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COMPARISONS OF THE EFFICIENCY OF PURSE SEINE NETS OF DIFFERENT DESIGNS IN RELEASING DOLPHINS

by

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CONTENTS

ABSTRACT

Data collected by National Marine Fisheries Service and IATTC technicians who observed 119 purse seine trips during 1977 to 1979 were used to compare the effectiveness of releasing dolphins from fine mesh and super apron nets. The comparisons were made by fitting linear models to dolphin kill per set, kill per ton, and frequency of sets in the following categories: no dolphin mortality, 15 or more dolphins killed, net collapses, and gear malfunctions. The variables included in the models were years, gear type, dolphin species, geographic location, number of dolphins captured and tons of tuna captured. The models were fitted by maximum likelihood, assuming appropriate error distributions. The significance of the variables in the models was judged by both formal significance tests and consistency of the results between two data sets. The consistency requirement suggested that the likelihood ratio test gave too many significant test results with these data. Overall the study showed no consistent differences between fine mesh and super apron nets.

INTRODUCTION

The purpose of this study is to evaluate the effectiveness of two purse seine net designs developed to reduce the incidental mortality of dolphins in the eastern tropical Pacific tuna fishery. These two modifications are the fine mesh Medina panel system (Coe and DeBeer 1977), and the super apron system (Holts 1977). Both of these systems employ safety panels of 1 1/4 inch mesh netting placed symmetrically around the apex of the backdown area.

The history of dolphin rescue procedures developed by fishermen is described by Barham, Taguchi, and Reilly (1977), Coe and DeBeer (1977), and IATTC (1977).

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METHODS

Data

The data used in this analysis were obtained by NMFS and IATTC technicians aboard U.S. purse seiners from January 1977 through May 1979. For each trip used in the analysis technicians recorded the location of each set, estimates of numbers and species of dolphins captured, numbers and species of dolphins killed, tonnage of tuna caught, and whether or not a net collapse or gear malfunction occurred while dolphins were in the net. All estimates were made by the technicians with the exception of the number of dolphins chased and captured. In most cases, this was the arithmetic mean of estimates made by three crew members. Each set record in the data file used in the analysis included the following information:

1) Cruise number
2) Gear type (fine mesh or super apron)
3) Set number
4) Location inside or outside CYRA (Figure 1)
5) Estimated tons of tuna caught
6) Estimated number of offshore spotted dolphins

(*Stenella attenuata*) captured
7) Estimated number of spinner dolphins (*S. longirostris*) captured
8) Estimated number of other species of dolphins captured
9) Estimated number of dolphins killed
10) Whether or not a net collapse occurred
11) Whether or not a net collapse caused dolphin mortality
12) Whether or not any gear malfunction occurred during the set
13) Whether or not dolphins were in the net at the time of a gear malfunction.

Trips which had incomplete tuna catch or dolphin mortality data were not used. Also to avoid problems associated with learning how to use a new gear the first ten sets for a captain uing a new gear were removed.

Analysis

Previous statistical analyses of the effect of gear on dolphin mortality, for example Coe and DeBeer (1977), and Powers, Lo and Wahlen (1979), have avoided parametric model fitting such as the analysis of variance or covariance because the distribution of the mortality data tends to be skewed. However, because of the possibility of confusing the effects of one factor with those of another we decided to fit linear models which incorporated all factors which were available and likely to affect kill rates.

Experience has shown that the performance of a modern tuna purse seiner is heavily dependent on its captain and crew, especially the former. This is true for both its ability to catch fish and to minimize the incidental mortality of dolphin during the fishing process. Different vessels have different operating characteristics associated with such factors as vessel design and power, deck equipment, net specifications, and crew procedures. Therefore it was necessary to ensure that differences that are caused by differing skills of captains or vessel characteristics do not obscure differences in mortality rates which are due to gear.

The design for which the linear models were estimated contained the following factors:

Factor 1: Captain-vessel combination. There were 53 combinations of captain and vessels (a particular captain, with a particular vessel) which had at least two technician trips where sets involving dolphins were made between 1977 and 1979. For brevity skipper-vessel combination is written "skipper". Rather than trying to rank or classify the skippers in different categories or ability, each skipper is treated as a level of the factor.

Factor 2: Year. There were 3 years (1977-1979) during which both fine mesh and super apron gear were used.

Factor 3: Gear. Three gears (fine mesh, inspected super apron, and uninspected super apron) were used. Super apron trips were stratified according to whether or not an NMFS inspection and trial set had been performed because improper installation of the super apron can seriously affect its performance (J. Coe personal communication). For brevity inspected super aprons are written "super apron".

Factor 4: Dolphin species. Sets were stratified into three types (sets on pure spotted, mixed spotted and spinner, and pure spinner or other species) depending on the species composition of the captured dolphin school.

Factor 5: Set Type. This factor was divided into four categories (normal, net collapse, gear malfunction after dolphins were released from the net, and gear malfunction while dolphin were in the net). If a malfunction caused a net collapse the set was classified as a net collapse not a malfunction.

Factor 6: Location. Inside or outside the IATTC's Yellowfin Regulatory Area (CYRA).

In addition, the following three covariates which may have an important effect, were included:

X_1 = number of dolphins captured
X_2 = tons of tuna caught
$X_3 = X_1X_2$

Figures 2-6 show the frequency distribution of kill per set for each of the factors except skipper.

These data were originally analyzed using BMD10V (Dixon,1974), and because of the program size all data could not be analyzed simultaneously. The 53 skippers were split randomly into two parts and each part was analysed separately. Table 1 gives an abstract of the data in terms of number and types of cruises for each skipper. Thus for skipper 3A there was one fine mesh trip in 1977 and two fine mesh trips in 1978, for skipper 5A there was one fine mesh and one uninspected super apron trip in 1978. The partitioning of the data also provided replication of the significance tests. Because of our uncertainty about the effects of departures from our assumptions about the models and the distribution of the data the original sub-sets were also used for subsequent analyses.

The analysis of the data was complicated by three serious problems. First, the data were collected from a survey rather than from a designed experiment, and consequently the factors were badly unbalanced. Second, the treatments (principally gear) were not assigned randomly to experimental units (skippers), and third, the residuals of the data were not normally distributed. These problems tended to aggravate one another and made both estimation and assessment of significance difficult.

The lack of balance was particularly bad with respect to skippers, which were a large contributor to variation in mortality rates, and also with respect to gear, which was the effect whose components were being measured. Table 2 clearly shows the lack of balance in the number of sets classified by skipper, year, and gear. Overall kill rates have declined over the years since the beginning of the fishery and we expected that this decline would have continued over the years 1977-1979. We also expected that kill rates would be lowest for super apron gear, followed by uninspected super aprons, and then fine mesh gear. Examination of the year-gear totals in Table 2 illustrates the difficulty of separating these expected effects because there had been a progressive move from fine mesh toward super-apron gear during the three years studied. Fitting linear models to the data overcame this problem to some extent, but because of the lack of balance we could not completely separate year effects from gear effects. The problem was even more serious when skipper effects were considered. For example, in data set A there was only one skipper in the uninspected super apron category in 1977. This skipper occurred at only one other time in the 1978 uninspected super apron category along with two others. In cases such as this we could not separate skipper effects from year and gear effects.

The second problem was that the gear used was not chosen randomly for each skipper. Use of the super apron in 1977 (regardless of inspection) was largely a matter of the skipper's preference. It is possible that, particularly in 1977, the skippers with super aprons tended to be different from the remainder.

The last problem was that the residuals were not distributed normally and thus standard analysis of variance techniques were not applicable. Instead, generalized linear models (Baker and Nelder, 1978) were fitted using maximum likelihood estimates (Kendall and Stuart, 1967) with Poisson errors for numbers killed per set (counted data), binomial errors for proportional data, and normally distributed errors for average kills per ton of tuna.

