9133

SC/42/SM42

Monitoring Trends in Dolphin Abundance in the Eastern Tropical Pacific: Analysis of 1989 Data

Tim Gerrodette

National Marine Fisheries Service, Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA 92038, USA

and Paul R. Wade

Scripps Institution of Oceanography, ULSD, La Jolla, CA 92093, USA

ABSTRACT

Between July and December, 1989, the National Marine Fisheries Service conducted the fourth in its series of long-term research vessel surveys to estimate the relative abundance of dolphin populations in the eastern tropical Pacific Ocean. The five species of primary interest for these surveys, spotted, spinner, striped, common and Fraser's dolphins, are taken incidentally by tuna purse seiners. The relative abundance of sixteen stocks of these five species were estimated using line transect surveys from two ships operating for approximately 120 days each. Estimates of relative abundance for all stocks of spotted, spinner and Fraser's dolphins were substantially higher than 1988 estimates. Estimates of relative abundance for all stocks of common and striped dolphins were lower than 1988, but higher than 1986 or 1987.

INTRODUCTION

The National Marine Fisheries Service (NMFS) is responsible for assessing the status of dolphin stocks taken incidentally by tuna purse seiners in the eastern tropical Pacific (ETP). The major populations affected by the fishery are the northern offshore stock of spotted dolphins, *Stenella attenuata* and eastern and whitebelly stocks of spinner dolphins, *S. longirostris* (Smith, 1983). Common dolphins, *Delphinus delphis*, striped dolphins, *S. coeruleoalba* and Fraser's dolphins, *Lagenodelphis hosei* are also taken. These five species are grouped together and termed target species.

In 1986, the NMFS initiated a long-term (six year) research program to monitor relative abundance of dolphin populations in the ETP. The program utilizes two research vessels annually for 120 days each. The research design for the surveys indicated that a 10% annual rate of decrease in northern offshore spotted dolphins could be detected (a total 41% decrease over six surveys) with alpha and beta error levels of 10% (Holt *et al.*, 1987). Annual surveys were carried out in 1986, 1987, and 1988, and the results have been published (Holt and Sexton, 1989; 1990a; b; Sexton *et al.*, 1991). In 1989, the NMFS conducted the fourth survey utilizing the same vessels during the same times of the year. Here we present relative abundance estimates for the 1989 data and briefly compare these results to earlier values. Analyses of overall trends in population sizes will be carried out after the series of six surveys is complete in 1991.

MATERIALS AND METHODS

Study area and survey coverage

The same stratified study area was surveyed as in 1986 (Holt and Sexton, 1990b). The NOAA research vessels *David Starr Jordan* and *McArthur* traversed predetermined tracklines in the ETP from 29 July through 7 December (Fig. 1). Each ship was scheduled to spend approximately 120 days at sea, surveying tracklines similar to the previous three years. Due to logistical problems, however, the *Jordan* had to make several unscheduled port stops. Both ships also had to be diverted from scheduled port calls in Panama due to unsettled political conditions. Detailed data collection procedures and data summaries for each ship are presented by Hill *et al.* (1990a; b).

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

When possible, schools were approached and observers recorded independent 'best' estimates of school size. In some cases, an observer obtained a 'minimum' estimate but could not provide a best estimate. Estimates were averaged to obtain mean minimum and best estimates. When weather conditions were suitable, a Hughes 500D helicopter, based aboard the *Jordan*, was used to photograph schools whose sizes were estimated by the observers. The photographs will be used to calibrate observer estimates of school sizes.

Relative abundance estimation

Methods of estimating relative abundance of ETP dolphin populations followed Sexton *et al.* (1991) in order to provide comparable numbers. Estimates of relative population abundance (N_{ij}) of stock j, species i were computed as

$$N_{ij} = (D\ S\ P_t\ P_i\ A)\ ((A_{ij} + P'_{ij}\ A'_{ij})/\ A_i), \qquad (1)$$

