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AERIAL CENSUS OF THE BOTTLENOSE DOLPHIN, *TURSIOPS TRUNCATUS*, IN A REGION OF THE TEXAS COAST

ERIC G. BARHAM,[1] JAY C. SWEENEY,[2] STEPHEN LEATHERWOOD,[3] ROBERT K. BEGGS,[4] AND CECILIA L. BARHAM[5]

ABSTRACT

On five replicate aerial surveys in late March 1978, the bottlenose dolphin, *Tursiops truncatus*, herds were sighted and their numbers estimated in 21 strip transects flown across bays and channels between barrier islands and the coast from Port Aransas northeast to Matagorda, Texas. The transects were spaced at 4.63 km intervals and herds were scouted in about 800 m wide strips totaling 436 km in length, providing approximately 17% coverage of the area. On surveys 1-4 (survey 5 was excluded from population calculations because it was conducted in adverse weather) 133 bottlenose dolphin herds were sighted, containing an estimated 916 animals. Within these strips the mean heard size was 6.95 animals and mean herd density was 0.0947/km², extrapolating to a population estimate of 1,319 dolphins and a density estimate of 0.752/km² for the entire area. These figures are relatively high in contrast to recent studies in other environments. About half the herds were feeding and approximately one-third were traveling. Sightings were most frequent in ship channels, shallow areas inside barrier islands, and near shore. There were several sources of bias in our measurements, and we consider the results to be conservative.

In the waters under jurisdiction of the United States, live capture of marine mammals is now limited by law to those species that are used for public exhibition and scientific research. With the exception of certain pinnipeds, the greatest demand is for the bottlenose dolphin, *Tursiops truncatus* Montagu, the most tractable of the smaller cetaceans.

This recent management regime has generated a need for assessment of marine mammal stocks that consider population size and reproductive rates of potentially impacted species (Odell et al.[6]). Obviously, rigorous density estimates are an essential starting point for such studies, but despite the long history of a live fishery for bottlenose dolphins (Townsend 1914) there are scant population data on which to base management decisions (Odell 1975).

The majority of bottlenose dolphins that are readily available for capture dwell in the coastal and inland waterways of Florida and the other states bordering the Gulf of Mexico. In such environments several factors make *T. truncatus*, in contrast to pelagic odontocetes, ideally suited for synoptic studies from aircraft: many of the environments are semienclosed waters of limited dimensions, the herds are usually small thus individuals can be relatively accurately counted, and *T. truncatus* is generally the only small cetacean in the area and therefore easily identified. Accordingly, recent studies of bottlenose dolphins off the northern Gulf of Mexico and the Indian River area of Florida have used and refined aerial survey tactics and methods (Leatherwood et al. 1978; Leatherwood 1979; Leatherwood and Platter[7]; Odell and Reynolds[8]). Using similar procedures

[1]Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, CA 92038.
[2]Dinnes Memorial Veterinary Hospital, 16133 Ventura Boulevard, Encino, CA 91436.
[3]Biomedical Branch, Naval Ocean Systems Center, San Diego, Calif.; present address: Hubbs-Sea World Research Institute, 1700 South Shores Road, San Diego, CA 92109.
[4]Sea Arama Marineworld, P.O. Box 3068, Galveston, TX 77552.
[5]Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331.

[6]Odell, D. K., D. B. Siniff, and G. H. Waring (editors). 1975. *Tursiops truncatus* assessment workshop. Final Report, U.S. Marine Mammal Commission, Contract MM5AC021, 141 p. Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149.

[7]Leatherwood, S., and M. F. Platter. 1975. Aerial assessment of bottlenosed dolphins off Alabama, Mississippi and Louisiana. *In* D. K. Odell, D. B. Siniff, and G. H. Waring (editors), *Tursiops truncatus* assessment workshop, p. 49-86. Final Report, U.S. Marine Mammal Commission, Contract MM5AC021. Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149.

[8]Odell, D. K., and J. E. Reynolds III. 1978. Distribution and abundance of the bottlenose dolphin, *Tursiops truncatus*, on the west coast of Florida. Draft - Final Report, Marine Mammal Commission, Contract MM5AC026, 55 p. Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149.

Manuscript accepted March 1979.
FISHERY BULLETIN: VOL. 77, NO. 3, 1980.

we report here on the size and density of the bottlenose dolphin population in the Port Aransas Pass-Matagorda Peninsula region of the Texas coast as observed in late March 1978 and compare the density figures with those obtained in the previous studies. Observations on *T. truncatus* distribution, behavior, sighting cues, and the perpendicular distances of the sightings, and alternative procedures and results are also presented and discussed.

STUDY AREA AND METHODS

Based on previous research (Leatherwood et al. 1978), a strip transect was designed (Eberhardt 1978). The dolphin herds were sighted and their numbers estimated within strips theoretically 804.5 m wide (0.435 n.mi.). All sightings, regardless of the numbers of animals, were statistically considered as a herd, and the term is used here in the general sense of a grouping of animals without implying more complex behavior. To achieve precision the same area was surveyed during five replicate flights. The extent of the area surveyed was limited to dimensions that could be covered in 7-8 h of flying time and that would provide approximately 17% coverage of the area on any one replicate survey.

