



ESTIMATES OF ABUNDANCE OF CETACEANS IN OFFSHORE WATERS OF THE NORTHWESTERN GULF OF MEXICO, 1992-1993

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ABSTRACT—In order to estimate cetacean abundance, seven vessel-based surveys were conducted in outer continental shelf and continental slope waters of the northwestern Gulf of Mexico from 1992 to 1993. Sixteen species were identified, and estimates of abundance were made using line transect methods for the most commonly seen species: sperm whales (*Physeter macrocephalus*), 442 ($CV = 35.7\%$); bottlenose dolphins (*Tursiops truncatus*), 451 ($CV = 36.5\%$) over the continental shelf, and 520 ($CV = 56.3\%$) over the continental slope; pantropical spotted dolphins (*Stenella attenuata*), 5,876 ($CV = 42.3\%$); and Clymene dolphins (*Stenella clymene*), 2,285 ($CV = 60.8\%$). Most line transect assumptions were satisfied, or were dealt with in the analyses. The major remaining bias is the probable underestimation of sperm whale abundance, due to missed animals on and near the transect line.

All cetaceans are protected in United States waters by the Marine Mammal Protection Act of 1972, and their abundance has been estimated in consideration of potential threats from oil and gas activities and fisheries interactions. Between 1978 and 1982, a long-term, large-scale project, using primarily aerial surveys, investigated cetaceans of the northeast U.S. coast (CeTAP surveys; Scott and Gilbert, 1982). Similar programs, again using mostly aerial surveys, surveyed cetaceans of southern California in 1975-1978 (surveys by T. P. Dohl and coworkers), central and northern California in 1980-1983 (T. P. Dohl and colleagues), and Oregon and Washington in 1989-1990 and 1992 (G. A. Green and coworkers). Recently (1991-1992), a more extensive project combined shipboard and aerial surveys to investigate cetaceans of California waters (Forney and Barlow, 1993; Barlow, 1995; Forney et al., 1995).

In comparison, the Gulf of Mexico cetacean fauna has been poorly studied. Only four short-term projects covering limited survey blocks in the Gulf have been conducted (T. H. Fritts and coworkers; K. Mullin et al., 1994; R. J. Esher and colleagues). The potential effects of offshore oil and gas activities on Gulf of Mexico cetaceans have only recently been widely acknowledged. As a result, from 1992 to 1994, Texas A&M University (TAMU), the National Marine Fisheries Service/Southeast Fisheries Science Center (NMFS),

and the Hatfield Marine Science Center (HMSC) conducted a collaborative study (called the Gulf-Cet Program) on the distribution, abundance, and habitat characteristics of offshore cetaceans of the northwestern Gulf of Mexico, an area of future planned oil lease sales. This program had five major components: 1) vessel-based visual surveys (TAMU and NMFS); 2) aerial visual surveys (NMFS); 3) vessel-based acoustic surveys, using a towed hydrophone array (TAMU); 4) sperm whale satellite tracking studies (HMSC); and 5) habitat studies, including shipboard hydrographic sampling and satellite imagery (TAMU and NMFS). This paper reports on the TAMU portion of the vessel-based visual surveys. These are the first large-scale ship surveys of Gulf of Mexico cetaceans with coverage during all four seasons.

MATERIALS AND METHODS—Cetacean distribution and abundance were studied in the northwestern Gulf of Mexico on seven GulfCet survey cruises between 1992 and 1993 (Table 1). The study area was defined as the region bounded by the 100 m and 2000 m isobaths, and the Florida/Alabama and Texas/Mexico borders (Fig. 1). Fourteen pre-determined transect lines running north/south from the 100 m to the 2000 m isobaths were chosen; the average distance between the transect lines was about 74 km. However, for logistical reasons, after the first survey, Line 1 was not surveyed and the study area was redefined to extend from line

TABLE 1—Summary of Texas A&M GulfCet survey cruises.

