Abundance and distribution of cetaceans in outer continental shelf waters of the U.S. Gulf of Mexico

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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 results in the maximum net productivity. To meet this requirement for each stock, the U.S. National Marine Fisheries Service (NMFS) estimates annual human-caused mortality and potential biological removal (PBR), 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. PBR is calculated by following specific criteria and using the estimated abundance of the stock, its maximum net productivity rate (theoretical or estimated), and a recovery factor (Barlow et al., 1995; Wade and Angliss, 1997). The NMFS is required to prepare an annual stock assessment report (SAR) for each stock to update abundance, stock structure, maximum net productivity, human-caused mortality, PBR, and status (e.g. Waring et al., 2001).

Cetaceans in the U.S. Gulf of Mexico (U.S. GOM) occur in two species assemblages that overlap in upper continental slope waters (~200–1000 m). The oceanic waters (>200 m) are routinely inhabited by 20 species that, in most cases, inhabit deep warm-temperate to tropical waters throughout the world. Bottlenose dolphins (*Tursiops truncatus*) and Atlantic spotted dolphins (*Stenella frontalis*) are the only two species commonly found in continental shelf waters (<200 m) (Mullin and Hansen, 1999).

In the U.S. GOM the distribution of *T. truncatus* ranges from inshore waters to deep waters of the continental slope (Blaylock and Hoggard, 1994; Hansen et al.[1]; Mullin and Hoggard[2]). In the U.S. GOM, the NMFS divides *T. truncatus* into 38 stocks: 33 inshore stocks (bays, sounds, and estuaries); 3 coastal stocks (western, northern, and eastern) from shore to 9 km seaward of the 18-m (10-fm) isobath; 1 outer continental shelf (OCS) stock from the coastal boundary to 9 km seaward of the 183-m (100-fm) isobath; and 1 continental shelf edge and slope stock from the OCS boundary out to the U.S. Exclusive Economic Zone (EEZ) (Waring et al., 2001). The abundance estimate for the OCS *T. truncatus* stock is 50,247 dolphins (CV=0.18) and is based on aerial surveys conducted during fall which covered all the U.S. GOM shelf waters over 3 years in sections, west, central, and east, in 1992, 1993, and 1994, respectively (Blaylock and Hoggard, 1994; Waring et al., 2001).

One U.S. GOM *S. frontalis* stock is recognized, and the abundance, 3213 dolphins (CV=0.44), is estimated from ship surveys of shelf edge and oceanic waters >100 m deep conducted from 1991–94 (Hansen et al.[1]). Abundance estimates for *S. frontalis* for the U.S. GOM OCS were not made from the 1992–94 aerial surveys although *S. frontalis* groups were sighted (Waring et al., 2001). The majority of *S. frontalis* are thought to inhabit the shelf-edge region. However, data from opportunistic sightings (e.g. Mills and Rademacher, 1996) and a summer 1994 ship survey of the eastern GOM (Hofstetter, 2002) have indicated that they are common throughout eastern GOM shelf waters >10 m deep, and in oceanic waters <500 m.

The NMFS Southeast Fisheries Science Center (SEFSC) conducts annual spring and fall ichthyoplankton surveys in the U.S. GOM. The spring survey targets the entire oceanic portion of the U.S. GOM, and the fall survey focuses on shelf waters from the U.S.-Mexico border to southern Florida. Since 1991, abundance estimates of oceanic cetacean species in the U.S. GOM have been based primarily on data collected during annual spring surveys (Hansen et al.[1]; Mullin and Hoggard[2]; Mullin and Fulling[3]). Because of the lack of current assessment information on and the uncertainty of abundance estimates for *T. truncatus* and *S. frontalis* in OCS waters, cetacean surveys were conducted during the fall ichthyoplankton surveys from 1998 to 2001. From these surveys, we report the abundance and distribution of cetaceans in OCS waters (20–200 m deep) of the U.S. GOM.

[1] Hansen, L. J., K. D. Mullin, and C. L. Roden. 1995. Unpublished report. Estimates of cetacean abundance in the northern Gulf of Mexico from vessel surveys, 20 p. Southeast Fisheries Science Center, 3209 Frederic St., Pascagoula, MS 39567.

[2] Mullin, K. D., and W. Hoggard. 2000. Visual surveys of cetaceans and sea turtles from aircraft and ships. *In* Cetaceans, sea turtles and seabirds in the northern Gulf of Mexico: Distribution, abundance and habitat associations. Volume II: Technical report (R.W. Davis, W. E. Evans, and D. Würsig, eds.), p. 111–172. OCS Study MMS 96-0027. Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 70123.

[3] Mullin, K. D., and G. L. Fulling. 2003. Unpublished report. Abundance of cetaceans in the oceanic northern Gulf of Mexico, 1996–2001, 35 p. Southeast Fisheries Science Center, 3209 Frederic Street, Pascagoula, MS 39567.