Tests of the effects of factors were made using likelihood ratios (Kendall and Stuart, 1967) which are asymptotically distributed as chi squared variates. Little is known about the exact distribution of these statistics from finite samples and consequently the nominal levels of significance from the tests were used only as a rough guide. The final decisions were made incorporating other information, principally the consistency of the estimates from the two sets of data.

There are several alternative measures for assessing performance in minimizing dolphin mortality. The most direct is kill per dolphin set. This has been used by Coe and DeBeer (1977) and Powers, Lo, and Wahlen (1979), and is also the most commonly used statistic for estimating total kill. The data were analysed by assuming that for any combination of factors the kill in a set would be represented by a Poisson variate with a parameter

$$\lambda = \exp(\Sigma B_i X_i).$$

Where the X_i are the factors and covariates, and B_i are the parameters to be estimated.

Because dolphin mortality is seen as a cost incurred in catching tuna, an alternative measure is kill per ton of tuna. For each trip, the average kill per ton was examined with an analysis of variance in which the averages were assumed to be normally distributed with variance proportional to the reciprocal of the number of sets.

The majority of sets on dolphin schools caused no mortality (Table 3) and conversely, most mortality was caused by a relatively small number of high mortality sets. Thus either increasing the proportion of sets with no mortality or reducing the proportion with high mortality would lead to a reduced overall mortality.

Two of the most important factors which are related to mortality are net collapses and gear malfunctions. Reductions in either would tend to reduce overall mortality. Thus differences in the frequency of these events among gear types may indicate some advantage of one gear type over another.

To test whether these components of mortality (frequency of sets with no kill, sets in which 15 or more were killed, sets with no collapses, and sets with malfunctions) vary for the different gear systems, the frequencies of occurrence of each were analysed using a logit model. That is, the model assumed that r sets out of n fell into the particular category where r was a binomial variable from the distribution B(n,p) where

$$P = \frac{e^Y}{1+e^Y}, \qquad Y = \Sigma B_i X_i$$

B_i being the parameters to be estimated and X_i the observed factors. In these analyses set type was not used as a factor.

With binomial data it is possible that all data for a particular category, for example a skipper, could be zero's. The corresponding parameter estimate would be $-\infty$. These data would have no influence at all on estimates of differences due to year or gear on this analysis because zero kill rates can not be affected by more or less efficient gears. Consequently for each of the four measures, skippers which always had a zero (or equivalently 100%) response were removed from the data set.

RESULTS

Kill per set

The first criterion used in judging most of the tests in this section was a formal significance test. This depended on the assumptions made about the structure of the model and the distribution of the residuals. Unless these assumptions were all satisfied the formal tests could give misleading results. To provide some protection against this we chose a relatively low significance level (90%) but required consistency between the significance tests and the parameter estimates for both data sets. If the 90% significance levels are accurate for each of the independent data sets the overall significance level would be 99%. This test was made even more stringent by examining the estimate for consistency.

The significance of the terms of the linear model was assessed using the likelihood ratio test. Following Baker and Nelder (1978) we use the term "deviance" for minus twice the log likelihood ratio. The results are presented as an analysis of deviance table which is similar to an analysis of variance table. Under the null hypothesis the deviances are asymptotically distributed as proportional to a chi square variate with the appropriate degrees of freedom. For the single parameter distributions such as binomial and Poisson distributions the scale factor is one and the statistics can be directly compared to chi squared tables. For distribution with two parameters the scale factor is unknown and is estimated, for example, from the residual mean square in the analysis of variance.

The analysis of deviance for kill per set assuming a Poisson distribution is shown in Table 4. Because of the lack of balance in years and gears and of the importance of these two effects a combined year-gear factor was fitted for this and subsequent analyses. In data set A this factor has only six degrees of freedom because there were no data for super aprons in 1977 or for fine mesh in 1979. For both data sets the pattern is similar, with the largest effects (per degree of freedom) associated with number of dolphins captured, tons of yellowfin captured, set type, and dolphin species. The model deviances are considerably larger than the degrees of freedom, indicating that either there are other important factors which determine kill per set which have not been included in the model, or that the Poisson distribution is not appropriate for the data. This situation is discussed by Baker and Nelder (1978), who note that even small deviations from the model are easily detected with large data sets. A formal chi-squared test showed all parameter effects with the exception of location to be significant in both data sets.

The estimated parameters (excluding skipper effects) are shown in Table 5. The estimates from the two sets of data are generally consistent. The most notable lack of consistency is in the effects for super aprons in 1978 which have different signs even though their magnitudes exceed the estimated standard errors by four times. However, since the deviances for the model are about five to six times larger than their expectation and the standard errors are calculated assuming a mean deviance of one, it is possible that the standard errors are underestimated by a factor of two or more. Within each year the parameters estimated for super apron gear are consistently higher than those for uninspected super aprons, which is contrary to the hypothesis that inspected super aprons perform better than uninspected super aprons. To test how important this difference is, and to compare super aprons overall with fine mesh, the two super-apron categories were pooled. This increased the deviance by 4 for data set A, and by 172 for data set B, with 2 and 3 degrees of freedom respectively. Thus even though the differences in parameter estimates for inspected and uninspected super aprons are consistent the tests of deviance are inconclusive. In any case, it is unlikely that the policy of inspecting super apron nets would be changed as a result of this analysis. Thus we compared the fine mesh gear to inspected and uninspected super aprons combined disregarding possible differences within the combined super apron group. The estimated parameters for the year-gear effect are shown in Table 6. These show that for data set A the super apron gear is better (i.e. has a smaller value) than fine mesh in both years for which comparisons are made, but in data Set B fine mesh is better than super apron gear in two of the three years.

The high deviance obtained when the full model was fitted showed that either the assumption of a Poisson distribution of kills, or the assumed model was not appropriate for these data. As an alternative the data were transformed to obtain a more symetrical distribution using log (kill+1), and analyzed using the analysis of variance. The transformation removed some but not all of the skewness in the data and the analysis of variance (Table 7) must be used with some caution. These tables show the same general features as those in Table 4. The largest effects, in terms of F statistics, are for the number and species of dolphins captured, tons of yellowfin, and set type as in Table 4. Using 90% significance levels for both data sets, the effects of location and the product of number of dolphins and tons of tuna captured are the only terms whose effects are not significant. In general the apparent differences shown by the analysis of variance tables are smaller than those shown by the analysis of deviance tables.

The consistency of the magnitude of the effects is also shown by the estimated parameters. Table 8 shows the estimated year-gear effects when uninspected and inspected super aprons are combined. Because of the different models the parameter values cannot be directly compared with those in Table 6. However, the relative values are much the same. That is for data set A super apron gear is better than fine mesh in both years for which comparisons can be made, and in data B fine mesh is better than super aprons in two of the three years.

Kill per ton

These data were constructed by taking averages of the kill per ton for each set in an attempt to obtain normally distributed data. This, however, was not successful; for example, in data set A the weighted mean was 0.37, the lowest 60% of the observations were zero, and the 95% quantile was 2.5. Thus, F tests could not be used although the analysis of variance table (Table 9) can still be used to compare the effects of the classification among themselves and with the error mean square. A feature of these tables is the large difference between the error mean squares for the two data sets, which shows the relatively large differences that can result from random choices (of partitioning skippers) with these data. The difference is due to the two largest observations in data set B which are more than twice as large as the greatest value in data set A. The relative magnitudes of the F values were generally consistent with those for kill per set. The effect of the year-gear interaction was large in data set A but not in data set B. After removing the interaction term the effect of year and gear were about the same size as the residuals for both data sets.