No.	Dates	Surveyed		Avg. Beaufort sea state	Number of herd sightings
		Hours	Kilometers		
1	April 14, 1992–April 30, 1992	33.63	418.3	2.5	33
2	August 10, 1992–August 24, 1992	79.04	1036.9	2.8	43
3	November 8, 1992– November 21, 1992	37.47	535.7	4.1	10
4	February 12, 1993– February 25, 1993	41.31	529.2	3.4	19
5	May 24, 1993–June 4, 1993	68.93	957.5	3.2	55
6	August 27, 1993– September 7, 1993	76.07	1041.7	2.7	89
7	December 4, 1993– December 14, 1993	54.70	729.0	3.4	15
Total		391.15	5248.1		264

2 to line 14, comprising 145,295 km². A total of 5248.1 km of survey effort was completed (967.4 km over the shelf and 4280.7 km over the slope).

The vessel used on the first cruise was the R/V *Longhorn*, a 32-m research vessel operated by the University of Texas. The remaining six cruises used the 32-m R/V *Pelican*, operated by the Louisiana Universities Marine Consortium. The research vessel traversed the

study area along the transect lines on each cruise, cruising at about 11 km/h when on a primary transect line, and at about 17 km/h when running between lines. Survey effort was conducted from atop the pilothouse on both vessels (observer eye height was approximately 7.7 m on the *Longhorn* and 8.9 m on the *Pelican*).

Survey procedures followed closely those developed for dolphin surveys in the eastern tropical Pacific, sum-

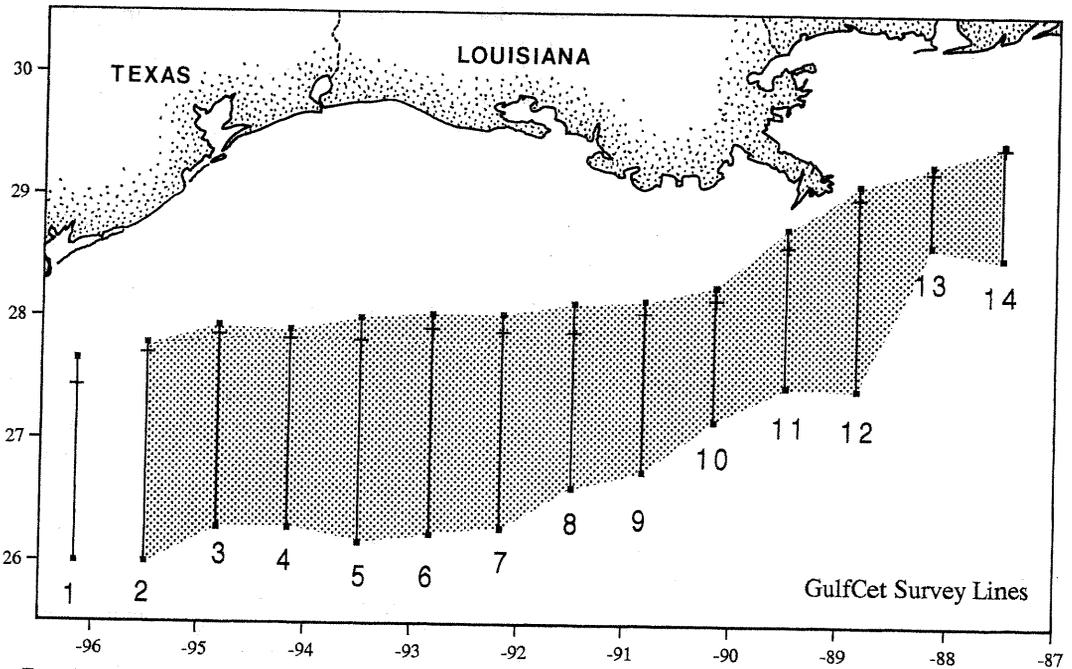


FIG. 1—Map of the GulfCet study area, showing survey lines running between the 100 m and 2000 m isobaths. Horizontal lines denote where lines cross the 200 m isobath. The shaded area denotes the study area, after deletion of line 1.