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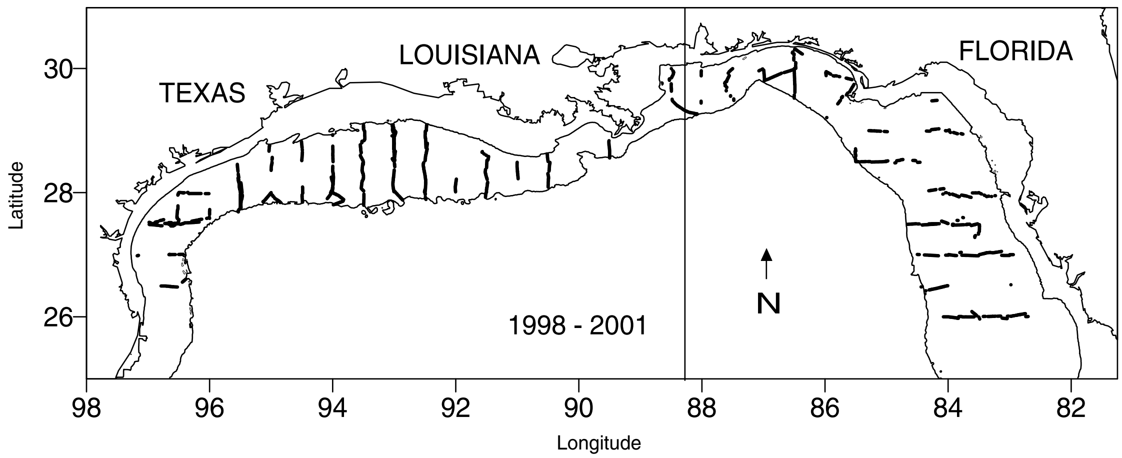

Figure 1

Survey effort in Beaufort sea state of ≤3 (dark lines), east (1342 km) and west (2202 km) of Mobile Bay, Alabama (bold vertical line), in the northern U.S. Gulf of Mexico outer continental shelf (20–200 m) during fall 1998–2001. The 20- and 200-m isobaths (thin lines) are shown.

Methods

Study area

The study area (245,800 km^2) included continental shelf waters of the U.S. GOM between the U.S-Mexico border and Key West, Florida, between the 20- and 200-m isobaths (Fig. 1). However, survey effort did not extend south of 26.0°N in the southeastern GOM and therefore abundance estimates were extrapolated for this region. The shelf is wide (up to 200 km) off the Florida peninsula and off northern Texas and Louisiana, and narrower off the Florida Panhandle near DeSoto Canyon, the Mississippi River Delta, and southern Texas. The continental slope is a steep escarpment from 1000 to 2000 m in the eastern GOM.

Survey design and data collection

Surveys were conducted from the 68-m NOAA Ship *Gordon Gunter* (1998, 1999, and 2001) and the 52-m NOAA Ship *Oregon II* (2000). The four surveys ranged from 28 to 32 days between 28 August and 2 October and were divided into two legs of 12 to 19 days. Standard ship-based, line-transect survey methods for cetaceans, similar to those used in the Pacific Ocean and U.S. GOM, were used (e.g. Barlow, 1995; Hansen et al.[4]). Surveys were conducted 24 hours a day along a predetermined trackline between plankton stations uniformly spaced 30 nmi apart. The trackline uniformly covered the shelf waters roughly 10–200 m deep in 1998–2001 (Fig. 1).

Data were collected by two teams of three observer—one team positioned on the flying bridge 14.5 m above the waterline (*Gunter*) and the other team positioned 9.2 m above the waterline (*Oregon II*) during daylight hours while the vessels moved between plankton stations, weather permitting (i.e. no rain, Beaufort sea state <6). Each team had at least two members experienced in ship-based, line-transect methods and in identification of tropical cetaceans. The left- and right-side observers searched to the horizon in the arc from 10° right and left of the ship's bow to the left and right beams (90°), respectively, using 25× binoculars. The third observer searched, using unaided eye or 7× hand-held binoculars, and recorded data. Observers changed position every 30–40 minutes, and the two teams alternated 2-h watches throughout daylight hours. Survey speed was usually 18 km/h (~10 knots) but varied with sea conditions.

Data were recorded on a computer interfaced with a global positioning system (GPS) by an in-house BASIC data acquisition program (Southeast Fisheries Science Center, NMFS, Pascagoula, MS). For each cetacean sighting, 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) were recorded. The bearing and radial distance for groups sighted without 25× binoculars and close to the ship were estimated. Survey effort data were automatically recorded every 2 minutes and included the ship's position and direction, effort status, observer positions, and environmental conditions that could affect the observers' ability to sight animals (e.g. Beaufort sea state, sun position). Typically, if a sighting was within a 5.5-km strip on either side of the ship, the ship was diverted from the trackline to approach the group to allow the observers to identify species and estimate group-size by consensus.

Cetaceans were identified to the lowest taxonomic level possible. Observers' ability to make identifications depended on weather and animal behavior. Differences between *T. truncatus* and *S. frontalis* could not always be

[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. Volume II: Technical report (R.W. Davis and G.S. Fargion, eds.), p. 55–132. OCS Study MMS 96-0027. Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 70123.

distinguished at long distances and were therefore sometimes recorded as "*T. truncatus* + *S. frontalis*."

Analytical techniques

Survey effort that was parallel to the bathymetry gradients, occurred in waters outside the OCS study area, or occurred in a Beaufort sea state ≥4 was excluded from analyses (Fig. 1). Survey effort used in analyses is summarized in Table 1. Survey effort was not uniformly distributed throughout the study area due to poor survey conditions, particularly in the eastern GOM, during two of the four years. Because *S. frontalis* sightings were clearly more numerous in the east, we delineated the study area into west (106,186 km^2) and east (139,614 km^2) regions at 88°15.0′W (ca. Mobile Bay, Alabama) and estimated abundances separately for each region. A combination of line-transect and strip-transect methods were used to make abundance estimates. Line-transect methods were used for sightings detected with 25(binoculars, which constituted the majority of sightings (129/140). Strip-transect methods were used for the 11 sightings that were made without the 25× binoculars (naked-eye sightings) and that were observed by the primary team.

