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Estimates of Dolphin Abundance in the Eastern Tropical Pacific: Preliminary Analysis of Five Years of Data

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ABSTRACT

Large-scale research vessel surveys were conducted annually from 1986 through 1990 by the US National Marine Fisheries Service to monitor the abundance of dolphin populations in the eastern tropical Pacific Ocean. The species of primary interest for the surveys were dolphin stocks taken incidentally by tuna purse seiners. A stratified analysis gave estimates of abundance of nine stocks of four species (spotted, spinner, striped, and common dolphins), using line transect methods, for all five years. No significant trends in population size were detected for any dolphin stock during 1986–90, although the statistical power of detecting a trend was low.

KEYWORDS: SMALL CETACEANS; SPOTTED DOLPHIN; SPINNER DOLPHIN; STRIPED DOLPHIN; COMMON DOLPHIN; EASTERN TROPICAL PACIFIC; SURVEY - SHIPBOARD; ASSESSMENT

INTRODUCTION

Dolphins from several stocks are killed during tuna purse-seining operations in the eastern tropical Pacific (ETP). The major populations affected by the fishery are the northern offshore stock of spotted dolphins, *Stenella attenuata*, and eastern and whitebelly stocks of spinner dolphins, *S. longirostris* (Smith, 1983). Common dolphins (*Delphinus delphis*), striped dolphins (*S. coeruleoalba*), and Fraser's dolphins (*Lagenodelphis hosei*) are also taken.

In 1986, the US National Marine Fisheries Service (NMFS) initiated a long-term, large-scale research program to monitor the abundance of dolphin populations in the ETP. The program utilises two research vessels annually for 120 days each. Surveys were carried out in 1986, 1987, 1988, and 1989, and the results have been published (Holt and Sexton, 1989; 1990a; b; Gerrodette and Wade, 1991; Sexton *et al.*, 1991). In 1990, the NMFS conducted the fifth survey utilising the same vessels during the same seasons. Here we present abundance estimates for the new data from 1990, as well as for the previous four years of data, using a stratified analysis incorporating line-transect methods that differs from previous publications.

MATERIALS AND METHODS

Study area and survey methods

The surveys were designed to be replicated each year as closely as possible. The surveys covered the same areas at the same season, using the same methods, the same vessels, and even many of the same observers each year. The outside boundary of the study area was described by Au *et al.* (1979). The study area was partitioned into four areas or strata: inshore, middle, west, and south (Fig. 1). The size of each stratum was calculated by Holt and Sexton (1990b). The number of ships, the total amount of survey effort needed to achieve a given precision of estimation, and the allocation of survey effort by stratum were described in Holt *et al.* (1987).

In 1990, the NOAA research vessels *David Starr Jordan* and *McArthur* traversed randomly placed predetermined tracklines in the ETP from 28 July through 6 December (Fig. 1). Each ship was scheduled to spend 120 days at sea, surveying tracklines similar to the previous four years. Detailed data collection procedures and data summaries for each ship are presented by Hill *et al.* (1991a; b).

Each vessel had two teams consisting of three observers each. The teams alternated watch every two hours. While on duty, two observers from the team used 25X binoculars to search from directly ahead to abeam of their respective sides of the ship. The third observer served as data recorder and searched directly ahead of the ship when not recording data. Each member of the team spent approximately equal time at each of these duty stations. Observers switched vessels at the mid-point of the cruises.

When a school was initially detected, the observers estimated the angle and radial distance to the school. When possible, schools were approached and observers recorded independent 'best' estimates of school size. When weather conditions were suitable, a *Hughes* 500D helicopter, based aboard the *Jordan*, was used to photograph schools whose sizes were estimated by the observers. Analyses comparing observer estimates to counts from the photographs are currently being conducted. The photographs will be used to calibrate observer estimates of school sizes.

Abundance estimation

Estimates of population abundance (N_j) of stock j were computed by line-transect methods (Burnham *et al.*, 1980) as:

$$N_j = \sum_{k=1}^{4} \frac{n_{jk} f_j(0)}{2 L_k} S_{jk} A_k \qquad (1)$$

where

n_{jk} = number of schools of stock j in stratum k,
$f_j(0)$ = detection function of stock j evaluated at zero distance,
S_{jk} = mean school size of stock j in stratum k,
L_k = total effort in stratum k in kilometres,
A_k = total area in stratum k in square kilometres.