where

D = density of schools of all dolphin species over total study area,

S = mean size of schools of all target species,

P_t = proportion of all dolphin schools which are target schools,

P_i = proportion of individuals of species i in target schools,

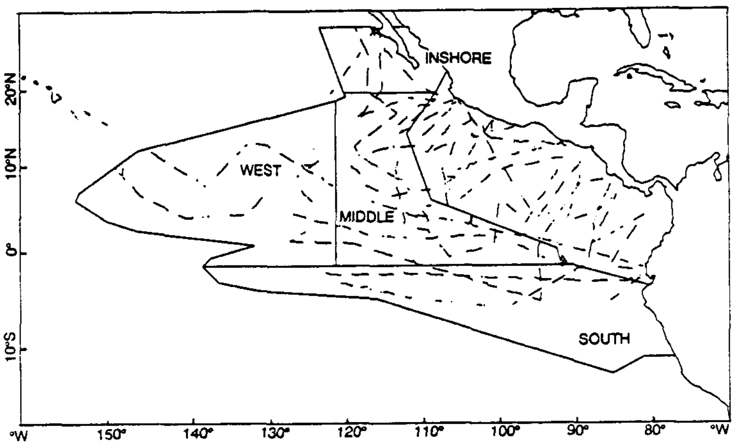

Fig. 1. Tracklines traversed while on searching effort by the NOAA R/V *David Starr Jordan* and *McArthur* during the 1989 survey.

P'_{ij} = proportion of individuals of stock j of species i in target schools in overlap region containing two stocks of species i (overlap region discussed below),

A = total area inhabited by all target species,

A_i = area inhabited by species i,

A_{ij} = area inhabited by species i, stock j, not overlapping with any other stock of species i, and

A'_{ij} = area inhabited by species i, stock j, in overlap region (discussed below).

This is the same method of estimation of abundance as in previous years, although the notation of equation (1) is somewhat different from that of Holt and Sexton (1990a; b). The summation has been eliminated because pooled estimates of D, S, P_t, and P_i have been used (Sexton *et al.*, 1991). Values for A_i, A'_{ij}, and A_{ij} are given in Holt and Sexton (1990b). Estimates of D, S, P_t, and P_i are based on sightings made while on searching effort within the study area in sea state conditions of Beaufort 5 or less.

The variance of N_{ij} was calculated using bootstrap methods (Efron, 1982). Over the entire study area, the number of legs of searching effort was tabulated and then an equal number of legs was randomly selected with replacement. This effort and the associated sightings were used to calculate D, P_t, S, P_i and, finally, estimates of N_{ij}s. This process was repeated 100 times. The variance of N_{ij} for each stock was calculated using these 100 estimates.

Formulae used to estimate school density are from Burnham *et al.* (1980), Holt (1985; 1987) and Hayes and Buckland (1983). The hazard rate model (Hayes and Buckland, 1983; Buckland, 1985) provided adequate fits (chi-square test) to the data and was used in the 1986, 1987 and 1988 analyses. Because of small sample sizes, *f(0)*, the sighting probability density function evaluated at the trackline, was calculated for data pooled over all strata and used to calculate density for the entire study area. Of schools containing both target and non-target species, only the proportion of individuals of the target species was used in estimating S. Estimates of the P_t were calculated using formulae presented by Holt and Powers (1982). Formulae to estimate P_i are given by Barlow and Holt (1986).

All species of dolphins encountered in the study area were included in the density analyses. Estimates of density, school size and species proportions were calculated using only schools containing 15 or more animals. Smaller schools were not used because they are difficult to detect, especially during rough weather (Holt, 1987). Similarly, because there is a direct correlation between the size of a school and the probability of it being detected (Drummer and McDonald, 1987), schools detected at increasing distances from the trackline tend to include disproportionately more large schools. This biases school size estimates upward and species proportions toward species which occur in large schools. However, the bias may be constant from year to year and hence not a serious source of error for detecting trends. Finally, schools for which there were no 'best' estimates were not used in the school size or species proportion calculations, but were used in the school density estimates if the 'minimum' estimate was 15 or more animals.

Only schools detected within 3.7 km (2.0 n.miles) perpendicular distance of the trackline were used for calculating components. A 3.7-km truncation point provided an adequate fit of the hazard model to the perpendicular distance distribution data while minimizing bias due to sighting larger schools at greater distances. Schools detected at distances greater than 3.7 km had little effect on the density estimates (Sexton *et al.*, 1991).

The outside boundary of the study area (Fig. 1) was described by Au *et al.* (1979) while the boundaries for each stock within the study area were described by Perrin *et al.* (1984). The study area was partitioned into four strata. The size of each stratum and the area occupied by each stock in each stratum were calculated by Holt and Sexton (1990b).

Most stocks are defined by geographic area, but some stocks of the same species overlap geographic areas. The last factor in Equation (1) contains terms to adjust for the overlap areas (A'_{ij}s). The overlapping stocks include (1) coastal and northern spotted, (2) eastern and whitebelly spinner and (3) Baja neritic and northern common dolphins (Perrin *et al.*, 1984). However, few data were available to determine relative proportions of the overlapping Baja neritic and northern common dolphins. Therefore, population estimates for these were combined. For overlapping stocks of spotted and spinner dolphins, the relative proportions of coastal and northern offshore spotted and of eastern and whitebelly spinner stocks within their area of overlap (P'_{ij}) were calculated as the bootstrap averages of their percent occurrence. As with the other estimates, data were pooled over strata within the region of overlap when calculating the bootstrap estimates.

