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# Research Vessel Survey Design for Monitoring Dolphin Abundance in the Eastern Tropical Pacific, 1986-1990

by

Rennie S. Holt

Southwest Fisheries Center, National Marine Fisheries Service, NOAA
La Jolla, CA, 92037, USA

and

Tim Gerrodette

National Marine Fisheries Service, NOAA
Honolulu, HA

and

John B. Cologne

Center of Quantitative Science, University of Washington
Seattle, WA, USA

## ABSTRACT

The National Marine Fisheries Service (NMFS) have initiated plans to conduct long-term monitoring of population levels of spotted dolphins which are taken incidentally in the eastern tropical Pacific by the yellowfin tuna fishery. Data collected from 1977 through 1983 during NMFS marine mammal research vessel surveys were used to determine levels of population declines during specific sampling periods or the number of years required to detect specific declines that may be expected during future surveys assuming specific Type I and Type II errors and use of one to three ships. Assuming Type I alpha Type II are 5% and with the use of three ships, an 11% or greater decline in spotted dolphins can be detected during a 5-year sampling period. A 5% annual decline can be detected if the survey is conducted for 9 years or during a 5-year period if Type I and Type II are assumed to be 20%.

SPECIAL SESSION ON BIOLOGICAL SURVEYS

## INTRODUCTION

The National Marine Fisheries Service (NMFS) has the responsibility of determining the status of dolphin stocks which are taken incidentally by the yellowfin tuna purse seine fishery in the eastern tropical Pacific (ETP) (Richey 1976). The status of spotted dolphins (*Stenella attenuata*) is of special concern since it is the major species taken by the fishery (Smith 1979).

Of the spotted dolphins, the northern offshore stock is of more concern since it has been fished more frequently than the southern offshore stock. The spinner dolphin (*S. longirostris*) and the common dolphin (*Delphinus delphis*) are also taken. In addition, the striped dolphin (*S. coeruleoalba*) and the Fraser's dolphin (*Lagenodelphis hosei*) are occasionally caught but are difficult to distinguish from the other three species at a distance (Holt and Powers 1982). These 5 species are herein termed target species.

The NMFS conducted assessments of population status in 1976 (SWFC 1976) and again in 1979 (Smith 1979) based on estimates of *absolute* stock abundance. The validity of the absolute estimates depended on several assumptions being met. Unfortunately, some assumptions, such as not allowing systematic errors in data recording or the assumption that dolphin schools do not move prior to being detected by shipboard observers, may not have been met and thus the assessments were not entirely satisfactory. An alternative approach for assessing stock status, therefore, is to use relative population estimates to detect trends in stock sizes over a long time period. Relative estimates may provide a better assessment of stock condition as long as the biases in the abundance estimates are consistent over the sampling period. Therefore, the NMFS is presently considering using annual estimates of population abundance as relative estimates to detect declines in population size of spotted dolphins during at a sampling period of at least five years.

In this paper, we investigate the annual changes in the size of spotted dolphin population that can be detected given various levels of research vessel survey effort or within specified time periods. We investigated how many research vessels, assuming 120 days searching per vessel per year, would be required to survey the physical area inhabited by the major stocks. We also investigated how many vessels would be required to detect various levels of population declines in spotted dolphins during five years or, given fixed number of vessels, how many years of survey effort it would take to detect various population declines or, given fixed number of vessels for fixed number of years, the probability of detecting a decline (i.e., the power). We used historical data and current abundance techniques to predict variability of data collected during the sampling period.

## AREA INHABITED AND DATA SOURCES

For our analyses, the study area included the area described by Au et al. (1979) as being inhabited by the target species (Figure 1). The area north of 20°N was excluded because spotted dolphins do not usually occur there. We partitioned the study area into four strata: the inside, middle, and west strata, which are located north of 1°S, and a south stratum. The three northern strata were collectively termed the north area and all strata were termed the total area.. In addition, a calibration area was defined as including part of the inside stratum (Figure 1).

Data used in our analyses were collected from 1977 through 1983 by scientific observers aboard the research vessels *David Starr Jordan* and *Townsend Cromwell*. Survey coverage from the two ships for all years combined was thorough (Figure 1). Data collected for each school included line transect observations, which we used to calculate school density estimates, estimates of dolphin school size, species identification and species composition.

## SURVEY COVERAGE

We investigated the physical coverage of the area that is possible when using 1, 2 or 3 ships for 120 days each by plotting hypothetical tracklines. Approximately 370 km (200 nautical miles) of trackline could be covered in each survey day; with searching restricted to daylight hours, only about one-half of this distance would be searched. Approximately 40,700 km of trackline could be covered by each ship with less than 50% of this distance searched during daylight hours. Each ship's searching distance was allocated to each stratum by the square root of school density in the stratum. Effort of each ship was partitioned into 30 day segments between ports to meet logistical constraints of the vessels. We found that thorough coverage of the entire area was provided when three ships were used, two ships provided adequate coverage, and one ship provided very poor coverage with tracklines separated by large distances (Figure 2).

# DETECTION OF CHANGES IN POPULATION SIZE

## Survey Design

The relationship among the number of samples, the rate of change, the precision of the population estimate, and the levels of Type I and II ($\alpha$ and $\beta$) statistical errors for several models of change and sample variability was investigated by Gerrodette (1985). We assumed that population size would change exponentially (constant rate per year). From Gerrodette's Equation 8

$$Z_{1-\alpha} + Z_{1-\beta} = \left| \ln(1-r) \right| \Bigg/ \sqrt{\frac{a(a+1)^2(a+2)}{12 \sum_{i=0}^{a} \ln\left(\frac{CV_0^2}{(1-r)^i} + 1\right)}} \qquad (1)$$

where
- $a$ = number of years in the survey period
- $r$ = annual rate of decrease
- $Z_{1-\alpha}$ = percentile of standardized normal curve for 1-tailed Type I error,
- $Z_{1-\beta}$ = percentile of standardized normal curve for Type II error, and
- $CV_0$ = coefficient of variation of the population estimate at the present population size.

