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STATUS OF POPULATIONS OF SPOTTED DOLPHIN, *STENELLA ATTENUATA*, AND SPINNER DOLPHIN, *S. LONGIROSTRIS*, IN THE EASTERN TROPICAL PACIFIC

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Abstract

This paper reports progress on assessing the status of three populations of two species of dolphins of the genus *Stenella* involved in the purse-seine fishery for tuna in the eastern tropical Pacific Ocean. The types of data used, the methods used to collect and analyse them and the main assumptions and other sources of uncertainty in the study – as well as the measures taken in some cases to account for these – are summarized.

The size of the population of offshore spotted dolphins (*S. attenuata* sub-species) in 1974 was first estimated to be 2.3-4.9 million, based on an aerial survey. The annual capacity for increase (total births minus natural deaths) was estimated to be 1.4-4.0 %, and the annual rate of observed incidental mortality, based on an estimated kill in 1974 of 79 900-97 300 animals, was estimated to be 1.6-4.2 %. Comparison of these rates indicated that the number of spotted dolphins killed in the fishery in 1974 was at or near the population available after natural mortality. Revised estimates for 1974 give a population size between 3.1-3.5 million dolphins (a preferred, central estimate from a larger range), of which 72 000 were killed in the tuna fishery – this gives an incidental fishing mortality rate of 2.1-2.3 %. This rate was compared with the annual capacity for increase as originally estimated and with an independently figured estimate of the incidental mortality rate the population could tolerate. The population size of a second dolphin involved in the tuna fishery, the eastern spinner dolphin (*S. longirostris* sub-species) was given in revised estimates to be between 1.1-1.2 million (also a preferred, central estimate). The number of animals killed incidentally in 1974 was estimated to be 21 000 animals. The resulting incidental mortality rate, 1.8-1.9 %, was compared with an estimated annual reproductive rate of 8.3 %, the low value of which indicates no apparent response of the population to exploitation. For both the offshore spotted dolphin and the eastern spinner dolphin, the revised estimates indicate that if the sizes of their populations were increasing or decreasing under the levels of fishing mortality in 1974, they were probably doing so at low rates. The impact of the tuna fishery on the whitebelly spinner population (*S. longirostris* sub-species) has not yet been assessed. There is a need for increased acquisition of relevant biological and catch data, expanded surveys of population size and estimation of certain life history parameters.

Résumé

Les auteurs rendent compte des progrès accomplis dans l'évaluation de l'état de trois populations de deux espèces de dauphins du genre *Stenella* touchées par la pêche des thonidés à la senne coulissante dans le secteur est du Pacifique tropical. Un résumé porte sur les types de données utilisées ainsi que leurs méthodes de rassemblement et d'analyse, les principales hypothèses et les autres sources d'incertitude, de même que les mesures prises dans certains cas pour en tenir compte.

La population de dauphins tachetés (sous-espèce de *S. attenuata*) du large a d'abord été estimée en 1974 à 2,3-4,9 millions d'animaux d'après une enquête aérienne. La capacité annuelle d'accroissement (nombre total des naissances moins nombre de morts naturelles) était estimée à 1,4-4 % et le taux annuel de la mortalité accidentelle observée, fondé sur une estimation des morts de 79 900-97 300 animaux en 1974, était évalué à 1,6-4,2 %. La comparaison de ces taux indique que le nombre de dauphins tachetés tués dans les pêches en 1974 était égal ou presque égal à l'excédent de production. La révision des estimations pour 1974 fait apparaître une taille de population de 3,1-3,5 millions de dauphins (estimation centrale préférentielle dans une gamme plus large), dont 72 000 étaient tués dans les opérations de pêche au thon – ce qui donne un taux de mortalité par pêche accessoire de 2,1-2,3 %. Ce taux a été comparé à la capacité annuelle d'accroissement estimée à l'origine et avec une évaluation chiffrée, indépendante, du taux de mortalité accessoire que la population peut supporter. La taille de la population d'un second dauphin touché par la pêche au thon, le dauphin à long bec (sous-espèce de *S. longirostris*), a été indiquée, dans des estimations révisées, comme étant de 1,1-1,2 million d'animaux (ici aussi, une estimation centrale préférentielle). Le nombre de dauphins tués accessoirement en 1974 était estimé à 21 000. Le taux de mortalité accessoire qui en résulte (1,8-1,9 %) a été comparé à l'estimation du taux annuel de reproduction de 8,3 % dont la faible valeur indique que la population ne réagit apparemment pas à l'exploitation. Pour les deux espèces de dauphins, les estimations révisées indiquent que si la taille de leur population augmentait ou diminuait, compte tenu des niveaux de mortalité par capture de 1974, ces taux étaient probablement faibles. On n'a pas encore évalué l'impact de la pêche au thon sur la population de dauphins "white belly" à long bec (sous-espèce de *S. longirostris*). Il est nécessaire de rassembler un plus grand nombre de données sur la biologie et les captures, d'élargir les enquêtes sur la taille des populations et d'effectuer l'estimation de certains paramètres du cycle biologique.

Extracto

Se informa sobre los progresos realizados en la evaluación de la situación de tres poblaciones de dos especies de delfines del género *Stenella* que se capturan accidentalmente en la pesquería de cerco de atún de la parte oriental del Pacífico tropical. Se resumen los datos utilizados, los métodos empleados para recogerlos y analizarlos y las principales hipótesis y otras fuentes de incertidumbre, así como las medidas tomadas en algunos casos para tener estas últimas en cuenta.

