SOUTHWEST FISHERIES CENTER

NATIONAL MARINE FISHERIES SERVICE SOUTHWEST FISHERIES CENTER P.O. BOX 271 LA JOLLA, CA 92038

JUNE 1985

ESTIMATES OF ABUNDANCE OF DOLPHIN STOCKS TAKEN INCIDENTALLY IN THE EASTERN TROPICAL PACIFIC YELLOWFIN TUNA FISHERY

By

Rennie S. Holt

ADMINISTRATIVE REPORT NO. LJ-85-20

"This report is used to ensure prompt dissemination of preliminary results, interim reports, and special studies to the scientific community. The material is not ready for formal publication since the paper may later be published in a modified form to include more recent information or research results. Abstracting, citing, or reproduction of this information is not allowed. Contact author if additional information is required."

ESTIMATES OF ABUNDANCE OF DOLPHIN STOCKS TAKEN INCIDENTALLY IN THE EASTERN TROPICAL PACIFIC YELLOWFIN TUNA FISHERY

Rennie S. Holt
Southwest Fisheries Center
National Marine Fisheries Service, NOAA
La Jolla, California 92038

June 1985

Administrative Report No. LJ-85-20

CONTENTS

Introduction 1

Data sources and treatment 2

Population size estimate formulae 4

Density estimates ($\hat{D}_k$) 5

Assumption 1 6

Assumption 2 7

Assumption 3 7

Species proportions 7

Mean school size estimates 9

Species/stock areas inhabited (A_k, A_{ik}, A_{ijk}) 12

Population abundance estimates 13

Comparison with previous estimates of abundance 14

Concerns about population estimates 14

Summary 15

Literature cited 16

TABLES

1. Research ship cruises conducted each year in the eastern tropical Pacific Ocean from 1976 through 1983.............................. 18

2. Density of dolphin schools in the inshore and offshore areas.. 19

3. Proportion of target schools in all identified dolphin schools for each year for aerial and research ship data. Proportion weighted by inverse of log-school size.................................. 20

4. Species proportions for research vessel and tuna vessel data in inshore, northern offshore, and southern offshore areas. Values are given as both weighted and unweighted averages of the proportions within 5° strata. All sightings are weighted by the inverse of log-school size................................ 21

5. Weighted and unweighted mean school size and number of schools detected from tuna vessels, airplanes and research ships from 1977 through 1983. Weighting is by inverse of log-school size.......... 22

6. Weighted and unweighted mean school size and number of schools detected from tuna vessels, aerial and research ship data stratified by year. Weighting is by inverse of log-school size.... 23

7. Weighted and unweighted mean school size and number of schools detected from tuna vessel, aerial and research ship data stratified by area for data collected from 1977 through 1983. Weighting is by inverse of log-school size. 24

8. Weighted and unweighted mean school size and number of schools detected from tuna vessels, aerial and research ship data stratified by species types for data collected from 1977 through 1983. Weighting is by inverse of log-school size................. 25

9. Area inhabited (km^2) by various species/stocks for the inshore, northern offshore and southern offshore areas..................... 26

10. Proportion of dolphins of each stock within areas inhabited with another stock of the same species (overlapping areas of stock distributions). Number strata for stocks of spotted dolphins is number of overlapping 1.85 km (0.1 nm) wide coastal bands occupied and for stocks of spinner dolphins the number of overlapping 5° geographic squares occupied. Proportions calculated using tuna vessel data... 27

11. Estimates of population sizes (in thousands of animals) by stock for target species using pooled research vessel species proportion data calculated from 1977 through 1983. Values are given as both unweighted and weighted averages of the proportions within 5° strata. All sightings were weighted by the inverse of log-school size to calculated mean school size and species proportions. Standard errors are in parenthesis.............................. 28

FIGURES

1. Map of study area showing research ship tracklines searched from 1977 through 1983 29

2. Tracklines searched from research vessel during each year from 1977 through 1983 30

3. Tracklines searched from airplanes during 1977 and 1979 31

4. Fit of Fourier series model to data collected during the aerial experiment and aerial surveys during calm and rough seas, good and poor sun conditions, and all conditions 32

ESTIMATES OF ABUNDANCE OF DOLPHIN STOCKS TAKEN INCIDENTALLY IN THE EASTERN TROPICAL PACIFIC YELLOWFIN TUNA FISHERY

Rennie S. Holt
Southwest Fisheries Center
National Marine Fisheries Service, NOAA
La Jolla, California 92038

INTRODUCTION

Aerial and shipboard observations of dolphins in the Eastern tropical Pacific (ETP) yellowfin tuna purse seine fishery have been collected by the National Marine Fisheries Service (NMFS) (SWFC 1976[1], Smith 1979[2]) to estimate population sizes of the stocks in 1974 (Smith 1975[3]) and again in 1979 (Holt and Powers 1982). Additional data have been collected since 1979 that is relevant to estimating dolphin abundance (Holt 1984a[4], Holt 1984b[5], Cologne and Holt 1984[6], Barlow and Holt 1984[7], Perrin et al. 1983, Perrin et al. 1984[8]). In this paper, I review several analyses of sighting data collected between 1977 and 1983 from several sources and present estimates of dolphin population sizes using the most appropriate data and analyses.

---

[1] SWFC (Southwest Fisheries Center, Nat'l Mar. Fish. Serv., NOAA, La Jolla, CA 92038). 1976. Report of the workshop on stock assessment of porpoises involved in the eastern tropical Pacific yellowfin tuna fishery. Southwest Fish. Cent. Adm. Rept. No. LJ-76-29, La Jolla, Ca. 60pp.

[2] Smith, T.D. 1979. Report of the status of the porpoise stock workshop (August 27-31, 1979, La Jolla, California). Southwest Fish. Cent. Adm. Rept. No. LJ-79-41. 120 pp.

[3] Smith, T.D. 1975. Estimates of sizes of two populations of porpoise (Stenella) in the Eastern tropical Pacific Ocean. Southwest Fish. Cent. Adm. Rept. No. LJ-75-67. La Jolla, Ca. 88pp.

[4] Holt, R.S. 1984a. Testing the validity of line transect theory to estimate density of dolphin schools. Southwest Fish. Cent. Admin. Rep. No. LJ-84-31. 56pp.

[5] Holt, R.S. 1984b. Estimation of density of dolphin schools in the eastern tropical Pacific ocean using line transect methods. Southwest Fish. Cent. Rep. No. LJ-84-32. 72pp.

[6] Cologne, J.B. and R.S. Holt. 1983. Observer effects in shipboard sighting surveys of dolphin abundance. Southwest Fish. Cent. Rep. No. LJ-84-30. 42pp.

[7] Barlow, J. and R.S. Holt. 1984. Geographic distributions of species proportions for dolphins of the eastern tropical Pacific. Southwest Fish. Cent. Admin. Rep. No. LJ-84-27. 44 pp.

[8] Perrin, W.F., M.D. Scott, G.J. Walker, and V.L. Cass. 1984. Review of geographic stocks of tropical dolphins (*Stenella spp.* and *Delphinus delphis*) in the eastern pacific. Southwest Fish. Cent. Admin. Rep. No. LJ-84-02. 68 pp.

DATA SOURCES AND TREATMENT

Dolphin sighting survey and experimental test data, used in this paper, were collected from airplanes, research vessels and tuna vessels through 1983. Before 1977, data were collected using less precise techniques than the techniques used in later years and were only used to define area inhabited by the dolphins.

Aerial surveys were completed in 1977 and 1979. Research ship surveys were conducted during 1977, 1979, 1980, 1982 and 1983 (Table 1). Aerial surveys and all but two of the ship surveys were conducted during the northern winter (January-April). Coverage of the survey area is complete when all research ship data are combined (Figure 1) although it was limited within any single year because of logistical constraints (Figure 2). Aircraft flights were conducted along tracklines located almost uniformly from Manzanillo, Mexico to Lima, Peru and covered the inshore region of the ETP (Figure 3).

Field experiments to test population size estimation methods and certain critical assumptions were completed in 1980 and 1981 using airplanes and in 1979, 1982, and 1983 using ships and ship-based helicopters. The 1979 ship and 1980 aerial experiments were supervised by the Inter-American Tropical Tuna Commission (IATTC), and included personnel and equipment from both IATTC and the NMFS (Allen et al. 1980[9], Clark 1983[10], Scott et al. 1984[11]). The objectives of these experiments were to investigate the ability of aerial observers to accurately estimate dolphin school sizes. Observers estimated sizes of dolphin schools from aboard a helicopter and a tuna vessel in 1979 and from an airplane in 1980. Dolphin schools were also photographed from the aerial platforms. Later in the laboratory, estimates from observers and photographic counts were compared.

In the 1981 experiment (Holt 1983a, 1984a[4]), Holt investigated effects of sun glare and sea state upon observers' abilities to detect dolphin schools from the aircraft. In the 1983 experiment (Hewitt 1984)[12], the reaction of dolphins to a ship as the ship proceeded along predetermined tracklines was investigated. Finally several experiments testing searching techniques and performance of shipboard observers were completed during the 1982 and 1983 survey cruises (Cologne and Holt 1984)[6].