In this formulation, r is a positive number, and, since the first survey occurs at time 0, the total number of samples (i.e., number of annual surveys) is a+1. In addition to the annual rate of decrease (r), the total population decrease which would occur over the entire survey period was calculated as

$$\text{Total decrease} = [\, 1 - (1 - r)^a \,].$$

The survey design to detect changes in dolphin abundance was investigated in three ways. Using equation 1, we computed (1) the number of years (a), given one to three ships per year and 120 searching days per ship per year, required to detect various annual decreases in spotted dolphin abundance; (2) the proportional annual change (r) that could be detected in 5 years given one to three ships per year at various levels of alpha and beta; and (3) power ($1-\beta$) or the probability of detecting various decreases in population size in 5 years, given one to three ships per year.

To use equation 1, the relationship of CV ($\hat{N}$), the coefficient of variation of the population estimate, and n, the number of schools detected (n) must be determined. In addition, the rate per day at which dolphin schools are expected to be encountered per day must be known. We used the 1977-1983 research vessel data to investigate these factors assuming these data would be representative of data that we will obtain during the proposed sampling period of 1986-1990.

## Abundance Estimation

Relative estimates of population abundance of spotted dolphins in the north and total areas were calculated using two methods, Methods A and B. In Method A, density and mean school size estimates were calculated in each stratum and abundance was determined (Holt and Powers 1982) as

$$\hat{N} = \hat{P}_t \sum_{k=1}^{m} \hat{D}_k \hat{S}_{tk} \hat{P}_k A_k . \qquad (2)$$

In Method B, density and mean school size estimates were calculated for data pooled for the entire area (north or total areas) and abundance was determined as

$$\hat{N} = \hat{P}_t \hat{D} \hat{S} \sum_{k=1}^{m} \hat{P}_k A_k. \qquad (3)$$

where

- $m$ = number of strata (3 for the north area and 4 for the total area),
- $k$ = 1, 2, 3, or 4 denotes the inside, middle, west or south stratum, respectively,
- $\hat{N}$ = estimated number of spotted dolphins in the survey area,
- $\hat{D}$ = density estimate of number of schools of all dolphin species in the survey area (schools/1000 $km^2$),
- $\hat{D}_k$ = density estimate of number of schools of all dolphin species in the kth stratum (schools/1000 $km^2$),
- $\hat{S}$ = mean school size estimate for target species in the survey area (number of animals),
- $\hat{S}_{tk}$ = mean school size estimate for target species in the kth stratum (number of animals),
- $\hat{P}_t$ = proportion of all dolphins that were target species in the survey area,
- $\hat{P}_k$ = proportion of spotted dolphins in the target schools in the kth stratum, and
- $A_k$ = area inhabited by all dolphins in the kth stratum.

The variance of $\hat{N}$ for equation 2 was estimated using Taylor series expansion as

$$\hat{Var}(\hat{N}) = \sum_{k=1}^{m} [(\hat{S}_{tk}\hat{P}_t\hat{P}_k A_k)^2 \hat{Var}(\hat{D}_k) + (\hat{D}_k\hat{P}_t\hat{P}_k A_k)^2 \hat{Var}(\hat{S}_{tk})$$

$$+ (\hat{D}_k\hat{S}_{tk}\hat{P}_k A_k)^2 \hat{Var}(\hat{P}_t) + (\hat{D}_k\hat{S}_{tk}\hat{P}_t A_k)^2 \hat{Var}(\hat{P}_k)]. \quad (4)$$

The variance of $\hat{N}$ in equation 3 was determined using equation 4, but density and school size estimates that were calculated for the entire area were substituted for the respective stratified estimates.

Specific formulae to estimate variables and associated theoretical variances in equations 2 through 4 are from Burnham et al (1980), Holt (1984 , 1985 ) and Barlow and Holt (1984) . Variances for estimates of school sizes and school densities were calculated using jackknife techniques (Miller 1974).

Since serial correlation among sampling units (days of effort) will yield biased estimates of standard errors using the jackknife method, we analyzed serial correlation of dolphin school detection rates among various combinations of successive days of effort. Analyses indicated that correlation was significant among successive single days but was not significant for periods of two or more days. Therefore, the data were grouped by two-day increments for the jackknife analyses.

Estimates of spotted dolphin population abundance and values used in equations 2 and 3 to calculate the estimates are presented in Table 1. CV($\hat{N}$)s were smaller for estimates calculated using Method B than for estimates using Method A.

## Relationship Between Var($\hat{N}$) and Number of Schools Detected

In order to minimize the number of years required to detect a specific trend, Var ($\hat{N}$) should be as small as possible (Gerrodette 1985 ). Var ($\hat{N}$) depends on the variance of the estimates of school size, school density, and proportions of the various dolphin species, as shown in equation 4. Each of the variances of these estimates, in turn, depends on n, the number of sighted schools. Therefore, the dependence of Var ($\hat{N}$) on n must be known to calculate the number of sightings needed to attain a given level of precision (Var ($\hat{N}$)). We investigated the dependence of each of the individual variance terms on n.

<u>Dependence of Var($S_{tk}$), Var ($\hat{P}_t$) and Var($\hat{P}_k$) on n.</u> Since $\hat{S}_{tk}$ is the mean of n individual school size estimates, its variance is Var($\hat{S}_{tk}$) = Var($S_{tk}$)/n where Var($S_{tk}$) is the variance of school size. The Var($\hat{P}_t$) = $P_t(1-P_t)/n$ where $P_t$ is the true proportion of target schools among all dolphins. Var($S_{tk}$) and $P_t(1-P_t)$ are both constant with respect to n, so Var($\hat{S}_t$) = O(1/n) and Var($\hat{P}_t$) = O(1/n), where O(1/n) means "of the same order as 1/n" and implies that as 1/n approaches zero, the variance approaches zero at the same rate. Similarly, Var($\hat{P}_{ik}$), which is also a proportion, is equal to O(1/n).

