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FURTHER ESTIMATES OF THE RATES OF MORTALITY OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN DERIVED FROM TAGGING EXPERIMENTS

by

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La Jolla, California

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ABSTRACT

Tag release and return data for six areas of the eastern Pacific Ocean, the Gulf of California, the Revillagigedo Islands, Mexico-Central America, the Gulf of Panama, the Galapagos Islands, and the areas outside the CYRA, were used to estimate the rates of total mortality and shedding for yellowfin. The returns of tags per unit of fishing effort for one or more experiments in each area were used to estimate the coefficients of total mortality and shedding. The coefficient of annual natural mortality was estimated to be less than 2.0, but the crudeness of this estimate limits its usefulness. The estimates of the coefficients of catchability are 0.73×10^{-3} for the Revillagigedo Islands area and 0.23×10^{-3} for the Mexico-Central America area.

INTRODUCTION

Tag return data were used by Bayliff (1971) to estimate the rates of total, fishing, and natural mortality of yellowfin tuna, *Thunnus albacares*, in the Baja California and Gulf of Guayaquil areas. The mortality rates of tagged fish released in six other areas are estimated in the present report. These two reports include all the available tag return data which are sufficient for estimating the rates of mortality of yellowfin in the eastern Pacific Ocean. The methods, assumptions, etc., employed for this study are similar to those used in the previous one, so for brevity frequent references will be made to that paper.

ACKNOWLEDGMENTS

Unpublished data on the dates of release of the tagged fish for one California Department of Fish and Game cruise were furnished by Messrs. Harold P. Clemens and Robert R. Bell. The manuscript was read critically by Dr. James Joseph.

MATERIALS AND METHODOS

The materials and methods used in this study were the same as those employed by Bayliff (1971), except that a modified version (Anonymous, 1972: pages 17-18) of Tomlinson's (1970) computer program was used to calculate solutions to the Murphy catch equation.

DATA EMPLOYED

Tag releases and returns

The areas of release (shaded) and return (outlined) of the tagged fish are shown in Figures 1 through 6. Only the 1-degree areas which produced usable returns (see below) are shaded in these figures. The areas of return were chosen because tagged fish released at various locations within the areas were frequently recaptured in all parts of the areas where substantial fishing effort was exerted, but rarely outside the areas. The only exceptions are the fish released in the Gulf of Panama area. Fink and Bayliff (1970) demonstrated that tagged fish released in that area leave it quickly, travelling either west and northwest toward Central America and southern Mexico or south toward the Gulf of Guayaquil area. The tagged fish released there in 1959 and 1961 went mostly to the west and northwest, while those released there in 1962 went mostly to the south (Fink and Bayliff, 1970: pages 36-37). Therefore the areas of return were chosen accordingly (Figure 4).

The tag release and return data are listed in Tables 1 through 7. The return data include fish recaptured through the end of 1973. Cruise 56C5 was conducted by the California Department of Fish and Game (Blunt and Messersmith, 1960), while the others were conducted by the Tuna Commission. In most cases the numbers of returns in Table 1 are slightly higher than those for the same cruises in Tables 2 through 7. This is because all the returns are included in Table 1, whereas the other tables include only the ones which were usable for estimation of the mortality rates.

The returns which resulted from fish recaptured outside the areas of release or in unknown areas were not used. The returns for which the years of recapture were unknown were also not considered, but those for which the months were unknown but the years were known were prorated among the months of the year of recapture according to the portions of the known recaptures made during each month of the years in question. Since 1966 the fishery for yellowfin has been regulated by an annual quota on the total catch of that species in the Commission's Yellowfin Regulatory Area (CYRA) (Anonymous, 1973: Figure 1). Vessels which leave port prior to the date that regulation begins may fish for yellowfin without restriction until that fishing trip is completed; also, vessels which are in port on that date may fish without restriction on their next trip, provided they leave port within 30 days. Vessels which do not meet either of these requirements are subject to various restrictions after the date the regulation begins. Only the tag returns from fish caught by vessels fishing without restriction inside the CYRA and by vessels fishing outside the CYRA are considered in this report.

Statistics of the fishery

The statistics of the fishery were assembled in the same way as were those of Bayliff (1971) except that different areas were used, of course. Only the statistics of vessels fishing without restriction inside the CYRA and a vessels fishing outside the CYRA are used in this report. For the sake of brevity these statistics are not listed.

REQUIREMENTS, ASSUMPTIONS, AND SOURCES OF ERROR

Mortalities and shedding

It is assumed that when several or all members of a group of fish are tagged an unknown and varying portion of them die due to the effects of tagging and handling or shed their tags before there is a chance for any of them to be recaptured

(Type-1 loss). The remainder are subject to four types of exponential decrease, fishing mortality, mortality due to carrying the tags, shedding of the tags, and natural mortality. The following notation for these is used in this report:

q = coefficient of catchability;

f = fishing effort;

$F = qf$ = coefficient of fishing mortality;

G = coefficient of mortality due to carrying the tags;

L = coefficient of loss due to shedding of the tags;

$Q = G + L$;

M = coefficient of natural mortality;

$X = Q + M$;

$Z' = F + X$.

G and L are defined as Type-2 losses. All these types of attrition except F are assumed to be constant among years and within years. Neither of the two components of F, q or f, is assumed to be constant either among years or within years. The subscripts m and a following the coefficients are used to designate monthly and annual values of them, respectively.

Availability

It is assumed that the availability of the fish remains constant among years and within years, *i.e.* that there is no emigration, either permanent or temporary, from the areas of study. This assumption is believed to be fairly well satisfied (Fink and Bayliff, 1970; Anonymous, 1971, 1972, and 1973; unpublished data) except for the fish released in the Gulf of Panama area; the data for these fish will be subjected to a different method of analyses to compensate for this.

Tag returns

The problem of non-return of tags borne by recaptured fish has been discussed by Bayliff (1971). Additional test tagging (placing tags on dead fish aboard fishing vessels to determine what portion are returned by cannery workers) was conducted in 1970 and 1971, but the results were inconclusive. These experiments were abandoned due to the inadequacy of the method and the realization that gradual temporal changes in the portions of the tags returned are not likely to greatly affect the estimates of the mortality rates, since most of the returns are made within 1 year of release.

Persistent reports were received in 1971 that some fishermen were discarding tags found at sea instead of returning them. Apparently these reports were truthful, for 14.5 percent of the returns in 1970 from fish caught by Class-6 purse seiners were from fishermen, while in 1971 only 2.8 percent of them were from fishermen. No downward trend among months was evident for either year. This would cause the mortality rates of tagged fish released in late 1969 and early 1970 to appear slightly higher than they actually were. This is not believed to be a major source of error, however, due to the fact that most of the returns are made within 1 year of release.

Statistics of the fishery

The portion of the catches and effort for which usable logbook data were obtained is believed to be about 90 percent for all the areas studied. Thus in some cases in this report the values obtained by calculations involving effort data must be corrected by this factor.

All fishing effort by tuna purse seiners and baitboats is assumed to be directed toward yellowfin (and also toward skipjack) except that for the few trips for which species other than yellowfin or skipjack made up more than one third of the total weight of the catch. Actually, in some areas at some times skipjack are much more abundant than yellowfin and the fishing effort could be directed primarily or entirely toward skipjack. Unfortunately, no method has been devised to separate the effort directed toward yellowfin from the total effort (Bayliff and Orange, 1967), so this could constitute a source of error in the analysis.

RESULTS

Coefficients of total mortality and shedding

The adjusted numbers of tag returns for the years prior to 1973 were calculated by Bayliff s (1971) method. For 1973 the unadjusted tag return data were used because the effort statistics for that year were not available. The data are shown in Tables 2-7 and Figures 7-12. These were used to make the estimates of Z_m' by the methods of Chapman and Robson (1960), Robson and Chapman (1961), and Paulik (1962). These are shown in Table 8 and Figures 7-12. The likelihood of a single-tagged fish losing its only tag is greater than that of a double-tagged fish losing both its tags, so the estimates of Z_m' should be slightly higher for single-tagged fish than for double-tagged fish of the same experiments. Such does not appear always to be the case, however.

The catch curves are quite irregular, just as were those for the Baja California and Gulf of Guayaquil areas (Bayliff, 1971). The reasons for this could be one or more of the following: (1) emigration of the tagged fish from the areas in question and possible later return of them to these areas; (2) temporal variation in the vulnerability of the tagged fish to capture; (3) temporal variation in the portion of the fishing effort directed toward yellowfin; (4) secondary effects of (2) or (3) or any other factors, such as temporal variation in G, L, or M, which would cause the total rate of attrition to be non-constant.

Emigration is not considered to have been a serious problem, except for the fish released in the Gulf of Panama area, as explained previously.

Temporal variation in the vulnerability of the tagged fish to capture is believed to have been an important cause of the irregularity of the catch curves. Among the possible causes of this variation are failure of the tagged and untagged fish to mix completely during the periods of recapture of the former coupled with uneven distribution of the fishing effort with respect to the distribution of the fish, differences in the behavior of the fishermen relative to fish of different ages, differences in the behavior of the fish of different ages which affect their vulnerability to the gear, and differences in the weather which affect the efficiency of the gear and/or the behavior of the fish.

It is believed that the error caused by failure to fulfill either of the first pair of requirements is greater in this study than in that of Bayliff (1971). The data for Cruise 1038 (Gulf of Panama area) provide a good example of this. The fishing effort in 1961 was considerably lower in 5-degree areas 0-05-075, 0-05-080, and 0-05-085 than in 5-degree areas 0-10-085 and 0-10-090. The method of designating the 5-degree areas is described by Shimada and Schaefer (1956: page 379). Briefly, the first digit indicates whether the area is north or south of the equator (0 = north, 2 = south), the second and third digits indicate the southern edge of the area, and the last three digits indicate the eastern edge of the area. Thus 0-05-075 is the area bounded on the south by 5°N and on the east by 75°W.) During April and May the tagged fish had not reached 0-10-085 or 0-10-090, and hence the adjusted tag returns were lower than in later months. In June the tagged fish still had not reached those areas, but the effort in them was less than that in the first three 5-degree areas, which explains the higher adjusted tag returns in June. In July the tagged fish had finally reached the areas north of 10°N. This, coupled with heavy fishing effort there, resulted in 30 returns from fish caught there, which caused the adjusted number of tag returns to be higher. This situation continued through November 1961.

Partial avoidance by the fishermen of the fish of less than legal size obviously decreases their vulnerability to the fishery. The minimum legal size for yellowfin landed in California is 7 1/2 pounds (about 55 cm), and a great many of the tagged fish released in the Revillagigedo Islands and Gulf of Panama areas were less than legal size (Fink and Bayliff, 1970: Appendix 1). This might reduce the slopes of the catch curves, or even make them positive, for all or part of the first few months after the experiments were initiated. To eliminate the possibility of such bias the returns from fish which were less than 55 cm long when released were eliminated from the data for Cruises 1033, 1046, and 1047-1048 (Revillagigedo Islands area) and Cruise 1038 (Gulf of Panama area), and the returns per unit of effort for the remainder of the data were calculated. The shapes of the catch curves (not shown) were not much changed, which indicates that the fact that many of the tagged fish were of sublegal size when released was not an important cause of the irregularity of the catch curves for these two areas. Bayliff (1971) obtained the same results for the experiments initiated in the Baja California and Gulf of Guayaquil areas.

Nothing is known about temporal differences in the behavior of the fish of different ages within the range of ages under consideration which might affect their vulnerability to the gear.

Differences in the weather can certainly cause differences in the efficiency of the gear, and when the catches of both yellowfin and skipjack are high in same month or <u>vice versa</u> it is likely that unusually good or bad weather is mostly responsible. Unfortunately, however, it is not possible to correct the fishing effort for variations in efficiency due to the weather, except that when the weather is too bad to search for fish on certain days those days are not counted as days of fishing effort. Nothing is known about the effect of the weather on the behavior of the fish.

Temporal variation in the portion of the fishing effort directed toward yellowfin could be an important cause of the irregularity of the catch curves. Bayliff (1971) investigated this for the Baja California and Gulf of Guayaquil areas by comparing the monthly returns of tagged yellowfin and skipjack released in the same areas at the same times. In general, the months which produced high returns of yellowfin also produced high returns of skipjack and vice versa, whereas the converse would be expected if the vessels directed most of their effort toward yellowfin in some months and skipjack in others. Those data, therefore, tend to support the assumption that all the fishing effort is directed toward yellowfin. Similar comparisons were made for the data for the Revillagigedo Islands and Gulf of Panama areas. (There were insufficient skipjack return data to make such comparisons for the other areas.) The results were similar to those obtained with the data for the Baja California and Gulf of Guayaquil areas, with the exception of the data for Cruise 1027. For this cruise 1 of the 26 total usable yellowfin returns was from a fish caught in May 1959, but for skipjack 79 of the 92 usable returns were from fish caught in that month. Obviously vessels fishing in and near the Gulf of Panama in May 1959 were fishing primarily for skipjack, probably because at that time they were more vulnerable than were the yellowfin.

Nothing is known about temporal variation in the natural mortality rates of yellowfin of the ages under consideration, nor about temporal variations in the mortality due to carrying tags or in shedding of the tags.

Joseph and Calkins (1969) used the method of Beverton and Holt (1957: pages 196-198) to calculate the fishing effort to be used to make their estimates of the mortality of tagged skipjack released in the Gulf of Panama area. This is accomplished by

$$\underset{\sim}{\overline{f}}_i = \frac{\sum_{j=1}^{n} r_{ij}}{\sum_{j=1}^{n} \left(\frac{r_{ij}}{f_{ij}} \right)} \qquad (1)$$

where

$\tilde{f}_i$ = weighted mean fishing intensity for month i for the cruise in question,

r_{ij} = number of tag returns during month i in 1-degree area j,

f_{ij} = effort exerted during month i in 1-degree area j, and

n = number of 1-degree areas for which there was at least one tag return.

Effort data for the four Gulf of Panama cruises obtained by this method were used with the tag return data to calculate the adjusted tag returns by the method described earlier. This was done to examine the possibility that the catch curves derived from effort data calculated by the Beverton and Holt method are superior or inferior to catch curves derived from effort data calculated by the old method in cases where the tagged fish are increasing their average distances from the locations of release during most or all of the period of their recapture. The data were grouped by 5-degree areas instead of 1-degree areas, however. The superior method would probably be the one which produced more regular catch curves. The adjusted returns calculated with the effort data obtained by the Beverton and Holt method are shown as dots on Figure 10. It is evident that catch curves drawn with these points would be about as irregular as those produced by the old method, so the two methods are probably about equal.

In addition to irregularity of the catch curves, it appears that some of them are extremely steep due to heavy fishing effort in the immediate area of release of the tagged fish during the month of release and the following one or two months. This phenomenon causes Z_m' to be overestimated, of course. Such appears to have been the case for the fish released in the Mexico-Central America area on Cruise 1056, for during February and March 1970 the fishing effort was considerably greater in 0-20-105 than in any other 5-degree area of the area of study. When several months have elapsed since release of the tagged fish they are likely to have dispersed away from the location of release and spread well over the study area, so the adjusted tag returns for these months are likely to be more realistic no matter what the distribution of the fishing effort. The converse situation, low effort in the immediate area of release during the month of release and the following one or two months, is not likely to produce a low estimate of the mortality rate, for the method which is used to estimate the total rate of mortality and shedding includes a feature which causes the data for early time periods to be eliminated when the returns for these are considerably lower than those for the following time periods. The first months used for the estimation of the total mortality rates for the various cruises are indicated by small circles on the catch curves in Figure 7-12.

Coefficients of natural mortality and catchability

Beverton and Holt method

Beverton and Holt (1956) pointed out that when the fishing effort in different years for which estimates of Z are available varies considerably the linear relationship $Z = M + qf$ can be fitted by the method of least squares to obtain estimates of the constants M and q. For the present data the linear relationship is

$$Z_m'' = X_m + q\overline{f_m} \qquad (2)$$

where

Z_m'' = coefficient of total mortality and shedding adjusted to what it would be if all the fish had been single tagged,

but the method is the same.

This method was employed with the data for the Revillagigedo Islands and Mexico-Central America areas. For the experiments initiated in the years prior to regulation of the fishery, which began in September 1966, the $\overline{f_m}$ values were calculated from the effort data for the months the experiments were initiated and the following 11 months. For the experiments initiated after September 1966 the $\overline{f_m}$ values were calculated from the data for the months in the 12-month period after initiation during which few or none of the vessels were regulated. The values of Z_m' for single- and double-tagged fish combined were calculated from the adjusted tag return data for the same periods. The Z_m' values for the experiments in which some or all of the fish were double tagged were adjusted upward to make them comparable to those for the experiments in which all the fish were single tagged. This was accomplished by

$$Z_m'' = Z_m' + \left(0.025 \times \frac{r_d}{r_s + r_d}\right) \qquad (3)$$

where

r_d = returns of double-tagged fish,

r_s = returns of single-tagged fish, and

0.025 = approximate value of L_m (Bayliff, 1971).

The values of $\overline{f_m}$, the time periods used in calculating these, and the estimates of Z_m' and Z_m'' are listed in Table 9. The Z_m' estimates in this table differ slightly from those in Table 8 because not all the data were used to calculate the values for Table 9, as explained above. For calculation of the regressions the data were weighted by the numbers of tag returns for the experiments in question.

The regressions are shown in Figures 13 and 14. Seven of the nine points for Figure 14 occurred in almost a straight line, so the regression was calculated without the two outliers (heavy line), as well as with them (light line). The 95-percent confidence limits of the heavy line are also shown in Figure 14. The estimate of X_m is 0.135, which is close to the value of 0.1 used by Bayliff (1971). The 95-percent confidence limits range from -0.138 to 0.408, however, so the estimate is of limited value.

The estimates of $\underline{q}$ in Figures 13 and 14 are 1.061×10^{-3} for the Revillagigedo Islands area and 0.209×10^{-3} for the Mexico-Central America area. The effort data are only about 90-percent complete, however, as mentioned previously, so these values should be adjusted by multiplying them by 0.9. The adjusted estimates are 0.955×10^{-3} and 0.188×10^{-3}, respectively.

Murphy-Tomlinson method

A modification (Anonymous, 1972: pages 17-18) of Tomlinson's (1970) computer program for use with the Murphy (1965) method was used to try to estimate $\underline{F}_{\underline{m}}$ and $\underline{X}_{\underline{m}}$, using the data for the Revillagigedo Islands and Mexico-Central America areas. The input for this program is a vector of unadjusted tag returns for the months (or combinations of months if there occur two or more consecutive months with no returns) before and including the last time period for which there was at least one return, a vector of effort values for the same time periods, a trial value of $\underline{F}_{\underline{m}}$ for the last time period for which there was at least one return, and a trial value of $\underline{X}_{\underline{m}}$. The output includes estimates of $\underline{q}$ for each time period and of the population of tagged fish at the beginning of each time period.

Use of trial values of $\underline{F}_{\underline{m}}$ which are too low or too high is likely to produce estimates of $\underline{q}$ for the other time periods which decrease or increase precipitously, while use of trial values of $\underline{X}_{\underline{m}}$ which are too low or too high is likely to produce estimates of the initial population (the number of tagged fish remaining alive after the Type-1 losses have taken place) which are too low or too high. It is likely that $\underline{q}$ at first increases with time when the fish are smaller, and perhaps later decreases with time when the fish are very large, but it is not believed that it should change precipitously during the portion of the life span of the fish included in the present study. The estimate of the initial population should be somewhat less than the number of tagged fish released because of Type-1 losses. If it is higher than the number of fish released the trial value of X_m is believed to be too high, but since the extent of the Type-1 loss is not known, and probably varies considerably among experiments (Bayliff, 1973), it is not possible to determine from the estimates of the initial population when the trial values of X_m are too low.

Trial values of F_m of 0.05 through 0.40 at intervals of 0.05 and trial values of X_m of 0.04 through 0.26 at intervals of 0.02 were used. The upper limit of 0.26 was used for X_m because the results of Bayliff (1971) indicated that X_m is probably less than 0.20.

The occurrence of precipitously changing estimates of q was of little or no use in deciding which of the trial values of F_m were poor estimates, as it was sometimes difficult to decide which were precipitously changing and because the precipitously changing estimates tended to occur with all trial values for a few of the experiments and none for most of the experiments. Furthermore, within these experiments all the precipitously changing estimates of q were increasing or decreasing at all trial values of the final F_m, whereas they would be expected to increase at high trial values and decrease at low trial values.

The occurrence of impossibly high estimates of the initial population was helpful, however. In Figures 15-18 are shown the occurrence of these impossibly high values for the first four areas listed in Table 1. (There were no such values for the other two areas, so no figures for them have been prepared.) The impossibly high estimates occur most frequently when X_m = 0.20, 0.22, 0.24, and 0.26, which tends to confirm Bayliff's (1971) statement that X_m is probably less than 0.20. This leads, using his value of 0.4 for Q_a, to an estimate that M_a is less than 2.0. As stated in his 1971 paper, the crudeness of this estimate limits its usefulness.