---

[9] Allen, R.L., D.A. Bratten, J.L. Laake, J.F. Lambert, W.L. Perryman, and M.D. Scott. 1980. Report on estimating the size of dolhin schools, based on data obtained during a charter cruise of the M/V Gina Anne, October 11-November 25, 1979. Inter-American Tropical Tuna Commission Data Report No. 6. 28pp.

[10] Clark, W.G. 1983. Analysis of variance of photographic and visual estimates of dolphin school size. Marine Mammal Comm. Southwest Fish. Cent. Admin. Rep. No.

[11] Scott, M.D., W.L. Perryman, and W.G. Clark, 1984. The use of aerial photographs for estimating school sizes of cetaceans. ms.

[12] Hewitt, R.P. 1984. Reaction of dolphins to a survey vessel: effects on census data. ms submitted to Journal.

The experiments included investigation of watch length on observer performance, observer searching patterns while using the binoculars, and performance of observers with different amounts of experience searching for dolphins aboard tuna vessels or aboard research vessels.

Since 1973, the NMFS has placed scientific observers aboard United States tuna purse seine vessels in the ETP to gather information on the biology, rates of incidental mortality and rates of encounters of dolphins during tuna fishing. Information collected by the observers include dolphin school size, species/stock composition of schools encountered, number of schools encountered, and species/stock distribution in the ETP. Although only data collected from 1977 through 1983 are used here all historical data were used to define area inhabited by the stocks (Perrin et al. 1983, Perrin et al. 1984[8]).

For estimating population size, I partitioned the ETP into more homogenous regions, determined in part by logistic limitations of the airplanes (Figure 3). The "inshore" area, which extends from Puerto Vallarta, Mexico, to Lima, Peru, and offshore for approximately 1110 km (600 nm), was the area surveyed by aircraft. The "offshore" area, which extends westward beyond the inshore area and was not accessible by the aircraft, was surveyed by the research vessels (Figure 1). I divided this area along the equator into northern and southern areas. In addition, I designated a "calibration" area in the inshore area, which extends from Manzanillo, Mexico, to Puntarenas, Costa Rica, and offshore for approximately 1000 km (550 nm) (Figure 3). Both research vessels and aircraft operated in the calibration area in 1979 for calibrating observations on the different platforms. This area was selected because high densities of dolphins usually occur in this area.

Data collection methods and data collected aboard ships were described in the various Cruise Reports[13], in Holt (1983b) and in Cologne and Holt (1983)[6]. Similar data for the 1977 and 1979 aerial surveys were reported by Barham (1977)[14] and Jackson (1979)[15], respectively. Searching was conducted along preselected tracklines, where each leg of searching effort had constant sighting conditions and the same observers searched through the binoculars.

Sightings were grouped into target and non-target species. The target species are the five species of dolphins which are either affected by the fishery or have similar appearance and characteristics that make them relatively more difficult to distinguish from species involved in the fishery. The target species are: spotted dolphin, *Stenella attenuata*; spinner dolphin, *S. longirostris*; striped dolphin, *S. coeruleoalba*; common dolphin, *Delphinus delphis*; and Frazier's dolphin, *Lagenodelphis hosei*.

---

[13]Unpublished reports available from the Southwest Fisheries Center, P.O. Box 271. La Jolla, CA. 92038.

[14]Barham, E. 1977. Aerial survey trip report, January-June 1977. Southwest Fish. Cent. Admin. Rep. No. LJ-78-01. 73pp.

[15]Jackson, T.D. 1980. Trip report: porpoise population aerial survey of the eastern tropical Pacific Ocean January 22-April 25, 1979. Southwest Fish. Center Admin. Rept. No. LJ-80-1. 74pp.

Dolphin schools with fewer than 15 animals were omitted because the probability that all animals of small schools would be submerged at one time and hence undetectable may be high (Holt and Powers 1982). Less than 1% of the target-species schools fell in this category (Barlow and Holt 1984)[7].

POPULATION SIZE ESTIMATE FORMULAE

Population size estimates for the target species are computed as the product of the (1) density of all dolphin schools, (2) proportion of all schools that are target-species schools, (3) mean school size of all target-species schools, (4) proportion of individuals of each species within the target-species schools and (5) total area inhabited by the target-species (Holt and Powers 1982). To obtain estimates for each species-stock, the estimate for each species was multiplied by the proportion of area inhabited by the stock in the area inhabited by that species. The estimate of the number of individuals (N) of stock j of species i is (Holt and Powers 1982):

$$\hat{N}_{ij} = \hat{P}_t * \hat{\bar{S}}_t [\sum_{k=1}^{3} (\hat{D}_k)(\hat{P}_{ik})(A_k/A_{ik})[(A_{ijk}) + (\hat{P}'_{ijk})(A'_{ijk})], \quad (1)$$

where $\hat{N}_{ij}$ = abundance estimate of target species i, stock j,

$\hat{P}_t$ = estimate of proportion of dolphin schools which are target schools,

$\hat{\bar{S}}_t$ = estimate of mean size of target schools,

$\hat{D}_k$ = estimate of density of dolphin schools in area k with D_1 = density estimate of inshore area; D_2 = density estimate of northern offshore area; D_3 = density estimate of southern offshore area; where $D_2 = D_3$,

$\hat{P}_{ik}$ = estimate of proportion of individuals of species i in target schools in area k,

$\hat{P}'_{ijk}$ = estimate of proportion of individuals of species i, stock j, in target schools in region of area k 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 $\hat{N}_{ij}$ can be approximated using the Taylor series expansion by

$$\begin{aligned}\hat{V}ar(\hat{N}_{is}) = {} & \hat{V}ar(\hat{S}_t)\left(\frac{\partial \hat{N}_{ij}}{\partial S_t}\right)^2 + \hat{V}ar(\hat{P}_t)\left(\frac{\partial \hat{N}_{ij}}{\partial P_t}\right)^2 \\ & + \sum_{k=1}^{3}\left[Var(\hat{P}_{ik})\left(\frac{\partial \hat{N}_{ij}}{\partial \hat{P}_{ik}}\right)^2\right] + \sum_{k=1}^{3}\left[Var(\hat{P}'_{ik})\left(\frac{\partial \hat{N}_{ij}}{\partial \hat{P}'_{ik}}\right)^2\right] \\ & + Var(\hat{D}_1)\left(\frac{\partial \hat{N}_{ij}}{\partial \hat{D}_1}\right)^2 + Var(\hat{D}_2)\left(\frac{\partial \hat{N}_{ij}}{\partial \hat{D}_2}\right)^2 + \\ & + \left(\frac{\partial \hat{N}_{ij}}{\partial \hat{D}_1}\right)\left(\frac{\partial \hat{N}_{ij}}{\partial \hat{D}_2}\right) 2 \text{ COV } \hat{D}_1, \hat{D}_2\end{aligned} \qquad (2)$$

DENSITY ESTIMATES ($\hat{D}_k$)

Estimates of density of dolphin schools were calculated using line transect (LT) methods. The basic equation is

$$\hat{D} = n\ \hat{f}(0)\ /\ 2\ L \qquad (3)$$

where $\hat{D}$ is the estimated density of dolphin schools per km^2, n is the number of schools sighted, L is the total linear distance searched, and f(0) is an estimate of the probability density function (pdf) evaluated at perpendicular distance, x= 0 (Burnham et al 1980). The Fourier series model (Crain et al. 1978) was used to provide estimates of $\hat{f}(0)$. The variance of $\hat{D}$ can be estimated as

$$\hat{V}ar(\hat{D}) = \hat{D}^2\ [\hat{V}ar(n)/n^2\ +\ \hat{V}ar(\hat{f}(0))/(\hat{f}(0))^2] \qquad (4)$$

where formulae for estimating the $\hat{V}ar(n)$ and $\hat{V}ar(\hat{f}(0))$ are provided by Burnham et al (1980).

The Fourier series model was applied directly to the aerial sighting data, which were grouped into intervals of 0.18 km. This method was not applied directly to the shipboard sighting data because errors in estimating radial distances and sighting angles occurred which would bias LT estimates upward (Holt 1984b)[5]. To minimize the effects of these errors, the shipboard sighting data was smoothed using the technique "smearing" (Butterworth 1982, Hammond 1983).[16]

The estimate of density in the inshore area, from aerial data, was 4.18 schools/1000 km^2 with a standard error of 0.902 (Table 2) (Holt 1983b). The offshore density estimate, from research ship data, was 2.04 schools/1000 km^2 with a standard error of 0.263.

