PRELIMINARY ESTIMATES OF 1998 ABUNDANCE

OF FOUR DOLPHIN STOCKS

IN THE EASTERN TROPICAL PACIFIC

Tim Gerrodette

Southwest Fisheries Science Center

La Jolla, California

March 18, 1999

ABSTRACT

The sizes of 4 dolphin populations affected by the purse-seine fishery for tuna were estimated using distance sampling. A line-transect survey was carried out in the eastern tropical Pacific Ocean by 3 research vessels from July 31 to December 9, 1998. The study area was designed to include the entire range of coastal spotted, northeastern offshore spotted, and eastern spinner dolphins. Within the study area, searching effort was stratified into 4 areas based on densities of the target dolphin populations. Searching was carried out primarily with pedestal-mounted 25x150 binoculars fitted with azimuth rings and reticles for angle and distance measurements. Bias reduction methods based on aerial photography were applied to observers' estimates of school size. Estimates of dolphin density and abundance for each population (stock) were based on encounter rate and school size estimates within each stratum, while modelling of the detection probability required some pooling across strata or sighting categories. Variances of abundance estimates were estimated by a bootstrap procedure that included the variance due to model selection at each iteration. Abundance estimated from sightings not identified to stock was prorated among appropriate stocks in proportion, by stratum, to the estimated abundance of those stocks based on identified sightings. Total estimates of 1998 abundance (in numbers of animals) were 108,289 (CV=0.41) for coastal spotted dolphins, 1,011,104 (CV=0.26) for northeastern offshore spotted dolphins, 743,166 (CV=0.30) for western/southern offshore spotted dolphins, and 1,157,746 (CV=0.34) for eastern spinner dolphins.

INTRODUCTION

The 1997 International Dolphin Conservation Program Act (Public Law 105-42) directed the National Marine Fisheries Service to determine if the chase and encirclement of dolphins in the purse-seine fishery for tuna in the eastern tropical Pacific (ETP) is having a significant adverse impact on depleted dolphin stocks. As part of this determination, Congress specified that population surveys be undertaken in 1998, 1999, and 2000 to generate new estimates of dolphin abundance.

On December 17-18, 1997, the Southwest Fisheries Science Center (SWFSC) convened a technical meeting in La Jolla, California, to discuss the design of the *Stenella* Population Abundance Monitoring (SPAM) surveys (Gerrodette *et al.* 1998). The participants agreed that line-transect methods similar to those used on surveys from 1986-90 should be continued on the 1998-2000 surveys, but, based on updated information about spotted and spinner dolphin distributions, that the study area should be changed slightly. A stratified survey effort was recommended, along with a number of other small changes.

Following the conclusion of the cruise in December, 1998, another meeting was held at the SWFSC on January 21, 1999, to review a preliminary analysis of the data (Olson and Gerrodette 1999). The suggestions of the participants at that meeting have been incorporated in the present report, as much as time allowed. A thorough analysis of the data requires more time than permitted by the Congressional deadline; therefore, the estimates of 1998 dolphin abundance in this report are considered preliminary estimates and are restricted to 4 dolphin stocks that

include the stocks most affected by the tuna fishery.

SURVEY DESIGN AND METHODS

The dolphin species most affected by the tuna purse-seine fishery are spotted dolphins (*Stenella attenuata*) and spinner dolphins (*S. longirostris*) (Smith 1983; Wade 1993a, b). The species are divided into stocks for management (Dizon *et al.* 1994). The stocks that have been designated as depleted under the Marine Mammal Protection Act, and which were therefore of primary interest in designing the survey, were the northeastern offshore spotted dolphin, *Stenella attenuata attenuata*, north of 5°N and east of 120°W (Perrin *et al.* 1994), and the eastern spinner dolphin, *Stenella longirostris orientalis* (Perrin 1990). The legal status of the coastal spotted dolphin, *Stenella attenuata graffmani* (Perrin *et al.* 1985), was uncertain, but since it might also be considered depleted, the survey was designed to produce an estimate of abundance for this stock as well. The outer boundaries of the survey area were drawn well beyond the limits of the target stocks, to be certain to include the entire populations (Gerrodette *et al.* 1998).

Based on densities of animals and stocks of interest, searching effort was stratified into 3 areas: a core stratum centered on the main stocks of interest, an outer stratum of lower density and effort, and a coastal stratum to obtain more information on coastal dolphins (Fig. 1). The geographic strata roughly correspond to the 3 stocks of spotted dolphins in the ETP: coastal spotted in the coastal stratum, northeastern offshore spotted in the core stratum, and western-southern offshore spotted in the outer stratum. Eastern spinner dolphins are found primarily in the core stratum, but are also found in the outer and coastal strata. Within each stratum, transect lines were randomly but not uniformly spaced, given the logistical constraints of ship range and speed. Effort in the coastal stratum was approximately 2 times the effort in the core stratum, which in turn was approximately 3 times the effort in the outer stratum, per square unit area.

The 1998 SPAM survey was carried out from July 31 to December 9, 1998. Three ships participated in the survey: NOAA Ships *David Starr Jordan* and *McArthur*, and the *Endeavor* from the University of Rhode Island. All ships are oceanographic research vessels, ranging in length from 52m to 57m. Observer eye height above the sea surface was nearly the same on all vessels (10.7m, 10.4m and 10.4m, respectively). Any differences among ships were further minimized by having each ship conduct transects in all parts of the study area and by rotating observers among ships at port stops.