Additional estimates of the coefficients of catchability

If M_a and Q_a are 0.8 and 0.4. respectively (Hennemuth, 1961; Bayliff, 1971), then X_a is 1.2 and X_m is 0.1. This estimate was subtracted from each of the estimates of Z_m'' in Table 10 to get estimates of F_m. These were divided by the mean values of f_m in the same table to obtain estimates of q. The effort data are only about 90-percent complete, however, as explained previously, so the estimates of q were adjusted by multiplying them by 0.9. These are shown in Table 10.

Combining these data with those of Bayliff (1971), the following estimates of q are now available: Baja California, 2.02×10^{-3}; Revillagigedo Islands, 0.73×10^{-3}; Mexico-Central America, 0.23×10^{-3}; Gulf of Guayaquil, 0.67×10^{-3}. The coefficient of catchability for the first four areas combined is calculated by

$$q_J = 1 \Big/ \left(\sum_{j=1}^{4} \frac{1}{q_j} \right) \qquad (4)$$

where

q_J = coefficient of catchability for the four areas combined and

q_j = coefficient of catchability for area j.

This estimate is 1.30×10^{-4}. Since most of the major fishing areas in the eastern Pacific Ocean exploited prior to the mid-1960's are included, the estimate of q for the entire area should be not much lower, perhaps about 1.00×10^{-4}. Schaefer (1957) and Pella and Tomlinson (1967), using baitboat effort data, estimated q to be 0.38×10^{-4} and 4.5×10^{-4}, respectively. Class-3 purse seiners are roughly two to three times as efficient as Class-4 baitboats within the range of catch per unit of effort most frequently encountered in the fishery (Broadhead, 1962), so the estimate of q obtained in the present report is compatible with Schaefer's estimate, but not that of Pella and Tomlinson.

SUMMARY AND CONCLUSIONS

Tag release and return data for six areas of the eastern Pacific Ocean, the Gulf of California, the Revillagigedo Islands, Mexico-Central America, the Gulf of Panama, the Galapagos Islands, and the area outside the CYRA, were used to estimate the rates of total mortality and shedding for yellowfin. This report and a previous one which treated data for the Baja California and Gulf of Guayaquil areas include all the available tag return data which are sufficient for estimating the rates of mortality of yellowfin in the eastern Pacific Ocean.

The graphs on semilogarithmic paper of the tag returns per unit of effort plotted against time are very irregular; this is apparently caused principally by temporal variation in the vulnerability of the tagged fish to capture. This, in turn, is principally the result of failure of the tagged and untagged fish to mix completely during the periods of recapture of the former coupled with uneven distribution of the fish. Such being the case, it is not possible to make good estimates of the rates of total, fishing, and natural mortality. X_m appears to be less than 0.2, which is the same result obtained by Bayliff (1971).

If M_a and Q_a are 0.8 and 0.4, respectively (Hennemuth, 1961; Bayliff, 1971), then X_a is 1.2 and X_m is 0.1. Subtraction of this from Z_m'' estimates for the various experiments gives estimates for F_m, and from these and the corresponding f_m estimates the values of q can be estimated. The unweighted means of these are 0.73×10^{-3} for the Revillagigedo Islands area and 0.23×10^{-3} for the Mexico-Central America area.

A combined estimate of q for the two areas above, plus the Baja California and Gulf of Guayaquil areas, is 1.30×10^{-4}. Since most of the major fishing areas in the eastern Pacific Ocean exploited prior to the mid-1960's are included, the estimate of q for the entire area should not be much lower, perhaps about 1.00×10^{-4}.

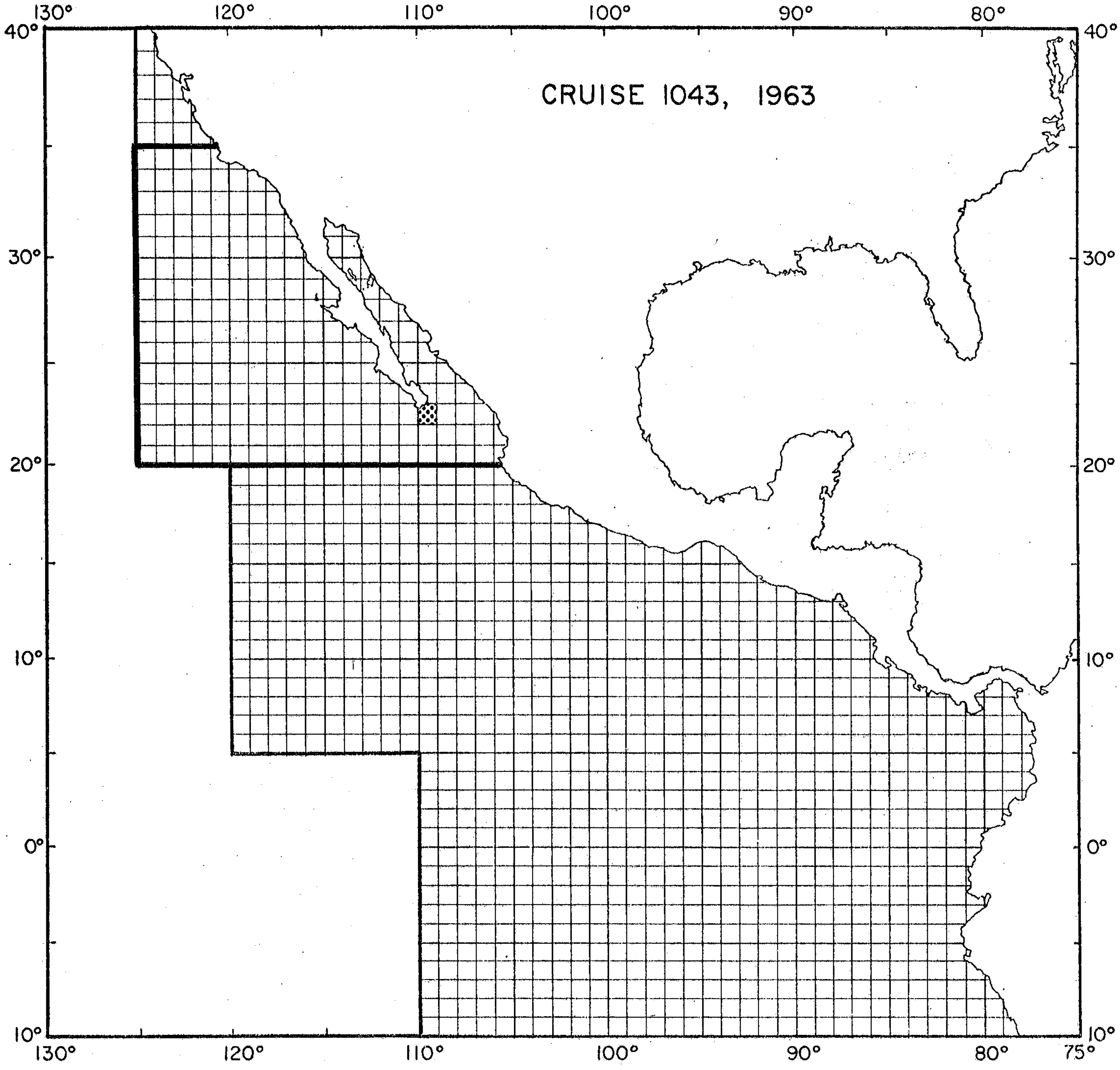


Figure 1. Area of release (shaded) of tagged fish used for estimation of the coefficient of total mortality and shedding in the Gulf of California area (outlined).

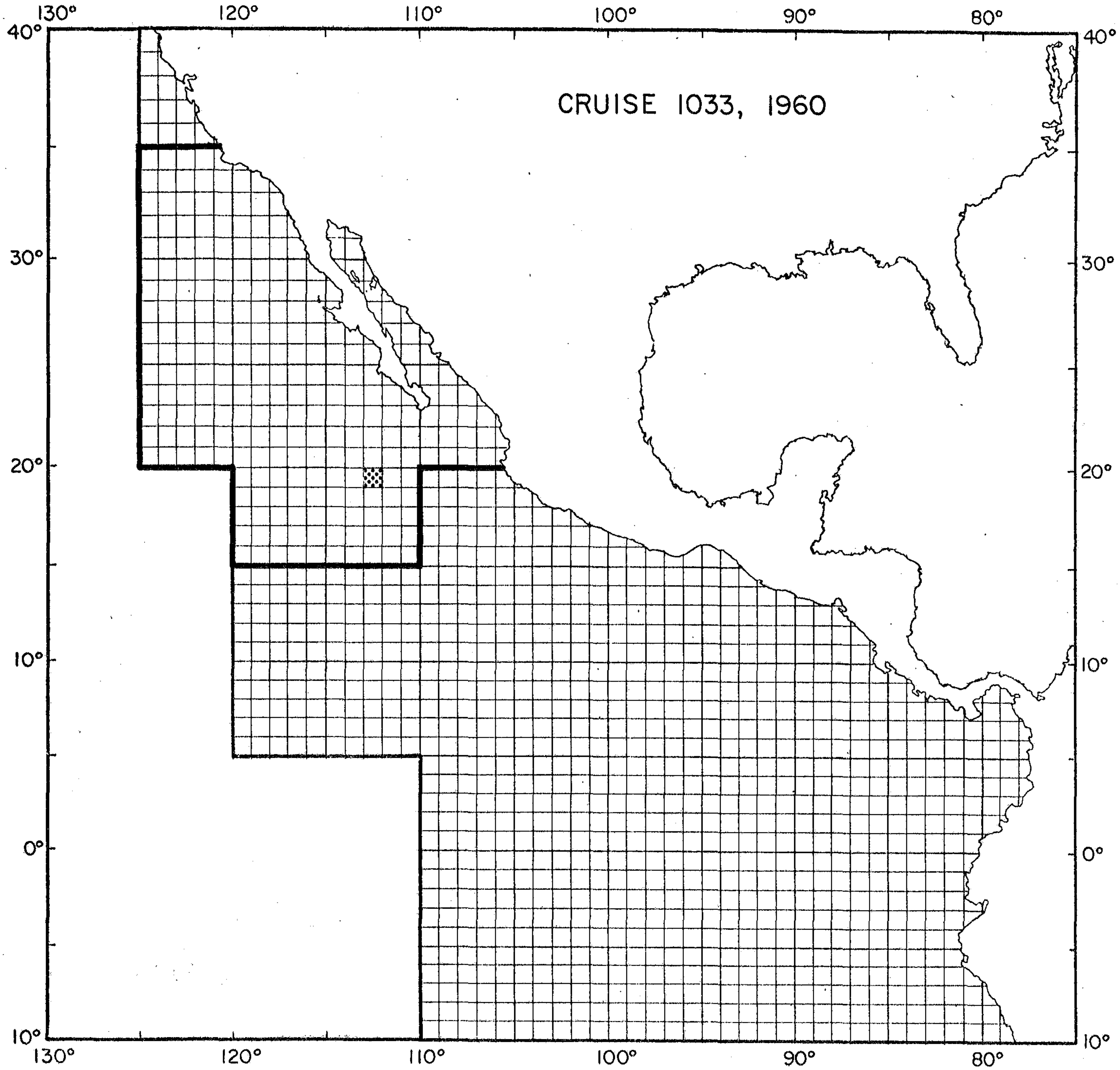
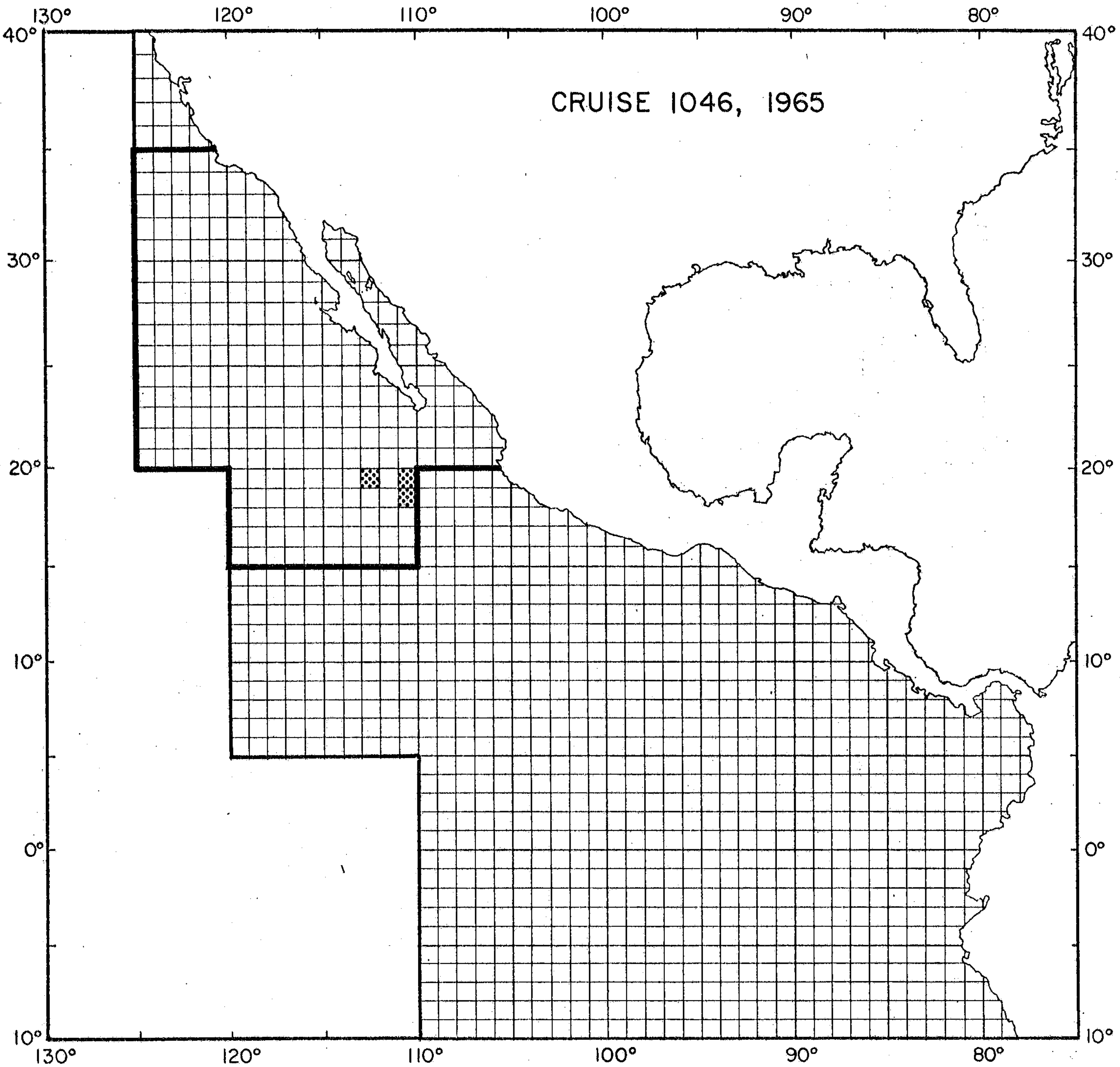


Figure 2. Areas of release (shaded) of tagged fish used for estimation of the coefficient of total mortality and shedding in the Revillagigedo Islands area (outlined).



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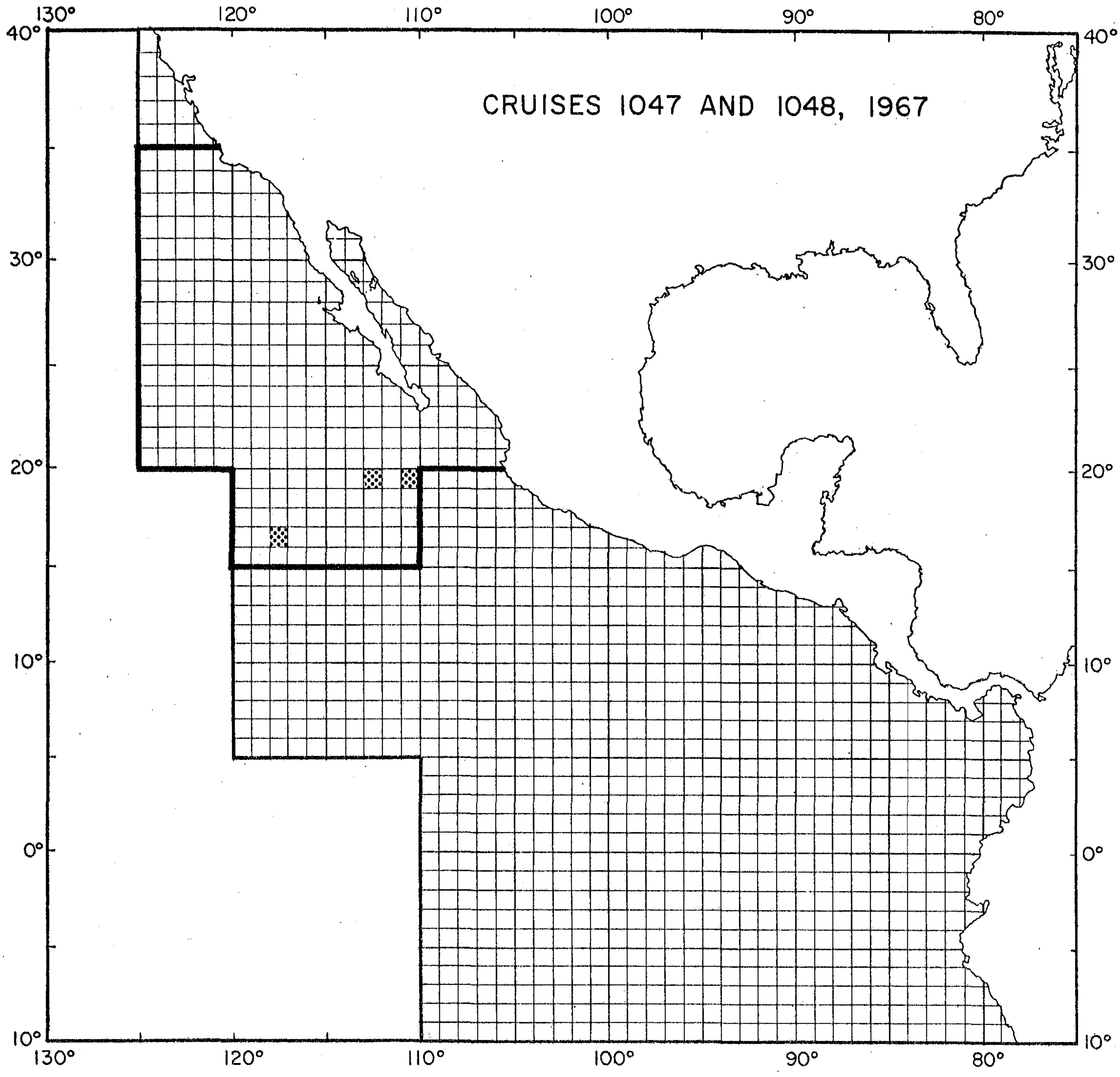

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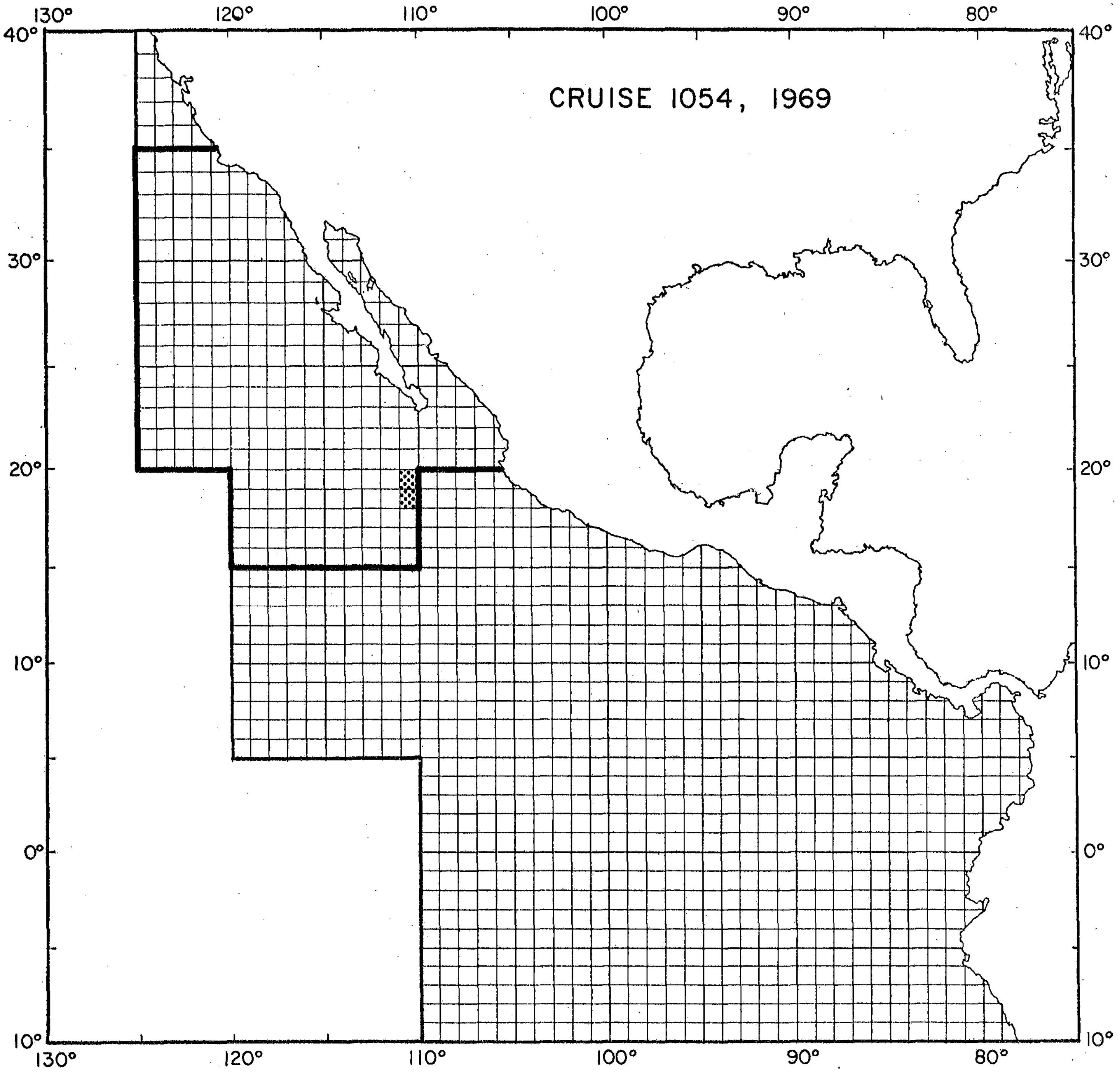