Line-transect estimates

For each species or species group (i) [i.e. *T. truncatus*, *S. frontalis*, rough-toothed dolphins (*Steno bredanensis*) and *T. truncatus*+*S. frontalis*] detected by 25× binoculars, and for each region (j) (east and west), abundance estimates were made with line-transect methods ($N_{Li,j}$) by using the software program DISTANCE (Colorado Coop. Fish and Wildlife Research Unit, Colorado State Univ., Fort Collins, CO) (Laake et al., 1993; Buckland et al., 2001) and by incorporating data into the following equation:

$$N_{Li,j} = \frac{A_j \cdot n_{Li,j} \cdot S_{Li,j} \cdot f_i(0)}{2 \cdot L_j \cdot g(0)}, \quad (1)$$

where A_j = area of region j;
$n_{Li,j}$ = number of group sightings of species i in region j;
$S_{Li,j}$ = mean group size of species i in region j;
$f_i(0)$ = sighting probability density function at perpendicular distance zero for species i;
L_j = total length of transect line in region j; and
$g(0)$ = probability of seeing a group on the transect line.

The parameter $g(0)$ was not estimated; $g(0) = 1$ was used for each abundance estimate. Abundances were negatively biased because observers usually miss some groups at the surface on the transect line, and some groups were under the surface while in the observation area, therefore $g(0) < 1$ (see "Discussion" section). The log-normal 95% confidence interval was computed (Buckland et al., 2001) for each abundance estimate because it was a product of estimates and tended to have a skewed distribution. The variance of $N_{L\,i,j}$ was estimated by using

$$\mathrm{var}(N_{Li,j}) = N_{Li,j}^2 \left(\frac{\mathrm{var}(n_{Li,j})}{n_{L_{i,j}}^2} + \frac{\mathrm{var}(S_{Li,j})}{S_{L_{i,j}}^2} + \frac{\mathrm{var}\left[f_i(0)\right]}{f_i(0)^2} \right). \quad (2)$$

Table 1

Total survey effort (km) during 1998–2001 in waters 20–200 m and under Beaufort sea state conditions ≤3.

Year	West	East	Total
1998	174	67	241
1999	477	120	597
2000	281	0	281
2001	448	629	1077
Total	1380	816	2196

The sampling unit was the length of the transect completed on-effort each day with Beaufort sea state ≤3 in a region. The formula used to estimate each component of the variance is given in Buckland et al. (2001). Var($n_{L\,i,j}$) was length-weighted and based on the variation in the number of on-effort group sightings between sampling units that ranged up to 191 km/d.

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; $y=R\sin(b)$, where b=angle between the sighting and the transect line). Because of the difference in observer height (5.3 m) between the *Oregon II* and *Gunter*, each ship could potentially yield a different sighting function, *g(x)*. However, only seven sightings were made in sea states ≤3 from the *Oregon II* during the one year it was used; therefore data from both ships were pooled. Estimates of $f_i(0)$ were made by using a hazard-rate, uniform, or half-normal model with exact perpendicular sighting distances and no adjustments. Model selection was determined by using Akaike's Information Criterion (AIC; Buckland et al., 2001).

The number of *S. bredanensis* groups and the number of *T. truncatus*+*S. frontalis* groups sighted was insufficient to estimate $f(0)$ for each. Because the *S. bredanensis* group and *T. truncatus*+*S. frontalis* group had similar sighting characteristics (e.g. body size, group-size, surface behavior), we pooled them with sightings of *T. truncatus* to estimate $f_i(0)$. Total number of sightings for both *T. truncatus* and *S. frontalis* was sufficient to estimate $f_i(0)$ for each without pooling with other species. Truncation for *T. truncatus*, *S. bredanensis*, and *T. truncatus* + *S. frontalis* was 3300 m, and was 5000 m for *S. frontalis*. Each estimate of $f_i(0)$ was based on pooled sightings from the east and west regions.

Estimation of mean group-size

Group-sizes tend 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) and it was used if the regression was significant ($P<0.15$). Var(S_L) was the analytical variance for mean group-sizes based on arithmetic means or was estimated as in Buckland et al. (2001:74) 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., 2001). 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. During previous U.S. GOM surveys, groups of *T. truncatus* or *S. frontalis* were consistently attracted to ride the bow waves as the ship approached (Würsig et al., 1998). Therefore, the abundance and variance of groups sighted by naked eye (N_S) were estimated by

$$N_{Si,j} = \frac{A_j \cdot n_{Si,j} \cdot S_{Si,j}}{2 \cdot L_j \cdot w_i} \quad (3)$$

and

$$\mathrm{var}(N_{Si,j}) = N_{Si,j}^2 \left(\frac{\mathrm{var}(n_{Si,j})}{n_{S_{i,j}}^2} + \frac{\mathrm{var}(S_{Si,j})}{S_{S_{i,j}}^2} \right), \quad (4)$$

where $w_i = 1/f_i(0)$ which was treated as a constant, i.e. strip width, w_i, was equal to the line-transect effective strip half-width $[1/f_i(0)]$ with var(w_i) = 0.