Components of mortality

The analysis of deviance for these measures is shown in Table 10. For these analyses the model deviances are close to the degrees of freedom, indicating that these models fit better than the kill per set models do. Using the criterion of both data sets showing significance at the 90% level the skipper effect was significant for zero-mortality sets, net collapses, and malfunctions; year-gear effects were significant only for net collapses. As we expected, species had a significant effect on the frequency of sets with zero mortality and those with 15 or more killed, but did not affect the frequency of malfunctions or net collapses. Geographical location had no effect on any of the four components. Of the covariates, the only significant effect was tons of yellowfin on frequency of sets with malfunctions.

The estimates of the parameters and their standard deviations (except for the skipper effects) are shown in Table 11. Aside from the covariates, the estimates have magnitudes either of orders of 1 or of orders of 10 for some year-gear effects. The estimates with large values have standard errors several times larger than the estimates themselves. These large imprecise estimates are the result of the lack of balance in the data. For example, using the frequency of sets with 15 or more killed from data set A the value of -9.26 for super aprons in 1978 is associated with only two skippers having data in that category, neither of whom had any sets in 1978 in which 15 or more animals were killed. Similarly the value of 7.63 for super aprons in 1978 with data set B is associated with only one skipper who had a small proportion of sets killing more than 15 in 1978 and with no sets which killed 15 or more in other year and gear classes.

This partial confounding of skipper effects with year and gear effects can be reduced by looking only at estimates whose standard errors are small, arbitrarily chosen to be less than 5. These estimates are shown in Table 12.

Of the four components the only one for which the year-gear effects were significant was the frequency of sets with net collapses. For data set A the only comparison of gear within years is between inspected and uninspected super aprons for 1979, while in data set B the only available comparison was between uninspected super aprons and fine mesh, which showed fewer net collapses for fine mesh than for uninspected super aprons for each of the three years.

The other test of the reliability of the results is that effects (other than skipper) which are formally determined to be significant should have consistent parameter estimates for the two data sets. Of the effects judged significant above, the year-gear effects for frequency of net collapses cannot be compared, and the effect of species are consistent for sets with no mortality and for sets with 15 or more killed. The effect of tons of yellowfin are not consistent for sets with malfunctions. Thus, one of the three significant tests results was inconsistent between data sets, suggesting that the tests of deviance give too many significant results for these data.

Although data from skippers which consistently have zero proportions for a particular measure do not tell anything about differences among gear types in the model used above, a preponderance of these in any particular year-gear cell or group of cells would show another sort of difference. For example a gear type used by many skippers who had no sets with any mortality would indicate some advantage for that gear. The frequencies of zero proportions for each measure are shown in Table 13, and these show no differences among gears.

DISCUSSION

Attempts to calibrate statistically the effectiveness of developments in fishing gear in capturing fish (for example, Broadhead, 1962) or in releasing dolphins are typically complicated by the manner in which the change occurs. Radical changes such as those being investigated here often take place over a short time span. The first operators to change are seldom a random sample of the population and may well be more skilled than the remainder. The change from one gear type to another is normally a progression from old to new gear, and thus is often confounded with other temporal trends.

All of these problems were present in this study, and we attempted to deal with them by using linear models and isolating effects of skippers, gear, and year. Because of the lack of balance in the data these attempts were only partially successful.

Another major problem was the interpretation of the tests of significance based on likelihood ratios. The assumptions made in applying these tests, that the distributions were appropriate, and that asymptotic theory applied, were not verified and little is known about the effects of departures from the assumptions. The results of the formal tests were considered together with the consistency of the estimates from the two data sets. The consistency criteria tended to cast doubt on a high proportion of tests judged significant by formal tests of both F statistics and likelihood ratios. We concluded that the real size of the tests was higher than the nominal size, that is the formal statistical tests tended to reject the null hypothesis too often.

The study showed no important or consistent differences between fine mesh and super apron gear. Such differences, or indeed differences among different types of gear which may be tested in the future are difficult to detect because of the very high variability in mortality data. It is not unusual to have a fishing trip in which most sets have a very low mortality and yet have one disaster set which kills many dolphins. While some gear modifications may increase the proportion of sets with very low or no mortality they may not be effective overall if they do not also reduce the frequency or numbers killed in disaster sets. These highly skewed distributions pose severe problems in interpreting the effect of different types of fishing gear and it is unfortunate that the problems are aggravated by the lack of experimental design. The differences in kill rates among dolphin species, skippers, and the presence or absence of a malfunction are considerably larger than the effects of alternative gears available now. Consequently, in order to determine the effects of gear changes, a carefully designed experiment would have to be conducted in which factors such as skippers and species caught are controlled .

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TABLE 1. Skipper cruises by gear type and year.

DATA SET A				DATA SET B			
Skipper	1979	1978	1977	Skipper	1979	1978	1977
1A		FM	FM	1B		FM	FM
2A	SA	FM	FM	2B		NSA	NSA
3A		FM,FM	FM	3B		FM	FM
4A		FM	FM	4B		FM,FM	FM
5A		FM,NSA		5B		NSA,NSA	NSA
6A	NSA	FM		6B		NSA,NSA	NSA
7A	SA		FM	7B		FM	FM
8A	NSA,NSA	NSA,NSA		8B		FM	FM
9A	SA	FM		9B	SA,SA	FM	FM
10A	SA	SA	FM,FM	10B	SA	FM,SA	
11A		FM	FM	11B	NSA	NSA	NSA
12A	SA	FM		12B	NSA	NSA	NSA
13A	SA	FM		13B	SA	FM	
14A		FM,FM	FM	14B	NSA		FM
15A		FM	FM	15B	FM	FM	FM
16A		FM,SA	FM	16B		FM	FM
17A	SA	FM		17B		FM	FM
18A		FM	FM	18B		FM	FM
19A	NSA		FM	19B		SA,SA	SA
20A		FM	FM	20B		FM	FM
21A	NSA	FM		21B		FM,SA	
22A	NSA	FM		22B		FM,FM	
23A		NSA	NSA	23B		FM	FM
24A	SA		FM	24B	NSA	FM	
26A			FM	25B			FM
27A			FM	26B			FM
				27B			FM

FM fine mesh
SA inspected super apron
NSA uninspected super apron

TABLE 2. Number of sets classified by skipper, year, and gear.

DATA SET A

Skipper	1979 SA	1979 NSA	1979 FM	1978 SA	1978 NSA	1978 FM	1977 SA	1977 NSA	1977 FM	TOTAL
1	0	0	0	0	0	10	0	0	41	51
2	34	0	0	0	0	13	0	0	56	103
3	-	-	-	-	-	52	0	0	58	110
4	0	0	0	0	0	26	0	0	52	78
5	0	0	0	0	1	11	0	0	0	12
6	0	58	0	0	0	10	0	0	0	68
7	5	0	0	0	0	0	0	0	15	20
8	0	81	0	0	6	0	0	0	0	87
9	32	0	0	0	0	12	0	0	0	44
10	26	0	0	13	0	0	0	0	22	61
11	0	0	0	0	0	12	0	0	32	44
12	31	0	0	0	0	33	0	0	0	64
13	18	0	0	0	0	15	0	0	0	33
14	0	0	0	0	0	41	0	0	39	80
15	0	0	0	0	0	5	0	0	39	44
16	0	0	0	40	0	30	0	0	60	130
17	45	0	0	0	0	11	0	0	0	56
18	0	0	0	0	0	18	0	0	40	58
19	0	16	0	0	0	0	0	0	68	84
20	0	0	0	0	0	5	0	0	17	22
21	0	2	0	0	0	6	0	0	0	8
22	0	7	0	0	0	2	0	0	0	9
23	0	0	0	0	8	0	0	57	0	65
24	44	0	0	0	0	0	0	0	40	84
26	0	0	0	0	0	0	0	0	36	36
27	0	0	0	0	0	0	0	0	7	7
TOTAL	235	164	0	53	15	312	0	57	622	1458

SA inspected super apron
NSA uninspected super apron
FM fine mesh

TABLE 2. Number of sets classified by skipper, year, and gear (continued).