marized in Hill et al. (1991a, b). There were two three-person survey teams, one of which was on duty during all daylight hours with acceptable conditions (including both primary transects and runs between transect lines). The teams switched every 2 h. Two primary observers searched for marine mammals through pedestal-mounted 25 × 150 *Fujinon* binoculars, while the third observer recorded data and assisted in searching with naked eye and 7× binoculars. Each primary observer searched a 100° swath, from 90° on their side to 10° past the bow on the opposite side; the data recorder focussed effort near the ship and around the trackline (i.e., the line surveyed by the vessel). Thus the total primary search path was 180°, with a 20° overlap centered around the bow. Observers rotated positions every 30 min to minimize fatigue.

Sighting angle was recorded with the aid of a graduated scale at the base of the binoculars, and radial distance to the sightings was either estimated by eye (for sightings within a few hundred meters of the ship) or calculated with the assistance of reticles etched into the right eyepiece of the binoculars (for sightings further out). Radial distance was estimated from reticle readings, using the formula developed by Smith (1982) and modified by Barlow and Lee (1994). Perpendicular distance was calculated from radial distance and sighting angle.

Sighting effort was conducted during all daylight hours in which sighting conditions were acceptable. Acceptable conditions were defined as Beaufort sea states of less than 6, with good visibility. Occasionally rain, fog, glare, or excessive ship roll resulted in suspension of survey effort in sea states lower than Beaufort 6. During daylight hours when survey effort was suspended, at least one observer was stationed on the bridge to collect off-effort sightings of marine mammals. Sighting and effort data were collected on standardized forms developed by the NMFS (Hill et al., 1991a, b).

Density and abundance were calculated using line transect methods, with the computer program DISTANCE (Laake et al., 1993). Because sightings of individuals for most species of cetaceans are not independent events, herds were considered the targets of the survey. Abundance of individuals (*N*) and its associated coefficient of variation (*CV*) were calculated following Buckland et al. (1993):

$$\hat{N} = \frac{n \hat{f}(0) \hat{E}(s) A}{2 L \hat{g}(0)}$$

$$CV(\hat{N}) = \sqrt{\frac{\hat{\text{var}}(n)}{n^2} + \frac{\hat{\text{var}}[\hat{f}(0)]}{[\hat{f}(0)]^2} + \frac{\hat{\text{var}}[\hat{E}(s)]}{[\hat{E}(s)]^2}}$$

where

n = number of objects sighted,
f(0) = the value of the probability density function of the perpendicular distance data,

evaluated at zero distance (see Buckland et al., 1993 for a detailed explanation),

E(*s*) = unbiased estimate of herd size in the study area (not necessarily the same as the observed mean herd size),

A = total size of the study area,

L = total length of transect, and

g(0) = the detection function (the probability that an object on the line is detected).

The effective strip width (*ESW*), an index of the sight ability of the species (or group), was also computed for each species group as twice the effective strip half-width [*μ*] of Buckland et al. (1993).

There were too few sightings to produce separate probability density functions for each species, so pooling across species was necessary to obtain a minimum of 30 sightings for each group. Only species with similar sighting characteristics were pooled. Buckland et al. (1993) suggested truncation of at least 5% of the data to eliminate outliers and long tails, thereby facilitating modelling of the data. Truncated estimates were computed, but the truncated data for each species group were only used if they resulted in more precise estimates of *f*(0) (with lower coefficients of variation).

