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**Abstract.**— We summarize the methods for estimating relative abundance of seven dolphin stocks in the eastern tropical Pacific Ocean using sightings data collected on commercial tuna vessels by trained observers, developed by Buckland and Anganuzzi (1988a) and Anganuzzi and Buckland (1989). Their estimates of relative abundance, which may show large year-to-year fluctuations, are smoothed to provide estimates of the underlying trend in dolphin abundance between 1976 and 1988. The bootstrap method provides estimation of precision in a way that allows trend estimates to be used for management purposes, without the need to assume that trends in abundance are linear. Concerns about the validity of the estimates are addressed.

## Estimating trends in abundance of dolphins associated with tuna in the eastern tropical Pacific Ocean, using sightings data collected on commercial tuna vessels

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Incidental mortality of dolphins in the tuna fishery in the eastern tropical Pacific since 1959 has been sufficient to affect abundance of stocks of at least two species of dolphin: the spotted dolphin *Stenella attenuata* and the spinner dolphin *S. longirostris* (Smith 1983). Although there is less information available on stocks of the common dolphin *Delphinus delphis*, mortality estimates (e.g., Hall and Boyer 1988) suggest that abundance of stocks of this species may also have been reduced. To monitor possible effects of incidental mortality on the size of dolphin stocks, several attempts to estimate abundance have been made, usually applying line-transect methodology to data collected on either commercial tuna vessels ("tuna vessel data") or research vessels ("research vessel data") or both. Holt and Powers (1982) and Holt (1985, 1987) considered analyses of research vessel data alone, and of tuna vessel data combined with research vessel data. More recently, Holt and Sexton (1989, 1990a,b) analyzed data from research vessels alone. Tuna vessel data alone were analyzed by Hammond and Laake (1983), by Polacheck (1987), by Buckland and Anganuzzi

(1988a), and by Anganuzzi and Buckland (1989).

The tuna vessel data are collected by scientific technicians placed by two organizations onboard commercial tuna purse seiners. The Inter-American Tropical Tuna Commission (IATTC) places technicians on vessels of the international fleet (including U.S.-registered vessels), and the National Marine Fisheries Service (NMFS) of the United States places technicians on U.S.-registered vessels only. Data were first collected by NMFS in 1974, and by IATTC in 1979.

Tuna vessel data provide a large database, with regular coverage of a substantial portion of the area occupied by the dolphin stocks. However, due to the nature of the fishery operations, the assumptions necessary for line-transect sampling to yield unbiased estimates of absolute abundance are often violated. Therefore, analytic procedures should as far as possible be insensitive to those violations. We summarize here the procedures of Buckland and Anganuzzi (1988a), as modified by Anganuzzi and Buckland (1989). Since these procedures are unlikely to remove all biases, the estimates should

be treated as indices of relative abundance, rather than estimates of absolute abundance of the stocks. The definition of a stock, and its boundaries, is problematic, but we follow the recommendations of Au et al. (1979), for reasons stated by Anganuzzi and Buckland (1989), except in two cases. A more southerly southern boundary was found to be necessary for the southern offshore stock of spotted dolphins (Anganuzzi et al. 1991), and we adopt the recommendation of Perrin et al. (1991) to combine the northern and southern whitebelly stocks of spinner dolphins. We also derive estimates for pooled offshore stocks of spotted dolphins and pooled stocks of common dolphins, since they are not differentiable in the field.

Buckland and Anganuzzi (1988a) provided three types of test for assessing whether abundance of a stock had changed over time. For several stocks, the tests failed to provide a clear indication of recent changes, since the occasional large fluctuation in annual estimates indicated that there were significant changes in abundance that were biologically implausible. We present here a method of smoothing the sequence of estimates of relative abundance. Used in conjunction with the bootstrap, it yields a simple method of assessing change over time which does not require that trends are assumed to be linear, and which does not yield biologically implausible rates of change.

Edwards and Kleiber (1989) have questioned the validity of estimating trends in abundance from sightings data collected on commercial tuna vessels. We carry out a simple simulation study to assess their assertions, and compare the relative abundance estimates calculated from tuna vessel data with those calculated from research vessel data for the years 1986–89, for which data from both sources are available.

## Methods

The number of dolphins  $N$  in an area for a given stock and year is estimated by

$$\hat{N} = A \cdot \hat{s} \cdot \hat{D}$$

where  $A$  is the size of the area,  
 $\hat{s}$  is the estimated average school size for the stock in area  $A$ , and  
 $\hat{D}$  is the estimated density of schools in area  $A$ .

The line-transect method provides the estimate  $\hat{D}$  (Burnham et al. 1980). Suppose schools farther than a distance  $w$  from the trackline are discarded from the analyses. Then

$$\hat{D} = \frac{n \cdot \hat{f}(0)}{2L} \quad (1)$$

where  $n$  is the number of schools detected in the area that are within the truncation distance  $w$ ,  $\hat{f}(0)$  is the estimated probability density function of the  $n$  perpendicular distances, evaluated at perpendicular distance zero, and  $L$  is the total length of transect in nautical miles within the area.

If we define the encounter rate  $E$  to be the expected number of sightings detected within  $w$  of the trackline per nautical mile of search, then its estimate is given by

$$\hat{E} = n/L.$$

Hence, 
$$\hat{D} = \frac{\hat{E} \cdot \hat{f}(0)}{2} \quad (2)$$

and 
$$\hat{N} = \frac{\hat{E} \cdot \hat{f}(0) \cdot \hat{s} \cdot A}{2}. \quad (3)$$

If  $\hat{D}$  and  $\hat{N}$  were estimates of absolute abundance, then the following assumptions would be required:

- (i) Within each area or stratum, either the search effort of the tuna vessels is random or the dolphin schools are randomly distributed;
- (ii) any movement of schools is slow relative to the speed of the vessel, at least before detection;
- (iii) all schools on or close to the trackline are detected and identified;
- (iv) sighting distances and angles are measured without error;
- (v) sightings of schools are independent events;
- (vi) school size is recorded without error, and for mixed schools percent of each species is recorded without error;
- (vii) probability of detection of a school is independent of its size, at least out to perpendicular distance  $w$ .

If the estimates are used solely as indices of relative abundance, as here, then any or all of the above assumptions may fail without invalidating the estimates, provided that bias arising from the failure of an assumption is consistent across time. Even this proviso may be relaxed when trends in abundance over a long sequence of years are estimated; in this case it is merely necessary to assume that bias shows no trend with time. Catch-per-unit-effort methods for estimating relative abundance are known to show trends in bias over time in some instances, due to increased efficiency of vessels (Cooke 1985). We attempt to avoid such problems by incorporating a parameter that measures the

efficiency of search of the tuna vessels. This parameter, the effective search width, is estimated using line-transect theory. It may be interpreted as twice the distance at which the number of undetected dolphin schools closer to the vessel is equal to the number of detected schools further from the vessel, and is therefore the effective width of the strip of ocean searched by the vessel. As efficiency of the fleet to detect dolphin schools increases (e.g., through the use of helicopters, high-resolution radar, etc.), the effective search width increases, and bias in abundance estimates should remain unaffected.