For each region, species total abundance ($N_{T\,i\,,j}$) was the line-transect and strip-transect estimates added, $N_{T\,i\,,j} = N_{L\,i\,,j} + N_{S\,i\,,j}$. Total U.S. GOM OCS abundance for each species was $N_{T\,i} = \Sigma N_{T\,i\,,j}$. The coefficient of variation (CV) for each abundance was estimated as $\mathrm{CV}(N) = [\mathrm{var}(N)]^{1/2} N$ and the CV for each summed abundance as

$$CV(N_{sum}) = \left(\sum CV^2(N) \cdot N^2 \right)^{1/2} \Big/ \sum N. \quad (5)$$

Results

Abundance estimates were based on 2196 km of effort and 140 sightings (Figs. 1 and 2). For east and west regions, there was 816 km of effort and 73 sightings, and 1380 km of effort and 67 sightings, respectively (Tables 1 and 2). Only three cetacean species were encountered. Groups of *T. truncatus* (30 east region, 45 west region) and *S. frontalis* (34 east, 12 west) were the most frequently encountered (Fig. 2, Table 2) and *S. bredanensis* groups (1 east, 2 west) were also sighted. *Tursiops truncatus* and *S. frontalis* were estimated to have $f(0)$ of 0.6238/km (CV=0.12) and 0.4101/km (CV=0.11), and an effective strip half-width of 1603 and 2438 m, respectively (Figs. 3 and 4). *Steno bredanensis* and *T. truncatus+S. frontalis* abundances were based on an $f(0)$ = 0.6059/km (CV=0.11) and an effective strip half-width of 1650 m.

Mean group-sizes (from 25× binocular sightings) of *T. truncatus* for east (9.8, 0.25) and west (10.0, 0.18) regions were similar (Table 2), and had an overall range of 1–68 animals. The mean group size of *S. frontalis* was larger in the east (24.3, 0.19) than the west (15.6, 0.21) with an overall range of 1–267 animals. Group-sizes of *S. bredanensis* were 8, 11, and 20 animals. The east mean group-size for both *T. truncatus* and *S. frontalis* is the size-biased or expected mean group-size because the expected mean was significantly smaller that the arithmetic mean, 10.9 (P=0.14) and 31.9 (P=0.08), respectively.

The most abundant species (number of individuals; CV) found in U.S. GOM OCS waters was *S. frontalis* (30,772; 0.27); the vast majority (91%) occurring in the east (27,997; 0.29). The density of *S. frontalis* was about eight times greater in the east compared to the west (20.1 and 2.6 dolphins/100 km^2, respectively). The abundance of *T. truncatus* was 25,320 (0.26); there was greater abundance in the east (15,198; 0.34) than in the west (10,122; 0.29) but with similar densities (10.9 and 9.5 dolphins/100 km^2, respectively). The total OCS abundance of *S. bredanensis* was 1238 (0.65), and that of *T. truncatus+S. frontalis*, 1868 (0.37).

Discussion

Both *T. truncatus* and *S. frontalis* occur in northern GOM waters outside the OCS (i.e. waters <20 m or >200 m). About 23,000 *T. truncatus* inhabit inshore and coastal waters (≤20 m) (Waring et al., 2001) and nearly 3000 occur in oceanic waters (Mullin and Fulling[2]). Both the "coastal" and "offshore" ecotypes of *T. truncatus* (Hersh and Duffield, 1990) occur in the northern GOM (LeDuc and Curry, 1998). How these ecotypes are distributed in the northern GOM and western North Atlantic is being investigated from skin biopsy samples collected, in part, during the 1998–2001 OCS surveys. Using mitochondrial DNA, obtained from biopsy samples collected during a U.S. Atlantic ship survey, Torres et al. (2003) 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. Forty-seven percent (35/75) of the GOM OCS *T. truncatus* groups were in waters >34 m deep.

Ship surveys of northern GOM waters indicate that very few *S. frontalis* (<500 animals) occur in oceanic waters, and those that do are usually found close to the shelf edge in waters <500 m deep (Davis et al., 1998; Mullin and Fulling[2]). The smaller "offshore" or "Gulfstream" *S. frontalis* that occurs in parts of the oceanic Atlantic (Perrin, 2002) has not been recorded for the northern GOM. During the 1998–2001 surveys, *S. frontalis* was sighted in waters <20 m deep. However, because sampling was not perpendicular to bathymetry, abundance estimates were not calculated. This species is not known to occur in U.S. GOM inshore waters (Mullin and Hansen, 1999).