The surveyed territory extended along 160 km (86 n.mi.) of the central Texas coast from Port Aransas at the northern end of Corpus Christi Bay to the base of the Matagorda Peninsula (Figures 1-3). This terrain is a complex of bays, bayous, lakes, and channels bordered seaward by long, low barrier islands. Convoluted arms of the larger bays extend inland into river deltas surrounded by agricultural lands. Marshes fringe much of the barrier and outer bay shorelines and numerous sand and shell reefs, small islands, and spoil dumps interrupt the water areas. Extensive shoals are covered by water of <1 m, and the deeper parts of the bays are limited to about 4 m depths. Oil well platforms and well heads are numerous in some parts of the bays and man-made

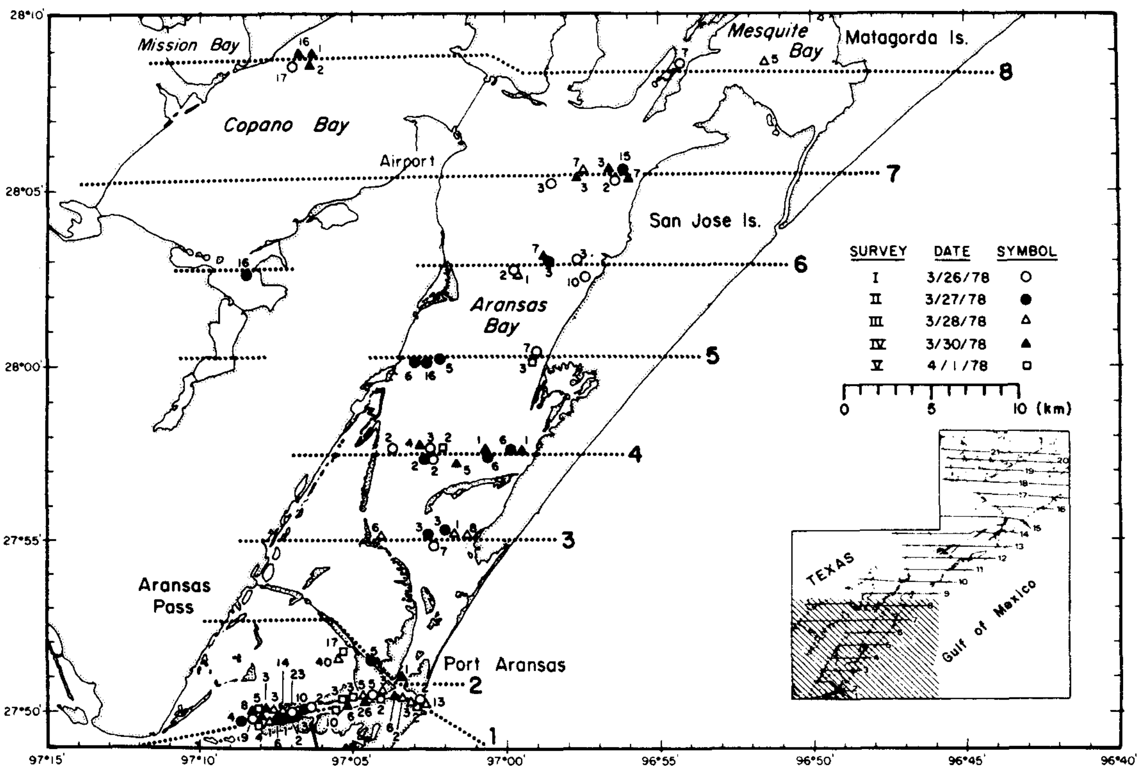

FIGURE 1.—Distribution of bottlenose dolphin herds and their estimated numbers from Aransas Pass to Mesquite Bay (transects 1-8), Texas.

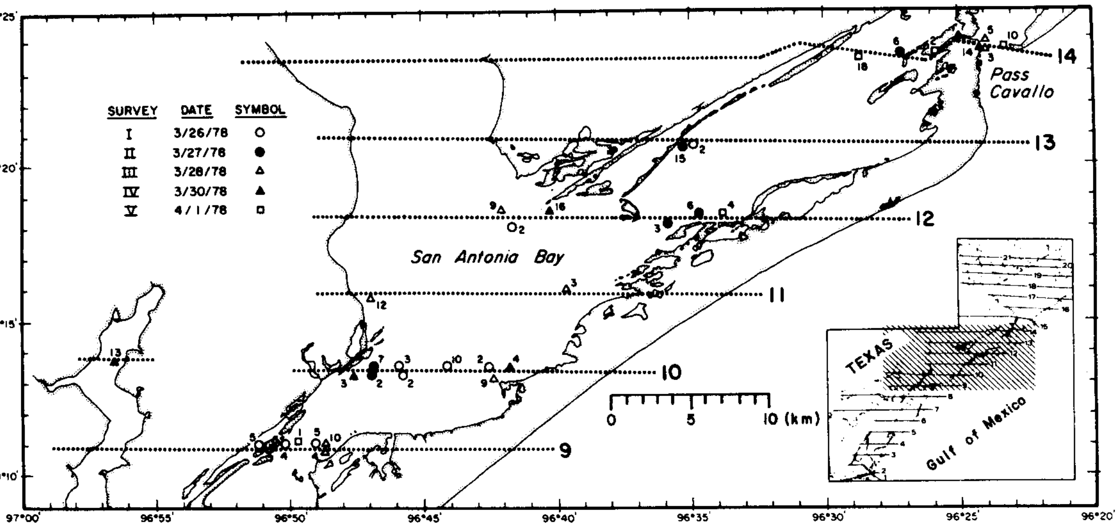

FIGURE 2.—Distribution of bottlenose dolphin herds and their estimated numbers from Ayres Bay to Pass Cavallo (transects 9-14), Texas.