RESULTS

During the 1989 survey, observers aboard both vessels searched 27,464 km and made 1,245 marine mammal sightings (Hill *et al.*, 1990a; b). In the study area (Fig. 1) and during Beaufort sea states of 5 or less, observers searched 26,846 km and detected 350 dolphin schools within 3.7 km of the trackline and for which a best or minimum estimate of school size was 15 or more (Table 1). Searching effort varied among strata according to the study design; for example, the inshore stratum had 30% of the area, 41% of the searching effort in 1989, and 52% (182/350) of all dolphin schools sighted. The estimate of $f(0)$ was 0.6025 for the whole study area.

Estimates of dolphin school density and species proportions are also presented in Table 1. Estimates of D calculated using the pooled $f(0)$ value above ranged from 2.25 to 4.99 schools/1000 km^2 among the different strata, with an estimate for the total area of 3.93. Estimates of S ranged from 139 to 240, with a total mean estimate of 165.0. The proportion of identified dolphin schools that included target species ranged from 0.776 to 0.931, with a total mean estimate of 0.872. The species proportions of target dolphin schools varied among strata. In the inshore and middle areas, for example, 36% of the target dolphins were spotted dolphins, while in the southern stratum, common (46%) and striped (35%) predominated. The estimated proportions of animals in each of the five target species for the whole study area were 0.332, 0.222, 0.239, 0.172, and 0.035 for spotted, spinner, common, striped and Fraser's dolphins, respectively.

Data on species proportions in the regions of stock overlap are presented in the lower part of Table 1. Only six spotted dolphin schools were seen in the overlap region of the coastal and offshore spotted stocks, and five of these were of the offshore stock. In the overlap area of eastern and whitebelly spinner stocks, 85 schools were seen of which 64 were eastern spinner schools.

Estimates of relative abundance in 1989 for each target species based on Equation 1 are presented in Table 2. The indices of relative abundance are calculated using the pooled estimates of D, S, P_t and P_i given in the right hand column of Table 1. Estimates of relative abundance for each stock of each species are also presented in Table 2. Note, as explained above, that these stock estimates are derived from the species estimates, with the stock estimates proportional to the areas the stocks are thought to occupy as described in Perrin *et al.* (1984), with adjustments made in the two cases (eastern/whitebelly spinner, coastal/northern offshore spotted) of stocks that overlap geographically. The relative abundance of spotted dolphins in the study area is estimated at nearly 3,600,000, with 79% being northern offshore spotted dolphins. The relative abundance of spinner dolphins is approximately 2,400,000, half from the eastern spinner stock. Relative indices of common dolphins are estimated at 2,600,000, striped dolphins at 1,900,000 and Fraser's dolphins at 376,000.

DISCUSSION

The research vessel surveys reported here have carefully replicated previous surveys, using the same vessels, the same area, the same time of year, the same sighting and recording methods, and most of the same observers. While questions remain about whether all assumptions of line transect theory have been satisfied, and thus whether the estimates of abundance can be considered absolute, the surveys were designed to detect trends in relative abundance (Holt, 1987). The analysis of the data has concentrated on producing a consistent index of abundance; for this reason, dolphin schools fewer than 15 in number and more than 3.7 km (2.0 n.miles) distant from the trackline have not been included in the analysis (Holt

Table 1

Summary of 1989 dolphin survey in eastern tropical Pacific. Symbols corresponding to equation 1 are in parentheses after description. Abundance estimates in Table 2 are derived from Total column only.

