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Internal Report - Informe Interno

No. 15

SOME PROBLEMS IN ESTIMATING THE DENSITY OF DOLPHIN POPULATIONS IN THE EASTERN TROPICAL PACIFIC USING DATA COLLECTED ABOARD TUNA PURSE SEINERS

By

P. S. Hammond

La Jolla, California

1981

PREFACE

The Internal Report series is produced primarily for the convenience of staff members of the Inter-American Tropical Tuna Commission. It contains reports of various types. Some will eventually be modified and published in the Commission's Bulletin series or in outside journals. Others are methodological reports of limited interest or reports of research which yielded negative or inconclusive results.

These reports are not to be considered as publications. Because they are in some cases preliminary, and because they are subjected to less intensive editorial scrutiny than contributions to the Commission's Bulletin series, it is requested that they not be cited without permission from the Inter-American Tropical Tuna Commission.

PREFACIO

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Estos informes no deben considerarse como publicaciones, debido a que en algunos casos son datos preliminares, y porque están sometidos a un escrutinio editorial menos intenso que las contribuciones hechas en la serie de Boletines de la Comisión; por lo tanto, se ruega que no sean citados sin permiso de la Comisión Interamericana del Atún Tropical.

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INTRODUCTION

At the 33rd meeting of the Inter-American Tropical Tuna Commission (IATTC), held in Managua in October 1976, it was agreed that the Commission should become involved with the problems of incidental dolphin mortality caused by tuna purse seining operations. As objectives it was agreed that "(1) the Commission should strive to maintain a high level of tuna production and (2) also to maintain dolphin stocks at or above levels that assure their survival in perpetuity, (3) with every resonable effort being made to avoid needless or careless killing of dolphins." In September 1978 funding became available for the tuna-dolphin program of data collection, analysis and scientific research.

One section of the research program involves the assessment of the effect of management strategies on the tuna-dolphin complex. An important part of this assessment is the monitoring of the levels of the commercial tuna populations and the levels of the dolphin populations which are found in association with tuna. Since the Commission's work begun in 1951, part of the research effort has been directed towards estimating the population levels of tunas, particularly the yellowfin tuna, Thunnus albacares, (Cole, 1980) which constitutes practically all the catch of fish associated with dolphins. However, population estimation of the species of dolphin involved in this association, the spotted dolphin Stenella attenuata, the spinner dolphin S. longirostris and the common dolphin Delphinus delphis, is a relatively recent concern.

Following the passage of the Marine Mammal Protection Act in 1972, the United States National Marine Fisheries Service (NMFS) initiated a program with the aim of collecting data from tuna purse seiners involved in fishing for tuna associated with dolphins. These data were to be used to assess the impact of the fishery on the dolphins, both at the population level and in terms of the efficiency of the fleet in releasing dolphins uninjured. For the former assessment, the scientific technicians (frequently called observers) were to stand a marine mammal watch whenever feasible and record pertinent data when a sighting was made, such as the position of the vessel, the distance and bearing of the school of marine mammals from the vessel, and the size and species composition of the school.

The NMFS has convened two workshops with the purpose of assessing the status of the species and stocks of those dolphin populations which are affected by the purse seine fishery for tuna in the eastern tropical Pacific (Figure 1). Most of the work concerned with estimating the density of dolphins in this area has been in preparation for these workshops. For the first workshop, held in 1976, estimates of density were based on the work of Smith (1975) who analyzed data from an aerial survey, a research cruise and commercial fishing trips in 1974. Density estimates for the second workshop, held in 1979, were based on the work of Holt and Powers (1981) who analyzed data from aerial surveys and research cruises in 1977 and 1979.

The data collected by technicians aboard tuna purse seiners have essentially unknown properties. Since Smith (1975), no attempts have been made to calculate density estimates from them. The greatest potential problem envisioned was the effect on analyses of a search pattern by seiners which was unlikely to be random. Other potential problems with these data include changes in the distribution of fleet effort over the area of the fishery, the response of dolphin schools to approaching seiners, a lack of sufficient accuracy in the collection of data needed for density estimation and the omission from the data base of certain information which would have led to more accurate estimates of density. However, the data collected aboard tuna seiners are extensive compared to the data collected on aerial surveys and research cruises. The analyses of these latter data have suffered from inadequate coverage of the region for which their results were intended and inadequate sample size.

The purpose of this report is to discuss some of the problems in estimating the density of marine mammal populations by line transect sampling. In particular, the study is concerned with dolphin populations in the eastern tropical Pacific affected by the tuna purse seine fishery, and especially with data collected by scientific technicians aboard purse seiners. The assumptions necessary to obtain accurate estimates of density from the data are described and discussed with respect to the tunaboat data, so that their value can be assessed. After the discussions of the assumptions, some results are presented for those species most involved in the tuna fishery. Finally, an assessment is made of the tunaboat data and some recommendations are made which, if followed, should improve the quality of future data and make them more conducive to accurate density estimation. Although this study is concerned solely with NMFS data, the work is equally relevant to the data collected since 1979 by the Tuna-Dolphin program of the IATTC.

ESTIMATION OF DENSITY FROM LINE TRANSECT SAMPLING

Advances in the techniques of line transect analysis in recent years have led to fairly reliable methods of estimating the density of terrestrial populations. Scientists involved in conducting censuses of marine mammal populations have now begun to turn to these techniques; Smith (1975), Holt and Powers (1981), Leatherwood, Gilbert and Chapman (1978) Ljungblad, Platter-Rieger and Shipp (1980) Best and Butterworth (1980). These and other studies have highlighted some of the problems associated with using line transect methods to sample marine mammal populations. In particular, Eberhardt, Chapman and Gilbert (1979) have reviewed some of the difficulties arising from this approach. These problems are essentially violations of the necessary assumptions which are described below after a brief outline of line transect methodology.

Perhaps the clearest way to describe line transect methodology is to treat the search track of a transect as an area to be sampled, recognizing that not all the targets in this area will be detected. Let the transect length be L and half the width of the search track be W, so that the area to be sampled is 2LW. The actual width of the track is unimportant since it drops out of the derivation. Let the true number of targets in this area be N, so that the true density is N/2LW. Now let the number of targets detected be n so that n = pN, where p is the proportion of total targets which are actually detected. Density can then be described as

$$D = \frac{n/p}{2LW}$$

Let g(x) be the probability of detecting a target given that x is the perpendicular distance from the target to the line of search Then the average probability of detecting a target within the area 2LW, estimated by the proportion of targets detected, is

$$p = \frac{\int_o^w g(x)\, dx}{\int_o^w dx} = \frac{1}{w} \int_o^w g(x)\, dx.$$

The function g(x) can be readily converted to a valid probability density function, f(x), such that

$$f(x) = \frac{g(x)}{\int_o^w g(x)\, dx} = \frac{g(x)}{pw}$$

so that if g(0) = 1, i.e. all targets on the line of search are detected,

$$f(0) = \frac{1}{pw}$$

and density can be written

$$D = \frac{n\ f(0)}{2L}$$

It is the quantity f(0) that is estimated in line transect analyses.

The crucial factor in the estimation procedure is the choice of a suitable model to fit to the set of observed perpendicular distances. Since an unknown distribution of sightings is to be fitted empirically, the model should conform to expectations dictated by what it is considered the "true" sighting distribution might look like. Burnham, Anderson and Laake (1980) have discussed certain properties which they feel a sighting model should possess. These are: the ability to fit a range of likely observed distributions, the ability to give a pooled estimate approximately equal to the mean of a series of suitably weighted stratified estimates, the presence of a "shoulder" in the shape of the model and a small sampling variance of the function evaluated at zero, f(0).

Several sighting models comply, more or less, to these criteria. They include the Fourier series described by Crain, Burnham, Anderson and Laake (1978), the exponential polynomial (Crain, 1974), the exponential power series (Quinn, 1977; Pollock, 1978) and the reversed logistic (Eberhardt, 1978). The Fourier series has been found to be a good general model by Burnham _et al_.. (1980). The latter three can suffer from lack of efficiency in comparison with the Fourier series. The models used in the analyses are discussed further below.

The assumptions which should be met for unbiased estimation of density from line transect sampling fall into three categories. There are two assumptions related to obtaining an adequate sample from a target population.

1) Either the distribution of sampling effort is at random with respect to the target population or the target population is distributed at random.
2) Targets are identified without error.

In addition, there are five assumptions pertaining to the estimation of density of groups (schools of dolphins in this study) e.g. Gates, Marshall and Olson (1968); Seber (1973); Burnham and Anderson (1976); Burnham _et al_ (1980).

3) All targets on the line of search are detected,
4) Angle and distance measurement is without error,
5) There is no undetected movement of targets in response to the searcher,
6) Sightings are independent events
7) Each target is recorded once only.

Finally , there are two assumptions related to the conversion of group density into density of individuals (dolphins in this study).

8) Group size is recorded without error,
9) The probability of target detection is independent of group size.

ASSUMPTIONS NECESSARY FOR ADEQUATE SAMPLING

From all indications, dolphin populations in the eastern tropical Pacific are not distributed in a random manner. Consequently, for assumption 1 to be satisfied, searching must be at random. Controlled surveys, such as the NMFS research cruises and aerial surveys, should be able to satisfy this condition. However, it has often been thought that the data collected by scientific technicians aboard tuna seiners were subject to bias caused by the non-random searching pattern of the fishing vessels of the tuna purse seine fleet. One would indeed expect any commercial fishing captain to spend more time in areas where he expected to catch the greatest amount of fish by expending the least amount of effort. In areas of the eastern Pacific where tuna and dolphins are found in mixed species aggregations, dolphin schools are used by fishermen to locate tuna. Consequently, one might expect individual vessels to respond to areas where the most dolphin schools are sighted, which are likely to be areas of high density, by spending proportionally more time searching for tuna there. Sampling effort would then be biased towards areas of high dolphin concentration and estimates of density would be positively biased also. In other areas, mostly inshore, fishermen tend not to use dolphin schools to locate and catch fish. Rather fishing is for tuna associated with floating debris, "logs", or for free swimming schools of tuna.

The problem can be viewed on two scales; attraction to a general area of the ocean because of a predetermined plan or because of fishing conditions in that area at that time of year, and attraction to a much smaller local area within a general area because local fishing conditions happen to be better there.

The distribution of searching effort in the eastern tropical Pacific tuna fishery changes considerably over time. This is true not only within years but also between years. This is demonstrated by the example in Figure 2 which represents searching effort by NMFS technicians aboard seiners for the same quarter of different years. In 1977, approximately 55% of the total yellowfin landed had been caught in sets made on dolphin-associated tuna, compared with 35% in 1978. Complementing this is the fact that 1978 was a year of exceptional abundance of skipjack, whereas 1977 was not. The relative availability of yellowfin associated with dolphins, the relative availability of skipjack, which is generally not associated with dolphins, and oceanographic features all play important roles in affecting the distribution of fleet searching effort.

In practice, the pattern of searching is a highly complicated matter involving several factors such as the fishing captain's historical knowledge, his intuition, the weather, code groups, the season, current fishing conditions, to name but a few; but it is probably reasonable to assume that the majority of any non-random element in searching is on a large scale, and once within a relatively small area searching is effectively at random. If this is so, it is possible to test for large-scale non-randomness in the following manner.

If sighting success and searching effort are related such that

$$n = aL^{b}$$

where a and b are constants, n is number of sightings and L is search effort, then any non-linearity in the data representing a non-random searching pattern will be evident as a deviation of the quantity b from unity. In logarithmic form, the above equation becomes

$$\ln(n) = \ln(a) + b \ln(L)$$

so that a simple test of non-randomness is to regress $\ln(n)$ on $\ln(L)$ and test if the slope is different from unity. This has been done by stratifying the data into $5^{\circ} \times 5^{\circ}$ "squares" within which searching is assumed to be effectively at random, and using two different measures of sighting success. The first is simply the number of sightings and the second is the number of sightings corrected for sighting conditions. This latter quantity is $nf(0)$, where $f(0)$ is the sighting model function fitted to the set of observed perpendicular distances and evaluated at zero, and is proportional to density multiplied by searching effort.

In Table 1 the results are shown for the case where sighting success is measured as number of sightings. Using all available data, there is no evidence that there is a positive response by the fleet to areas where sighting success was high. Rather, the opposite seems to be more likely to be true especially in 1976. In Table 2, where sighting success is measured as number of schools adjusted for sighting conditions, a component of density, the results are similar to those in table 1. This latter result is the important one. Although it is likely that fishermen respond to the number of schools seen and whether or not they are associated with tuna regardless of sighting conditions, the important factor is whether or not they spend proportionally more time searching in areas of high density.