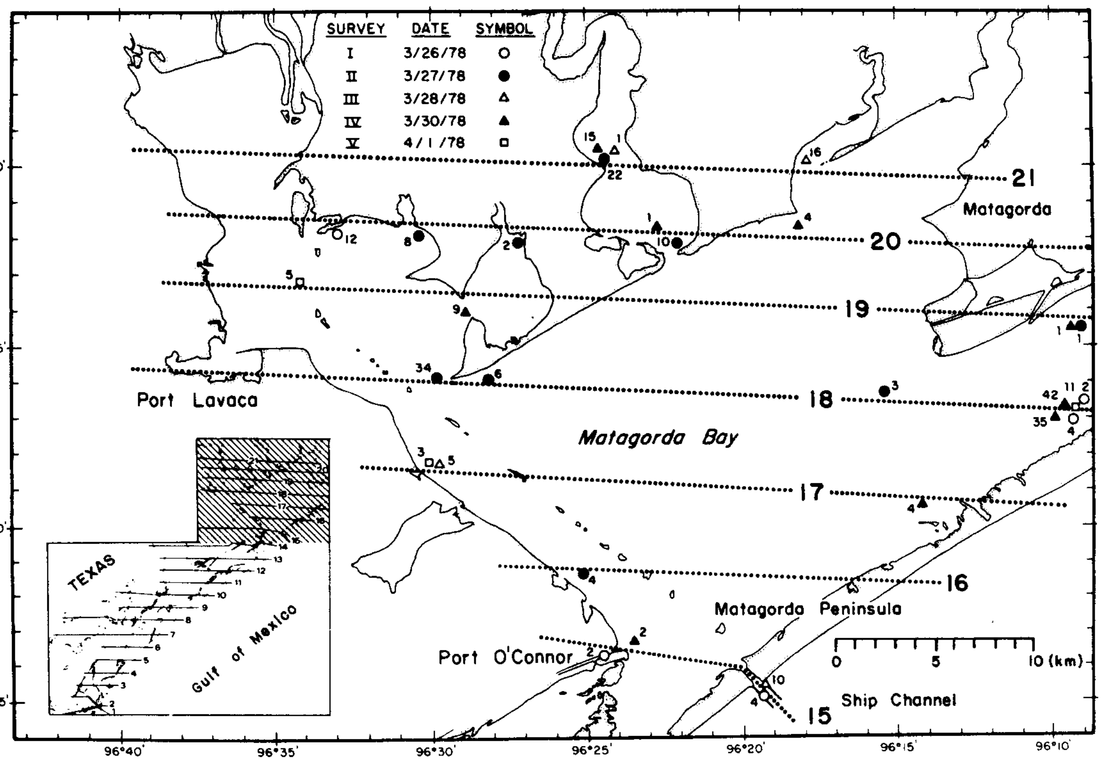

FIGURE 3.—Distribution of bottlenose dolphin herds and their estimated numbers from Port O'Connor ship channel to Tres Palacios Bay (transects 15-21), Texas.

cuts and channels run through the area. Five channels, two man-made, open to the Gulf of Mexico.

Operating from Aransas County Airport, a high-wing, four-seat airplane was flown along 21 transect lines spaced at approximately 4.63 km (2.5 n.mi.) intervels across the study area (Figures 1-3). With some exceptions the transect lines were oriented due east to west. To provide a reference point with a previous population study (Shane 1977) the first two lines were bent to conform to the narrow Corpus Christi and Aransas ship channels (Figure 1). Line 8 was jogged slightly to the north over the Lamar Peninsula so that its western extension would cross Mission Bay (Figure 1). Lines 14 and 15 were altered to overfly the Pass Cavallo and ship channel entrances into Matagorda Bay in the region of Port O'Connor, the location of a proposed *T. truncatus* study. In 12 cases the transects were interrupted by land that divided them into two or more parts, so that in all, 42 overwater crossings were flown. Eight of these crossings were 2 km or less in length while the longest was 42 km. Their average length was 10.2 km. Time of these crossings ranged from <1 to about 18 min.

Most transects were flown at 167 km/h and an altitude of approximately 152 m (500 ft). The first part of transect 1 was flown at 213 m (700 ft) to safely maneuver around large cranes and other structures. When not fully occupied with flying the plane, the pilot searched for bottlenose dolphins. An observer sat in the right front seat next to the pilot. This observer also functioned as the "navigator," talking the pilot onto transect landmarks, calling out the start and stop times for each transect, and charting the dolphin sightings. Two observers sat in the rear of the plane. The observer in the right seat mainly functioned as a recorder who kept a transect log noting the time of starting and ending of each transect and comments on visibility, weather, and other observations of interest. A sighting form was also kept in which was noted: the observer making the sighting, the nature of the observation which first alerted us to the presence of a dolphin herd, the sighting cue; the estimated numbers of adult animals and calves and their assumed behavior; and the estimated right angle, or perpendicular, distance of the sighted dolphin herds from the plane's track. While a strip transect design had been planned, the perpendicular distance estimations were essential for alternative dolphin density calculations utilizing line transect theory (Seber 1973). If time allowed, the herd configuration relative to the environment was also sketched.

Because of the low flying speed, the airplane was relatively quiet and voice communication between party members was feasible. The shortness of the transects and rest intervals between transect lines alleviated observer fatigue.

Observers searched outward to about 400 m (we estimated distances in yards). This distance was estimated with the aid of tape markings on the wing struts that had been calibrated against range marks on the landing strip. When a dolphin sighting was made, the pilot deviated from the transect line and usually orbited the herd twice while all observers counted the animals and noted the presence of calves. A consensus opinion was scored for these counts. Rarely only one circle was necessary, and on occasion three or more circuits were flown before the observers felt confident with the count. On occasion, individual animals or small herds could not be relocated and limited data based on the original sighting were logged.