Methods of collecting data followed standard protocols for line-transect surveys conducted by the Southwest Fisheries Science Center (Holt and Sexton 1990; Wade and Gerrodette 1993; Barlow 1995). In workable conditions, a visual watch for cetaceans was conducted on the flying bridge of each vessel during all daylight hours as the ship moved along the trackline at a speed of 10 knots. The team of 3 observers rotated positions every 40 minutes; thus, each observer stood watch for 2 hours, then had 2 hours rest. Two observers, one on each side of the ship, searched with pedestal-mounted 25x150 binoculars. Each 25X observer scanned from abeam (90° from the trackline) on the side of the vessel where the binoculars were mounted to 10° past the trackline on the opposite side. Together, the two 25X observers thus searched the 180° forward of the ship with an area of overlap near the trackline. The 25X binoculars were

fitted with azimuth rings and reticles for angle and distance measurements. Angle and distance measurements made in this way have been checked against radar measurements and found to be accurate (unpub. data). The third observer searched by eye and with hand-held 7X binoculars, covering areas closer to the ship over the whole 180°. When a marine mammal was sighted, the angle and distance to the sighting were measured, and the third observer entered the data in a portable computer. If the sighting was less than 5.6 km (3 nm) from the trackline, the team went "off-effort" and directed the ship to leave the trackline and to approach the animal(s) sighted. The observers identified the sighting to species or subspecies (if possible) and made group size estimates. Each observer team had at least one observer highly experienced in the field identification of marine mammals in the ETP. Observers discussed distinguishing field characteristics in order to obtain the best possible identification, but they estimated group sizes and, in the case of mixed-species schools, group compostion, independently. The computer was connected to the ship's Global Positioning System, recording the position of each sighting and also the positions at the beginning and end of each search effort segment.

ANALYSIS

Effort and stratification

Two kinds of post-cruise adjustments to the stratification were made. First, the boundary of the coastal stratum was changed slightly in several places so that coastal survey effort occurred entirely within the stratum; also, the coastal stratum was divided into northern and southern parts with the dividing line at 5°N. Second, the northern part of the core stratum was ended at 25°N instead of extending to the U.S.-Mexican border (Fig. 1). There were 2 reasons for this change: (1) due to bad weather, the northern corner of the original core stratum was sampled at a rate closer to the outer stratum; and (2) few spotted or spinner dolphins occur in this area, so that it is more properly included as part of the low-density stratum. With these changes, there were 4 strata used in the analysis: core, outer, north coastal and south coastal (Fig. 1). Stratum areas, calculated as total area less the areas of islands within the stratum, ranged from 168,700 to 15,172,500 km^2, with a total of 21,654,100 km^2 for the whole study area (Table 1).

The analysis used search effort and sightings that occurred during on-effort periods. As in past analyses, sightings and effort in very poor conditions (visibility < 4 km or Beaufort >5) were not included in the analysis, due to very low cetacean sighting rates under these conditions; this amounted to a loss of 6.6% of the effort and 0% of the sightings. Sightings and effort within a day were summed; thus, one day of search effort was considered the sampling unit. Ships moved at night, providing some independence among samples. Due to a variety of factors, numbers of kilometers searched each day were not equal. To reduce heterogeneity among sampling units, effort < 50 km/day in offshore areas, and < 30 km/day in coastal areas, was combined with effort on previous or following days. A few transects remained small because there was no nearby effort with which they could be combined.

Stocks and sightings

This analyis considered 4 dolphin stocks affected by the tuna fishery in the ETP:

4

northeastern offshore spotted, western/southern offshore spotted, coastal spotted, and eastern spinner. As noted above, eastern spinner and northeastern offshore spotted dolphins are designated as depleted under the Marine Mammal Protection Act, while the legal status of coastal spotted dolphins is ambiguous. A determination of the status of western/southern offshore spotted dolphins has not been published; data indicate that the reduction in abundance for this stock has been less than for eastern spinner or northeastern offshore spotted dolphins (Gerrodette and Wade 1995).

Six sighting categories contributed to the abundance estimates of these 4 stocks:

Offshore spotted dolphin   (*Stenella attenuata attenuata*)
Coastal spotted dolphin   (*Stenella attenuata graffmani*)
Unidentified spotted dolphin   (*Stenella attenuata*, unidentified subspecies)
Eastern spinner dolphin   (*Stenella longirostris orientalis*)
Unidentified spinner dolphin   (*Stenella longirostris*, unidentified subspecies)
Unidentified dolphin

Abundance estimation

Estimation of abundance was based on distance sampling (Buckland *et al.* 1993). Thus, the cruise was designed to sample distances to objects (dolphin schools) along a transect, and line-transect methods were used to estimate the density of schools. For each sighting category, abundance *N* was estimated by multiplying estimated school density by expected school size $E(S)$ and area *A* in each stratum, using the equation

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

where *n* = number of sightings, *L* = search effort (transect length), and *f*(0) = estimated value of the sighting probability density function evaluated at zero distance from the trackline. In some cases, as noted below, pooling across sighting categories or geographic strata was necessary in order to obtain sufficient sample size for *f*(0) estimation. For the dolphin schools that were the sampled objects on this survey, the assumption that *g*(0)=1, *i.e.*, that all objects on the trackline are detected, was easily satisfied, because the dolphins occur in large schools, individual dolphins do not have long dive times, and diving is not synchronous among individuals in a school. The assumption of detection before reaction to the vessel was less easily satisfied, because dolphins have become wary of tuna vessels that chase them frequently. Observation from helicopters has shown that most dolphin schools are detected before they react to the research vessel (Au and Perryman 1982; Hewitt 1985). In addition, there was no consistent indication of a deficit of sightings near the trackline, further supporting the idea that no strong reaction occurs before most dolphin schools are detected.

For reasons of comparability, the analysis closely followed methods used to produce previous estimates of dolphin abundance in the ETP (Wade and Gerrodette 1993; Wade 1994). The estimation was carried out using Distance, version 3.5, Release 4 (Thomas *et al.* 1998). After being checked and edited, data were extracted and formatted for import into Distance using a

Fortran program written for the purpose. Estimates of encounter rates and expected schools sizes were based on data within a stratum only. Estimates of $f(0)$ had to pool sightings in some cases in order to have sufficient sample size; this pooling for $f(0)$ estimation is discussed by stock in the Results section. Variance of each abundance estimate was estimated using the bootstrap procedure within Distance (999 resamplings), which includes the variance due to model selection at each iteration.

Encounter rate

Within each stratum, encounter rate was estimated as the number of dolphin school sightings per km. The variance of this rate was the empirically observed variance among transects, using day as the sampling unit.