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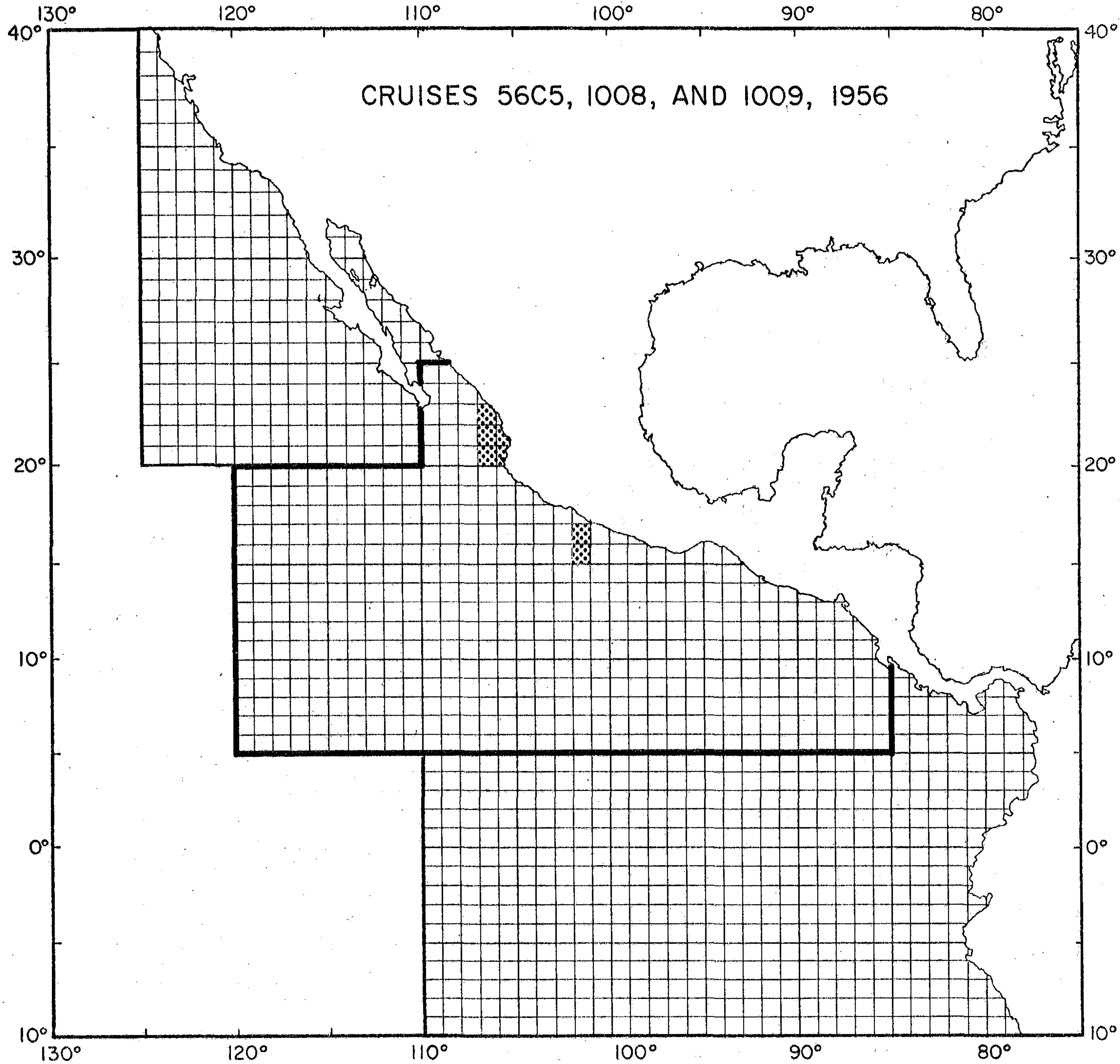


Figure 3. Areas of release (shaded) of tagged fish used for estimation of the coefficient of total mortality and shedding in the Mexico-Central America area (outlined).

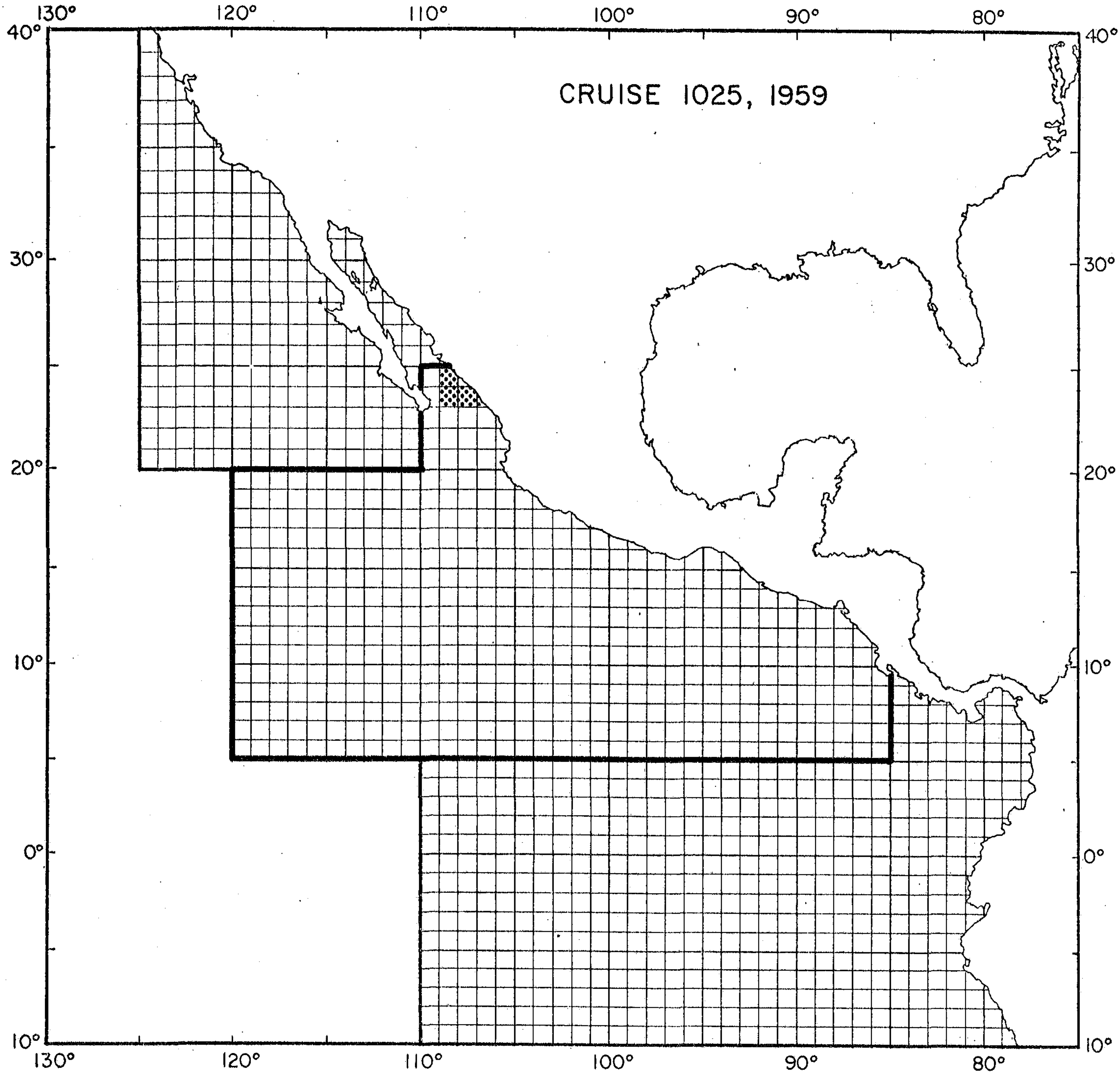
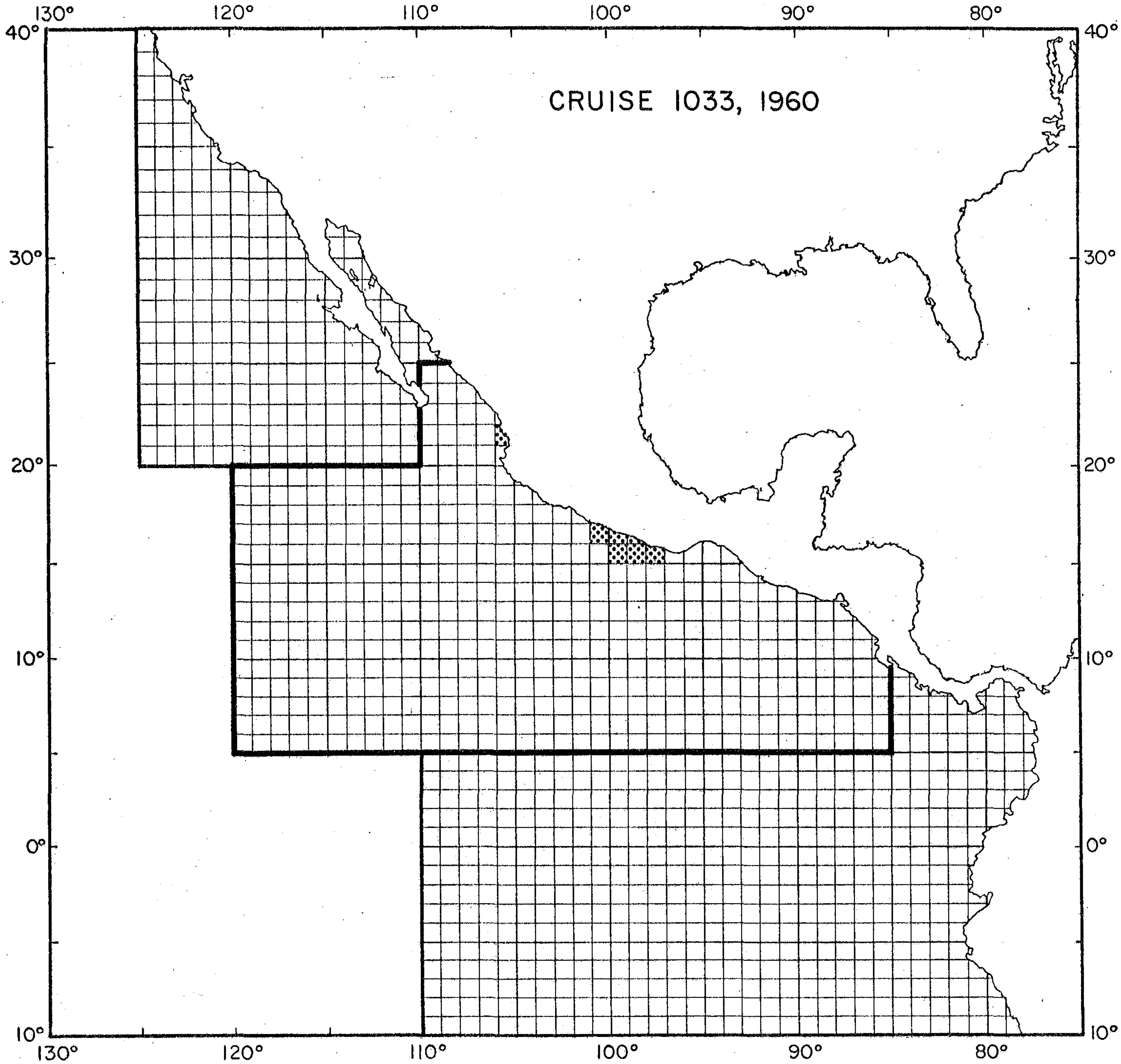


Figure 3 (continued)



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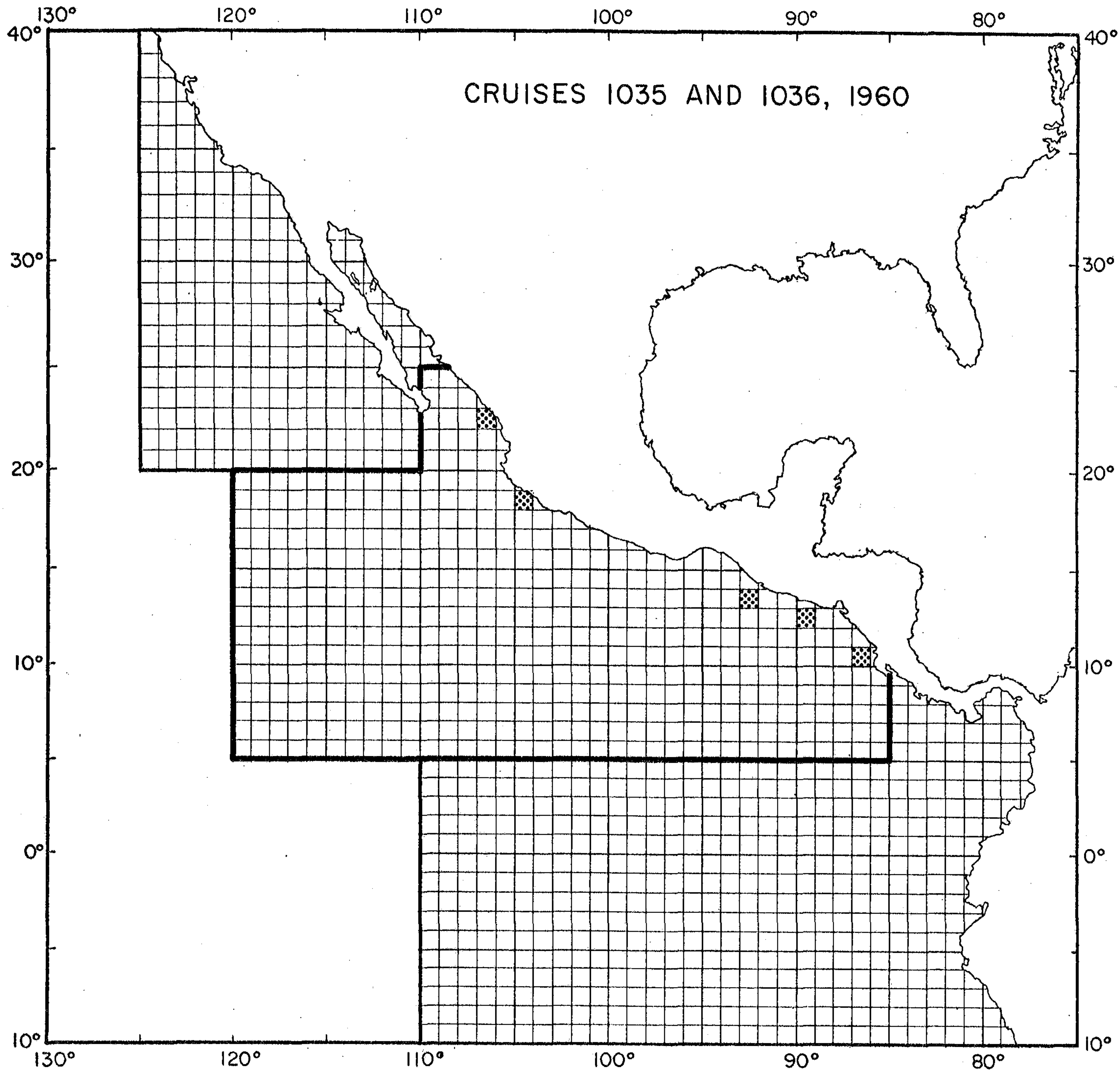

Figure 3 (continued).

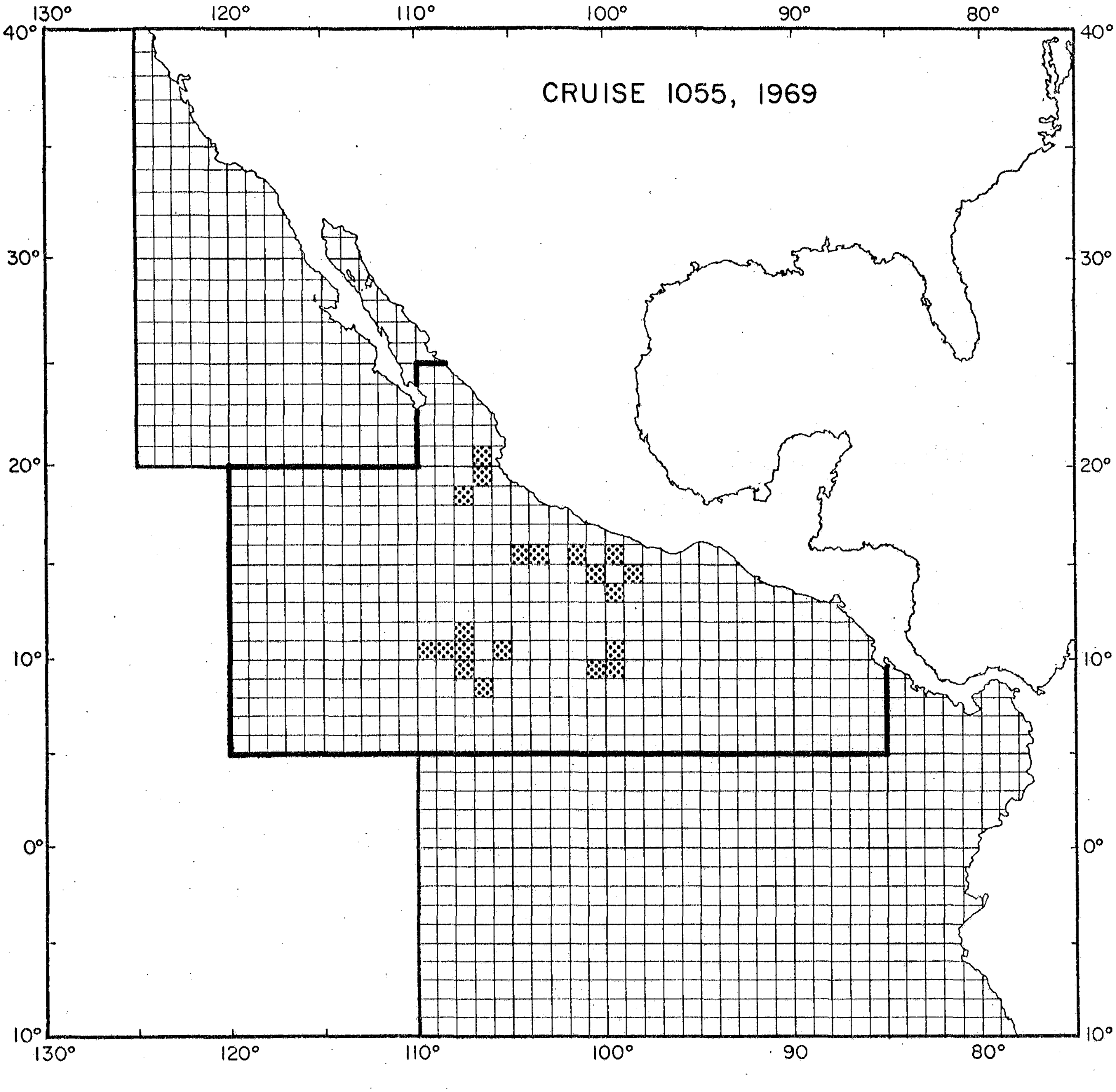

Figure 3 (continued)