These estimates were based upon several assumptions of LT theory (Seber 1973, Burnham et al 1980); some may not have been valid. Holt and Powers (1982) investigated these assumptions and concluded that tracklines were systematically placed in the ETP and sightings were detected as independent events (Holt and Powers 1982). They also accepted the assumptions that (1) schools directly on the trackline are never missed, or

---

[16]Hammond, P.S. 1983. An investigation into the effects of different techniques of smearing the IWC/IDCR Minke whale sightings data and of the use of different models to estimate density of schools. ms submitted to IWC.

at least seldom missed, by shipboard observers, (2) schools do not move in response to an approaching airplane, and (3) no systematic data measurement errors occur for aerial data. However, they concluded that (1) aerial observers may miss trackline schools, (2) schools may move in response to approaching ships, and (3) systematic data measurement errors may occur on board ships. Therefore, several experiments have been conducted to test the validity of these three assumptions using the platform in doubt.

Assumption 1: Schools directly on the trackline are never missed by aerial observers.

The assumption that all trackline schools were detected from airplanes was investigated during the 1981 aerial experiment during which the effects of sun and sea state conditions were tested (Holt 1984a)[4]. Severe sun glare on the trackline resulted in a significant reduction in the estimate of school density, but sea state conditions between Beaufort states 1 and 5 (Bowditch 1966) did not significantly affect the density estimates. However, rates at which trackline schools were detected during rougher seas (higher Beaufort states) were slightly lower than rates estimated during calm seas. Unfortunately, there were few experimental data at the most severe sea state (Beaufort 5).

Adjustment of the survey data for the impact of sun glare from results of the aerial experiment is appropriate only if all factors that affect detection of dolphins from airplanes equally affected observers during the surveys and during the experiment. However, some conditions can be identified which differed between the surveys and the experiment; these included differences in environmental conditions encountered, structural differences between the airplanes utilized, and differences between the experimental and survey protocols, e.g., when searching effort was halted due to adverse sun conditions (Holt 1984b)[5].

If the variables tested in the aerial experiment account for the variation in the density estimates for the aerial survey data, then the same relative patterns in detection functions should be evident in both data sets. Comparisons of the detection functions for calm and rough sea states or good and poor sun conditions between the two data sets should indicate the same relative trends. Detection functions, however, were not similar (Figure 4). This may indicate factors other than sun glare which affected the density estimates occurred disproportionately in the two data sets. Although results from the experiment indicated sun glare can adversely affect density estimates, an adjustment factor calculated for sun glare effects using the experimental data would probably not accurately correct the survey data.

Instead of using an adjustment factor to account for missing trackline schools during poor sun conditions, all survey effort conducted during poor sun conditions could be eliminated. However, because of spatial confounding of density with sun glare conditions (Holt 1984b)[5], removal of the poor sun data would eliminate coverage in the lower density outside region of the inshore area and seriously bias the estimates.

Because few data at Beaufort 5 conditions were collected in the aerial experiment, the effect upon the density estimates of missing trackline schools during extreme sea states could not be determined. Holt (1984b[5]) removed Beaufort 5 conditions from the aerial survey data but this biased the density estimates because these conditions only occurred in the most offshore region of the inshore area where dolphin density was lower than in the nearshore region. Holt (1984b[5]) also excluded data recorded during Beaufort 4 and 5 sea states; however, removal of this data from the survey area essentially left coverage only in a high density "coastal" band.

Assumption 2: Schools do not move in response to an approaching ship.

In the 1983 ship-helicopter experiment Hewitt (1984)[12] investigated the reaction of dolphins to survey vessels. Observers aboard a helicopter searched ahead and to either side of the ship as it proceeded along a predetermined trackline. Shipboard observers searched for dolphins using standard survey techniques (Holt 1983b)[5]. Although sample size was small, dolphin schools only occasionally reacted to the approach of the survey vessel prior to being detected by shipboard observers. Of 19 schools tracked by the helicopter observers, only 1 (5%) exhibited an avoidance reaction. Six of the 19 schools were never detected by shipboard observers and one school was not a target species; therefore, 8% of the schools detected by the ship observers (1 of 12 schools) reacted before they were detected.

Hewitt (1984)[12] noted that these results do not imply a corresponding degree of survey bias. If the school was not on the trackline before it moved to avoid the ship, the bias in the density estimate may be minimal. In fact, a change in school behavior due to its avoidance may increase the school's detectability. The ship data were not adjusted to account for dolphin avoidance of the ships.

Assumption 3: No systematic data measurement errors occur for ship data.

The assumption that radial distances and sighting angles were recorded without error for ship data was not accepted. An inordinate proportion of dolphin schools (25% of all schools) were recorded as being on the trackline (Holt 1984b)[5]. Because these errors would bias the density estimates, the "adjusted LT" estimation technique, discussed earlier, was used to calculate density estimates in the offshore area. The shipboard density estimates are probably still biased to an unknown degree.

SPECIES PROPORTIONS

The estimate of the total number of dolphins was allocated to the several species in two steps. First, the proportion of all dolphin schools which were of the "target-species " group ($\hat{P}_t$) was determined and then the proportion of each species in the target-species group in the kth area (P_{ik}) was determined.

Proportion of Target Schools ($\hat{P}_t$)

I determined the proportion of all schools that were target species using pooled aerial and research vessel data. Tuna vessel data were not used because, by definition, tuna vessels search for these species.

The proportion of target schools and its variance were calculated using formulae presented by Holt and Powers (1982). Because school size is related to species (Barlow and Holt 1984)[7] and because sightability of larger schools is probably greater, the estimated species proportion based on sighting data may be biased accordingly. Holt and Powers (1982) attempted to adjust for the suspected bias by weighting the proportions by the probability that a particular school size, and thus a particular species group, was seen. They selected the inverse of log-school size as an appropriate weighting factor (Holt and Powers 1982).

The estimate of the proportion of target schools, using the log-school weighting factor, was 0.7484 with a standard error of 0.0181 (Table 3). The proportion of target schools varied among platforms and among years. However, the surveys were conducted in different areas and seasons (Figure 2 and Table 1).

Species Proportion of Target Schools ($\hat{P}_{ik}$)

Barlow and Holt (1984)[7] estimated species proportions, using research vessel data, that were both unweighted and weighted by the rates in which dolphin schools of each species were encountered from tuna vessels (schools/100 km) in each 5° square. The weighted proportions were calculated to account for geographic variability. However, they may be biased toward areas with high spotted dolphin abundance because, as already mentioned, tuna vessels may search selectively for this species. Values from unweighted and weighted averages of geographic strata probably bracket the true estimates of proportion of ETP dolphin species (Barlow and Holt 1984)[7]. Species proportions calculated by Barlow and Holt (1984)[7] were also adjusted by the inverse of log-school size as discussed earlier by Holt and Powers (1982).

The proportions of spotted dolphins in the target species, utilizing research vessel data both unweighted and weighted, ranged from 0.24 to 0.52 among the various area strata (Table 4). The proportions of spotted dolphins in the strata were generally larger for weighted data than unweighted data (Table 4).

Barlow and Holt (1984)[7] also calculated estimates of the proportion of each species in the target group using tuna vessel data. A much larger proportion of the target species detected from tuna vessels were spotted dolphins than were those detected from research vessels (Table 4).

They investigated factors which might account for differences between species proportions from tuna vessel and research vessel data. These may be due to differences in (1) abilities of observers aboard the two platform types to identify the target species or to estimate the proportion of each species within that group and (2) the samples of schools encountered by the two vessel types. However, Cologne and Holt (1984)[6] found no significant difference in abilities of observers with research vessel experience and observers with tuna vessel experience to identify target species or to estimate proportion of each species in each school during a research vessel cruise.

Differences in the samples of schools encountered by the two vessel types may be due to differences in searching patterns and operating characteristics aboard the vessels. Research vessel observers searched along predetermined tracklines using 20 or 25 power binoculars and, in order to facilitate accurate species identification and species composition estimates, the ships were directed towards schools for closer inspection. In addition, from 1977 through 1980, estimates of species identification and school composition for each school detected from research ships were recorded as a concensus of from 1 to 6 observers. During the 1982 and 1983 cruises, individual observer estimates were recorded independently for each school and a mean estimate was calculated.

Tuna vessels do not search predetermined tracklines but attempt to search areas of the ETP and use techniques that maximize the possibility of encountering tuna. Estimates derived from this data may be biased if the searching process is directed at specific species of the target group, at specific schools having large number of animals, or schools in specific geographic areas. Observers aboard tuna vessels search for marine mammal cues using hand held 7 power glasses and rely upon the crew members, who search through 25 power glasses, to inform them of schools away from the ship. In some cases, observer may not be informed of all schools detected by crew members. If the ship does not approach the school, the observer, even if informed of its presence, may not identify it or make accurate school size or species composition estimates.

Several workers have investigated the problem of nonrandom searching by the tuna vessels (Hammond 1981, Hammond and Laake 1983, Laake 1981, Polacheck 1983, Barlow and Holt 1984[17]). Hammond and Laake (1983) found tuna vessel effort was concentrated in areas of high dolphin density. Polacheck concluded that results seen in his analyses were unlikely unless vessels search nonrandomly.