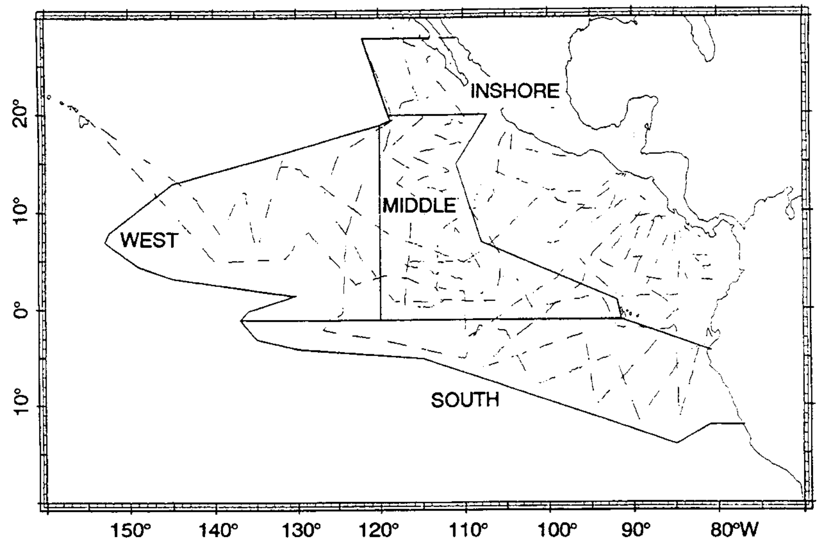

Fig. 1. Study area for the stratified survey of dolphins in the eastern tropical Pacific Ocean. Tracklines traversed while on searching effort by the NOAA vessels *David Starr Jordan* and *McArthur* during the 1990 survey are shown. Tracklines were similar in other years.

This represents a stratified analysis, where only dolphin sightings from stock j were used to calculate the density and therefore abundance of stock j within stratum k, with the abundance summed across the four strata for a total estimate for the stock.

The only exception to the stratification was the estimate of $f(0)$, which was based on perpendicular distances pooled across strata within a stock due to inadequate sample sizes. This resulted in only one estimate $f_j(0)$ for each stock j, and so the same estimate is used in the formula in each stratum. Some stocks had inadequate sample sizes even after pooling across strata. In such cases we also pooled across stocks within a species to obtain an adequate sample size. Details for each stock are explained below. A hazard rate model (Hayes and Buckland, 1983; Buckland, 1985) was fitted to the data to estimate $f_j(0)$.

The variance of N_j was estimated using bootstrap methods (Efron, 1982). Within each stratum, the total distance of searching effort (L_k) was tabulated, and then legs of effort were randomly selected with replacement until the amount of effort equalled L_k. This effort and the associated sightings were used to calculate $f_j(0)$, S_{jk}, n_{jk} and finally N_j. This process was repeated 200 times. The variance of N_j was calculated using these 200 estimates. A 90% confidence interval on N_j was estimated by the central 90% of the bootstrap estimates.

Data selection

Legs of effort from Beaufort states 0–5 were used, discarding a small amount of Beaufort 6 effort. Only schools detected within 7.4km (4.0 n.miles) perpendicular distance of the trackline were used. This resulted in the elimination of approximately 2% of the sightings, depending upon stock and year, which was within the 1–3% range recommended by Burnham *et al.* (1980). A 7.4km truncation point provided an adequate fit of the hazard model to the perpendicular distance distributions. The perpendicular distances were grouped into ten bins for the analysis, with the first four bins 0.46km (0.25 n.miles) wide and the rest 0.926km (0.5 n.miles) wide.

For each sighting, from one to six observers estimated school size, with the most frequent number being three. Therefore, school size estimates were averaged across observers to obtain the mean of their 'best' estimates. Sightings without any 'best' estimate of school size were not used.

Stock identification

Boundaries for each stock within the study area were described by Perrin *et al.* (1985). The current analysis used their boundaries for spotted and spinner dolphins and their recommended management unit boundaries for common and striped dolphins. The only exception, on the recommendation of Perrin *et al.* (1991), was that only one whitebelly stock was recognised rather than separate northern and southern stocks. In addition, since insufficient information existed to distinguish sightings of offshore and Baja neritic common dolphins consistently, all common dolphin sightings in the north were pooled into one estimate. This left three spotted dolphin stocks (northern offshore, southern offshore and coastal), three spinner dolphin stocks (eastern, whitebelly and Central American), three common dolphin stocks (northern including Baja neritic, central, and southern), two striped dolphin stocks (northern and southern) and one stock of Fraser's dolphins. Too few coastal spotted (14 total identified in 5 years) and Fraser's dolphin (22 in 5 years) sightings were made to estimate the abundance of those stocks. The stock of Central American spinner dolphins, previously referred to as Costa Rican spinner dolphins but recently given sub-specific status as *Stenella longirostris centroamericana* (Perrin, 1990), was not readily identified in the field. Additionally, the research vessels spent little time in its coastal stock area. No estimate of abundance was possible for this stock, as no identified sightings and few unidentified spinner sightings in the Central American stock area were made. Estimates of abundance were thus made only for the nine remaining stocks.