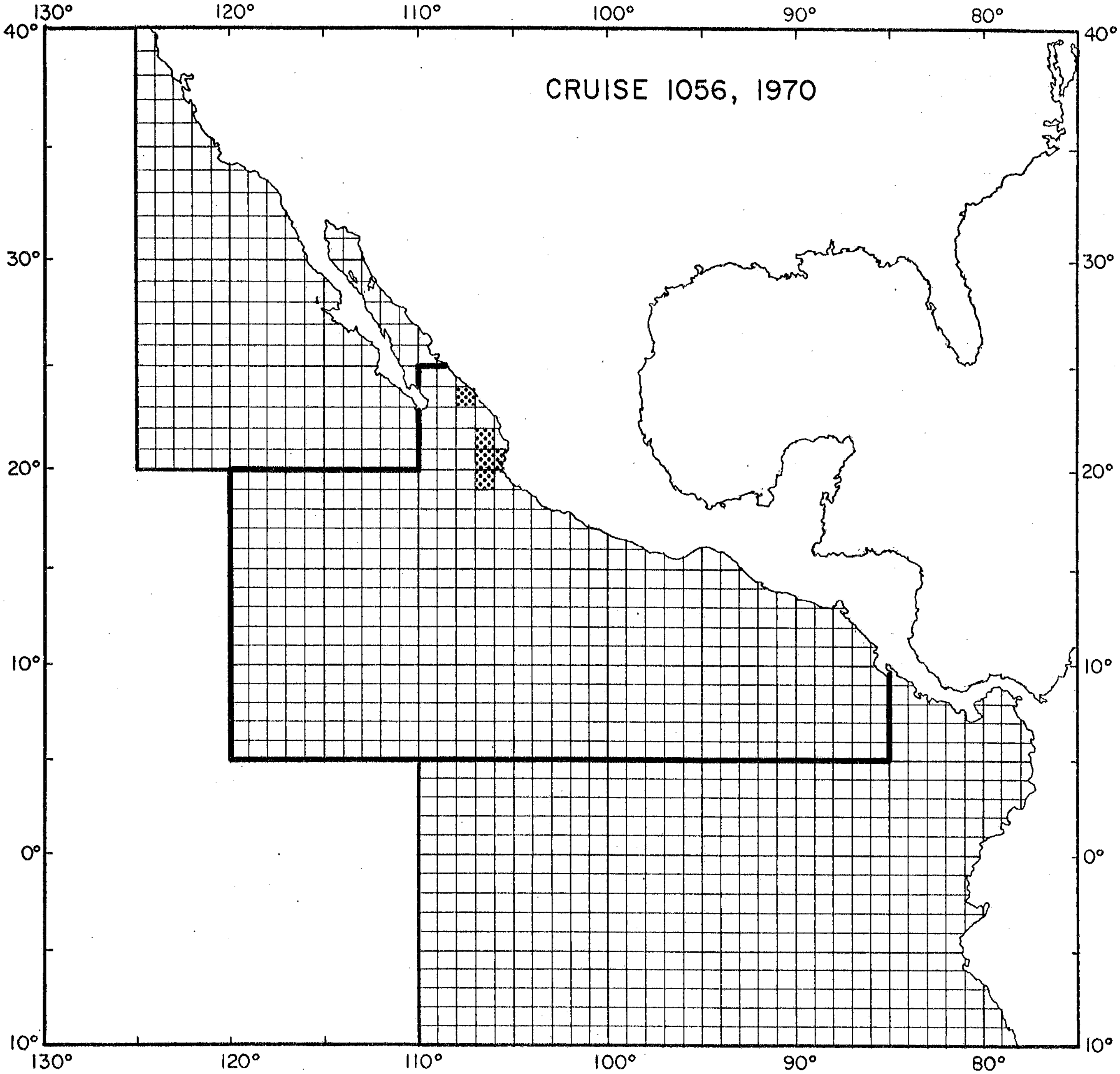

Figure 3 (continued).

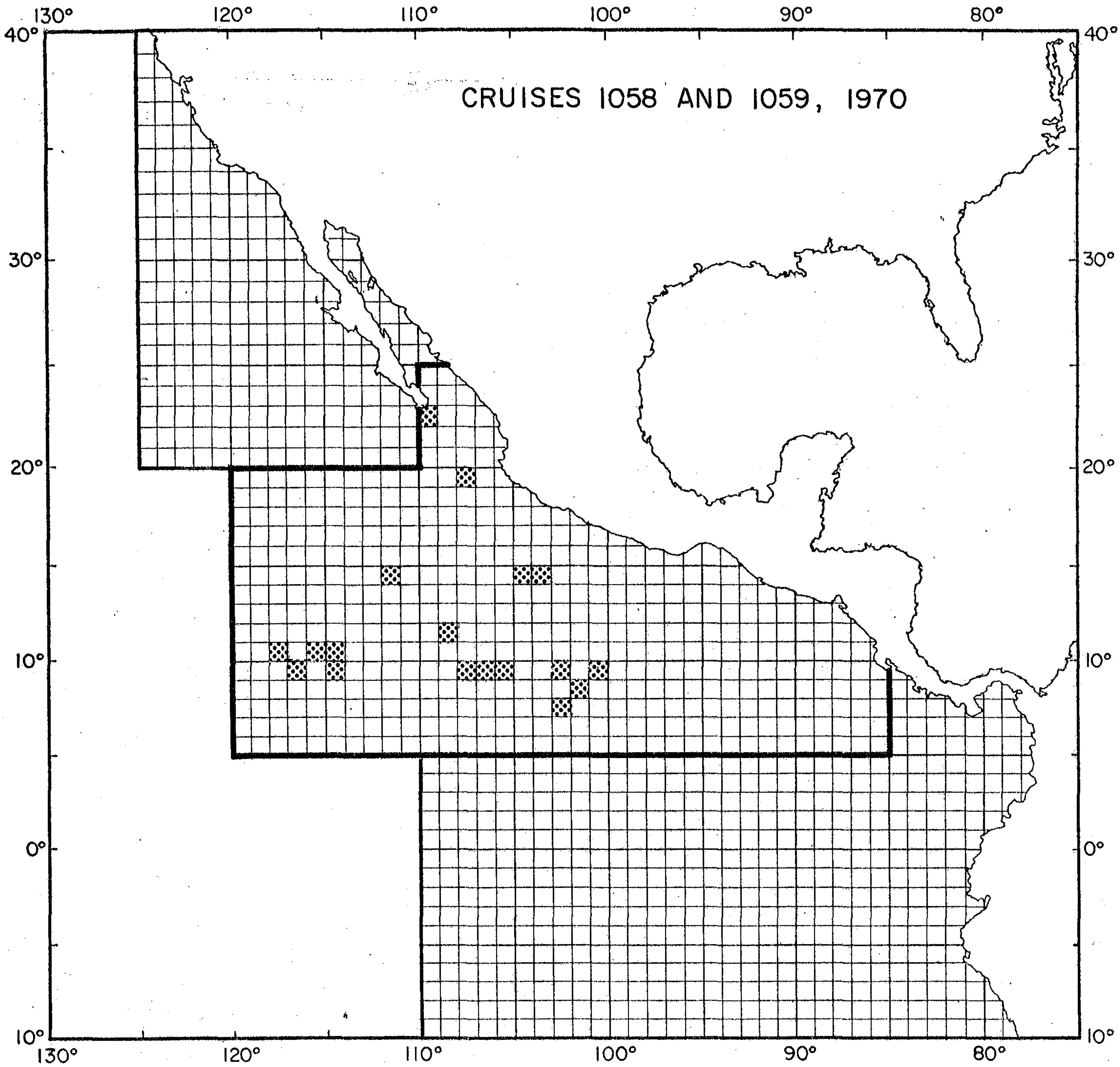

Figure 3 (continued).

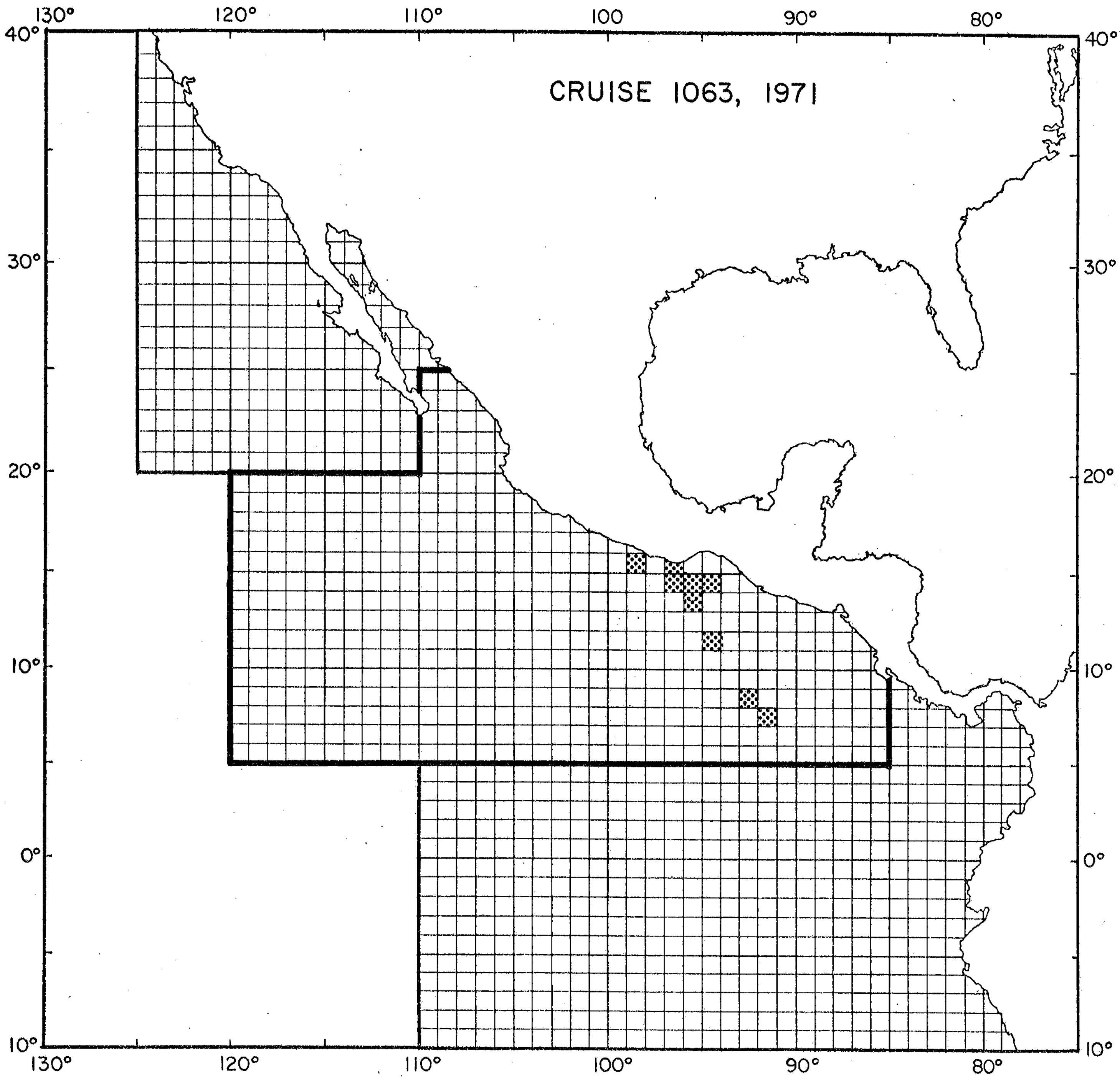

Figure 3 (continued).

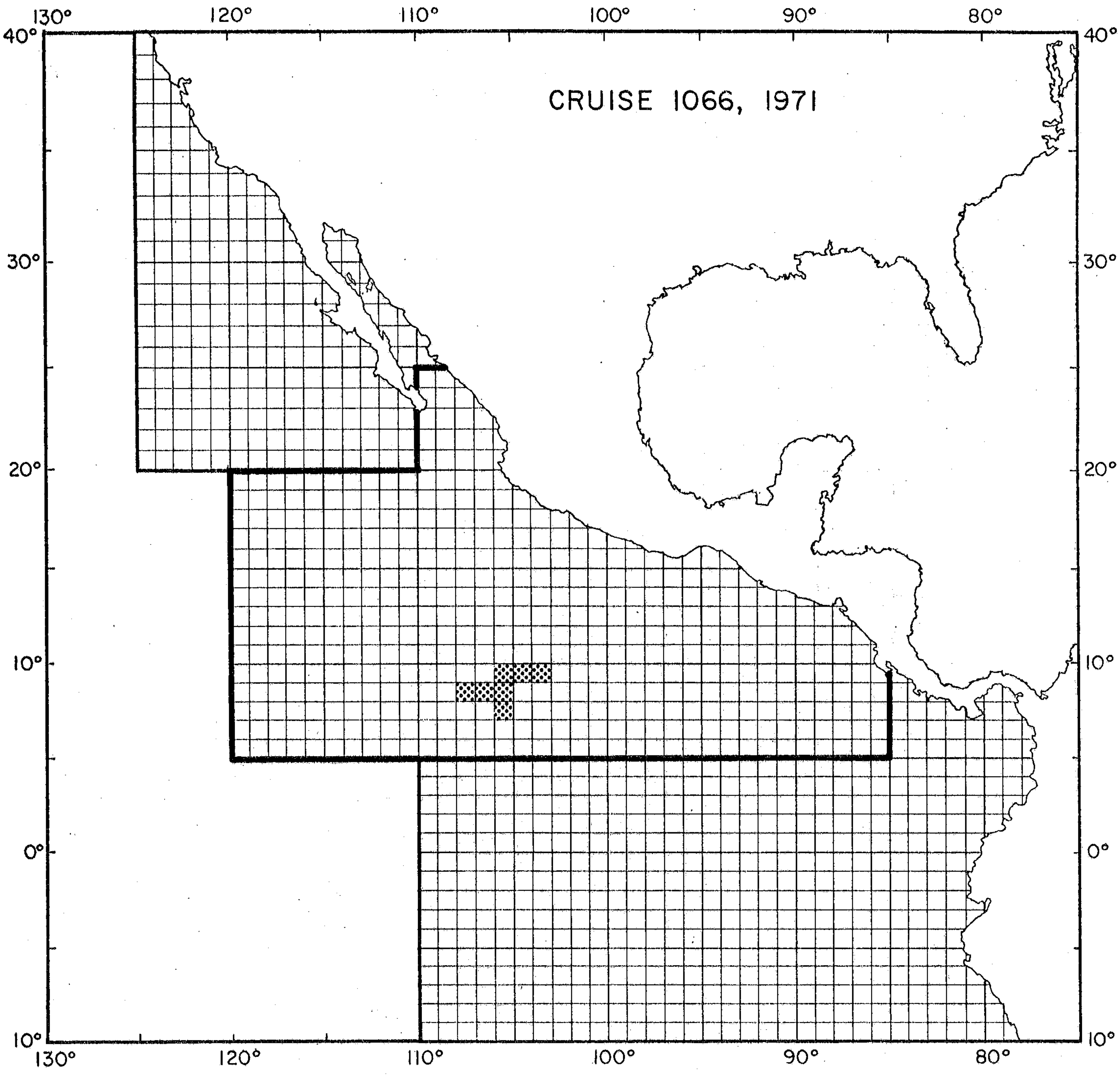

Figure 3 (continued).

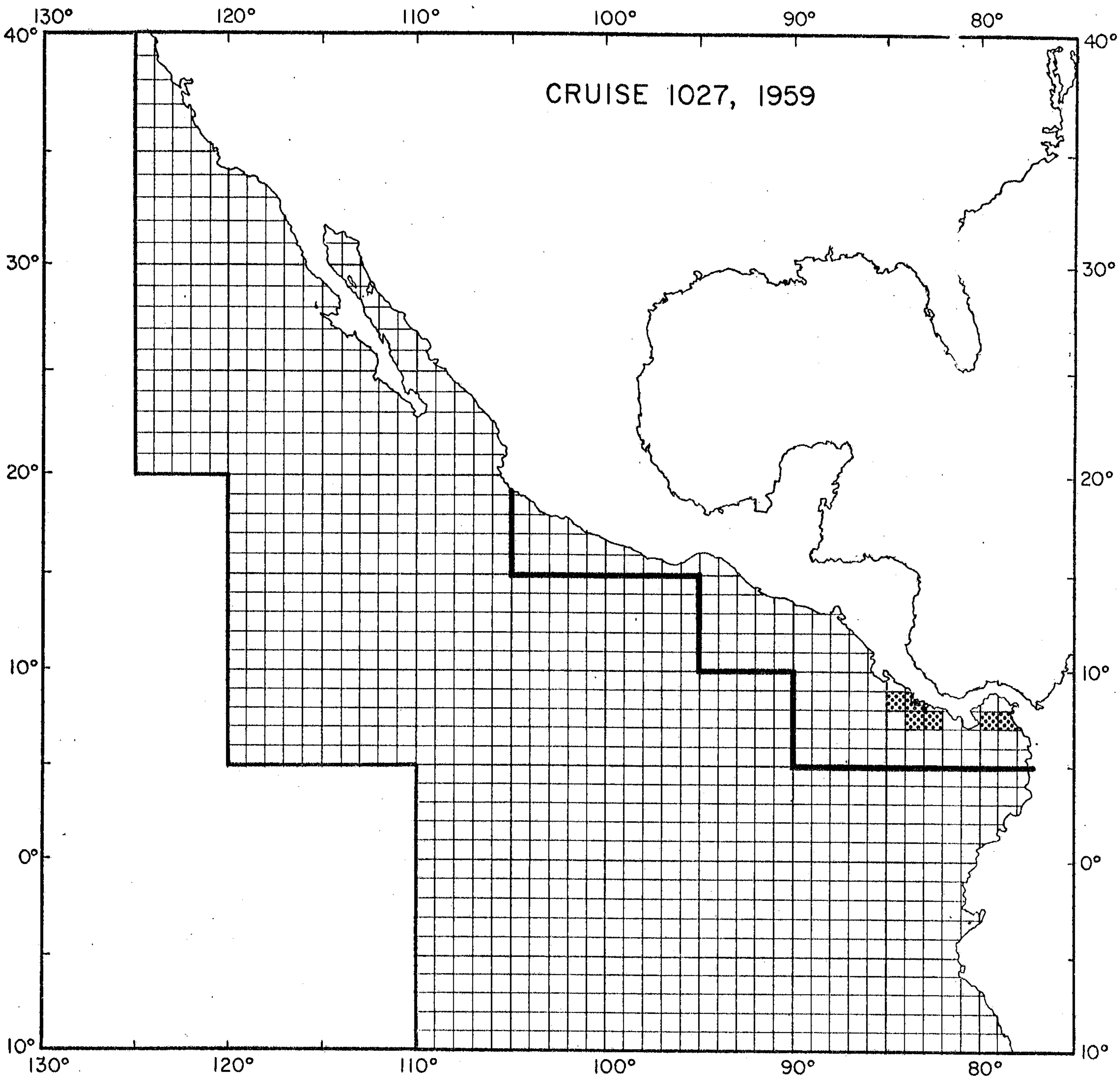

Figure 4. Areas of release (shaded) of tagged fish used for estimation of the coefficient of total mortality and shedding in the Gulf of Panama-Central America- southern Mexico area (outlined).