Detection function

For modelling the probability of detecting objects, Distance uses the concept of a key function with an adjustment function (Buckland *et al.* 1993). For each analysis, the histograms of dolphin school sighting frequency against perpendicular distance were first examined in order to select a truncation distance which eliminated long tails to the distribution. This procedure is recommended to provide more accurate modelling (Buckland *et al.* 1993). Four key/adjustment function pairs, with up to 2 parameters in the adjustment function of each pair, were used to model the data in each analysis: half-normal/cosine, half-normal/simple polynomial, uniform/cosine, and hazard-rate/Hermite polynomial. Distance provides a variety of tools by which to gauge the model fit, including histograms, χ^2 goodness-of-fit tests, likelihood, Bayes Information Criterion, and Akaike Information Criterion (AIC). Provided the fit was reasonable, the model with the lowest AIC was selected as the most parsimonious model in each analysis.

School size

A sighting consisted of a school of dolphins; therefore, to estimate numbers of animals, estimates of school size were needed. In the case of mixed schools, the school size of a sighting category was calculated as the mean proportion of the category times the school size. Because estimating dolphin school size is a difficult but critical part of estimating abundance, the SWFSC has put considerable effort into developing methods that produce unbiased estimates of school size (Gerrodette and Perrin 1991; Gilpatrick 1993; Barlow *et al.* 1998). Three kinds of bias correction procedures were applied to obtain the best possible estimates of group size.

First, calibration factors (regression coefficients) were used for each observer to correct for that observer's tendency to under- or overestimate dolphin school size. Observers made estimates of school size independently, refraining from discussing their estimates with other observers. Individual calibration factors were based on comparing observers' estimates of school size with high resolution aerial photographs of the same schools taken from a helicopter (Gilpatrick 1993). Direct calibration was used for observers for whom calibration factors from previous cruises between 1987 and 1993 could be calculated. In this procedure, an observer's best, high and low estimates of each school were combined according to weightings that gave the least variable

estimates of school size for that observer, and this weighted estimate was adjusted by multiple regression coefficients specific for that observer (Gerrodette and Perrin 1991; Barlow *et al.* 1998). Indirect calibration was used for observers for whom direct factors were not available. In this procedure, an observer's best school size estimates from the 1998 cruise were adjusted by coefficients estimated by regressing that observer's estimates against the corrected estimates made by observers for whom direct calibration factors were available (Barlow *et al.* 1998).

Second, the school size for each sighting was estimated as a weighted average of all the available estimates for a sighting (typically 3). The inverses of the mean squared difference between the observer's calibrated estimates and the aerial photographic estimates (for direct calibration) or the calibrated estimates (for indirect calibration) were used as weights, thus giving more weight to observers whose estimates were more accurate and more precise. The application of calibration factors to observers' estimates together with the weighted averaging of these calibrated estimates has been shown to reduce bias and improve precision in the estimation of dolphin school sizes (Barlow *et al.* 1998).

Third, the logarithms of all school size estimates for a sighting category were regressed against the detection function $g(x)$, and, if this regression was significant at the $\alpha=0.15$ level, the regression estimate of school size, rather than the observed mean, was used as the expected school size (Buckland *et al.* 1993). This procedure within the program Distance reduces bias that arises when there is a tendency to detect only larger schools at longer distances from the ship. When this tendency is present, the observed mean school size is too large (*i.e.*, is positively biased).

Expected school size was estimated separately for each stratum. The variance of the expected school size was the empirically observed variance among school size estimates. Variance estimated in this way includes variability due to different group sizes as well as variability due to observer estimation of group size (Buckland *et al.* 1993).

Proration of unidentified sightings

Not all sightings could be identified to stock level. To obtain an unbised estimate of abundance, the abundance represented by unidentified sightings had to be prorated to stock. There were three kinds of unidentified sightings that had to be prorated to the following stocks: unidentified spotted dolphins to northeastern offshore spotted, western/southern offshore spotted, and coastal spotted dolphins; unidentified spinner dolphins to eastern spinner dolphins; and unidentified dolphins to all 4 stocks. The abundance represented by unidentified sightings was estimated in the same way as for identified sighting categories, and this abundance was then prorated among appropriate stocks in proportion, by stratum, to the estimated abundance (from identified sightings) of those stocks. In some cases, this meant estimating the abundance of sighting categories not covered in this report. For example, to prorate unidentified dolphin abundance in the core stratum, estimates of abundance in the core stratum were needed for coastal spotted dolphins, northeastern offshore spotted dolphins, eastern spinner dolphins, and an aggregate estimate of abundance for the other 17 sighting categories that could be included in the category "unidentified dolphin."

Total abundance estimation

Total abundance N_{total} for each stock was estimated by adding the appropriate sub-estimates. The coefficients of variation (CV) of the total abundance estimates were estimated by adding variances of the sub-estimates, allowing for correlation when data had been pooled for $f(0)$ estimation. That is, for each stock in stratum or sighting category i,

$$\hat{N}_{total} = \sum_{i=1}^{s} \hat{N}_i ,$$

$$CV(\hat{N}_{total}) = \frac{\left[\sum_{i=1}^{s} \text{var}(\hat{N}_i)\right]^{1/2}}{\sum_{i=1}^{s} \hat{N}_i} \quad \text{when estimates were independent,}$$

$$\text{and} \quad CV(\hat{N}_{total}) = \frac{\left[f^2 \sum_{j=1}^{r} \text{var}(R_j S_j) + \left[\sum_{j=1}^{r}(R_j S_j)\right]^2 \text{var}(f) + \sum_{i=1}^{t} \text{var}(\hat{N}_i)\right]^{1/2}}{\sum_{i=1}^{s} \hat{N}_i}$$

when r of the s sub-estimates shared some data for estimation of $f = f(0)$, encounter rate estimates $R = n/L$ and expected school size estimates $S = E(S)$ were made independently for each of the r sub-estimates, and the remaining $t = s - r$ sub-estimates were independent. This slightly overestimated the value of $CV(N_{total})$, because it assumed that the same data were used for each of the r strata to estimate f, whereas the sharing of data was only partial and different estimates of f were actually used for each sub-estimate. However, given the partial data pooling, this was a more conservative assumption than independence, which would have underestimated $CV(N_{total})$. The calculation of $CV(N_{total})$ did not include the variance of proration factors.