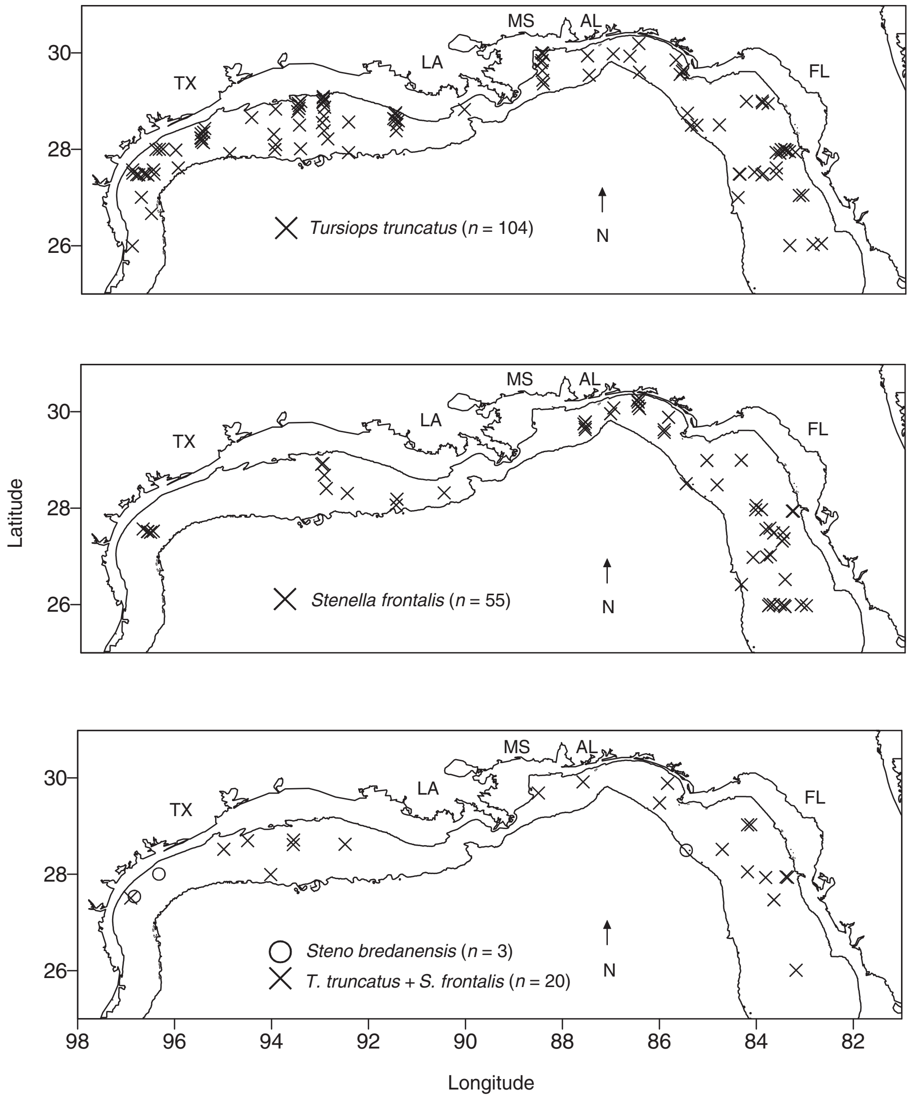

Figure 2

Locations of all on-effort sightings of *Tursiops truncatus* (top), *Stenella frontalis* (center), *Steno bredanensis*, and *T. truncatus+S. frontalis* (bottom) in the northern U.S. Gulf of Mexico outer continental shelf (20–200 m) during fall 1998–2001. Numbers of sightings shown are prior to truncation. The 20- and 200-m isobaths (thin lines) are shown (AL=Alabama, FL=Florida, LA=Louisiana, MS=Mississippi, TX=Texas).

Abundance

The abundance estimates for cetaceans reported in the present study are the first ship-based estimates for the U.S. GOM OCS. Abundance estimates for *T. truncatus* on the OCS (25,320; 0.26) are half the estimate in the pre-2002 SARs (50,247; 0.18) (e.g. Waring et al., 2001), that were based on aerial surveys conducted during fall 1992–94 (Blaylock et al., 1994; Waring et al., 2001). The abundance estimate for *S. frontalis* for the entire U.S. GOM in SARs prior to 2002 (3,213; 0.44) was based on data from ship surveys of OCS and oceanic waters >100 m deep (Waring et al., 2001; Hansen et al.[1]). Our current abundance estimate of *S. frontalis* (30,772; 0.27) for the OCS is almost an order of magnitude larger.

During the 1991–94 aerial surveys, there were 13 sightings of *S. frontalis* groups and 10 sightings that were identified as *T. truncatus+S. frontalis* in OCS waters (SEFSC, NMFS, Pascagoula, MS, unpubl. data). Using these sightings and 139 *T. truncatus* sightings to estimate $f(0)$, we estimated the abundance of *S. frontalis* from the aerial survey data to be 14,866 (0.37) for the U.S. GOM OCS [west, 3,526 (0.86); east, 11,340 (0.40)].

There are several potential reasons for the differences in abundances of the two species from ship and aerial surveys. The U.S. GOM OCS east of 85.5°W makes up about 44% of the U.S. GOM OCS. Aerial survey abundance estimates in this area were based on a small number of transect lines grouped in two places and most of the area was not

Table 2

Group-size, density and abundance estimates of cetaceans in the northern U.S. Gulf of Mexico outer continental shelf (waters 20–200 m deep) during fall 1998–2001 (n=number of group sightings, S=mean group-size, D=animals/100 km^2, N=abundance estimate, CV=coefficient of variation, R=reticle sightings, and K=naked eye sightings).