Two observers worked all the flights, whereas one person was relieved as recorder-observer for the last three flights. The same pilot flew the plane on surveys 1-4. A different pilot took over on the last survey.

RESULTS

Operations

The survey design called for six replicate transect runs on successive days. The period of the operation (26 March-1 April 1978), however, was plagued by strong winds (33-46 km/h) that caused a 1-day postponement of survey 4, cancellation of survey 6, and affected the results of survey 5 to the extent that those data are of limited value (the specific effects of weather on the survey will be discussed later). Weather conditions were good to excellent on two runs, surveys 2 and 4, and marginal to fair on surveys 1 and 3. A malfunctioning airplane engine caused curtailment of the last three transects on survey 2. These were made up at the end of survey 4 under similar environmental conditions. A total of 436 track kilometers (235 n.mi.) was flown on each survey. Assuming a 402.25 m scan on each side of the aircraft, an area of 351 km^2 (102 n.mi.^{2}) was searched. With the 4.63 km transect line spacing, this would represent about 17% coverage of the survey area on any one replicate.

Dolphin Counts

During the first four survey flights 133 dolphin herds were sighted, containing an estimated 916 animals. A mean of 33.3 herd sightings per survey, composing 229 dolphins, was calculated for the four flights (Table 1). On survey 5, affected by adverse weather, only 19 herds estimated to contain 107 dolphins were sighted. Because these scores fell well below two standard deviations of the mean that was calculated for the first four replicates (Table 1), the results of survey 5 were excluded from our population calculations. Data from the last survey were used, however, for analyzing behavioral observations, sighting cues, and the perpendicular distances of dolphin herds from the trackline.

TABLE 1.—Bottlenose dolphin herd sightings, individuals, and calves estimated on surveys 1-4 Port Aransas to Matagorda, Texas.

Date (1978)	Survey number	Total no. of herds	Total no. of animals	Total no. of calves	Percent of calves
Mar. 26	1	36	175	17	9.7
Mar. 27[1]	2	36	260	17	6.5
Mar. 28	3	29	209	20	9.6
Mar. 30	4	32	272	31	11.4
Total		133	916	85	
Mean		33.3	229.0	21.3	9.3
SD		3.4	45.2	6.7	2.0

[1]The last four transects were run on March 30.

Calves

Among the animals sighted in surveys 1-4, some 85 were classified as calves, and they represented 9.3% of the total population observed (Table 1). Because the surveys were made just prior to the peak of the calving season, it was not always possible to differentiate between older calves of the year and young yearlings. Some 13 animals were in this questionable category.

Herd Size and Herd Density

While the estimated sizes of herds ranged from 1 to 42 animals, generally the aggregations were small. Groups of two and three *T. truncatus* represented the mode and composed 28.6% of all sightings, and 96 of the 133 sightings (72.2%) were composed of 7 or less animals (Figure 4).

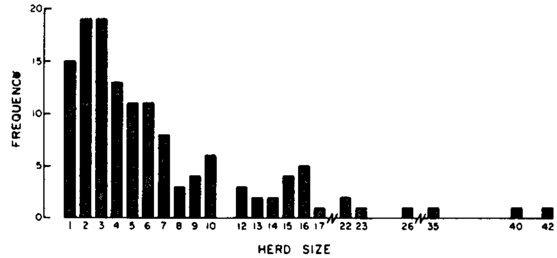

FIGURE 4.—Frequency distribution of bottlenose dolphin herd sizes on surveys 1-4, Port Aransas to Matagorda, Texas.

The mean herd size for each daily survey replicate was computed as:

$$\bar{h}_j = \sum_{i=1}^{n_j} \frac{h_{ij}}{n_j} \quad (1)$$

where $\bar{h}_j$ = mean herd size,
h_{ij} = herd size of the ith sighted herd on replicate j,
n_j = the number of herds sighted during replicate j.

The estimated herd density for each replicate was obtained from:

$$\hat{D}_j = \frac{n_j}{a} \quad (2)$$

where $\hat{D}_j$ = the estimated herd density on replicate j,
a = the surveyed area in km^2,
n_j = is defined as before.

These calculations produced a mean herd size of 6.95 and a mean herd density of 0.0947/km^2 (Table 2).

Estimated Population Size (Numbers of Dolphins)

In previous aerial assessments of bottlenose dolphin populations by Leatherwood and his coworkers, variance of the population size was calculated according to Goodman's (1960) equation for estimating the variance of a product of two independent variables. However, in these cases Goodman's equation was used to estimate variance of the mean population size over all the replicates

TABLE 2.—Basic terms and figures for population size and density estimates of bottlenose dolphin in the Texas bays resulting from replicate surveys 1-4.