The tendency for seiners to apparently spend more time in areas of low dolphin density may be due to the fact that some vessels prefer to concentrate their efforts on tuna not associated with dolphins. One solution is to stratify data for each year into three area types. First where fishing is primarily for tuna associated with dolphins, second where fishing is primarily for tuna not associated with dolphins and third where fishing may be either mode, depending upon conditions. Then, estimates for each area type, or subsets of them, should be able to be compared between years without the variation in searching effort distribution being a problem; except for areas where fishing may be of either mode which may still be affected. This has been done for 5° x 5° "squares" within the area covered by the tuna fishery in the eastern tropical Pacific using IATTC data on the proportion of sets made on tuna associated, or not associated, wth dolphins. Figure 3 shows these areas based on data from 1970-1979.

Table 3 shows the results of the test for random search within areas where fishing has been primarily for tuna associated with dolphins, where success is measured as number of sightings recorded. Only the data for spotted dolphins in 1977 show evidence of positive non-random search for areas of high sighting rate. Table 4 shows the results of the same test where success is measured as number of schools adjusted for sighting conditions. Evidence of non-random search for areas of high dolphin density is absent in this case. Again, this is the important result since this study is concerned with responses to dolphin density.

From these results, it seems that the fleet as a whole, as represented by the sample of vessels with NMFS technicians, searches effectively at random and that density can be estimated without bias in this respect. Several plausible explanations can be suggested for the results. Firstly, the areas of highest dolphin density may not be the areas of greatest tuna availability. Secondly, searching may be non-random, but the increased set time in areas of highest dolphin density reduces the time spent searching. Thirdly, searching is potentially non-random, but areas of high density change faster than the fleet can keep up with. Fourthly, the assumption that searching is at random within a 5° x 5° "square" may not be true. Probably the real explanation is a combination of some or all of the above and other factors, so that it may suffice to say that the highly complex nature of fishing for tuna results in a fleet search pattern that can be considered to be at random.

There are sufficient data for spotted dolphins in 1977 in a block of nine 5° x 5° "squares to be able to conduct a simple test to see whether searching is at random within a 5° x 5° "square". The area used in this test is comprised of the numbered "squares" in Figure 1. Figure 4 shows the distribution of searching effort as represented by line length, 4(a), and the distribution of sightings per 1000 nm searched, 4(b). Searching effort is certainly not randomly distributed within the area, but is this true with respect to the distribution of dolphins? The sightings per 1000 nm statistic seems to be distributed differently to the searching effort.

An analysis was conducted in the same manner as described above, but using 1° x 1° "squares" as units within 5° x 5° "squares". The measure of sighting success used was the number of sightings. Table 5 gives the results of the analysis. The test shows a significant departure from b = 1 for both data treatments in three instances but in each case the non-random element in the searching is towards areas of low dolphin sighting rate. Evidence of non-random searching for areas of high dolphin density is once again practically absent. This lends support to the notion that fleet searching patterns as a whole do not differ from random.

Even when searching is known to be at random, there is still the question of sufficient coverage of the area in question. Any sampling regime should adequately cover the area for which the results are intended. Surveys should be designed to sample comprehensively so that density estimates do not have to be extrapolated to areas about which no information is available. This is often difficult for purely practical reasons of time or funds available or the size of the area in question. Sampling should also be intense enough so that the data are able to yield sufficiently accurate estimates of density. Holt and Powers (1981) encountered both these problems with the data they worked with. Results from research cruise data, which covered almost all the area but were sparse, had to be calibrated with results from aerial survey data, which were more plentiful but only covered approximately half the area under investigation.

The sampling of a population assumes that the target of the sampling can be accurately identified (assumption 2). Incorrect identification will clearly bias estimates of density calculated from such a sample. The most likely bias is a negative one caused by a failure to positively identify a given species. This is usually not a problem for terrestrial surveys, but is more so for censuses of marine mammals. Holt and Powers (1981), in their analysis of data from aerial surveys of dolphin in the eastern tropical Pacific, were forced to make estimates of density for schools of all species combined, partly due to a large proportion of "unidentified" sightings. They then used independent information to divide this figure into various species.

The inability to positively identify a target species may also be a problem in density estimation from data collected by technicians aboard tuna seiners. Each year, a certain proportion of sightings are recorded as "unidentified". The possibility of incorrect identification is small due to editing. For species termed "small whales" there has been a decreasing trend in the proportion of unidentified sightings from 0.67 in 1974 to 0.37 in 1979. For dolphins, however, this proportion has fluctuated from 0.24 to 0.38 with no discernable trend during the same period. It is likely that schools of spotted and/or spinner dolphins are positively identified more often than average, since fishermen are more interested in these species which most often associated with tuna and will tend to watch them more closely. Of those schools that remain unidentified, only those directly on the line of search will affect estimates of density since this violates assumption 3, discussed below.

What these last three points emphasize is that there are several practical difficulties in obtaining an adequate, unbiased sample from an oceanic population. For the dolphin populations affected by the tuna purse seine fishery in the eastern tropical Pacific, data from both the controlled surveys on research vessels and aircraft and the uncontrolled surveys on tuna purse seiners present problems in analysis. An ideal sampling regime would perhaps combine the coverage of the fishery data with the random sampling of the research cruises and aerial surveys.

ASSUMPTIONS NECESSARY FOR UNBIASED DENSITY ESTIMATION OF GROUPS

Of the five assumptions listed above numbers 6 and 7 seem to be readily satisfied by data collected from sampling oceanic populations. It is not a problem to ensure that a school is only counted once during any one period in time. Of course, a school may be encountered more than once during a survey but on another transect in a different time/area stratum. An exception to this could arise if a population shows a general non-random movement during a survey, such as during a migration. This has presented problems in aerial surveys of bowhead whales, <u>Balaena mysticetus</u>, off the north slope of Alaska (Ljungblad <u>et al</u>., 1980). A suitably designed survey should be able to eliminate this problem. Neither is it unreasonable to assume that sightings are independent events, at least under present methods of collecting data. In most surveys, when a sighting is made, the observers cease to search in the normal way and go "off effort". Consequently, any sightings made while circling or tracking down the initial target would not be included in the data. The problem of how to treat these "secondary" sightings is important to several surveys, for example the IDCR minke whale assessment surveys in the southern ocean (Best and Butterworth, 1980) and the surveys for dolphins in the eastern tropical Pacific discussed here. At present, there is no accepted method of including these data in estimations of density, resulting in considerable numbers of sightings being discarded.

Assumption 3, that targets are never missed on the line of search, that is, g(0) equals unity, is perhaps the most important. It is important because it is likely to be violated in a number of ways. Firstly, marine mammals spend a large proportion of their lives submerged beneath the surface of the ocean where they cannot be detected. For species which typically travel singly or in small groups this is likely to cause animals to be missed on the line of search. Doi (1974) has estimated that for large whales in the Antarctic ocean, only 11.2 - 22.1% of the animals present could be expected to be seen within a strip transect specified by his particular conditions. Doi assumed a constant probability of detection within the strip, implying that large whales present on the line of search cannot be expected to be detected with unit probability. Smaller cetaceans, which typically travel in larger schools, are probably not subject to this problem to the same extent. In particular, those species of interest to the tuna fishery in the eastern tropical Pacific seem to travel in schools of sufficient numbers so that part of the school is always at the surface. Secondly, animals present on the line of search and at the surface may still be unable to be detected due to adverse sighting conditions. There is some suggestion that sightings of whales begin to drop off at about Beaufort scale 3-4 (Gulland and Kesteven, 1964; Christensen, 1977) but this may not be the same for schools of dolphins. If animals or schools are missed on the line of search, g(0) is less than unity and estimates of f(0), and therefore density, will be biased downwards.

The questions concerning this assumption appear to be: can the proportion of schools which go undetected be estimated, and, is this proportion a constant? Clearly, the proportion will vary between species, but it may also vary within species in different time/area strata since sighting conditions at sea, whether from aircraft or ships, are very much affected by the weather, as measured by the Beaufort scale. It seems highly likely that the proportion of undetected schools, and therefore estimates of f(0) would be a function of sighting conditions and thus it is necessary to test whether estimates of density are affected by Beaufort scale. Unfortunately, these data were not collected in a suitable form by NMFS technicians between 1974 and 1980. However, NMFS technicians are collecting these data in 1981 and IATTC technicians have collected similar data since 1979 and an analysis is planned to investigate this problem. At Beaufort scale zero, g(0) is probably equal to unity for schools of dolphins affected by the eastern tropical Pacific tuna purse seine fishery. It remains to be seen whether higher Beaufort scales cause g(0) to be depressed to less than unity.

A third way in which targets may not be detected on the line of search involves a further assumption, number 4, that targets do not move in response to an approaching ship or aircraft before they have been detected. Aircraft travel quickly enough for this not to be a problem, but it may be so for shipboard surveys. If undetected evasive movement occurs, estimates of f(0) and density will be biased downwards. If undetected attractive movement occurs, estimates of f(0) and density will be biased upwards. There have been many reports of bottlenose dolphins, Tursiops truncatus, and common dolphins, Delphinus delphis, in some areas running towards vessels when they were first sighted. It is also well-known that spotted dolphins, Stenella attenuata, and spinner dolphins, Stenella longirostris, will run from approaching vessels. What is not clear is whether this movement occurs before or after the schools have been sighted and their relative position fixed by the recording of angle and distance data. Some recent analysis (Au and Perryman, personal communication) suggests that schools of spotted and spinner dolphins can begin to move away from a vessel's line of search before they have been detected by shipboard personnel. However, these results are based on little data and need corroboration. Until this important point can be clarified, the question of whether estimation of density is affected by the movement of schools in response to an approaching vessel must remain unanswered. Two methods of assessing the problem are currently being discussed. Firstly, ship-based helicopters could be used to track the relative position of a school as a vessel approaches. This method was used in the experiment analyzed by Au and Perryman. Secondly, two or more vessels on parallel tracks could be used to test whether sighting distributions differ "inside" and "outside" the vessels. A number of crucial factors affect experiments of this latter type, such as the distance between the vessels' tracks. It is not clear whether this approach has enough resolution to detect slight amounts of movement which may nevertheless have an important effect on the estimation of density.

The final assumption (number 5) in this section concerns the accurate collection of angle and distance data, so that the perpendicular distance of a sighted school from the line of search may be calculated without error. Data from which transect lengths can be calculated can usually be collected without error and therefore do not present a problem in this respect. On aerial surveys, perpendicular distance is usually measured directly and although the methods used still contain an element of error, the problem is far less acute than it is on shipboard surveys. In these cases, perpendicular distance is calculated from estimates of sighting angle and sighting distance. Clearly, some degree of error is inevitable and the important factors are to ensure that this error is restrained to a minimum and is unbiased. The effect of variable or biased recording of angles and distances on resulting perpendicular distance distributions has not been thoroughly analyzed, although the problem has been recognized by Eberhardt (1978) and Eberhardt, Chapman and Gilbert (1979) and briefly investigated by Butterworth (personal communication). It is clear, though, that these distributions will be affected in the important region close to zero mostly by errors in angle measurement.

It was found, while using data collected by NMFS technicians aboard tuna seiners to make estimates of school density, that it often proved difficult to obtain a good fit of the sighting model f(x) to the observed perpendicular distances. The distribution of these data, close to zero, was frequently too uneven to allow accure estimation of f(0). Also, different models frequently gave very different estimates of f(0). Figure 5 shows an example set of data for spotted dolphins taken from a single 5° x 5° "square" in an area where fishing was primarily for tuna associated with dolphins. Clearly, the choice of model is crucial where the data are distributed in a similar manner to the figure. When the data were examined closely it was found that technicians typically rounded angles to convenient values, usually the nearest 10°. Simulations show that perpendicular distance distributions can be produced which, by rounding data to convenient values, display a similar shape to some of the field data. An investigation was conducted using simulated data based on distribution of angles and distances which correspond to those actually recorded at sea. Figure 6 shows perpendicular distance distributions calculated from sighting distance and angle data typical of spotted or spinner dolphins in areas where fishing is primarily for tuna associated with dolphins. Two factors make the distributions smoother and therefore more likely to allow a good fit of the sighting model. These are: 1) collecting angle and distance data more accurately and 2) grouping the perpendicular distance data into larger intervals. The former is the ideal solution and, although angles have mostly been rounded to the nearest 10° in the past, it should be possible for technicians to collect data to the nearest 5° and 1.0 nautical miles. This would produce distributions more like that shown in Figure 6b demonstrating that it is more important to estimate sighting angles accurately than it is distances. Data collected up until now are distributed more like the simulated data in Figure 6a. Clearly, the accuracy in fitting the sighting model to perpendicular distances will be greater if the data can be collected more accurately.