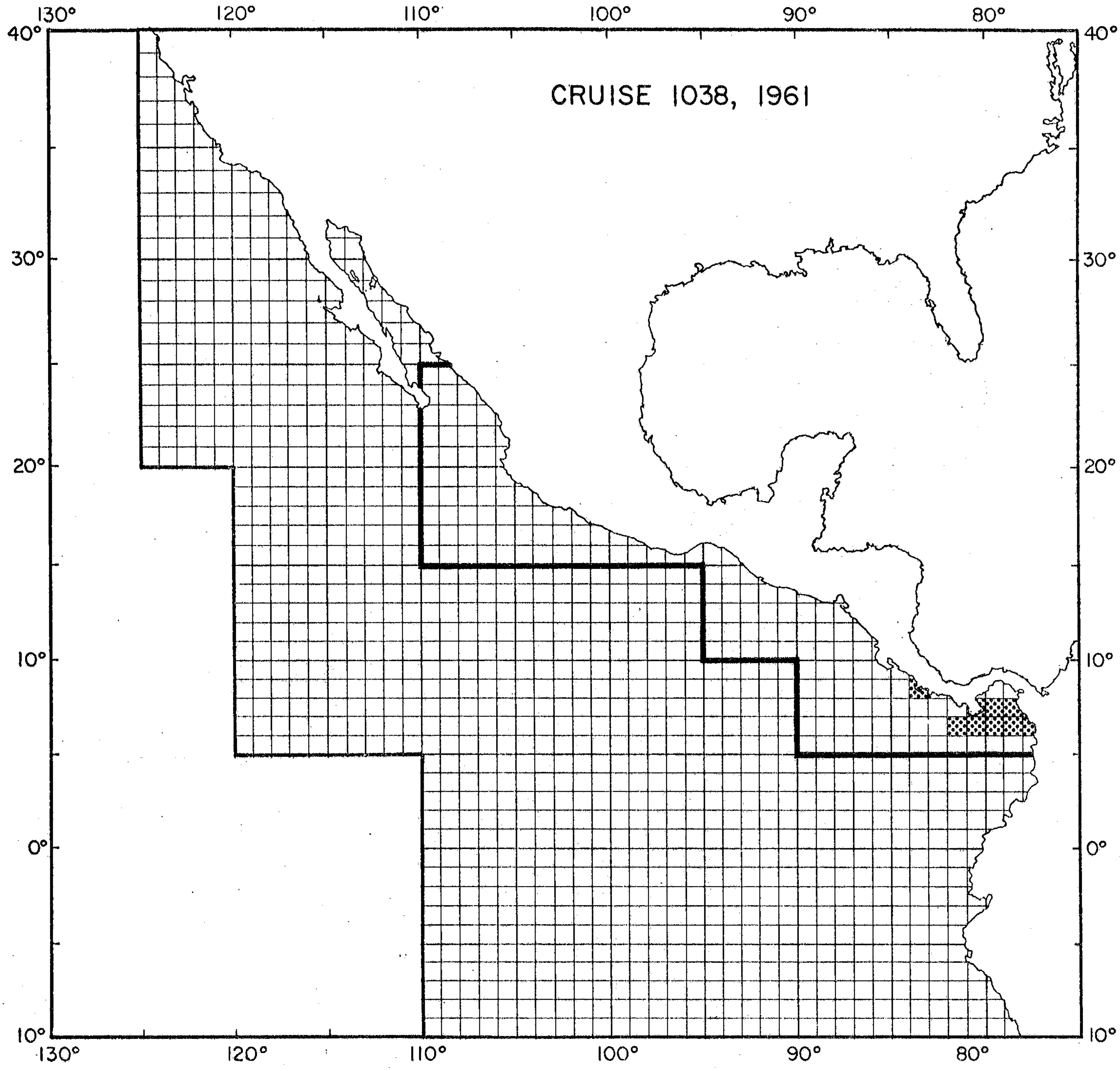

Figure 4 (continued).

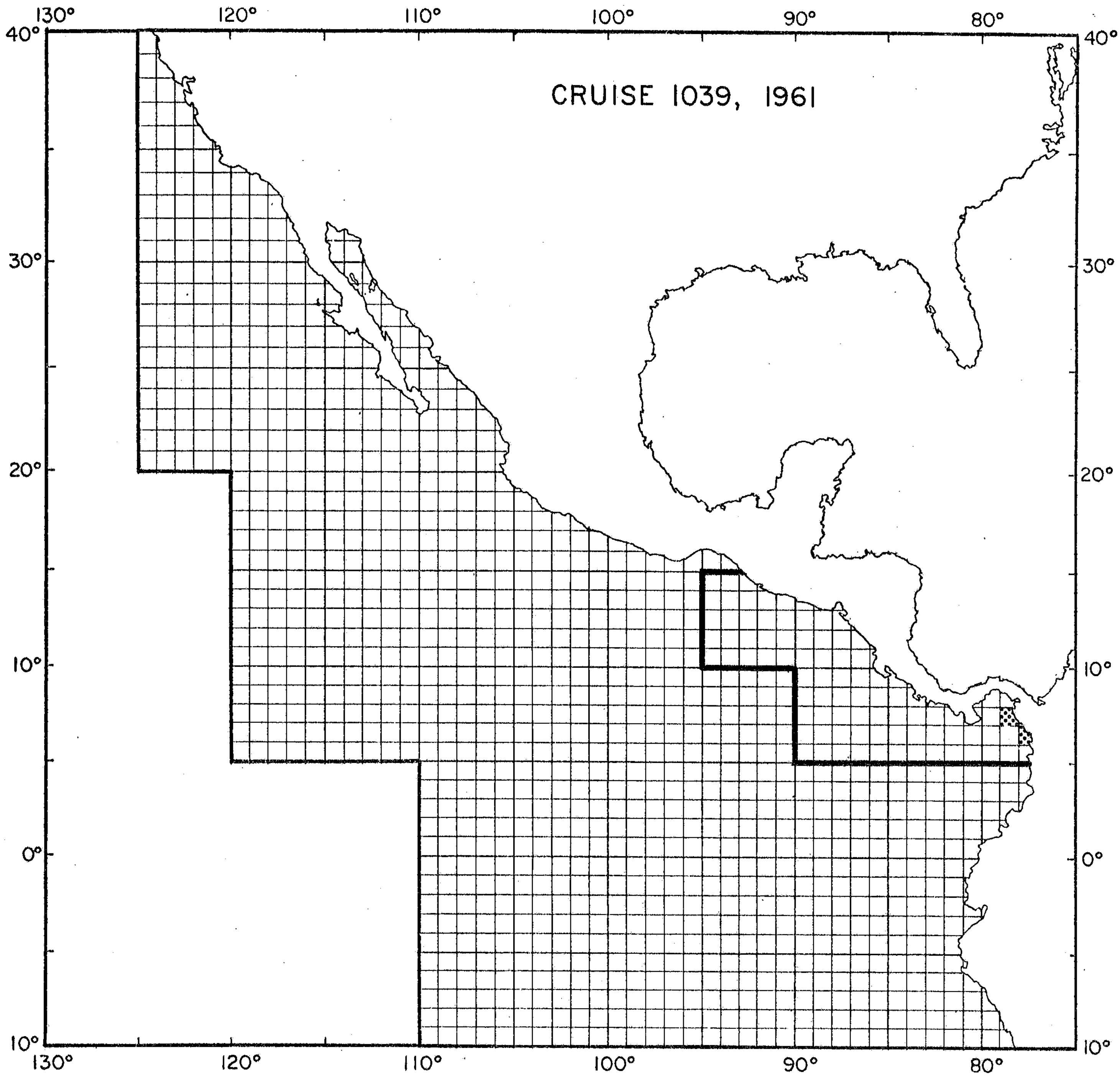

Figure 4 (continued).

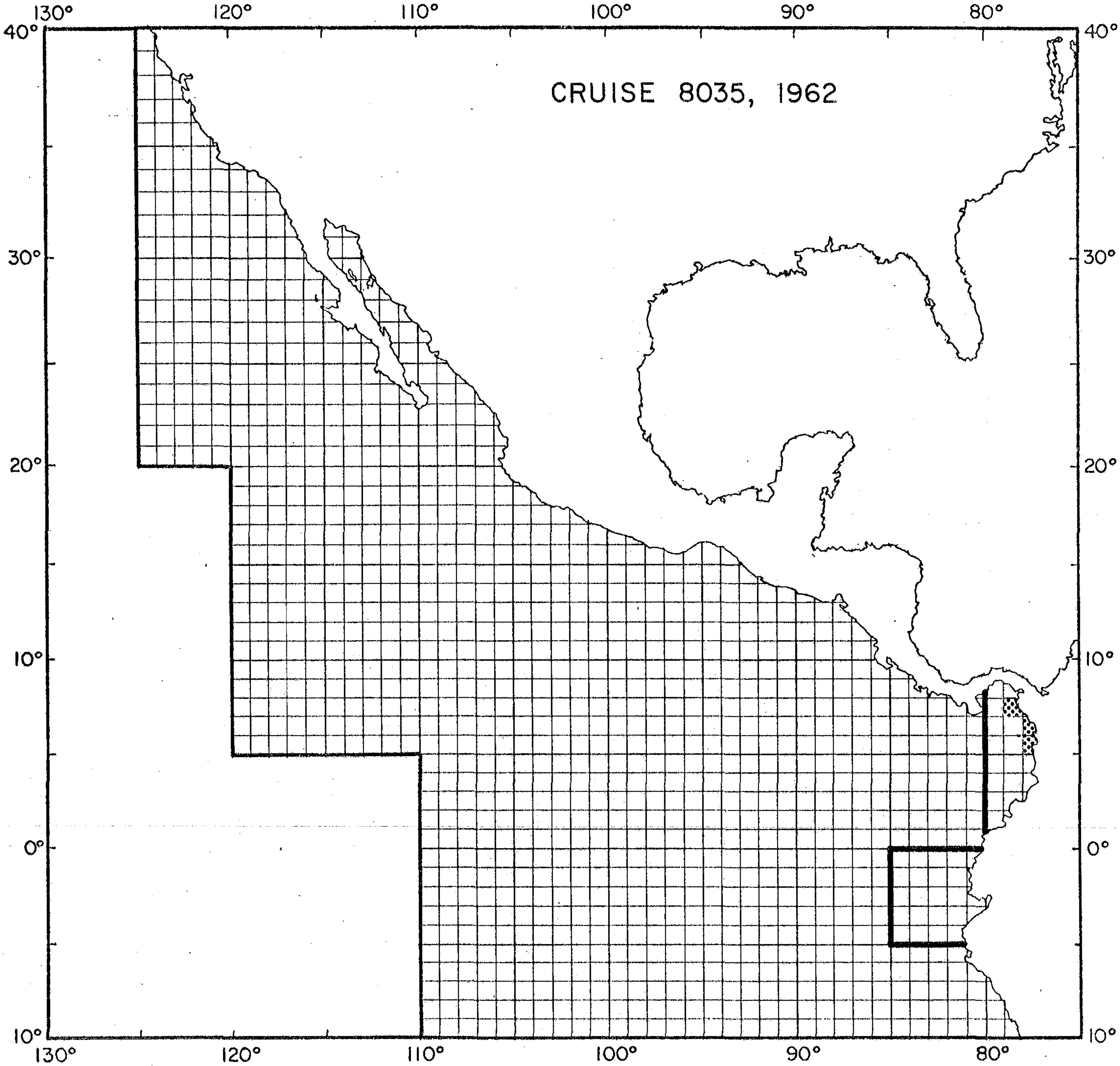

Figure 4 (continued).

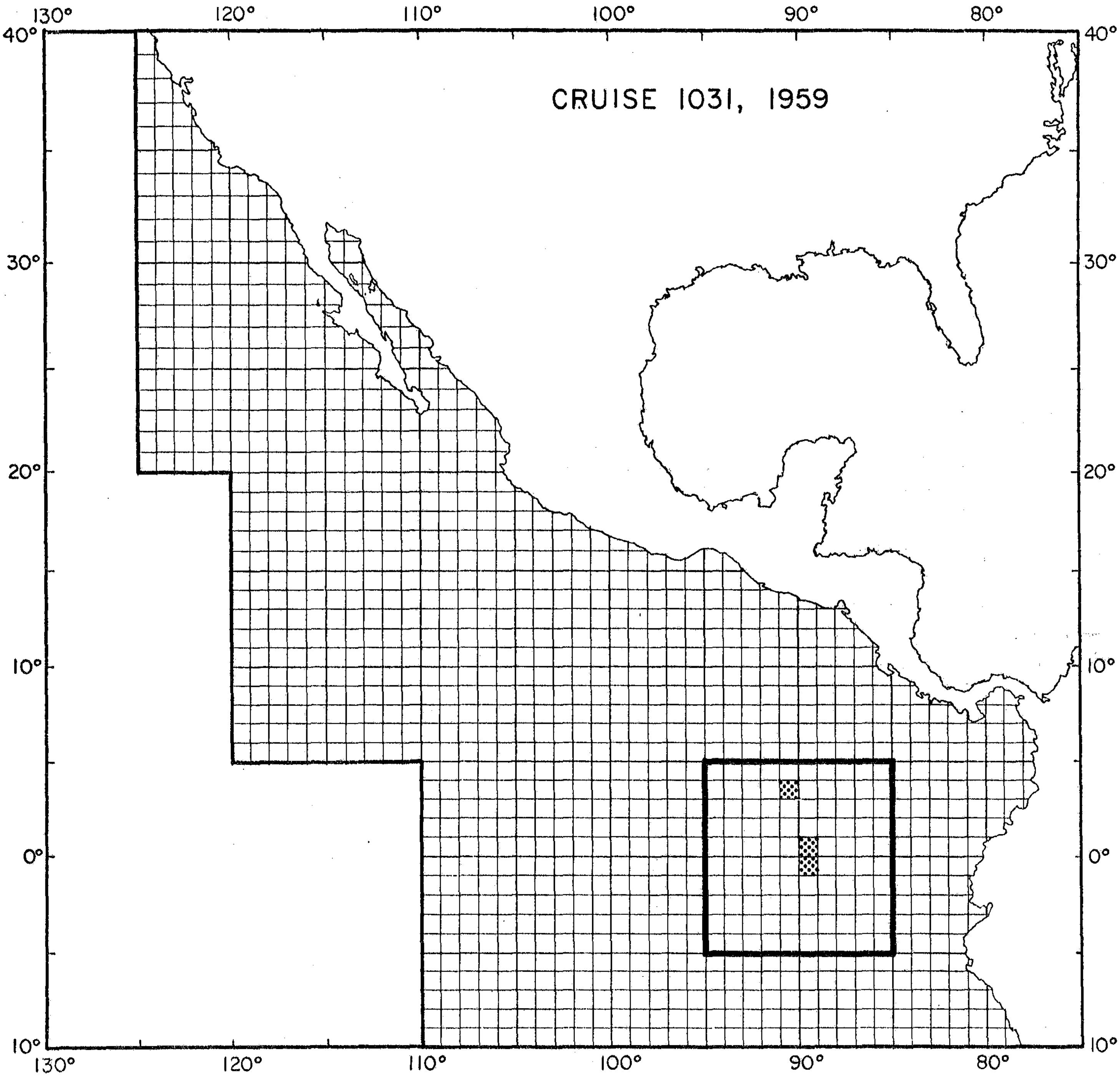

Figure 5. Areas of release (shaded) of tagged fish used for estimation of the coefficient of total mortality and shedding in the Galapagos Islands area (outlined).

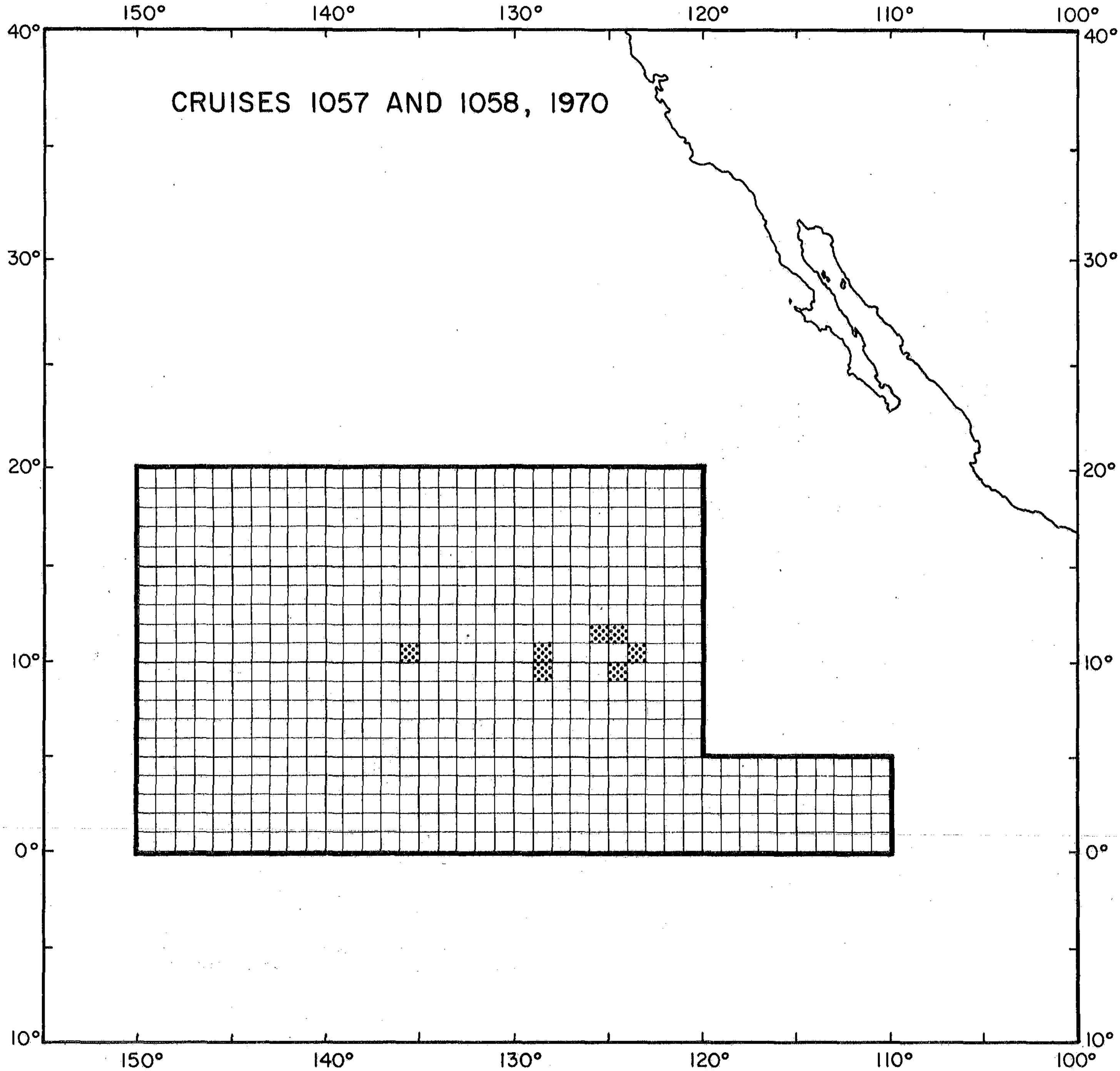

Figure 6. Areas of release (shaded) of tagged fish used for estimation of the coefficient of total mortality and shedding in the area outside the CYRA (outlined).

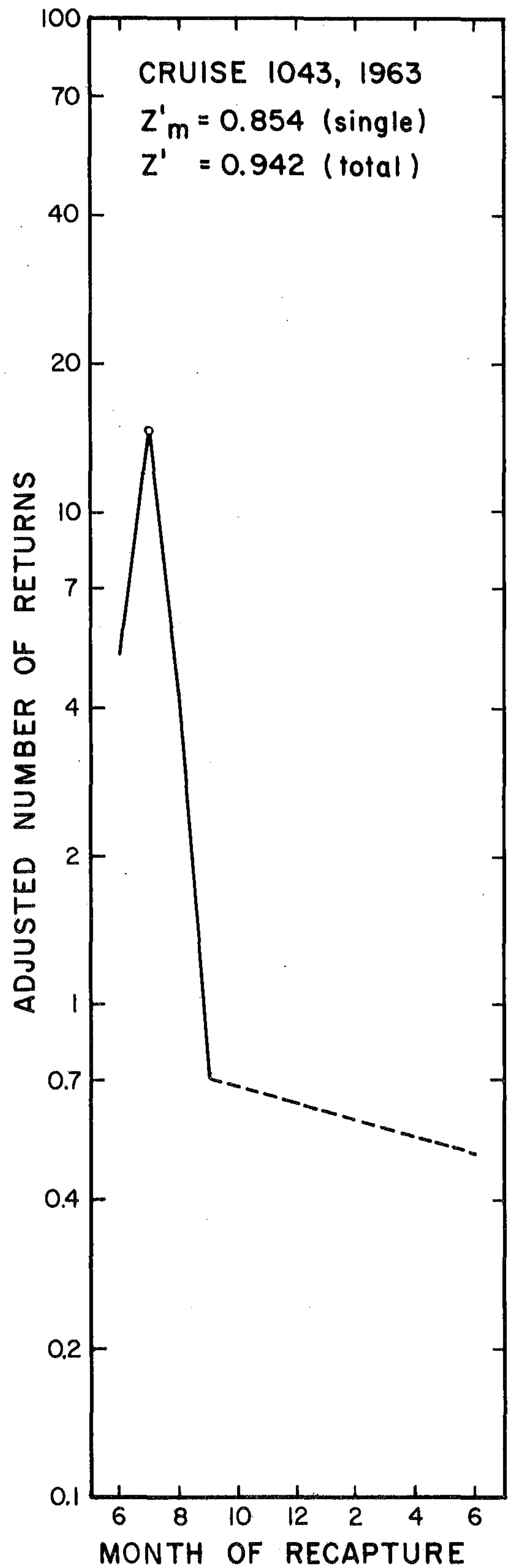

Figure 7. Adjusted tag returns by month of recapture for the Gulf of California area releases.