La población de delfines moteados de media altura (subespecie de *S. attenuata*) se estimó en 1974, por primera vez, en 2,3-4,9 millones, sobre la base de un reconocimiento aéreo. La capacidad anual de aumento (nacimientos totales menos muertes naturales) se estimó en 1,4-4,0 por ciento, y el índice anual de mortalidad accidental se ha calculado en 1,6-4,2 por ciento, sobre la base de las estimaciones de los animales muertos accidentalmente en 1974 (79 900-97 300). Comparando esos índices se llega a la conclusión de que el número de delfines moteados que se capturaron en la pesquería en 1974 correspondía a la producción excedentaria o se acercaba mucho a ella. Las estimaciones revisadas correspondientes a 1974 arrojan una población de 3,1 a 3,5 millones de delfines (estimación central, preferida, obtenida a partir de una zona de distribución más amplia), de los que 72 000 resultaron muertos en la pesquería de atún, lo que da una mortalidad accidental por pesca de 2,1-2,3 por ciento. Se comparó luego ese índice con la capacidad anual de aumento tal como se había estimado originalmente y con una estimación hecha independientemente de la mortalidad accidental que la población podría tolerar. Por lo que se refiere a la población del otro delfín que se encuentra también en la pesquería de atún, el delfín hilador oriental (subespecie de *S.*

longirostris), las estimaciones revisadas de su población arrojan cifras de 1,1-2,1 millones (se trata también de una estimación central). El número de animales que murieron accidentalmente en 1974 se ha estimado en 21 000. La mortalidad accidental consiguiente (1,8-1,9 por ciento) se comparó con un índice anual estimado de reproducción de 8,3 por ciento, que, al ser tan bajo, indica que no existe respuesta aparente de la población a la explotación. Tanto por lo que se refiere al delfín moteado como al delfín hilador oriental, las estimaciones revisadas indican que, si en 1974 la población estaba aumentando o disminuyendo por debajo de los límites de mortalidad por pesca, probablemente ese aumento o disminución era muy lento. Las repercusiones de la pesquería de atún en la población de delfín hilador de vientre blanco (subespecie de *S. longirostris*) no se han evaluado aún. Es necesario recoger más datos biológicos y de captura, hacer más reconocimientos de la población y hacer estimaciones de algunos parámetros de su ciclo vital.

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Introduction

Tuna fishermen in the eastern tropical Pacific kill dolphins incidentally in the course of their seining operations (Perrin, 1969; NOAA, 1972). About 3 years ago, we set out to assess the impact of this on the dolphin populations.

This report is a very brief summary of portions of a draft report entitled "The porpoise-tuna problem: review of research progress" (draft title), which was written at this laboratory in August-September 1974, and was made available to the public by the National Marine Fisheries Service (NMFS) in October 1974. There have since been adjustments and corrections to the material in that report, mainly because we were working with preliminary 1974 estimates that changed as the year progressed. Details of the data and analyses referred to in this paper are in the draft report. Revised 1976 estimates of 1974 figures have been used in the relevant sections and were derived from NOAA (1975).[1]

Methods

General approach

Our chief goal in assessing the impact of the fishery was to establish whether or not the populations are declining. We have done this by comparing estimated exploitation rate (number incidentally killed ÷ population size) with capacity for increase (in simplistic terms, birth rate minus natural death rate). The inputs into these 2 basic parameters are laid out in the flow diagram (Fig. 1). Incidental kill was estimated from the landings of yellowfin tuna from dolphin schools, the number of net sets, and an estimate of average kill per set. Population size was estimated from density estimates extrapolated to known range. Capacity for increase was calculated from estimates of reproductive parameters in the exploited eastern Pacific population and of natural mortality rates in the relatively unexploited western Pacific population.

Two forms of *Stenella attenuata* and 3 of *S. longirostris* exist in the eastern Pacific. The distributions and bases for separation of these forms and their relative importances in the fishery have been described previously (Perrin, 1975). We have concentrated on assessing the status of the most important form, the offshore spotted dolphin (Table 1). We also gave major attention to the eastern spinner dolphin, but have so far only estimated the exploitation rate and not the capacity for increase. For the third major form, the whitebelly spinner, we have thus far estimated only the incidental kill.

Major sources of data

Our major sources of data were the Inter-American Tropical Tuna Commission (I-ATTC), an aerial survey, and the Tunaboat Observer Program.

I-ATTC

The I-ATTC provided data on numbers of purse seine sets on dolphin schools, by vessel class, for the U.S. fleet, and on landings of tuna caught with dolphins by all nations.

Aerial Survey

An aerial survey conducted in January-February 1974 provided data on density of dolphin schools in the eastern tropical Pacific. Approximately 12 000 track miles were flown

[1] Since this report was written (1974) and revised (1976) a report of further assessments of status of *Stenella* stocks in the eastern tropical Pacific has been issued: Report of the Workshop on Stock Assessment of Porpoises Involved in the Eastern Pacific Yellowfin Tuna Fishery. Southwest Fisheries Center, Admin. Rep. LJ-76-29, La Jolla, CA, Sept. 1976.

