aerial surveys of the continental shelf and southern Blake Plateau off central

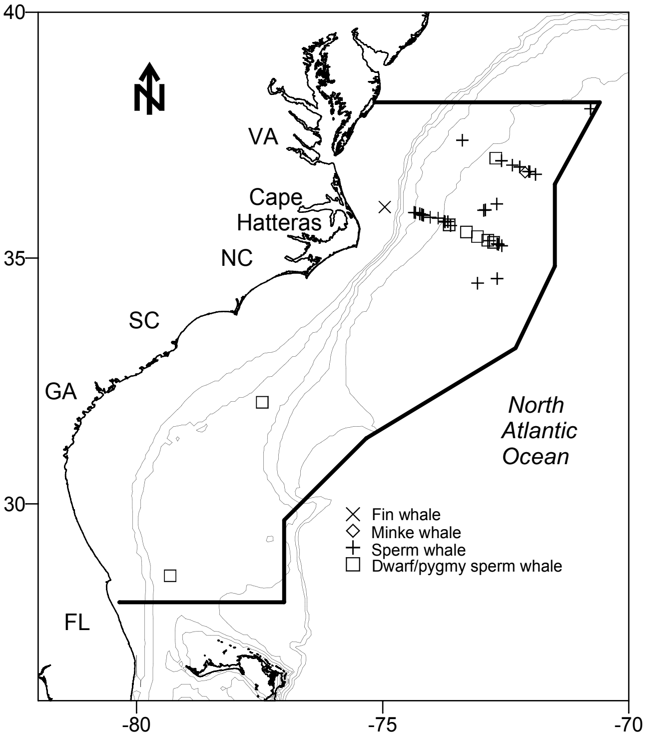

Figure 4

Locations of on-effort sightings of sperm whales (n=29), minke whales (n=1), fin whales (n=1), and dwarf and pygmy sperm whales (n=9). The 200-, 500-, 1000-, 2000-, and 3000-m isobaths are shown.

Florida from 1980 to 1981; eight of these were sighted during our survey.

The abundance estimate reported in the present study for the Clymene dolphin represents the first for this species in any portion of the U.S. Atlantic EEZ. However, the estimate was based on only three sightings and has a large 95% confidence interval (1293–28,652 dolphins). The Clymene dolphin was recognized as a valid species in 1981 and is sympatric with the spinner dolphin in the tropical Atlantic (Perrin et al., 1981). The two species have similar color patterns, and in previous studies both were possibly recognized as *S. longirostris* and were not distinguished (CeTAP[2]; Fritts et al.[3]). The identifications of Clymene dolphins were made by observers with experience from the Gulf of Mexico where both species are relatively common (Hansen et al.[4]; Hansen et al.[6]). There is currently no stock designation for the Clymene dolphin in U.S. Atlantic waters (Waring et al., 2001).

Our estimate of bottlenose dolphins is for waters >10 m in depth; however, this estimate does not include their entire water depth range in U.S. Atlantic waters south of Maryland. Bottlenose dolphins occur year-round in coastal waters <10 m in depth (the inshore boundary of the study area) and in some bays and estuaries from Cape Hatteras south. North of the Cape they have been found close to shore in waters <25 m in depth only during warm months

[6] Hansen, L. J., K. D. Mullin, and C. L. Roden. 1995. Estimates of cetacean abundance in the northern Gulf of Mexico from vessel surveys, 9 p. Southeast Fisheries Science Center, P.O. Drawer 1207, Pascagoula, Mississippi 39568.

Table 4

Mean water depth and sea surface temperature of cetacean species sighted in the southern U.S. Atlantic Ocean during summer 1998 (n=number of groups sighted on–effort; SE = standard error).

		Water depth (m)			Sea surface temperature (°C)		
Species	n	Mean	SE	Range	Mean	SE	Range
Fin whale	1	48	—	—	25.1	—	—
Minke whale	1	3475	—	—	29.5	—	—
Sperm whale	29	3252	122	2195–4389	29.0	0.28	22.8–29.9
Dwarf and pygmy sperm whale	9	2586	493	766–4079	29.6	0.37	26.9–30.9
Mesoplodon spp.	4	2699	735	774–4353	27.2	1.65	24.0–31.1
Unidentified Ziphiidae	3	1817	832	878–3475	29.8	0.15	29.6–30.1
Pilot whale	10	1527	387	251–4280	28.5	0.73	23.2–31.5
Bottlenose dolphin	38	371	89	12–2561	29.3	0.27	23.2–31.3
Risso's dolphin	22	1300	285	44–4755	28.4	0.62	22.9–31.3
"coastal" Atlantic spotted dolphin	27	216	117	13–2524	29.1	0.26	25.1–31.3
"offshore" Atlantic spotted dolphin	1	4298	—	—	27.9	—	—
Rough-toothed dolphin	1	4353	—	—	27.3	—	—
Pantropical spotted dolphin	6	1498	708	598–5030	30.5	0.61	27.6–31.6
Striped dolphin	5	2736	237	2012–3475	23.9	0.37	22.9–25.1
Clymene dolphin	3	756	538	139–1829	27.9	0.59	26.8–28.8