To avoid large peaks in the distance data at the origin, which violate the shape criterion and make the data difficult to model (Buckland et al., 1993), sightings made within 0.458 km of the vessel were not used to estimate *f*(0), although they were used in the line transect equation to estimate abundance. This distance corresponds to the closest point at which reticle readings can be taken through the 25× binoculars; thus all sightings closer than 0.458 km were naked eye sightings, with estimated distances. Most of these sightings were of dolphin groups that were attracted to the ship and were approaching it to bowride, thus these data also violate one of the primary assumptions of line transect theory (Buckland et al., 1993). Discarding these naked eye sightings made estimation of *f*(0) more precise and resulted in shoulders near the origin, thereby satisfying the shape criterion discussed by Buckland et al. (1993).

Sightings were pooled into three groups: 1) sperm whales; 2) bottlenose dolphins/Atlantic spotted dolphins; and 3) continental slope small delphinids. Four sightings of unidentified large whales were pooled with sperm whale sightings,

because sperm whales were the only large whales seen during the surveys. Furthermore, most of the unidentified large whale sightings were suspected to be sperm whales at the time of sighting (but identification was not confirmed), and sightings of other large whales in the Gulf are extremely rare (Jefferson and Schiro, 1997). Pooling resulted in a total of 40 sightings, eight of which were <0.458 km and were thus discarded. Truncation resulted in a less precise estimate of $f(0)$, and so the untruncated data were used, with 32 sightings available for modelling.

Only two species, bottlenose dolphins and Atlantic spotted dolphins, were observed over the continental shelf. Most bottlenose dolphin, and all Atlantic spotted dolphin, sightings occurred in shelf waters. Both species have similar sighting characteristics (they occur in small to moderate groups) and sometimes school together. Sightings of unidentified dolphins and unidentified *Stenella* sp. from continental shelf waters were also pooled with this group, because they were all likely to be one of these two species. Pooling for this group resulted in a sample size of 38. Twenty sightings were <0.458 km and were thus discarded. Truncation at 3.0 km eliminated one additional observation (5.6% of the data). The probability density function was modelled using the remaining 17 sightings.

Small delphinids of continental slope waters include Fraser's dolphins, melon-headed whales, and all species of the genus *Stenella*, except *S. frontalis*. These are species that form moderate to large herds, and often exhibit much aerial behavior and create highly-visible splashes. Unidentified dolphins sighted in slope waters were not included, because some of these sightings may have been of bottlenose dolphins or larger delphinids. A total of 36 sightings was obtained by pooling (most of them *Stenella* spp.), eight of them were discarded (<0.458 km), and truncation was rejected. Thus, a total of 28 sightings was available for estimation of $f(0)$.

Abundance was estimated separately for two geographic strata, representing the two major habitat types of cetaceans in the Gulf. The continental shelf stratum was defined as that part of the study area shoreward of the 200 m isobath points on each of the survey lines. The slope stratum was offshore of the 200 m points. Only bottlenose dolphins are known to inhabit both habitat types, so for all other species density estimates are only for their respective strata.

Because of potential problems resulting from rounding errors (Hammond, 1986), reticle readings and sighting angles were smeared before analysis. This was done using program SMERBRRT (written by L. J. Hansen, SEFSC, NMFS), which adds or subtracts a random value to each measurement, thus smoothing out a heaped distribution.

There is a tendency to overestimate herd size because small herds have a lower probability of being sighted at great distances. This can seriously bias resulting population estimates upwards (Buckland et al., 1993). There are several methods of dealing with this potential problem. In the present analysis, program DISTANCE was used to compute a size-bias estimate of herd size, by regressing the logarithm of herd size against detection probability. If the size-bias estimate was smaller than the observed mean herd size, it was used instead in the line transect equation.

Because a large proportion of sightings (38%) were not identified to species, estimates of abundance were also calculated, adding in these unidentified sightings after prorating to species, based on the proportions in the identified sample (following Wade and Gerrodette, 1993). These prorated population estimates are presented for comparison only; the estimates based only on the identified sample are more conservative and should thus be used for management purposes.