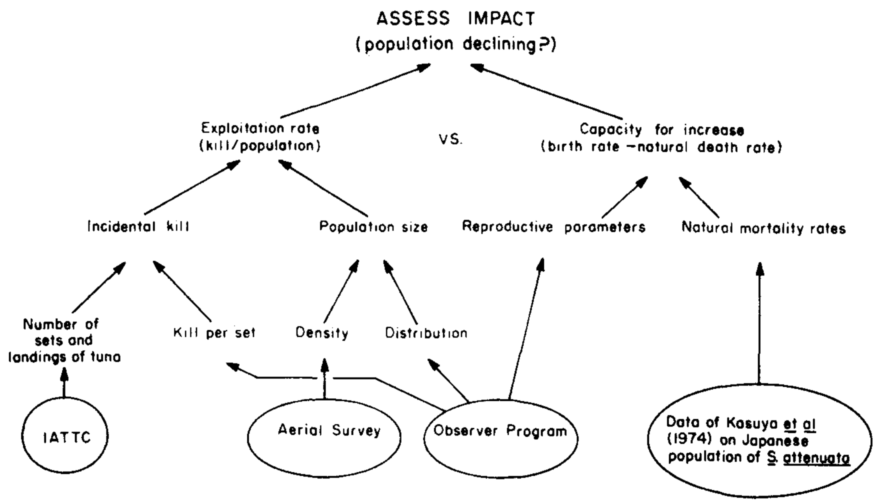

FIG. 1. – Flow diagram for assessing impact of incidental fishing mortality on dolphin populations. Major data sources circled.

in a specially modified Gruman Goose, at an average altitude of about 1 500 ft (Fig. 2). Two observers scanned ahead and to the side. The track lines were selected before the survey, independently of any knowledge of the density of dolphin schools. Range capabilities of the aircraft and locations of suitable airports constrained the choice of track lines.

Observer Program

We have had observers on purse seiners every year since 1971. The observers have collected data on numbers of dolphins killed, on their distribution, and on the sex, age and reproductive condition of a sample of the animals killed. We had observers on 5 cruises in 1971, 12 in 1972, 23 in 1973, and about 40 in 1974. We have also collected data during several cruises chartered to NMFS for gear research.

ESTIMATING INCIDENTAL KILL

Our approach in estimating the incidental kill was to extrapolate from estimates of kill per net set in our observer sample to the entire fishery, based on data from the I-ATTC (Fig. 3). We were faced with several problems in this approach:

- the structure of our sample may or may not be representative of the US fleet;
- we did not sample the non-US fleet;
- the Observer Program was effectively limited to the Commission Yellowfin Regulatory Area (CYRA) (Fig. 4) and did not sample the "outside the line" area to the west where roughly 1/3 of the tuna caught with dolphins is taken.

Adjusting for structure of the observer sample

In looking at our earlier data, we found that dolphin kill per net set is correlated with characteristics of the vessel, mainly size. Beginning in 1974 the tunaboats have been required by law to carry observers when requested, so we have been able since then to design our sample to have about the same

Table 1. Populations of spotted and spinner dolphins in the eastern Pacific, and scope of analyses reported in this working paper

Population	Involvement in fishery[1]			Assessment of status[2]				
				Exploitation rate		Capacity for increase		
	Major	Minor?	Negligible	Incidental kill	Population size	Reproductive parameters	Natural mortality	Impact assessed
Coastal spotted dolphin (*S. attenuata* subspecies)		X						
Offshore spotted dolphin (*S. attenuata* subspecies)	X			X	X	X	X	X
Costa Rican spinner dolphin (*S. longirostris* subspecies)			X					
Eastern spinner dolphin (*S. longirostris* subspecies)	X			X	X			X
Whitebelly spinner dolphin (*S. longirostris* subspecies)	X			X				

[1] Major = 1 000 killed incidentally; minor = 100s killed; negligible = 10s or fewer killed.
[2] X = estimates made in present study.

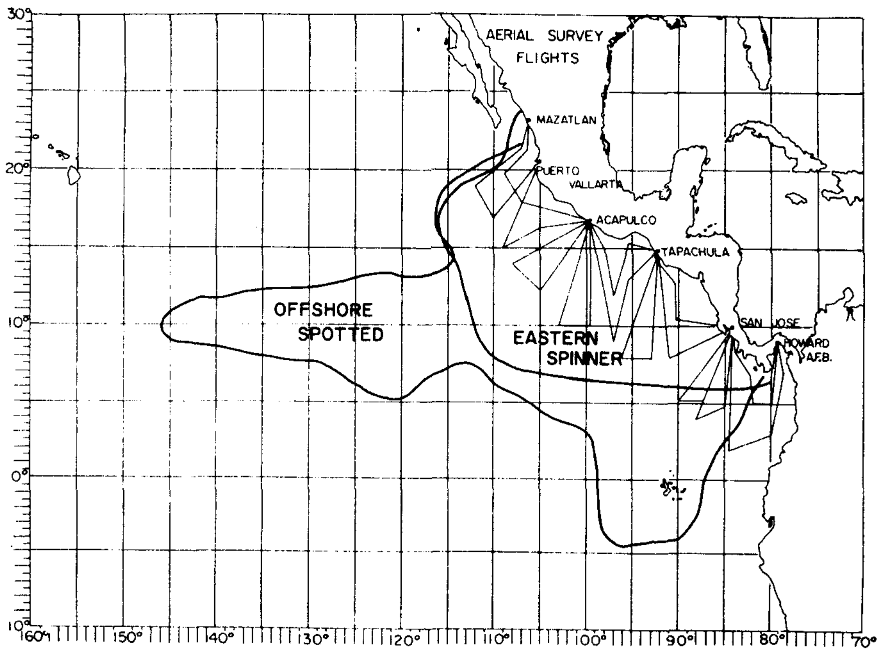

FIG. 2. – Location of track lines on the aerial survey in early 1974. Historical ranges of offshore spotted dolphin and eastern spinner dolphin from Perrin (1974).