The 95% confidence intervals of the total estimates of abundance were calculated from the CVs of the estimates, assuming a log-normal error distribution (Burnham *et al.* 1987):

$$\hat{N}_{lower} = \hat{N}_{total} / C$$

$$\text{and} \quad \hat{N}_{upper} = \hat{N}_{total} \cdot C ,$$

$$\text{where} \quad C = \exp\left\{z_{.975}\left[\ln\left(1 + CV^2(\hat{N}_{total})\right)\right]^{1/2}\right\},$$

and where $z_{.975} = 1.96$ is the upper 2.5 percentile of the normal distribution.

RESULTS

Transects, sightings and effort

In general, the cruise was carried out as designed. Difficulty in obtaining research clearances on time from several countries was the main cause of adjustments to the transect lines during the cruise. All 3 ships had to wait for 3 days at the beginning of the cruise due to lack of clearance from Mexico and Ecuador, and several more days were lost as the ships passed through Ecuadorian and Peruvian waters on dates before clearance was received. In the case of Peru, clearance was received for only 1 of the 3 ships, and for only the last leg of the cruise. Despite these difficulties, a good geographic distribution of sampling was obtained (Figs. 2-4). The ships spent a total of approximately 340 days in the study area and achieved over 43,000 km of transect effort. In conditions of Beaufort < 6 and visibility > 4 km, the length of search effort in each stratum ranged from 489 to 18,623 km, with a total transect length of 40,113 km (Table 1). After combining some days with small amounts of effort, the number of samples (transect-days) in each stratum varied from 7 to 131, with a total of 291 (Table 1).

There were totals of 325 spotted dolphin and 154 spinner dolphin sightings in all strata (Table 1). As expected, most sightings of spotted (Fig. 2) and spinner (Fig. 3) dolphins occurred in the core and coastal strata. The number of sightings in each of the 6 sighting categories varied widely by stratum, reflecting the geographic distribution of the stocks (Table 2). A large number of unidentified dolphin sightings was recorded (Fig. 4, Table 2). An unidentified dolphin sighting could potentially be any of a number of species, including spotted and spinner dolphins. Unidentified dolphin sightings were usually small groups of animals seen at a large radial distance from the ship that subsequently could not be relocated and approached for identification, or groups seen at >5.6 km from the trackline that were not approached for identification. Although the number of unidentified dolphin sightings was large, the contribution of these sightings to total abundance was not large because group size was small, and because only a fraction of the estimated unidentified dolphin abundance was assigned to the stocks of interest.

Parameter estimates

Estimates of school encounter rates, estimated school sizes, $f(0)$, and effective half-strip widths [$1/f(0)$] are shown by sighting category and strata in Table 3. All estimates of encounter rates were stratified, and estimates of school size were stratified except for offshore spotted dolphins and unidentified dolphins in the south coastal stratum, which had 2 sightings each. In these cases the south coastal data was pooled with north coastal data for school size estimation. For detection function modelling and $f(0)$ estimation, there were 6 cases in which data were pooled across geographic strata in order to achieve sufficient sample size (Table 2). In the case of unidentified spinner dolphins, all spinner dolphin sightings (eastern, whitebelly, Central American, Tres Marias, and unidentified) were pooled within each stratum for $f(0)$ estimation. Unidentified spotted dolphin sightings were pooled with offshore spotted sightings in the core stratum for encounter rate, school size, and $f(0)$ estimation, as noted earlier. With this stratification and pooling, the modelling of detection probability was adequate for all categories (Fig. 5). None of the detection function models differed significantly from the observed frequency of sightings, as measured by a χ^2 test at the α=0.05 level. Sightings closer to the trackline were binned at smaller

intervals for this test (Fig. 5), to examine the fit close to the trackline where it is most critical. Truncation distance varied among categories from 3 to 5.5 km for best model fit. The modeling was based on sightings in Beaufort 0-5 except in the case of coastal spotted dolphins in the coastal strata, where sightings in calm conditions (Beaufort 0-3) gave a better fit. In this case, estimates of encounter rate and expected school size were based on data in Beaufort 0-3 also.

Abundance of coastal spotted dolphins

All sightings of coastal spotted dolphins occurred in the 2 coastal strata. Because the range of this stock includes both the northern and southern coastal strata, sightings of coastal spotted dolphins in these strata were combined to estimate a detection function and abundance. The histogram of identified coastal spotted dolphin sightings was initially quite peaked near the trackline, but better modeling of the detection function and an estimate of abundance with lower CV was achieved using sightings and effort under Beaufort conditions 0-3 (Fig. 5D), even though this reduced sample size. This gave an estimate of 70,044 (CV=0.49) coastal spotted dolphins (Table 4). Unidentified spotted dolphin sightings in the coastal stratum were combined with similar sightings in the core stratum for $f(0)$ estimation (Table 2, detection function Fig. 5E). There were an estimated 78,332 unidentified spotted dolphins in the coastal stratum, of which 47% (36,807, CV=0.74) were prorated to the coastal stock. There were an estimated 19,082 unidentified dolphins in the coastal stratum, of which 7.5% (1,438, CV=1.24) were prorated to the coastal stock. The total estimated abundance of coastal spotted dolphins was 108,289 with a CV of 0.405 (Table 4).

Abundance of northeastern offshore spotted dolphins

The core stratum includes most of the area where the northeastern (NE) stock of offshore spotted dolphins is found. Within the core area, it was assumed that all sightings of spotted dolphins not identified to stock were of the NE stock. The detection function was well defined (Fig. 5A). The estimate based on sightings in the core stratum was 877,590 (CV=0.24). In the outer stratum, offshore spotted dolphins were mostly of the western/southern stock, but 2.3% of the estimated offshore spotted abundance, based on the area in the northern part of the outer stratum within the stock area of the NE offshore spotted dolphin, was allocated to the NE stock (16,485, CV=0.31, Table 4). Additional NE offshore spotted dolphins were found in the north coastal stratum. The detection function was based on combining sightings in both coastal strata (Fig. 5C). An estimated 60,057 (CV=0.33) NE offshore spotted dolphins were in the north coastal stratum based on identified sightings. An additional 41,525 (CV=0.74) NE offshore spotted dolphins were estimated from the proration of unidentified spotted sightings in the coastal stratum (53% of that abundance). Unidentified dolphin sightings in the core stratum (detection function Fig. 5J) led to an estimated abundance of 43,276, of which 30.8% (13,325, CV=0.25) were of the NE offshore spotted stock. Unidentified dolphin sightings in the outer stratum (detection function Fig. 5K) led to an estimated abundance of 92,130, of which 0.5% (502, CV=0.41) were of the NE offshore spotted stock. Finally, unidentified dolphin sightings in the coastal strata (detection function Fig. 5L) led to an estimated abundance of 18,843, of which 8.6% (1,620 CV=1.24) were of the NE offshore spotted stock. The total estimated abundance of northeastern offshore spotted dolphins was 1,011,104 with a CV of 0.264 (Table 4).

