Monitoring Trends in Dolphin Abundance in the Eastern Tropical Pacific using Research Vessels over a Long Sampling Period: Analyses of 1987 Data

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ABSTRACT

During 1987, the National Marine Fisheries Service conducted the second in its series of long-term research ship surveys to determine status of dolphin stocks taken incidentally by tuna purse seiners in the eastern tropical Pacific. Line transect methodology was used by observers aboard two vessels for 120 days each. Relative abundance estimates of northern offshore spotted dolphins are approximately 1,300,000 animals with a coefficient of variation of 0.262. This estimate was larger than the 1986 estimate of 929,000 northern offshore spotted dolphins. Relative sizes of other stocks also varied. We examine reasons for these differences and discuss alternative methods of stratifying the data.

INTRODUCTION

The National Marine Fisheries Service (NMFS) is responsible for assessing the status of those dolphin stocks taken incidentally by tuna purse seiners in the eastern tropical Pacific (ETP) (Richey, 1976). The status of the spotted dolphin, *Stenella attenuata*, is of special concern because it is the major species taken by the fishery (Smith, 1979). Of the spotted dolphins, the northern offshore stock is considered to be the most affected by the fishery because it has been fished more frequently than any other stock. The spinner dolphin, *S. longirostris*, and the common dolphin, *Delphinus delphis*, are also taken. The striped dolphin, *S. coeruleoalba*, and 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 five species are herein grouped and termed target species.

In 1986, the NMFS initiated a research program to monitor relative abundance of dolphin populations in the ETP using two research vessels for at least five years during which six surveys will be conducted. The research design for the surveys, presented by Holt, Gerrodette and Cologne (1987), 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%. Analyses of the 1986 data are presented by Holt and Sexton (1988a). In 1987, the NMFS conducted a second survey using the same vessels at the same time of the year. Herein, we present relative abundance estimates for the 1987 data and compare these to the 1986 estimates. We also discuss effects of several alternate stratification methods and data treatment factors on these estimates. Because we desire to determine change in population size over several years and not estimate absolute abundance, data from several years will eventually be used to select the most consistent relative indicator of population change.
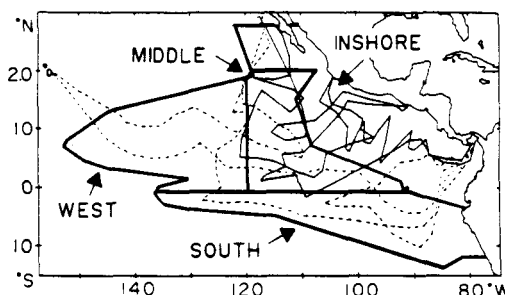

Fig. 1. Tracklines traversed by the NOAA R/V *David Starr Jordan* (solid) and *McArthur* (dash) during the 1987 survey. Tracklines generated using noontime positions.

MATERIALS AND METHODS

Study area and survey coverage

The study area and area strata were those used during the 1986 survey (Holt and Sexton, 1988a). The research vessels *McArthur* and *David Starr Jordan* traversed predetermined tracklines in the ETP from 30 July and 8 August, respectively, through 10 December (Fig. 1). Each ship was scheduled to spend approximately 120 days at sea but the *Jordan* departed 10 days late. Ship itineries, list of scientific personnel, survey equipment, data collection procedures and preliminary data summaries for each ship are presented by Holt and Sexton (1988b) and Holt and Jackson (1988). Only those factors important to this paper are presented here.

On each ship, two observers used 25X binoculars located on each side of the ship to search from directly ahead to abeam of their respective sides of the ship. A third observer served as data recorder and searched directly ahead of the ship when not recording data. Two teams of three observers each alternatively occupied the three duty stations. Each team was on duty for 2-hour shifts. During

each shift. members spent approximately equal time occupying each duty station. Two of the six observers had completed several marine mammal cruises in the ETP and were experts in identifying marine mammals. These two identification specialists were assigned to separate teams such that one would always be on duty. Teams members did not change during the cruises. Observers switched ships 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. Independent 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.*

Abundance estimation

Relative estimates of population abundance of the target species (N_{ij}) were computed as (Holt and Sexton, 1988a):

$$N_{ij} = \sum_{k=1}^{4} (D_k S_{tk} P_{tk} P_{ik} A_k / A_{ik})(A_{ijk} + P'_{ij} A'_{ijk}), \quad (1)$$

where

D_k = estimate of density of schools of all dolphin species in area k.