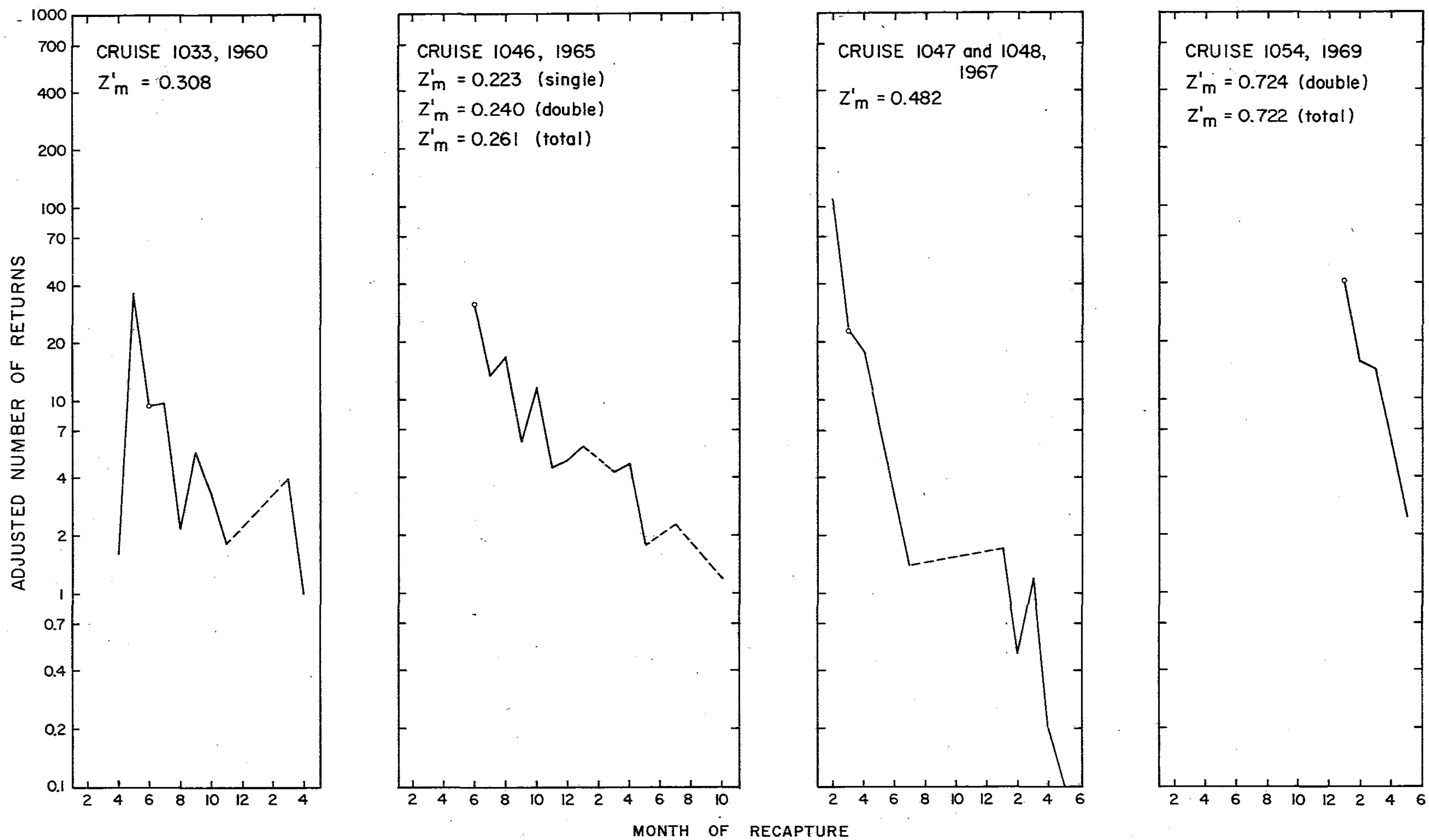

Figure 8. Adjusted tag returns by month of recapture for the Revillagigedo Islands area releases.

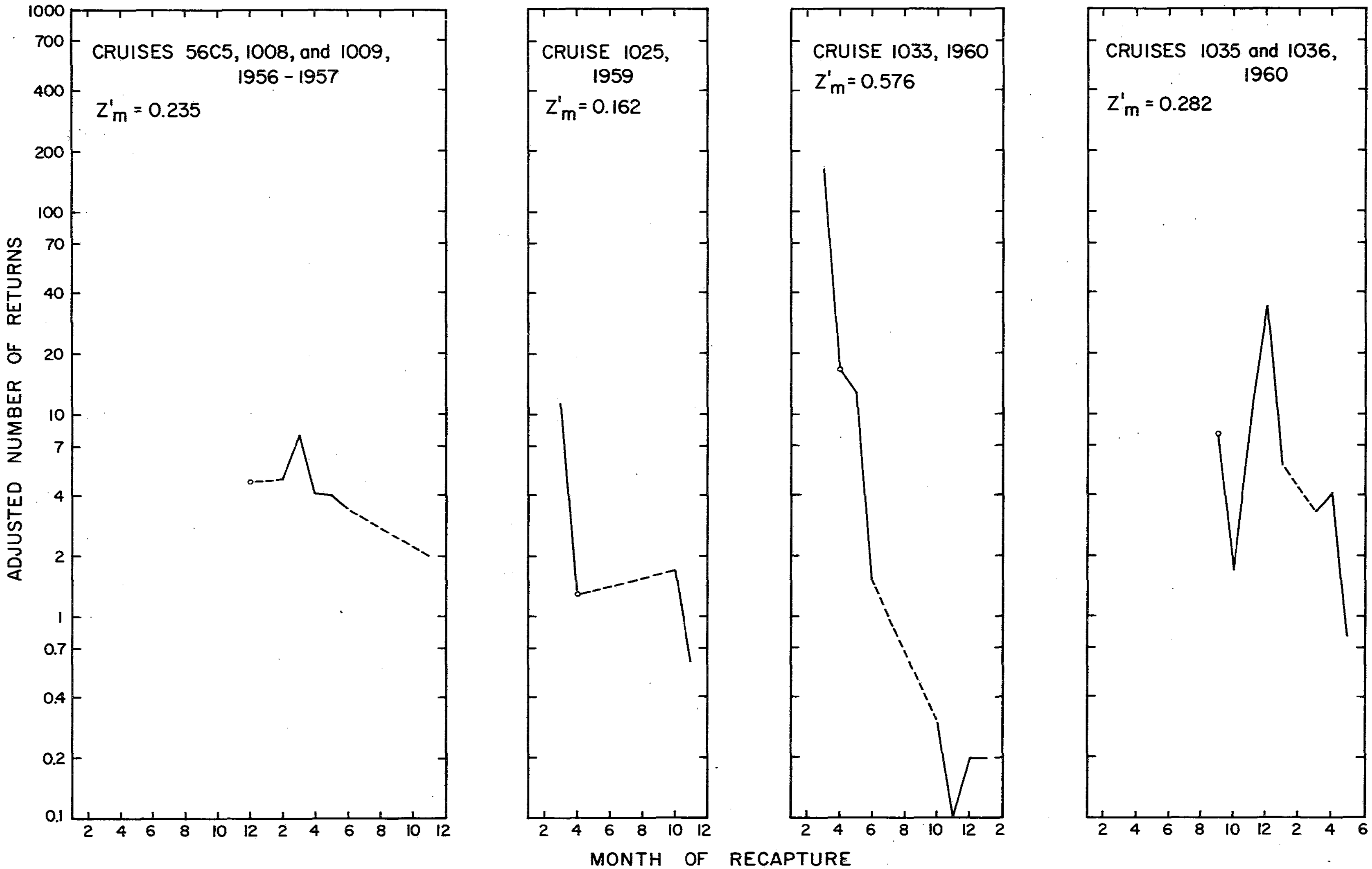

Figure 9. Adjusted tag returns by month of recapture for the Mexico-Central America area releases.

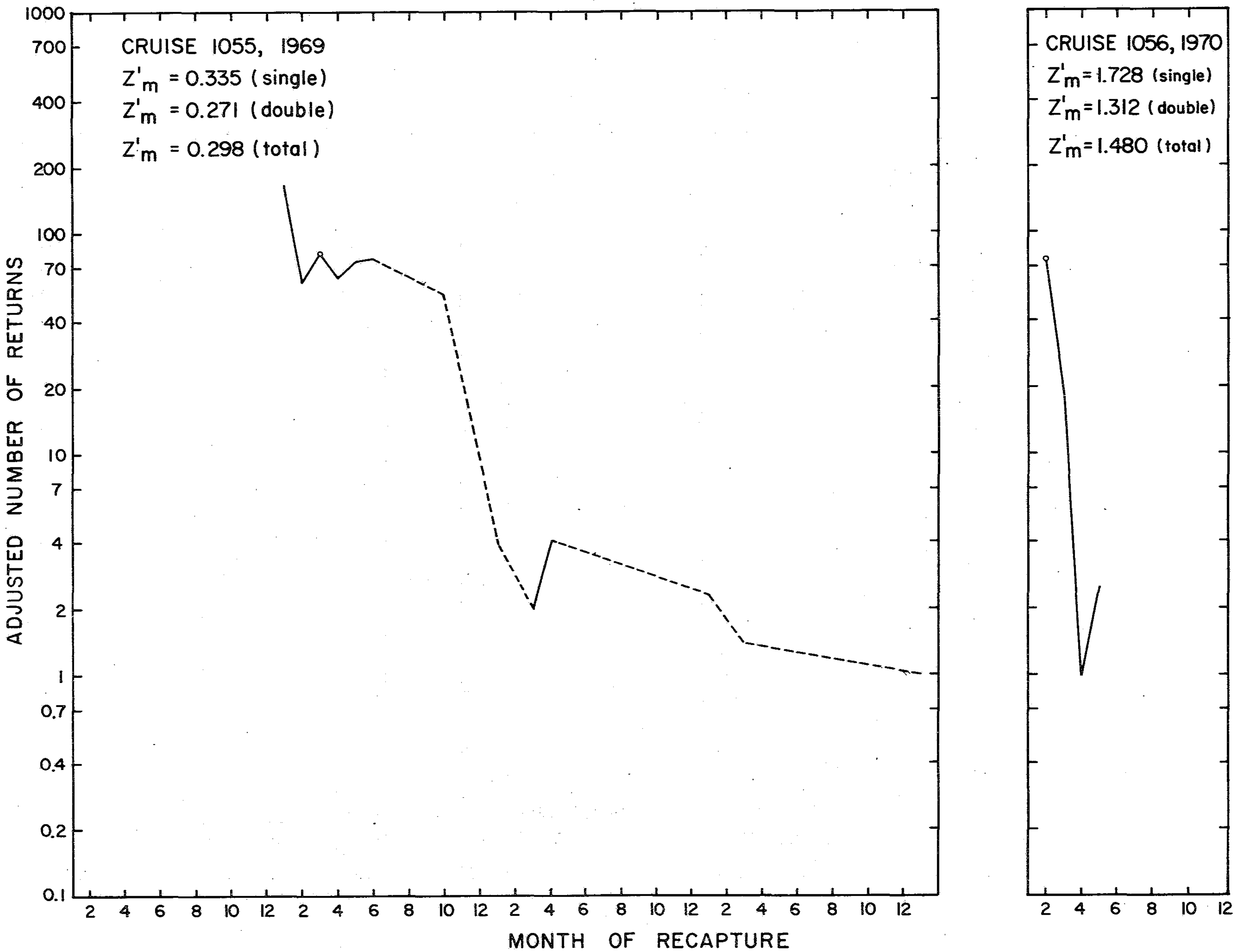

Figure 9 (continued).

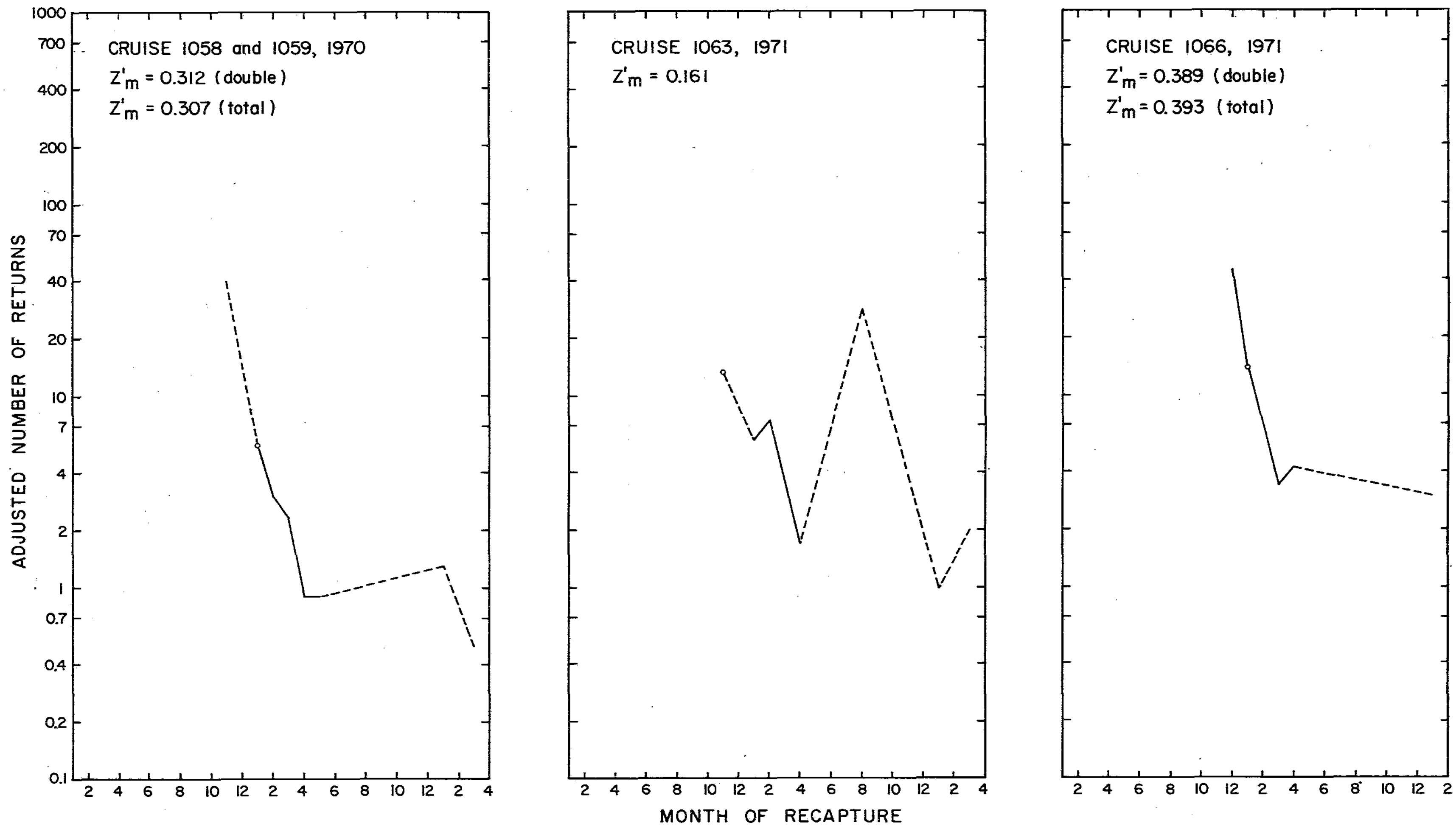

Figure 9 (continued).

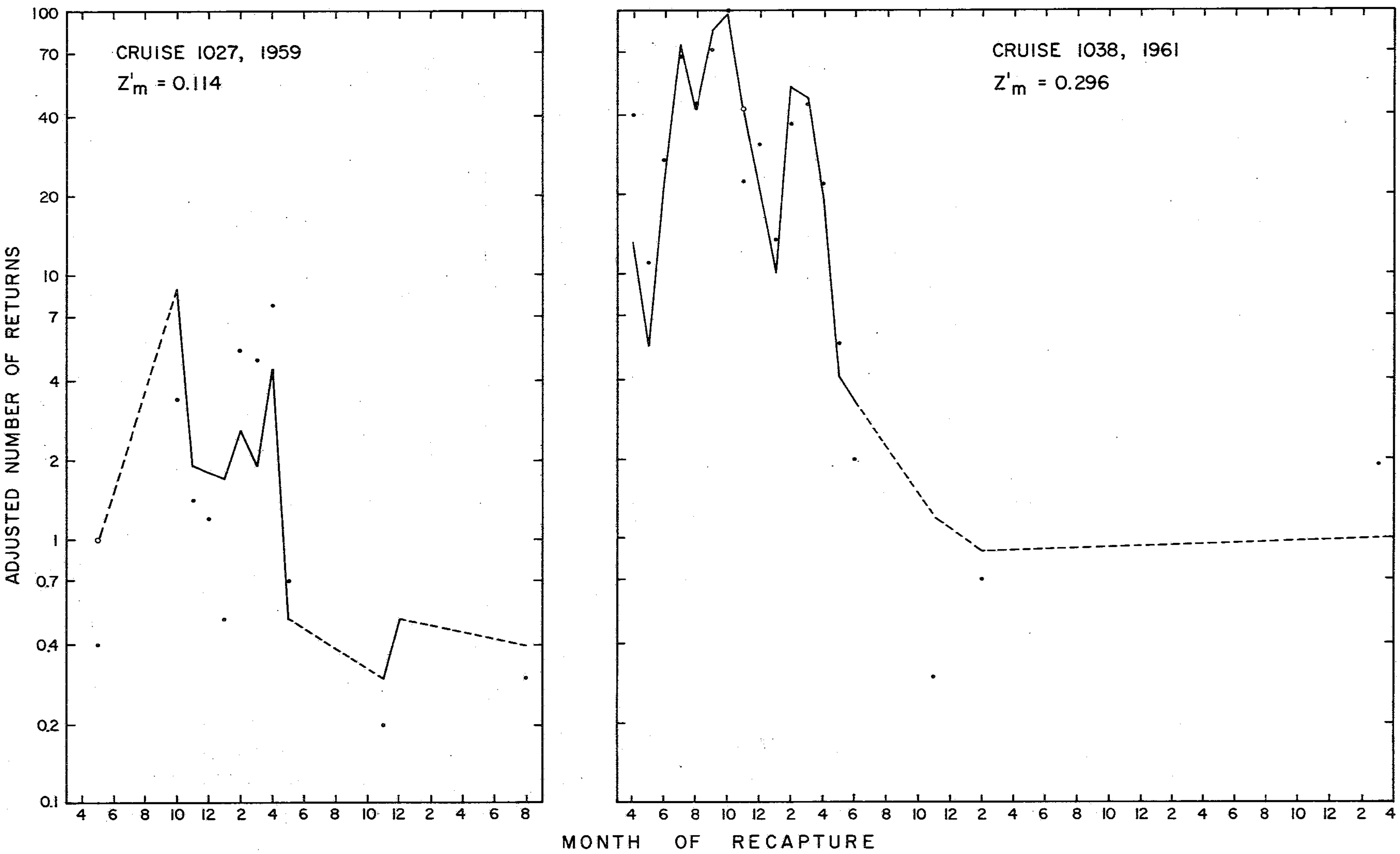

Figure 10. Adjusted tag returns by month of recapture for the Gulf of Panama area releases.

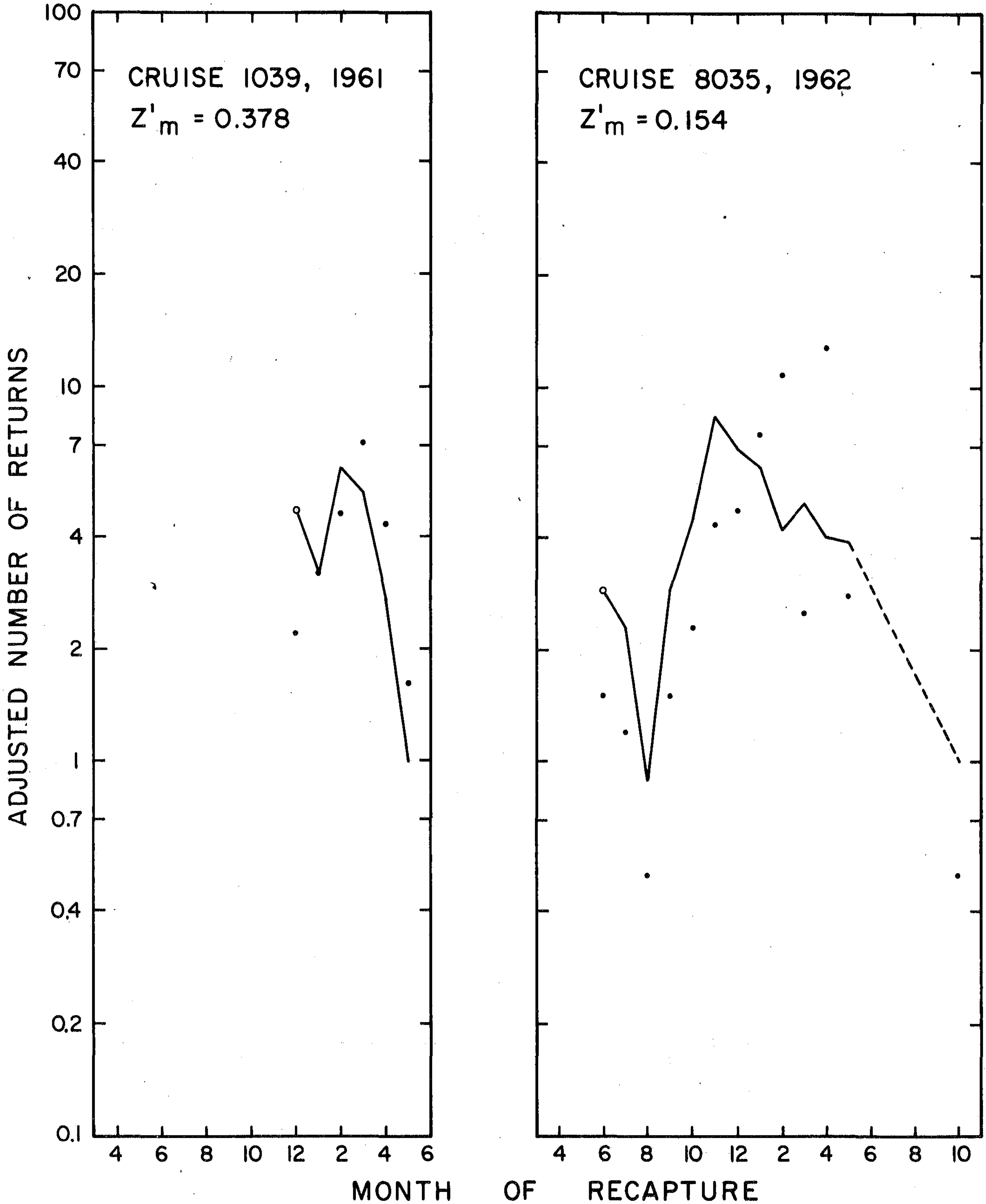

Figure 10 (continued).