and are assumed to have migrated along-shore from the south (Mead, 1975; Kenney, 1990). Aerial surveys of bottlenose dolphins conducted in the past along the U.S. Atlantic included waters from the shore to 10 m in depth. For waters typically <75 m deep south of Cape Hatteras, the winter 1992 abundance from an aerial survey was 12,435 (0.18) (Blaylock and Hoggard, 1994). For waters <25 m deep from Cape Hatteras to northern New Jersey, the abundance from a summer 1994 aerial survey was 26,809 (0.40) (Blaylock, 1995). The frequency of bottlenose dolphin sightings during these surveys increased substantially inshore of the 10-m isobath boundary of the ship study area and, compared with the estimate from the ship, may account for the generally larger aerial survey estimates even though they are for smaller study areas.

There are currently two genetically distinguishable bottlenose dolphin stocks designated in the U.S. Atlantic: the coastal stock and the offshore stock (LeDuc and Curry, 1998; Waring et al., 2001). Using mitochondrial DNA from skin biopsy samples obtained during the summer 1998 study and other sampling efforts, Torres et al. (in press) reported no offshore form was sampled within 6 km of shore and no coastal from was sampled beyond 39 km from shore or in waters >34 m deep. Therefore an area of overlap of the two forms occurs within the 1998 study area but the fraction of each stock in our estimate (13,085; 0.40) is unknown because the number of biopsy samples between the two boundaries was very small in the Torres et al. (in press) study. However, 20 of the 38 bottlenose groups we used to estimate abundance were found in waters >50 m deep.

Abundances were estimated for ten species and three other genera of cetaceans, but other species are known or expected to occur in the study area. Three of these species, right whales (*Eubalaena glacialis*), humpback whales (*Megaptera novaeangliae*), and harbor porpoises (*Phocoena phocoena*), occur in the study area seasonally, primarily in months other than summer months, and abundances have been estimated from studies of their primary summer ranges north of the study area (e.g. Knowlton et al., 1994; Palka, 1995; Smith et al., 1999).

Additional species expected in at least part of the study area include Bryde's whale (*B. edeni*), Cuvier's beaked whale (*Ziphius cavirostris*), pygmy killer whale (*Feresa attenuata*), false killer whale (*Pseudorca crassidens*), melon-headed whale (*Peponocephala electra*), killer whale (*Orcinus orca*), common dolphin (*Delphinus delphis*), spinner dolphin, and Fraser's dolphin (*Lagenodelphis hosei*). Each of these species is thought to have a tropical to subtropical or broader distribution worldwide (Jefferson et al., 1993), and except for the common dolphin, an abundance estimate for each species is available for the adjacent northern Gulf of Mexico (Hansen et al.[6]). However, except for the spinner dolphin, each of these species is relatively uncommon in the northern Gulf of Mexico and was not encountered every year during four annual spring surveys with effort similar to that in our survey (Hansen et al.[6]). Therefore, many of these species may also be uncommon in the Atlantic study area and were simply not encountered during the 1998 survey. During a late summer 1999 ship survey of the inner half of the southern Atlantic study area that targeted bottlenose dolphins, a group of Fraser's dolphins and melon-headed whales was sighted in water 3000 m deep east of Cape Hatteras (Roden[7]).

Some species may also inhabit the study area seasonally. During the 1992 winter ship survey south of Cape Hatteras (Mullin and Ford[1]), five groups of balaenopterid whales were recorded, three of which were classified as unidentified Bryde's or sei whales. Also during the winter 1992 survey, groups of false killer whales and Cuvier's beaked whales were sighted twice, and pygmy killer whales once. Common dolphins were sighted between Cape Hatteras and Maryland in all seasons, except summer, during the CeTAP[2] study but were sighted once in this area during the late summer 1999 survey (Roden[7]). Common dolphins are expected to occur throughout the area surveyed in 1998 but they may not. Although there are stranding records south of Cape Hatteras (Schmidly[5]), there are no valid stranding or sighting records of common dolphins in the adjacent Gulf of Mexico despite extensive seasonal surveys of the northern Gulf (Jefferson, 1995; Hansen et al.[4]).

Precision

The precision of the abundance estimates was generally poor. For species or genera abundances, only the estimate for bottlenose dolphins (the most commonly sighted species), Risso's dolphins, and pilot whales had a CV ≤ 0.50 (Table 3). The abundance estimate for the Atlantic spotted dolphin, the most abundant species, had a CV = 0.63. In cases where there is human-caused mortality in a cetacean stock, abundance estimates with a CV < 0.50 are generally required to avoid incorrectly classifying a cetacean stock as "strategic" under the U.S. MMPA (i.e. annual human-caused mortality > annual PBR) less than 10% of the time (Wade and DeMaster, 1999). For most species, the variance in the encounter rate, var(n), accounted for more than 70% of the var(N). The distribution of most species was not uniform in the study area and precision might be improved by stratifying estimates by water depth (e.g. shelf and nonshelf) and by area (e.g. north and south of Cape Hatteras).