Stocks were based on morphological differences from the study of specimens (Perrin *et al.*, 1985; 1991), but in the field, most sightings of a species were assigned to a stock on the basis of where the sighting was made. However, some stocks of the same species overlapped geographic areas and were, under good conditions, identifiable in the field. The overlapping stocks included (1) coastal and northern spotted and (2) eastern and whitebelly spinner. On the basis of observations recorded in the field, sightings of these species were either coded as having been visually identified as of a particular stock or were recorded as being an unidentified sighting of that species. An unidentified sighting, however, could still be assigned unambiguously to a stock unless it occurred in the overlap zone between two stocks.

Therefore, unidentified spinner sightings outside of the overlap zone between the two stocks were assigned either to the eastern or whitebelly stock, depending on location. If it is assumed that the two stocks have an equal probability of being unidentified in the overlap zone, unidentified spinner sightings within the overlap zone could be allocated to the stocks by the observed ratio of the identified stocks in the overlap zone. However, there were only 2 to 4 sightings of this kind each year, so an adjustment of this type would have little effect on the total estimate of abundance. These 2–4 sightings were not used in the current analysis.

Similarly, very few (14 total in 5 years) unidentified spotted dolphin sightings were made each year in the overlap zone between the coastal and northern offshore spotted stocks. Again, a ratio adjustment based on the observed ratio of the stocks could be made, but was not in the current calculation. This represents a slight negative bias in the northern offshore, eastern spinner, and whitebelly spinner stocks, but one that should be relatively constant from year to year.

Estimates of $f(0)$ for each stock

If a stock had more than 20 sightings in each year, $f(0)$ was estimated for that stock from those sightings alone. Stocks meeting this criteria were northern offshore spotted, eastern spinner, whitebelly spinner, and southern striped. All of these stocks in fact had more than 30 sightings in each year, with the exception of the whitebelly spinner stock in 1990, which had only 24 sightings.

If a stock did not meet this criterion, perpendicular distances were pooled across stocks of the same species to obtain an adequate sample size. None of the three common dolphin stocks met this criterion, and it was necessary to pool across all three common stocks to get enough sightings. This resulted in only one estimate of $f(0)$ for all three stocks of common dolphins.

It was also necessary to pool southern spotted sightings with northern spotted sightings to obtain a sample size large enough to estimate $f(0)$ for the southern stock. Although all northern spotted sightings could be pooled with the southern sightings, the much larger number of northern spotted sightings would make this estimate nearly identical to that of the northern stock. Therefore, only all northern spotted sightings south of 8°N were pooled with all the southern spotted sightings to estimate an $f(0)$ for the southern stock. This latitude was chosen such that the sample size criterion was met in each year.

A similar method was used for the northern striped stock. All sightings of southern striped dolphins north of 8°N, east of 130°W, and west of 95°W, were pooled with the sightings of northern striped dolphins to estimate $f(0)$ for the northern stock.

Table 1

Area A_k (in thousands of km^2, from Holt and Sexton, 1990a), percent of total study area, target distribution of percent effort (from Holt *et al*, 1987), and achieved effort L_k in each year (in km), for a stratified survey of dolphins in the eastern tropical Pacific, 1986-90.

	Inshore	Middle	West	South	Total
Area (1000 km^2)	5,693.0	3,798.0	5,298.0	4,359.0	19,148.0
Percent of total	29.7	19.8	27.7	22.8	100.0
Target effort dist.	35.8	28.7	14.0	21.5	100.0
1986 Effort (km)	11,769.1	7,858.8	3,875.9	4,041.6	27,545.1
Percent	42.7	28.5	14.1	14.7	100.0
1987 Effort (km)	11,176.5	7,983.4	3,558.6	3,881.6	26,600.1
Percent	42.0	30.0	13.4	14.6	100.0
1988 Effort (km)	8,932.9	6,079.6	3,209.0	5,053.4	23,274.8
Percent	38.4	26.1	13.8	21.7	100.0
1989 Effort (km)	10,907.2	7,446.9	3,527.5	4,777.4	26,659.1
Percent	40.9	27.9	13.2	17.9	100.0
1990 Effort (km)	10,031.2	8,945.4	5,599.2	6,669.2	31,245.0
Percent	32.1	28.6	17.9	21.3	100.0

Differences in methodology from previous publications

Published estimates from the first four years of data (Holt and Sexton, 1989; 1990a; b; Gerrodette and Wade, 1991; Sexton *et al.*, 1991) used methods of estimating abundance of ETP dolphin populations that followed Holt and Powers (1982) and Holt (1987). The current analysis differs in several ways, and a summary of the main differences is presented below.