MEAN SCHOOL SIZE ESTIMATES

Mean school size estimates for target schools were calculated from data collected by observers aboard the aerial surveys, research ships, and tuna vessels. For aerial and the 1982 and 1983 research ship data, an average school size estimate was calculated for each school using individual estimates from 1 to 6 observers. Aboard other research cruises the observers reached a consensus of the best mean estimate for each school. The observer aboard the tuna vessel recorded his estimate of school size for each sighting. Estimates were weighted by the inverse of log-school size to compensate for oversampling large schools, as previously discussed.

Only school size estimates of aerial observers were used to calculate population abundance estimates because I believe aerial data are the least biased. Mean school size estimate using aerial data was 199.8 animals with a standard error of 21.95 (Table 5). Research vessel data yielded mean

---

[17] Parks, W.W. 1984. Effects of various sighting factors on estimates of sizes of dolphin schools in the eastern tropical Pacific Ocean.

estimates that were similar to but statistically significantly less than aerial estimates (Parks 1984)[17]. Tuna vessel data yielded estimates that were more than twice as large as aerial estimates. These differences between tuna vessel and aerial data were evident when the data were stratified by year (Table 6), area (Table 7), or species (Table 8). Holt and Powers (1982) found similar results when they compared observer estimates for the 1979 research ships, aerial and tuna vessel data collected approximately simultaneously in the calibration area (Table 17-Holt and Powers 1982).

Holt and Powers (1982) discussed sources of possible biases in aerial, research vessel and tuna vessel data. These included errors in the estimate of an individual school's size (measurement bias) and in the sample of schools available (sampling bias). They examined data from all three platforms for effects of measurement and sampling biases and concluded that use of aerial data was appropriate. This was based upon the observations that mean school size estimates of observers correlated closely with the mean photographic counts. The means of the observer estimates and photographic counts for a sample of 15 schools taken during the 1979 aerial survey were very close (344 and 307 animals, respectively). However, sample size was small and the variabilities between and within individual observer estimates were large.

Since 1979, several experiments have been conducted to further study school size biases. Allen et al. (1980)[9] investigated the relationships between aerial and shipboard observer estimates and photographic counts. Scientists made school size estimates from a helicopter and from the deck of a tuna vessel. The schools were photographed from the air and then captured in the vessel's net. Estimates of animals released (backdown counts) were made for comparison with visual estimates. The median school size estimates for the shipboard observers and of the helicopter-based observer of all schools captured were very close to the median backdown count. However, as noted for the 1979 data, the individual variabilities between and among observers were very large (Table 7 in Allen et al. 1980)[9].

Finally, analyses of data collected during an aerial experiment in 1980 suggested school size comparisons were not significantly different from photographic counts for schools of 200 or fewer animals, although observers tended to underestimate school size for very large schools (Clark 1983[10], Scott et al. 1984[11]). The relationships between visual estimates and photographic counts varied greatly among observers such that no common relationship existed (Clark 1983)[10].

In summary, photographic evidence generally indicated that aerial observers can estimate mean school sizes for small schools, but their estimates of large school sizes may be biased. However, the evidence that observers underestimate sizes of large schools is based upon estimates of three observers; aerial observers in other studies overestimated school sizes (Wartzok and Ray 1975).

A major concern is that because airplane coverage is restricted to the inshore area, aerial data may not be representative of the ETP. Analyses by Holt and Powers (1982) did not indicate that school size differed by area for tuna vessel data. Using additional data, Parks (1984)[17] found that school sizes differed significantly by area for tuna vessel data but not for research vessel data.

Several studies which have investigated the occurrence of measurement and sampling errors for research vessel data indicate that research vessel data are susceptible to the same biases as aerial data. Allen et al. (1980)[9] indicated that scientists participating in a research cruise aboard a tuna vessel could estimate school sizes as accurately as an aerial observer aboard an accompanying helicopter. However, viewing dolphins from aboard ships is more difficult than from an airplane. Thus shipboard observers may not detect submerged animals as well as aerial observers, especially during adverse sighting conditions. This may account for the smaller school size estimates from research vessel data than from aerial data.

Few data exist to examine either measurement or sampling biases for tuna vessel observer data. Although the Allen et al. (1980)[9] experiment was conducted aboard a tuna vessel, their results are not comparable to estimates received from observers aboard fishing vessels. The estimates were collected during research operations, observers were either experienced or were familiar with the study objectives, observers were aware of estimates made by other observers for schools detected previously, and estimates were made for relatively small school sizes compared to those estimates available from tuna vessels (mean school size for the 30 captured schools was 290 animals).

Cologne and Holt (1984)[6] compared school size estimates from observers with tuna vessel experience (TVE) and those with research vessel experience (RVE) collected during research vessel cruises in 1982 and 1983. Although school size estimates for TVE and RVE teams were not significantly different during either year, the vessels operated in a research mode and the TVE observers may not have been representative of the overall pool of tuna vessel observers. The TVE observers were not randomly selected for the cruise but were selected because they had considerable experience (the 6 observers had collectively completed 30 trips aboard tuna vessels) and were available. Their school size estimates while aboard tuna vessels were significantly lower than the school size estimates of all tuna vessel observers (Cologne and Holt 1984)[6].

Finally, Hammond and Laake (1983) reported annual relative estimates of abundance using data from tuna vessel observers. The estimates of school size from observers steadily declined from 1977 to 1981 while relative estimates of density remained approximately constant. They suggested that there was no indication that school size had actually decreased, but the decrease in school size estimates may have occurred due to improved training techniques which reduced measurement error.

The downward trend in mean school size estimates continued through 1983 (Table 6). The magnitude of the decrease was substantial, but statistical significance was not indicated at the 5% probability level by an ANOVA (Parks 1984)[16]. However, more comprehensive tests are required to investigate this complex problem. Nonetheless, the occurrence of the trend indicates that the tuna vessel observer estimates may have been positively biased for the earlier years, their present estimates may be negatively biased, or area fished may have shifted over time; therefore, the accuracy of the estimates cannot be determined.

Finally, school size estimates from tuna vessel data may be biased because observers must depend upon crew members, who search for dolphins through the 25X glasses, to notify them of the presence of dolphin schools. Because the crew selectively search for schools that are associated with tuna, schools without tuna may not be approached to obtain an estimate of school size or species identification. If school size or species are correlated with the presence of tuna, the mean estimate of target school size would be biased.

SPECIES/STOCK AREAS INHABITED (A_k, A_{ik}, A_{ijk})

The area inhabited by each target species (Table 9) used to calculate the population abundance estimates were those defined by Au et al. (1979)[18]. As of 1979 boundaries for each target species represented the extent of the known range of the stocks during all seasons and years determined using all available data. Maps depicting species boundaries for the inshore, northern offshore, and southern offshore areas are presented by Holt and Powers (1982).

Perrin et al. (1983) reviewed all available sightings data gathered through 1983 and extended the known ranges of some species. However, neither Au et al. nor Perrin et al. addressed seasonal or annual variations. Recent studies (Au and Perryman 1984[19], Polacheck 1983, Reilly 1984[20]) indicate seasonal and annual movements may be large and that the area occupied at any one time may be smaller than the known range. In fact, for some species, the 1979 boundaries may be large compared to the area occupied at the time of the surveys. Use of ranges extended beyond the 1979 boundaries may severely bias the population estimates because the research ship surveys concentrated survey effort in the most central portion of the 1979 range, and little effort exists in the outer boundary areas. Therefore, the 1979 species boundaries were used in these analyses.

Dolphin species in the ETP have been partitioned into several stocks (Perrin 1975, Perrin et al. 1979), where a stock is defined as a species subgroup which occupies a distinct oceanographic region and differs morphologically from other subgroups of the same species. The area inhabited by each dolphin stock of each target species was determined by Perrin et al (1984)[8].

---

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

[19]Au, D. and W.L. Perryman. 1984. Dolphin habitats in the eastern tropical Pacific. ms

[20]Reilly, S.B. 1984. Seasonality of dolphin distribution in the eastern tropical Pacific, from tuna vessel relative encounter rates. ms.

Some stocks of the same species overlap geographic areas (denoted by A'_{ijk} in equation 1). These overlapping stocks include (1) coastal and northern spotted, (2) eastern and whitebelly spinner, and (3) Baja Nertic and northern common dolphins. The relative number of dolphins of each overlapping stock in each statistical area (denoted by P'_{ijk} in equation 1) was calculated (Table 10) using data provided by Perrin et al. (1984)[8].

For overlapping stocks of coastal and offshore spotted dolphins, Perrin et al (1984)[8] defined a coastal strip within 185 km (100 nm) of shore (see Figure 11 of their report). The relative proportions of the two stocks within this area were calculated as the average of their relative abundance (percent occurrence) in each successive 18.5 km (10 nm) band from the coast. They also determined the relative frequency of eastern and whitebelly spinner dolphins in each 5° square of overlapping distribution (Figure 18 of their report). The relative proportion of each spinner stock in the area of overlap was calculated as the average of the 5° square relative frequencies weighted by the area (km^2) of each square. Relative proportions were calculated for the three statistical areas by prorating squares located on boundary lines. Few data were available to determine relative proportions of the overlapping Baja Nertic and northern common dolphins. Therefore, population estimates were calculated for both stocks combined in this area.