Abundance of western/southern offshore spotted dolphins

The outer stratum includes the main area of the western/southern (WS) stock of offshore spotted dolphins; by definition of the stock (Perrin *et al.* 1994), WS offshore spotted dolphins are not found in the core or north coastal strata. Based on identified offshore spotted sightings, the abundance of the WS offshore spotted stock in the outer stratum was estimated to be 709,715 (CV=0.31). This was 97.7% of the total offshore spotted abundance in the stratum, a small part being allocated by area to the NE offshore spotted stock. An additonal 11,835 (CV=0.49) dolphins of the WS offshore stock were estimated to be in the south coastal stratum. Of the estimated 92,130 unidentified dolphins in the outer stratum, 23.5% (21,615, CV=0.41) were estimated to be WS offshore spotted animals. Finally, a single dolphin (0.6% of an estimated 239) was contributed by unidentifed dolphin sightings in the south coastal stratum. The total estimated abundance of western/southern offshore spotted dolphins was 743,166 with a CV of 0.298 (Table 4).

Abundance of eastern spinner dolphins

Eastern spinner dolphins are a subspecies of spinner dolphin with a distinct external appearance, found primarily in the core stratum of this survey, but also in the north coastal and outer strata. The detection function for eastern spinner dolphins in the core stratum is shown in Fig. 5F. Estimation of the detection function for eastern spinners in the outer and north coastal strata was based on pooling eastern spinner sightings in the core area with each of those strata (Table 2); the detection functions appear similar to Fig. 5F and hence are not shown. Based on identified eastern spinner sightings, there were an estimated 742,540 (CV=0.32) dolphins in the core stratum, 133,880 (CV=0.78) in the outer stratum, and 130,240 (CV=0.50) in the north coastal stratum (Table 4). There were a relatively small number of unidentified spinner sightings in each stratum (Table 2), so for $f(0)$ estimation all spinner (eastern, whitebelly, Central American, Tres Marias, and unidentified) were combined within each stratum (Figs. 5G, 5H, 5I). Of the estimated 7,114 unidentified spinner dolphins in the core stratum, 99.1% (7,051, CV=0.61) were estimated to be eastern spinners (Table 4).   Of the estimated 646,530 unidentified spinner dolphins in the outer stratum, 14.7% (94,777, CV=0.84) were eastern spinners, while of the estimated 58,133 unidentified spinner dolphins in the north coastal stratum, 52.3% (30,392, CV=0.64) were eastern spinners. Similarly for unidentified dolphins, of the estimated 43,276 unidentified dolphins in the core stratum, 26.1% (11,275, CV=0.25) were estimated to be eastern spinners (Table 4). Of the estimated 92,130 unidentified dolphins in the outer stratum, 4.4% (4,077, CV=0.41) were eastern spinners, while of the estimated 18,843 unidentified dolphins in the north coastal stratum, 18.6% (3,513, CV=1.24) were eastern spinners. The calculation of CV for this stock made the conservative assumption that all estimates of abundance for identified eastern spinners and for unidentified spinner shared the same detection function. While this was not strictly true (Fig. 5), the estimates did share eastern spinner sightings, the most frequent category.   The total estimate of abundance for eastern spinner dolphins was 1,157,746 with a CV of 0.336 (Table 4).

REFERENCES

Au, D., and W. Perryman. 1982. Movement and speed of dolphin schools responding to an approaching ship. Fishery Bulletin 80:371-379.

Barlow, J. 1995. The abundance of cetaceans in California waters. Part I: Ship surveys in summer and fall of 1991. Fishery Bulletin 93:1-14.

Barlow, J., T. Gerrodette, and W. Perryman. 1998. Calibrating group size estimates for cetaceans seen on ship surveys. Southwest Fisheries Science Center, Administrative Report LJ-98-11:1-39.

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance Sampling: Estimating Abundance of Biological Populations. Chapman & Hall, London.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture. American Fisheries Society Monograph 5, Bethesda, Maryland. .
Dizon, A. E., W. F. Perrin, and P. A. Akin. 1994. Stocks of dolphins (*Stenella* spp. and *Delphinus delphis*) in the eastern tropical Pacific: a phylogeographic classification. NOAA Technical Report, National Marine Fisheries Service 119:1-20.

Gerrodette, T., and C. Perrin. 1991. Calibration of shipboard estimates of dolphin school size from aerial photographs. Southwest Fisheries Science Center, Administrative Report LJ-91-36:1-71.

Gerrodette, T., and P. Wade. 1995. Status of dolphin stocks affected by the tuna purse-seine fishery in the eastern tropical Pacific: a 36-year summary. Presentation at the 11th Biennial Conference on the Biology of Marine Mammals, Orlando, FL, December 16, 1995. .

Gerrodette, T., P. Olson, D. Kinzey, A. Anganuzzi, P. Fiedler, and R. Holland. 1998. Report of the survey design meeting for estimating abundance of eastern tropical Pacific dolphins, 1998-2000. Southwest Fisheries Science Center, Administrative Report LJ-98-03:1-25.

Gilpatrick, J. W., Jr. 1993. Method and precision in estimation of dolphin school size with vertical aerial photography. Fishery Bulletin 91:641-648.

Hewitt, R. P. 1985. Reaction of dolphins to a survey vessel: effects on census data. Fishery Bulletin 83:187-193.

Holt, R. S., and S. N. Sexton. 1990. Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: analyses of 1986 data, the first year. Fishery Bulletin 88:105-111.

Olson, P., and T. Gerrodette. 1999. Report of the meeting to review the preliminary estimates of eastern tropical Pacific dolphin abundance in 1998. Southwest Fisheries Science Center, Administrative Report LJ-99-03:1-28.

