

DISTRIBUTION AND ABUNDANCE OF THE BOTTLENOSE DOLPHIN, *TURSIOPS TRUNCATUS* (MONTAGU, 1821), IN VIRGINIA¹

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ABSTRACT

The distribution and abundance of the bottlenose dolphin, *Tursiops truncatus*, was examined by conducting aerial surveys of the Chesapeake Bay mouth and nearshore coastal waters of Virginia in 1980 and 1981. Bottlenose dolphin density was estimated using line transect methods and a 4-term Hermite polynomial was chosen to model the detection function. Six surveys in the Chesapeake Bay mouth resulted in an average density estimate of 0.159 dolphins/km². Ten surveys along the southern Virginia coast produced an average density estimate of 3.446 bottlenose dolphins/km² within 2 km of shore. Average bottlenose dolphin abundance in the Chesapeake Bay mouth and along the southern Virginia coast was estimated at 340 dolphins (± 104 , 95% C.I.). An estimate of 0.208 bottlenose dolphins/km² along the northern Virginia coast is tenuous because only one survey was conducted there. Dolphin sightings were distributed uniformly along the southern Virginia coast with the exception of some clustering of herd sightings at the capes bordering the Chesapeake Bay mouth. The percentage of calves per herd averaged 7.5% in Chesapeake Bay mouth, 4.3% in the southern coastal area, 9.0% in the northern coastal area, and peaked in June. Five of seven bottlenose dolphins identified by unique dorsal fin shapes in 1980 were resighted in 1981, suggesting seasonal residency of individuals.

Of the 23 cetacean species occurring along the Virginia coast (Leatherwood et al. 1976; Blaylock 1985) the bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821), is the only cetacean found near shore regularly and in large numbers. However, there are few quantitative data available to assess the abundance, distribution, and seasonal occurrence of *Tursiops truncatus* (hereafter referred as *Tursiops*) in Virginia coastal waters.

Those bottlenose dolphins occurring seasonally in Virginia are believed to form part of a population distributed from northern North Carolina to New Jersey during the summer. This population was the focus of a sporadic fishery along Hatteras Island, NC from circa 1797 to 1929, the primary products of the fishery being hides and oil (True 1891; Townsend 1914; Mead 1975). From cumulative catch records, Mitchell (1975) estimated a historical population size of 13,748–17,000 dolphins and inferred annual migration from biannual peaks in catches during the fall and spring. True (1891) earlier suggested a north-south migration, reporting on fishermen's observations that bottlenose dolphins were usually seen traveling south in the fall and north in

the spring, with only a few remaining near Hatteras during the summer.

Analysis of large-scale aerial surveys along the northern and mid-Atlantic U.S. coast revealed a bimodal longitudinal *Tursiops* distribution, interpreted as separate nearshore and offshore areas of abundance (CETAP 1982). These areas represent the habitats of two distinct morphological types of *T. truncatus*. The offshore type is slightly larger at the onset of physical and sexual maturity than the nearshore types and ultimately attains a greater size³.

An important finding of the CETAP surveys was the presence of multiple latitudinal peaks in coastal sightings indicating discontinuities in the north-south distribution of nearshore *Tursiops* (CETAP 1982). These observations indicate either an uneven distribution of nearshore *Tursiops* or the presence of multiple coastal populations or subpopulations. However, a recent epidemic suggests that the U.S. east coast *Tursiops* may represent a single stock.

Tursiops mortalities south of North Carolina during autumn of 1987 increased sharply with the apparent emigration of *Tursiops* from Virginia

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waters.⁴ If the high level of *Tursiops* mortalities experienced in the mid-Atlantic coast during the summer of 1987 was because of an infectious agent, then its spread to conspecifics in more southerly regions may have been caused by contact between individuals from different areas and more extensive migration than has been previously suggested.

In the present study I used aerial surveys to estimate the abundance and examine the distribution of *T. truncatus* in Virginia coastal waters, including the Chesapeake Bay mouth. I also investigated natality periods by monthly comparison of the average percentage of calves present and residency patterns using photographic records of identifiable individuals.