Although rounding of sighting angles to convenient values accounts for much of the irregular shape of the perpendicular distance distributions, there is another factor involved. There seems to be an inverse relationship between the frequency of sightings and sighting angle, implying that fishermen on tuna purse seiners spend proportionally less time searching as they sweep from ahead to abeam. Figure 7 shows sighting angle data for spotted and spinner dolphins collected from 1977 to 1979 in areas where fishing has been primarily for tuna associated with dolphins. The decrease in frequency with increasing angle is easily seen. The figure is a little misleading in that most of these data have been rounded to multiples of 10°, some to multiples of 5°, and the first interval therefore contains mostly angles of 0° and 10°, whereas the second contains mostly angles of 20° only, and so on. However, this does not alter the general picture. These data, when combined with sighting distance data, produce perpendicular distance distributions of a similar shape. This is of no consequence in itself, but when it is combined with the problem of rounding error, as discussed above, distributions can be produced to which it is even more difficult to fit a sighting model. Figure 8 shows perpendicular distance data for spotted and spinner dolphins collected in areas where fishing has been primarily for tuna associated with dolphins between 1977 and 1979. Although there is some variation, the distributions typically show a high frequency of sightings in the first interval and a lower frequency in following intervals which gradually declines further. The same general shape is observed whatever the interval width chosen, although the smaller the width the greater the variation in the distribution. It seems that these distributions can be explained by a combination of the effects of rounding error and more intense searching closer to the bow. Of the many distributions observed in this study, a range of shapes has been found corresponding to varying relative influences of these two factors. For future data to be readily analyzed, they should be collected with greater accuracy or, if this proves difficult, it may be possible for data to be grouped into intervals large enough to smooth out irregularities in the distributions but small enough to allow density estimation of sufficient accuracy. Investigations are continuing on this subject.

What the discussions and analyses of this section show is that there are several problems associated with making accurate estimates of density from data collected by technicians aboard tuna purse seiners. The investigation of the assumptions and the data has shown that we are closer to being able to use the data to make unbiased estimates of school density, but that problems still remain. Experiments and analyses undertaken in the near future should allow us even more confidence in being able to quantify the biases inherent in the data.

ASSUMPTIONS NECESSARY FOR UNBIASED CONVERSION TO DENSITY OF INDIVIDUALS

Two assumptions should be met if the conversion from density of groups to density of individuals is to be unbiased. Firstly, it must be assumed that group size is measured without error (assumption 8). Clearly, this is unlikely to be true for surveys of marine mammal populations, especially the smaller cetaceans. The size of a dolphin school is extremely difficult to estimate, both from aircraft or ships. From ships, the accuracy of school size estimation ranges from educated guesses if the school is not seen clearly to fairly accurate counts if the school is tracked down and/or set on. Results from data collected aboard the IATTC chartered seiner M/V GINA ANNE suggest that school size can be estimated fairly accurately by both technicians and crew (Allen, Bratten, Laake, Lambert, Perryman and Scott, 1980). For the crew as a whole and for each individual technician the mean overall difference between estimates and a "ground truth" count at the backdown channel was within 20% in each case. However, this does not imply that all data collected in the past can boast this degree of accuracy. Estimates made by technicians can differ widely from estimates made by crew members so that mean school sizes are not comparable. Additionally, trends in mean school sizes differ in many instances. Typically, mean school sizes estimated from technician data have declined more rapidly in recent years than estimates from crew data. Figure 9 shows mean school size estimates for spotted and spinner dolphins made by technicians and crews from 1974-1979 for the whole area of the eastern tropical Pacific tuna fishery. It is not clear which results most accurately reflect the truth. At present there seems to be no way to ascertain this, although improved methods of training technicians to estimate school size using films taken during the chartered cruise of the M/V GINA ANNE should result in increased confidence in estimates made by technicians in the future. Indeed, changing techniques of estimation by technicians is one possible explanation for the greater decline in these results. A further source of error in mixed species schools is the estimation of the percentage composition of each species present. This may be fairly small for schools which have been the target of a chase and set so that the technician has a good look at the animals, but may be fairly large for schools which are not followed up after sighting.

The second assumption (number 9) that the probability of detecting a target is independent of group size, may also be violated. It would seem likely that larger schools of marine mammals would be easier to detect simply because of their size. Indeed, Holt and Powers (1981) have shown that the probability of detecting a school from aerial and research vessel platforms in 1977 and 1979 was approximately proportional to the logarithm of school size. However, there are factors which complicate the simple application of such models for adjusting mean school sizes. Many sightings of dolphin schools are cued by flocks of associated birds, especially in areas where fishing is primarily for tuna associated with dolphins, and there may not necessarily be a correlation between the size of bird flock and the size of an associated school of dolphins. A study is planned to test for correlations between the sizes of aggregations of birds, dolphins and tuna found together. Also, the probability of detecting a group of dolphins of a given species is not dependent upon its size if that group is part of a mixed species dolphin school. Clearly, until there has been more analysis identifying the effects of school size on the probability of detection, this must be treated with caution.

It is probably true to say that there remain more problems with the assumptions in this section than in the two preceding sections. Neither of the problems discussed above has an immediate solution in the forseeable future. Where estimates of numbers of animals is not the ultimate goal of an analysis it may be more reasonable to assume that mean school size has not changed greatly over the last few years, despite some evidence to the contrary, and to use density of schools as a measure of abundance.

ESTIMATES OF DENSITY FROM AVAILABLE DATA

It is clear from the discussions in the preceding pages that there are a number of biases to be expected in estimates of dolphin density made from existing data collected aboard tuna purse seiners. It is also clear that several of these biases are capable of being at least reduced in estimates made from data collected in the future, while others need to be clarified by experimentation. The question posed in this section is how much confidence can be placed in estimates of density (absolute or relative) made from data currently available? The uncertainties discussed above suggest that absolute density estimation from these data is impossible at this stage. However, some degree of confidence may be expected for density estimates which are relative measures, capable only of being compared with each other and thus showing possible trends in population sizes.

There is no reason to believe that the proportion of schools remaining undetected on the line of search of the vessel has changed over the last few years of the fishery. If weather does affect sighting conditions, as seems probable, there will be some variation between years due to changes in the distributions of searching effort and weather over time and area, but this is unlikely to be a serious problem. Similarly, although measurement error in sighting distances and, particularly, angles does cause problems in fitting sighting models to some distributions, the effect of this may be expected to have remained constant through this period. However, the variation that does exist between years can lead to differences in the validity of the various sighting models available, as is discussed further below. The existence of undetected evasive movement in response to an approaching vessel, and the magnitude of this phenomenon if it is significant, are also unlikely to have changed since data collection began in 1974. During the 1960's, one might have expected target species of dolphins to become more and more wary of tuna boats as the purse seine fishery developed, but since the early 1970's it is reasonable to assume that any learned behavior of this kind has reached a plateau in areas which have been heavily fished for some time.

The conflicting evidence between crew and technician estimates of mean school size do present a problem with respect to the comparison of relative measures of density between years, but any bias in estimates of mean school size due to larger schools being over-represented in the sample should be constant between years. It is true that methods of school size estimation have improved greatly in recent years, and this may, at least partly, account for the decreasing trend in mean school size estimates calculated from technician data (Figure 9). It is also possible that mean school size has dropped and that crew estimates have increased in some manner. It may also be a combination of these factors. The two extreme courses of action would be to assume either that technician data were correct and to treat density of individuals using technician school size data as a relative measure of population size, or that crew data were correct and there has been essentially no significant change in mean school size so that density of schools is a valid relative measure.

Before a selection of results are presented, it is first necessary to examine the effects of different sighting models on the estimation of f(0). Two causes of problems in fitting models to distributions of perpendicular distances have been discussed; the rounding of sighting data, particularly angles, to convenient values and the more intense searching ahead of the vessel relative to abeam. The two sighting models chosen in this analysis for comparison were the Fourier series, a robust estimator capable of providing an accurate fit to any set of data and the exponential power series, a monotonically decreasing estimator with great flexibility able to approximate functions ranging from almost uniform to those decreasing very steeply at the origin. Given accurate perpendicular distance data, both models estimate similar values for the quantity f(0). Given inaccurate data, these estimates can be very different as demonstrated by Figure 5. The question of which model should be used is not easily answered. If it were assumed that observed distributions were spiked close to zero entirely due to more intense searching ahead of the vessel so that the frequency of observed sightings close to the line of search accurately represented the true frequency of schools, then the Fourier series would provide the most accurate estimate of f(0). Conversely, if it were assumed that distributions were spiked close to zero entirely due to measurement error, then the exponential power series would estimate f(0) more accurately. Since the truth seems to lie somewhere between these two extremes, perhaps the most just way to represent the results of the analyses of these data is to use both models for comparison.

The data from the NMFS merged effort and sighting files have been edited in the following manner. Data collected outside the eastern tropical Pacific have been eliminated, as have data collected aboard research or chartered cruises. In addition, cruises were excluded where perpendicular distances could be calculated for less than 75% of the sightings. Although some cruises span calendar years, analyses are limited to single years. The analysis has dealt only with sightings made while the observer was on marine mammal watch. Data collected while the vessel was "circling" logs or free swimming tuna have been ignored. Sightings where perpendicular distance could not be calculated have necessarily been omitted, as have those where no species code was recorded. Legs of effort, and sightings made within them were discarded if there were errors in the beginning and/or end times or if the vessel speed was zero. If vessel speed was not recorded for a leg it was assumed to be the same as in the previous leg. If position was not collected for a leg it was assumed to be the same as in the previous leg unless this was not on the same day, in which case it was discarded. Finally, some positions erroneously recorded as south of the equator instead of north, and conversely north instead of south, were corrected.

The results presented are for the years 1977-1979. Data collected before 1977 have been ignored in the analyses for two reasons. Firstly, in 1975 and 1976 technicians were apparently incorrectly trained in data collection methodology such that sighting distances and angles were not recorded until the school of marine mammals was physically seen. Many sightings of dolphin schools, particularly in areas where fishing is primarily for dolphin-associated tuna, are cued by flocks of birds which can be detected at greater distances than the dolphin schools themselves. Consequently, the vessel had frequently turned towards the school before sighting data were recorded, resulting in much greater proportions of small sighting angles (mostly 0°) and in greater proportions of small sighting distances. Such severe biases in the data render them useless for density estimation. Secondly, in 1974 there was an inflated proportion of angles recorded as 0° suggesting that sighting angles had been rounded non-randomly to zero. This renders the data for this year suspect, also.

Figure 10 shows estimates of school density for spotted and spinner dolphins calculated using both the Fourier series sighting model and the exponential power series model for areas where fishing has been primarily for tuna not associated with dolphins and for areas where fishing has been primarily for tuna associated with dolphins both inside and outside the CYRA (see Figure 3). The estimates have remained approximately constant during the three year period except for estimates made using the Fourier series model in areas where fishing has been primarily for tuna associated with dolphins inside the CYRA. The Fourier series is strongly dependent on the proportion of perpendicular distances which are zero. This declined between 1977 and 1979 in the area in question and the declining trend in density is considered to be due to this and not to a real decrease in density.

Figure 11 shows estimates of animal density for the same data stratifications as above. For both spotted and spinner dolphins in areas where fishing has been primarily for tuna associated with dolphins inside the CYRA there is evidence of a declining trend in density, this being stronger for estimates made using the Fourier series model than for estimates made using the exponential power series model. There is also evidence of a declining trend in the density of spotted dolphins in areas where fishing has been primarily for tuna associated with dolphins outside the CYRA. These declining trends in animal density are due largely to declining trends in mean school size calculated from technician school size estimates (Figure 8).

It is interesting to note that the Fourier series is not necessarily the best model to use in the analyses of data from areas where fishing has been primarily for dolphin-associated tuna. This demonstrates that although the Fourier series is frequently an automatic choice of model if data are good, it is best treated with caution if data are poor.

SUMMARY

The increased application of line transect sampling methods to marine mammal populations in recent years has highlighted many of the problems in adopting this approach. The aim of a marine mammal survey is usually to obtain an absolute density estimate of the species in question which can then be converted to total number of animals present. If this cannot be achieved, relative density estimates capable of being compared between years or areas may be possible. In this report, data collected by NMFS technicians aboard tuna purse seiners have been analyzed to demonstrate the effects of violating some of the assumptions necessary for line transect sampling to give unbiased estimates of density. The analyses have been used to assess the validity of making estimates of density from these data using these methods. With respect to these data, some problems seem to be under control, others are being studied and others remain to be investigated by experimentation and analysis.