Biases in abundance estimates

The survey was designed to meet the assumptions of line-transect theory (Buckland et al., 1993). However, the abundance estimates are negatively biased to varying degrees because the central assumption, that cetacean groups on the transect line are detected with certainty (i.e. $g(0)=1$), was not met, and data were not available to correct estimates for perception and availability bias. By using the CIO methods described by Barlow (1995), we attempted to estimate the fraction of groups missed on the transect line by the primary observers due to perception bias. How-

[7] Roden, C. L. 1999. Report of NOAA ship *Oregon II* cruise 99-05 (236) (a cetacean survey of U.S. Atlantic continental shelf and slope waters between New Jersey and central Florida, August–September 1999), 32 p. Southeast Fisheries Science Center, P.O. Drawer 1207, Pascagoula, Mississippi 39568.

ever, there were too few sightings to make $g(0)$ estimates because the overall group encounter rate was lower than anticipated and the CIO was only used for 35% of the total survey effort. In the future, a CIO should be used whenever the primary team is on-effort and the CIO should search an area larger than 30° left and right of the bow. Although the data in proximity of the transect line are most critical for estimating $g(0)$, it is also necessary to have enough data to estimate $f(0)$ for groups missed by the primary team.

More work is needed to develop methods for estimating $g(0)$ in relation to perception bias in the southern U.S. Atlantic. Completely independent observers cannot be used because the ship has to be diverted from the transect line to identify species and make group-size estimates. Because many groups can easily be lost once sighted, the ship must be diverted well before the group passes abeam. Barlow (1995) used a CIO that searched the same area as the primary team with unaided eye or 7× binoculars. The 25× binoculars were used in our study to increase the number of CIO sightings and avoid attraction bias in $f(0)$. Previous experience in the Gulf of Mexico has indicated that many unaided-eye sightings would be of small groups of species that are attracted to the ship to ride the bow waves. Conversely, small groups are the most difficult for an independent observer to track with 25× binoculars because the ship is not diverted and the bearing to the group is constantly changing.

Similar to Barlow's (1995) findings on perception bias, the majority of groups missed by the primary team were apparently small groups, although the group-sizes were not estimated at close range. Barlow (1995) estimated $g(0)$ ranging from 0.73 and 0.79 for small groups of delphinids (<21) and cryptic species (which usually occur in small groups), and $g(0) = 1$ for groups of >20 delphinids. In addition to group-size, the magnitude of perception bias is dependent on behavior, weather (e.g. Beaufort sea state), and the observer: active groups are less likely to be missed than resting groups or species whose behavior does not produce pronounced cues (e.g. blows, splashes).

Availability bias varies by species because of differences in individual dive cycles, group diving behavior, and group-sizes. Long-diving sperm whales and beaked whales will be at the surface for much less time than will many small delphinids, which have much shorter dive cycles. Diving synchrony among members of a group also affects availability bias; if dives are asynchronous, the probability that at least one animal will be at the surface increases with group size.

Barlow (1999) estimated both availability and perception bias for long-diving whales during ship surveys using 25× binoculars in a simulation study and estimated that for dwarf and pygmy sperm whales, Cuvier's beaked whales, and *Mesoplodon* spp., abundance estimates need to be increased 2 to 4 times (i.e. $g(0)=0.50$ to $g(0)=0.25$) to account for these biases. Barlow's (1999) estimates of $g(0)$ for perception or availability bias (or both) are probably representative of the bias in the southern Atlantic survey because similar ship survey methods were used. However, it may not be valid to apply them directly to our abundance estimates because cetacean diving behavior and group sizes may be temporally and geographically specific, and survey conditions and observers may vary among surveys.

For the strip-transect estimates (Table 2), use of the line-transect strip width [$2\times 1/f(0)$] from the 25× binocular sightings as the strip width was assumed to be conservative and somewhat negatively biased. The distance from which animals will come to the ship to ride the bow is unknown, and variable, depending on factors such as the animals' previous behavior, number of opportunities for riding bow waves, and the type of ship. If the strip width was too narrow, the strip-transect estimates would overestimate abundance.

The geographical bathymetric range of the bottlenose dolphin was not covered during the survey. Because bottlenose dolphins undertake seasonal movements in the study area, in order to estimate the entire population size, ship survey estimates need to be combined with same-season abundance estimates from coastal waters <10 m and inshore waters (bays, sounds, and estuaries).

Distribution

Water-depth distributions of cetacean species were for the most part similar to those in the Gulf of Mexico (Mullin et al., 1994; Davis et al., 1998). Bottlenose dolphins and Atlantic spotted dolphins inhabit the continental shelf and shelf-edge region, whereas most other species have primarily oceanic distributions. The offshore form of the Atlantic spotted dolphin has not been identified in the northern Gulf of Mexico. The sightings of some species were highly regional (e.g. sperm whales, striped dolphins, Clymene dolphins, pantropical spotted dolphins) were probably heavily influenced by oceanographic features such as the Gulf Stream. Much more survey effort is needed in summer and other seasons before conclusions can be drawn about each species' distribution.

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