First, as described above, $f(0)$ was estimated separately for each stock rather than estimating one $f(0)$ from sightings of all dolphins, including additional species such as *Tursiops truncatus*, *Grampus griseus* and *Steno bredanensis*. Second, the previous method produced estimates of abundance for each species, and then allocated each species abundance to the stocks of the species by the ratio of the area occupied by a stock to the area occupied by the species. These areas were determined from Perrin *et al.* (1985) and were thus constant from year to year, so that estimates of abundance were completely correlated for all the stocks of a species. The current method estimated abundance for a stock, as much as possible, from just sightings of that stock. Third, the current method of analysis was stratified, as is appropriate for a stratified (unequal effort per unit area in each stratum) survey design (Burnham *et al.*, 1980).

Other differences will be mentioned here briefly. All size schools rather than only schools greater than 15 animals were used. Schools with only a 'minimum' rather than 'best' estimate of school size were not used. Unidentified dolphin schools were not included. School size was not weighted as had been previously done in some of the years. The truncation of the perpendicular distance distribution was changed from 3.7km to 7.4km. Bootstrap re-sampling was continued until the total distance was matched, rather than until the number of legs of effort was matched, and the number of bootstrap iterations was increased from 100 to 200.

RESULTS

According to Equation 1, estimates of dolphin abundance depended on five quantities: n_{jk}, $f_j(0)$, L_k, S_{jk} and A_k. The study area in each stratum (A_k) was fixed (Table 1). The

Table 2

Number of school sightings (n_{jk}), school encounters per 1000km ($1000*n_{jk}/L_k$) and mean school size (S_{jk}) for each stock in each stratum and year.

a. 1986

	Inshore	Middle	West	South	Total
Number of school sightings (n_{jk})					
N. Offshore spotted	69	32	17	0	118
S. Offshore spotted	0	0	0	5	5
Eastern spinner	41	15	3	1	60
Whitebelly spinner	7	12	10	5	34
N. Common	11	0	0	0	11
C. Common	10	0	1	0	11
S. Common	4	4	0	12	20
N. Striped	18	20	0	0	38
S. Striped	52	25	7	12	96
School encounters per 1000km ($1000*n_{jk}/L_k$)					
N. Offshore spotted	5.9	4.1	4.4	0.0	4.3
S. Offshore spotted	0.0	0.0	0.0	1.2	0.2
Eastern spinner	3.5	1.9	0.8	0.2	2.2
Whitebelly spinner	0.6	1.5	2.6	1.2	1.2
N. Common	0.9	0.0	0.0	0.0	0.4
C. Common	0.8	0.0	0.3	0.0	0.4
S. Common	0.3	0.5	0.0	3.0	0.7
N. Striped	1.5	2.5	0.0	0.0	1.4
S. Striped	4.4	3.2	1.8	3.0	3.5
Mean school size (S_{jk})					
N. Offshore spotted	86.9	89.6	86.0	0.0	87.5
S. Offshore spotted	0.0	0.0	0.0	234.1	234.1
Eastern spinner	105.2	78.3	119.5	44.3	98.1
Whitebelly spinner	100.8	55.3	119.4	68.4	85.4
N. Common	223.6	0.0	0.0	0.0	223.6
C. Common	185.8	0.0	26.0	0.0	171.3
S. Common	554.0	182.7	0.0	412.6	394.9
N. Striped	38.5	17.5	0.0	0.0	27.4
S. Striped	49.5	67.8	57.3	33.4	52.8