The problems which have been at least partially accounted for are those concerning non-random search, irregular perpendicular distance distributions and variable distributions of searching effort. The analyses in this study showed that effort has not been concentrated in areas where dolphin school density hass been estimated to be

highest in ares where fishing has been primarily for tuna associated with dolphins. In other words, fleet searching is effectively at random. Irregular distributions of observed perpendicular distances can be explained by two factors; the rounding of sighting angles and distances to convenient values and a greater searching intensity towards the bow of the vessel. There also may be other factors involved but distributions typical of the data investigated here could be accounted for by a combination of rounding error and non-uniform searching with respect to angle. Differences in distributions of searching effort between years can be minimized by stratifying the area of the tuna fishery in the eastern tropical Pacific into areas where fishing has been primarily for tuna associated with dolphins and areas where fishing has been primarily for tuna not associated with dolphins.

Problems currently being investigated include the effect of weather conditions as measured by Beaufort scale on density estimates, the effect of detecting schools through bird cues on estimates of mean school size, and the feasibility of grouping perpendicular distance data. The IATTC has searching effort data which is stratified by Beaufort scale so that density estimates can be made for different weather conditions. A study to determine whether density is correlated to Beaufort scale is planned. From 1974 to 1978 the NMFS collected data on the size of bird aggregations associated with dolphin schools, and a further study is planned to determine whether size of bird flock is correlated with size of dolphin school or with size of tuna school where this information is available. A study is also planned to investigate the effects of grouping perpendicular distances calculated from sighting distance and angle distributions on the estimation of f(0) in order to provide more accurate estimates of density.

Problems which remain to be investigated include the bias in assuming that g(0) is equal to unity, undetected movement away from the line of search and variations in mean school size estimates. It is not clear how to estimate the proportion of dolphin schools missed on the line of search, but if the not unreasonable assumption that in perfect sighting conditions g(0) equals unity is made, the problem reverts to one of changes in g(0) due to weather conditions. Undetected movement should be able to be estimated directly. A brief preliminary study has already shown that schools can be tracked by a helicopter as the vessel approaches on its line of search. A more comprehensive study may provide the information needed to assess whether movement is a problem in density estimation of dolphins affected by the eastern tropical Pacific tuna fishery. Problems with mean school size estimates can probably never be completely solved. The best that may be hoped for is to be able to train technicians sufficiently well so that mean school sizes from their data can be accepted as true estimates. Crew school size estimates harbor so much uncertainty and variation that it is unreasonable to use them as absolute measures of school size. However, during periods where technician mean school size estimates change considerably, crew estimates may provide a useful relative comparison.

It seems clear that absolute estimates from these tunaboat data are not feasible at this stage, either from historical data or from data collected in the immediate future. Until the problems involving schools missed on the line of search, movement and weather conditions are investigated estimates will have to be treated as relative to one another. Stratification of the data into areas of different fishing modes allows the density of schools in any one area to be compared from year to year with a reasonable degree of confidence. In the future, methods of collection and analysis of tunaboat data may be developed which will allow density estimates to be taken as absolute measures, but until then estimates should be treated as relative measures only.

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FIGURE LEGENDS

Figure 1. Approximate area of the eastern tropical Pacific tuna fishery.

Figure 2. Representation of sampling effort by NMFS technicians aboard tuna seiners in (a) the 2nd quarter of 1977 and (b) the 2nd quarter of 1978.

Figure 3. Areas of the eastern tropical Pacific tuna fishery where (A) fishing has been primarily for tuna associated with dolphins and (B) fishing has been primarily for tuna not associated with dolphins. Data from IATTC records of the proportion of "porpoise" sets and "non-porpoise" sets in 5° x 5° "squares" from 1970 to 1979.

Figure 4. Distribution of data collected by NMFS technicians for spotted dolphins in 1977 in a 15° x 15° "square". (a) Searching effort as line length of track searched. (b) Sightings per 1000 nm searched.

Figure 5. Observed perpendicular distances recorded by NMFS technicians aboard tuna purse seiners in a single 5° x 5° "square" in 1977 for schools of spinner dolphins, fitted by the Fourier series model and the exponential power series model.

Figure 6. Perpendicular distance distributions calculated from simulated sighting angle and sighting distance data typical of data collected by NMFS technicians aboard tuna purse seiners for (a) angles rounded to nearest 10°, distances rounded to nearest 1.0 nm; (b) angles to 5°, distances to 0.5 nm, (c) angles to 2°, distances to 0.2 nm. Each series of three distributions shows the same data with different groupings.

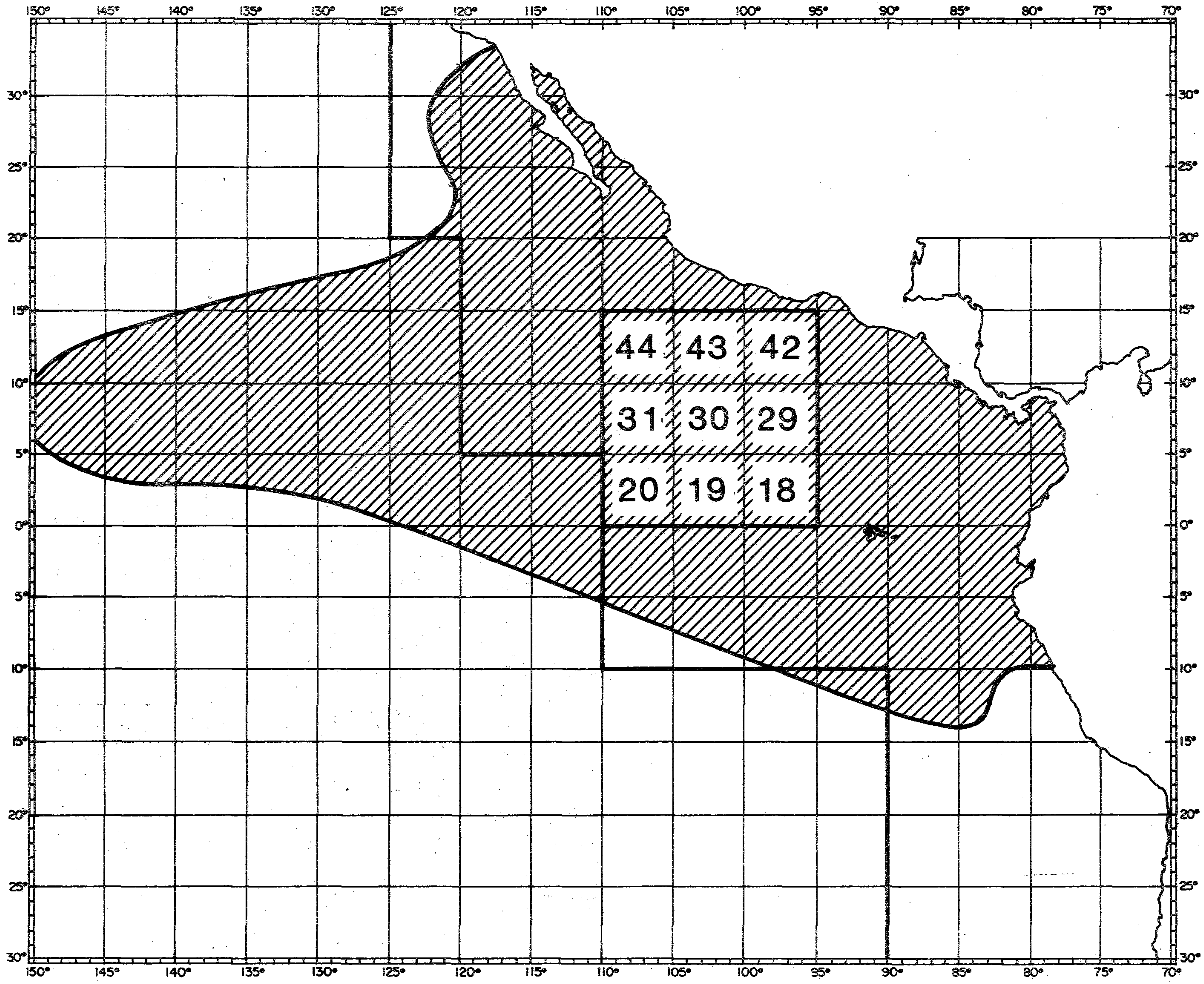
Figure 7. Distributions of sighting angles recorded by NMFS technicians aboard tuna purse seiners for spotted dolphin schools and spinner dolphin schools in 1977, 1978 and 1979 in areas where fishing has been primarily for tuna associated with dolphins.

Figure 8. Distributions of perpendicular distances calculated from data collected by NMFS technicians aboard purse seiners for spotted dolphin schools and spinner dolphin schools in 1977, 1978 and 1979 in areas where fishing has been primarily for tuna associated with dolphins.

Figure 9. Estimates of mean school sizes calculated from data recorded by NMFS technicians aboard tuna purse seiners from 1977 to 1979 for spotted dolphin schools made by (a) crew and (b) technician and for spinner dolphin schools made by (c) crew and (d) technician.

Figure 10. Estimates of school density calculated from data collected by NMFS technicians aboard tuna purse seiners for the years 1977 to 1979 for spotted dolphin schools (a)-(f) and spinner dolphin schools (g)-(l), using the Fourier series sighting model (a)-(c) and (g)-(i) and the exponential power series sighting model (d)-(f) and (j)-(l), for areas where fishing has been primarily for tuna not associated with dolphins (a), (d), (g) and (j) and areas where fishing have been primarily for tuna associated with dolphins inside the CYRA (b), (e), (h) and (k) and outside the CYRA (c), (f), (i) and (l).

Figure 11. Estimates of animal density calculated from data collected by NMFS technicians aboard tuna purse seiners from 1977 to 1979 for the same stratifications as Figure 10. Technicians estimates of mean school size have been used in these calculations.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43
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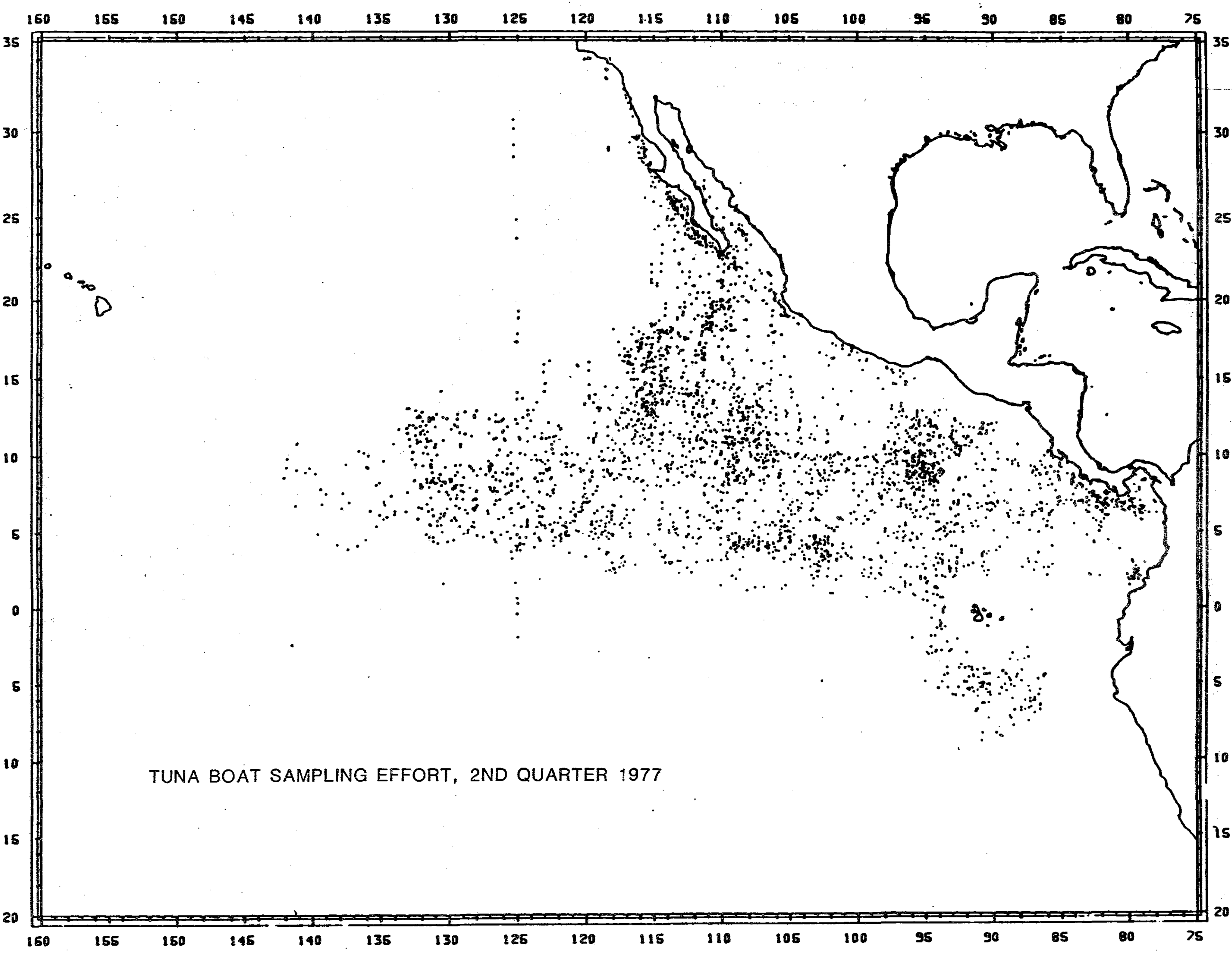
Figure 1