Survey number (replicate)	Mean herd size ($\bar{h}_j$)	Variance mean herd size (Var $\bar{h}_j$)	Herd density (no./km²) ($\hat{D}_j$)	No. of dolphins ($\hat{N}_j$)	Variance no. of dolphins[1] (Var $\hat{N}_j$)	Dolphin density (no./km²) ($\hat{d}_j$)	Variance dolphin density[2] (Var $\hat{d}_j$)
1	4.86	0.613	0.1026	1,008	58,828	0.575	0.0175
2	7.22	0.918	0.1026	1,498	100,613	0.854	0.0326
3	7.21	1.967	0.0826	1,204	103,000	0.685	0.0334
4	8.50	2.994	0.0912	1,567	175,232	0.893	0.0569
Mean	6.95		0.0947	1,319		0.752	
SD	1.52		0.0097	260.4		0.148	
SE	0.76		0.0049	130.2		0.074	
SE from theory					[3]189.43		[4]0.1080

[1]From Equation (9). [2]From Equation (12). [3]From Equation (10). [4]From Equation (13).

and not the variances of each replicate. Quinn[9] has suggested a more refined treatment that is applicable if two conditions are met: the numbers of sightings for each replicate follows a Poisson distribution, and no real differences exist in the replicate herd densities. If these assumptions hold, a variance can then be legitimately computed for each replicate survey and these numbers pooled to produce a more precise estimate of mean population size variance. Accordingly, we proceeded as follows. The estimation of the population size for each replicate was calculated as:

$$\hat{N}_j = A\hat{D}_j\bar{h}_j \tag{3}$$

where $\hat{N}_j$ = estimated population size on replicate j,
A = total area assumed to be 5.76× of the searched area (a),
$\hat{D}_j$ = estimated herd density on replicate j,
$\bar{h}_j$ = mean herd size on replicate j.

Results are shown as "number of dolphins" in Table 2.

The computed variance of the estimated population size for each replicate was:

$$\text{Var}\,\hat{N}_j = A^2\,\text{Var}(\hat{D}_j\bar{h}_j) \tag{4}$$

which simplifies to:

$$\text{Var}\,\hat{N}_j = \left(\frac{A}{a}\right)^2 \text{Var}\,(n_j\bar{h}_j) \tag{5}$$

where a is assumed to be 17% of the total area (A).

The estimated variance of mean herd size within replicates was then estimated from:

$$\hat{\text{V}}\text{ar}\,\bar{h}_j = \sum_{i=1}^{n_j} \frac{(h_{ij}-\bar{h}_j)^2}{n_j\,(n_j-1)}\,. \tag{6}$$

Following Elliott (1971), a chi-square value utilizing the index of dispersion was computed for the number of herd sightings on replicate surveys 1-4 to test agreement with a Poisson series. The index of dispersion was 0.35 with a resulting χ^2 value of 1.05. These values support the Poisson distribution assumption. This allows us to consider the variance of replicate herd sightings as equal to the numbers of herd sightings. Thus:

$$\hat{\text{V}}\text{ar}\,n_j = n_j. \tag{7}$$

Using the chi-square test again we also found that there was no difference at the 5% significance level in the herd densities of the replicate surveys. The mean herd size ($\bar{h}_j$) and the numbers of herds sighted (n_j), however, were obtained from the same set of observations, and as one reviewer has rightly pointed out, it is not known if in fact these estimates were independent. We therefore tested for interrelationship using Spearman's Rank Correlation Test (Zar 1974). Finding no demonstrable correlation at the 5% significance level, we proceeded to treat the results of the replicate surveys generated from Equation (5) in terms of Goodman's (1960) equation for estimating the variance of a product as suggested by Leatherwood et al. (1978). Thus:

$$\hat{\text{V}}\text{ar}\,\hat{N}_j =$$

$$5^2(n_j{}^2\,\hat{\text{V}}\text{ar}\,\bar{h}_j + \bar{h}_j{}^2\,\hat{\text{V}}\text{ar}\,n_j - \hat{\text{V}}\text{ar}\,n_j\,\hat{\text{V}}\text{ar}\,\bar{h}_j)\,, \tag{8}$$

and substitution of n_j for $\hat{\text{V}}\text{ar}\,n_j$ results in:

[9]Terrance J. Quinn II, Center for Quantitative Science, University of Washington, Seattle, WA 98195, pers. commun. to S. Leatherwood, March 1978.

$$\hat{\text{V}}\text{ar}\,\hat{N}_j = 5^2(n_j^2\ \hat{\text{V}}\text{ar}\,\bar{h}_j + \bar{h}_j^2\ n_j - n_j\ \hat{\text{V}}\text{ar}\,\bar{h}_j)\ . \quad (9)$$

Before proceeding, a one-way analysis of variance with unequal sample sizes was performed on herd sizes with a $\log_{10}$ transformation for counts. No significant differences ($\alpha = 0.05$) between replicate herd sizes were found, thereby allowing the pooling of the four variances as:

$$\hat{\text{V}}\text{ar}\,\bar{N} = \hat{\text{V}}\text{ar}\left(\frac{\sum_{j=1}^{4} \hat{N}_j}{4}\right) = \left(\frac{1}{4}\right)^2 \sum_{j=1}^{4} \hat{\text{V}}\text{ar}\,(\hat{N}_j)\ . \quad (10)$$

These computations produced an estimated mean *T. truncatus* population size of 1,319 with a standard error (SE) of 189 (Table 2).

The susceptibility of the above analysis to possible nonindependence of the mean herd size and herd density parameters was recognized by Leatherwood et al. (1978), and they suggested that mean herd size be established in preliminary flights before the herd counting phase of the survey is initiated. In the case of our work, however, because of inclement weather and limited resources we decided to make as many replicate surveys as possible rather than dividing the flight functions.

Despite the assurance of ranking tests, if independence between h_j and n_j does not hold, use of Equation (9) will probably underestimate the variance of N_j. An alternative more robust approach suggested by one reviewer was to compute the SE of the replicate estimates of numbers of dolphin on the four surveys (Table 2). This procedure produces a SE of 130.0 which is reasonably close to the theoretical value of 189 obtained from Equation (9) and tempers to some extent doubts of the validity of this approach.