S_{tk} = estimate of mean size of schools of all target species in area k.

P_{tk} = estimate of proportion of all dolphin schools which are target schools in area k.

P_{ik} = estimate of proportion of individuals of species i in target schools in area k,

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

A_k = total area inhabited by all target species in area k,

A_{ik} = area inhabited by species i in area k,

A_{ijk} = area inhabited by species i, stock j, in area k, and

A'_{ijk} = area inhabited by species i, stock j, in overlap region of area k.

The variance of N_{ij} was calculated using bootstrap methods. For each stratum, the number of legs of searching effort was tabulated and then effort legs equal to that number were randomly selected with replacement. This effort and the associated sightings were used to calculate school density, school size, species proportions and finally estimates of N_{ij}s. This 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. Anderson and Laake (1980), Holt (1985, 1987), and Hayes and Buckland (1983). The Fourier series (Cain *et al.*, 1979) and hazard rate (Hayes and Buckland, 1983; Buckland, 1985) models both provided adequate fits (similar point estimates and chi-square values) to the data but the hazard rate model was used because, unlike the Fourier series model, its use does not require subjective selection of the number of terms in the model and, therefore, could be used in the bootstrap procedures. Of schools containing both target and non-target species, only the proportion of individuals of the target species was used in the school size estimate. Estimates of the proportion of all dolphin schools that were target schools (P_{tk}) were calculated using formulae presented by Holt and Powers (1982). Formulae to estimate the proportions (P_{ik}) of the

number of individuals for each species of all target individuals are given by Barlow and Holt (1986).

All species of dolphins encountered in the study area were included in the density analyses. Estimates were calculated using only schools containing 15 or more animals. Smaller schools were not used because we believe small schools both on and off the ships' tracklines may be difficult to detect especially during rough weather and may have been missed at a variable rate depending upon prevailing weather conditions (Holt, 1987).

Only schools detected within 3.7km (2.0 n.miles) perpendicular distance of the trackline were used to estimate school density because a 3.7-km truncation point provided the best fit of the model to this data. It was chosen because the perpendicular distance distributions of schools detected at greater distances were 'spiked' and because schools detected at greater than 3.7km have little effect on the density estimates. Schools detected at increasing distances from the trackline tend to include disproportionately more large schools because there is a direct correlation between the size of a school and the probability of it being detected (Drummer, 1985). This biases school size estimates upwards and species proportions toward species which occur in large schools. We attempted to adjust for this bias by weighting school size and species proportion estimates by the inverse of logarithm of school size (Holt and Powers, 1982). Finally, schools for which there were no 'best' estimates were not used in the school size or species proportion calculations.

Some stocks of the same species overlap geographic areas (A'_{ijk}). These 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). The relative number of dolphins of each overlapping stock (P'_{ij}) was calculated for data pooled over strata. Because of small sample sizes, the pooled estimate of P'_{ij} was used in each of the bootstrapped iterations. For overlapping stocks of spotted dolphins and for spinner dolphins, the relative proportions of coastal and northern spotted and of eastern and whitebelly spinner stocks within their area of overlap were calculated as the averages of their relative abundances (percent occurrence). Few data were available to determine relative proportions of the overlapping Baja Neritic and northern common dolphins. Therefore, population estimates for Baja Neritic were combined with northern common dolphins.

The area inhabited by each target species (A_k) used to calculate the population abundance estimates were those defined by Au *et al.* (1979) and Perrin *et al.* (1984). The study area was partitioned into four strata (Holt and Sexton, 1988a). All four strata comprise the total area. The size of each stratum and the area occupied by each stock in each stratum was calculated by Holt and Sexton (1988a).