Perrin, W. F. 1990. Subspecies of *Stenella longirostris* (Mammalia: Cetacea: Delphinidae). Proceedings of the Biological Society of Washington 103:453-463.

Perrin, W. F., M. D. Scott, G. J. Walker, and V. L. Cass. 1985. Review of geographical stocks of tropical dolphins (*Stenella* spp. and *Delphinus delphis*) in the eastern Pacific. NOAA Technical Report, National Marine Fisheries Service 28:1-28.

Perrin, W. F., G. D. Schnell, D. J. Hough, J. W. Gilpatrick Jr., and J. V. Kashiwada. 1994. Reexamination of geographic variation in cranial morphology of the pantropical spotted dolphin, *Stenella attenuata*, in the eastern Pacific. Fishery Bulletin 92:324-346.

Smith, T. D. 1983. Changes in size of three dolphin (*Stenella* spp.) populations in the eastern tropical Pacific. Fishery Bulletin 81:1-13.

Thomas, L., J. L. Laake, J. F. Derry, S. T. Buckland, D. L. Borchers, D. R. Anderson, K. P. Burnham, S. Strindberg, S. L. Hedley, M. L. Burt, F. Marques, J. H. Pollard, and R. M. Fewster. 1998. Distance 3.5. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK.

Wade, P. R. 1993a. Assessment of the northeastern stock of offshore spotted dolphin (*Stenella attenuata*). Southwest Fisheries Science Center, Administrative Report LJ-93-18:1-21.

Wade, P. R. 1993b. Estimation of historical population size of the eastern spinner dolphin (*Stenella longirostris orientalis*). Fishery Bulletin 91:775-787.

Wade, P. R. 1994. Abundance and population dynamics of two eastern Pacific dolphins, *Stenella attenuata* and *Stenella longirostris orientalis*. Ph.D. dissertation. University of California (San Diego).

Wade, P. R., and T. Gerrodette. 1993. Estimates of cetacean abundance and distribution in the

eastern tropical Pacific. Report of the International Whaling Commission 43:477-493.

Table 1. Eastern tropical Pacific study area, survey effort, number of samples, and number of sightings of spotted and spinner dolphins, total and by stratum, during on-effort periods in conditions of Beaufort < 6 and visibility > 4 km during the 1998 SPAM cruise.

	Core	Outer	No. Coastal	So. Coastal	Total
Area (1000 km^2)	5773.6	15172.5	539.3	168.7	21654.1
Effort (km)	18623	16838	4161	489	40113
Samples (transect days)	131	109	44	7	291
Spotted dolphin sightings	177	47	97	4	325
Spinner dolphin sightings	89	38	27	0	154

Table 2. Number of sightings of 6 sighting categories, by stratum, during on-effort periods in conditions of Beaufort < 6 and visibility > 4 km, before truncation for $f(0)$ estimation. A pair of numbers with the same color means that these data were pooled for $f(0)$ estimation. An underlined number will be matched to another cell with the same color means that data for that cell were added for $f(0)$ estimation.

Stratum	Coastal spotted	Offshore spotted	Unid. spotted	Eastern spinner	Unid. spinner	Unid. dolphin
Core	0	165	12	79	8[*]	138
Outer	0	47	0	8	6[*]	78
No. Coastal	49	27	23	13	9[*]	78
So. Coastal	2	2	0	0	0	4

* All spinner dolphin sightings within each stratum were combined for $f(0)$ estimation for each stratum.

Table 3. Parameter estimates for line-transect analyses, by sighting categories and strata. n = number of dolphin school sightings after truncation, R = school encounter rate in schools/1000 km, $f(0)$ = probability density at the trackline in km^{-1}, ESW = effective half-strip width in km, S = expected school size, CV=coefficient of variation.

Sighting category	Stratum	n	R	CV(R)	$f(0)$	ESW	CV($f(0)$)	S	CV(S)
Coastal spotted	N.+S. Coastal	28	9.87	0.316	0.530	1.89	0.126	37.8	0.368
Offshore spotted	Core	170	9.13	0.126	0.481	2.08	0.089	69.2	0.101
Offshore spotted	Outer	46	2.73	0.247	0.279	3.59	0.103	125.7	0.155
Offshore spotted	N. Coastal	27	6.49	0.322	0.441	2.27	0.064	77.8	0.108
Offshore spotted	S. Coastal	2	4.09	0.385	0.441	2.27	0.064	77.8	0.108
Eastern spinner	Core	76	4.08	0.206	0.475	2.11	0.220	132.6	0.193
Eastern spinner	Outer	8	0.48	0.548	0.466	2.14	0.183	79.6	0.445
Eastern spinner	N. Coastal	13	3.13	0.330	0.432	2.32	0.222	357.8	0.308
Unid. spotted	N. Coastal	17	4.09	0.368	0.589	1.70	0.104	120.7	0.612
Unid. spinner	Core	7	3.76	0.458	0.527	1.90	0.146	12.4	0.273
Unid. spinner	Outer	6	0.36	0.551	0.332	3.01	0.109	715.3	0.625
Unid. spinner	N. Coastal	9	2.20	0.385	0.306	3.26	0.173	319.4	0.312
Unid. dolphin	Core	80	4.30	0.181	0.648	1.54	0.084	5.4	0.151
Unid. dolphin	Outer	37	2.20	0.201	0.571	1.75	0.098	9.7	0.345
Unid. dolphin	N. Coastal	42	10.10	0.236	0.855	1.17	0.149	8.1	0.300
Unid. dolphin	S. Coastal	2	4.09	1.017	0.855	1.17	0.149	8.1	0.300

Table 4. Estimates and sub-estimates of 1998 abundance (N) for 4 ETP dolphin stocks, with coefficients of variation (CV). An entry of

zero means no dolphins were estimated for that cell, while a blank means an estimate does not apply to that cell. N_{lower} and N_{upper} are the 95% confidence interval limits of the total estimates.