We adopt a strategy of reducing bias as much as possible, so that the effect of any trend in bias over time on estimated trends in abundance is minimized. To estimate the different components of the estimator of Equation (3), separate stratification schemes are applied for encounter rate, effective search width, and school size. In stratifying for a given component, our aim is to define strata such that each stratum is relatively homogeneous with respect to that component, so that non-random search effort and non-random distribution of schools generate only small bias in any given stratum. Crude encounter rates, average school sizes, and average detection distances are estimated by  $1^\circ$  square. Where data are insufficient, the crude estimates are smoothed, and the same smoothing procedure interpolates for squares in which there was no tuna vessel effort. These estimates are used to allocate  $1^\circ$  squares to strata, yielding the separate stratifications for encounter rate, school size, and effective search width, respectively. Full details are given by Anganuzzi and Buckland (1989).

Thus the problem of abundance estimation has been reduced to three simpler problems: For a random point in the stock area, the expectations of encounter rate, school size, and effective search width are estimated, and the three estimates are multiplied together to obtain the final abundance estimate. Lack of independence between the three estimates does not bias the overall estimate, and independence is not assumed when estimating variance. A nonparametric bootstrap technique is used to obtain variances. The resampling unit in the bootstrap is the individual cruise, and for each bootstrap replicate the full estimation procedure is applied, thus generating bootstrap estimates of abundance. The sample variance of these estimates yields the required variance estimates, and confidence intervals are obtained by the percentile method. (See Buckland and Anganuzzi 1988a, for details.)

Bias arising from rounding errors in the recorded sighting distances  $r$  and angles  $\theta$  is reduced by smearing the data, using the method favored by Buckland and Anganuzzi (1988b). The recorded location of each school relative to the tuna vessel at the time of

detection is defined by  $r$  and  $\theta$ , and that location is "smeared" over the sector defined by  $r \cdot (1 \pm d)$  and  $\theta \pm \phi/2$ , to allow for inaccuracy in the recorded values. The smearing parameters  $d$  and  $\phi$  are estimated from the data. When a small sighting angle is rounded to zero, the calculated perpendicular distance is zero, giving a spurious spike in the perpendicular distance distribution at zero distance. Smearing yields more robust estimation by removing or reducing this spike.

Here we take the estimates of Anganuzzi and Buckland (1989) and of Anganuzzi et al. (1991) and attempt to estimate the underlying trends in dolphin abundance by smoothing them. Various smoothing methods such as moving averages, running medians, and polynomial regression were investigated (Smith 1988). The chosen method was a compound running median known as "4253H, twice" (Velleman and Hoaglin 1981), which is constructed as follows.

Suppose that  $\{X(t)\}$ ,  $t = 1, \dots, N$ , is a time-series of length  $N$ , and let  $\{S_i(t)\}$  be a smoothed version of it, found by calculating an  $i$ -period running median. We can construct compound smoothing methods such as  $\{S_{ij}(t)\}$ , which is simply  $\{S_j(S_i(t))\}$ . Thus, a 4253 running median method smooths a time-series using a 4-period running median, which is in turn smoothed by a 2-period running median, smoothed again by a 5-period running median, and then by a 3-period running median (i.e.,  $\{S_{4253}(t)\} = \{S_3(S_5(S_2(S_4(t))))\}$ ). Near the endpoints, where there are not enough values surrounding a point to be smoothed using the specified running median, a shorter-period running median may be used. The endpoints of the resultant time-series are calculated by estimating  $X(0)$  and  $X(N+1)$ , the "observed" values at  $t=0$  and  $t=N+1$ , and then calculating

$$S_{4253}(1) = \text{median} \{\hat{X}(0), X(1), S_{4253}(2)\} \text{ and}$$

$$S_{4253}(N) = \text{median} \{S_{4253}(N-1), X(N), X(N+1)\}.$$

$\hat{X}(0)$  is found by extrapolating from the straight line which passes through the smoothed values at  $t=2$  and  $t=3$ , i.e.,  $\hat{X}(0) = 3 \cdot S_{4253}(2) - 2 \cdot S_{4253}(3)$ ; similarly,  $\hat{X}(N+1) = 3 \cdot S_{4253}(N-1) - 2 \cdot S_{4253}(N-2)$ .

The H in "4253H, twice" denotes a linear smoothing method commonly used with running medians, which is known as Hanning. It is a 3-period weighted moving average for  $t=2, \dots, N-1$ , with weights  $\{0.25, 0.5, 0.25\}$ . The endpoints remain unchanged.

The pattern of the time-series may be recovered by calculating the residuals of the series (i.e., the differences between the smoothed and unsmoothed estimates), smoothing the residual series using the same method as for the time-series, and then adding the smoothed values of the residuals to the smoothed

values of the series. This is known as smoothing "twice." For example, if we define the residuals of the time-series smoothed by 4253H to be  $\{E(t)\} = \{X(t) - S_{4253H}(t)\}$ , then the values of the time-series smoothed by "4253H, twice" can be defined by

$$\{S_{4253H, \text{twice}}(t)\} = \{S_{4253H}(t) + S_{4253H}(E(t))\}.$$

Thus the "4253H, twice" running median method uses a 4253 running median to smooth the time-series, estimates the endpoints of the smoothed series, and then smooths the resultant series by Hanning. The residuals of the series are calculated and are also smoothed, using the same method as above. The smoothed values of the residuals are then added to the smoothed values of the time-series to produce a time-series smoothed by "4253H, twice." The advantage of using running medians is that the magnitude of an extreme estimate does not affect the resultant smoothed time-series. The above method is sufficiently complex that its behavior cannot be readily understood. However, simpler methods were found to suffer from one or more of the following shortcomings: Estimated trends were not always smooth; implausible rates of change were sometimes indicated; trends near the start or end of the sequence of estimates were often poorly estimated.

Nonparametric bootstrap replicates are generated as described by Anganuzzi and Buckland (1989). We select here the bootstrap estimates that correspond to an 85% confidence interval for relative abundance in each year. The rationale for the choice of confidence level is that if two 85% confidence intervals do not overlap, the difference between the corresponding relative abundance estimates is significant at roughly the 5% level ( $P \leq 0.05$ ); whereas if they do, the difference is not significant ( $P > 0.05$ ). If the abundance estimates are assumed to be lognormally distributed, each with the same coefficient of variation, then the exact confidence level that gives this property is 83.4%. If one estimate has twice the coefficient of variation of the other, the confidence level increases slightly to 85.6%. Thus a choice of 85% makes some allowance for variability in the coefficient of variation.