TUNA BOAT SAMPLING EFFORT, 2ND QUARTER 1977

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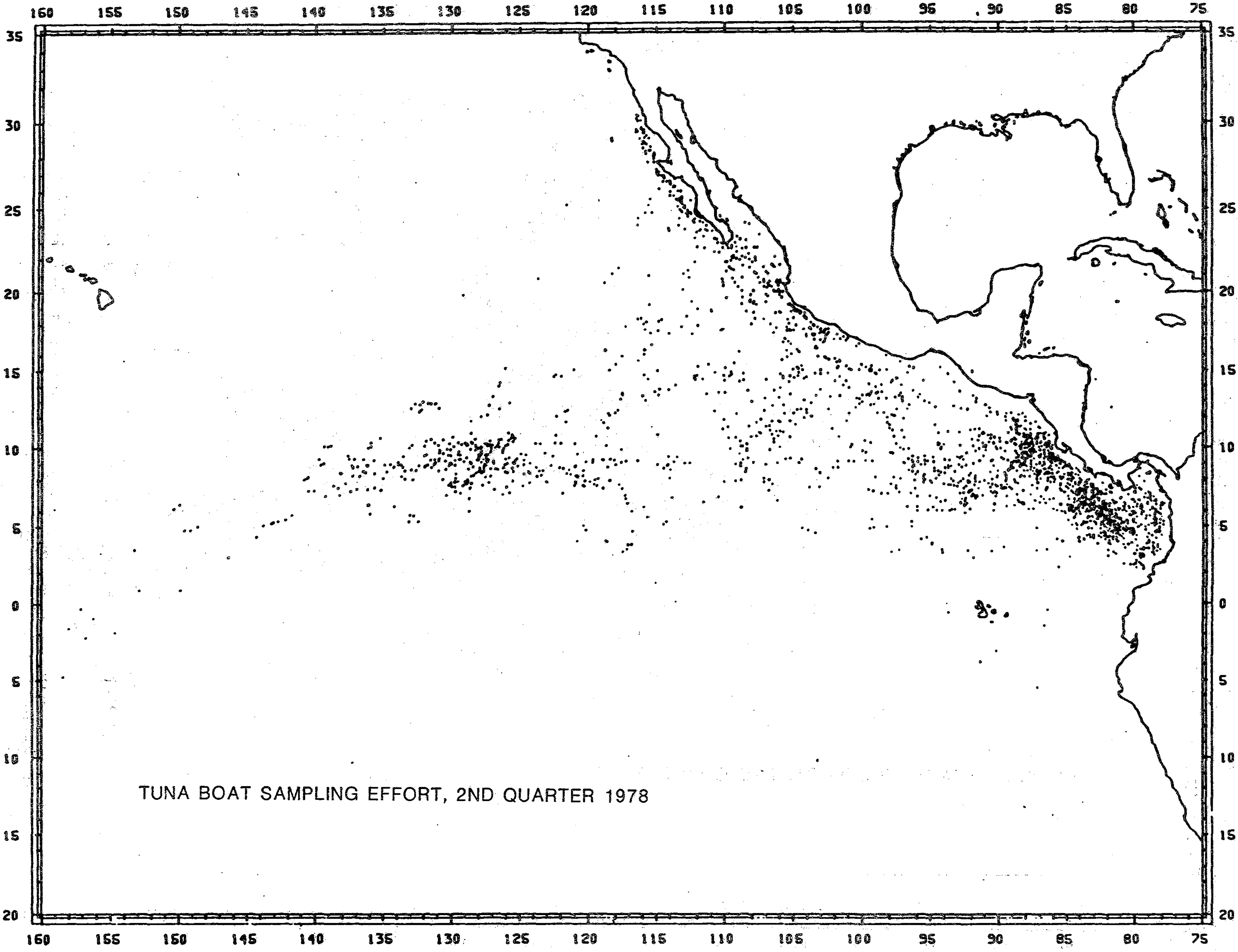
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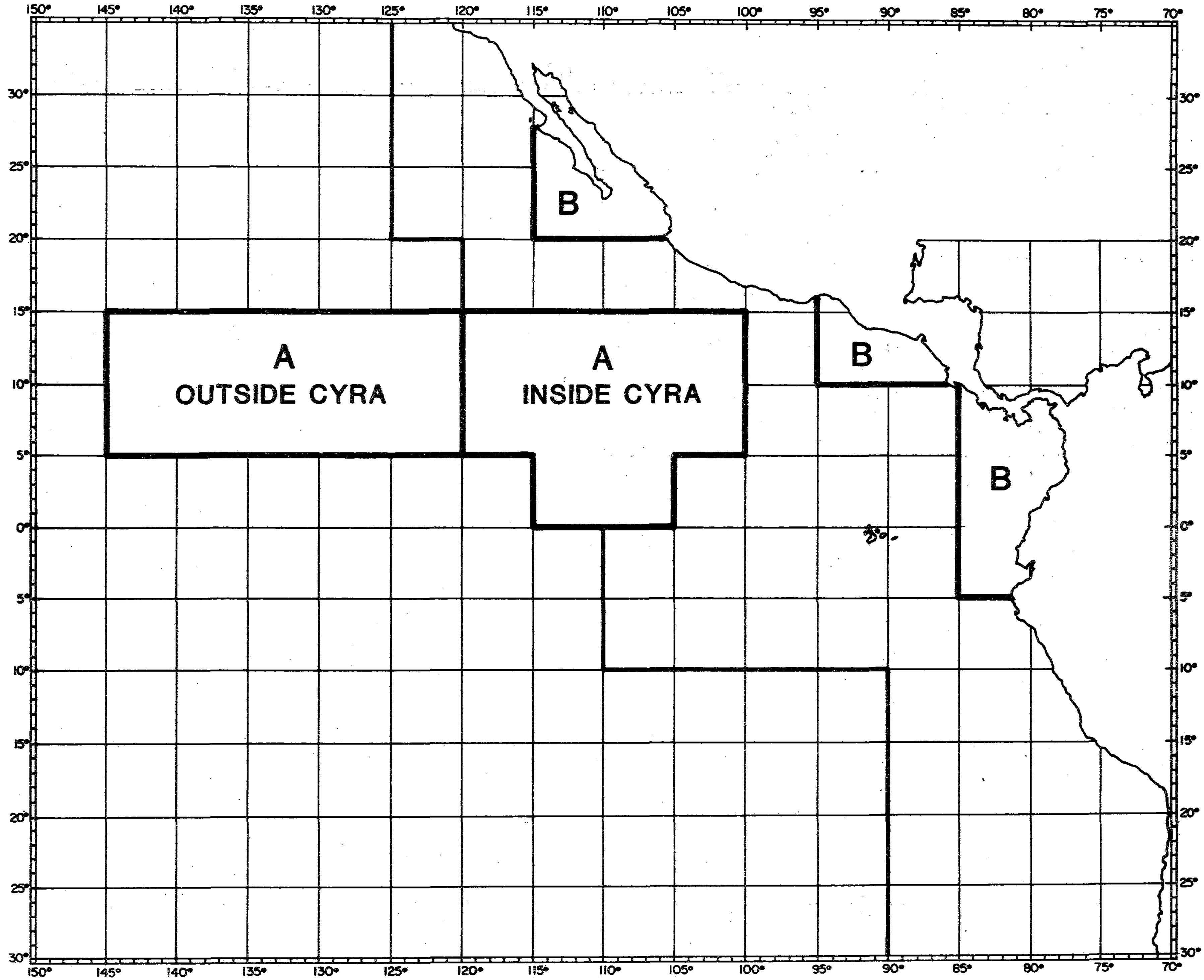
20
TUNA BOAT SAMPLING EFFORT, 2ND QUARTER 1978

Figure 2(b)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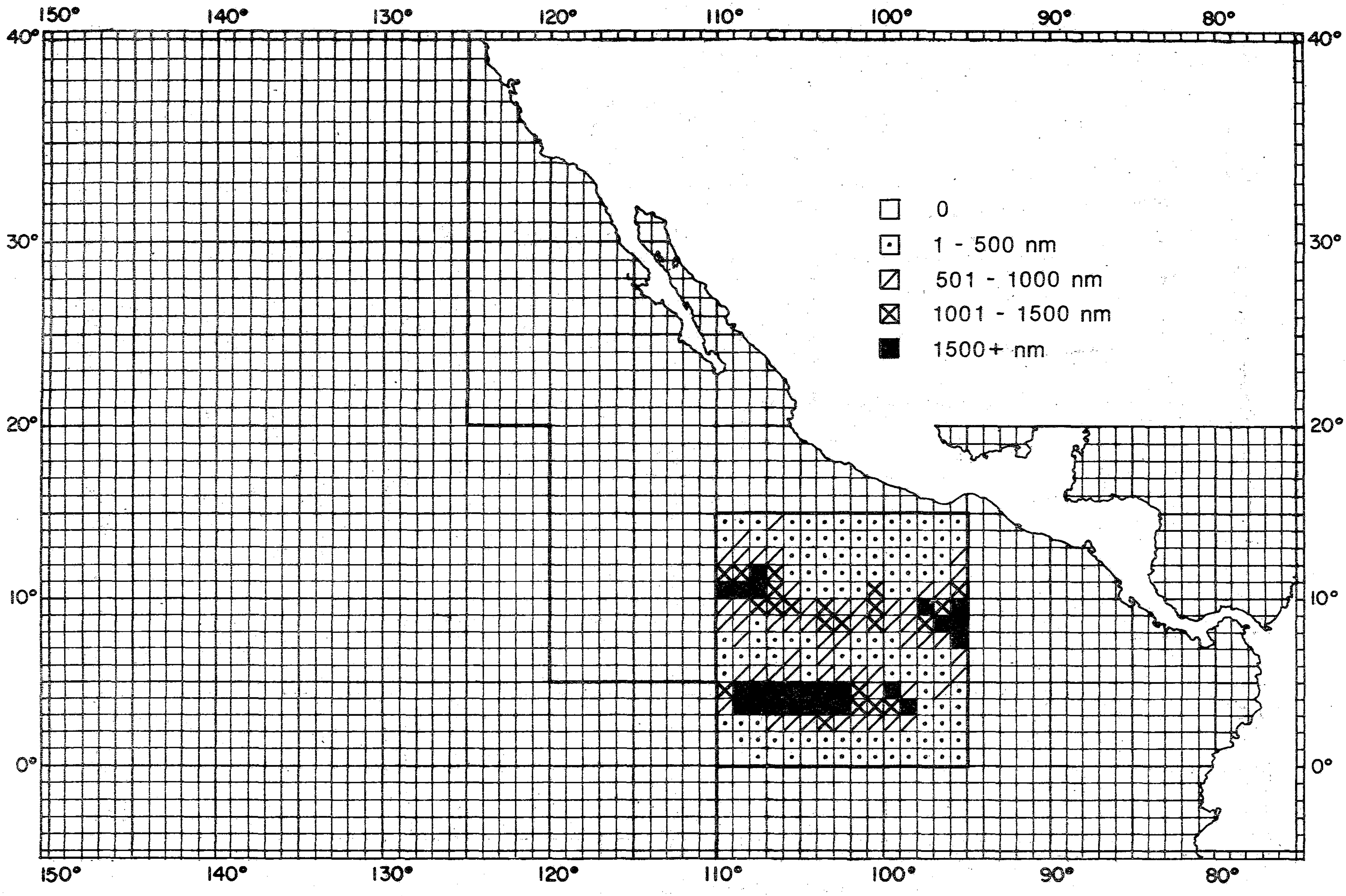
30°
A
OUTSIDE CYRA
A
INSIDE CYRA
B
B
B