Three models were considered for estimation of $f(0)$, based on ungrouped perpendicular distances: the uniform, hazard rate, and half-normal models. Program DISTANCE selected the appropriate model, with the minimum value of Akaike's Information Criterion (Buckland et al., 1993).

Generally, in line transect analysis, the assumption is made that all objects on the transect line are detected (i.e., $g(0) = 1$). For species that spend significant amounts of time below the surface (e.g., sperm whales), this assumption may be violated. There were no available data to estimate $g(0)$ for this study, so the assumption that $g(0) = 1$ was used as a default.

RESULTS—A total of 264 cetacean herds was sighted in the study area during the project, 179 of them on-effort. Because some herds contained more than one species, a total of 193 on-effort species sightings was available for density and

TABLE 2—Total number of sightings (n_t), on-effort sightings (n_e), off-effort sightings (n_o); mean observed herd size (s), standard deviation [$SD(s)$], and range; and herd sighting rate, for sightings identified to species.

Species	n_t	n_e	n_o	s	$SD(s)$	Range	Sighting rate
Sperm whale <i>Physeter macrocephalus</i>	48	36	12	3.7	3.01	1–17	8.41
Pygmy sperm whale <i>Kogia breviceps</i>	3	3	0	1.3	—	1–2	0.70
Dwarf sperm whale <i>Kogia simus</i>	3	2	1	4.0	—	1–7	0.47
Cuvier's beaked whale <i>Ziphius cavirostris</i>	2	2	0	1.0	—	1–1	0.47
Short-finned pilot whale <i>Globicephala macrorhynchus</i>	3	2	1	14.0	—	2–20	0.47
False killer whale <i>Pseudorca crassidens</i>	3	2	1	2.3	—	1–4	0.47
Risso's dolphin <i>Grampus griseus</i>	5	5	0	10.4	14.17	1–35	1.17
Bottlenose dolphin <i>Tursiops truncatus</i>	46	32	14	6.2	6.05	1–24	6.10
Atlantic spotted dolphin <i>Stenella frontalis</i>	7	4	3	19.6	20.32	3–55	4.13
Pantropical spotted dolphin <i>Stenella attenuata</i>	29	18	11	26.0	28.94	3–148	4.21
Striped dolphin <i>Stenella coeruleoalba</i>	3	3	0	37.3	—	5–70	0.70
Spinner dolphin <i>Stenella longirostris</i>	1	1	0	9.0	—	—	0.23
Clymene dolphin <i>Stenella clymene</i>	6	5	1	44.8	24.08	10–85	1.17
Rough-toothed dolphin <i>Steno bredanensis</i>	2	1	1	13.0	—	12–14	0.23
Melon-headed whale <i>Peponocephala electra</i>	2	2	0	203.0	—	156–250	0.47
Fraser's dolphin <i>Lagenodelphis hosei</i>	2	2	0	32.0	—	20–44	0.47

abundance estimation. Of this total, 120 (62%) were identified to species (Table 2).

As expected, sperm whales had the lowest value for $f(0)$ and the greatest ESW (Table 3). In general, histograms of perpendicular sighting distances showed expected shapes and the models for the three pooled species groups showed good fits (Fig. 2). Abundance estimates were made only for those species with at least five on-effort sightings. This included sperm whales, bottlenose dolphins, pantropical spotted dolphins, and Clymene dolphins. Estimates of abundance were highest for pantropical spotted dolphins and lowest for sperm whales (Table 4).

DISCUSSION—The overall encounter rate of cetacean herds in the present study (34.1 herds/

1000 km) was similar to that found for the eastern tropical Pacific (32.2 herds/1000 km; Wade and Gerrodette, 1993). Although the density of cetacean herds is similar for both areas, the individual density may be higher in the eastern tropical Pacific because dolphins generally occur in much larger herds there.