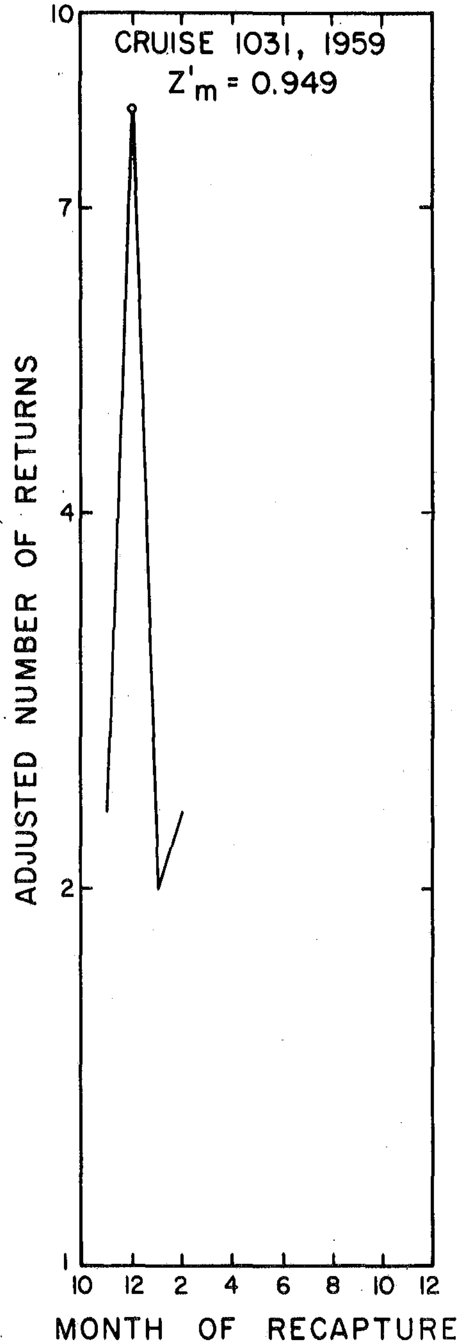

Figure 11. Adjusted tag returns by month of recapture for the Galapagos Islands area releases.

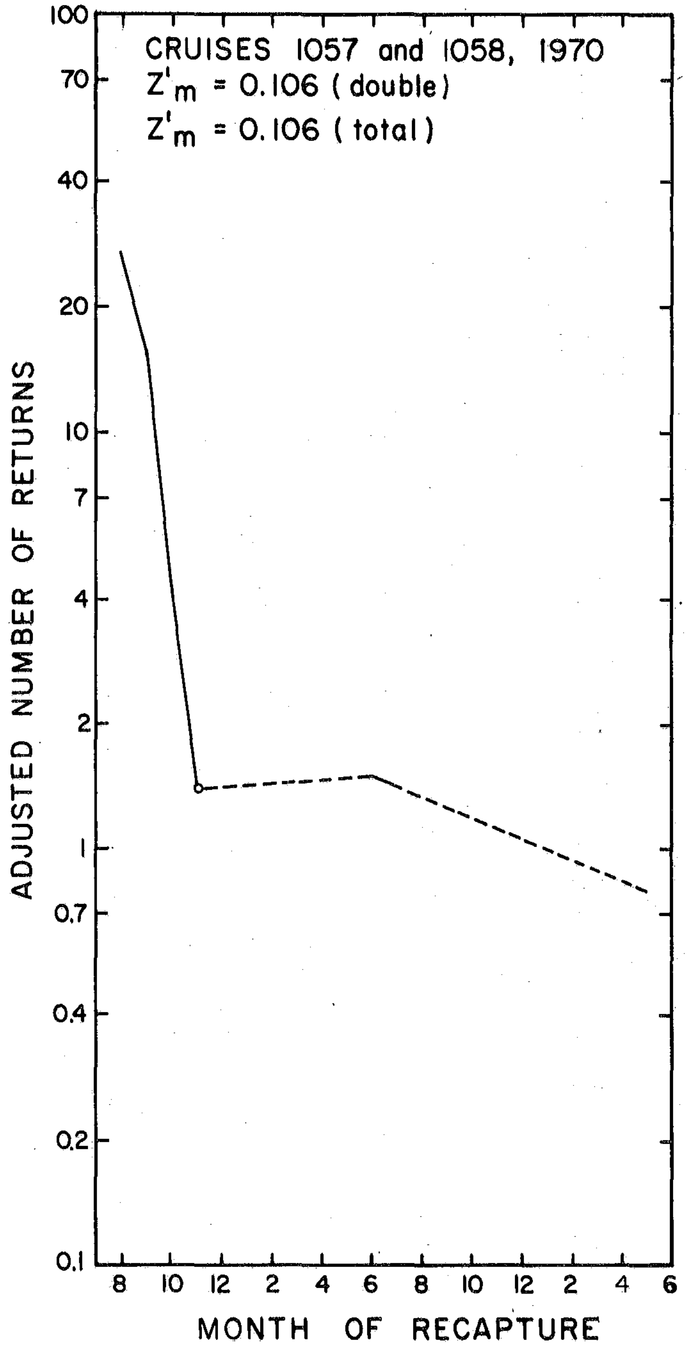

Figure 12. Adjusted tag returns by month of recapture for the releases in the area outside the CYRA.

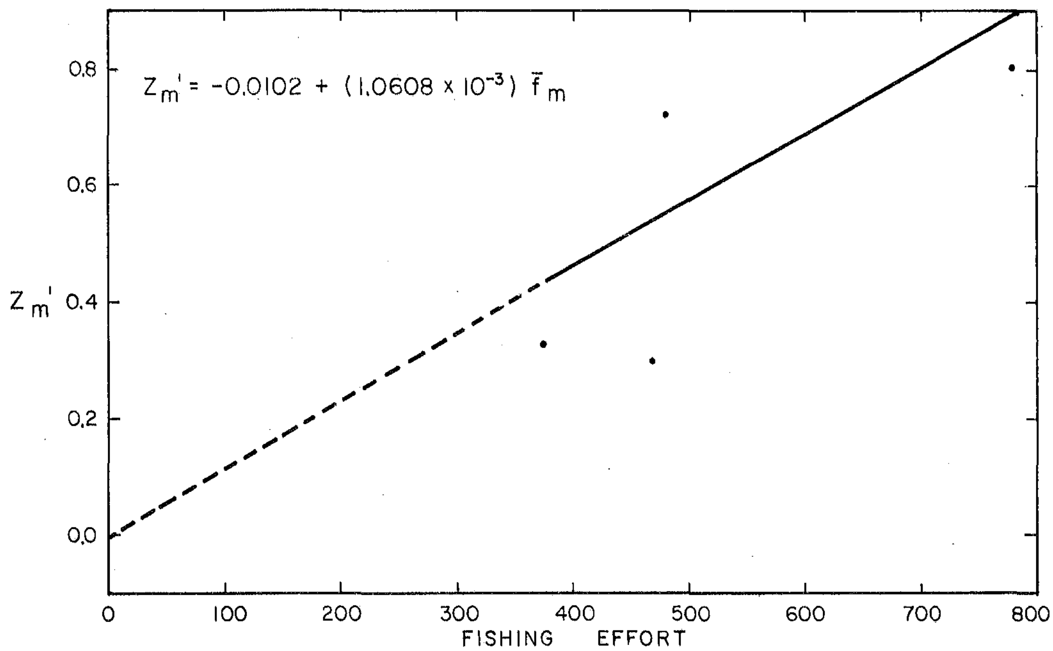

Figure 13. Least-squares regression line for estimation of $\underline{X_m}$ and $\underline{q}$ for the Revillagigedo Islands area.

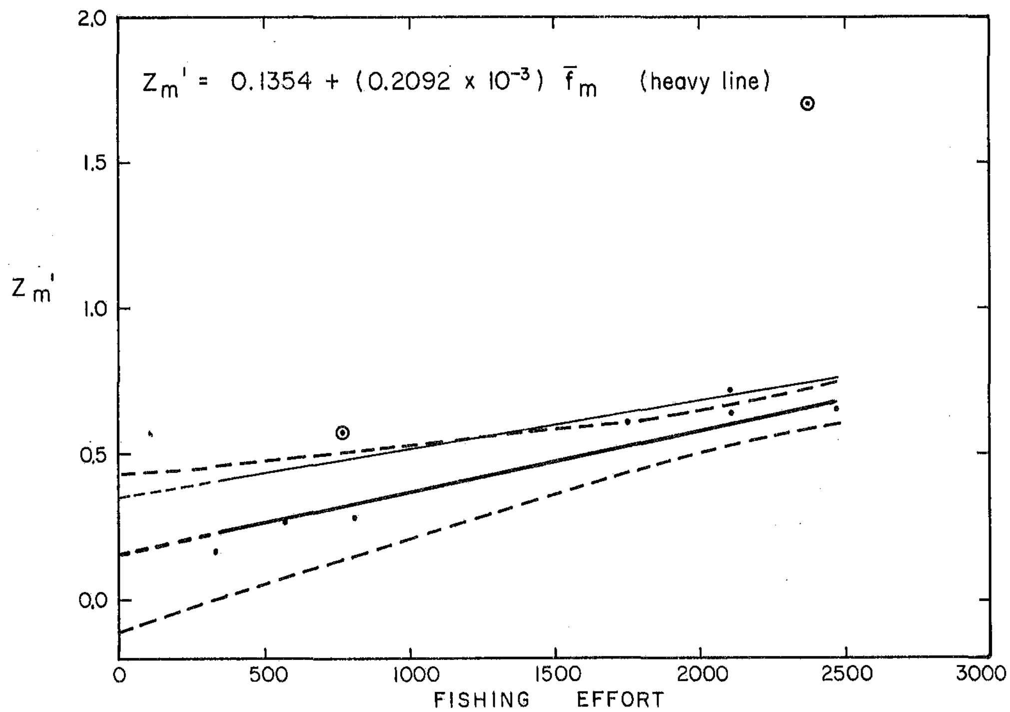

Figure 14. Least-squares regression lines for estimation of $\underline{X_m}$ and $\underline{q}$ for the Mexico-Central America area. The light line was calculated from all the data, while the heavy line was calculated from all the data except the two outliers, indicated by circles. The 95-percent confidence limits for the heavy line are also shown.

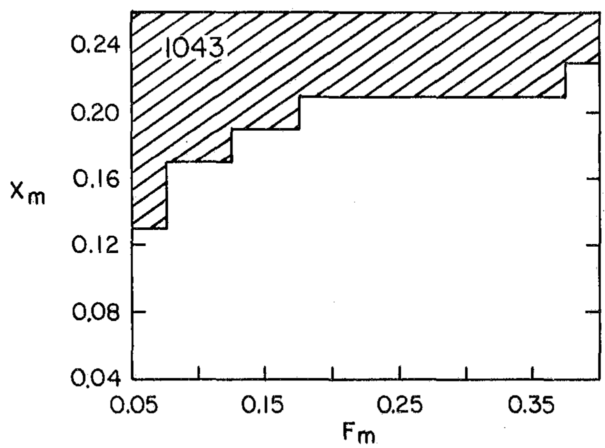

Figure 15. Data for estimation of $\underline{X_m}$ for the Gulf of California area with Tomlinson's (1970) computer program. The shaded area represents combinations of $\underline{F_m}$ and $\underline{X_m}$ which result in impossibly high estimates of the initial population.

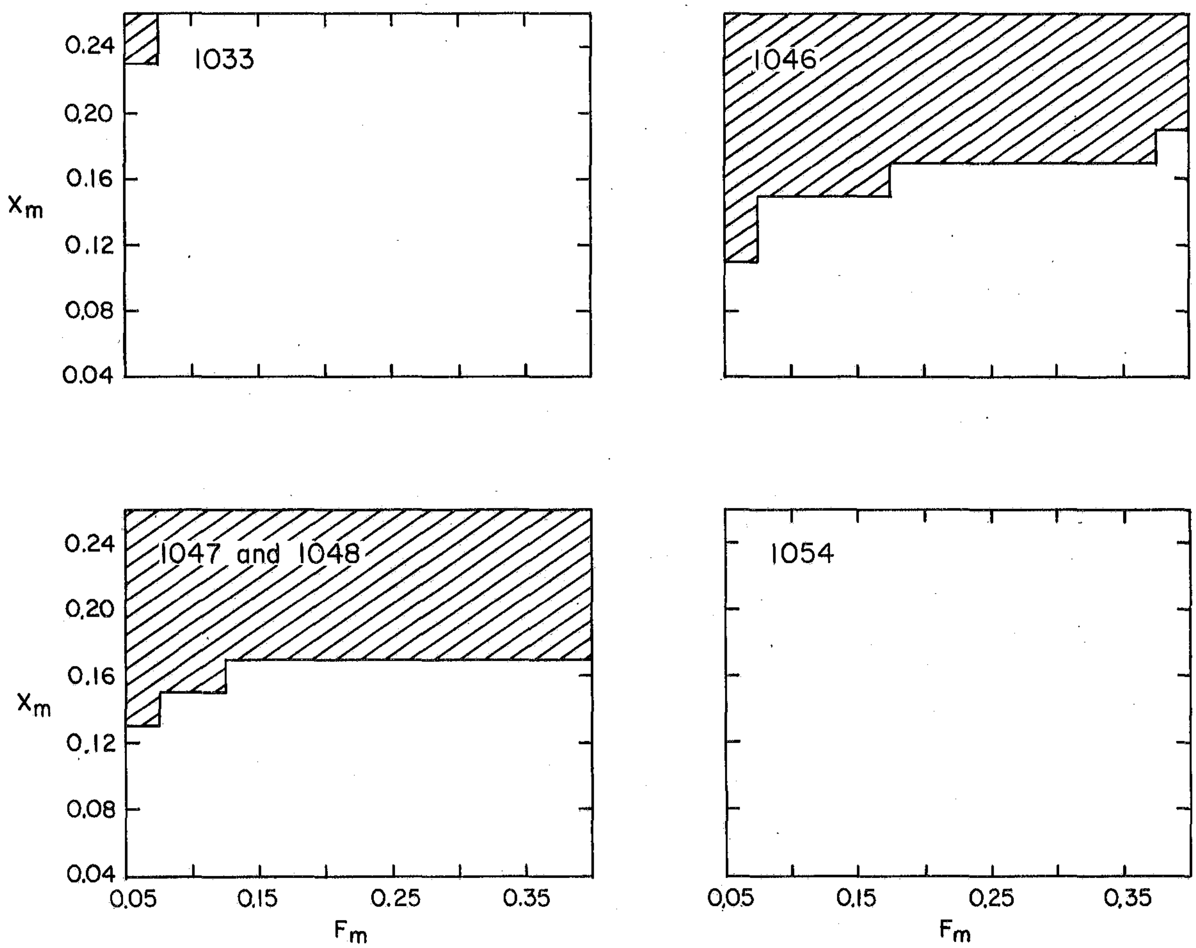

Figure 16. Data for estimation of $\underline{X_m}$ for the Revillagigedo Islands area with Tomlinson's (1970) computer program. The shaded areas represent combinations of $\underline{F_m}$ and $\underline{X_m}$ which result in impossibly high estimates of the initial population.

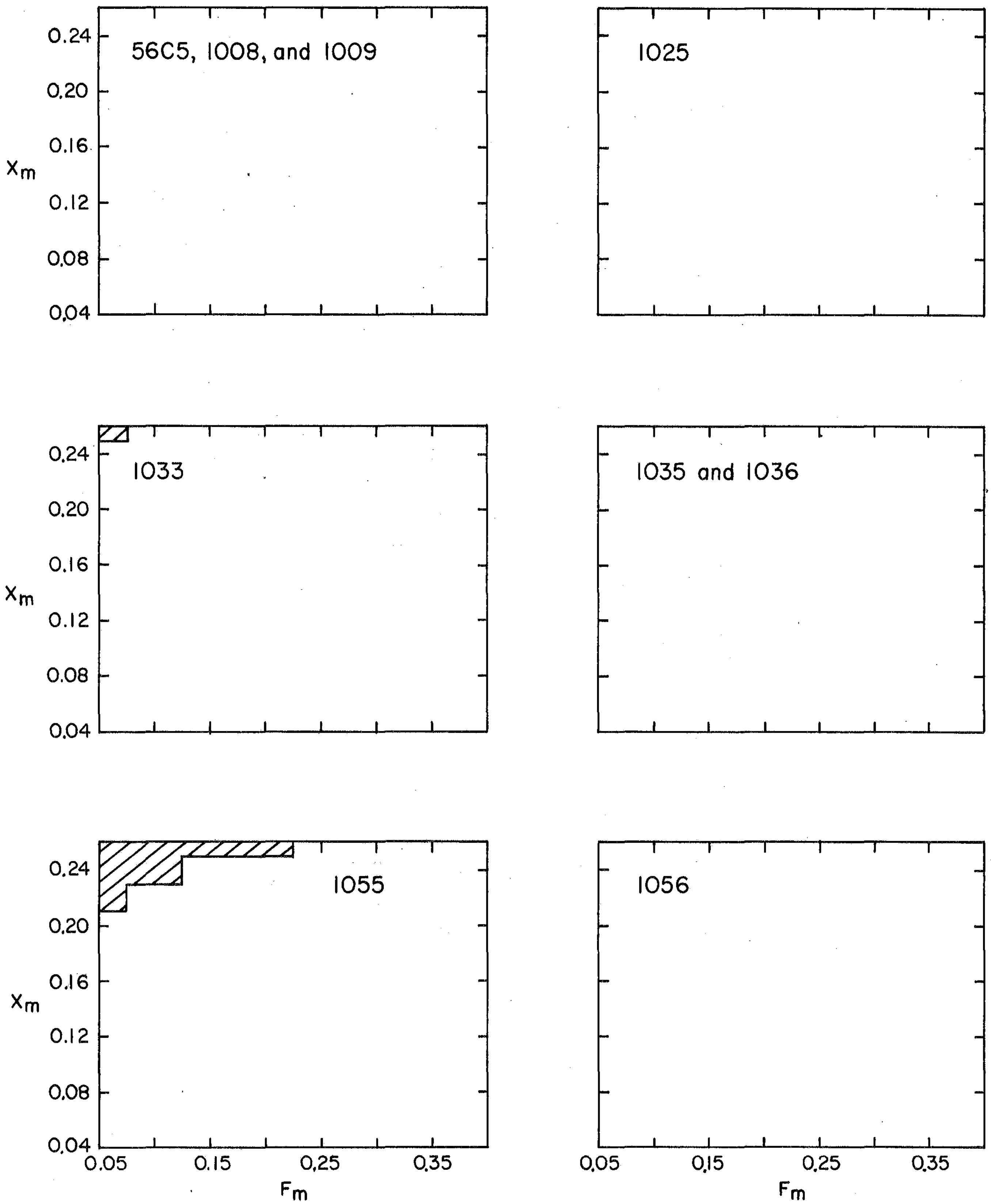

Figure 17. Data for estimation of $\underline{X_m}$ for the Mexico-Central America area with Tomlinson's (1970) computer program. The shaded areas represent combinations of $\underline{F_m}$ and $\underline{X_m}$ which result in impossibly high estimates of the initial population.