RESULTS

During the entire survey, observers aboard both vessels searched 28,611km and detected 1,249 marine mammal schools. Dolphins were present in 891 of these schools. While searching in the study area (Fig. 1). within 3.7km perpendicular distance of the trackline. and during Beaufort Sea states of 5 or less, observers on both vessels searched 26.519km and detected 352 dolphin schools (Table 1). The amount of effort and schools detected varied among strata; 42% of the total trackline searched and 53% of all schools detected were in the inshore area.

Table 1

1987 cruise data and results (see text). Data were truncated at 3.7km perpendicular distance. Schools with less than 15 animals were omitted from analyses. School sizes and species proportions were weighted by inverse of school size. Effort collecting during sea states 0 – 5 included in analyses. Data summed for both vessels. Total is for data summed over all four strata.

	Inshore	Middle	West	South	Total
Area (1,000km²)	5,693	3,798	5,298	4,359	19,148
% Total area	30	20	28	22	100
Trackline searched (km)	11,145	7,974	3,529	3,871	26,519
% searching effort	42	30	13	15	100
Density (D_k)[1]	4.74	3.15	2.16	3.58	3.75
No. schools detected°	187	89	27	49	352
Mean target species school size (S_{tk})	81.57	84.56	94.12	121.64	88.39
No. target schools[b]	151	77	23	38	289
Proportions:					
Target schools (P_{tk})	0.826	0.858	0.802	0.865	0.837
Spotted dolphins	0.284	0.524	0.367	0.319	0.360
Spinner dolphins	0.201	0.258	0.315	0.167	0.219
Common dolphins	0.272	0.009	0.056	0.080	0.152
Striped dolphins	0.242	0.159	0.046	0.295	0.214
Fraser's dolphins	0.000	0.050	0.217	0.139	0.055
Overlap area:					
Prop. Coastal Spotted					0.182
Prop. Offshore Spotted					0.818
No. Spotted schools					18
Prop. Eastern Spinner					0.677
Prop. Whitebelly Spinner					0.323
No. Spinner schools					83

[1] schools/1.000 km²
° including unidentified dolphin schools.
[b] including schools identified as target species but for which a best estimate of school size was not made.

The estimate of f(0) for data in the total area was 0.577. Density estimates (D_k) in the four strata, calculated using the pooled f(0), ranged from 2.21 to 4.84 schools/1000km² (Table 1). Estimates of mean school size (S_{tk}) of target species ranged from 81.57 to 121.64 animals (Table 1). The proportion of identified dolphin schools that included target species (P_{tk}) ranged from 0.826 to 0.900 among strata (Table 1).

The proportions of individuals of target species that were spotted dolphins (P_{ik}) ranged from 0.284 to 0.524 among the strata (Table 1). The proportions of the other target species among strata also varied greatly. For example, the proportion of common dolphins ranged from 0.009 to 0.272 (Table 1). Only 18 spotted dolphin schools were detected in the overlap region of the coastal and offshore spotted stocks. The proportion (P'_{ij}) of these that were offshore spotted dolphins was 0.818 (Table 1). Of 83 spinner dolphin schools detected in the area of overlap of eastern and whitebelly spinner stocks, 0.677 were eastern spinner dolphin schools

The estimate of relative abundance for each stock of the target species is presented in Table 2. Spotted dolphins were the most abundant target species. The estimate of 1,275,400 northern offshore spotted dolphins represented 70% of the estimate of all stocks of spotted dolphins. The coefficient of variation of the abundance of the northern offshore spotted stock, $CV(N_{ij})$, was 0.262. The abundance estimate for eastern spinner dolphins was 533,100 animals with a CV of 0.281.