METHODS

Aerial surveys were conducted during July–October 1980, and May–June 1981, from a high-winged, single-engine aircraft (U6A DeHavilland Beaver⁵) at an altitude of 152 m and at an air-speed of 147 km/h. Observers sitting in the two passenger seats searched each side of the transect for bottlenose dolphins. A recorder/navigator sitting forward of the observers and next to the pilot helped to maintain predetermined transect lines and recorded sightings which were communicated via intercom.

Upon sighting a bottlenose dolphin herd, the perpendicular distance from the flight path to the herd center was determined from calibrated, taped markings on the wing struts with the aircraft in level flight or a hand-held inclinometer. The transect was then temporarily halted and the herd circled at a lower altitude to count individuals. The herd location, direction of travel, behavior, and the number of calves were also noted. Transect lengths and the survey area were measured with a digital planimeter from NOS/NOAA navigation charts.

Depending upon the area surveyed (Fig. 1), two types of survey schemes were used. Systematic, latitudinally oriented transects were used in the Chesapeake Bay mouth (CBM) during 1980. The northern starting point for each survey was randomized, and each transect was located 7.4 km south of the previous transect. Two exceptions to this regime oc-

curred, but in neither case was the distance between transects less than 3.7 km. Three or four transects were flown during each CBM survey and each survey covered approximately 30% of the total survey area. CBM surveys were not conducted in 1981.

Longshore surveys were flown from north to south in 1980 and 1981, parallel to the coast and 1 km offshore from Cape Charles to False Cape (32.3 km). Those conducted in 1980 were flown immediately upon completing the CBM surveys so that there was no possibility of counting herds in the longshore area that were counted during CBM surveys, except perhaps during transit between Cape Charles and Cape Henry, which was flown over open water on the shortest line between the two points. One additional survey was flown along the northern Virginia coast.

After subtracting the minimum distance from the transect that could be observed because of limited visibility directly beneath the aircraft, the perpendicular sighting distance data were truncated at 1 km. Data from all three study sites were then pooled for the calculation of $g(x)$, the detection function for line transect, and $[\hat{f}(0)]$, the probability density function of perpendicular sighting distances evaluated at the transect. In line transect the detection function $g(x)$ is the conditional probability of observing an object at perpendicular distance x from the transect line and $f(x)$ is $g(x)$ scaled to integrate to one (Burnham et al. 1980). Each survey was treated as a replicate to determine the analytical variance of $\hat{f}(0)$. Herd density was then calculated separately for each of the survey areas using $\hat{f}(0)$ estimated from the pooled sightings.

Several estimates of $\hat{f}(0)$ and its analytical variance were calculated by fitting parametric and nonparametric models to the distribution of perpendicular sighting distances using the Fortran programs TRANSECT (Laake et al. 1979) and HAZARD and HERMITE (Buckland 1985). Maximum likelihood estimates and large-sample variances were found using the procedure of Burnham et al. (1980: 135–136). The Fortran program SIZE-TRAN (Drummer and McDonald 1987) was used to test the hypothesis of independence between herd size and perpendicular sighting distance using a likelihood ratio test and thus determine if the detection function was biased by herd size.

Herd density was estimated as (Burnham et al. 1980, p. 18, eq. 1.3):

$$\hat{D} = n\hat{f}(0)/2L$$

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⁵Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