For each abundance estimate, 79 bootstrap replicates are run, so that the 6th smallest and 6th largest bootstrap estimates provide an approximate 85% confidence interval (Buckland 1984). If this procedure is carried out independently for each year, confidence intervals are wide. Provided the assumed stock area spans the whole range of the stock, numbers of dolphins within it are unlikely to vary greatly in successive years, and a procedure that calculates confidence intervals for a given year incorporating information from years immediately preceding and following that year

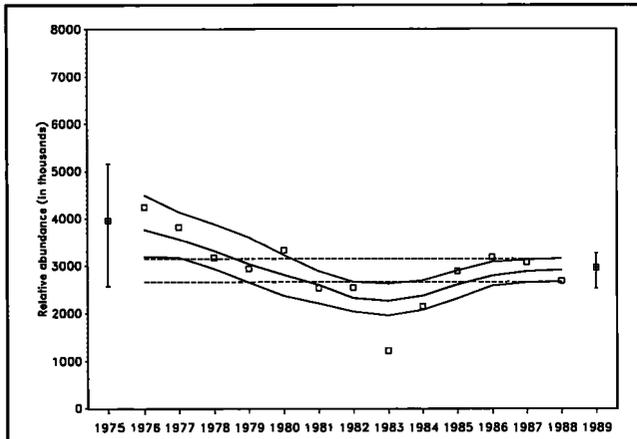
is more informative. For a given stock, we achieve this by carrying out one bootstrap replication for each year that a relative abundance estimate is available. These estimates are smoothed using the routine described above, and the process is repeated 79 times. For each year, the 6th smallest and 6th largest smoothed estimates provide approximate 85% confidence limits. We use the sequence of medians of the smoothed bootstrap estimates (i.e., the 40th estimate of each ordered set of 79) as the "best" indicator of trend, so that it is calculated in a comparable manner to the confidence limits. Larger numbers of bootstrap replicates are preferable, but available computer power was limited. Repeat runs for the northern offshore stock of spotted dolphins were carried out, to assess the Monte Carlo variability.

By using overlapping confidence intervals to test for a difference between years, independence between smoothed estimates for different years is assumed. Given the strong positive correlation in the smoothed estimates between successive years, the test is unlikely to detect a large change between one year and the next, but should be reliable for detecting trends over a period of perhaps five or more years, for which correlations between smoothed estimates are small.

## Results

Figures 1–10 show the estimates of underlying trend for each of the main stocks associated with tuna in the eastern tropical Pacific Ocean. Since stock boundaries and stock identity are both uncertain, we also show trend estimates after pooling data from stocks that are not differentiable in the field. The broken horizontal lines in these plots correspond to the upper and lower 85% confidence limits for the 1988 relative abundance estimate. Years for which the entire confidence interval lies outside the region between the broken horizontal lines show a relative abundance significantly different from that for 1988. Because the smoothed estimate for the first or final year of a sequence can be poor, we show the unsmoothed estimate and corresponding 85% confidence limits for the first and last year on each plot.

Figures 1 and 2 show estimated trends for northern offshore spotted dolphins, with and without the abnormally low 1983 estimate, which corresponded with a very strong El Niño event. It is clear that the 1983 estimate affects the smoothed estimate of trend, but its effect is no greater than if it had been just smaller than the 1984 estimate. Thus abnormal estimates may be more safely retained when using this procedure, and subjective decisions of whether to treat an estimate as an outlier are avoided.

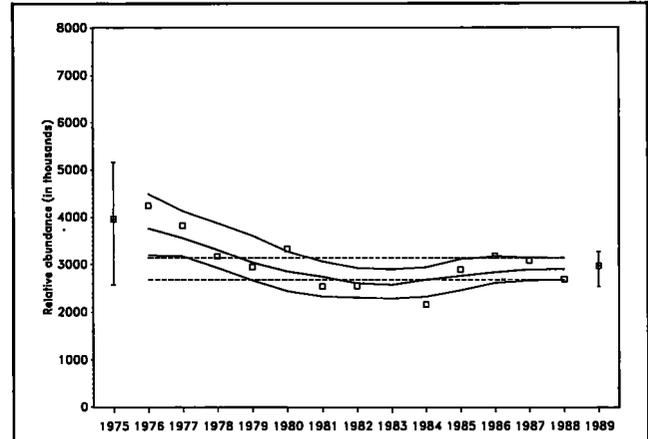


**Figure 1**

Smoothed abundance trends of northern offshore stock of spotted dolphin *Stenella attenuata* in the eastern tropical Pacific. Broken lines indicate approximate 85% confidence limits. Horizontal lines correspond to 85% confidence limits for the 1988 estimate. If lower limit lies above upper limit for an earlier year, abundance has increased significantly between that year and 1988 ( $P < 0.05$ ); if upper limit lies below lower limit for an earlier year, abundance has decreased significantly.

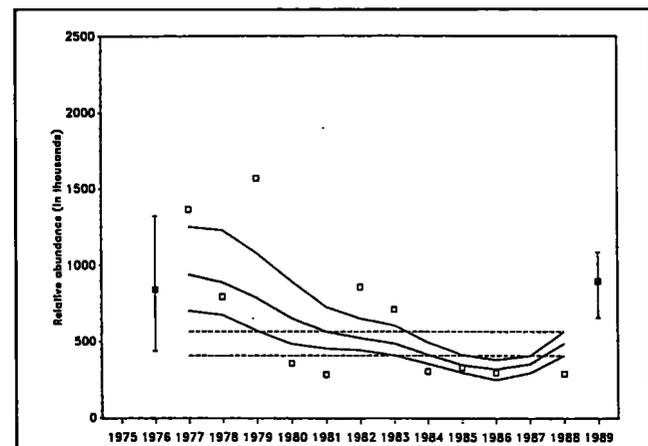
The estimated trend from Figure 1 is downwards until around 1983. Estimated abundance in 1976 and 1977 was significantly higher than in 1988 ( $P < 0.05$ ), but there is some evidence of a recovery between 1983 and 1988 ( $P < 0.05$ ). Thus northern offshore spotted dolphins appeared to decrease through the 1970s and early 1980s, with numbers remaining stable or increasing since.

Figure 3 suggests there may have been a marked decline in numbers of southern offshore spotted dolphins since the late 1970s. The smoothed 1988 estimate is significantly lower than the smoothed estimates for 1977 and 1978, but there is evidence of an increase since 1986 ( $P < 0.05$ ), after a relatively high unsmoothed estimate for 1989. As shown by Anganuzzi et al. (1991), southern offshore spotted dolphins appear to occupy appreciably different regions from one year to another, and the extent of mixing with northern offshore spotted dolphins remains unclear. We therefore believe that trend estimates for this stock are unreliable. The estimated trends obtained by pooling data from the offshore stocks are shown in Figure 4. The estimates are dominated by the data from the larger northern offshore stock, and the plot is similar to Figure 1. The 1988 smoothed relative-abundance estimate is significantly higher than the 1983 and 1984 estimates, and significantly lower than all estimates preceding 1979.