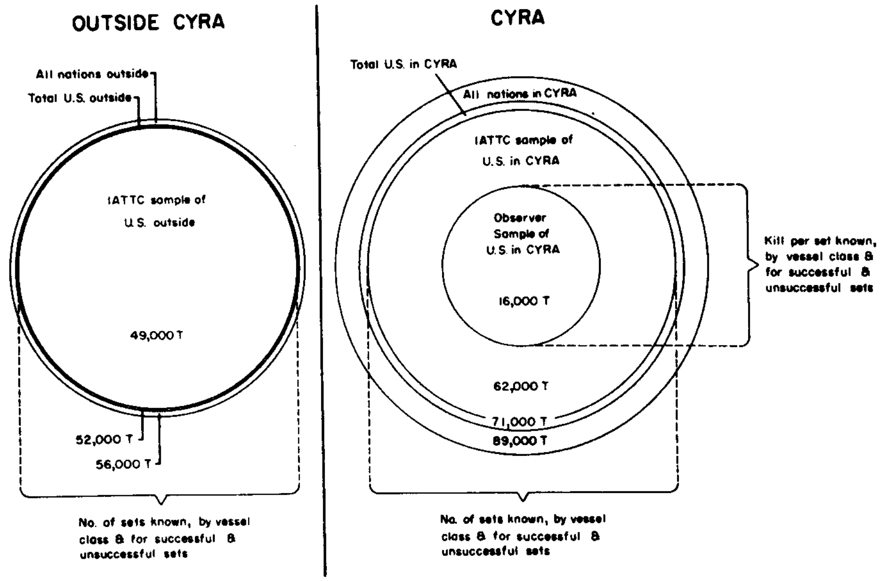

FIG. 3. – Samples used to estimate incidental kill of dolphins in the yellowfin tuna purse seine fishery in the eastern tropical Pacific. Areas of circles are proportional to landings of yellowfin tuna taken in net sets on dolphin schools in 1973. Landings data from I-ATTC.

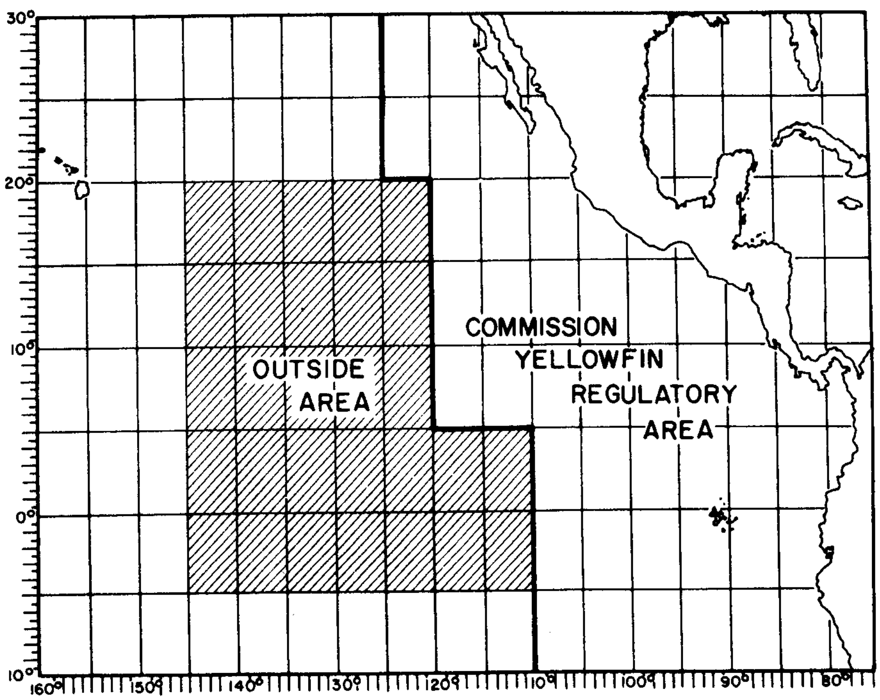

FIG. 4. – The major part of the Inter-American Tropical Tuna Commission regulatory area (CYRA) is shown above. Principal zone of "outside" fishing is also indicated.

structure as the fleet in terms of size of vessels. In the earlier years, however, carrying an observer was voluntary, and we know that some of those samples did not well represent the fleet. In 1971, for example, the sample contained proportionately more small, old vessels than did the fleet. Detailed descriptions of the samples and the fleet are in the draft progress report. We attempted to correct for this sample bias by extrapolating on the basis of kill per set for size-age classes of vessels. We used eight strata ranging from 101-200 (short) tons capacity to over 1 200 tons. We also found that dolphin kill is correlated with whether or not the net set is successful in capturing yellowfin tuna, so we stratified our extrapolating procedure also on the basis of success or failure of the set. A successful set was defined as one in which at least 0.025 ton of yellowfin tuna was taken.