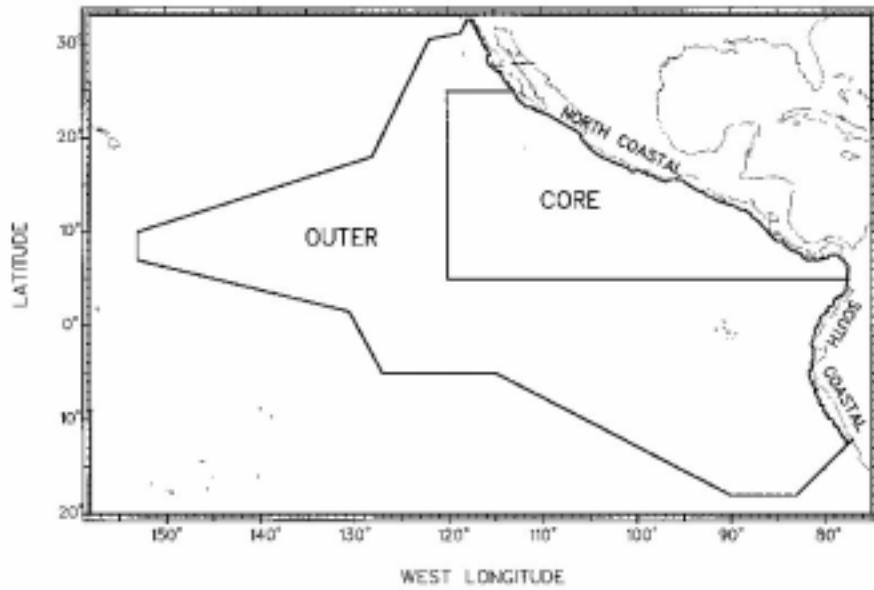| Level of identification	Source of estimate	Coastal spotted		NE offshore spotted		WS offshore spotted		Eastern spinner	
		N	CV	N	CV	N	CV	N	CV
Stock	identified in core stratum	0		877,590	0.240			742,540	0.318
	identified in outer stratum	0		16,485	0.312	709,715	0.312	133,880	0.784
	identified in coastal stratum	70,044	0.490	60,057	0.327	11,835	0.487	130,240	0.503
Species	unid. spinner in core stratum							7,051	0.607
	unid. spinner in outer stratum							94,777	0.841
	unid. spinner in N. coastal stratum							30,392	0.635
	unid. spotted in coastal stratum	36,807	0.741	41,525	0.741	0			
Family	unid. dolphin in core stratum	0		13,325	0.250			11,275	0.250
	unid. dolphin in outer stratum	0		502	0.411	21,615	0.411	4,077	0.411
	unid. dolphin in coastal stratum	1,438	1.237	1,620	1.237	1	1.237	3,513	1.237
	N_{total}	**108,289**	0.405	**1,011,104**	0.264	**743,166**	0.298	**1,157,746**	0.336
	N_{lower}	50,482		607,763		419,336		609,302	
	N_{upper}	232,292		1,682,123		1,317,073		2,199,854	

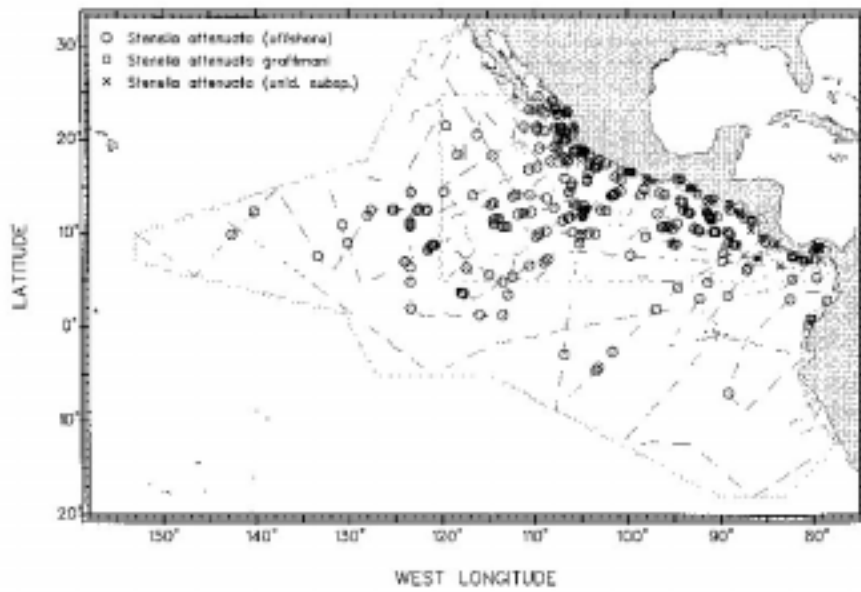Fig. 1. Sampling strata for the 1998 SPAM survey.