POPULATION ABUNDANCE ESTIMATES

In the preceding sections, several estimates for each of the variables required to calculate population abundances (equation 1) were discussed and an appropriate estimate(s) was chosen for each variable. Population estimates were calculated using: (1) school density estimates (D_k) determined for the inshore area using aerial data not adjusted for sun or sea state effects and for the offshore areas using research ship "adjusted LT" estimates (Table 2), (2) proportion of target schools (P_t) using pooled aerial and research ship data adjusted by the inverse of log-school size (Table 3), (3) proportion of each species in the target group (P_{ik}) using research ship data adjusted by the inverse of log-school size and unweighted and weighted by the relative density in 5° squares using tuna vessel data (Table 4), (4) mean school size (S_t) using aerial data adjusted by the inverse of log-school size (Table 5), (5) area inhabited by all species in each statistical area (A_k), by each species in each statistical area (A_{ik}), by each stock of each species in each statistical area (A_{ijk}), and by each overlapping stock in each statistical area (A'_{ijk}) (Table 9), and (6) proportion of each overlapping stock in each overlapping area in each statistical area ($\hat{P}'_{ijk}$) (Table 10).

Population size estimates were largest for spotted dolphins and smallest for striped dolphins (Table 11). Abundance estimates of spotted dolphins ranged from 3.1 to 3.5 million animals for unweighted and weighted proportions, respectively. Estimates of striped dolphins, however, were only 1.3 and 1.1 million animals for unweighted and weighted species proportions, respectively. Estimates of spotted and and spinner dolphins were larger when calculated with weighted species proportions than those calculated with unweighted proportions, while estimates of common and striped dolphins were smaller when calculated with weighted species proportions than those calculated with unweighted proportions.

COMPARISON WITH PREVIOUS ESTIMATES OF ABUNDANCE

Population abundance estimates for the ETP dolphins were made for data collected in 1974 (SWFC 1976)[1] and in 1979 (Holt and Powers 1982). Holt and Powers compared their estimates with the 1974 data. Generally, the estimates in this study were calculated using data similar to those used in the 1979 analyses. Specifically, both the 1979 and the present estimates used density estimates from research platform data, school size and species proportion estimates corrected for sighting bias, and the 1979 area inhabited by the target species. However, population estimates for the present assessment incorporate information and analyses not available in 1979:

1. LT estimates were calculated for ship data to estimate offshore density; in 1979 only relative detection rates were used.

2. Density estimates calculated for the offshore area were adjusted for sea state effects.

3. Vessel survey coverage in both inshore and offshore areas was substantially increased from the 1979 estimates.

4. Species proportions were calculated using research ship data; in 1979 proportions were calculated using data from research vessels and tuna vessels.

5. Species proportions were calculated unweighted and weighted by rates of detecting animals in 5° strata; in 1979 the data were not weighted.

6. Species proportions were calculated using estimates of individual animals weighted by school size; in 1979 species proportions were calculated using estimates of the proportion of dolphin schools.

CONCERNS ABOUT POPULATION ESTIMATES

Although the population estimates in this study incorporate new data and techniques from those used in 1979, many of the same problems identified by Holt and Powers (1982) are still relevant and others have been identified.

1. Data Sources: The population estimates presented here are not absolute estimates for any point in time but are "average" estimates for the years 1977-1983. Annual changes in population sizes can not be determined within these years.

2. Estimation of School Density: The fit of the Fourier series model to the data was marginal for strata that had "spiked" sighting distributions at the origin. Density estimates were positively or negatively biased depending upon the relationship of the spike to the true underlying distribution. Sun glare effects may negatively bias the density estimates. Measurement errors were evident for sighting angles and distances made from ships and, although a data smoothing technique was used, estimates may be biased depending upon the relationship between the correction made and the severity of the recording errors. Ship data for all years were calibrated to aerial

data using the 1979 calibration data; the calibration may be biased if the relationship observed between aerial and ship data in 1979 was not representative of all years. The sensitivity of the estimates to each of these factors has not been determined.

3. School Size Estimation: Individual observer variability in estimating school sizes is great, regardless of platform used. A "calibration" factor, using aerial photography, is needed for each observer on each platform and the observer must be "recalibrated" periodically. Generally, the mean estimate of all observers' estimates was a much better predictor of true school size than was any one observer's estimate. Therefore, future surveys should obtain the maximum number of independent school size estimates possible for each school.

4. Proportions of Species: Problems associated with estimation of proportions of species are similar to those of estimating school size. Few data exist to determine the accuracy of observers' abilities to estimate proportion of each species in a school. Aerial photography must be used in future surveys to investigate estimates of species proportions.

5. Area Inhabited: The historical ranges of the ETP target species, as known in 1979, were used as approximations to the actual areas inhabited during the surveys. Additional investigations, accounting for factors such as seasonal movements, are needed to further determine these areas.

SUMMARY

Estimates of population sizes of dolphins taken incidentally by the ETP tuna purse seine fisheries were calculated from aerial, research vessel and tuna vessel data collected from 1977 through 1983. The estimates were calculated as a product of school density, mean school size of all dolphin species that are fished (target schools), proportions of target species of all dolphins in the ETP, proportion of each species in the target schools, and area inhabited. Estimates were calculated in inshore, northern offshore, and southern offshore areas and summed to determine total numbers in the ETP.

Maximum estimates of population sizes of spotted, spinner, common and striped dolphins in the ETP were 3.5, 1.7, 1.4, and 1.3 million animals, respectively.

Estimates calculated in this paper were very similar to those calculated during an earlier assessment. Although more refined techniques and more comprehensive data were used in this assessment, several problems were identified which still need further investigation.

LITERATURE CITED

Bowditch, N. 1966. American practical navigator, an epitome of navigation. U.S. Naval Oceanographic Office. H. O. Pub. No. 9. Washington, DC. 1524pp.

Burnham, K.P., D.R. Anderson, and J. L. Laake. 1980. Estimation of density from line transect sampling of biological populations. J. Wildl. Manage. Monogr. No. 72. 202pp.

Butterworth, D.S. 1982. On the functional form used for g(y) for Minke whale sightings, and bias in its estimation due to measurement inaccuracies. Rep. Int. Whal. Commin. 32:883-888.

Crain, B.R., K.P. Burnham, D.R. Anderson and J.L. Laake. 1978. A Fourier series estimator of population density for line transect sampling. Utah State University Press, Logan. 25pp.

Hammond, P.S. (ed). 1981. Report on the workshop on tuna-dolphin interactions. Inter-Amer. Trop. Tuna Comm. Spec. Rept. No. 4. 259pp.

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, 1977-1981. Rep. Int. Whal. Comm. 33:565-588.

Holt, R.S. 1983a. Report of eastern tropical Pacific research vessel marine mammal survey, May 15 - August 3, 1982. NOAA-TM-NMFS-SWFC-29. 151pp.

Holt, R.S. 1983b. Report of porpoise experiment testing detection of on-track schools (PET DOTS), March 7-April 5, 1981. NOAA-TM-NMFS-SWFC-27. 80pp.

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. NOAA-TM-NMFS-SWFC-23. 95pp.

Laake, J.L. 1981. Abundance estimation of dolphins in the eastern tropical Pacific with line transect sampling. Hammond, P.S. (ed). Report on the workshop on tuna-dolphin interactions. Inter-American Trop. Tuna Comm. Special Rept. No. 4. 56:96.

Perrin, W.F. 1975. Distribution and differentiation of populations of dolphins of the genus Stenella in the eastern tropical Pacific. J. Fish. Res. Bd. Canada 32(7):1059-1067.

Perrin, W.F., P.A. Sloan and J.R. Henderson. 1979. Taxonomic status of the "southwestern" stocks of spinner dolphin Stenella longirostris and spotted dolphin S. attenuata. Rep. Int. Whal. Commin 29: 175-184.

Perrin, W.F., M.D. Scott, G.J. Walker, F.M. Ralston and D.W.K. Au. 1983. Distribution of four dolphins (Stenella spp. and Delphinus delphis) in the eastern tropical Pacific, with an annotated catalog of data sources. NOAA-TM-NMFS-SWFC-38, 65pp.

Polacheck, T. 1983. The relative abundance of dolphins in the eastern tropical Pacific based on encounter rates with tuna purse seiners. PhD dissertation. Univ. of Oregon. 444 pp.

Seber, G.A.F. 1973. The estimation of animal abundance. Hafner, New York. 506pp.

Table 1. Research ship cruises conducted each year in the eastern tropical Pacific Ocean from 1977 through 1983.

Year	Number Cruises	Survey Season	Principal Area Surveyed
1977	3	Jan-Feb; Nov-Dec	western offshore boundary; central northern offshore
1979	2	Jan-Mar	calibration area, equator; eastern northern offshore
1980	2	Jan-Mar	10°N latitudinal; calibration area
1982	1	May-Jul	10°N latitudinal; calibration area
1983	1	Jan-Apr	10°S latitudinal; calibration area

Table 2. Density of dolphin schools in the inshore and offshore areas.