Species and stratum	n	S	CV(S)	D	N	CV(N)	95% CI
Tursiops truncatus							
East-R	27	9.8	0.25	10.1	14,132	0.40	6426–31,082
East-K	3	6.7	0.70	0.8	1066	0.85	139–8182
East total	30			10.9	15,198	0.38	7442–31,035
West-R	41	10.0	0.18	9.2	9786	0.30	5502–17,406
West-K	4	3.5	0.34	0.3	336	0.67	94–1201
West total	45			9.5	10,122	0.29	5790–17,696
OCS total	75			10.3	25,320	0.26	15,457–41,478
Stenella frontalis							
East-R	32	24.3	0.19	19.5	27,226	0.30	15,093–49,113
East-K	2	11.0	0.09	0.6	771	0.55	252–2358
East total	34			20.1	27,997	0.29	15,978–49,057
West-R	11	15.6	0.21	2.6	2712	0.42	1192–6169
West-K	1	4	—	0.6	63	1.17	9–433
West total	12			2.6	2775	0.41	1279–6023
OCS total	46			12.5	30,772	0.27	18,418–51,412
Steno bredanensis							
East-R	0	—	—	—	0	—	—
East-K	1	11	—	0.4	586	0.85	118–2902
East total	1			0.4	586		
West-R	2	14	0.43	0.6	652	0.98	115–3715
West-K	0	—	—	—	0	—	—
West total	2			0.6	652		
OCS total	3			0.5	1238	0.65	384–3990
T. truncatus+S. frontalis							
East-R	8	2.4	0.22	0.7	983	0.57	324–2983
East-K	0	—	—	—	0	—	—
East total	8			0.7	983		
West-R	8	4.8	0.28	0.8	885	0.47	355–2207
West-K	0	—	—	—	0	—	—
West total	8			0.8	885		
OCS Total	16			0.8	1868	0.37	920–3793

surveyed (see Fig.1 in Baumgartner [1997]). Complete coverage would have certainly led to more *S. frontalis* sightings and it is possible the lines that were surveyed were in areas with more *T. truncatus*. Blaylock and Hoggard (1994) estimated from aerial surveys that about 31% of the *T. truncatus* in OCS waters west of Mobile Bay were in rather a small area from the Mississippi River Delta west to about 90.5°W. Our ship survey effort in this area was small and resulted in only one sighting of *T. truncatus* (Fig. 2). Therefore, our ship-based estimates may have underestimated the abundance of *T. truncatus* in the western OCS. Aerial abundances were based on survey lines that extended from 9.3 km past the 18 m (10 fm) curve to 9.3 km past 183 m (100 fm) curve; therefore the area surveyed was somewhat different than our 20–200 m OCS study area for ship surveys. Aerial survey effort in waters >200 m may have resulted in more sightings of *T. truncatus* than *S. frontalis* because the deeper waters are not the common habitat of *S. frontalis* (Mullin and Fulling[2]) and sightings in waters <20 m would have also been biased toward *T. truncatus*.

Stenella frontalis and *T. truncatus* are similar in length and shape. *Stenella frontalis* are born without spots and become progressively more spotted with age, but young animals look very similar to *T. truncatus* (see Herzing, 1997). Therefore, depending on the composition of the group, from a distance *S. frontalis* are not always easily distinguished from *T. truncatus*; therefore it is possible that some groups were misidentified as *T. truncatus* during aerial surveys, leading to bias in the relative abundance of each species.

The annual PBR for the OCS stock of *T. truncatus* was 432 dolphins, and for the U.S. GOM stock of *S. frontalis*,

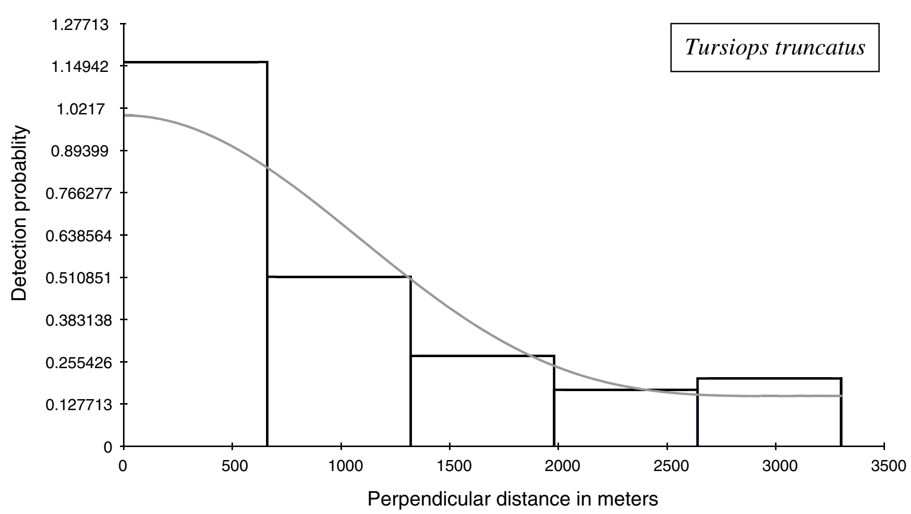

Figure 3

Plot of the detection function of pooled sightings of *Tursiops truncatus* in the northern U.S. Gulf of Mexico.