DATA SET B

Skipper	1979 SA	1979 NSA	1979 FM	1978 SA	1978 NSA	1978 FM	1977 SA	1977 NSA	1977 FM	TOTAL
1	0	0	0	0	0	8	0	0	59	67
2	0	0	0	0	16	0	0	32	0	48
3	0	0	0	0	0	11	0	0	29	40
4	0	0	0	0	0	68	0	0	36	104
5	0	0	0	0	29	0	0	37	0	66
6	0	0	0	0	27	0	0	26	0	53
7	0	0	0	0	0	21	0	0	39	60
8	0	0	0	0	0	13	0	0	48	61
9	43	0	0	0	0	6	0	0	35	84
10	20	0	0	38	0	14	0	0	0	72
11	0	29	0	0	15	0	0	42	0	86
12	0	38	0	0	34	0	0	49	0	121
13	20	0	0	0	0	13	0	0	0	33
14	0	7	0	0	0	0	0	0	37	44
15	0	0	34	0	0	6	0	0	45	85
16	0	0	0	0	0	31	0	0	13	44
17	0	0	0	0	0	26	0	0	42	68
18	0	0	0	0	0	12	0	0	7	19
19	0	0	0	10	0	0	23	0	0	33
20	0	0	0	0	0	1	0	0	55	56
21	0	0	0	2	0	1	0	0	0	3
22	0	0	0	0	0	15	0	0	0	15
23	0	0	0	0	0	5	0	0	11	16
24	0	24	0	0	0	24	0	0	0	48
25	0	0	0	0	0	0	0	0	35	35
26	0	0	0	0	0	0	0	0	35	35
27	0	0	0	0	0	0	0	0	41	41
TOTAL	83	98	34	50	121	275	23	186	567	1437

SA inspected super apron
NSA uninspected super apron
FM fine mesh

TABLE 3. Frequency distribution of number of sets and numbers of dolphins killed, by number killed per set. When the observer was uncertain about whether animals were alive or dead the numbers were prorated and thus there are a few cases of kills being non-integers. This explains why the values in Column 3 are not always equal to the products of those in Column 1 and 2.

Number killed per set	Number of sets	Number killed
0	1805	7
1	356	360
2	193	388
3	107	321
4	81	325
5	62	312
6	34	205
7	32	225
8	26	208
9	30	271
10	19	190
11	14	154
12	12	144
13	10	130
14	8	112
15 or more	106	4355
TOTAL	2895	7713

TABLE 4. Analysis of deviance for kill per set.

Source	Data set A		Data set B	
	df	deviance	df	deviance
Skipper	25	2439	26	1988
Year–gear	6	238	8	376
Species	2	440	2	1393
Location	1	15	1	1
Set type	3	858	3	684
Dolphins captured	1	366	1	724
Tons yellowfin	1	461	1	1680
Dolphins x yellowfin	1	12	1	616
Model	1417	8231	1393	6452
Mean only	1457	15510	1436	14250

Table 5. Estimated parameters and standard deviations for kill per set data.

	Estimates		Standard deviations	
	Data set A	Data set B	Data set A	Data set B
Super apron 1979	-0.52	0.45	0.10	0.11
Uninspected super apron 1979	-0.79	-1.37	0.10	0.13
Fine mesh 1979	-	-1.56	-	0.22
Super apron 1978	-1.70	1.31	0.20	0.23
Uninspected super apron 1978	-1.55	-1.34	0.28	0.17
Fine mesh 1978	-0.00	-0.48	0.06	0.08
Super apron 1977	-	2.08	-	0.56
Uninspected super apron 1977	-2.30	-2.13	0.36	0.17
Fine mesh 1977 (Standard)	0	0	0	0
Pure spotted	-0.93	-1.84	0.05	0.05
Mixed spinner and spotted	-0.34	-1.59	0.05	0.06
Other (Standard)	0	0	0	0
Inside CYRA	-0.27	-0.05	0.07	0.06
Outside CYRA (Standard)	0	0	0	0
Normal set	-0.48	-0.60	0.05	0.04
Net collapse	0.98	0.90	0.06	0.07
Gear malfunction A	-0.42	-0.21	0.08	0.09
Gear malfunction B (Standard)	0	0	0	0
Tons of yellowfin captured	2.3×10^{-2}	4.3×10^{-2}	9.9×10^{-4}	9.8×10^{-4}
Number of dolphins captured	4.1×10^{-4}	6.0×10^{-4}	2.2×10^{-5}	2.1×10^{-5}
Dolphins x yellowfin	-1.7×10^{-6}	-7.1×10^{-6}	4.9×10^{-7}	3.2×10^{-7}

A - malfunction occurred after dolphins were released from the net

B - malfunction occurred while dolphins were in net

TABLE 6. Estimated parameters and standard errors for effects of year and gear on kill per set when super aprons and uninspected super aprons are pooled.

Data set A

	Estimates		Standard errors	
	Combined super aprons	Fine mesh	Combined super aprons	Fine mesh
1979	-0.66	-	0.07	-
1978	-1.63	-0.04	0.17	0.06
1977	-2.36	0(Standard)	0.27	0

Data set B

	Estimates		Standard errors	
	Combined super aprons	Fine mesh	Combined super aprons	Fine mesh
1979	-0.29	-1.57	0.09	0.22
1978	-0.04	-0.28	0.13	0.07
1977	-0.90	0(Standard)	0.14	0

TABLE 7. Analysis of variance for kill per set.

Source	Data set A				Data set B			
	DF	SS	MS	F	DF	SS	MS	F
Skipper	25	73.0	2.9	5.5	26	75.9	2.9	6.1
Year-gear	6	5.3	0.9	1.7	8	9.3	1.2	2.4
School type	2	66.3	33.2	62.7	2	72.4	36.2	75.1
Location	1	0.1	0.1	0.2	1	0.2	0.2	0.4
Set type	3	45.0	15.0	28.4	3	38.7	12.0	26.8
Dolphins captured	1	38.2	38.2	72.2	1	46.0	46.0	95.4
Tons yellowfin	1	27.0	27.0	51.1	1	78.0	78.0	161.8
Dolphins x yellowfin	1	0.3	0.3	0.6	1	4.5	4.5	9.3
Residual	1417	749.4	0.5		1393	671.6	0.5	

TABLE 8. Estimated parameters and standard errors for the effects of year and gear on kill per set when super aprons and uninspected super aprons are combined. Analysis of variance estimates for log(Kill-1).

Data set A

	Estimates		Standard errors	
	Combined super aprons	Fine mesh	Combined super aprons	Fine mesh
1979	-0.18	-	0.08	-
1978	-0.16	-0.08	0.15	0.06
1977	-0.46	0(Standard)	0.30	0

Data set B

	Estimates		Standard errors	
	Combined super aprons	Fine mesh	Combined super aprons	Fine mesh
1979	0.06	-0.39	0.10	0.17
1978	-0.03	-0.09	0.13	0.07
1977	-0.15	0(standard)	0.14	0

TABLE 9. Analysis of variance tables for kill per ton.