<u>Dependence of $\hat{Var}(\hat{D})$ on n.</u> The $\hat{Var}(\hat{D})$, based on replicate tracklines (Burnham et al. 1980), is:

$$\hat{Var}(\hat{D}) = \hat{D}^2 \left[ \frac{\hat{Var}(n)}{n^2} + \frac{\hat{Var}[\hat{f}(0)]}{[\hat{f}(0)]^2} \right] \qquad (5)$$

where n is the number of sightings and $\hat{f}(0)$ is the estimate of the probability density function of perpendicular distances extrapolated to the trackline. First,

$$\hat{Var}(n) = \frac{R \sum_{i=1}^{R} (n_i - \bar{n})^2}{R - 1}$$

where R is the number of replicate lines of equal length (l). For R of moderate size, R $\tilde{=}$ (R-1). Thus

$$\hat{Var}(n) = \sum_{i=1}^{R} (n_i - \bar{n})^2 = O(R)$$

This is because $\hat{Var}(n)$ is the sum of the variances of R independent values ($n_i$, i=1,2,...,R) each having the same expected variance. But R = n/E($n_1$), the total number of sightings divided by the expected number of sightings for a line of length 1. Thus, R = O(n), and

$$\frac{\hat{Var}(n)}{n^2} = \frac{O(n)}{n^2} = O(1/n) \qquad (6)$$

Second, $\hat{f}(0)$ was estimated using a Fourier series (FS) model (Burnham et al 1980), therefore,

$$\hat{Var}[\hat{f}(0)] = \sum_{j=1}^{m} \sum_{k=1}^{m} Cov(\hat{a}_j, \hat{a}_k)$$

k=1,2,3,... and k>j>1

where the $\hat{a}$'s are the coefficients in the series:

$$\hat{a}_k = \frac{2}{nw}\left[\sum_{i=1}^{n} \cos\left(\frac{k\pi x_i}{w}\right)\right] = O(1)$$

with $x_i$ equal the perpendicular distance to the ith sighting and w equal the truncation point for the perpendicular distance. Therefore, we only need to know the dependence of cov($\hat{a}_j, \hat{a}_k$) on n. If n is much larger than one, $(n-1) \hat{=} n$ and

$$Cov(\hat{a}_j, \hat{a}_k) = \frac{1}{n-1}\left[\frac{1}{w}(\hat{a}_{k+j} + \hat{a}_{k-j}) - \hat{a}_j\hat{a}_k\right] = O(1/n)$$

$k > J > 1.$

Since $\hat{f}(0)$ estimates a quantity which is constant with respect to n,

$$\frac{\hat{Var}[\hat{f}(0)]}{[\hat{f}(0)]^2} = O(1/n). \qquad (g76)$$

Combining equations 6 and 7 with equation 5, $[C.V.(\hat{D})]^2 = O(1/n)$. This confirms discussions presented by Burnham et al. (1980).

In addition to investigating the theoretical dependence of $[C.V.(\hat{D})]^2$ on n, we tested its empirical dependence on n using the research vessel data which included 479 days of survey effort. Data were truncated at 3.70 km perpendicular distance from the ship. Paired days of shipboard searching effort were randomly selected using a uniform random number generator until the number of associated sightings (n) equaled or exceeded a previously selected sample size. Sample sizes selected were 20, 30, 40, 50, 60, 80, 100, 200, 500, and 1000. The resultant perpendicular distance distributions were smeared (a data smoothing technique described by Butterworth 1982, Hammond In press, and Holt 1984 ) and density, variance and coefficient of variation estimates were calculated for each data set. The simulation was completed three times for each value of n.

The relationship between C.V.($\hat{D}$) and $1/\sqrt{n}$ (Figure 3) was linear ($F_{lack-of-fit}$=0.83; p=0.59) with intercept not significantly greater than zero (t=1.56; p>0.10). This confirms the analytical result above, that C.V.($\hat{D}$) = $O(1/\sqrt{n})$; however, as n increased, the probability of randomly selecting data from each of the 240 pairs of days (479 survey days) multiple times increased which may have biased C.V.($\hat{D}$) if the distribution of sightings for the days were biased due to the effects of season or area. If we had included more large samples in our simulation, the linear relationship may not have been evident.

Calculation of K Values. Because all terms used to calculate Var($\hat{N}$) equal $O(1/n)$ and Var($\hat{N}$) is a linear sum of the terms, Var($\hat{N}$) = $O(1/n)$ or C.V.($\hat{N}$) = $O(1/\sqrt{n})$. Therefore, the relationship

$$C.V.(\hat{N}) = K/\sqrt{n} \qquad (8)$$

can be used to determine the change in C.V.($\hat{N}$) for various values of n, where K is a constant. This relationship is true if the number of schools sighted is proportional to population size. This seems to be a reasonable assumption, although a more complicated relationship between density and school size, based on dolphin social structure and its interaction with the fishery process, is possible. K values for spotted dolphins in the North and Total areas were calculated for methods A and B using the 1977-1983 data (Table 1). These K values were then used to determine C.V.($\hat{N}$)s for specified values of n which would be expected assuming from one to three annual ship surveys.

## Detection Rates

The number of expected sightings with use of one to three ships was calculated by computing detection rates as the average number of dolphin sightings per searching day. A day's searching effort generally consisted of searching from sunrise to sundown; therefore, we assumed most survey days covered approximately the same trackline distance. However, distance searched may vary inversely with rates of detecting dolphin schools because effort is halted so that observers can identify schools and make school size estimates. The number of survey days, and hence number of ships, required to obtain a specified C.V.($\hat{N}$) was determined by dividing the number of required sightings by the rate of detecting schools.