Area	Density ($\hat{D}$) (Schools/1000 km^2)	Standard error $\hat{D}$
Inshore	4.18	0.902
Offshore	2.04	0.263

Source: Holt (1984b)[5]

Table 3. Proportion of target schools in all identified dolphin schools for each year for aerial and research ship data. Proportion weighted by inverse of log-school size.

Year	Proportion Target Schools (P_t)	S.E. P_t	Total Schools
Aerial Surveys			
1977[a]	0.5264	0.1436	39
1979	0.6414	0.0634	125
Pooled Aerial	0.6141	0.0634	164
Ship Surveys			
1977	0.7598	0.0366	163
1979	0.6846	0.0412	248
1980	0.8435	0.0351	165
1982	0.8364	0.0330	103
1983	0.8389	0.0297	125
Pooled Ships	0.7758	0.0175	804
All Data	0.7484	0.0181	968

[a]1977 PBY Data

Table 4. Species proportions for research vessel and tuna vessel data in inshore, northern offshore, and southern offshore areas. Values are given as both weighted and unweighted averages of the proportions within 5-degree strata. All sightings are weighted by the inverse of log-school size.

	Inshore Area		Northern Offshore Area		Southern Offshore Area	
Species	Proportion	Standard Error	Proportion	Standard Error	Proportion	Standard Error
Unweighted Research Vessel:						
Spotted	0.38	0.039	0.51	0.048	0.26	0.085
Spinner	0.16	0.028	0.26	0.029	0.30	0.116
Common	0.26	0.039	0.12	0.054	0.10	0.059
Striped	0.19	0.029	0.09	0.039	0.30	0.090
Fraser's	0.01	0.003	0.02	0.023	0.04	0.071
Weighted Research Vessel:						
Spotted	0.48	0.037	0.52	0.049	0.24	0.086
Spinner	0.19	0.026	0.25	0.028	0.29	0.118
Common	0.18	0.034	0.12	0.055	0.13	0.061
Striped	0.14	0.025	0.09	0.038	0.31	0.094
Fraser's	0.01	0.003	0.02	0.022	0.03	0.074
Unweighted Tuna Vessel:						
Spotted	0.61	0.009	0.70	0.011	0.63	0.024
Spinner	0.15	0.006	0.20	0.008	0.16	0.021
Common	0.21	0.009	0.08	0.011	0.12	0.018
Striped	0.03	0.002	0.01	0.003	0.08	0.010
Fraser's	0.001	0.001	0.01	0.002	0.01	0.001
Weighted Tuna Vessel:						
Spotted	0.66	0.007	0.71	0.010	0.62	0.023
Spinner	0.17	0.005	0.20	0.007	0.16	0.020
Common	0.15	0.007	0.06	0.010	0.12	0.017
Striped	0.02	0.001	0.01	0.002	0.08	0.010
Fraser's	0.001	0.001	0.01	0.002	0.01	0.001

Source: Barlow and Holt (1984)[7]

Table 5. Weighted and unweighted mean school size and number of schools detected from tuna vessels, airplanes and research ships from 1977 through 1983. Weighting is by inverse of log-school size.

Platform	Number Schools	Unweighted Mean School Size ($\bar{s}$)	S.E. $\bar{s}$	Unweighted Mean School Size ($\bar{s}$)	S.E. $\bar{s}$
Tuna vessel[a]	19,364	727.2	7.7	564.2	6.5
Research vessel	612	152.5	8.5	119.9	7.1
Aerial	133	246.6	25.7	199.8	22.0

[a]Schools detected from helicopter omitted.

Table 6. Weighted and unweighted mean school size and number of schools detected from tuna vessels, aerial and research ship data stratified by year. Weighting is by inverse of log-school size.

Platform	Number Schools	Unweighted Mean School Size ($\bar{s}$)	S.E. $\bar{s}$	Unweighted Mean School Size ($\bar{s}$)	S.E. $\bar{s}$
Tuna vessel[a]					
1977	2,729	1130.5	29.4	895.9	25.6
1978	2,221	930.4	25.2	737.9	22.1
1979	5,065	665.5	12.9	522.8	11.0
1980	2,749	690.7	21.3	527.5	17.7
1981	2,794	579.4	15.9	459.0	13.4
1982	2,153	601.9	18.9	482.2	16.0
1983	1,653	451.0	17.2	347.5	14.2
Research vessel					
1977	81	244.9	41.3	176.7	34.0
1979	194	161.6	13.7	128.2	11.9
1980	146	95.0	7.0	83.0	6.3
1982	74	199.9	27.3	157.2	23.6
1983	96	112.8	13.4	92.3	11.4
Aerial					
1977	56	245.5	35.3	201.0	31.5
1979	77	247.4	34.9	199.0	30.2

[a]Schools detected from helicopter omitted.

Table 7. Weighted and unweighted mean school size and number of schools detected from tuna vessel, aerial and research ship data stratified by area for data collected from 1977 through 1983. Weighting is by inverse of log-school size.

Platform	Number Schools	Unweighted Mean School Size ($\bar{s}$)	Unweighted S.E. $\bar{s}$	Unweighted Mean School Size ($\bar{s}$)	Unweighted S.E. $\bar{s}$
Tuna vessel[a]					
Calibration	6,627	723.5	12.8	570.7	10.9
Inshore	10,337	692.9	10.0	540.0	8.4
Offshore, North	8,493	765.0	12.6	588.0	10.6
Offshore, South	534	790.6	40.1	660.6	35.6
Research Ship					
Calibration	235	171.5	12.2	137.8	10.8
Inshore	342	153.6	9.8	123.5	8.5
Offshore, North	214	130.4	11.8	104.6	9.8
Offshore, South	56	230.5	54.0	156.5	42.7
Aerial					
Calibration	57	236.6	41.6	189.8	34.2
Inshore	112	238.2	26.7	193.2	23.3
Offshore, North	21	291.2	69.9	236.6	62.6

[a]Schools detected from helicopter omitted.

Table 8. Weighted and unweighted mean school size and number of schools detected from tuna vessels, aerial and research ship data stratified by species types for data collected from 1977 through 1983. Weighting is by inverse of log-school size.

		Unweighted		Unweighted	
Platform	Number Schools	Mean School Size ($\bar{s}$)	S.E. $\bar{s}$	Mean School Size ($\bar{s}$)	S.E. $\bar{s}$
Tuna vessel[a]					
Spotted	9,626	642.2	9.4	509.0	8.0
spinner	1,270	589.5	23.9	460.0	20.3
Striped	798	244.6	22.8	170.6	16.6
Common	3,726	832.2	22.7	600.8	18.6
Spotted/ Spinner[b]	13,256	741.1	8.7	596.6	7.5
Spotted/ Unidentified	19,036	615.4	6.8	464.9	5.7
Research vessel					
Spotted	169	144.9	13.7	117.7	11.7
Spinner	49	168.7	35.3	130.7	29.2
Striped	141	59.8	4.7	53.4	4.0
Common	96	176.2	24.31	138.4	20.4
Spotted/ Spinner[b]	286	185.0	12.4	149.8	10.8
Spotted/ Unidentified	372	155.2	10.1	120.7	8.6
Aerial					
Spotted	29	235.3	45.3	202.3	40.4
Spinner	12	467.3	161.1	359.1	143.9
Striped	8	124.9	27.6	113.5	27.4
Common	59	241.0	29.7	201.9	27.4
Spotted/ Spinner[b]	33	272.9	52.2	232.4	46.4
Spotted/ Unidentified	106	145.9	20.5	109.0	16.7

[a]Schools detected from helicopter omitted.
[b]Includes any school with identified spotted and/or spinner dolphins.

Table 9. Area inhabited (km^2) by various species/stocks for the inshore, northern offshore and southern offshore areas.

Species/Stock	Inshore Area (km^2)	Northern Offshore Area (km^2)	Southern Offshore Area (km^2)
<u>Spotted</u>			
Coastal, non-overlapping	106,032	21,723	
Northern offshore, non-overlapping	3,897,201	7,660,438	385,637
Coastal and northern, offshore overlapping	765,353	173,792	
Southern offshore, non-overlapping	932,108		2,210,247
Coastal and southern offshore, overlapping	82,901		
Total	5,783,595	7,855,853	2,595,884
<u>Spinner</u>			
Costa Rican	194,172		
Northern whitebelly, non-overlapping	38,222	2,164,701	
Eastern and northern whitebelly overlapping	4,384,243	6,540,500	
Southern whitebelly non-overlapping	276,021		2,698,819
Eastern and southern whitebelly overlapping	881,372		99,430
Total	5,774,031	8,705,200	2,798,250
<u>Common</u>			
Northern tropical, non-overlapping	432,351	1,498,747	
Northern tropical & Baja Neritic overlapping		580,915	
Guerrero	147,606		
Central tropical	3,823,997	3,960,572	
Southern tropical	1,260,052	450,048	487,296
Total	5,664,005	6,490,282	487,296
<u>Striped</u>			
Northern tropical	768,327	1,110,844	
Southern tropical	4,983,133	5,542,444	3,405,350
Total	5,751,460	6,553,289	3,405,350
Fraser's[a]	5,783,595	7,855,953	2,595,884
All species/stocks	6,002,470	9,586,710	3,681,053

Source: Modified from Holt and Powers (1982) and Perrin et al. (1984).[8]

[a]Used total spotted area for Fraser's area inhabited.