**Figure 2**

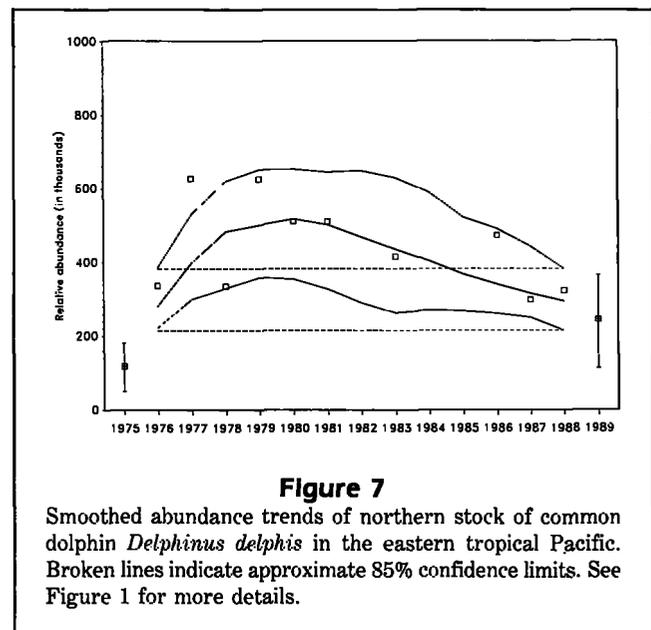
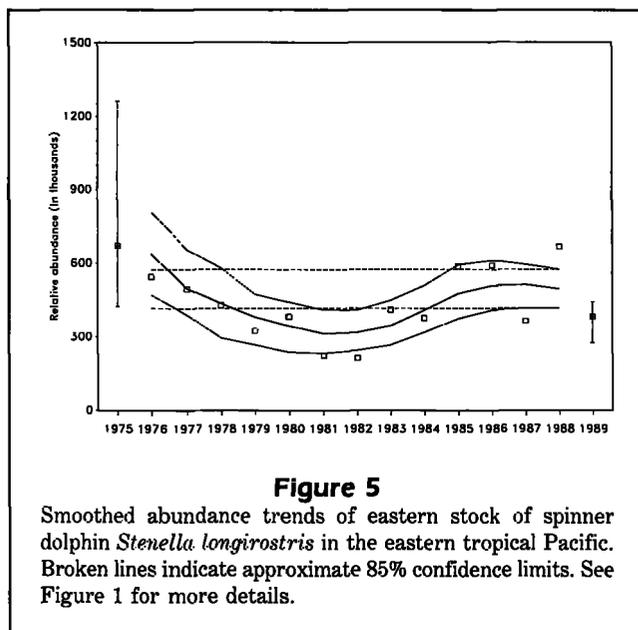
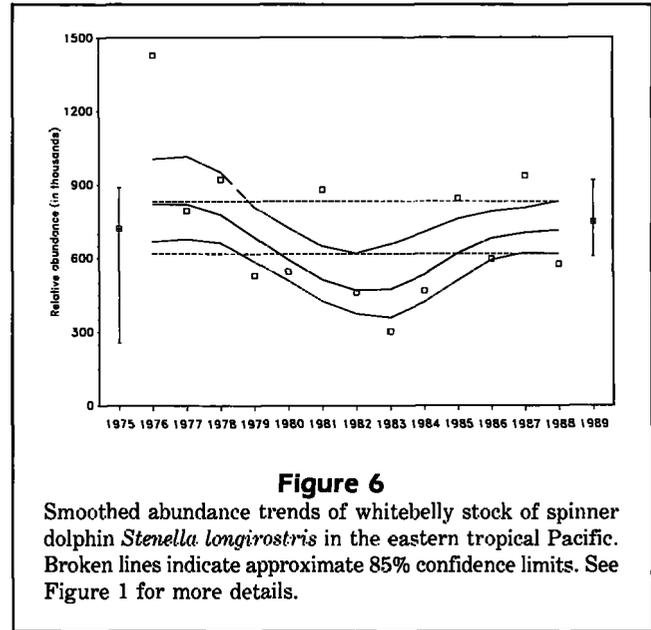
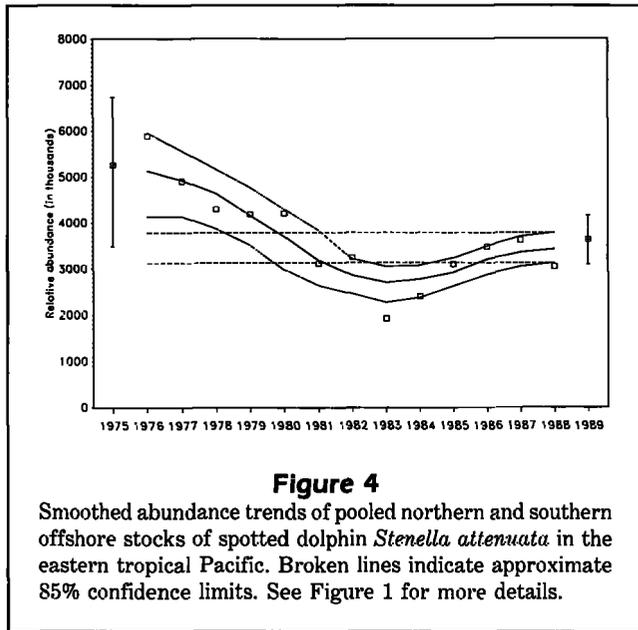
Smoothed abundance trends of northern offshore stock of spotted dolphin *Stenella attenuata* in the eastern tropical Pacific, excluding 1983 estimate. Broken lines indicate approximate 85% confidence limits. See Figure 1 for more details.



**Figure 3**

Smoothed abundance trends of southern offshore stock of spotted dolphin *Stenella attenuata* in the eastern tropical Pacific. Broken lines indicate approximate 85% confidence limits. See Figure 1 for more details.