Model including year-gear interaction

	Data set A				Data set B			
Source	DF	SS	MS	F	DF	SS	MS	F
Skipper	25	88	3.5	0.8	26	455	17.5	1.0
Species	2	73	36.5	8.6	2	466	233.0	12.7
Set type	3	53	17.7	4.2	3	570	190.0	10.3
Year-gear interaction	2	77	38.5	9.1	4	5	1.3	0.1
Residual	295	1250	4.2		312	5732	18.4	

Model without year-gear interaction

	Data set A				Data set B			
Source	DF	SS	MS	F	DF	SS	MS	F
Year	2	12	6	1.3	2	40	20	1.1
Gear	2	16	8	1.8	2	20	10	0.6
Residual	297	1327	4.5		316	5737	18.2	

TABLE 10. Analysis of deviance of frequencies of sets with no mortality, sets with 15 or more dolphins killed, sets with net collapses, and sets with malfunctions while dolphins were in the net.

Data set A

Source	No mortality		15 or more killed		Net collapse		Malfunction	
	df	deviance	df	deviance	df	deviance	df	deviance
Skipper	24	68.8	19	39.2	16	41.3	24	106.3
Year Gear	6	14.7	6	12.4	6	11.3	6	4.8
Species	2	107.3	2	8.8	2	20.4	2	1.3
Location	1	1.8	1	0.8	1	3.7	1	1.5
Dolphins captured	1	33.1	1	3.3	1	1.4	1	5.1
Tons yellowfin	1	15.7	1	1.3	1	0.0	1	4.5
Dolphins x tons	1	18.0	1	0.4	1	0.0	1	3.6
Model	125	157.3	103	78.4	94	78.8	123	148.9
Mean only	161	422.9	134	152.0	122	171.7	159	281.2

Data set B

Source	No mortality		15 or more killed		Net collapse		Malfunction	
	df	deviance	df	deviance	df	deviance	df	deviance
Skipper	26	88.1	16	16.7	16	32.3	26	83.2
Year gear	8	11.1	7	8.2	7	16.0	8	17.6
Species	2	61.6	2	27.7	2	4.4	2	0.3
Location	1	0.3	1	3.9	1	0.3	1	0.6
Dolphins captured	1	0.0	1	0.0	1	0.3	1	0.1
Tons yellowfin	1	2.0	1	8.2	1	0.8	1	2.7
Dolphins x tons	1	0.7	1	0.0	1	0.2	1	1.0
Model	140	180.0	92	52.5	94	67.6	140	204.1
Mean only	180	423.7	121	148.1	124	120.5	180	323.5

TABLE 11a. Estimates of parameters for components of mortality.

	Sets with no mortality		Sets with 15 or more killed		Sets with collapses		Sets with malfunctions	
	A	B	A	B	A	B	A	B
Super apron 1979	0.93	-0.19	0.52	-0.53	0.14	9.44	-0.07	-0.45
Uninspected super apron 1979	0.56	0.47	-1.62	-0.97	-0.76	2.95	-0.65	0.07
Fine mesh 1979	-	1.55	-	-9.80	-	2.55	-	1.09
Super apron 1978	0.51	0.17	-9.26	7.70	-8.41	9.09*	0.41	-1.19
Uninspected super apron 1978	0.59	0.63	-1.03	-0.28	-9.43	2.84	0.86	0.75
Fine mesh 1978	0.23	0.23	-0.29	-1.05	-1.20	1.43	-0.04	0.34
Super apron 1977	-	0.59	-	-	-	0*	-	-3.10
Uninspected super apron 1977	1.78	0.63	-13.34	-1.28	-10.18	2.89	-0.06	1.26
Fine mesh 1977 (Standard)	0	0	0	0	0	0	0	0
Pure spotted	1.86	1.37	-1.09	-2.52	-1.30	-0.92	0.28	0.06
Mixed spotted/spinner	1.30	0.64	-0.31	-2.24	-1.98	-1.50	0.34	0.17
Other (Standard)	0	0	0	0	0	0	0	0
Inside CYRA	-0.27	-0.11	-0.59	1.18	1.07	-0.27	-0.32	-0.17
Outside CYRA (Standard)	0	0	0	0	0	0	0	0
Tons of yellowifn caught	-0.08	-0.03	0.05	0.13	0.00	-0.05	-0.05	0.04
Number of dolphins captured	-1.7×10^{-3}	-3.7×10^{-5}	1.1×10^{-3}	-1.8×10^{-4}	6.9×10^{-4}	3.9×10^{-4}	-8.2×10^{-4}	-7.0×10^{-4}
Dolphins x tons	6.9×10^{-5}	-1.1×10^{-5}	-1.9×10^{-5}	4.2×10^{-7}	-2.6×10^{-6}	1.6×10^{-5}	3.8×10^{-5}	-1.5×10^{-5}

* The data for super aprons in 1977 and 1978 came from one skipper which did not appear in any other year-gear combination. thus these estimates cannot be related to other year-gear combinations.

TABLE 11b. Estimates of standard deviations for components of mortality.

	Sets with no mortality		Sets with 15 or more killed		Sets with collapses		Sets with malfunctions	
	A	B	A	B	A	B	A	B
Super apron 1979	0.30	0.40	0.99	1.17	0.89	36.4	0.42	0.62
Uninspected super apron 1979	0.47	0.58	0.99	1.36	1.57	1.24	0.60	0.63
Fine mesh 1979	-	0.59	-	45.1	-	1.30	-	0.68
Super apron 1978	0.41	0.62	31.6	31.5	35.0	33.9	0.52	1.00
Uninspected super apron 1978	1.01	0.68	45.6	1.91	52.4	1.85	1.07	0.88
Fine mesh 1978	0.19	0.23	0.61	0.69	0.58	0.57	0.27	0.27
Super apron 1977	-	1.13	-	-	-	0	-	1.42
Uninspected super apron 1977	1.36	0.67	45.6	1.95	52.4	1.74	1.43	0.86
Fine mesh 1977 (Standard)	0	0	0	0	0	0	0	0
Pure spotted	0.19	0.20	0.40	0.52	0.33	0.47	0.26	0.24
Mixed spotted/spinner	0.24	0.29	0.45	0.83	0.52	0.79	0.34	0.34
Other (Standard)	0	0	0	0	0	0	0	0
Inside CYRA	0.20	0.20	0.68	0.59	0.57	0.51	0.27	0.23
Outside CYRA (Standard)	0	0	0	0	0	0	0	0
Tons yellowfin caught	0.02	0.02	0.04	0.05	0.04	0.05	0.03	0.02
Number of dolphins captured	3.5×10^{-4}	2.4×10^{-4}	5.8×10^{-4}	1.1×10^{-3}	5.7×10^{-4}	7.1×10^{-5}	3.6×10^{-4}	3.1×10^{-4}
Dolphins x tons	2.0×10^{-5}	1.4×10^{-5}	3.2×10^{-5}	4.3×10^{-5}	3.0×10^{-5}	3.9×10^{-5}	1.8×10^{-5}	1.6×10^{-4}

TABLE 12. Estimates of parameters with small standard errors for components of mortality.

	Data set	Year	Inspected super apron	Uninspected super apron	Fine mesh
Frequency of sets with no mortality	A	1979	0.93	0.56	-
		1978	0.51	0.59	0.23
		1977	-	1.78	0(Standard)
	B	1979	-0.19	0.47	1.55
		1978	0.17	0.63	0.23
		1977	0.59	0.63	0(Standard)
Frequency of sets with 15 or more dolphins killed	A	1979	0.52	-1.62	-
		1978	-	-	-0.29
		1977	-	-	0(Standard)
	B	1979	-0.53	-0.97	-
		1978	-	-0.28	-1.05
		1977	-	-1.28	0(Standard)
Frequency of sets with net collapses involving dolphins	A	1979	0.14	-0.76	-
		1978	-	-	-1.20
		1977	-	-	0(Standard)
	B	1979	-	2.95	2.55
		1978	-	2.84	1.43
		1977	-	2.89	0(Standard)
Frequency of sets with malfunctions	A	1979	-0.07	-0.65	-
		1978	0.41	0.86	-0.04
		1977	-	-0.06	0(Standard)
	B	1979	-0.45	0.07	1.09
		1978	-1.19	0.75	0.34
		1977	-3.10	1.26	0(Standard)

TABLE 13. Fraction of occurences of skippers who have only zero counts in each category.