b. 1987

	Inshore	Middle	West	South	Total
Number of school sightings (n_{jk})					
N. Offshore spotted	61	46	16	0	123
S. Offshore spotted	0	0	0	12	12
Eastern spinner	37	14	1	0	52
Whitebelly spinner	1	16	17	6	40
N. Common	3	1	0	0	4
C. Common	14	2	2	0	18
S. Common	3	0	0	5	8
N. Striped	5	11	0	0	16
S. Striped	86	29	5	23	143
School encounters per 1000km ($1000*n_{jk}/L_k$)					
N. Offshore spotted	5.5	5.8	4.5	0.0	4.6
S. Offshore spotted	0.0	0.0	0.0	3.1	0.5
Eastern spinner	3.3	1.8	0.3	0.0	2.0
Whitebelly spinner	0.1	2.0	4.8	1.5	1.5
N. Common	0.3	0.1	0.0	0.0	0.2
C. Common	1.3	0.3	0.6	0.0	0.7
S. Common	0.3	0.0	0.0	1.3	0.3
N. Striped	0.4	1.4	0.0	0.0	0.6
S. Striped	7.7	3.6	1.4	5.9	5.4
Mean school size (S_{jk})					
N. Offshore spotted	86.9	134.0	102.4	0.0	106.5
S. Offshore spotted	0.0	0.0	0.0	149.3	149.3
Eastern spinner	76.1	206.7	84.2	0.0	111.4
Whitebelly spinner	572.9	94.1	58.8	171.7	102.7
N. Common	98.0	47.0	0.0	0.0	85.3
C. Common	314.4	33.5	93.0	0.0	258.6
S. Common	241.7	0.0	0.0	132.6	173.5
N. Striped	34.0	31.4	0.0	0.0	32.2
S. Striped	53.6	49.4	49.6	90.3	58.5

c. 1988

	Inshore	Middle	West	South	Total
Number of school sightings (n_{jk})					
N. Offshore spotted	54	18	13	0	85
S. Offshore spotted	0	0	0	5	5
Eastern spinner	33	4	0	0	37
Whitebelly spinner	2	10	21	4	37
N. Common	8	0	0	0	8
C. Common	19	1	1	0	21
S. Common	0	12	0	15	27
N. Striped	20	3	0	0	23
S. Striped	80	23	19	38	160
School encounters per 1000km ($1000*n_{jk}/L_k$)					
N. Offshore spotted	6.0	3.0	4.1	0.0	3.7
S. Offshore spotted	0.0	0.0	0.0	1.0	0.2
Eastern spinner	3.7	0.7	0.0	0.0	1.6
Whitebelly spinner	0.2	1.6	6.5	0.8	1.6
N. Common	0.9	0.0	0.0	0.0	0.3
C. Common	2.1	0.2	0.3	0.0	0.9
S. Common	0.0	2.0	0.0	3.0	1.2
N. Striped	2.2	0.5	0.0	0.0	1.0
S. Striped	9.0	3.8	5.9	7.5	6.9
Mean school size (S_{jk})					
N. Offshore spotted	176.5	112.5	210.0	0.0	168.1
S. Offshore spotted	0.0	0.0	0.0	173.7	173.7
Eastern spinner	214.8	61.0	0.0	0.0	198.2
Whitebelly spinner	352.2	41.3	99.6	292.2	118.4
N. Common	1083.2	0.0	0.0	0.0	1083.2
C. Common	516.8	58.0	98.0	0.0	475.0
S. Common	0.0	330.6	0.0	780.1	580.3
N. Striped	80.8	101.0	0.0	0.0	83.4
S. Striped	71.3	56.0	57.3	84.2	70.5

d. 1989

	Inshore	Middle	West	South	Total
Number of school sightings (n_{jk})					
N. Offshore spotted	72	29	14	0	115
S. Offshore spotted	0	0	0	6	6
Eastern spinner	51	11	1	0	63
Whitebelly spinner	3	12	11	5	31
N. Common	7	2	0	0	9
C. Common	7	0	0	0	7
S. Common	7	7	0	12	26
N. Striped	21	24	0	0	45
S. Striped	62	20	8	27	117
School encounters per 1000km ($1000*n_{jk}/L_k$)					
N. Offshore spotted	6.6	3.9	4.0	0.0	4.3
S. Offshore spotted	0.0	0.0	0.0	1.3	0.2
Eastern spinner	4.7	1.5	0.3	0.0	2.4
Whitebelly spinner	0.3	1.6	3.1	1.0	1.2
N. Common	0.6	0.3	0.0	0.0	0.3
C. Common	0.6	0.0	0.0	0.0	0.3
S. Common	0.6	0.9	0.0	2.5	1.0
N. Striped	1.9	3.2	0.0	0.0	1.7
S. Striped	5.7	2.7	2.3	5.7	4.4
Mean school size (S_{jk})					
N. Offshore spotted	127.7	190.9	170.9	0.0	148.9
S. Offshore spotted	0.0	0.0	0.0	273.8	273.8
Eastern spinner	121.8	163.1	100.3	0.0	128.7
Whitebelly spinner	124.0	101.7	303.1	279.4	204.0
N. Common	341.6	50.0	0.0	0.0	276.8
C. Common	196.0	0.0	0.0	0.0	196.0
S. Common	418.1	384.9	0.0	652.8	517.5
N. Striped	37.9	34.7	0.0	0.0	36.2
S. Striped	45.0	64.0	57.5	116.4	65.6