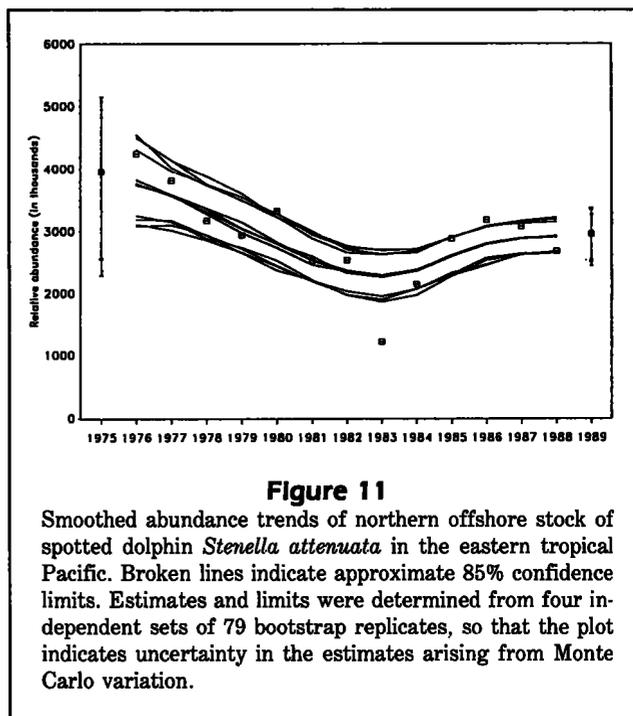
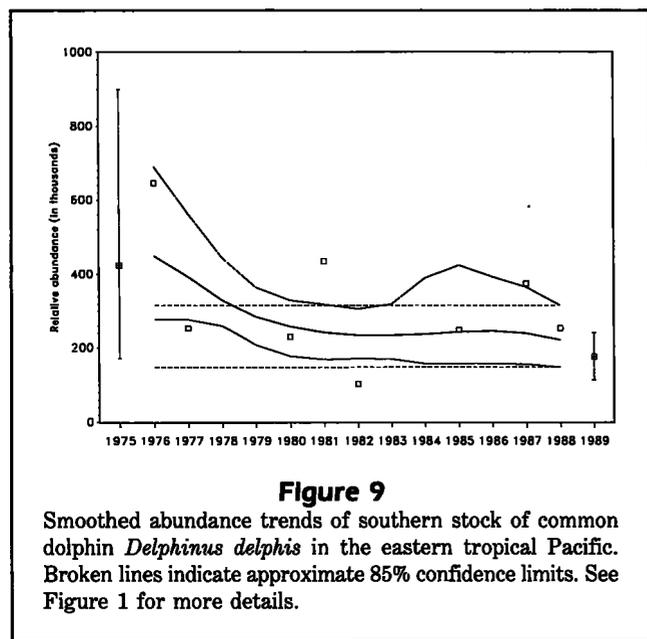
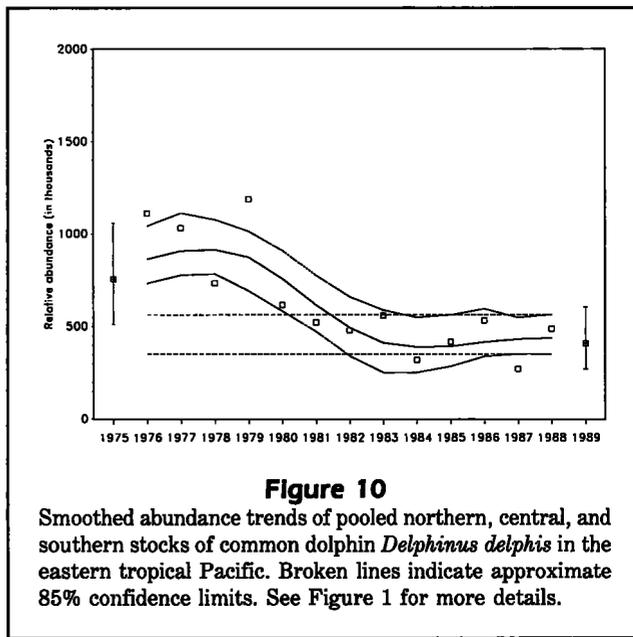
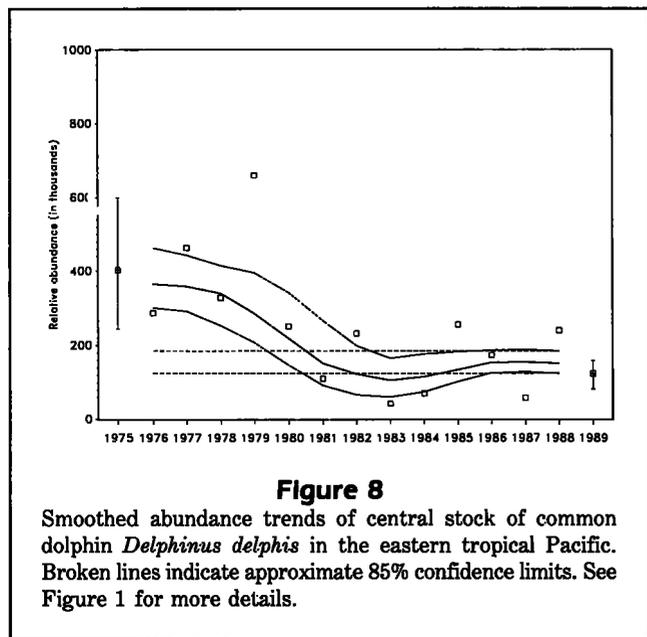
Figure 5 suggests that the eastern spinner dolphin might have had a pattern of change similar to the northern offshore spotted dolphin, although estimated abundance in the late 1980s is roughly equal to that in the mid-1970s, so depletion between 1975 and 1983 may have been less than for northern offshore spotted dolphins. The 1988 smoothed estimate is just significantly higher than the smoothed estimates for 1981 and 1982 ( $P < 0.05$ ).



The estimated trend for whitebelly spinner dolphins (Fig. 6) is similar to that for eastern spinner dolphins and northern offshore spotted dolphins. There is some evidence that abundance in 1988 was higher than in 1982 ( $P \cong 0.05$ ), but no other comparisons with 1988 are significant. The 1982 smoothed estimate is significantly lower than those for 1976–78.

End effects in Figure 7 give rise to an implausible trend in numbers of northern common dolphins during 1975–78. Since 1980, there may have been a decline

in this stock, but no smoothed estimates differ significantly. The central stock of common dolphins (Fig. 8) shows evidence of a steep decline from 1977 to 1983, with stability since. The smoothed estimate for 1988 is significantly lower than for all years preceding 1980 ( $P < 0.05$ ), but does not differ significantly from any later estimates. Data on the southern stock of common dolphins are sparse. There may have been a decreasing trend (Fig. 9), but unsmoothed estimates fluctuate widely and no smoothed estimates differ significantly.



If data are pooled across stocks of common dolphins (Fig. 10), the 1988 smoothed estimate is significantly lower than all those preceding 1981.