Estimated Dolphin Density

For comparative purposes we also estimated the density of dolphins in the study area from:

$$\hat{d}_j = \hat{D}_j\bar{h}_j = \frac{n_j}{a}\bar{h}_j\ . \quad (11)$$

The same rationale and procedures for calculating the replicate and overall variances of population estimates were used to calculate the variances for dolphin density. Thus:

$$\hat{\text{V}}\text{ar}\,\hat{d}_j = \frac{1}{a^2}(n_j^2\ \hat{\text{V}}\text{ar}\,\bar{h}_j + \bar{h}_j^2\ n_j - n_j\ \hat{\text{V}}\text{ar}\,\bar{h}_j) \quad (12)$$

and

$$\hat{\text{V}}\text{ar}\,\bar{d} = \left(\frac{1}{4}\right)^2 \sum_{j=1}^{4} \hat{\text{V}}\text{ar}\,\hat{d}_j\ . \quad (13)$$

This treatment gave an estimate of 0.752 dolphins/km^2 with an SE of 0.074. The SE calculated from the variance of the mean of the replicates was 0.108 (Table 2).

Comparisons with Other Population Studies

We can roughly compare our counts from the Aransas Pass area with those of Shane's (1977) who counted *T. truncatus* in the same area from a skiff run on a meandering course through the ship channels and cuts almost on a daily basis over a 1-yr period. For March and April 1977, her mean was 95 dolphins. The mean of our scores for transects 1 and 2 that covered part of her study area was 53. Considering the differences in methods and area covered, the results do not seem unreasonably diverse.

Our mean density estimate for all transects is compared with the results of recent aerial surveys of *T. truncatus* populations in waters adjacent to Florida, Mississippi, and Louisiana in Table 3. While it is clearly tenuous to contrast densities from different environments, it is worth noting that the two semienclosed areas, Indian River, Fla., and the Texas bays, appear to support similar densities, 0.52 dolphins/km^2 and 0.75 dolphins/km^2, respectively. The mean percent of the calves

TABLE 3.—Density estimates of bottlenose dolphin populations in southeastern U.S. coastal waters, based on recent aerial surveys. There are considerable differences in the nature and extent of the areas covered in these studies, thus the results are not strictly comparable.

Location	Reference	Dolphins per km²	Dolphins per n.mi.²
Florida			
Indian River	Leatherwood 1979	0.52	1.79
Florida[1]	Odell and Reynolds		
West coast	(text footnote 8)	0.27	0.93
Mississippi	Leatherwood et al.		
Gulf coast	(1978)	0.23	0.79
Louisiana	Leatherwood et al.		
Gulf coast	(1978)	0.44	1.51
Texas			
Gulf coast	This paper	0.75	2.57

[1]Derived from their table 10 by computing the product of mean herd size (5.43) and mean herd density (0.0497).

to the total number of animals counted (9.3 ±2.0%) is about the same as previously reported (Leatherwood 1979).

Distribution and Behavior

As can be seen from Figures 1-3 the distribution of dolphin herds in the area was hardly homogeneous. Some 28 herds (21%) of the total were sighted in the narrow Aransas Pass ship channels (mainly transect 1) and 211 (23%) of the animals counted were in these herds. (This marked difference in densities is discussed below.) Transect 18 across Matagorda Bay was another area of high dolphin density. While we noted only eight herds on this line they were relatively large and accounted for 14% of the dolphins sighted. In general, aside from the ship channels, the shoreward side of the barrier islands and locations close to the beach appeared to be favorable situations for *T. truncatus*, whereas sightings were rare in the middle of large bays.

When possible, the apparent behavior of the herds was coded as either traveling, playing, feeding, or resting. Of the 97 herds classified, about half (48.5%) were considered to be feeding. Side or upside down swimming by dolphins actively pursuing prey as reported by Leatherwood (1975) was frequently observed. This was particularly true in the shallow regions inside the barrier islands where Gunter (1954) reported that bottlenose dolphins frequently chase mullet, *Mugil cephalus*. Feeding appeared to be associated with herd size, for of the 17 herds composed of 15 or more individuals, 13 (76.5%) were considered to be feeding. The next most common behavior was "traveling," and 36 herds (37.1%) were assigned to that behavioral mode.

Perpendicular Sighting Distances and Sighting Cues

As previously indicated, in most cases we estimated the perpendicular distance from the plane's track to the sighted herd. In addition we also logged the nature of the observation which first alerted us to the presence of a dolphin herd, the "sighting cue" (Figure 5). During the field work, 11 different codes were used but these could be reduced to four classes: 1) surface perturbations such as mud trails or boils, scars, and splashes; 2) an animal's body seen below the water (most easily noted when the dolphins are rolling or swimming upside down and their contrasting light ventral surfaces are showing); 3) an animal's body, or part of it, or its condensed respiratory exhalation "blow" noted above the water surface; and 4) "cue uncertain or unnoted."

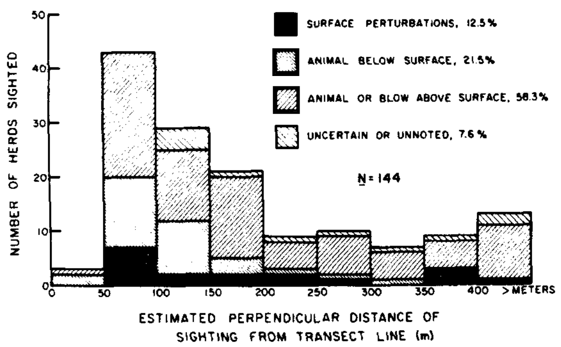

FIGURE 5.—Frequency distribution of estimated perpendicular distances of bottlenose dolphin herd sightings from transect lines on surveys 1-5, Port Aransas to Matagorda, Texas. Histograms are divided into the relative ratios of sighting cue classes.