Detection rates were calculated separately for data from the Jordan cruise and from the and Cromwell cruise due to the wide disparity in detection rates of dolphins from the two vessels when operating simultaneously in the calibration area (Table 2). Pooled Jordan and Cromwell detection rates were calculated by standardizing the Cromwell rates to Jordan rates (Table 2) as

$$DR = \frac{R_j T_j + R_c T_c C}{T_j + T_c} \qquad (9)$$

where

DR = pooled standardized detection rate for all dolphin schools,

$R_j$ = dolphin schools detected per day by observers aboard the Jordan,

$R_c$ = dolphin schools detected per day by observers aboard the Cromwell,

$T_j$ = days searched aboard the Jordan, and

$T_c$ = days searched aboard the Cromwell.

C = ratio of schools detected per day by observers aboard the Jordan in the calibration area during 1979 to schools detected per day by observers aboard the Cromwell in the calibration area during 1979.

The percent of searching days when one to three ships were used was allocated to each stratum (Table 3) by the square root of school density. The number of schools which would be expected to be detected based on the standardized detection rates then was calculated (Table 4).

Population Size Changes

For either the north or total area, the same decrease in spotted dolphin populations can be detected 2 to 4 years earlier using Method B, which uses pooled density and school size estimates, than when using Method A, which uses estimates calculated for each stratum (Table 5). This is because large variances associated with the Method A population size estimates occur due to small sample sizes in some strata. Therefore, Method B was used in subsequent calculations.

The same number of years is required to detect a specific trend if the north or total areas are surveyed (Table 5). This result is true only if the 1977-83 data, which contain small sample sizes in the south stratum, are representative of future data. However, the northern offshore spotted dolphin stock occurs only in the north area and elimination of the south stratum will ensure better coverage of this north area, especially in the west stratum where sample sizes are minimal for applying the FS model (Table 4). Therefore, subsequent calculations were made only for the north area. Annual population estimates for the northern stock would be biased only if substantial variation in the amount of dolphin migration between the north area and south stratum occurred during survey years.

At the 5% error level, only rates of change of 11% per year or greater can be detected in a 5-year survey period, even using three ships per year (Table 6). This is a rather high rate of decrease, and may lead to a 44% reduction in population size over the 5-year period. If one or two ships are used, however, the minimum detectable rate of decrease is higher still. When the power of the survey design is considered, the same dilemma is evident (Table 7). Even when three ships are used, the power is acceptably high only if the rate of decrease is at least 10% per year. The probability of detecting a 5% per annum decrease at a 5% alpha level, for example, is only 0.51. This means that there is a probability of 0.49 that we would conclude that no decrease had taken place, when in fact it had. Power is even less if only one or two ships are used.

Alternatively, we may have to either conduct the surveys for more than 5 years and/or relax the acceptable alpha and beta error level (Table 8). With three ships and 5% error levels, 5 years is sufficient to detect a 10% per annum decline, but 9 years are required to detect a 5% per annum decline and 13 years are required to detect a 3% per annum decline. For alpha and beta levels equal 0.10 or equal 0.20 and use of three ships, a 5% decrease can be detected in 7 or 5 years, respectively.

Our analyses thus indicate that our ability to detect changes in the size of spotted dolphin populations in the ETP is not very great without substantial long-term ship time. This is not surprising given the vast area of ocean inhabited by the dolphins and the low sighting rate from ships. We feel our results represent a generally accurate picture based on available data. However, the analyses must be qualified by noting that the data used to generate these results were accumulated during all seasons over 5 years. Data collected in future surveys within a single season may be less variable. In addition, more precise data gathering techniques or data fitting models may become available. If so, this would yield greater ability to detect lower rates of decrease, greater power, and lower required number of years. However, the estimates of expected variance have dealt with survey precision (measurement error) only. If environmental variability is important, data collected in future surveys may be more variable than we have calculated. In long-lived animals with many year-classes contributing to reproduction, however, environmental variability will tend to be less important than survey imprecision (Gerrodette 1985 ).

The selection of appropriate alpha and beta errors may depend upon one's perspective. A type I (alpha) error occurs when a true hypothesis is rejected, and a type II (beta) error occurs when a false hypothesis is accepted. Therefore, if the null hypothesis is that no significant decrease in population size occurred during the sampling period and we are testing for alpha and beta errors of 5%, the null hypothesis may be incorrectly rejected 5% of the time (Type I error), while it may be accepted 5% of the time when it is in fact false (Type II error). A type I error may be of more concern to the fishery, so they may prefer to test with small alpha values. A type II error may be of more concern to conservation groups, so they may prefer to test with small beta values. In our analyses, we used a range of equal alpha and beta errors.

At least two ships are required to provide representative coverage of the survey area. Although use of a third ship provides better coverage, it does not substantially improve detection of population decreases. For alpha and beta levels of 0.05, a 5% per year decrease can be detected in 9 years with use of three ships or 10 years with use of two ships (Table 8). For other alpha and beta levels, use of the third ship only increases our ability to detect specific decreases by about 1 year. Given the annual cost of each ship, it may be more desirable to conduct the surveys for an additional year using only two ships.

If a 5% annual decrease in population size occurred, the number of spotted dolphins killed would have to be large. Assuming a spotted dolphin population of 2.5 million animals (Table 1) and disregarding natural mortality and reproduction, approximately 125,000 animals would be killed each year. The estimates of all dolphins taken by the fishery during each of the last few years are only about 40,000 animals per year (Hammond and Tsai 1983). It may be unreasonable to expect annual decreases at the 5% annual level; rather decreases of 3% or 1% per year would be more reasonable. If so, considerably longer time will be required to detect the decline (Table 8).

Nonetheless, the number of dolphins actually killed may exceed 40,000 animals per year because dolphin mortality aboard the unsampled trips of U.S. and non-U.S. registered vessels, which is assumed to be similar to that on the sampled trips, may in fact be substantially higher. In addition, the effects of chasing and capturing dolphins several times per year are not estimated in our analyses.

## SUMMARY

Use of three ships provides excellent physical coverage of the ETP dolphin area. Coverage using two ships appears adequate while use of one ship yields very sparse coverage.