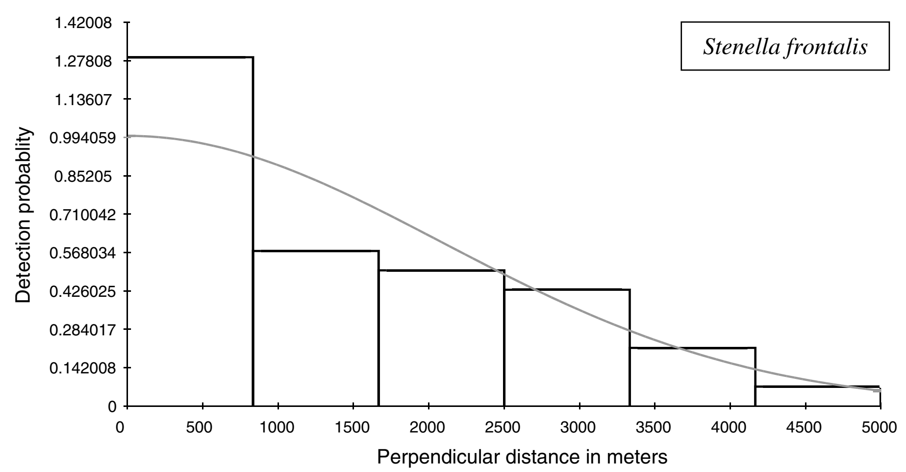

Figure 4

Plot of the detection function of pooled sightings of *Stenella frontalis* in the northern U.S. Gulf of Mexico.

23 dolphins (Waring et al., 2001). Using the abundances, we estimated that the annual PBR would be 204 dolphins for *T. truncatus* and 246 dolphins for *S. frontalis* (Table 2). Although these changes in both PBRs are large, the annual fishery-related mortality and serious injury for each species is estimated to be <3 dolphins in the U.S. GOM OCS (Waring et al., 2001).

Precision

The precision of the abundance estimates for *T. truncatus* (CV=0.26) and *S. frontalis* (CV=0.27) was good, although they were achieved after four years of effort. 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).

Bias

The surveys were designed to meet the assumptions of line-transect theory (Buckland et al., 2001). However, the abundance estimates were negatively biased because the central assumption that all cetacean groups on the transect line are detected (i.e. $g(0)=1$), certainly was not met, and data were not collected to correct estimates for perception and availability bias (Marsh and Sinclair, 1989). Barlow (1995) estimated perception bias in a ship survey in the Pacific Ocean, and although the group-sizes were not estimated at close range, the majority of groups missed by the primary team were apparently small groups. From this, Barlow (1995) estimated $g(0)$ to range from 0.73 and 0.79 for small groups of delphinids (<21 animals). Delphinids have relatively short dive-cycles but diving synchrony among members of a group can affect availability bias; if dives are asynchronous, the probability that at least one animal will be at the surface increases with group-size. Because availability bias varies by species due to differences in individual dive cycles, group diving behavior, and group-sizes, we were not able to address this potential bias based on Barlow's (1995) results.

The use of the effective strip half-width $[1/f_i(0)]$ from the 25× binocular sightings for the strip width for the strip-transect estimates (Table 2) 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 bowriding opportunities, and the type of ship. If the strip width was too narrow, the strip-transect estimates of abundance would be positively biased.

Our abundance estimates were for the entire U.S. OCS, but the surveys did not extend south of 26.0°N in the eastern Gulf. Sightings from a 1994 survey of the eastern Gulf (Hoffstetter, 2002) indicated that the distribution of *T. truncatus* and *S. frontalis* does not change dramatically between 26.0°N and Key West; therefore we believe this potential bias is minimal.

Because our estimates are from four combined years, another source of bias would occur if there were annual shifts in cetacean distribution, that is, if the majority of animals of any species occurred in a different part of the OCS in one year during fall compared to others years. However, there was no indication that this variation in distribution occurred and therefore potential bias is probably minimal. Potential bias due to the seasonality of the survey is also possible but cannot currently be addressed.

Additionally, survey effort from the 2001 cruise was the most complete effort of all years and may have carried more weight than all the other cruises. However, the 2001 survey provided adequate eastern GOM coverage. Variable survey effort in the fall is common because tropical weather can create rough sea conditions. Additionally, fall surveys always began in the west and terminated in the east. Because the same cruise track was always followed, we rarely had the opportunity to survey those areas not surveyed previously during nighttime transit, and thus may have created both a spatial and temporal bias.

Distribution

The observed distributions of both *T. truncatus* and *S. frontalis* were not surprising given previous descriptions of their distributions. The greater number of *S. frontalis* in the U.S. GOM off Florida compared to the western GOM was suggested by Schmidley and Melcher (1974), and the distribution of sightings reported by Mills and Rademacher (1996) supported this finding. The density of *S. frontalis* was much greater in the eastern GOM OCS than the western GOM OCS but the density of *T. truncatus* was similar in the two regions (Table 2).