	Inshore	Middle	West	South	Total
Study area (1000 km^2) (A)	5,693	3,798	5,298	4,359	19,148
Percent of total study area	30	20	28	22	100
Trackline searched (km)	10,986	7,475	3,613	4,772	26,846
Percent of searching effort	41	28	13	18	100
School density (schools/1000km^2)(D)	4.99	3.67	2.25	3.16	3.93
Number dolphin schools detected	182	91	27	50	350
Mean target species school size (S)	139.11	170.79	240.48	205.03	165.04
Proportion target schools (P_t)	0.860	0.931	0.926	0.776	0.872
Proportion of dolphins within target school (P_i)					
Spotted	0.362	0.364	0.401	0.131	0.332
Spinner	0.236	0.204	0.417	0.049	0.222
Common	0.248	0.216	0.000	0.462	0.239
Striped	0.153	0.145	0.087	0.345	0.172
Fraser's	0.000	0.071	0.095	0.012	0.035
Stock proportions in overlap areas (P'_{ij})					
Coastal Spotted					0.042
Offshore Spotted					0.958
Number of schools in calculation					6
Eastern Spinner					0.707
Whitebelly Spinner					0.293
Number of schools in calculation					85

Table 2

Estimates of population size N_{ij} (in thousands of animals), standard error SE(N_{ij}), and coefficient of variation CV(N_{ij}) by stock and by species for all target dolphin species in the total study area of the eastern tropical Pacific. Stock estimates are proportional to the area occupied by each stock as determined in Perrin *et al.*, (1984), with additional adjustments made for the overlap between offshore and coastal spotted and between eastern and whitebelly spinner dolphins.

Dolphin Species and Stock	N_{ij}	SE(N_{ij})	CV(N_{ij})
Spotted *(Stenella attenuata)* total	3596.0	640.9	0.178
Coastal	36.3	6.5	0.178
Northern Offshore	2838.3	505.8	0.178
Southern Offshore	721.4	128.6	0.178
Spinner *(Stenella longirostris)* total	2,405.3	509.1	0.212
Costa Rican	35.1	7.	0.212
Eastern	1200.1	254.0	0.212
Northern Whitebelly	713.9	151.1	0.212
Southern Whitebelly	456.2	96.6	0.212
Common *(Delphinus delphis)* total	2,585.7	586.7	0.227
Northern tropical	411.2	93.3	0.227
West central tropical	735.9	167.0	0.227
East central tropical	825.1	187.2	0.227
Southern tropical	613.5	139.2	0.227
Striped *(Stenella coeruleoalba)* total	1855.9	286.3	0.154
Northern tropical	210.5	32.5	0.154
West central tropical	338.4	52.2	0.154
East central tropical	543.9	83.9	0.154
South tropical	763.1	117.7	0.154
Fraser's *(Lagenodelphis hosei)* total	375.8	172.7	0.460
Total of all target species	10,818.7	2,195.7	0.203

and Sexton, 1989; 1990a; b). The results for dolphin stocks reported here, therefore, should be considered relative indices of abundance to be compared to previous years, not estimates of absolute numbers of dolphins.

Results of the 1986, 1987 and 1988 surveys have been reported by Holt and Sexton (1989; 1990a; b). However, the methods of analysis varied slightly among these reports and the numbers are not strictly comparable, either with each other or with this report. Sexton *et al.* (1991) compared various methods of analysis, and concluded that an analysis using data pooled over all strata and species, with dolphins having an unweighted mean school size 15 or more at a distance not more than 3.7 km from the trackline, produced estimates of relative abundance with the smallest coefficient of variation. Sexton *et al.* (1991) reanalyzed the 1986–1988 data using these criteria to produce a set of comparable indices of abundance. The present report analyzes the data in the same way, and the results can thus be compared.

The estimate of relative abundance for each stock of spotted dolphins was considerably higher in 1989 than in 1988. The total estimate for all stocks of spotted dolphins increased 41% to nearly 3,600,000. Similarly, the estimate of relative abundance for each stock of spinner dolphins was substantially higher than in 1988. The total estimate for all stocks of spinner dolphins increased 38% to 2,400,000. The estimate of relative abundance for Fraser's dolphins increased from 110,800 to 375,800 between 1988 and 1989. Few of these dolphins were seen, however, and the standard errors of both the 1988 and 1989 estimates are large (Table 2). Increases of 41% and 38% for the more abundant spotted and spinner dolphins are clearly not possible in one year based on reproduction alone (Reilly and Barlow, 1986); such large changes between successive years may be due to immigration into the study area or estimation error; if so, this implies that the actual precision of the estimates is underestimated. These possible explanations for the increases seen between 1988 and 1989 (recruitment, immigration, and estimation error) are not mutually exclusive, and some combination of them may explain the results.

The estimate of relative abundance for each stock of common dolphins was substantially lower in 1989 than in 1988. The total estimate for all stocks of common dolphins decreased 51% to 2,600,000. The 1986 and 1987 estimates, both total and for each stock of common dolphins, were also much lower than the 1988 estimates. The 1989 estimates are therefore more similar to the 1986 and 1987 than to the 1988 estimates, but remain higher than either of the former. Likewise, the estimate of relative abundance for each stock of striped dolphins was lower in 1989 than in 1988, but higher than in either 1986 or 1987. The estimate of relative abundance for all stocks of striped dolphins combined declined 18% to 1,900,000.