Estimating non-US kill

Since we have very few kill-per-set data and no data on sets by vessel class for the non-US fleet, we simply assumed that over-all kill per set is the same as for the US fleet and extrapolated from the US sample on the basis of tons of tuna taken with dolphins.

Estimating kill outside the CYRA

Virtually no observer data were available from outside the CYRA, so we assumed for the purpose of our estimates that kill per set is the same as in the CYRA.

With this approach, we made 4 estimates of incidental kill (of all species):

(1) US kill in the CYRA
(2) kill by all nations in the CYRA
(3) US kill outside the CYRA
(4) kill by all nations outside the CYRA,

using the model

$$\hat{K}_g = \hat{C}_g \left(\sum_{i=1}^{8} \sum_{j=1}^{2} N_{ij} k_{ij} \right),$$

where

$\hat{K}_g$ = estimated kill

k_{ij} = kill per set in observer sample stratum ij

N_{ij} = number of net sets in I-ATTC sample of US landings of yellowfin from dolphins

$\hat{C}_g$ = extrapolation factor to account for landings not in I-ATTC sample of US landings

i = vessel size class

j = type of set class (successful or unsuccessful)

g = estimate [(1) to (4) above]

An approximate estimate of variance for $\hat{K}_g$ is

$$\text{var}(\hat{K}_g) = C_g^2 [\Sigma\Sigma N_{ij}^2 \text{ var}(k_{ij})]$$

and the approximate 95 % confidence interval for $\hat{K}_g$ is

$$\hat{K}_g \pm 2 \sqrt{\text{var}(\hat{K})}.$$

We broke down the total estimates (CYRA + outside) to estimates by species based on the species compositions of samples examined in the Observer Program. The estimates for the spinner dolphin for 1974 were prorated to the eastern and whitebelly populations, based on the ranges of the forms and on the relative percentages of sets in the observer sample known to have been made on each.

Estimating population size

We estimated the density of schools of the offshore spotted dolphin and eastern spinner dolphin from data collected in the aerial survey. The basic analytical tool used was line transect theory. When a school was sighted, the perpendicular distance from the track line was estimated. The manner in which the number of sightings declined with distance from the track line was used to determine how much area was effectively searched. Four basic conditions must be met in this approach:

(1) schools are distributed at random

(2) transects are placed at random

(3) probability of sighting a school decreases exponentially with distance from the track line, and

(4) probability of seeing a school directly on the track line is 1.0.

Making these assumptions, we estimated density as

$$\hat{D} = (n - 1)/2L\bar{Y},$$

where

n = number of schools sighted,

L = total track miles surveyed, and

$\bar{Y}$ = average perpendicular sighting distance, in this case about 1 mile.

Variance of the density can be estimated as

$$V(D) = \frac{\hat{D}^2}{n}\left(1 + \frac{n}{n-2} - \frac{n}{DA}\right)$$

We prorated the overall density estimates into estimates for each stock based on the proportion of the total sightings which were of that stock. We also estimated separately for mixed schools because size of single-stock components in mixed schools is different than size of single-stock schools. We estimated separately for pure spotted schools, pure eastern spinner schools, spotted in mixed schools, and eastern spinner in mixed schools.

We then estimated the total number of schools of each stock and school type by extrapolating the density to the known historical range (Perrin, 1975). This makes the assumption that density of schools in the area sampled is representative of the entire historical range. Variance of the estimate of total schools can be calculated as

$$V(\hat{S}_i) = A_i^2 V(\hat{D}_i),$$

where

$\hat{S}_i$ = number of schools or schools components of stock-school type i, and

A_i = area inhabited by schools of stock-school type i

Then, using estimates of average school size (or single-stock component size) from the Observer Program, we estimated the total number of dolphins for each stock-school component type as

$$\hat{N}_i = \hat{C}_i\hat{S}_i,$$

where

$\hat{N}_i$ = total number of dolphins in stock-school type i, and

$\hat{C}_i$ = average size of schools of stock-school type i.

Variance can be calculated as

$$V(\hat{N}_i) = V(\hat{C}_i)S_i^2 + V(\hat{S}_i)\hat{C}_i + V(\hat{C}_i)V(\hat{S}_i).$$

We then added the single-stock school and mixed-stock school components to obtain an estimate for each of the 2 stocks:

$$\hat{P}_j = \Sigma N_i,$$

where

$$\hat{P}_j = \text{population of stock j.}$$

The variances of N_i are additive. We expressed the population estimates as interval estimates, which were ± 2 standard deviations from the point estimates. This interval should contain the true value at least 75 % of the time.

We used average school size estimates from the Observer Program, because the sample size from the aerial survey was very small and if used would have greatly increased the variance of the population estimate. This was justified because the aerial estimates did not differ significantly from the Observer Program estimates.

For the 1974 estimates, porpoise-school density estimates from the aerial and ship surveys were made in the aggregate. The ship survey density estimates were also made by stratifying by season and sub-area and computing an average, weighted by the geographical area of each stratum. Additional estimates of density were made which combined the aerial and ship survey. Assuming that the ship survey estimates of density tend to be biased, either due to concentrated fishing for yellowfin tuna associated with dolphins or alternately fishing for yellowfin tuna and other species not associated with dolphins, a correction factor was obtained by the ratio of the aerial survey density to the ship survey density in the period and area of overlap. This ratio was applied to the full range of the ship survey, which is more extensive in areal coverage than the aerial survey. This combined approach additionally assumes that the aerial survey density estimates are accurate and the degree of bias in the ship survey is constant throughout its range.