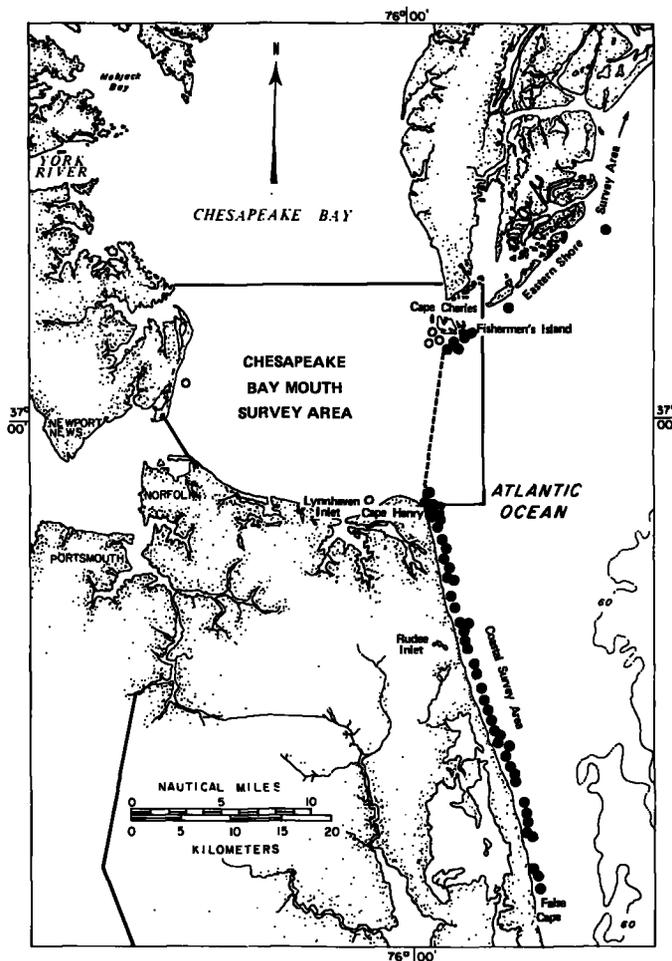


FIGURE 1.—Coastal survey areas and bottlenose dolphin sightings (closed circles) and Chesapeake Bay mouth survey area (enclosed by dark lines) with dolphin sightings (open circles). Dashed line represents transit during coastal surveys. Sightings near Fishermen's Island and Cape Henry which occurred during coastal surveys were included only in the coastal survey analyses.

where n is the number of herds detected and L is the transect length in kilometers. The variance of \hat{D} was estimated as (Burnham et al. 1980, p. 51, eq. 1.17):

$$S^2(\hat{D}) = \hat{D}^2[(\hat{c}v(n))^2 + (\hat{c}v(\hat{f}(0)))^2].$$

Herd size was not significantly different between study areas (Kruskal-Wallis test (K-W test), $\chi^2 = 0.9953$, $df = 2$, $P = 0.61$, Sokal and Rohlf 1981) and sightings were pooled to determine the overall mean herd size. Herd sizes were not normally distributed (Fig. 2) and therefore were normalized by log trans-

formation to calculate the geometric mean (Sokal and Rohlf 1981) and its variance. Bottlenose dolphin density (\hat{P}) is the product of herd density (\hat{D}) and mean herd size (\bar{H}). The variance of \hat{P} , following Goodman (1960, p. 710, eq. 7) is

$$\hat{s}^2(\hat{P}) = \frac{\bar{H}^2 s^2(\hat{D})}{n(\hat{D})} + \frac{\hat{D}^2 s^2(\bar{H})}{n(\bar{H})} - \frac{s^2(\hat{D}) s^2(\bar{H})}{n(\hat{D}) n(\bar{H})}$$

with $n(\hat{D})$ equal to the number of herd sightings in the survey area and $n(\bar{H})$ equal to the number of herds used in the estimation of \bar{H} . This assumes

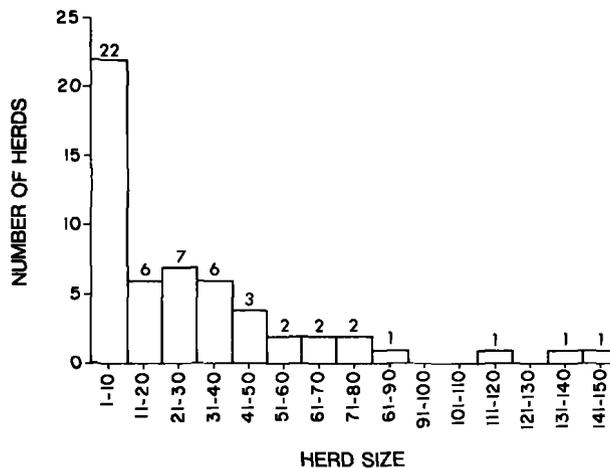


FIGURE 2.—Distribution of bottlenose dolphin herd sizes. Numbers above bars denote the number of herds in that size class.

independence between herd size and perpendicular sighting distance.

Bottlenose dolphin abundance is the product of \hat{P} and the area surveyed. In the CBM area this may be extrapolated to the total area if the transects are distributed randomly with respect to dolphin sightings.

The recorder did not distinguish between observer's sightings when recording them, thus observer bias was not investigated. The effects of sea state and sun glare on detectability were not investigated. Surveys were not conducted when sea states were above two on the Beaufort scale, and it is unlikely that sea state influenced the results. However, the effect of glare reduced the observers' field of view, which decreased the number of animals detected and resulted in an underestimation of \hat{P} .