The West Florida Shelf and Texas-Louisiana Shelf are very different marine environments, but how habitat differences specifically affect cetacean density patterns is not clear. The oceanography of the U.S. GOM continental shelf is complex, variable both spatially and temporally, and difficult to characterize briefly. Nevertheless, there are some clear distinctions between eastern and western OCS. First, there are 3415 active oil and gas platforms in the U.S. GOM OCS (0–200 m); the vast majority of these platforms (with their attendant boat and helicopter traffic) occur in waters west of Mobile Bay (MMS[5]). Also, ~95% of the U.S. GOM fisheries landings by weight occur west of Mobile Bay (10 years of NMFS[6] data). Additionally, sediment- and nutrient-laden fresh water from the Mississippi River and its distributary, the Atchafalaya River, usually moves west and predominately affects the Texas-Louisiana and Mississippi-Alabama shelves. The bottom of the Texas-Louisiana Shelf is primarily clay-slit mud and sand, and that of the West Florida Shelf is a mosaic of sand, gravel, shell, and coral (Rabalais et al., 1999). Primary production associated with the Mississippi River outflow is the highest measured in the GOM (Lohrenz et al., 1999). However, productivity on the West Florida Shelf can be enhanced by a variety processes (e.g. Gilbes et al., 1996). The deep eastern GOM is subject to the quasi-annual incursion of the Loop Current, which can extend to the Mississippi-Alabama Shelf (Wiseman and Sturges, 1999). This incursion can lead to upwelling episodes along the Loop Current front that may increase productivity along the shelf edge and on the West Florida Shelf (Paluszkiewicz et al., 1983; Gilbes et al., 1996). Baumgartner et al. (2001) reported greater sighting rates of cetaceans in the eastern GOM shelf-edge and oceanic waters and suggested that greater feeding opportunities may occur because of the influence of the Loop Current. Griffin and Griffin (2003), whose study included coastal waters (<20 m), reported that *S. frontalis* on the West Florida Shelf was found in deeper, more saline, and less turbid water than those where *T. truncatus* was found.

Demersal fish (e.g. sciaenids) are abundant and diverse on the western GOM OCS, but less abundant on the eastern OCS (Darnell et al.[7]; Darnell et al.[8]). The known prey of

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[5] Mineral Management Service, Gulf of Mexico Region website: http://www.gomr.mms.gove/hompg/fastfacts/WaterDepth/WaterDepth.html. [Accessed on 7/8/2003.]

[6] National Marine Fisheries Service web site: http://www.st.nmfs.gov/st1/commercial/. [Accessed on 8 July 2003.]

[7] Darnell, R. M., R. E. Defenbaugh, and D. Moore. 1983. Northwestern Gulf shelf bio-atlas; a study of the distribution of demersal fishes and penaeid shrimp of the soft bottoms of the continental shelf from the Rio Grande to the Mississippi River Delta. Open File Report No. 82-04, 438 p. Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA 70123.

T. truncatus from the GOM consist primarily of demersals, at least close to shore, but they also prey on pelagic species (Barros and Odell, 1990). The prey of *S. frontalis* are not well characterized but descriptions include epipelagic and mesopelagic fish and squid, and benthic invertebrates (Perrin, 2002). Richard and Barbeau (1994) observed "spotted dolphins" feeding on flyingfish (Exocoetidae) in waters 28–35 m deep on the West Florida Shelf. This is not uncommon because *S. frontalis* have been routinely observed feeding on flyingfish at night during haulback of longline gear during NMFS fisheries assessment surveys (Grace[9]). Fertl and Würsig (1995) describe *S. frontalis* feeding on a school of small clupeid fish at the surface south of the Florida Panhandle. A *S. frontalis* satellite-tracked for 24 days off Texas stayed in waters 12–63 m deep (mean, 32.6 m) and 58.1% of its dives were <10 m (Davis et al., 1996). These shallow dives observed by Davis et al. may indicate feeding on epipelagic species.

The occurrence of *S. bredanensis* in continental shelf waters of the U.S. GOM is interesting because this species is usually described as inhabiting oceanic waters (e.g. Jefferson, 2002). In the northern GOM, the estimated density of *S. bredanensis* was larger in OCS waters during fall (0.50 dolphins/100 km^2; Table 2) than that estimated for oceanic waters during spring (0.32 dolphins/100 km^2) (Mullin and Fulling[2]). In fact, if there is no OCS-oceanic shift in distribution between spring and fall, there may be similar numbers of *S. bredanensis* in northern GOM shelf waters (1238; 0.65) as in oceanic waters (1231; 0.45). One of the groups sighted in OCS waters was near the shelf-edge (183 m) but the other two sightings were at depths of 31 m and 33 m off Texas (Fig. 2). The use of shelf waters in the U.S. GOM by this species may not be atypical; two sightings of *S. bredanensis* were made on the West Florida Shelf in waters <55 m deep during August 1994 (Hofstetter, 2002). Pitman and Stinchomb (2002) provide evidence that *S. bredanensis* may be specialized predators of dolphinfish (*Coryphaena hippurus*) in the Pacific Ocean. Dolphinfishes have a circumtropical distribution but occur in oceanic and shelf waters in the northern GOM commonly associated with *Sargassum* and other drifting materials (Hoese and Moore, 1998). *Steno bredanensis* in the northern GOM are commonly found near flotsam, as they are in the Pacific—a place where dolphinfish tend to aggregate.

The abundance estimates presented in this study are the first ship-based estimates of *T. tursiops* and *S. frontalis* from Gulf of Mexico OCS waters. Although probably negatively biased, these estimates provide reliable data for the management of these species. Our results suggest that the diverse U.S. GOM environments provide an excellent natural experiment and opportunity to further understand the ecology of these sympatric cetacean species in OCS pelagic waters.

[8] Darnell, R. M., J. A. Kleypas, and R. E. Defenbaugh. 1987. Eastern Gulf shelf bio-atlas; a study of the distribution of demersal fishes and penaeid shrimp of the soft bottoms of the continental shelf from the Mississippi River Delta to the Florida Keys. OCS Study 86-0041, 548 p. Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA 70123.

[9] Grace, M. A. 2003. Personal commun. NOAA, 3209 Frederic Street, Pascagoula, MS 39567.

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