It is important to note that the estimated population size ranges are ranges of *point* estimates rather than probabilistic confidence intervals. Even though approximate variances were computed for the density and school size estimates and their combination, it is meaningless to try to place a probabilistic confidence interval on the current estimates, because neither the geographical range of each stock is known precisely nor does an estimate of its variance exist. More extensive aerial surveys, ship surveys independent of fishing, or alternate methods will have to be mounted to establish single point estimates with probabilistic confidence bounds.

The major criticisms that can be made of the population estimates are:

- Density of schools may not be the same throughout the ranges. There may be areas of higher or lower density in the unsurveyed offshore parts of the ranges. This could bias the estimates either way.
- The actual range at any time is probably smaller than the historical range. There may be seasonal migrations and year-to-year changes in the range occupied, caused by large-scale environmental fluctuations, e.g. the El Niño condition in 1973. This would bias the estimates upward.
- The assumption that all schools directly on the track line were seen may not be valid. If some schools were missed, this would bias the estimate downward.

ESTIMATING REPRODUCTIVE PARAMETERS

The samples, methods and analyses used in the studies of the life history of *S. attenuata* are described in detail in Perrin, Coe and Zweifel (1976). The studies were based on about 10 000 specimens collected in the Observer Program. The primary inputs into the status assessment are the estimates of age-specific pregnancy rate. We estimated age by looking at growth layers in the teeth. There are 2 sources of uncertainty in the pregnancy rate estimates. One has to do with the number of growth layers deposited yearly in the teeth, and the other concerns the rate of change of pregnancy rate with age. We could not satisfactorily resolve either of these uncertainties, so the inputs into the assessment model were in terms of alternatives, i.e., 1 layer or 2 tooth layers accumulated yearly in adults, and pregnancy rate being either constant, decreasing "slowly", or decreasing "rapidly" with age (defined below).

Estimating capacity for increase

The capacity for increase is basically the difference between the gross annual production and the average annual natural mortality. It changes when the environment or the size of a population changes. It is to be expected that capacity for increase increases when a population is exploited.

The basic approach used to estimate capacity for increase is based on Leslie matrix models. The basic inputs are age-specific pregnancy rates and age-specific natural mortality rates. These rates are combined in a matrix which can be used to project the population forward in time and to determine the capacity for increase implied by the naturality and mortality rates. The model equation of interest here is:

$$\underline{M}\,\vec{N} = \lambda\,\vec{N},$$

where

$\underline{M}$ is the Leslie matrix describing the western Pacific stock,

$\vec{N}$ is the age structure vector, and

λ (lambda) is a scalar constant indicating the annual change in the population size with the life history parameters incorporated in the Leslie matrix $\underline{M}$.

If λ is equal to 1.0, the population neither increases nor decreases in size. If it is less than or greater than 1.0, the population decreases or increases, respectively. The capacity for increase is defined as $(\lambda - 1)/\lambda$.

We do not have estimates of natural mortality rates from the fishery because we cannot separate natural mortality from incidental mortality. Biological data are available for an unexploited spotted dolphin population near Japan (Kasuya, Miyazaki and Dawbin, 1974). These data can be used to derive natural mortality rates to use as first approximations for the rates for the eastern Pacific stock. Kasuya, Miyazaki and Dawbin (1974) did not give estimates of the mortality rates of immature animals more than 1 year old. They did give estimates for the mortality rate of first-year calves. These estimates are very low and are not consonant with an equilibrium population, given the calving intervals, which are more directly calculated and seem reasonable.

Therefore, we estimated new mortality rates for calves and rates for older immature animals indirectly. If the adult mortality rates and the reproductive rates estimated for this stock hold, and if the population is in equilibrium, certain values of mortality rates for calves and older immature spotted porpoise are implied. These implied values are determined as those which satisfy the model equation when $\lambda = 1.0$.

We then determined the capacity for increase for the eastern Pacific stock by combining in one matrix the mortality schedule estimated for the western Pacific stock and the reproductive schedule estimated for the eastern Pacific stock. Analysis of this model yielded the desired estimates of capacity for increase. A basic assumption is that the reproductive rates have increased in the eastern Pacific stock due to a decrease in stock size, while the natural mortality rates have not changed.

These estimates of capacity for increase can be directly compared to the annual incidental exploitation rate determined as the ratio of the estimate of numbers killed to the estimated population size. If the incidental exploitation rate is less than the capacity for increase, the population should increase; and if it is greater than the capacity for increase, the population should decrease.

It should be noted that this analysis assumed that the incidental mortality occurs equally over all age classes. It also assumes that the population age structure has had time to achieve a stable form. Both of these assumptions, especially the latter, need to be examined further.

Results

Offshore spotted dolphin

Incidental kill

The estimated incidental kill as declined each year since 1972 (Table 2) to about 72 000 in 1974, of which about 75 % is ascribable to the US fleet.

We stress the fact that these estimates must be considered minimal estimates for several reasons, to wit.

- Only animals known to be dead were counted; we have made no attempt to take into account the injured animals, some of which can be presumed to have died after release from the net.

- Kill data were gathered only from US vessels, which probably perform better in preventing incidental mortality than do most non-US seiners. The non-US fleets contain many small, old vessels that were formerly in the US fleet.