Four independent sets of 79 bootstrap replicates were generated for the northern offshore stock of spotted dolphins. The resulting plots, one of which corresponds exactly to Figure 1, are superimposed in Figure 11. If an infinite number of replicates could be carried out for each set, the four plots would be identical. Thus Figure 11 indicates the uncertainty that can

be expected in the median and interval estimates due to Monte Carlo variation.

### Discussion

Unsmoothed estimates of relative abundance sometimes show larger year-to-year variation than is

plausible, even if full allowance is made for the precision of the estimates. An example is the 1983 estimate for the northern offshore stock of spotted dolphins, which is significantly lower than either the 1982 or the 1984 estimate. This has been attributed to the strong El Niño event of that year (Buckland and Anganuzzi 1988a). The change in environmental conditions appeared to cause spotted dolphins to split into smaller schools and to disperse more widely than is normal, so that tuna vessels were unable to locate areas of concentration. If, in normal years when concentrations occur in known areas, there is positive bias in the abundance index, then a relatively low estimate might be expected for 1983. This effect would be enhanced if many animals wandered beyond the normal range of the stock, so that the abundance index for 1983 corresponded to only that portion of the stock remaining within its normal bounds. Such effects may be regarded either as bias that fluctuates over time or as an additional source of variability that is unaccounted for in the variances of the abundance indices. Provided the effects are essentially random, and do not exhibit a consistent linear trend over time, the smoothing algorithm described above smooths out the large fluctuations and, in conjunction with the bootstrap, provides variance and interval estimates for the smoothed abundance indices that take full account of variability not allowed for in the variance estimates of the unsmoothed indices.

The validity of estimating trends in dolphin abundance from tuna-vessel sightings data has been questioned by Edwards and Kleiber (1989). They used a simple simulation model of non-random search vessel effort coupled with clustered distributions of dolphin schools to investigate bias. By allowing the clustering of schools to be slight in one year and extreme in the next, they showed that bias in the relative abundance estimates can be inconsistent between years. They define a change estimate as the ratio of relative abundance estimates for the two years. They state, "This two-sample change estimate is only a rough approximation to a trend estimate derived from a series of measurements. . . . However, conclusions about the effects of inconsistent biases on this **change** estimate will be valid for **trend** estimates also, except for the unlikely case in which effects of various inconsistent biases cancel each other out, so that the trend estimate reflects the actual trend, but only fortuitously." (The emphasis on "change" and "trend" is theirs.) They also note that "It is obvious. . . . that even relatively small changes of bias can lead to considerably inaccurate estimates of change and, by implication, estimates of trend." If this is so, there would be little value in estimating trends in abundance from tuna-vessel sightings data. We question whether the simulation model of Edwards and Kleiber (1989), which is a considerable

**Table 1**

Actual abundance (millions), and expected and simulated relative-abundance estimate by year for a hypothetical stock, declining at an annual rate of 5%. Expected abundance is calculated assuming estimates are biased down by 20% in El Niño years (\*) and up by 100% in other years.

Year	Actual abundance	Expected estimate	Simulated estimate
1975	4.00	8.00	8.04
1976*	3.80	3.04	3.37
1977	3.61	7.22	6.86
1978	3.43	6.86	5.86
1979	3.26	6.52	6.87
1980	3.10	6.19	8.66
1981	2.94	5.88	6.26
1982*	2.79	2.23	1.97
1983*	2.65	2.12	3.22
1984	2.52	5.04	4.98
1985	2.39	4.79	5.72
1986	2.28	4.55	4.02
1987*	2.16	1.73	1.65
1988	2.05	4.11	4.01
1989	1.95	3.90	4.75

simplification of reality, allows such strong conclusions. However, we use their results to assess the validity of their arguments. We take their worst-case scenario of a static environment, using the stratified and smoothed option, and average across their four replicates for the high-density case. The calculations indicate a downward bias of about 20% for the "simple, gentle" environmental topography of year 1 and an upward bias of about 100% for the "complex, steep" topography of year 2. Thus, if the population comprised 2500 schools (as in their simulations), the expected estimate would be around 2000 schools in the first year and 5000 in the second, a 2.5-fold estimated increase for a population that has constant size. Is this conclusion "valid for **trend** estimates also"? Suppose a population comprised 4 million animals in 1975, and decreased at a rate of 5% per annum until 1989. Suppose we again take an extreme scenario in which the "simple, gentle" environmental topography applied in El Niño years, and the "complex, steep" topography applied in all other years. The expectations of the estimates are shown in Table 1. Also shown are simulated estimates, for which errors were generated from a lognormal distribution which yields a coefficient of variation of 15%, close to that observed for estimates based on tuna vessel data. The errors were then added to the expected estimates. The estimated rate of decrease for the expected estimates is 5.0% per annum (SE 2.5%), and that for the simulated estimates is 4.7% per annum (SE 2.6%). Thus a scenario of extreme and inconsistent

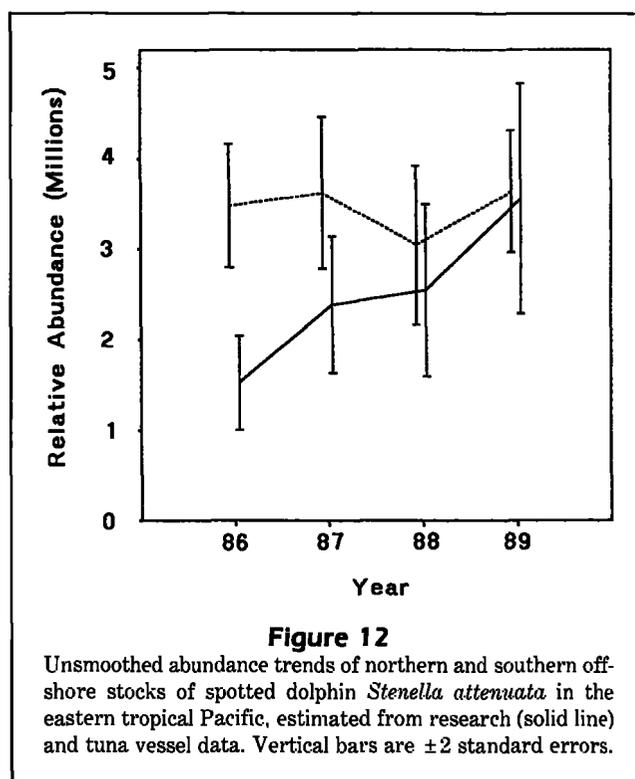
bias does not invalidate the procedures when applied to a long sequence of estimates. In practice, a rate of change in abundance is unlikely to be roughly constant over such a long time-period, yet tests for trend over a short time-period have low power. Figures 1–10 provide a simple method to test for change over longer time-periods without the necessity of assuming the rate of change is constant.