Assuming alpha and beta levels equal 0.05, use of three ships for each of 5 years will only allow us to detect an 11% annual decrease in spotted dolphin abundance. This means that the population will decline at least 44% during the survey period. If three ships are used for 9 years, a 5% decrease per year could be detected.

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Table 1. School density of all dolphin schools, proportion of all schools which were target schools, mean school size of target schools, proportion of target animals which were spotted dolphins, area of each stratum, abundance and K values for spotted dolphins. S.E. and C.V. denotes standard error and coefficient of variation, respectively. Methods A and B refer to different ways of pooling data on school size and denisty (see text).

| | Stratum | | | | Area | |
|---|---|---|---|---|---|---|
| Variable | Inside | Middle | West | South | North | Total |
| School Density ($\hat{D}$) (Schools/1000 km$^2$) | 5.33 | 3.42 | 0.82 | 1.93 | 3.20 | 3.03 |
| S.E. ($\hat{D}$) | 0.87 | 1.13 | 0.30 | 0.39 | 0.54 | 0.51 |
| C.V. ($\hat{D}$) | 16.3 | 33.1 | 37.2 | 20.2 | 17.0 | 16.8 |
| Prop. Target ($P_t$)$^a$ | - | - | - | - | 0.775 | 0.775 |
| Mean School Size ($S_t$) (Number animals) | 108.59 | 113.89 | 121.06 | 157.65 | 111.62 | 118.21 |
| S.E. ($S_t$) | 9.82 | 11.24 | 23.28 | 29.84 | 7.44 | 7.92 |
| C.V. ($S_t$) | 8.6 | 9.9 | 19.2 | 18.9 | 6.7 | 6.7 |
| Area (km$^2$*10$^6$) | 4.602 | 3.764 | 5.298 | 4.359 | 13.664 | 18.024 |
| Prop. Spotted ($P_k$)$^b$ | 0.38 | 0.51 | 0.51 | 0.26 | - | - |
| S.E($P_k$)$^b$ | 0.039 | 0.048 | 0.048 | 0.085 | - | - |
| Abundance and K Values | | | | | | |
| Method A | | | | | | |
| $\hat{N}$ (Animals*10$^6$) | | | | | 1.571 | 1.839 |
| S.E. ($\hat{N}$) | | | | | 0.283 | 0.294 |
| C.V. ($\hat{N}$) | | | | | 0.18 | 0.16 |
| Sample size (n) | | | | | 507 | 602 |
| K | | | | | 4.05 | 3.93 |
| Method B | | | | | | |
| $\hat{N}$ (Animals*10$^6$) | | | | | 1.761 | 2.081 |
| S.E.($\hat{N}$) | | | | | 0.240 | 0.250 |
| C.V.($\hat{N}$) | | | | | 0.14 | 0.12 |
| Sample size (n) | | | | | 507 | 602 |
| K | | | | | 3.06 | 2.94 |

a= Source Holt(1985) ; b= Source Barlow and Holt (1984)

Table 2. Detection rates of all dolphin schools from the Jordan and Cromwell in the calibration area and pooled standardized detection rates for both vessels combined calculated in each stratum. Standardized detection rates were calculated using the ratio of Jordan to Cromwell detection rates in the calibration area.

| Stratum/Area | Jordan (J) Number of schools (n) | Jordan (J) Days searched (D) | Jordan (J) n/D | Cromwell (C) Number of schools (n) | Cromwell (C) Days searched (D) | Cromwell (C) n/D | J/C Ratio of detection rates |
|---|---|---|---|---|---|---|---|
| Calibration Area | 102 | 28 | 3.643 | 49 | 31 | 1.581 | 2.304 |
| | | | | | | | Pooled standardized n/D |
| 1. Inside | 237 | 106 | 2.24 | 87 | 56 | 1.55 | 2.70 |
| 2. Middle | 108 | 80 | 1.35 | 18 | 22 | 0.82 | 2.10 |
| 3. West | 43 | 54 | 0.80 | 14 | 56 | 0.25 | 0.69 |
| 4. South | 91 | 60 | 1.52 | 4 | 5 | 0.80 | 1.54 |
| North Area (Pooled strata 1-3) | 388 | 226 | 1.72 | 119 | 128 | 0.93 | 1.87 |
| Total Area (Pooled strata 1-4) | 479 | 282 | 1.70 | 123 | 132 | 0.93 | 1.84 |

Table 3. Percent of searching days allocated by square root of density to each stratum in the north and total areas.

| Stratum | North Area | Total Area |
|---|---|---|
| Inside | 45.6 | 35.8 |
| Middle | 36.5 | 28.7 |
| West | 17.9 | 14.0 |
| South | - | 21.5 |

Table 4. Number of days searched and number of schools detected per year of effort with use of 1, 2, or 3 ships allocated to the various strata by square root of density.

| Stratum | North Number days | North Number schools | Total Number days | Total Number schools |
|---|---|---|---|---|
| 1 Ship =120 days | | | | |
| Inside | 55 | 149 | 43 | 116 |
| Middle | 44 | 92 | 34 | 71 |
| West | 21 | 14 | 17 | 12 |
| South | - | - | 26 | 40 |
| | 120 | 255 | 120 | 239 |
| 2 Ships=240 days | | | | |
| Inside | 110 | 298 | 86 | 232 |
| Middle | 88 | 184 | 68 | 142 |
| West | 42 | 28 | 34 | 24 |
| South | - | - | 52 | 80 |
| | 240 | 510 | 240 | 478 |
| 3 Ships=360 days | | | | |
| Inside | 165 | 447 | 129 | 348 |
| Middle | 132 | 276 | 102 | 213 |
| West | 63 | 42 | 51 | 36 |
| South | - | - | 78 | 120 |
| | 360 | 765 | 360 | 717 |