Wade and Gerrodette (1993) computed effective strip widths ($ESWs$) for their study in the eastern tropical Pacific. They calculated an ESW for sperm whales of 7.30 km, which is similar to the present one for the Gulf of Mexico (8.39 km). Because dolphin species were pooled in this study and not in Wade and Gerrodette's (1993), other estimates are not directly comparable. However, Wade and Gerrodette (1993) calculated an ESW for bottlenose dolphins of 3.85 km.

TABLE 3—Truncation distance (w), number of sightings used (n), estimated value of the probability density function [$f(0)$], effective strip width (ESW), and model used for different species groups.

Species group	w (km)	n	$f(0)$ (km^{-1})	ESW (km)	Model
Sperm whale	7.3*	32	0.2384	8.39	Uniform/Cosine
Bottlenose/Atlantic spotted dolphins	3.0	17	0.5058	3.95	Uniform/Cosine
Continental slope small delphinids	5.8*	28	0.6402	3.12	Hazard Rate/Cosine

* No truncation.

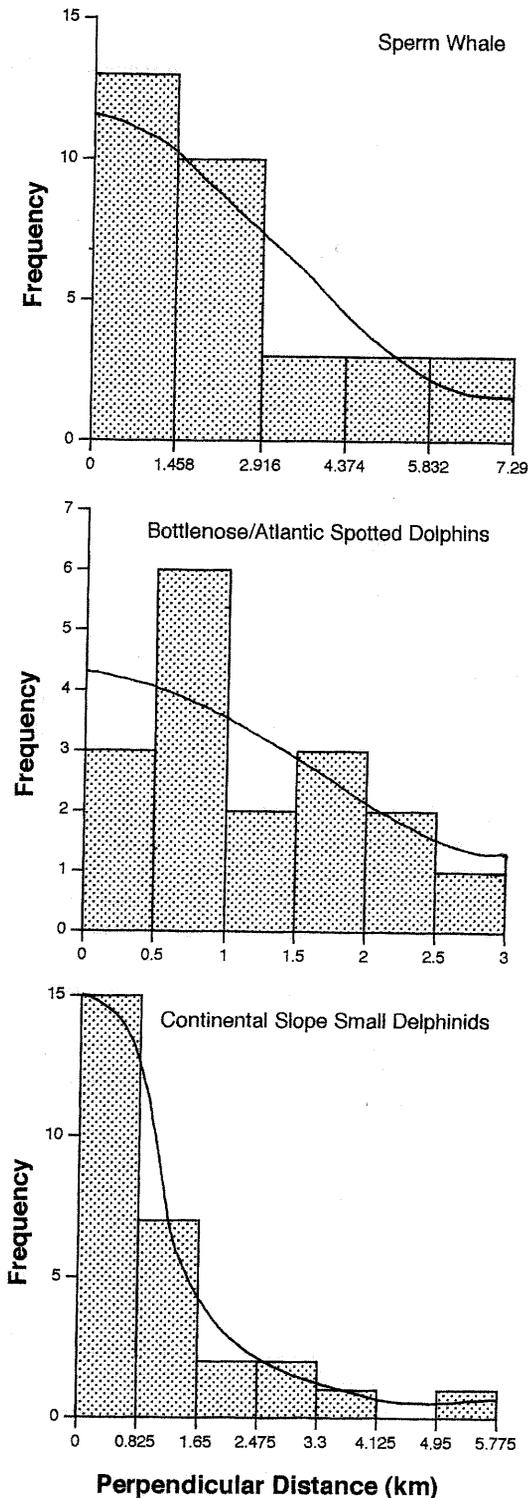


FIG. 2—Histograms of perpendicular sighting distance data and fitted models for the three pooled species groups.

In the present study, the *ESW* for bottlenose dolphin/Atlantic spotted dolphin (3.95 km) was calculated mostly from bottlenose dolphin sightings and is very similar.

Line transect estimates of abundance are subject to many potential biases, mostly resulting from assumption violations. Burnham et al. (1980), in their classic monograph on line transect sampling, identified four critical assumptions behind this technique. These are discussed below and an attempt is made to assess the validity of these assumptions to this study.