Overlap by Species/Stock	Inshore Area			Northern Offshore Area			Southern Offshore Area		
	Proportion	Standard error	Number strata	Proportion	Standard error	Number strata	Proportion	Standard error	Number strata
Spotted									
Northern Offshore	0.667	0.090	8	0.740	0.108	8	0	0	0
Coastal	0.260	0.074	16	0.260	0.108	8	0	0	0
Southern Offshore	0.072	0.061	8	0	0	0	0	0	0
Spinner									
Northern Whitebelly	0.322	0.059	23	0.739	0.058	30	0	0	0
Eastern	0.518	0.066	24	0.261	0.058	30	0.075	0	1
Southern Whitebelly	0.159	0.070	7	0	0	0	0.925	0	1

[a]Description of stock boundaries given by Perrin et al. (1984).

Table 10. Proportion of dolphins of each stock within areas inhabited with another stock of the same species (overlapping areas of stock distributions). Number strata for stocks of spotted dolphins is number of overlapping 1.85 km (0.1 nm) wide coastal bands occupied and for stocks of spinner dolphins the number of overlapping 5° geographic squares occupied.[a] Proportions calculated using tuna vessel data.

Table 11. Estimates of population sizes (in thousands of animals) by stock for target species using pooled research vessel species proportion data calculated from 1977 through 1983. Values are given as both unweighted and weighted averages of the proportions within 5-degree strata. All sightings were weighted by the inverse of log-school size to calculated mean school size and species proportions. Standard errors are in parenthesis.

Species/Stock	Unweighted		Weighted	
Spotted				
Northern Offshore	2,533.3	(467.8)	2,837.8	(526.2)
Coastal	90.1	(26.8)	110.9	(33.0)
Southern Offshore	476.7	(118.6)	520.5	(127.9)
Total	3,100.1	(567.9)	3,469.1	(643.0)
Spinner				
Costa Rican	19.5	(6.0)	23.2	(6.7)
Northern Whitebelly	764.7	(155.1)	774.7	(155.7)
Eastern	419.2	(107.0)	465.0	(116.7)
Southern Whitebelly	436.5	(151.4)	446.6	(155.6)
Total	1,639.9	(318.9)	1,709.5	(330.9)
Common				
Northern/Baja Neritic	30.3	(14.8)	30.3	(15.0)
Northern Tropical	150.2	(45.4)	128.1	(43.1)
Guerrero	24.6	(7.2)	17.0	(5.4)
Central Tropical	843.1	(221.2)	647.3	(180.0)
Southern Tropical	341.6	(96.4)	309.7	(89.9)
Total	1,389.8	(349.0)	1,132.4	(293.3)
Striped				
Northern Tropical	134.4	(35.4)	110.2	(30.1)
Southern Tropical	1,133.9	(256.0)	987.75	(226.9)
Total	1,268.3	(288.0)	1,098.0	(253.0)

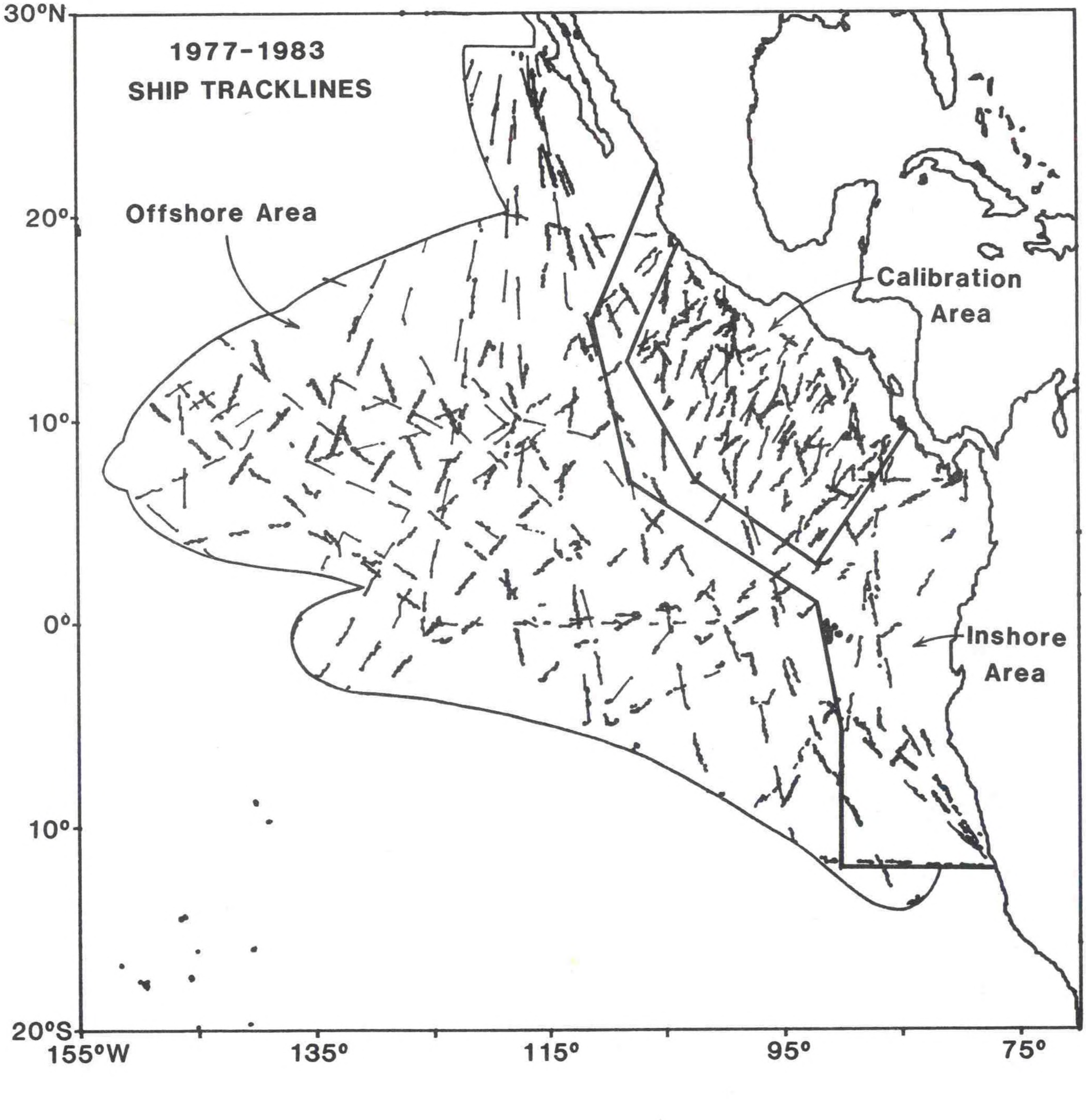

Figure 1. Map of study area showing research ship tracklines searched from 1977 through 1983.

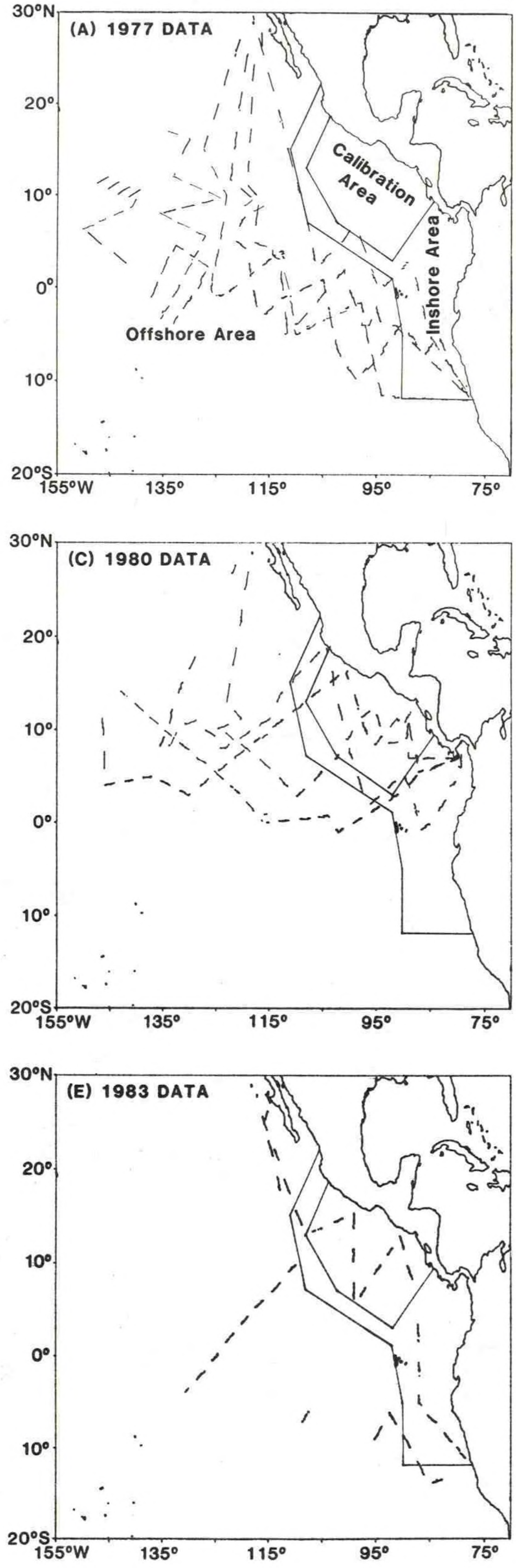

Figure 2. Tracklines searched from research vessel during each year from 1977 through 1983.