The "animal above surface" cue was effective at all ranges and was the predominant sighting cue, accounting for 58.3% of all sightings (Figure 5). The "animal below surface" instigated 21.5% of the sightings, but was more important at ranges under 200 m, contributing 28 of the 96 sightings (29.2%) at these ranges, whereas, at ranges >200 m, only 3 of 48 sightings (6.2%) were signaled by this cue. As will be discussed later, the effectiveness of both underwater sightings and surface perturbations appeared to be vulnerable to weather conditions. Most questionable or unrecorded sighting cues occurred on the initial survey.

DISCUSSION

Possible Biases to Population Estimates

Several factors, both operational and analytical, influenced the results, in some cases prejudicing the counts upward and in others to lowering them. We first discuss two factors, effects of weather and inability to sight all herds, that tended to cause underestimates.

Relatively strong southwest winds (22-41 km/h) blew constantly for several days during the field operations. The wind's major effect on searching efficiency was not sea state, as is the case in the open ocean, for splashes were seldom the sighting cue, but rather the stirring of bottom materials into suspension creating large areas of highly turbid water. On such days the only clear water was in the lee of barrier islands and headlands where the fetch was limited.

Increased turbidity limits the observer's chances of sighting underwater animals and noting mud boils and trails. For underwater animals, however, the overall effect on the number of sightings was tempered because submerged dolphins will frequently be spotted when they eventually surface. More important was the negative influence of high turbidity on the observer's ability to note surface signs. For example, on the two low-wind days 12 out of 68 (17.7%) sightings were cued by surface perturbations. In contrast, on the three medium to high-wind days only 8 of 83 (9.6%) of sightings were signaled by this cue. The effect was probably more important than those data indicate, for frequently the observer's attention was drawn to an area by subtle surface signs and then, if a dolphin's body showed at the surface, it was usually the second rather than the first cue that was logged. As stated earlier, we have reduced the effects of weather on the population estimates by excluding the results of survey 5, when the wind effects were extreme, from the density computations.

Regarding our inability to sight all herds, the supposition that all target animals will be seen is basic to the strip transect method (Eberhardt 1978). However, in terms of line transect theory (Seber 1973), which assumes that the herds will be randomly distributed, the frequency histogram of the estimated perpendicular sighting distances (Figure 5) gives strong evidence that one of these assumptions was incorrect, probably the former, as follows. First, only 3 of 144 sightings were made at under 50 m range. The aircraft's configuration which severely limits searching the water directly under and adjacent to the flight path was the major cause of this discrepancy. (A secondary factor was discomfort to the observer's neck caused by attempting to look down at a steep angle.) The only sightings made directly under or close to the track were when the aircraft was in a steep turn, and frequently herds were noted at moderate ranges when we were circling on a previous sighting. Secondly, the systematic decrease of the sighting frequencies from 50 to 200 m, suggesting a negative exponential curve, and the "tail" out to 400 m must at least in part reflect the inherent inefficiency of the observers to see beneath the water's surface at low angles or to detect relatively small, low-contrast objects at even moderate distances.

Three factors, dolphin movement, nature of the terrain, and observer experience, may have had mixed effects on the estimates, as follows.

Regarding effects of dolphin movement between the open Gulf of Mexico and the bay behind the barrier islands, it was originally planned that volunteer observers stationed adjacent to the passes would note the numbers and directional movements of bottlenose dolphins during the hours of the survey. However, a week's delay in starting the field work and the subsequent resumption of college classes following Easter vacation made it necessary to cancel that observational phase. At the termination of survey 4, however, we flew homeward just outside Matagorda Peninsula and Island. Outside Pass Cavallo at least 50 *T. truncatus* were seen loiling in small herds in and just outside the surf zone. These dolphins may have either been moving in from the Gulf or out of the bays, but their proximity to the beach and the pass indicates that there was frequent movement of dolphins between the two environments.

Factors of bathymetry of the bays and the nature of the terrain were not considered by the analysis. While *T. truncatus* were occasionally noted in shallow water just inside the barrier islands, extensive regions in the middle of the bays and in the shoreward areas were covered with a thin layer of water over sand and mud flats and there are numerous reefs and islands. Thus, within most of the 800 m swaths used to compute the density estimates there was territory that was not available to the dolphins that could legitimately be subtracted from the area searched. On the other hand, by multiplying the searched area by 5.76 (Equation (3)) to obtain an estimate of the total number of dolphins we were sometimes attributing dolphin habitat to dry land. This is particularly true for the Port Aransas ship channels that were limited to about 600 m width and were surrounded by large land areas.

We feel that observer experience possibly also biased the accounts. *Tursiops truncatus* herds appear to occupy a home range (Caldwell 1955; Shane 1977) and we frequently sighted herds that were of similar size and in the same approximate location of herds noted on previous surveys. The observers tended to concentrate their attention on these areas and thus searched them more efficiently in the latter surveys.

Despite the smallness of the herds, it was not easy to accurately count animals that were sometimes spread over a relatively large area, and in subgroups that only showed for brief periods at the surface. Obviously, accuracy of such counts will also improve with experience. However, by scoring a consensus opinion the judgment and bias of the most experienced observer probably carried more weight, and as a result we feel that in all cases the counts were conservative. Because of the experience factor we also think that, other influences being equal, the latter surveys were probably the more accurate.