- Some observer effect can be presumed. With the stratified approach, the problem of representation of the fleet in terms of vessel characteristics is solved, but kill rates may be higher on cruises not accompanied by observers than on cruises with observers.

Population size

We saw 54 schools containing offshore spotted dolphins along the 12 000 track miles of the aerial survey. The aerial and ship survey density estimates, along with the geographical ranges and average school sizes resulted in the following total range in estimated population size:

Stock	Estimated total range of population size (millions of animals)
Offshore spotted dolphin	2.8-4.2

The lowest values of the total range result from using the early-season density averages of the combined aerial and ship surveys. The highest values of the total ranges result from using the early-season density averages of the ship survey alone.

The estimated total ranges in population size can be centralized further, because certain of the density estimates are preferred over others. The ship survey is preferred over the aerial survey because of its broader areal coverage. The all-season density averages are preferred over the early-season density averages because of the biases discussed above. The sub-area density averages are preferred over the aggregate density averages because of apparent differences in density among subareas. Combining these preferences results in the following centralized ranges in estimated population sizes:

Stock	Estimated centralized range of population size (millions of animals)
Offshore spotted dolphin	3.1-3.5

The lowest values of the ranges result from the combined aerial and ship surveys and the highest result from the ship survey alone. We have no basis to choose between them.

Capacity for increase

The estimate of capacity for increase depends on the choice of alternative assumptions about life history. For tooth layering, the basic options are 1 or 2 layers per year. For reproduction, the basic options are the frequency of reproduction after sexual maturity being constant with age or declining with age. Consideration of all the reasonable alternatives results in a range of estimates of capacity for increase of −2.5 % to +6.6 % per year as shown in Table 3.

None of the alternatives shown in Table 3 can be eliminated with certainty. However, there is some basis for choice. One tooth layer deposited per year has been suggested for the western Pacific population of *S. attenuata* by Kasuya, Miyazaki and Dawbin (1974). One layer per year has also been suggested for other closely related delphinids, including *S. coeruleoalba* (Kasuya, 1972) and *Tursiops truncatus* (Sergeant, Caldwell and Caldwell, 1973). Two tooth layers have been suggested for *Delphinapterus leucas* (Sergeant, 1973), but this form is less closely related to *Stenella*. Thus, it is reasonable to assume the tooth layering for the spotted dolphin is basically 1 per year.

The estimates of frequency of reproduction with age are based on the relationship between pregnancy rates and numbers of tooth layers. The observed data suggest a decrease in pregnancy rate from 0.6 at 7 layers to 0.4 at 12 layers (Perrin, Coe and Zweifel, 1976). This is termed "decreasing rapidly" in Table 3. The determination of numbers of layers is difficult after the pulp cavity closes at about 12 layers. If the pregnancy rate observed for 12-layer animals is actually the pregnancy rate for all animals age 12 layers or older, then pregnancy rate declines more slowly with age. This is termed "decreasing slowly" in Table 3. Because of the difficulty in reading layers for older animals, it is most reasonable to assume that the reproduction rate either declines slowly with age or is constant with age.

Assuming 1 tooth layer per year and either constant, or slowly decreasing, reproductive rates with age, one obtains a range of estimates of capacity for increase of 1.4-4.0 % (Table 3). Although the other hypotheses cannot be completely ruled out and must be allowed as possibilities, this range represents the most likely values, given present information.

Table 2. Estimated incidental kills of spotted and spinner dolphins in the eastern tropical Pacific, 1971-74, in thousands

Year	Spotted dolphin [1]			Spinner dolphin		
	US	Non-US	Total	US	Non-US	Total
1971	179.7	4.6	184.3	126.4	3.2	129.6
1972	237.6	32.7	270.3	56.7	7.8	64.5
1973	90.6	17.1	107.7	56.9	10.7	67.6
1974			72.0			36.0
						21.0 (eastern)
						15.0 (whitebelly)

[1] Estimates are for 2 populations: (1) coastal spotted and (2) offshore spotted. All of this kill is assigned to the offshore spotted dolphin population, although some coastal spotted dolphin are involved.

Table 3. Possible capacity for increase for *Stenella attenuata* as percent of current population size under alternative assumptions

Reproductive rate with age	Numbers of tooth layers per year	
	One	Two
Constant	2.3 - 4.0	2.9 - 6.6
Decreasing		
Rapidly	− 1.0 - + 0.3	− 2.5 - − 0.8
Slowly	1.4 - 2.6	1.8 - 3.3

Impact of the fishery

The estimate of impact is based on the revised estimates of kill and population size, using 2 approaches to estimating sustainable yield.

Perrin, Coe and Zweifel (1976) estimated that the rate of gross annual production of calves is about 14.4 % of the offshore spotted dolphin population in the eastern Pacific. This estimate is predicted upon their assumption that the samples are representative of the actual population. Perrin, Holts and Miller (1975) estimated the gross annual production rate of calves for spotted dolphin of the western Pacific to be about 8.7 % from data presented by Kasuya, Miyazaki and Dawbin (1974). The western Pacific population is thought to be very lightly exploited and may be in equilibrium; the adult female annual natural mortality rate was estimated to be 7.4 % (Kasuya, Miyazaki and Dawbin, 1974) but juvenile and male mortality rates are probably higher, so the population's average natural mortality rate is probably near the gross annual production rate of calves. Perrin, Coe and Zweifel (1976) suggest that the higher reproductive rate in the eastern Pacific population might be a population response to exploitation, because the individual reproductive parameters differ between the 2 populations in a manner consistent with that hypothesis. If the hypothesis is true, then the reproductive rate of the western Pacific spotted dolphin, 8.7 %, is an estimate of the natural mortality rate, and carrying out the analogy with a simple model indicates that the present eastern Pacific population might sustain an annual incidental fishing mortality rate of 4.4 % or more, if the natural mortality rate were concomitantly depressed. Using this estimate is an alternative to the approach taken in calculating the preliminary estimates, where an age-specific model was used.