	Super apron	Uninspected super apron	Fine mesh
	Sets with no mortality		
1979	0	0	0
1978	0	0	0.00
1977	0	0	0.03
	Sets with 15 or more killed		
1979	0.27	0.22	0
1978	0.40	0.38	0.20
1977	1.00	0.50	0.16
	Sets with net collapses		
1979	0.45	0.11	0
1978	0.40	0.25	0.20
1977	0	0.33	0.25
	Sets with malfunctions		
1979	0	0.11	0
1978	0	0	0.03
1977	0	0	0

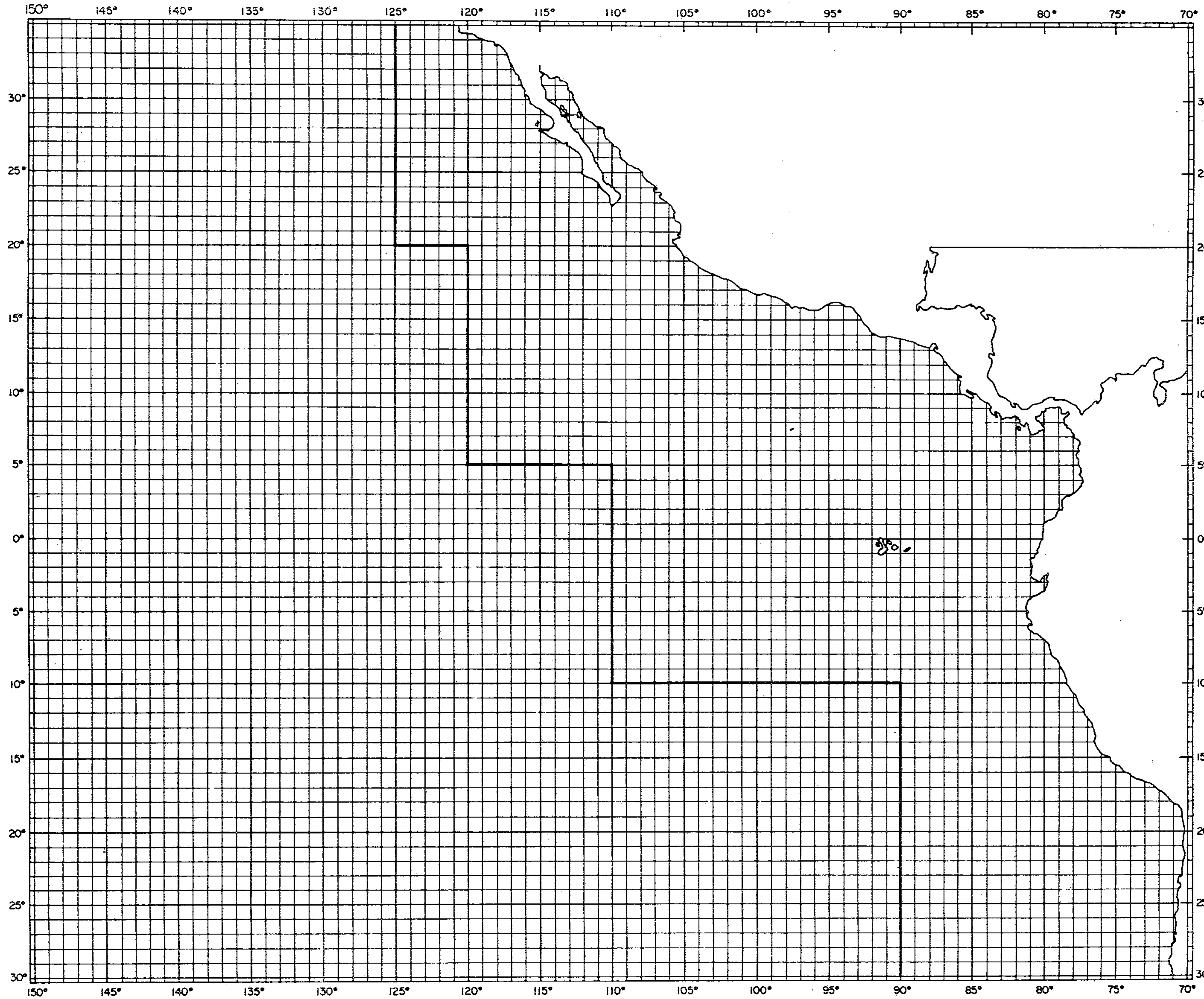
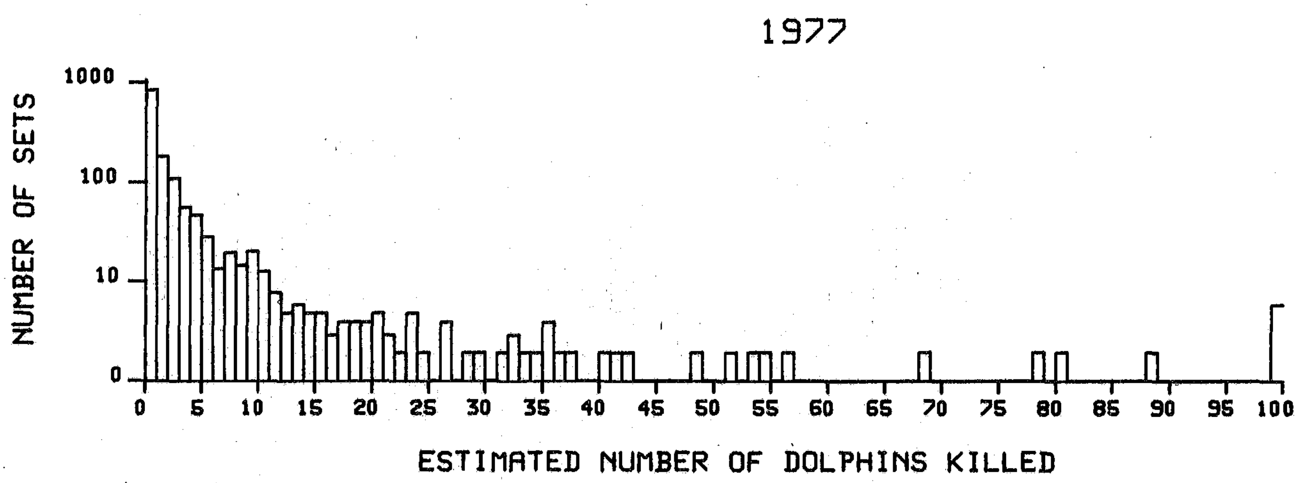
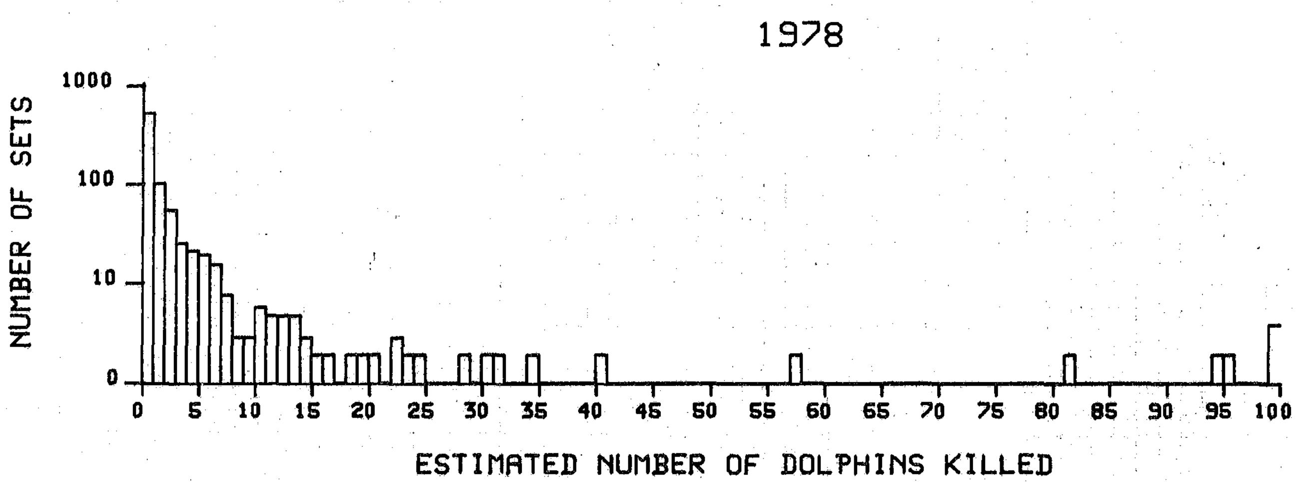