Assumption 1: All Animals on the Trackline Are Detected (i.e., $g(0) = 1$)—This is considered to be the central assumption in line transect sampling, and much attention has been devoted to ensuring that it is met. Line transect theory is based on the knowledge that, as an observer searches farther from the trackline of the survey platform, more animals will be missed because detection probability decreases with distance. However, those animals that are directly on and near the trackline of the platform should be detected with certainty.

Survey procedures for marine mammals have been set-up specifically to increase the opportunity to see animals on the trackline. Although the use of 25× binoculars greatly increases sighting efficiency, their limited field of view can result in observers using the binoculars missing animals near the ship. This is the main reason that the data recorder also acts as an observer, using naked eye and 7× binoculars to focus effort near the ship. This observer essentially “guards the trackline,” making sure that any groups missed by the 25× observers will still be seen.

The concept of perception bias was discussed by Marsh and Sinclair (1989). This is a situation in which a group of animals is potentially available to be detected, but is nonetheless missed. An observer focussing his or her effort near the ship helps to ensure that perception bias is minimized, and there is no reason to believe that this was a significant problem in this study.

Cetaceans present potential problems to observers because they dive, spending relatively small amounts of time at the surface between longer periods underwater. In most cases, when all members of a group are underwater, they are unavailable to be seen by the survey team. This is the most common type of availability bias facing cetacean observers (Marsh and Sinclair, 1989). For most delphinids, availability bias is probably not a serious problem, because group

TABLE 4—Components of the line transect equation used, and herd density and individual abundance estimates for each species.

Species	<i>n</i>	<i>f</i> (0) (km ⁻¹)	<i>E</i> (<i>s</i>)	<i>A</i> (km ²)	<i>L</i> (km)	<i>D</i> (1000 km ⁻²)	<i>N</i> (%CV)*	<i>N_p</i> [#]
Sperm whale	36	0.2384	3.3	133,427	4280.8	1.002	442(35.7)	528
Bottlenose dolphin								
Shelf	22	0.5058	6.6	11,868	967.4	5.752	451(36.5)	471
Slope	10	0.5058	6.6	133,427	4280.8	0.591	520(56.3)	833
Pantropical spotted dolphin	18	0.6402	32.7	133,427	4280.8	1.346	5876(42.3)	11,426
Clymene dolphin	5	0.6402	45.8	133,427	4280.8	0.374	2285(60.8)	4569

* Abundance estimate, based only on sightings identified to that species. Percent coefficient of variation is given in parentheses.

[#] Abundance estimate, based on identified sightings plus prorated unidentified sightings.

members often dive asynchronously, with some animals at the surface while others are on a dive. When an entire group does dive, the submergence time is rarely over 5 min. This still gives the survey team plenty of time to detect the animals at some point during the period that the group is within the search area.

Some cetaceans, however, spend very long periods of time below the surface and dive synchronously. Sperm whales may spend an hour or more underwater (Lockyer, 1977), making them potentially unavailable to be seen by the survey team during the entire time that they are within the search area. Even though I have accepted the assumption that $g(0) = 1$ as a default for this study, it is very likely that it is not valid for sperm whales. This will result in a negative bias in the resulting population estimate.

Assumption 2: Animals Do Not Make Responsive Movements Prior to Detection—Movements after detection and recording of sighting angle and distance are of no consequence to density estimation. Movements in response to the survey platform that occur before detection will cause biases in the resulting population estimates, however. Avoidance of the ship will result in underestimation of abundance, and attraction will cause overestimation.