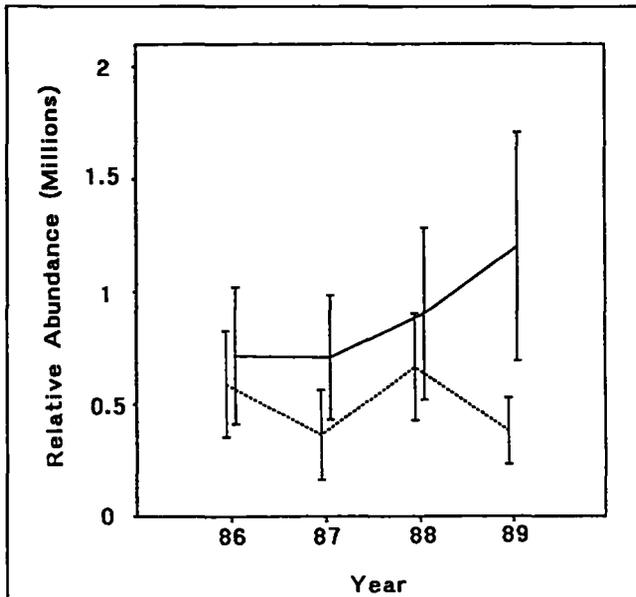
The smoothing procedure used for generating trend estimates can perform poorly at the start (e.g., Fig. 7) or at the end of a sequence of estimates, so that sharp increases or declines during the first or last year or two should be treated with suspicion. The first and last smoothed estimate in a sequence are especially unreliable, and are omitted from Figures 1–10. Thus, changes in abundance are assessed relative to 1988 rather than 1989.

To assess the current status of dolphin stocks, and the effects of recent levels of mortality, it is necessary to determine whether trends in dolphin abundance are best estimated from tuna vessel data or research vessel data, or whether some combination of estimates from both sources is preferable. Given sufficient data and adequate coverage of the entire range of each stock, research-vessel estimates of trend would be preferred, since they are likely to be less biased. However, Holt and Sexton (1989, 1990ab), to exploit fully the small number of research vessel sightings, made assumptions that might be seriously violated. Firstly, data are pooled across all sightings of dolphin schools of at least 15 animals, irrespective of species, to improve precision of effective search-width estimates. This may introduce bias which is not consistent over time, especially if non-target species (those which are seldom associated with tuna, and are therefore seldom encircled by purse seines) have a different effective search width and a different rate of change in abundance than target species. Secondly, although abundance estimates are given by stock, encounter-rate estimates by stock area are ignored for stocks that are not separated in the field. Thus for offshore spotted dolphins, a single abundance estimate per year is generated and then prorated by stock area, to yield separate estimates for the northern and southern offshore stocks. If the southern offshore stock became extinct, and the northern offshore stock increased at a rate that ensured overall abundance remained constant, the expected trend in research vessel estimates would be zero for both stocks. The same applies to common dolphin stocks. The estimates of Holt and Sexton indicate that there are large numbers of common dolphins in the western sector of the eastern tropical Pacific, yet the species is seldom recorded there. Using the estimation methods of Holt and Sexton, valid trend estimates from research vessel data are not available separately for northern and

southern offshore stocks of spotted dolphin or for the main stocks of common dolphin.

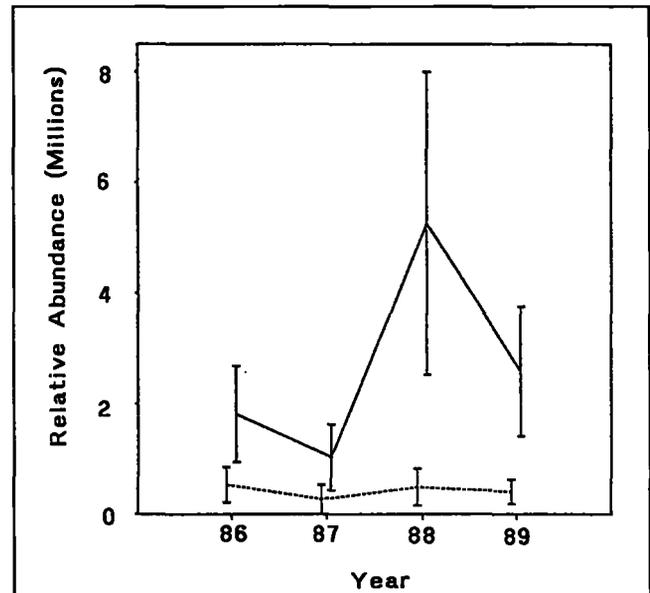
In Figures 12–15 we show the valid estimates of trend (i.e., those obtained after pooling data from stocks that are not differentiable in the field) from the research-vessel relative abundance estimates for 1986–89, taken from Sexton et al. (1991) and Gerrodette and Wade (1991). Also shown are the corresponding unsmoothed trend estimates from tuna vessel data. Vertical bars show  $\pm 2$  standard errors. Plots are based on the relative abundance estimates and standard errors of Tables 2 and 3. The research vessel estimates indicate changes in abundance that are biologically implausible, even with full allowance for the estimated precision of the estimates. Thus either the precision of the surveys is appreciably worse than estimated or there is strong and inconsistent bias in the estimates from one year to the next. By contrast, despite the concerns over the validity of tuna vessel estimates, they yield biologically plausible rates of change during 1986–89 when the precision of the estimates is accounted for.





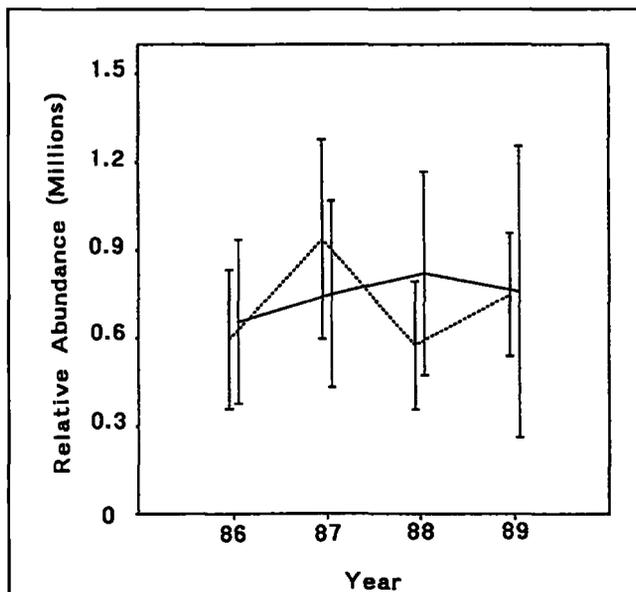
**Figure 13**

Unsmoothed abundance trends of eastern stock of spinner dolphin *Stenella longirostris* in the eastern tropical Pacific, estimated from research (solid line) and tuna vessel data. Vertical bars are  $\pm 2$  standard errors.