Table 5. Number of years required to detect an annual five percent decrease in spotted dolphin population size using 1, 2, or 3 ships and 2 different methods of pooling data. Method A utilized equation 2 in text while Method B utilized equation 3. Alpha and beta levels equal 0.05, and effort was allocated to the various strata by square root of density. Number of schools expected to be detected each year determined using detection rates from equation 9. K determined using equation 8. CV($\hat{N}$) denotes coefficient of variation of population abundance estimate.

| Stratum | Number ships | Number schools | K | CV(N) | Years required |
|---|---|---|---|---|---|
| North Area | | | | | |
| Method A | 1 | 228 | 4.05 | 0.27 | 17 |
| | 2 | 456 | | 0.19 | 12 |
| | 3 | 684 | | 0.15 | 11 |
| Method B | 1 | 228 | 3.06 | 0.20 | 13 |
| | 2 | 456 | | 0.14 | 10 |
| | 3 | 684 | | 0.12 | 9 |
| Total Area | | | | | |
| Method A | 1 | 218 | 3.93 | 0.27 | 17 |
| | 2 | 436 | | 0.19 | 12 |
| | 3 | 654 | | 0.15 | 11 |
| Method B | 1 | 218 | 2.94 | 0.20 | 13 |
| | 2 | 436 | | 0.14 | 10 |
| | 3 | 654 | | 0.11 | 8 |

Table 6. Minimum rates of annual decrease and minimum total decreases in spotted dolphin population size which could be detected in five years under different conditions. Changes were calculated for several alpha and beta levels, with a 1-tailed test, using 1, 2, and 3 ships, for CV(N) determined using jackknife formulae, and data in the north area pooled over all strata (Method B).

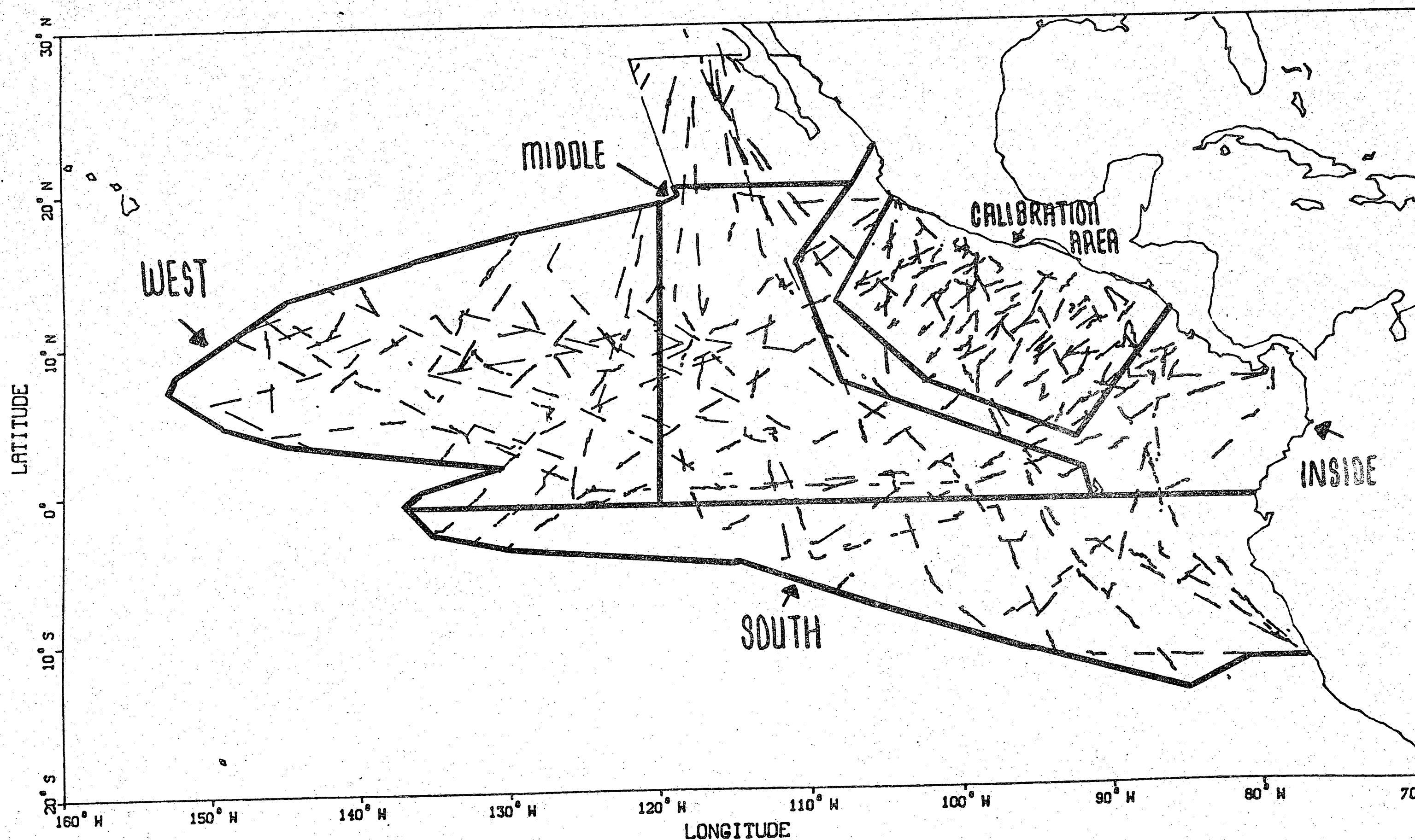
| Number ships | CV(N) | Decrease per year | Total decrease |
|---|---|---|---|
| $\alpha = \beta = 0.05$ | | | |
| 1 | 0.20 | 0.19 | 0.65 |
| 2 | 0.14 | 0.13 | 0.50 |
| 3 | 0.12 | 0.11 | 0.44 |
| $\alpha = \beta = 0.10$ | | | |
| 1 | 0.20 | 0.14 | 0.53 |
| 2 | 0.14 | 0.10 | 0.41 |
| 3 | 0.12 | 0.08 | 0.34 |
| $\alpha = \beta = 0.20$ | | | |
| 1 | 0.20 | 0.09 | 0.38 |
| 2 | 0.14 | 0.06 | 0.27 |
| 3 | 0.12 | 0.05 | 0.23 |

Table 7. Power, or the probability of detecting a decrease in spotted dolphin population size during a five year period. Power was calculated for surveys using 1, 2, or 3 ships, for various rates of annual and total population decrease, and for testing the regression of population size against time at various significance levels ($\alpha$).