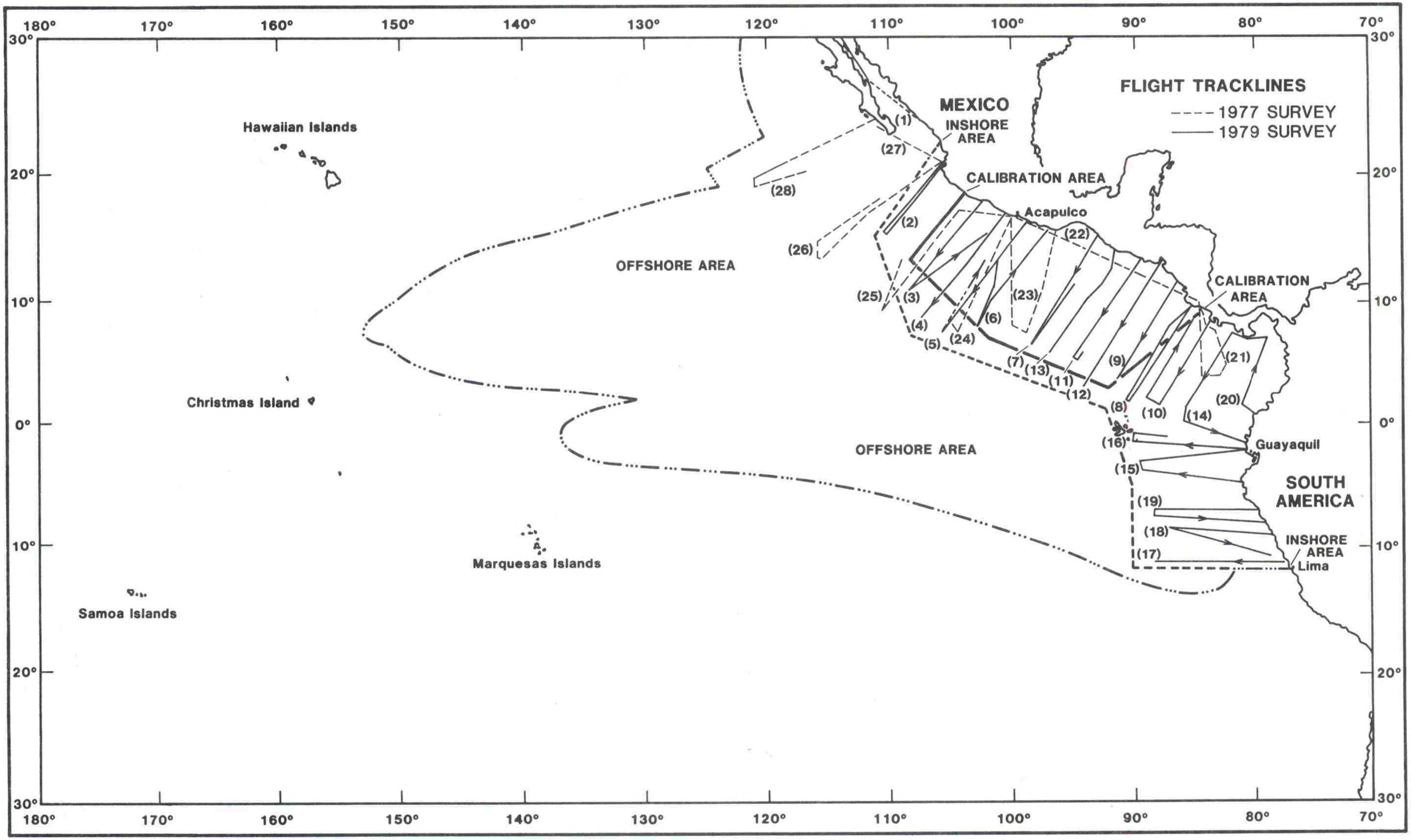

Figure 3. Tracklines searched from airplanes during 1977 and 1979.

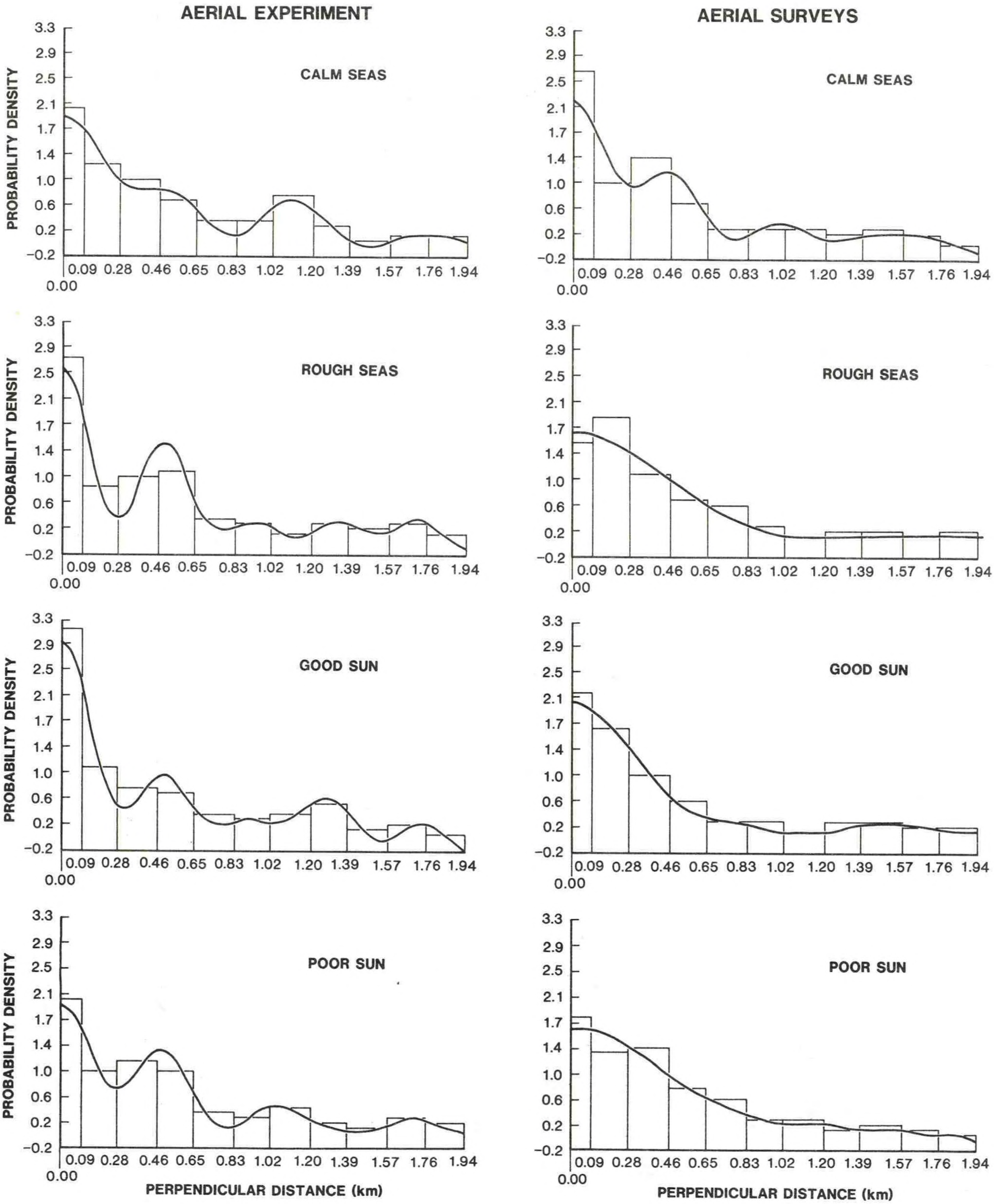

Figure 4. Fit of Fourier series model to data collected during the aerial experiment and aerial surveys during calm and rough seas, good and poor sun conditions, and all conditions.