[Continued]

Table 2 (continued)

	Inshore	Middle	West	South	Total
		e. 1990			
Number of school sightings (n_{jk})					
N. Offshore spotted	66	36	11	0	113
S. Offshore spotted	0	0	0	8	8
Eastern spinner	30	12	1	0	43
Whitebelly spinner	4	6	10	4	24
N. Common	6	1	0	0	7
C. Common	14	1	0	0	15
S. Common	1	2	0	10	13
N. Striped	12	7	1	0	20
S. Striped	51	33	17	18	119
School encounters per 1000km ($1000^*n_{jk}/L_k$)					
N. Offshore spotted	6.6	4.0	2.0	0.0	3.6
S. Offshore spotted	0.0	0.0	0.0	1.2	0.3
Eastern spinner	3.0	1.3	0.2	0.0	1.4
Whitebelly spinner	0.4	0.7	1.8	0.6	0.8
N. Common	0.6	0.1	0.0	0.0	0.2
C. Common	1.4	0.1	0.0	0.0	0.5
S. Common	0.1	0.2	0.0	1.5	0.4
N. Striped	1.2	0.8	0.2	0.0	0.6
S. Striped	5.1	3.7	3.0	2.7	3.8
Mean school size (S_{jk})					
N. Offshore spotted	124.6	147.9	89.5	0.0	128.6
S. Offshore spotted	0.0	0.0	0.0	199.9	199.9
Eastern spinner	113.6	64.5	31.2	0.0	98.0
Whitebelly spinner	90.4	62.0	75.2	534.3	150.9
N. Common	130.4	14.0	0.0	0.0	113.8
C. Common	172.2	165.0	0.0	0.0	171.8
S. Common	500.0	315.5	0.0	557.9	516.1
N. Striped	69.3	24.9	22.0	0.0	51.3
S. Striped	40.9	62.7	76.9	86.6	59.0

other quantities varied each year and are summarised in Tables 1–3 for the years 1986–1990. Each of these other quantities is discussed briefly below.

The survey employed a stratified design based on the densities of northern offshore spotted dolphins (Holt *et al.*, 1987). Although we attempted to keep the number of trackline miles searched within each stratum (L_k) a constant proportion of the total effort each year (target effort distribution in Table 1), the achieved percent effort varied somewhat by year due to mechanical breakdowns, variations in weather and difficulties in securing permits to conduct the surveys within the territorial waters of some countries (Table 1). Total trackline effort within the study area in conditions of Beaufort 5 or less was about 27,000km annually (range 23,275 to 31,245).

The number of sightings of dolphin schools (n_{jk}) of stocks numerous enough to make abundance estimates totalled about 350 annually (Table 2). Northern offshore spotted and southern striped dolphins were the most frequently sighted schools each year. Some stocks, for example, southern offshore spotted dolphins, consistently had few sightings. The rate of dolphin school encounters per 1000km reported in Table 2 is a relative measure of dolphin school density each year; it is not used in Equation 1 to estimate abundance but is given here for comparative purposes. The number of school sightings is multiplied by mean school size (S_{jk}) for each stock in each stratum to obtain an estimate of the number of dolphins seen. Mean school size varied considerably by stratum and year. Common dolphins tended to have the largest school sizes of the species reported here.

The fitting of a probability density function to the sighting data was the most difficult part of the analysis, and variability in this parameter appeared to contribute most to the bootstrap variance of the total population estimate. Additionally, the estimates of $f_j(0)$ varied substantially among years for some of the stocks (Table 3). As noted above, there were too few sightings to form reliable estimates of $f(0)$ by stratum, so data were pooled and a single $f_j(0)$ is reported for each stock j. For common dolphins, stocks also had to be pooled and a single value is given for the species. The number of sightings on which each estimate of $f_j(0)$ was based is also shown in Table 3.

These quantities were combined in Equation 1 to give estimates of dolphin abundance for each stock in each year (Table 4). The coefficient of variation for the abundance estimate of northern offshore spotted dolphins, the stock for which the surveys were designed, varied from 0.25 to 0.36; CVs for other stocks were generally higher. Annual changes in abundance are shown graphically in Fig. 2a-d.

Table 3

Estimated detection function evaluated at zero distance ($f_j(0)$) and the number of sightings used to make the estimate (n), for each stock in each year.