I conducted photographic surveys from a 7 m boat on five occasions in 1980 and six in 1981 for the purpose of identifying individual bottlenose dolphins by the shape of, or markings on, their dorsal fins. Contact prints of the 35 mm photographs were examined under a dissecting microscope at 40× magnification.

RESULTS

Six aerial surveys in the CBM averaged 119.4 km per survey, covered an area of 762 km², and resulted in five herd sightings of bottlenose dolphins. Ten surveys along the southern Virginia coast resulted in 49 herd sightings. Each coastal survey was 32.3 km in length and covered an area of 65 km².

An additional survey along the northern Virginia coast was 108 km in length, covering an area of 216 km², and resulted in two herd sightings.

In line transect the distance at which a bottlenose dolphin herd is sighted is assumed to be independent of its size (Burnham et al. 1980; Seber 1986). Although it seems reasonable that larger herds would be detected at greater distances, analysis of herd size and sighting distance using the method of Drummer and McDonald (1987) showed no significant size-bias ($P \geq 0.05$). As a check, I also regressed herd size against perpendicular sighting distance. There was no apparent association between herd size and distance from the transect ($r^2 = 0.001$) (Fig. 3). The geometric mean herd size was 14.4 bottlenose dolphins/herd (SE = 4.0, $n = 56$).

Truncation of bottlenose dolphin sightings at 1 km resulted in the discarding of one herd sighting in the southern coastal area, none in the CBM, and one in the northern coastal area. The truncated sighting in the northern coastal area was at approximately 1,200 m from the transect and the herd was apparently feeding in the wake of a trawler, thus the sighting was atypical of other sightings during this study and probably influenced by the presence of the trawler (see Leatherwood 1975). Both sightings in this area occurred farther offshore than sightings in the other study areas.

Several parametric and nonparametric models were investigated for fit to the pooled perpendicular sighting distances (Table 1). None of the models differed significantly from the observed distance distributions (chi-square test, $P > 0.05$). The coefficient

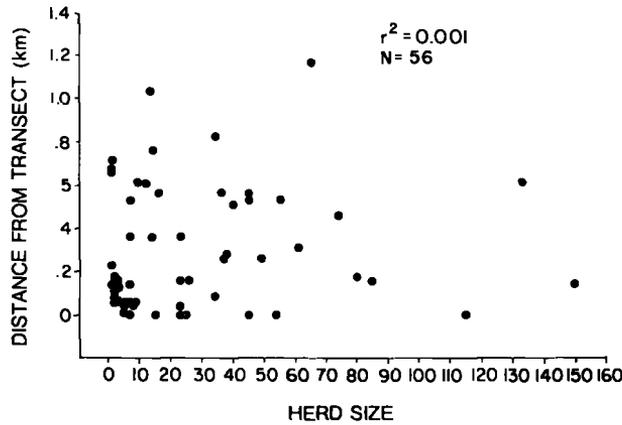


FIGURE 3.—Scatterplot of sighting distance (in kilometers) versus herd size of bottlenose dolphins. (Note that some of the points in the 1–10 size class and the interval 0–0.2 km represent more than one herd.)

TABLE 1.—Models used in calculation of the detection function $g(x)$ for bottlenose dolphin. N is the number of terms used in the model and $\hat{f}(0)$ is $f(x)$ evaluated at the transect. $SE[\hat{f}(0)]$ was calculated assuming asymptotic normality with $Z = 1.96$.

Model	N	$\hat{f}(0)$	$SE[\hat{f}(0)]$	Reference
Hermite polynomial	3	2.849	0.441	Buckland 1985
Hermite polynomial	4	3.104	0.522	Buckland 1985
Hazard rate	na	3.004	1.345	Buckland 1985
Fourier series	4	3.323	0.551	Burnham et al. 1980
Negative exponential	na	3.216	0.936	Burnham et al. 1980
Exp. power series	2	3.649	2.198	Burnham et al. 1980
Exp. polynomial	2	3.001	0.866	Burnham et al. 1980
Half normal	na	1.950	0.398	Burnham et al. 1980

of variation of the 3-term Hermite polynomial was slightly less than that of the 4-term (0.154 vs. 0.168), but the 4-term Hermite polynomial model provided a better fit to the observed perpendicular sighting

distance distribution than either the 3-term Hermite polynomial or the 4-term Fourier series models (Table 2).