For all five target species combined, the estimate of relative abundance decreased from 11,900,000 in 1988 to 10,800,000 in 1989, an overall decrease of 9%. Such a decrease is not statistically significant based on the estimated standard error of approximately 2,200,000. The estimated coefficients of variation for each species are similar to previous years, ranging from 0.15 to 0.23 for all species except Fraser's dolphins, which are much higher (0.46).

ACKNOWLEDGEMENTS

We thank Jay Barlow and Douglas DeMaster, National Marine Fisheries Service, Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA, 92038, USA, for reviewing this manuscript. Two anonymous reviewers provided helpful comments.

REFERENCES

Au, D., Perryman, W.L. and Perrin, W. 1979. Dolphin distribution and the relationship to environmental features in the eastern tropical Pacific. Southwest Fish. Cent. Adm. Rep. No. LJ-79-43. 59pp.

Barlow, J. and Holt, R.S. 1986. Proportions of species of dolphins in the eastern tropical Pacific. U.S. Dep. Commer., Report NOAA-TM-NMFS-SWFC-56. 44pp.

Buckland, S.T. 1985. Perpendicular distance models for line transect sampling. *Biometrics* 41:177–95.

Burnham, K.P., Anderson, D.R. and Laake, J.F. 1980. Estimation of density from line transect sampling of biological populations. *Wildl. Monogr.* 72:1–202.

Drummer, T.D. and McDonald, L.L. 1987. Size bias in line transect sampling. *Biometrics* 43:13–21.

Efron, B. 1982. The jackknife, the bootstrap, and other resampling methods. SIAM, monograph No.38, CBMS-NSF. 92pp.

Hayes, R.J. and Buckland, S.T. 1983. Radial distance models for the line transect method. *Biometrics* 39:29–42.

Hill, P.S., Jackson, A. and Gerrodette, T. 1990a. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *David Starr Jordan* July 29-December 7, 1989. U.S. Dep. Commer., NOAA-TM-NMFS-SWFC-142. 143pp.

Hill, P.S., Jackson, A. and Gerrodette, T. 1990b. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *McArthur* July 29-December 7, 1989. U.S. Dep. Commer., NOAA-TM-NMFS-SWFC-143. 132pp.

Holt, R.S. 1985. Estimates of abundance of dolphin stocks taken incidentally in the eastern tropical Pacific yellowfin tuna fishery. Southwest Fish. Cent. Adm. Rep. No. LJ-85-20. 32pp.

Holt, R.S. 1987. Estimating density of dolphin schools in the eastern tropical Pacific Ocean by line transect methods. *Fish. Bull., US* 85(3):419–34.

Holt, R.S. and Powers, J.E. 1982. Abundance estimation of dolphin stocks in the eastern tropical Pacific yellowfin tuna fishery determined from aerial and ship surveys to 1979. U.S. Dep. Commer., NOAA-TM-NMFS-SWFC-23, 95pp.

Holt, R.S. and Sexton, S.N. 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. Whal. Commn* 39:347–51.

Holt, R.S. and Sexton, S.N. 1990a. Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: analyses of 1988 data. *Rep. int. Whal. Commn* 40:471–6.

Holt, R.S. and Sexton, S.N. 1990b. 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., US* 88(1):105–11.

Holt, R.S., Gerrodette, T. and Cologne, J.B. 1987. Research vessel survey design for monitoring dolphin abundance in the eastern tropical Pacific. *Fish. Bull., US* 85(3):435–46.

Perrin, W.F., Scott, M.D., Walker, G.J. and Cass, V.L. 1984. Review of geographical stocks of tropical dolphins (*Stenella* spp. and *Delphinus delphis*) in the eastern Pacific. Southwest Fish. Cent. Adm. Rep. No. LJ-87-02, 68pp.

Reilly, S.B. and Barlow, J. 1986. Rates of increase in dolphin population size. *Fish. Bull., US* 84(3):527–33.

Sexton, S.N., Holt, R.S. and DeMaster, D.P. 1991. Investigating parameters affecting relative estimates in dolphin abundance in the eastern tropical Pacific from research vessels in 1986, 1987 and 1988. Paper SC/42/SM43 (published in this volume).

Smith, T.D. 1983. Changes in size of three dolphin (*Stenella* spp.) populations in the eastern tropical Pacific. *Fish. Bull., US* 81:1–14.