DISCUSSION

Abundance estimates may be calculated using equation (1) by pooling variables across geographical strata and/or species categories. In general, the greater the degree of pooling across variables, the more precise (lower CVs) but also the more biased are estimates of abundance. For

Table 2

Estimates of population sizes (N_{ij}) (in thousands of animals) by stock for target species in total area. Values given are weighted by stratum.

Species/stock	N_{ij}	$SE(N_{ij})$	$CV(N_{ij})$
Spotted			
Coastal	32.4	6.8	0.210
Northern Offshore	1,275.4	334.3	0.262
Southern Offshore	501.8	199.8	0.398
Total	1,809.6	540.9	0.299
Spinner			
Costa Rican	17.9	4.6	0.257
Eastern	533.2	149.8	0.281
Northern Whitebelly	334.2	96.9	0.290
Southern Whitebelly	252.2	105.1	0.417
Total	1,137.5	356.4	0.313
Common			
Northern Tropical	130.3	47.7	0.366
West Central Tropical	53.0	44.8	0.845
East Central Tropical	307.0	112.0	0.365
Southern Tropical	201.0	110.7	0.551
Total	691.3	315.2	0.456
Striped			
Northern Tropical	124.4	23.0	0.185
West Central Tropical	33.7	23.8	0.706
East Central Tropical	353.9	63.1	0.178
Southern Tropical	584.2	147.8	0.253
Total	1,096.2	257.7	0.235
Fraser's	451.0	282.5	0.626
Total	5,185.6	1,752.7	0.338

example, we calculated the density estimate (D_k) by pooling perpendicular distance distributions across strata such that

$$D_k = \sum_{k=1}^{4} n_k f(0)/2l_k.$$

where n_k is the number of dolphin schools detected in stratum k and l_k is the line length searched in stratum k.

An alternate method was examined which calculated f(0) for data in each stratum. This yielded an abundance estimate for northern offshore spotted dolphins of 1,576,600 animals compared to our estimate of 1,275,400 animals (Table 2) but the estimate of CV was 0.363 compared to 0.262 for our pooled f(0) method. The larger CV resulted because the hazard rate model was applied to small data sets in the south (27 schools) and west (49 schools) strata (Table 1).

We also investigated another alternate method by calculating abundance estimates for all variables in equation (1) pooled across all geographic strata. For the northern offshore spotted dolphins, this yielded an abundance estimate of 1,497,200 animals with a CV of 0.158. Although the estimate is very precise, it may be biased upwards because encounter rates were highest in the inshore stratum (Table 1) which received 42% of the total survey coverage but only represented 30% of the total geographic area.

We calculated school density using schools of all dolphin species; then calculated the proportion of those schools which were target species; and finally calculated the proportions of individuals of each species in the target species [equation (1)]. However, two alternate methods were investigated. They were to (1) calculate school density using only schools of target species and prorating to each species and (2) calculate abundance estimates using only data for each individual species. Method 1 does not require calculation of the proportion of all schools that are target schools, however, it utilises smaller samples than our

method and a proportion of the unidentified schools must be allocated to the perpendicular distance distribution to calculate school density. We calculated the proportion of identified target schools in each perpendicular distance interval and then assigned that proportion of the unidentified schools detected in the interval to that interval.

Method 2 does not require calculation of species proportions but it utilises very small data sets. Sufficient data only exists to calculate estimates for spotted and spinner dolphins. In this method, we assumed no unidentified dolphin schools contained spotted dolphins.

Estimates of northern offshore spotted dolphins using methods 1 and 2 were 1,235,300 (CV 0.2'5) and 1,119,600 (CV 0.320) animals, respectively. The estimate for method 2 may have been smaller than both the method 1 estimate and our estimate of 1,275,400 animals using all dolphin schools (Table 2) because it did not include any unidentified schools. However, based on field experience the senior author believes that spotted dolphin schools rarely are not identified. CV estimates were similar for method 1 and our method (0.265 and 0.262, respectively) but both were smaller than the method 2 CV (0.320) which was based on small samples.