The appropriate model for the observed perpendicular sighting distances should fit the data most closely near the centerline of the transect (Schweder 1977). The 4-term Hermite polynomial model closely approximates the observed sighting distances in the interval 0–200 m and also in the subsequent intervals (Fig. 4).

The nonparametric 4-term Hermite polynomial model yielded an estimate of $\hat{f}(0) = 3.104$ ($SE = 0.522$). Dolphin density in the southern Virginia coastal area (3.446 dolphins/ km^2) was much greater than that in the CBM area (0.159 bottlenose dolphins/ km^2); however, the abundance estimates are of similar magnitude (219 vs. 121 bottlenose dolphins, respectively) due to the greater area sampled

TABLE 2.—Observed and expected distribution of bottlenose dolphin herd sightings by distance intervals perpendicular to the transect (PSD in meters) with chi-square values. Figures in parentheses are degrees of freedom. Expected values are rounded to one decimal place for clarity of presentation.

PSD (m)	Observed	4-term Hermite		3-term Hermite		4-term Fourier series	
		Expected	χ^2	Expected	χ^2	Expected	χ^2
0–200	27	27.2	0.120E-2	26.1	0.320E-1	27.4	0.698E-2
200–400	10	9.8	0.441E-2	11.1	0.117	7.4	0.913
400–600	9	9.4	0.205E-1	8.2	0.803E-1	11.6	0.593
600–700	5	4.4	0.819E-1	4.5	0.423E-1	4.9	0.273E-2
700–800	2	2.3	0.338E-1	3.3	0.819	1.9	0.197E-2
800–1,000	1	1.0	0.400E-3	0.9	0.169E-1	0.7	0.114E-2
Cumulative χ^2			0.137 (1)		1.108 (2)		1.519 (1)

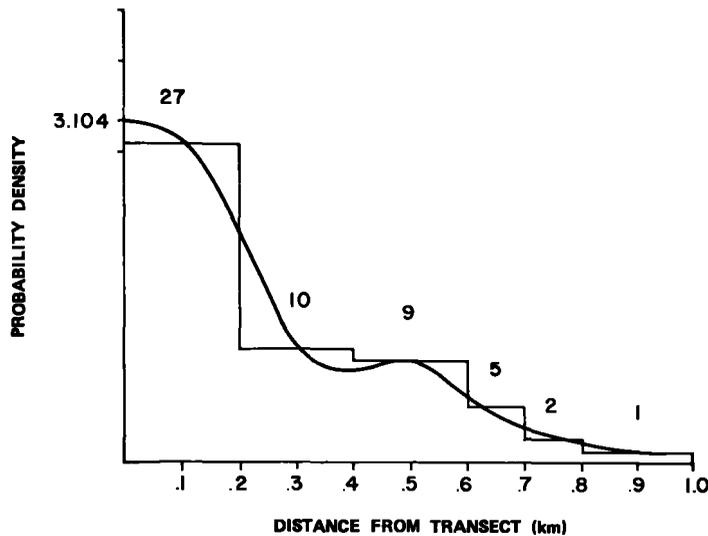


FIGURE 4.—Four-term Hermite probability density function fit to histogram of bottlenose dolphin sighting frequency and perpendicular distance (rescaled to account for the "blind spot" beneath the aircraft). Numbers above bars denote number of sightings in interval.

in the CBM (Table 3). CBM and coastal surveys were flown sequentially with no delay between them and the relatively high speed of the aircraft prevented counting of the same herd twice. Therefore, the abundance estimates in the CBM and the southern coastal survey areas may be considered additive and totaled 340 bottlenose dolphins (± 104 , 95% C.I.).