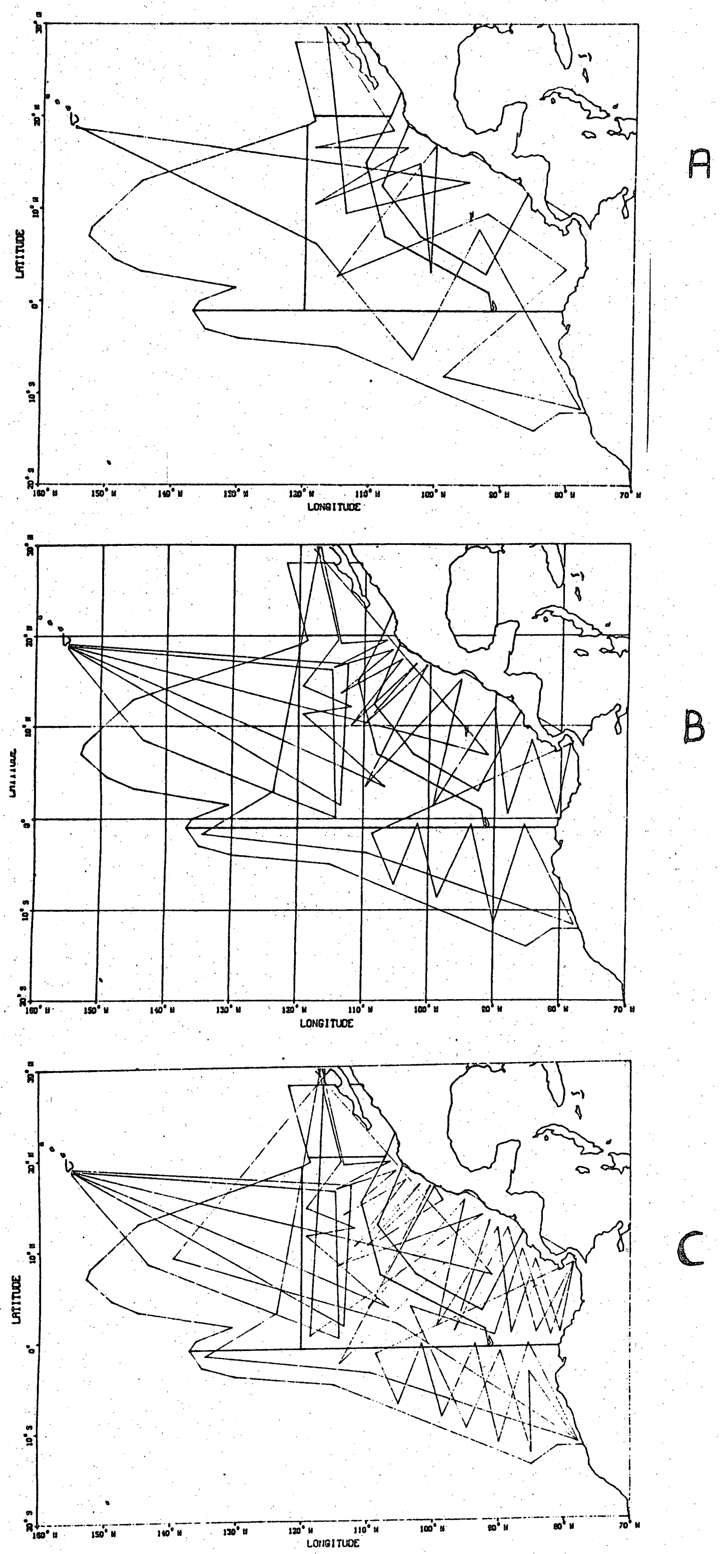
| Number of Ships | CV(N) | Rate of decrease per year | Total decrease | Power When $\alpha$ =0.05 | $\alpha$ =0.10 | $\alpha$ =0.20 |
|---|---|---|---|---|---|---|
| 1 | 0.20 | 0.01 | 0.05 | 0.08 | 0.14 | 0.26 |
| | | 0.03 | 0.14 | 0.15 | 0.25 | 0.41 |
| | | 0.05 | 0.23 | 0.26 | 0.40 | 0.57 |
| | | 0.10 | 0.41 | 0.62 | 0.75 | 0.86 |
| 2 | 0.14 | 0.01 | 0.05 | 0.09 | 0.16 | 0.29 |
| | | 0.03 | 0.14 | 0.22 | 0.34 | 0.52 |
| | | 0.05 | 0.23 | 0.42 | 0.56 | 0.73 |
| | | 0.10 | 0.41 | 0.87 | 0.93 | 0.97 |
| 3 | 0.12 | 0.01 | 0.05 | 0.10 | 0.18 | 0.31 |
| | | 0.03 | 0.14 | 0.27 | 0.40 | 0.57 |
| | | 0.05 | 0.23 | 0.51 | 0.66 | 0.80 |
| | | 0.10 | 0.41 | 0.94 | 0.97 | 0.99 |

Table 8. Number of years required to detect various annual decreases and total declines of spotted dolphins calculated for several alpha and beta levels using 1, 2, and 3 ships. CV(N)s were calculated using jackknife formulae and using data in the north area pooledover all strata (Method B).