Responsive movements, primarily vessel attraction, may be a significant factor in estimating abundance of dolphins in the Gulf of Mexico. Many groups of dolphins seen in the Gulf approached the ship to ride the bow wave, and many of them may not have been detected prior to their response to the ship. The practice of discarding sightings made within 0.458 km of the ship (naked eye sightings) when calculating $f(0)$ appears to have alleviated this problem to a great extent. For both pooled dolphin species groups,

population estimates made using these naked eye sightings were several times higher than corresponding estimates made after discarding naked eye sightings. Dolphins of most species in these groups are attracted to the ship to ride the bow wave. In contrast, discarding naked eye sightings for sperm whales, which generally do not show any obvious response to the vessel, changed abundance estimates only slightly.

Assumption 3: Distances and Angles Are Measured Without Error—Small and random errors will not likely cause serious biases; large or systematic errors are more problematic. The graduated scale at the base of the 25× binoculars allowed observers to read angles to cetacean groups to the nearest degree, and reticles etched into the binocular eyepiece made it possible to calculate a specific distance to a sighting, rather than simply estimating distance by eye. Although these methods still do not allow for exact measurement, any errors will be minimized and are probably random.

One potential source of error in data collection is heaping of distance data that may result from rounding angles and radial distances to convenient numbers, such as multiples of five (Hammond, 1986; Buckland et al., 1993). Observers in this project were repeatedly reminded to measure angle to the nearest degree, and to read reticles to the nearest tenth. Despite this, examination of sighting angle data showed some evidence of heaping. Smearing of sighting angles and reticle readings prior to calculation of perpendicular sighting distance, as was done in this study, effectively deals with this problem.

Assumption 4: Sightings Are Independent of Each Other—Using individual animals as the target of the survey would violate the assumption that sightings are independent events, since cetaceans

live in groups. Treating herds as the targets effectively solves this problem. However, this does add the additional requirement of providing an unbiased estimate of herd size to factor into the line transect equation.

Randomness of distribution is not a requirement of line transect sampling. As long as transect lines are placed randomly to density gradients (Buckland et al., 1993), the probability of sighting one herd does not generally affect the probability of sighting the next. Thus, the assumption of independence is considered to have been met.

Only a few factors are thus considered to have a potentially significant effect on abundance estimates derived in this study. Responsive movements by dolphins would most likely be in the form of attraction to the vessel to bowride. This problem was dealt with in this study by discarding naked eye sightings when calculating $f(0)$, but in future surveys measures should be taken to ensure that responsive movements prior to detection do not occur. For species that dive for long periods and may be missed on or near the transect line due to availability bias (e.g., sperm whales), estimates will be biased downwards by an unknown degree. Although it is only likely to be significant for some species, this is considered to be the problem most worthy of attention in applying line transect methods to cetaceans at the present time.

I am grateful to all the observers who assisted in data collection: S. R. Benson, S. Bräger, R. Clark, N. Clauss, V. G. Cockcroft, L. Delos Santos, K. Dudzinski, D. Fertl, A. Forest, T. Frohoff, A. Grundt, S. Kanatous, S. K. Lynn, L. May, L. Montaña, J. C. Norris, A. J. Schiro, L. Sharp, W. E. Stevens III, T. Tenbrink, D. W. Weller, B. Wilson, and B. Würsig. I am also grateful to the crews of the R/V *Longhorn* and R/V *Pelican* for their assistance in this project. I appreciate the advice on line transect analysis given by J. Barlow, K. A. Forney, T. Gerrodette, L. J. Hansen, K. D. Mullin, and P. R. Wade. S. Collier, M. Fellenstein, B. Gardner, and A. J. Schiro provided computer assistance. This project was completed with support from the U.S. Minerals Management Service (contract No. 14-35-001-30619) to the Texas Institute of Oceanography at Texas A&M University. I would like to thank R. W. Davis, B. Würsig, and the other GulfCet PIs for the opportunity to participate in this project. For reviewing earlier drafts of this manuscript, I would like to thank R. B. Ditton, W. E. Evans, K. A. Forney, D. W. Owens, P. R. Wade, B. Würsig, and two anonymous referees.

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