The survey altitude limited observations of herd composition to the percentage of calves in each herd. Bottlenose dolphins much smaller than the others and accompanied by a larger bottlenose dolphin were considered to be calves. The mean percentage

of calves in all herds from all study areas peaked in June at 9.5% (SE = 0.8, $n = 3$) and declined thereafter until September (Fig. 5); however, there were no significant differences between months (K-W test, $\chi^2 = 9.1930$, $df = 5$, $P > 0.10$). Considering the total study period, the mean percentage of calves in herds in the CBM area was 7.5% (SE = 3.2%, $n = 5$); in the southern coastal area, 4.3% (SE = 1.0%, $n = 49$); and in the northern coastal area, 9.0% (SE = 1.8%, $n = 2$). The mean percentage of calves in herds did not differ significantly among areas (K-W test, $\chi^2 = 2.8196$, $df = 2$, $P = 0.24$).

Bottlenose dolphins were never sighted more than 1.6 km from shore during CBM surveys nor during subsequent surveys up to 8 km offshore of the coastal study area. Also, bottlenose dolphins were not found in depths greater than 10 m except in the Eastern Shore area. Plotting of bottlenose dolphin sightings (Fig. 1) shows a uniform distribution along the southern coastal area with some clusters of sightings at Cape Henry and at Cape Charles.

During 1980, seven bottlenose dolphins which were recognizable by the shape of the trailing edge of their dorsal fins were identified and photographed. In 1981, 17 individuals identified from dorsal fin photographs included 5 which had been photographed in 1980. Thus, of the 19 recognizable

TABLE 3.—Summary of aerial survey results of bottlenose dolphins. N is the number of surveys; L is the total length of transects at each location in km; and n is the number of herd sightings within one km of the transect. \hat{D} is estimated herd density (herds/km²); $\hat{\rho}$ is estimated dolphin density; and \hat{A} is estimated dolphin abundance (standard errors in parentheses).

Survey location	N	L	n	\hat{D}	$\hat{\rho}$	\hat{A}	$\pm 95\%$ C.I.
Chesapeake Bay mouth	6	717	5	0.011 (0.003)	0.159 (0.017)	121 (13)	33
Southern Virginia coast	10	323	48	0.239 (0.063)	3.446 (0.193)	219 (54)	122
Eastern Shore	1	108	1	0.014 (0.004)	0.208 (0.058)	45 (13)	—

individuals present during either of those two years, at least 26% were present at some time during both summers.

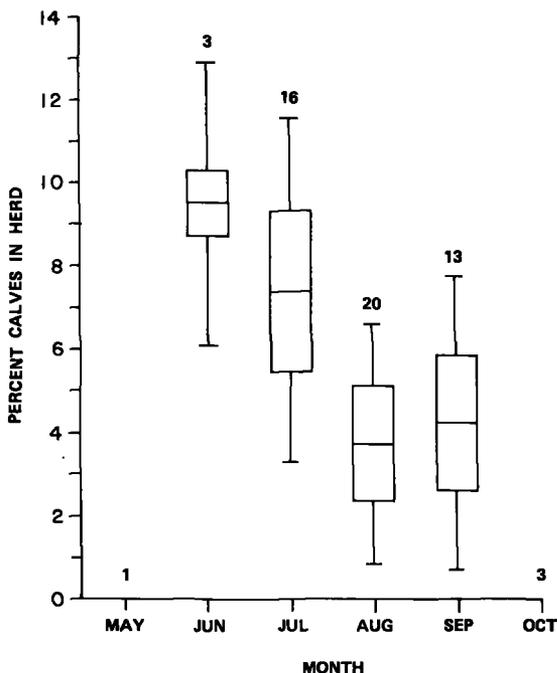


FIGURE 5.—Percentage of bottlenose dolphin calves in herds by month. Bars represent the standard error of the mean (horizontal line within bars) and vertical lines, 95% confidence intervals. Numbers above bars denote the number of herds sighted per month.

DISCUSSION

The choice of a model for $g(x)$, the probability of detecting an object at a distance x from the transect, is the primary analytical consideration in a line transect estimate of density (Burnham et al. 1980; Seber 1982, 1986). Burnham et al. (1980) thoroughly review the subject of density estimation from line transect surveys and recommended the Fourier series as a general model for $g(x)$. However, additional models which meet their criteria have since been proposed (Buckland 1985; Seber 1986). Buckland (1985) suggested the use of a model where the cosine terms in the Fourier series equation are replaced by Hermite polynomials.