Fig. 2. Search effort and sightings of spotted dolphins for the 1998 SPAM survey, during on-effort periods in Beaufort < 6 and visibility > 4 km.
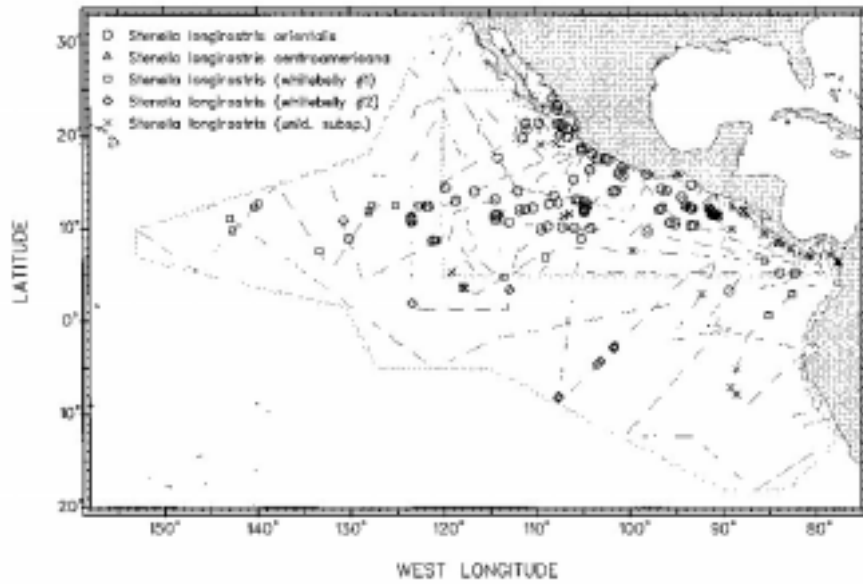
Fig. 3. Search effort and sightings of spinner dolphins for the 1998 SPAM survey, during on-effort periods in Beaufort < 6 and visibility > 4 km.
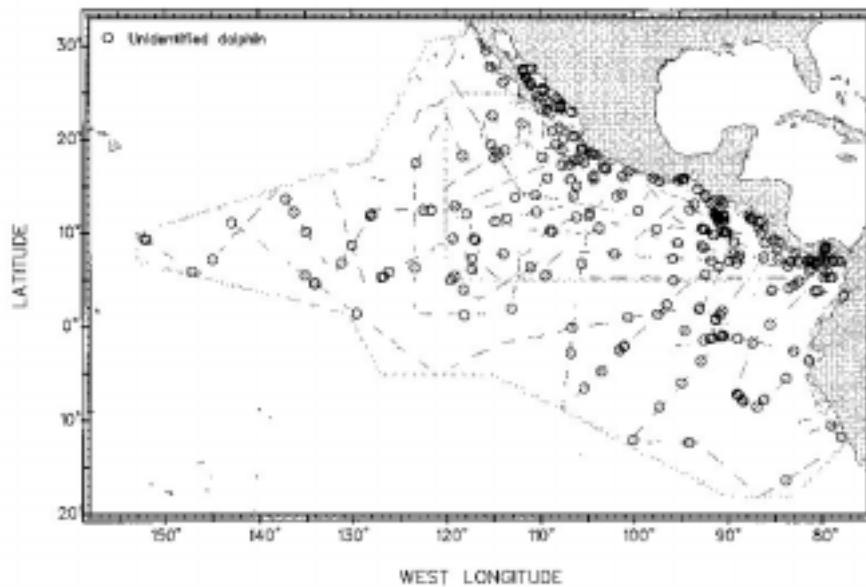

Fig. 4. Search effort and sightings of unidentified dolphins for the 1998 SPAM survey, during on-effort periods in Beaufort < 6 and visibility > 4 km.
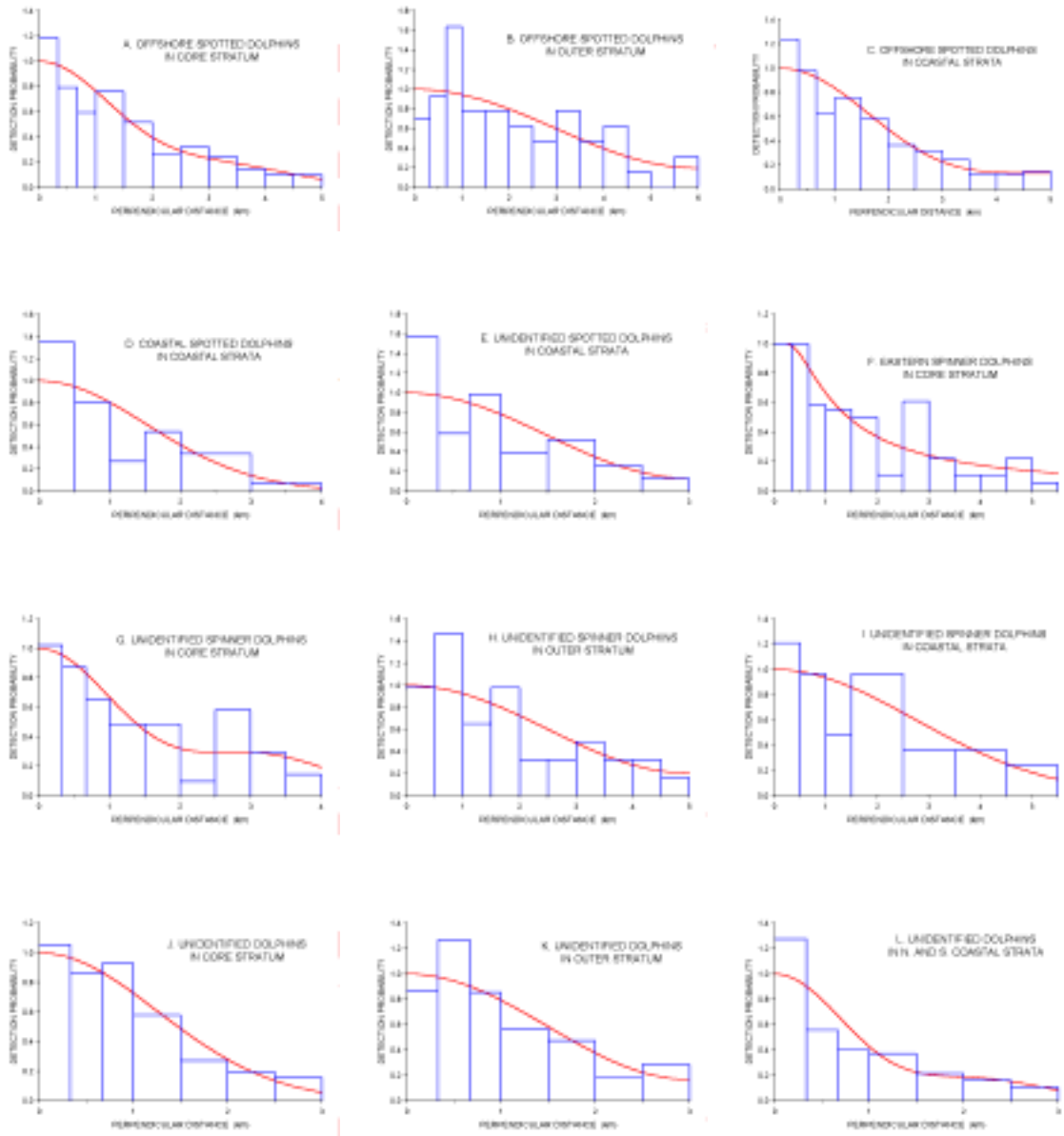
Figure 5. Detection probability functions (curved lines) and sighting frequency histograms (bars) for spotted, spinner, and unidentified dolphin sighting categories used in the 1998 abundance estimation. See text for further details. The histograms show relative frequency of sightings, not detection probabilities.