Abundance estimates calculated using all dolphin species and data pooled over all strata (total area in Table 1) may provide the most consistent *relative* abundance estimates during the six surveys. The method provides very precise estimates (CV for northern offshore spotted dolphins was 0.158 compared to our estimate of 0.262) because it avoids calculating estimates using small sample sizes. However, the abundance estimates may be biased upwards because proportionally more effort is expended in the high density inshore area (42%) compared to its relative size (30% of total survey area). This bias is acceptable if survey coverage among strata is relatively constant during all surveys as it was during the first two surveys. During 1986, the percents of the survey effort in the inshore, middle, west and south strata were 43, 28, 14 and 15%, respectively (Holt and Sexton, 1988a) and in 1987 they were 42, 30, 13 and 15%, respectively (Table 1).

The estimate of abundance for northern offshore spotted dolphins during 1987 was larger than the 1986 estimate. The 1986 and 1987 estimates were 929,000 (Holt and Sexton, 1988a) and 1,275,400 (Table 2) animals, respectively. These estimates were not statistically different (p>0.01). The larger 1987 estimate occurred because school density increased in 1987 in all strata. In addition, the proportion of spotted dolphins in the target species increased in the middle stratum. The 1986 estimates for density in the inshore, middle and west strata were 3.62, 2.56, and 1.89 schools/1000km², respectively (Holt and Sexton, 1988a); the corresponding 1987 estimates were 4.74, 3.15 and 2.16 schools/1000km², respectively (Table 1). The proportion of spotted dolphins of the target species in the middle stratum increased from 0.378 in 1986 to 0.524 in 1987. However, the proportion of all dolphins that were target species in the middle stratum slightly decreased from 0.906 in 1986 to 0.858 in 1987. In addition, school size estimates decreased slightly in the inshore and west strata and remained constant in the middle stratum. Estimates during 1986 in the inshore middle, and west strata were 89.41, 83.97 and 104.55 animals, respectively (Holt and Sexton, 1988a); in 1987 they were 81.57, 84.56 and 94.12 animals, respectively (Table 1).

The reason for the larger 1987 abundance estimate for northern offshore spotted dolphins may be attributed to sampling variability among surveys. Another factor is that dolphins in the south stratum during 1986 may have migrated into the northern strata during 1987. However, although the mean school size in the south stratum decreased from 179.04 animals (Holt and Sexton, 1988a) during the 1986 survey to 121.64 animals for 1987 survey (Table 1), the density estimate in the south stratum increased from 2.32 schools/1000km² in 1986 to 3.58 schools/1000km² in 1987. In addition, the proportion of target individuals that were spotted dolphins increased from 0.170 to 0.319. In fact, the abundance estimate for southern offshore spotted dolphins also increased (from 218,500 animals in 1986 to 501,800 animals in 1987).

Abundance estimates for the southern stocks varied greatly between 1986 and 1987. For example, the estimate for southern common dolphins was 943,200 animals during 1986 (Holt and Sexton, 1988a) but was 201,000 animals (Table 1) during 1987. This was because the proportion of common dolphins in the south stratum decreased from 0.661 during 1986 (Holt and Sexton, 1988a) to 0.080 during 1987 (Table 1). Estimates for the other species exhibited corresponding changes. This variability was because estimates in the south stratum were based upon few sightings. During 1986 and 1987, only 27 and 38 target schools, respectively, were detected in the south stratum. Species proportions in the west stratum were also based on few schools (Table 1) which may have yielded variable estimates for the western stocks.

Although estimates for some stocks varied greatly between years, the abundance estimates for all target species summed were similar. The 1986 and 1987 estimates for all target species were 4,471,200 (Holt and Sexton, 1988a) and 5,185,600 (Table 2) animals, respectively. The 1987 estimate is 16% larger than the 1986 estimate.

Selection of the best option to determine population changes will be investigated with additional years' data. We will also investigate several factors which may have contributed to differences observed between surveys. These include ship effects, observer variability, sea state effects and survey coverage variability (Holt and Cologne, 1987).

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