Figure 3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80°
40°
30°
20°
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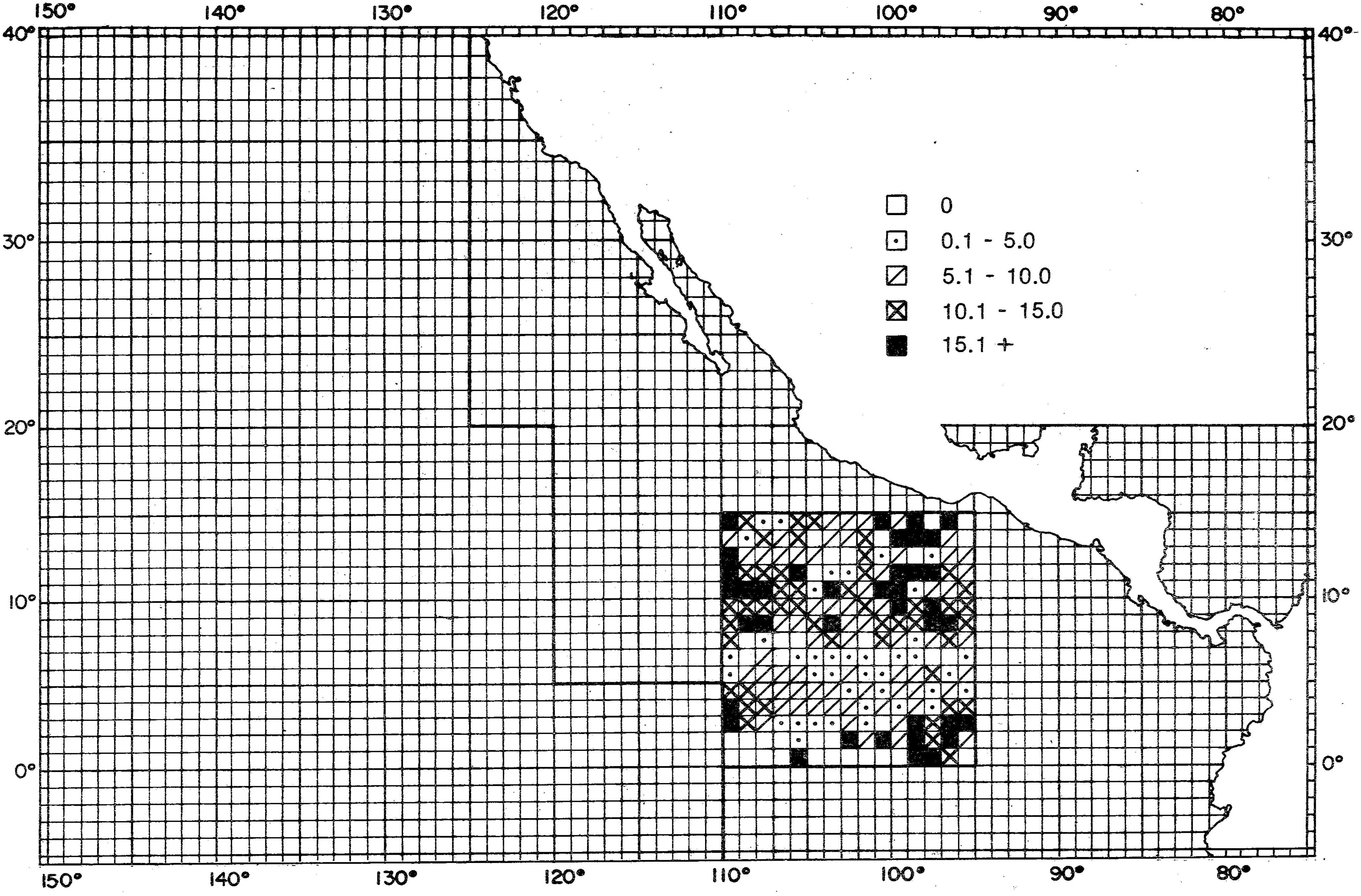
0°
□ 0
⊡ 1 - 500 nm
▨ 501 - 1000 nm
☒ 1001 - 1500 nm
■ 1500+ nm

Figure 4(a)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90°
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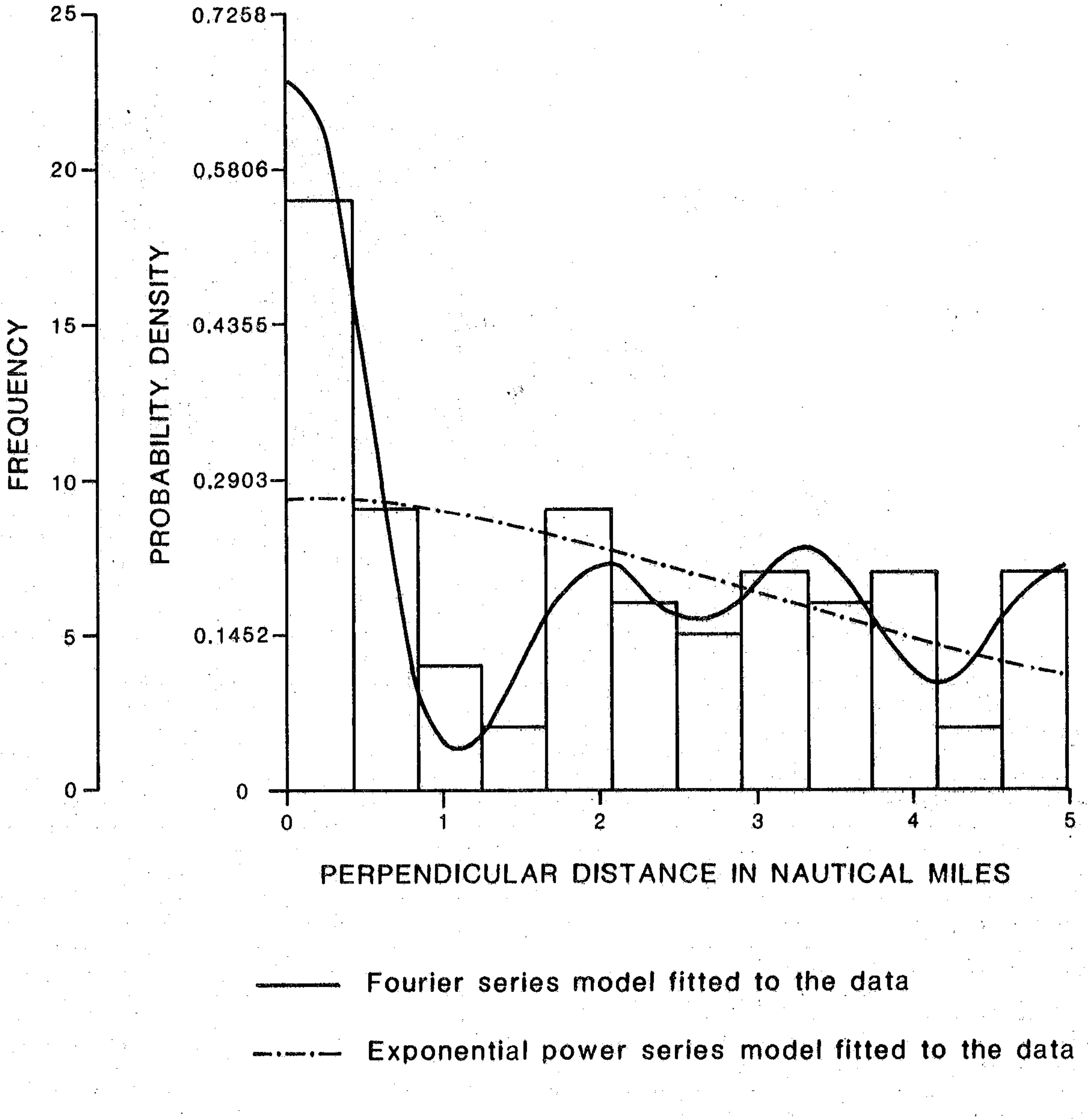
40°
30°
20°
10°
0°
□ 0
⊡ 0.1 - 5.0
◪ 5.1 - 10.0
☒ 10.1 - 15.0
■ 15.1 +

Figure 4(b)



FREQUENCY
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20
15
10
5
0
PROBABILITY DENSITY
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0.5806
0.4355
0.2903
0.1452
0
0
1
2
3
4
5
PERPENDICULAR DISTANCE IN NAUTICAL MILES
Fourier series model fitted to the data
Exponential power series model fitted to the data

Figure 5

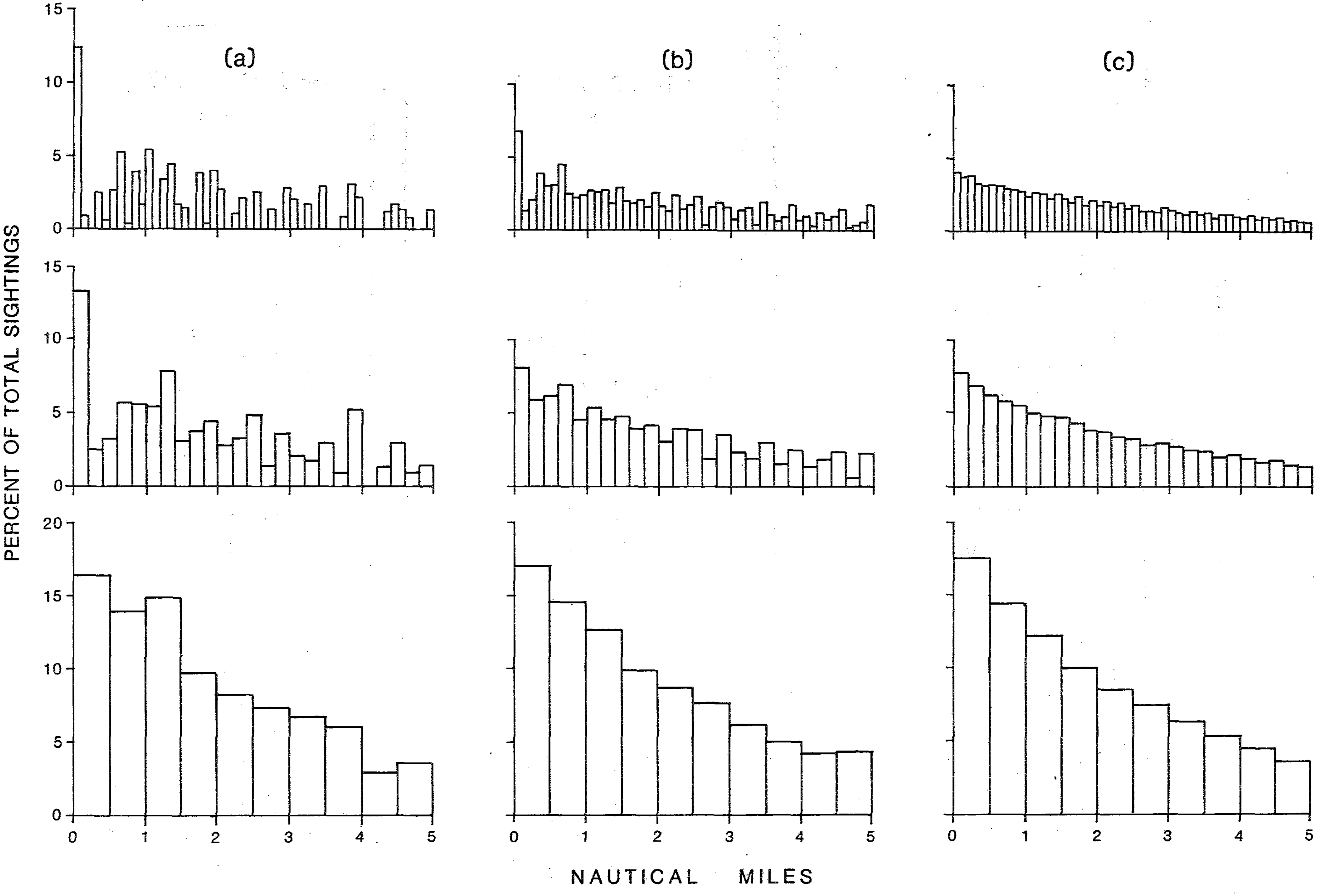
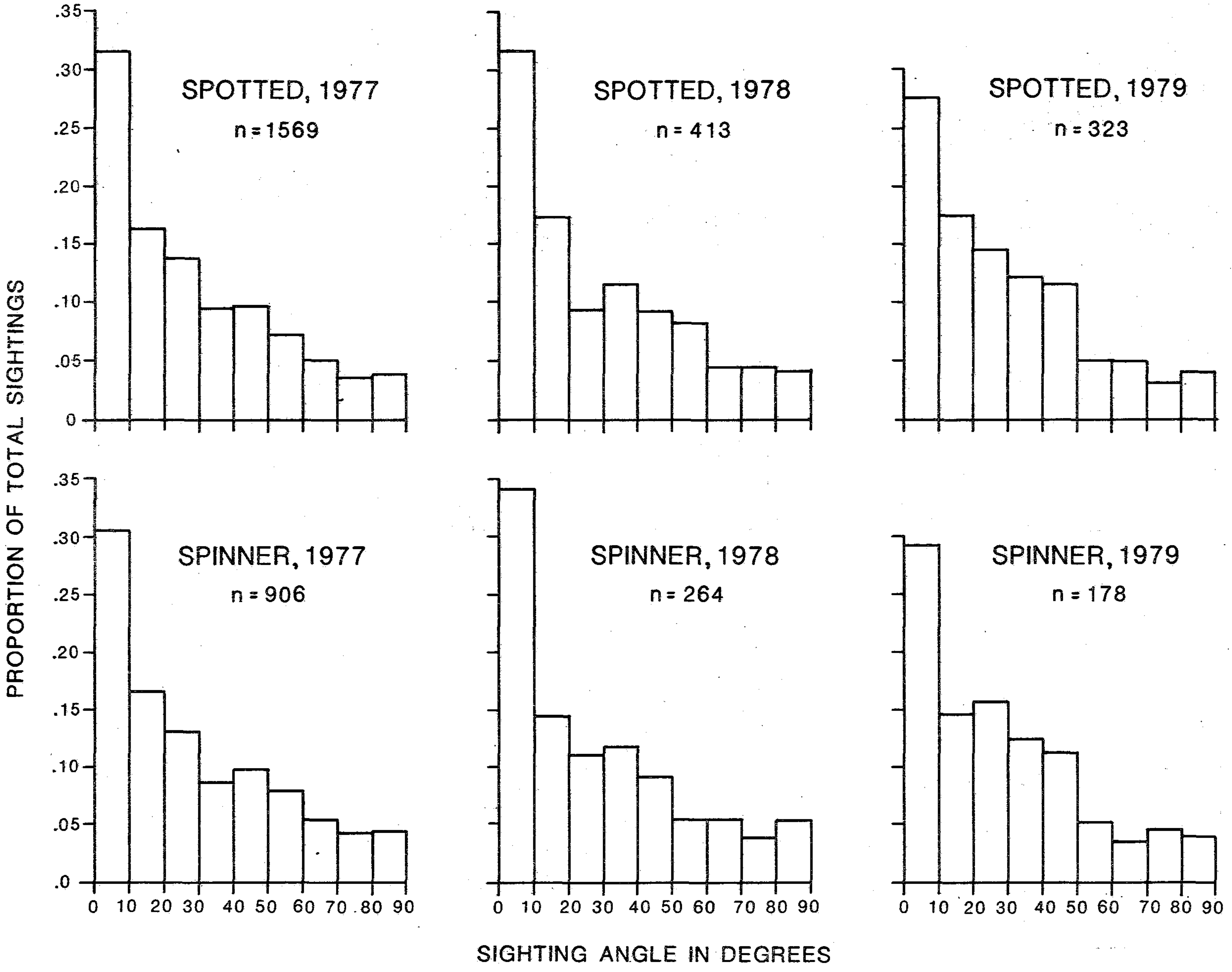