Last, one factor, the "gerrymandered" lines of transects 1 and 2, clearly tended to influence the counts upward. Our rationale for altering the line of these transects was based on the desirability of obtaining data in an area for which baseline information already was available (Shane 1977). Unfortunately, the terrain was not ideal for transect sampling, and flying an east-west line over the ship channels would have resulted in gross underestimation of an area known to hold a relatively large number of dolphins.

Clearly, the results for transects 1 and 2 (23% of the animals sighted in only 6.6% of the total area) were strikingly different from those data for the rest of the transects. Estimated dolphin density for the ship channels was 2.633/km^2, some 4.25 times greater than the 0.619/km^2 estimated for transects 3-21 (Table 4). Based on these densities the total population estimate could be partitioned into 304 dolphins for the ship channels and 1,015 animals in the rest of the area. Shane's (1977) maximum estimate for the ship channel area for any month of the year was about 280, thus the two estimates are in reasonable agreement. We still feel, however, that there were some unresolvable problems with our survey methodology as it applied to the Aransas Pass ship channels, and that the soundest procedure was to lump the results from the minority area with those from the major region, as we have done.

Alternative Density Estimate

As previously discussed, the decrease in the number of dolphin sightings at increasing ranges of the herds from the flight path (Figure 5) indicated violation of strip transect theory assumption that all herds within the delineated area were sighted. Line transect theory (Seber 1973) provided an alternative method of analyzing the results. Because there were few observations in the 0-50 m increment, creating a marked gap in the frequency distribution, and the "tail" of the frequency distribution was truncated, in part because we limited observations to about 400 m range, our data were not strictly applicable to line transect theory, either. Despite these discrepancies, however, we obtained for comparative purposes a rough approximation of the level of bias by applying a simple modification of the so-called exponential estimator (Gates et al. 1968) which corrects for the gap in the 0-50 m frequency distribution interval as follows:

TABLE 4.—The basic terms and figures for comparing the estimated bottlenose dolphin density in two parts of the survey, the Port Aransas ship channels (transects 1 and 2) and rest of the area (transects 3 to 21).

Survey number (replicate)	Total no. of herds	Total no. of animals	Mean herd size ($\hat{h}_j$)	Herd density no./km^2) ($\hat{D}_j$)	Dolphin density (no./km^2) ($\hat{d}_j$)	Variance dolphin density ($\hat{V}ar\ \hat{d}_j$)
Transects 1 and 2						
1	5	41	8.20	0.2165	2.045	1.6005
2	8	35	4.38	0.3465	1.749	0.5162
3	8	84	10.50	0.3465	4.191	5.0629
4	7	51	7.29	0.3032	2.546	2.0490
Total	28	211				
Mean	7	52.6	7.59	0.3032	2.633	
SD	1.4	21.9	2.53	0.0613	1.090	
SE	0.7	10.9	1.27	0.0307	0.545	
SE[1]						0.8750
Transects 3 to 21						
1	31	134	4.32	0.0946	0.471	0.0121
2	28	225	8.04	0.0854	0.791	0.0350
3	21	125	5.95	0.0641	0.439	0.0133
4	25	221	8.84	0.0763	0.776	0.0552
Total	105	705				
Mean	26.3	176.3	6.79	0.0801	0.619	
SD	4.3	54.1	2.05	0.0130	0.190	
SE	2.1	27.0	1.03	0.0065	0.095	
SE[1]						0.0980

[1]From Equation (13).

$$\hat{d} = \frac{n}{2L(\bar{Y} - 0.05)} \tag{14}$$

where $\hat{d}$ = estimated dolphin density,
n = total number of dolphin sightings,
L = length of the track line in km,
Y = mean perpendicular sighting distance (minus the 50 m gap).

These calculations gave a density estimate for herds of 0.28/km^2 compared with 0.095 for the strip transect method (Table 2), evidence that the latter method may have underestimated the dolphin density by about a factor of 3.

In conclusion, the relatively few sightings in the 0-50 m perpendicular distance interval and the exponential decrease in sightings at ranges >100 m, strongly indicate violation of the strip transect assumption that all herds within the delineated strip were noted. If this is true then the population has been underestimated to some degree, although the inclusion of transects 1 and 2 would tend to compensate for this. Conversely, one assumption of line transect theory is that the targets are randomly distributed. We found, however, that the distribution of the dolphin herds was strongly nonrandom. This factor may have caused an upward bias to those calculations, but the precise impact of this violation is presently unclear. These questions cannot be resolved until further surveys are done simultaneously with adequate "ground truth" counts.

ACKNOWLEDGMENTS

This study was a collaborative effort among organizations within the NOAA's National Marine Fisheries Service, the Marine Mammal Commission, Dinnes Memorial Veterinary Hospital, Sea Arama Marineland of Galveston, and the Naval Ocean Systems Center. We thank the administrators of these organizations for expediting the work. We are also indebted to James McGrew for his excellent piloting and Terrance Quinn II for his suggestions. Gary Stauffer advised on statistical matters; the art work was done by Kenneth Raymond and typing by Lorraine Prescott, all of the Southwest Fisheries Center. The originally submitted draft of this paper was read by William Fox, Joseph Powers, and Nancy Lo of the Southwest Fisheries Center and Pat Tomlinson of the Inter-American Tropical Tuna Commission. Following editorial review, Tim Smith of the Southwest Fisheries Center consulted with the senior author on additional statistical work in response to suggestions by the referees. We also thank Lee Eberhardt of Battelle Pacific Northwest Laboratories as well as an anonymous reviewer and the editor for their constructive comments and suggestions. Despite the many contributions from the junior authors, advisors, and reviewers, the senior author, of course, assumes full responsibility for the contents of this paper.

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