Figure 1. The Commission's Yellowfin Regulatory Area (CYRA) of the eastern Pacific Ocean.

Figure 2. Frequency distribution of kill per set by year





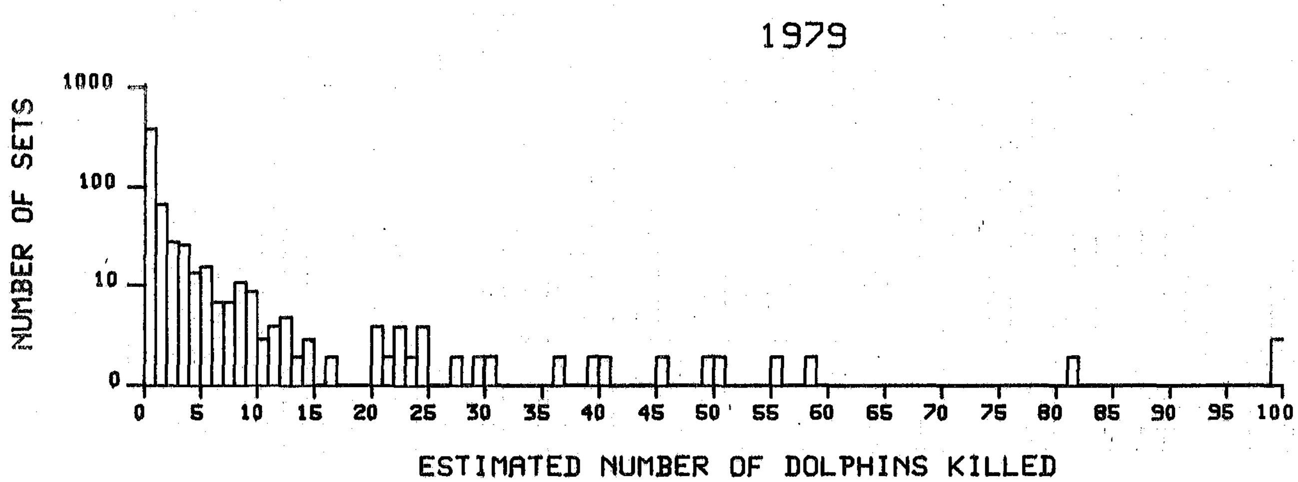


Figure 3. Frequency distribution of kill per set by gear

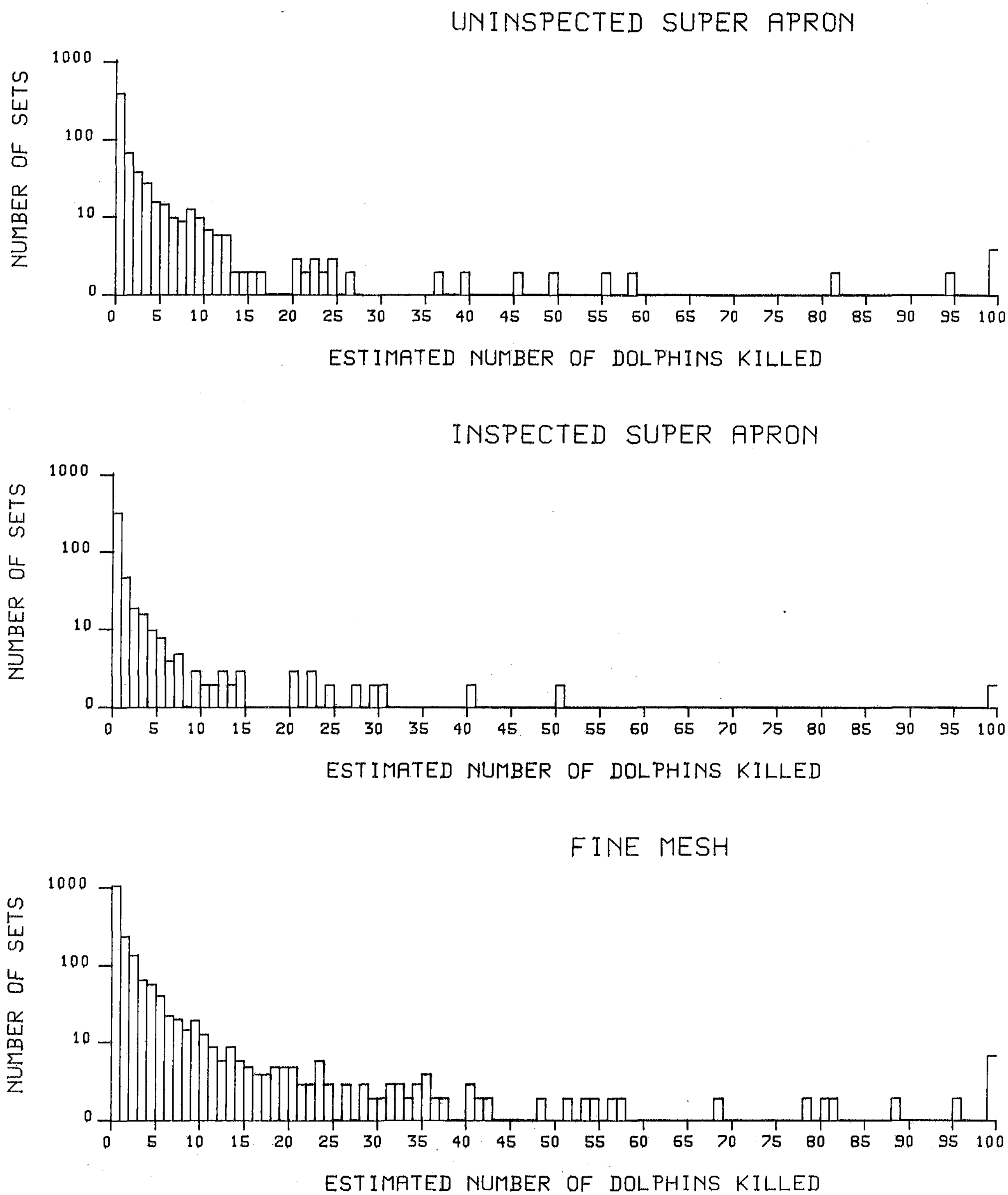