		1986	1987	1988	1989	1990
N. Offshore spotted	$f_j(0)$	0.67	0.73	0.69	0.66	0.31
	n	118	123	85	115	113
S. Offshore spotted	$f_j(0)$	0.69	0.88	0.42	1.12	0.31
	n	40	53	33	39	39
Eastern spinner	$f_j(0)$	0.70	0.56	0.60	0.64	0.63
	n	60	52	37	63	43
Whitebelly spinner	$f_j(0)$	0.98	1.24	1.00	0.67	0.54
	n	34	40	37	31	24
N. Common	$f_j(0)$	1.21	0.51	0.85	1.35	1.46
	n	47	30	57	46	37
C. Common	$f_j(0)$	1.21	0.51	0.85	1.35	1.46
	n	47	30	57	46	37
S. Common	$f_j(0)$	1.21	0.51	0.85	1.35	1.46
	n	47	30	57	46	37
N. Striped	$f_j(0)$	1.48	0.60	0.98	0.82	0.73
	n	45	36	51	59	43
S. Striped	$f_j(0)$	0.74	0.84	0.79	1.05	0.96
	n	96	143	160	117	119

DISCUSSION

The estimated number of dolphins of each stock in each year as reported in Table 4 and shown in Fig. 2a-d should be regarded as provisional estimates subject to further analysis. Ongoing work at the Southwest Fisheries Science Center is attempting to address the direction and magnitude of any potential sources of bias in these estimates. Some potential sources of bias are listed below.

(1) The proportion of schools detected on the trackline may be less than the assumed 1.0, which would result in a negative bias. However, an independent observer experiment in 1990 suggested that no large schools were missed on the trackline. If small schools were infrequently missed, the bias would be small.

(2) The estimate of mean school size may be positively biased because of the decreased probability of detection of smaller schools at greater perpendicular distances from the trackline. Our preliminary investigations have indicated an increasing trend in mean school size as the truncation point is increased, confirming that a positive bias of approximately 5–20% in mean school size exists, depending on the stock.

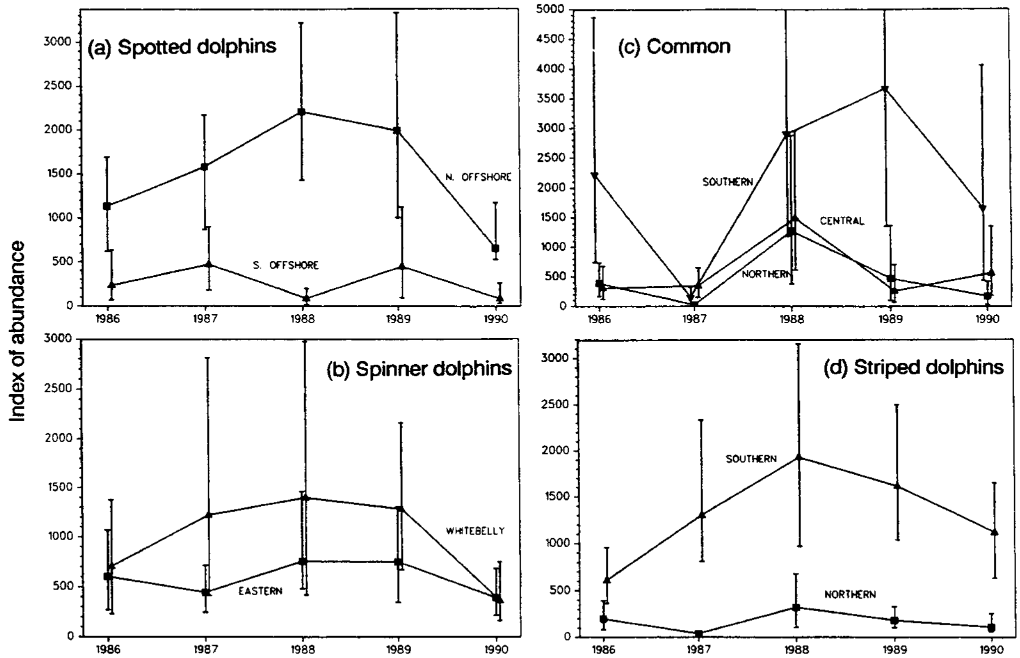

Fig. 2. Annual estimates of abundance for: (a) two stocks of spotted dolphins; (b) two stocks of spinner dolphins; (c) three stocks of common dolphins; and (d) two stocks of striped dolphins. Error bars are 90% bootstrap confidence limits.

Table 4

Abundance estimates N_j (in thousands), standard errors (SE), and coefficients of variation (CV) for estimates of 9 stocks of eastern tropical Pacific dolphins, 1986-90.