**Figure 15**

Unsmoothed abundance trends of northern, central, and southern stocks of common dolphin *Delphinus delphis* in the eastern tropical Pacific, estimated from research (solid line) and tuna vessel data. Vertical bars are  $\pm 2$  standard errors.



**Figure 14**

Unsmoothed abundance trends of whitebelly stock of spinner dolphin *Stenella longirostris* in the eastern tropical Pacific, estimated from research (solid line) and tuna vessel data. Vertical bars are  $\pm 2$  standard errors.

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## Citations

### Anganuzzi, A.A., and S.T. Buckland

1989 Reducing bias in estimated trends from dolphin abundance indices derived from tuna vessel data. Rep. Int. Whaling Comm. 39:323-334.

### Anganuzzi, A.A., S.T. Buckland, and K.L. Cattanch

1991 Relative abundance of dolphins associated with tuna in the eastern tropical Pacific, estimated from tuna vessel sightings data for 1988 and 1989. Rep. Int. Whaling Comm. 41: 497-506.

### Au, D., W.L. Perryman, and W. Perrin

1979 Dolphin distribution and the relationship to environmental features in the eastern tropical Pacific. Admin. Rep. LJ-79-43, Southwest Fish. Sci. Cent., NMFS, NOAA, La Jolla, CA 92038, 59 p.

**Table 2**

Unsmoothed relative-abundance estimates (standard errors in parentheses) of some stocks of dolphin in the eastern tropical Pacific, calculated from research vessel data collected 1986–89.

Year	Offshore spotted dolphin		Eastern spinner dolphin		Whitebelly spinner dolphin		Common dolphin	
1986	1527	(261)**	716	(152)	657	(140)	1810	(437)*
1987	2388	(377)	707	(138)	750	(159)	1026	(298)†††
1988	2549	(476)	902	(191)	821	(174)	5263	(1368)*††
1989	3560	(634)**	1200	(254)	759	(248)	2586	(587)‡

\* Estimates differ significantly ( $P < 0.05$ )

‡ Estimates differ significantly ( $P < 0.05$ )

\*\* Estimates differ significantly ( $P < 0.01$ )

†† Estimates differ significantly ( $P < 0.01$ )

**Table 3**

Unsmoothed relative-abundance estimates (standard errors in parentheses) of some stocks of dolphin in the eastern tropical Pacific, calculated from tuna vessel data collected 1986–89.

Year	Offshore spotted dolphin		Eastern spinner dolphin		Whitebelly spinner dolphin		Common dolphin	
1986	3484	(342)	590	(118)	595	(119)	532	(159)
1987	3627	(420)	363	(100)	937	(170)	271	(132)
1988	3048	(439)	665*	(119)	575	(109)	487	(167)
1989	3640	(337)	381*	(74)	748	(105)	408	(111)

\* Estimates differ significantly ( $P < 0.05$ )

#### Buckland, S.T.

1984 Monte Carlo confidence intervals. *Biometrics* 40: 811–817.

#### Buckland, S.T., and A.A. Anganuzzi

1988a Trends in abundance of dolphins associated with tuna in the eastern tropical Pacific. *Rep. Int. Whaling Comm.* 38: 411–437.

1988b Comparison of smearing methods in the analysis of minke sightings data from IWC/IDCR Antarctic cruises. *Rep. Int. Whaling Comm.* 38:257–263.

#### Burnham, K.P., D.R. Anderson, and J.L. Laake

1980 Estimation of density from line transect sampling of biological populations. *Wildl. Monogr.* 72, 202 p.

#### Cooke, J.G.

1985 On the relationship between catch per unit effort and whale abundance. *Rep. Int. Whaling Comm.* 35:511–519.

#### Edwards, E.F., and P.M. Kleiber

1989 Effects of nonrandomness on line transect estimates of dolphin school abundance. *Fish. Bull., U.S.* 87:859–876.

#### Gerrodette, T., and P.R. Wade

1991 Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: Analysis of 1989 data. *Rep. Int. Whaling Comm.* 41: 511–515.

#### Hall, M.A., and S.D. Boyer

1988 Incidental mortality of dolphins in the eastern tropical Pacific. *Rep. Int. Whaling Comm.* 38:439–441.

#### Hammond, P.S., and J.L. Laake

1983 Trends in estimates of abundance of dolphins (*Stenella* spp. and *Delphinus delphis*) involved in the purse-seine fishery for tunas in the eastern Pacific Ocean, 1977–81. *Rep. Int. Whaling Comm.* 33:565–588.

#### Holt, R.S.

1985 Estimates of abundance of dolphin stocks taken incidentally in the eastern tropical Pacific yellowfin tuna fishery. *Admin. Rep. LJ-85-20*, Southwest Fish. Sci. Cent., NMFS, NOAA, La Jolla, CA 92038, 32 p.

1987 Estimating density of dolphin schools in the eastern tropical Pacific Ocean by line transect methods. *Fish. Bull., U.S.* 85:419–434.

#### Holt, R.S., and J.E. Powers

1982 Abundance estimation of dolphin stocks involved in the eastern tropical Pacific yellowfin tuna fishery determined from aerial and ship surveys to 1979. *Tech. Memo. 23*, Southwest Fish. Sci. Cent., NMFS, NOAA, La Jolla, CA 92038, 95 p.

#### Holt, R.S., and S.N. Sexton

1989 Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: Analyses of 1987 data. *Rep. Int. Whaling Comm.* 39:347–351.

1990a 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. *Fish. Bull., U.S.* 88:105–111.

**1990b** Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: Analyses of 1988 data. Rep. Int. Whaling Comm. 40:471-476.

**Perrin, W.F., P.A. Akin, and J.V. Kashiwada**

**1991** Geographic variation in external morphology of the spinner dolphin *Stenella longirostris* in the eastern Pacific and implications for conservation. Fish. Bull., U.S. 89:411-428.

**Polacheck, T.**

**1987** Relative abundance, distribution and inter-specific relationship of cetacean schools in the eastern tropical Pacific. Mar. Mammal Sci. 3:54-77.

**Sexton, S.N., R.S. Holt, and D. DeMaster**

**1991** Investigating parameters affecting relative estimates in dolphin abundance in the eastern tropical Pacific from research vessel surveys in 1986, 1987, and 1988. Rep. Int. Whaling Comm. 41:517-524.

**Smith, K.L.**

**1988** Calibration and smoothing of relative dolphin abundance estimates. MSc. diss., University of Strathclyde.

**Smith, T.D.**

**1983** Changes in sizes of three dolphin (*Stenella* spp.) populations in the eastern tropical Pacific. Fish. Bull., U.S. 81:1-14.

**Velleman, P.F., and D.C. Hoaglin**

**1981** Applications, basics and computing of exploratory data analysis. Duxbury Press, Boston.