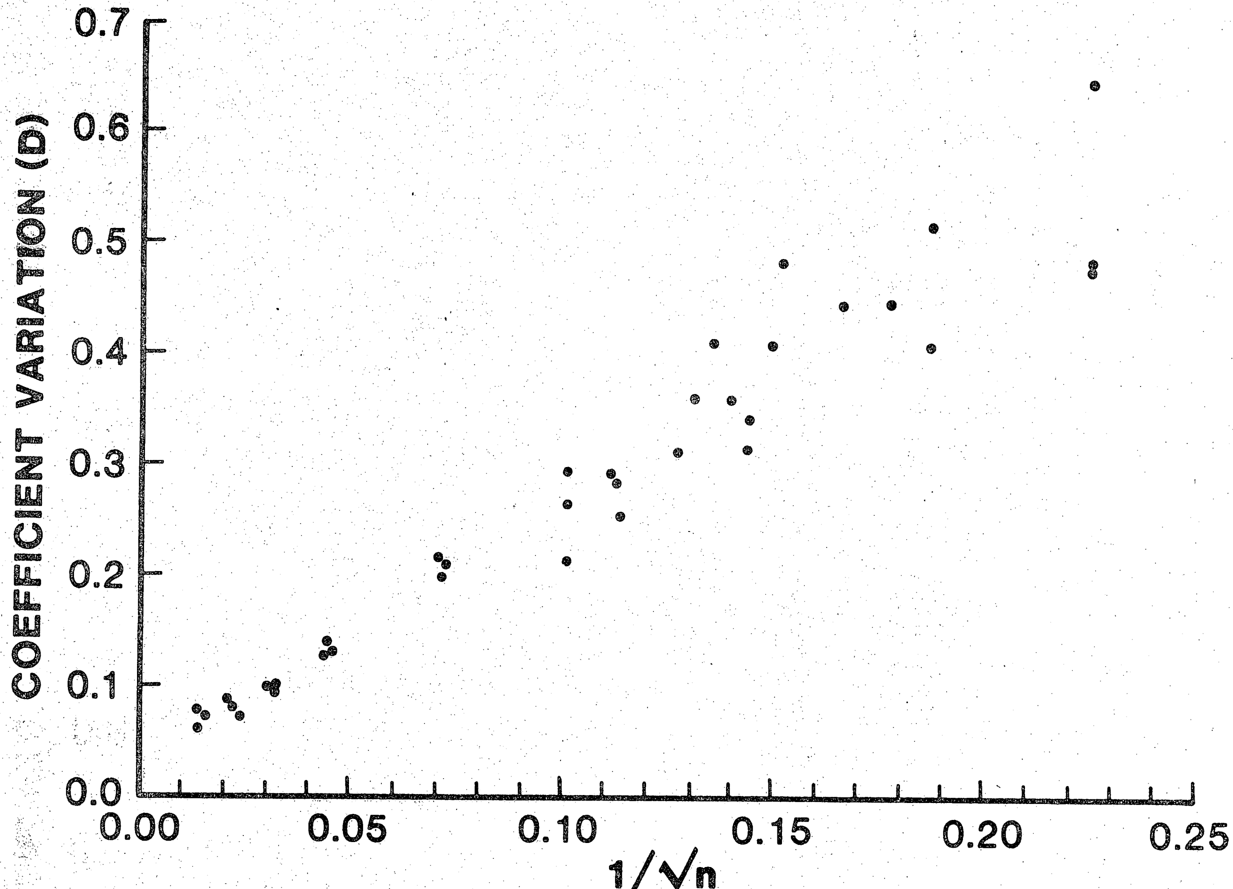
| Number ships | CV(N) | Decrease per year | Number years required | Total decrease |
|---|---|---|---|---|
| $\alpha = \beta = 0.05$ | | | | |
| 1 | 0.20 | 0.01 | 39 | 0.32 |
| | | 0.03 | 19 | 0.44 |
| | | 0.05 | 13 | 0.49 |
| | | 0.10 | 8 | 0.57 |
| 2 | 0.14 | 0.01 | 30 | 0.26 |
| | | 0.03 | 14 | 0.35 |
| | | 0.05 | 10 | 0.40 |
| | | 0.10 | 6 | 0.47 |
| 3 | 0.12 | 0.01 | 27 | 0.24 |
| | | 0.03 | 13 | 0.33 |
| | | 0.05 | 9 | 0.37 |
| | | 0.10 | 5 | 0.41 |
| $\alpha = \beta = 0.10$ | | | | |
| 1 | 0.20 | 0.01 | 32 | 0.28 |
| | | 0.03 | 15 | 0.37 |
| | | 0.05 | 11 | 0.43 |
| | | 0.10 | 7 | 0.47 |
| 2 | 0.14 | 0.01 | 25 | 0.22 |
| | | 0.03 | 12 | 0.31 |
| | | 0.05 | 8 | 0.34 |
| | | 0.10 | 5 | 0.41 |
| 3 | 0.12 | 0.01 | 23 | 0.21 |
| | | 0.03 | 11 | 0.28 |
| | | 0.05 | 7 | 0.30 |
| | | 0.10 | 5 | 0.41 |
| $\alpha = \beta = 0.20$ | | | | |
| 1 | 0.20 | 0.01 | 24 | 0.21 |
| | | 0.03 | 11 | 0.28 |
| | | 0.05 | 8 | 0.34 |
| | | 0.10 | 4 | 0.41 |
| 2 | 0.14 | 0.01 | 19 | 0.17 |
| | | 0.03 | 8 | 0.22 |
| | | 0.05 | 6 | 0.26 |
| | | 0.10 | 3 | 0.27 |
| 3 | 0.12 | 0.01 | 17 | 0.16 |
| | | 0.03 | 8 | 0.22 |
| | | 0.05 | 5 | 0.23 |
| | | 0.10 | 3 | 0.27 |




1. Research vessel tracklines in each stratum during 1977 through 1983.




2. Plot of hypothetical tracklines expected from use of one (A), two (B), or three (C) ships for 120 days each.




3. Comparison of number of dolphin sightings ($1/\sqrt{n}$) and precision of the population estimate (C.V.(D)).