	1986	1987	1988	1989	1990
N. Offshore Spotted	1,134.2	1,582.6	2,205.5	1,993.6	658.3
SE	346.5	402.8	575.1	720.7	195.2
CV	0.305	0.255	0.261	0.362	0.297
S. Offshore Spotted	236.0	475.8	85.8	451.9	87.7
SE	175.4	230.0	58.2	346.0	75.6
CV	0.743	0.483	0.678	0.766	0.863
Eastern Spinner	603.7	444.7	754.2	748.8	391.2
SE	286.1	146.0	327.9	318.8	163.6
CV	0.474	0.328	0.435	0.426	0.418
Whitebelly Spinner	706.1	1,220.7	1,398.4	1,280.0	363.3
SE	371.1	786.7	777.6	486.1	201.0
CV	0.526	0.644	0.556	0.380	0.553
N. Common	390.0	23.5	1,272.4	473.6	177.7
SE	192.4	18.2	921.7	345.5	128.7
CV	0.493	0.773	0.724	0.730	0.724
C. Common	306.2	348.1	1,487.6	261.0	568.0
SE	216.1	152.6	775.2	218.4	383.5
CV	0.706	0.438	0.521	0.837	0.675
S. Common	2,217.3	152.0	2,896.5	3,664.0	1,657.5
SE	1,525.3	85.1	1,712.0	2,601.5	1,147.9
CV	0.688	0.560	0.591	0.710	0.693
N. Striped	201.1	40.7	323.4	185.2	111.6
SE	108.6	15.2	180.5	76.5	69.2
CV	0.540	0.373	0.558	0.413	0.620
S. Striped	612.0	1,300.8	1,927.9	1,611.4	1,115.6
SE	174.2	454.2	685.3	485.4	309.7
CV	0.285	0.349	0.355	0.301	0.278

(3) These different probabilities of detecting large and small schools, while affecting the estimate of mean school size, should not bias the estimate of school density, as long as the estimator is pooling robust, as it should be (Burnham *et al.*, 1980).

(4) The estimate of mean school size may also be biased due to errors by the observers in estimating school size. However, aerial photography during the surveys has shown that, on average, observers estimated school size accurately, although for the largest schools there was a tendency to underestimate school size.

(5) A negative bias in the estimation of $f(0)$ may also result from pooling sightings across strata, as the stratum with the most effort (the inshore stratum) had the lowest average Beaufort sea state, and therefore the better sighting conditions.

(6) Reaction of the dolphins to the ship before detection could lead to a negative bias if they avoided the ship or a positive bias if they were attracted to the ship. To be a significant bias, dolphin schools would have to perceive and react to the ship at a large distance, because the average detection distance from the ship was approximately 5km. Aerial observations on a limited number of dolphin schools have shown that some dolphin schools turn away from the ship at more than this distance, but that most schools are detected by observers before they react to the ship (Au and Perryman, 1982; Hewitt, 1985). Therefore, ship avoidance behaviour by the dolphins probably results in a small negative bias in the estimates presented here.

(7) Unidentified dolphin sightings were not used in the current analysis, creating a negative bias. However,

assignment of those sightings to dolphin stocks would only increase the abundance estimates slightly, because the number of unidentified dolphins seen was less than 3% of the total number of dolphins seen during the study, and such schools were often far from the trackline.

Thus, some of these potential biases are positive and a few more are negative. Although there is still uncertainty in many of them, none appears to have a large effect. In such circumstances, these estimates would be fairly close to absolute estimates of abundance.

In addition, a large amount of information has been collected during the five years about the habitat where the dolphins were seen (Fiedler *et al.*, 1990; Reilly, 1990). A canonical correspondence analysis indicates that much of the interannual variability in species composition can be accounted for by two multidimensional axes of environmental variables (Reilly and Fiedler, 1990). Further work will attempt to use observed changes in dolphin habitat in the ETP to help explain changes in estimates of abundance.

The estimates of abundance in Table 4 differ from reports of previous years' surveys (Holt and Sexton, 1989; 1990a; b; Gerrodette and Wade, 1991) due to different methods of analysis. As noted in Methods, previous analyses pooled data over strata, stocks, and species before estimating $f(0)$ and S, then allocated total abundance according to various estimated proportions. The present analysis avoids pooling insofar as possible. The resulting stratified analysis gives less precise, but also less biased estimates of dolphin abundance. Work on improving the analysis is continuing.

The estimates of abundance shown in Fig. 2a-d are highly variable, and it is difficult to discern any common pattern. There is no overall declining trend during the five-year study period, as might be expected if mortality due to the tuna purse-seine fishery in the ETP were having a strong impact on the populations. However, the data also do not warrant any conclusion that no impact is occurring, because the statistical power of detecting even a large decline during a five-year period given the observed variability of the estimates is low (Gerrodette, 1987).

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