(a)
(b)
(c)
PERCENT OF TOTAL SIGHTINGS
15
10
5
0
20
0
1
2
3
4
5
NAUTICAL MILES

Figure 6



PROPORTION OF TOTAL SIGHTINGS
.35
.30
.25
.20
.15
.10
.05
0
.0
SPOTTED, 1977
n = 1569
SPOTTED, 1978
n = 413
SPOTTED, 1979
n = 323
SPINNER, 1977
n = 906
SPINNER, 1978
n = 264
SPINNER, 1979
n = 178
0 10 20 30 40 50 60 70 80 90
SIGHTING ANGLE IN DEGREES

Figure 7

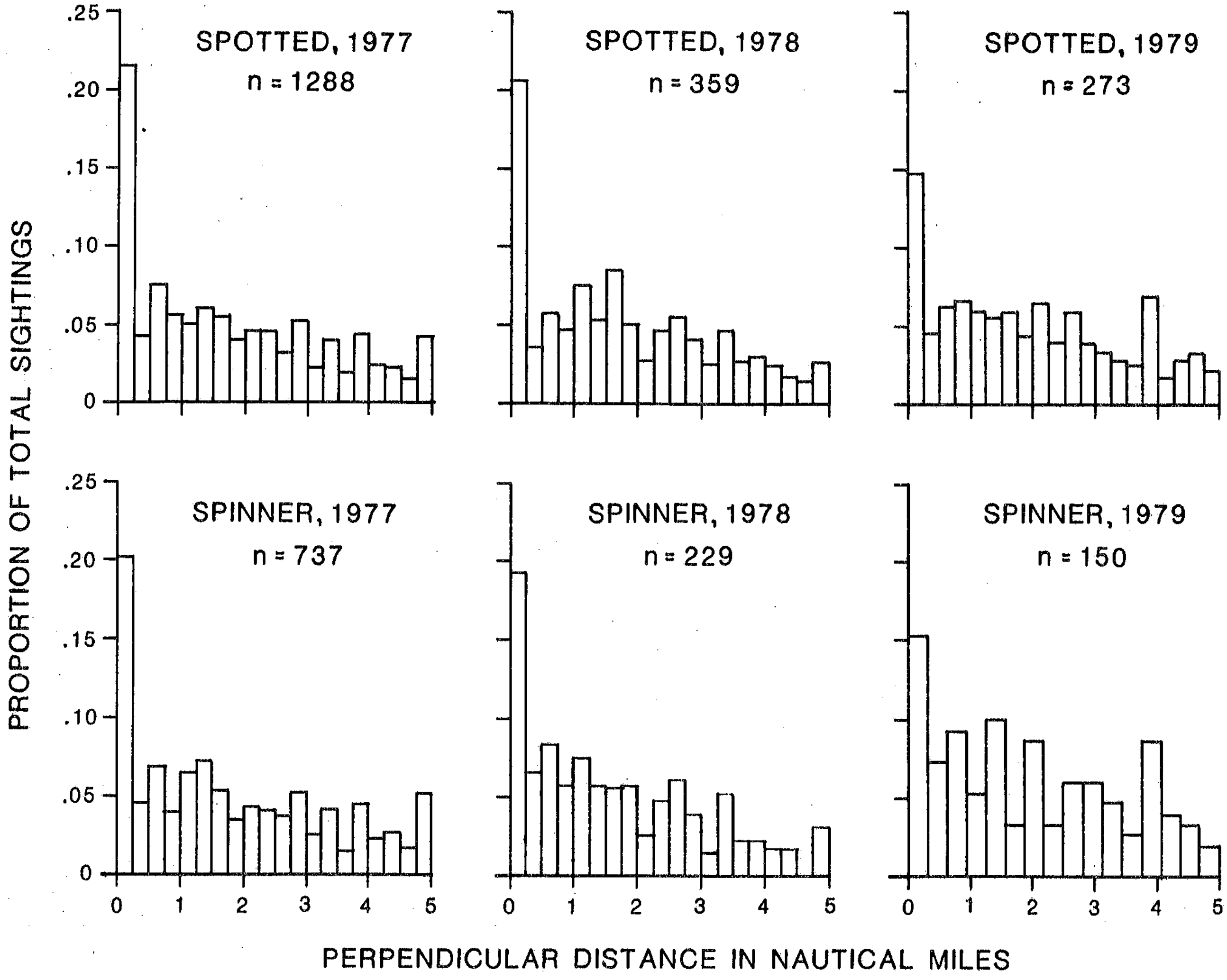
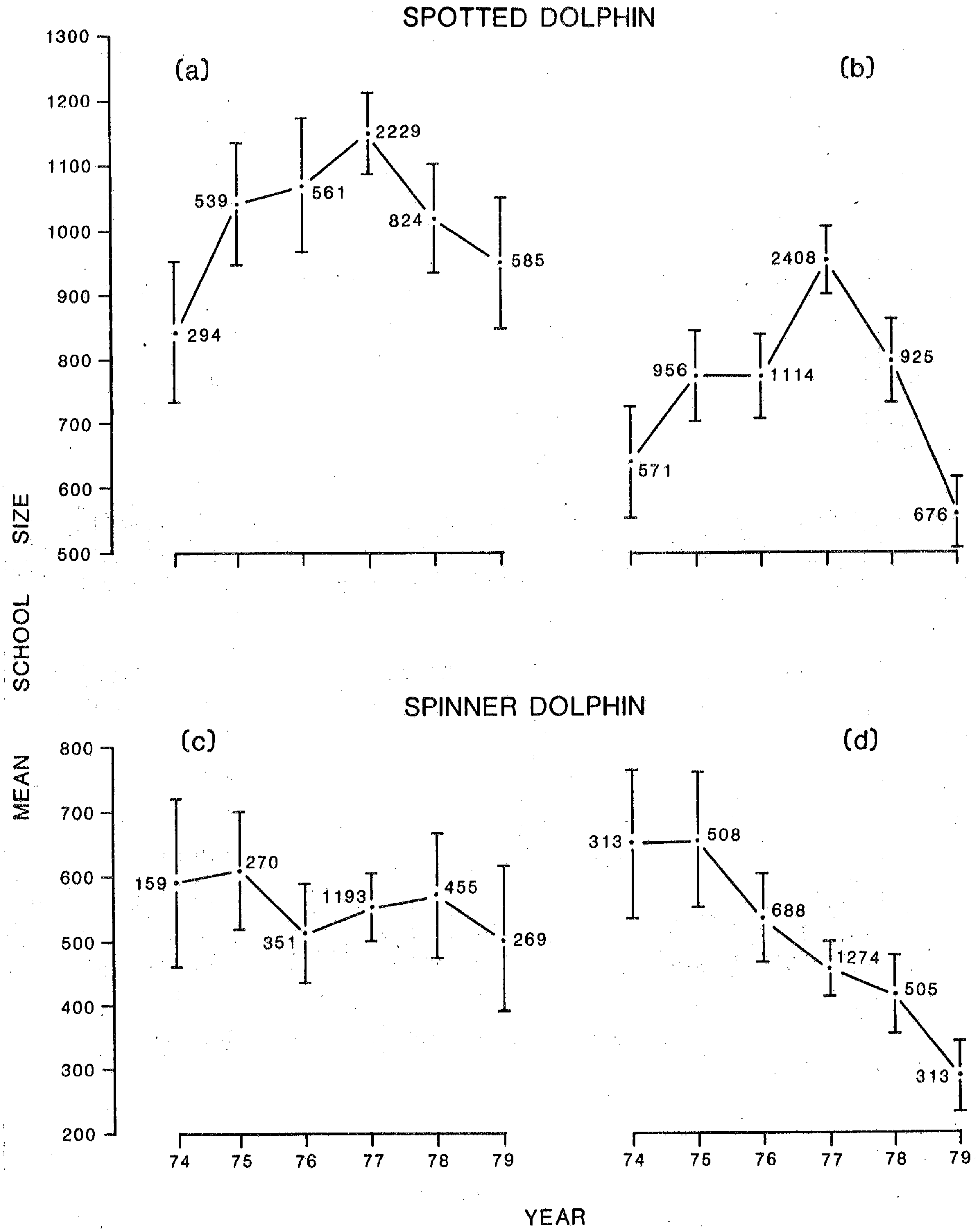

SPOTTED, 1977
n = 1288
SPOTTED, 1978
n = 359
SPOTTED, 1979
n = 273
SPINNER, 1977
n = 737
SPINNER, 1978
n = 229
SPINNER, 1979
n = 150
PROPORTION OF TOTAL SIGHTINGS
.25
.20
.15
.10
.05
0
0
1
2
3
4
5
PERPENDICULAR DISTANCE IN NAUTICAL MILES

Figure 8


SPOTTED DOLPHIN
SPINNER DOLPHIN
(a)
(b)
(c)
(d)
MEAN SCHOOL SIZE
YEAR
1300
1200
1100
1000
900
800
700
600
500
400
300
200
74
75
76
77
78
79
294
539
561
2229
824
585
571
956
1114
2408
925
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688
1274
505
313