The total mortality of offshore spotted dolphins in the eastern Pacific during 1974 is estimated to be 72 000 animals. The central estimates of population size are 3.1-3.5 million animals, with a total range of 2.8-4.2 million animals, giving a central range for the 1974 incidental fishing mortality rate of 2.1-2.3 % and a total range of 1.7-2.6 %. The estimates of the incidental fishing mortality rate are below that indicated as sustainable in the simple model, 4.4 % indicating that the population would increase but at a slow rate of 1.7 % per year or slightly more. The estimates of the incidental fishing mortality rate are within the probably range of that indicated as sustainable in the age-specific model, indicating that if the population were changing it would be doing so at a very low rate (i.e., between decreasing at 1.2 % and increasing at 2.2 % per year). This leads to the tentative conclusion that if the offshore spotted population were changing under the 1974 level of incidental fishing mortality, it was probably doing so at a low rate.

We have done some back extrapolations

on the basis of earlier fishing activity and kill rates to examine the question of whether or not the population is at its original size. The balance of evidence suggests that there has been a decline. We do not know yet how great it has been. These analyses are still being revised and refined.

Eastern spinner dolphin

Incidental kill

The estimated kill of spinner dolphins in 1974 was 36 000, of which 21 000 are estimated to have been eastern spinner dolphins.

Population size

We made 36 sightings of eastern spinner schools on the aerial survey. This extrapolates to a population of 1.0-1.5 million animals, which can be centralized as described for the spotted dolphin, to give a range of 1.1-1.2 million.

Impact of the fishery

Estimates of some life history parameters are available (Perrin, Holts and Miller, 1975). Gross annual reproductive rate was estimated to be 6.4 % for 1973 and 9.8 % for 1974, with a pooled estimate of 8.3 %. This is considerably below the rate estimated for offshore spotted dolphins in the eastern Pacific, suggesting that the stock of the eastern spinner dolphins cannot bear as much *total* mortality as the stock of spotted dolphins. However, depending on the natural mortality rate, it might sustain a higher or lower incidental fishing mortality rate than that of the offshore spotted dolphin. The relatively high rate of reproduction exhibited by the spotted dolphin may be a response to exploitation, as suggested by Perrin, Coe and Zweifel (1976) and Perrin, Holts and Miller (1975). It is possible that spinner dolphins have been less heavily exploited than spotted dolphins in the past (e.g., prior to 1971); comparisons of several biological parameters with other cetaceans support this contention (Perrin, Holts and Miller, 1975).

In 1974, the estimated central range of population size point estimates of eastern spinner dolphins was 1.1-1.2 million animals, with a total range of 1.0-1.5 million animals. The kill of eastern spinner dolphins in 1974 was estimated to be 21 000 animals. Thus the estimated central range of the annual rate of mortality caused by fishing was 1.8-1.9 %, with a total range of 1.4-2.1 %, which is not appreciably different from that for the offshore spotted dolphin. This, and the apparent absence of populational response to exploitation, lead, as for the offshore spotted dolphin, to the tentative conclusion that if the eastern spinner dolphin population was changing in 1974, either increasing or decreasing, it was doing so at a low rate.

Whitebelly spinner dolphin

For the whitebelly spinner, we know only that an estimated 15 000 were killed. We, as yet, have no estimates of population size or capacity for increase.

Discussion

Shortcomings of the studies

We have established that the aerial survey approach is feasible, but our population estimates are weak because they involve extrapolation to large portions of the ranges that were not surveyed. Also, the estimates based on aerial surveys have high variability due to small sample size. We need an estimate for the whitebelly spinner population. We have not yet surveyed on a large enough scale.

The problem of calibration of growth zones in the teeth remains. Until this is settled, the estimates of reproductive parameters are only provisional. We do not, of course, have any estimates yet for the spinner dolphins.

The estimates of measured incidental kill may be inaccurate because of the lack of data for the area outside the CYRA and for the non-US fleet. We also need to estimate the now unmeasured kill.

Recommendations for research

In order to assess the status of the stocks adequately there is a need to:

- Monitor the sizes of all dolphin stocks involved in the tuna fishery, using expanded surveys that adequately cover the geographical range of each stock. Population estimates should be made over a period of years, so that the existence or absence of trends can be firmly established. Additional sources of potential information, such as I-ATTC data, need to be explored to assist in establishing the history of the status of the stocks.
- Continue to monitor the incidental kill of dolphins in the tuna fishery, through a continued Observer Program or some other scheme. Kill should be estimated stock by stock. An attempt should be made to measure possible effects on dolphins stocks in addition to the presently measured direct incidental mortality.
- Estimate the life history parameters for the several spinner and whitebelly dolphin stocks and resolve the question of toothlayer deposition rate in the spotted dolphin, which is central to estimating parameters.

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