Buckland (1985) warned that if the model requires four or more terms to fit the distributional data, one or more of the assumptions of line transect theory may be violated. I suggest that, in aerial surveys

of cetaceans, the primary assumption that all objects on the transect are observed with a probability of one [$g(0) = 1$] is routinely violated. The diving behavior of cetaceans during different activities may vary widely, thus the probability of the animals being at the surface when the observers pass may also vary. Also, active dolphins may be more readily detected than resting dolphins. In spite of this, this assumption is somewhat less restrictive than the primary assumption of strip census which assumes that all objects within the strip are detected. If the other assumptions are met, the major consequence of failure to meet the assumption of $g(0) = 1$ is that density will be underestimated.

A further assumption is that perpendicular distances are measured without error. Even using an inclinometer, vertical motion of the aircraft and inaccuracy of the altimeter introduce error into distance measurements. Grouping distance measurements into discrete intervals is a logical way in which to compensate if the model used is robust to grouping.

The assumption of random location of transects with respect to bottlenose dolphin distribution was met by randomization of the starting point of each survey in the CBM. It is obvious from the cluster of sightings at Cape Henry and Fisherman Island that bottlenose dolphins were not distributed randomly in the coastal study area (Fig. 1). This could occur if bottlenose dolphins were counted more than once; however, their movement was slow compared with that of the observers and, because longshore surveys were flown immediately upon completion of CBM surveys, it is unlikely that dolphins were counted more than once. It is more likely that the cluster of sightings was because of an environmental factor, such as the attraction of dolphins to concentrations of prey in fronts between estuary and ocean waters.

According to Essapian (1963), mating by the bottlenose dolphin occurs in the spring and birth occurs about one year later (McBride and Kritzler 1951; Tavalga and Essapian 1957). Mead (1975), citing True (1891), stated that "Information received from the fishermen at the Hatteras fishery indicated that fetuses were generally small in September, increasing in size as the season progressed." This implies that natality occurs primarily in the spring. Townsend's (1914) data (also cited in Mead 1975) suggest an additional autumn peak in natality. The June peak in the percentage of calves agrees with those observations suggesting a spring natality peak; however, because of the slight increase in the

percentage of calves in September, a second autumn peak cannot be ruled out.

Resighting of 26% of the identifiable bottlenose dolphins in 2 successive years is evidence that some of these return to the same area. Although the probability of resighting individuals twice in 2 successive years is low if the individuals are transient, knowledge of the length of stay is required to infer seasonal residency. A study similar to that conducted on bottlenose dolphins in Argentina (Würsig and Würsig 1978) could provide information on the length of individual residency and should be considered. This would facilitate interpretation of the data presented here, as well as that gathered from currently ongoing surveys.

Because of the violation of several important assumptions, the accuracy of the density and abundance estimates reported here is difficult to assess. The CETAP (1982) summer average density estimate of nearshore *Tursiops* in the mid-Atlantic region was 0.0093 dolphins/km². This is much lower than my estimate of 0.159 dolphins/km² in the Chesapeake Bay mouth and 3.446 dolphins/km² in the southern coastal region. Besides differences in survey altitude and airspeed, one possible reason for this discrepancy is the larger area surveyed during the CETAP program. If the coastal *Tursiops* are generally found close to shore (within 2 km) and the area surveyed extends far beyond this distance, then the density of coastal *Tursiops* in its typical habitat will be underestimated. Alternatively, a heterogeneous coastal distribution could account for this discrepancy.

The importance of an average bottlenose dolphin density estimate which may be used as an index of abundance has recently been emphasized by an incidence of disease which resulted in the deaths of over 200 *Tursiops* along the Virginia coast and over 400 along the Mid-Atlantic Bight during the summer of 1987.⁶ The rather large gap in the coastal *Tursiops* abundance data base renders assessment of the impact of the 1987 mortalities on local *Tursiops* stocks problematic. Future monitoring of the coastal *Tursiops* may provide answers as to the rate of recovery and allow assessment of the impact of future catastrophic events. A coordinated, long-term program to monitor coastal *Tursiops* abundance would permit temporal comparisons of abundance indices and provide a greater understanding of natural population fluctuations. Because the coastal *Tursiops*

inhabit an area where human activity is rapidly increasing, such a monitoring program should receive high priority.

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⁶J. G. Mead, Division of Mammals, Smithsonian Institution, Washington, DC, pers. commun. June 1988.

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