Figure 9

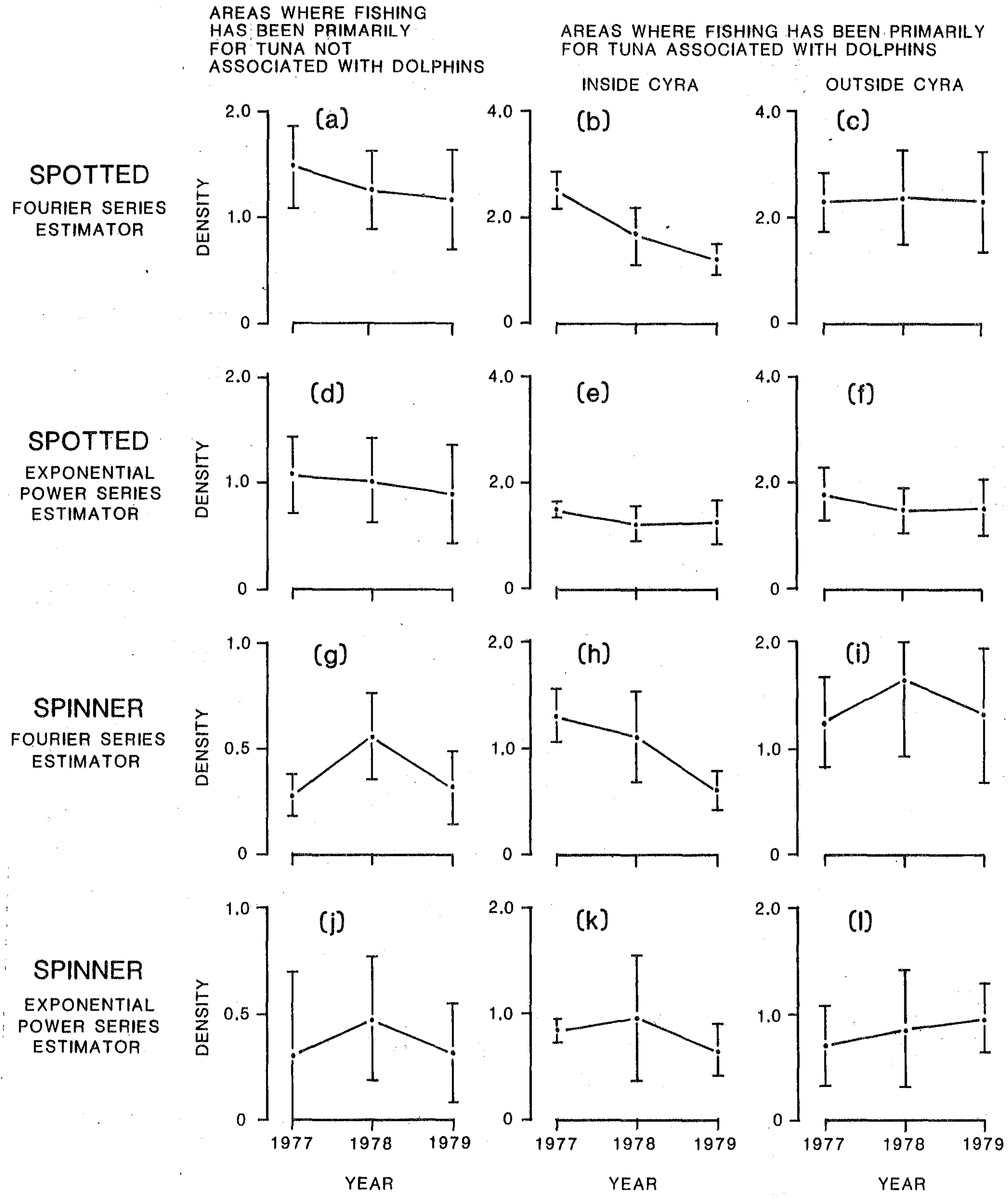
AREAS WHERE FISHING HAS BEEN PRIMARILY FOR TUNA NOT ASSOCIATED WITH DOLPHINS
AREAS WHERE FISHING HAS BEEN PRIMARILY FOR TUNA ASSOCIATED WITH DOLPHINS
INSIDE CYRA
OUTSIDE CYRA
SPOTTED
FOURIER SERIES ESTIMATOR
SPOTTED
EXPONENTIAL POWER SERIES ESTIMATOR
SPINNER
FOURIER SERIES ESTIMATOR
SPINNER
EXPONENTIAL POWER SERIES ESTIMATOR
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
DENSITY
0
0.5
1.0
2.0
4.0
1977
1978
1979
YEAR

Figure 10

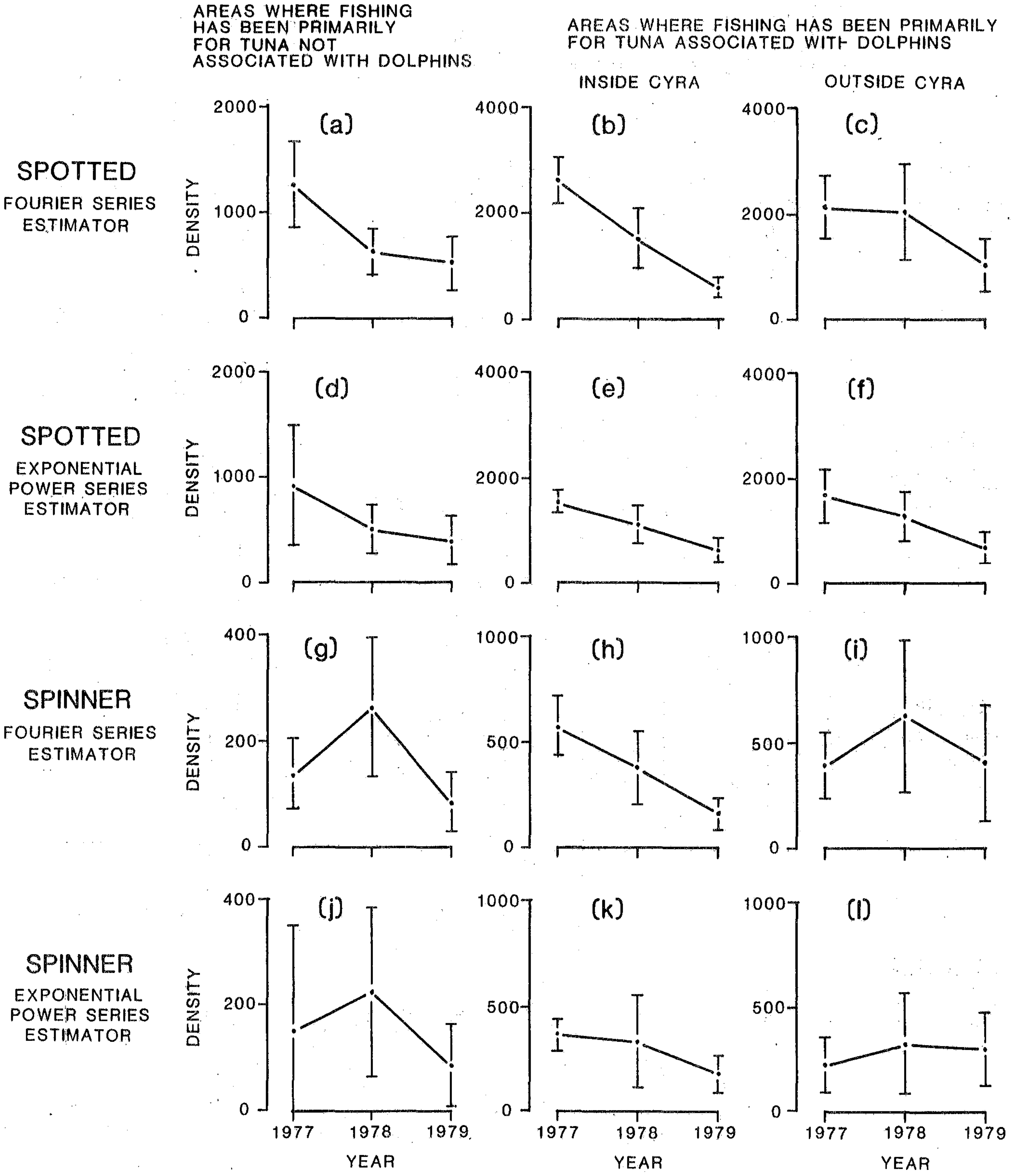
AREAS WHERE FISHING HAS BEEN PRIMARILY FOR TUNA NOT ASSOCIATED WITH DOLPHINS
AREAS WHERE FISHING HAS BEEN PRIMARILY FOR TUNA ASSOCIATED WITH DOLPHINS
INSIDE CYRA
OUTSIDE CYRA
SPOTTED
FOURIER SERIES ESTIMATOR
SPOTTED
EXPONENTIAL POWER SERIES ESTIMATOR
SPINNER
FOURIER SERIES ESTIMATOR
SPINNER
EXPONENTIAL POWER SERIES ESTIMATOR
DENSITY
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
0
1000
2000
4000
200
400
500
1977
1978
1979
YEAR

Figure 11

TABLE 1. Results of a test for non-random searching patterns using data from all areas. Significant departure of regression co-efficient (b) from unity represents evidence of non-randomness. Regression equation is $\ln(n) = \ln(a) + b \ln(L)$ where a and b are constants, n is schools sighted and L is length of search track.

Species	Year	b	S.E. (b)	Student's t	d.f.	Significant deviation from b=1 at 5% level
Spotted	1974	0.594	0.382	1.063	15	no
Spotted	1975	1.109	0.347	0.314	20	no
Spotted	1976	0.134	0.275	3.149	38	yes
Spotted	1977	1.111	0.166	0.669	45	no
Spotted	1978	0.665	0.207	1.618	41	no
Spotted	1979	0.489	0.278	1.838	35	no
Spinner	1974	0.487	0.366	1.402	14	no
Spinner	1975	0.746	0.411	0.618	18	no
Spinner	1976	-0.027	0.242	4.242	38	yes
Spinner	1977	1.205	0.185	1.108	44	no
Spinner	1978	0.619	0.200	1.905	41	no
Spinner	1979	0.357	0.318	2.022	35	no

TABLE 2. Results of a test for non-random searching patterns using data from all areas. Significant departure of the regression co-efficient (b) from unity represents evidence of non-randomness. Regression equation is $\ln(n\hat{f}(o)) = \ln(a) + b \ln(L)$ where a and b, are constants, $n\hat{f}(o)$ is the number of sighted schools adjusted for sighting conditions, and L is length of search track.

Species	Year	b	S.E. (b)	Student's t	d.f.	Significant deviation from b=1 at 5% level
Spotted	1977	0.848	0.172	0.884	27	no
Spotted	1978	0.902	0.174	0.563	15	no
Spotted	1979	0.518	0.338	1.426	11	no
Spinner	1977	0.690	0.237	1.308	22	no
Spinner	1978	0.450	0.153	3.595	9	yes

TABLE 3. Results of a test for non-random searching patterns using data from areas where fishing has been primarily for tuna associated with dolphins. Significant departure of regression co-efficient (b) from unity represents evidence of non-randomness. Regression equation is $\ln(n) = \ln(a)+b\ln(L)$ where a and b are constants, n is schools sighted and L is length of search track.

Species	Year	b	S.E. (b)	Student's t	d.f.	Significant deviation from b=1 at 5% level
Spotted	1976	0.615	0.238	1.618	15	no
Spotted	1977	1.223	0.101	2.208	17	yes
Spotted	1978	1.016	0.261	0.061	15	no
Spotted	1979	1.704	0.337	2.089	11	no
Spinner	1976	0.437	0.144	3.910	15	yes
Spinner	1977	1.359	0.287	1.251	17	no
Spinner	1978	0.874	0.324	0.389	15	no
Spinner	1979	1.685	0.369	1.856	11	no

TABLE 4. Results of a test for non-random searching patterns using data from areas where fishing has been primarily for tuna associated with dolphins. Significant departure of the regression co-efficient (b) from unity represents evidence of non-randomness. Regression equation is $\ln(n\hat{f}(o)) = \ln(a) + b\ln(L)$ where a and b, are constants, $n\hat{f}(o)$ is the number of sighted schools adjusted for sighting conditions, and L is length of search track.

Species	Year	b	S.E. (b)	Student's t	d.F.	Significant deviation from b=1 at 5% level
Spotted	1977	1.081	0.236	0.343	12	no
Spotted	1978	0.630	0.386	0.959	5	no
Spotted	1979	1.214	0.383	0.559	5	no
Spinner	1977	0.827	0.337	0.513	12	no