Figure 4. Frequency distribution of kill per set by school type

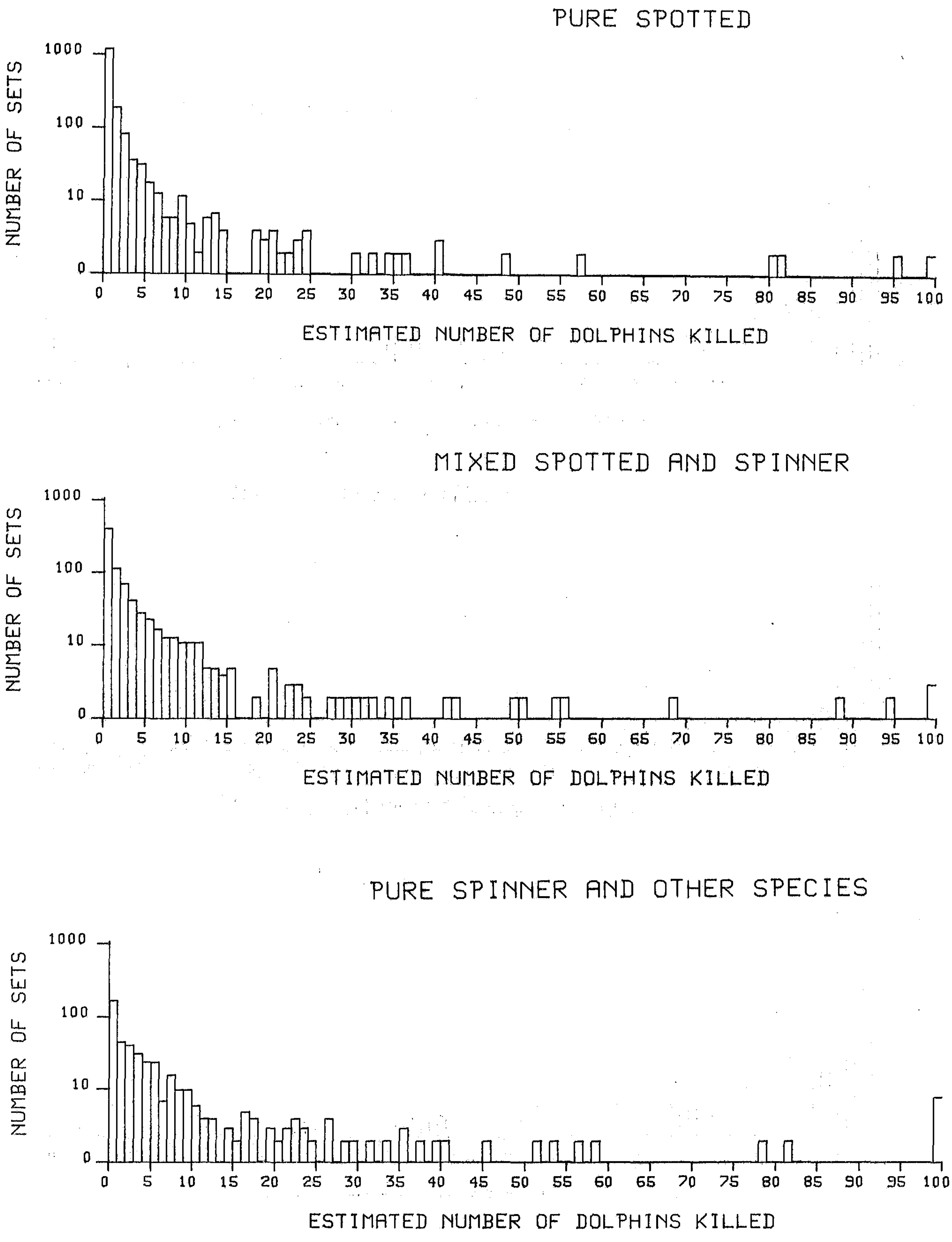


Figure 5. Frequency distribution of kill per set by set type

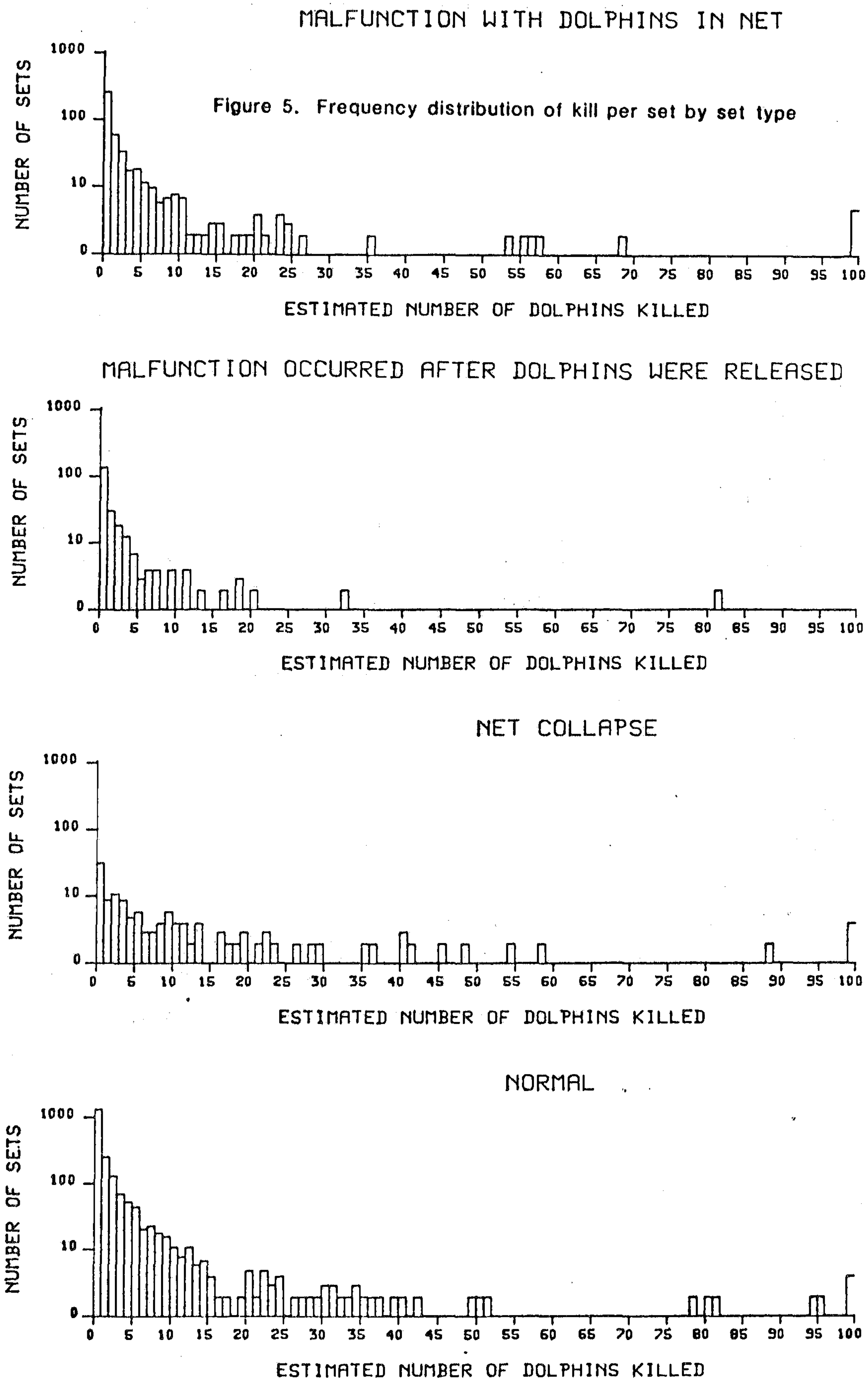


Figure 6. Frequency distribution of kill per set by location