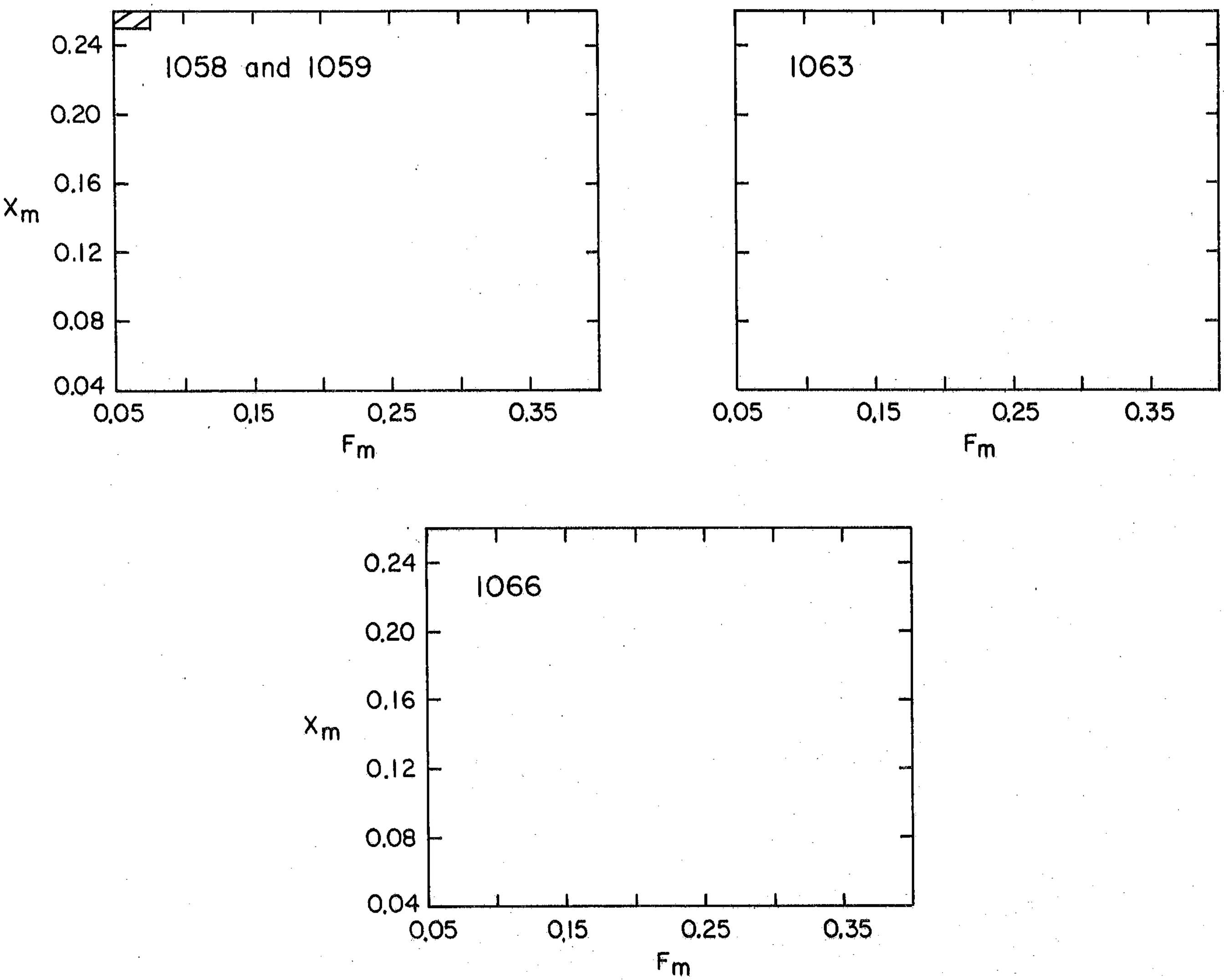

Figure 17 (continued).

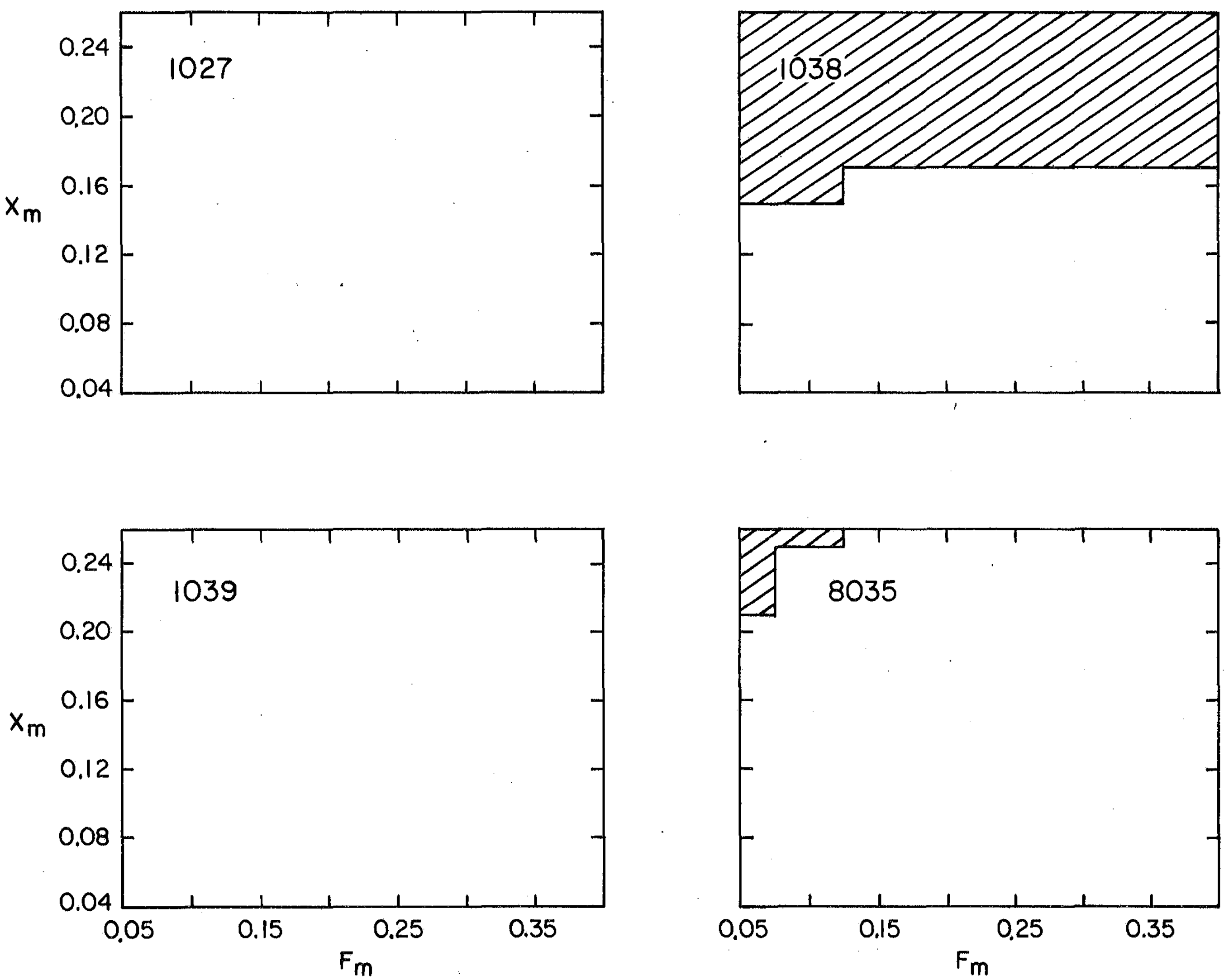

Figure 18. Data for estimation of X_m for the Gulf of Panama area with Tomlinson's (1970) computer program. The shaded areas represent combinations of F_m and X_m which result in impossibly high estimates of the initial population.

Table 1. Tagged fish release and return data used for estimation of the mortality of yellowfin tuna.

Area	Cruise number	Date of release	Tag type	Number released	Number returned
Gulf of California	1043	Jun. 21, 1963	single dart	37	20
			dart + loop	12	4
			double dart	2	1
Revillagigedo Islands	1033	Apr. 17-19, 1960	loop	263	15
			dart	643	63
	1046	Jun. 3-21, 1965	single dart	150	54
			double dart	145	59
	1047	Feb. 25-Mar.30,1967	single dart	460	153
	1048	Mar. 30-Apr.1,1967	single dart	98	33
	1054	Nov. 10-11, 1969	single dart	4	1
			double dart	211	85
Mexico-Central America	56C5	Nov. 8-Dec.3,1956	loop	99	2
	1008	Nov.21-Dec.20, 1956	loop	332	14
	1009	Jan.27-Feb.27, 1957	loop	303	18
	1025	Feb.27-Apr.10, 1959	loop	414	16
	1033	Mar.22-Apr. 9, 1960	loop	519	71
			dart	624	120
	1035	Aug.24-30, 1960	dart	355	33
	1036	Sep. 9-29, 1960	dart	502	15
	1055	Oct.25-Nov.19,1969	single dart	2,499	179
			double dart	6,021	503
	1056	Feb.9-22, 1970	single dart	303	54
			double dart	473	73

Table 1 (continued).

Mexico-Central America	1058	Sep.28-Nov.9,1970	single dart	2	1
			double dart	794	34
	1059	Nov.6-Dec.2, 1970	single dart	35	4
			double dart	1,948	42
	1063	Jun.10-23,1971	single dart	22	0
			double dart	1,768	92
	1066	Nov.7-23, 1971	single dart	52	1
			double dart	2,916	104
Gulf of Panama	1027	Apr.1-22, 1959	loop	6,329	39
	1038	Apr.7-May 2, 1961	dart	7,346	655
	1039	Sep.9-Oct.7, 1961	dart	276	30
	8035	Apr.24-May 26,1962	dart	1,048	69
Galapagos Islands	1031	Oct.30-Dec.8, 1959	loop	377	15
Outside CYRA	1057	Aug.1-18, 1970	single dart	36	3
			double dart	834	46
	1058	Sep.13-Oct.22,1970	single dart	10	0
			double dart	385	8

Table 2. Returns by month of recapture for tagged yellowfin released in the Gulf of California area and recaptured in the area shown in Figure 1.

	1043			
	Single		Total	
Month	Original	Adjusted	Original	Adjusted
Year 0				
Jun.	1	4.9	1	5.1
Jul.	13	11.2	16	14.4
Aug.	4	2.8	6	4.3
Sep.	1	0.7	1	0.7
Oct.				
Nov.				
Dec.				
Year 1				
Jan.				
Feb.				
Mar.				
Apr.				
May				
Jun.	1	0.5	1	0.5
Total	20	20.1	25	25.0

Table 3. Returns by month of recapture for tagged yellowfin released in the Revillagigedo Islands area and recaptured in the area shown in Figure 2.

Month	1033		1946						1047 and 1048		1054			
			Single		Double		Total				Double		Total	
	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
Year 0														
Feb.									8	110.2				
Mar.									23	23.0				
Apr.	1	1.6							32	17.8				
May	26	36.6							48	7.9				
Jun.	12	9.4	17	19.5	9	11.1	26	31.0	33	3.0				
Jul.	22	9.7	12	5.9	14	7.4	26	13.2	10	1.4				
Aug.	3	2.2	5	6.7	7	10.2	12	16.8						
Sep.	3	5.3	2	1.7	5	4.5	7	6.1						
Oct.	1	3.2	5	3.7	10	8.0	15	11.5						
Nov.	1	1.8	3	2.2	3	2.3	6	4.5						
Dec.			2	3.1	1	1.7	3	4.9						
Year 1														
Jan.			1	2.8	1	3.0	2	5.8	1	1.7	32	40.9	32	41.1
Feb.									4	0.5	22	15.1	23	15.8
Mar.	4	4.0	2	2.1	2	2.2	4	4.3	6	1.2	18	14.0	18	14.1
Apr.	2	1.0	2	2.2	2	2.4	4	4.7	1	0.2	6	6.6	6	6.6
May					1	1.9	1	1.8	1	0.1	1	2.4	1	2.5
Jun.														
Jul.			1	2.2			1	2.3						
Aug.														
Sep.														
Oct.					1	1.3	1	1.2						
Total	75	74.8	52	52.1	56	56.0	108	108.1	167	167.0	79	79.0	80	80.1

Table 4. Returns by month of recapture for tagged yellowfin released in the Mexico-Central America area and recaptured in the area shown in Figure 3.

Month	56C5, 1008, and 1009		1025		1033		1035 and 1036	
	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
Year 0								
Feb.								
Mar.			10	11.4	20	155.5		
Apr.			3	1.3	85	16.2		
May					69	12.2		
Jun.					7	1.5		
Jul.								
Aug.								
Sep.							2	8.0
Oct.			1	1.7	1	0.3	1	1.7
Nov.			1	0.6	1	0.1	13	9.1
Dec.	1	4.7			1	0.2	14	13.4
Year 1								
Jan.					1	0.2	6	5.6
Feb.	5	4.8						
Mar.	12	7.8					4	3.3
Apr.	6	4.1					5	4.1
May	5	4.0					1	0.8
Jun.	1	3.4						
Jul.								
Aug.								
Sep.								
Oct.								
Nov.	1	2.0						
Dec.					2	0.8		
Year 2								
Jan.								
Feb.								
Mar.								
Apr.								
May								
Jun.								
Jul.								
Aug.								
Sep.								
Oct.								
Nov.								
Dec.								
Year 3								
Jan.								
Feb.								
Mar.								
Apr.								
May								
Jun.								
Jul.								
Aug.								
Sep.								
Oct.								
Nov.								
Dec.								
Year 4								
Jan.								
Total	31	30.8	15	15.0	187	187.0	46	46.0

Table 4 (continued).

	1055						1056					
	Single		Double		Total		Single		Double		Total	
	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
Year 0												
Feb.							26.7	31.4	37.6	44.7	64.4	76.4
Mar.							10.3	6.1	20.4	12.3	30.6	18.2
Apr.							1	0.5	1	0.5	2	1.0
May									1	2.5	1	2.5
Jun.												
Jul.												
Aug.												
Sep.												
Oct.												
Nov.												
Dec.												
Year 1												
Jan.	81.7	49.6	186	117.8	267.6	167.6						
Feb.	16.3	12.5	61	48.7	77.4	61.1						
Mar.	25	18.9	80	63.0	105	81.8						
Apr.	23	14.4	75	49.0	98	63.3						
May	7	21.5	16	51.3	23	72.9						
Jun.	1	37.4	1	39.0	2	77.1						
Jul.												
Aug.												
Sep.												
Oct.			1	53.0	1	52.4						
Nov.												
Dec.												
Year 2												
Jan.			6	4.0	6	4.0						
Feb.												
Mar.			2	2.0	2	2.0						
Apr.			3	4.2	3	4.1						
May												
Jun.												
Jul.												
Aug.												
Sep.												
Oct.												
Nov.												
Dec.												
Year 3												
Jan.	1	0.8	2	1.6	3	2.3						
Feb.												
Mar.			2	1.4	2	1.4						
Apr.												
May												
Jun.												
Jul.												
Aug.												
Sep.												
Oct.												
Nov.												
Dec.												
Year 4												
Jan.			1	1	1	1						
Total	155	154.9	436	436.0	591	591.0	38	38.0	60	60.0	98	98.0

Table 4 (continued).

	1058 and 1059				1063		1066			
	Double		Total				Double		Total	
	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
Year 0										
Feb.										
Mar.										
Apr.										
May										
Jun.										
jul.										
Aug.										
Sep.										
Oct.										
Nov.	3	36.7	3	38.7	1	13.3				
Dec.							1	45.0	1	45.3
Year 1										
Jan.	23	4.8	25	5.5	20	5.9	37	13.6	37	13.7
Feb.	5	2.3	6	3.0	20	7.4	15	6.9	16	7.4
Mar.	7	2.1	7	2.3	14	3.8	10	3.4	10	3.4
Apr.	2	0.9	2	0.9	5	1.7	10	4.2	10	4.2
May	3	0.8	3	0.9						
Jun.										
Jul.										
Aug.					1	27.8				
Sep.										
Oct.										
Nov.										
Dec.										
Year 2										
Jan.	4	1.0	5	1.3	1	1	3	3	3	3
Feb.										
Mar.	2	0.4	2	0.5	2	2				
Apr.										
May										
Jun.										
Jul.										
Aug.										
Sep.										
Oct.										
Nov.										
Dec.										
Year 3										
Jan.										
Feb.										
Mar.										
Apr.										
May										
Jun.										
Jul.										
Aug.										
Sep.										
Oct.										
Nov.										
Dec.										
Year 4										
Jan.										
Total	49	49.0	53	53.1	63	62.9	76	76.1	77	77.0

Table 5. Returns by month of recapture for tagged yellowfin released in the Gulf of Panama area and recaptured in areas shown in Figure 4.

Month	1027		1038		1039		8035	
	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
Year 0								
Apr.			5	13.1				
May	1	1.0	7	5.4				
Jun.			11	23.2			3	2.9
Jul.			49	74.4			3	2.3
Aug.			42	42.0			1	0.9
Sep.			69	83.5			3	2.9
Oct.	4	8.9	118	95.7			3	4.5
Nov.	2	1.9	56	41.7			9	8.4
Dec.	1	1.8	21	21.7	3	4.7	8	6.9
Year 1								
Jan.	2	1.7	9	10.1	1	3.2	9	6.2
Feb.	5	2.6	52	50.3	6	6.1	3	4.2
Mar.	2	1.9	67	46.7	9	5.2	4	4.9
Apr.	5	4.4	21	18.8	3	2.7	4	4.0
May	1	0.5	5	4.1	1	1.0	2	3.9
Jun.			2	3.3				
Jul.								
Aug.								
Sep.								
Oct.							1	1.0
Nov.	1	0.3	1	1.2				
Dec.	1	0.5						
Year 2								
Jan.								
Feb.			1	0.9				
Mar.								
Apr.								
May								
Jun.								
Jul.								
Aug.	1	0.4						
Sep.								
Oct.								
Nov.								
Dec.								
Year 3								
Jan.								
Feb.								
Mar.								
Apr.								
May								
Jun.								
Jul.								
Aug.								
Sep.								
Oct.								
Nov.								
Dec.								
Year 4								
Jan.								
Feb.								
Mar.			1	1.0				
Total	26	25.9	537	537.1	23	22.9	53	53.0

Table 6. Returns by month of recapture for tagged yellowfin released in the Galapagos Islands area and recaptured in the area shown in Figure 5.

Month	1031	
	Original	Adjusted
Year 0		
Nov.	2	2.3
Dec.	7	8.4
Year		
Jan.	4	2.0
Feb.	2	2.3
Total	15	15.0

Table 7. Returns by month of recapture for tagged yellowfin released outside the CYRA and recaptured in the area shown in Figure 6.

	1057 and 1058			
	Double		Total	
Month	Original	Adjusted	Original	Adjusted
Year 0				
Aug.	17.8	26.7	17.8	27.2
Sep.	19.7	13.9	15.6	15.6
Oct.	6.3	3.6	4.2	4.2
Nov.	2.2	1.4	1.4	1.4
Dec.				
Year 1				
Jan.				
Feb.				
Mar.				
Apr.				
May				
Jun.	1	1.5	1.5	1.5
Jul.	1	1.3	1.4	1.4
Aug.				
Sep.				
Oct.				
Nov.				
Dec.				
Year 2				
Jan.				
Feb.				
Mar.				
Apr.				
Mar.				
Apr.				
May	1	0.8	0.8	0.8
Total	49	49.2	52	52.1

Table 8. Estimates of the coefficients of total mortality plus shedding, and the upper and lower 95-percent confidence limits, for tagged yellowfin.

Area	Cruise	Tag type	Released	Returned	Z_m'	Z_{mL}'	Z_{mU}'
Gulf of California	1043	single	37	20	0.854	0.375	1.332
		total	51	25	0.942	0.481	1.404
Revillagigedo Islands	1033	single	906	75	0.308	0.205	0.411
	1046	single	150	52	0.223	0.144	0.302
		double	145	56	0.240	0.176	0.305
		total	295	108	0.261	0.210	0.311
	1047 and 1048	single	558	167	0.482	0.352	0.612
	1054	double	211	79	0.724	0.555	0.892
		total	215	80	0.722	0.555	0.888
Mexico-Central America	56C5, 1008, and 1009	single	734	31	0.235	0.149	0.320
	1025	single	414	15	0.162	-0.014	0.337
	1033	single	1,143	187	0.576	0.367	0.785
	1035 and 1036	single	857	46	0.282	0.198	0.365
	1055	single	2,499	155	0.335	0.281	0.389
		double	6,021	436	0.271	0.238	0.305
		total	8,520	591	0.298	0.266	0.329
	1056	single	303	38	1.728	1.050	2.407
		double	473	60	1.312	0.938	1.686
		total	776	98	1.480	1.146	1.814
	1058 and 1059	double	2,742	49	0.312	0.129	0.495
		total	2,779	53	0.307	0.141	0.472
	1063	double	1,768	63	0.161	0.120	0.201
	1066	double	2,916	76	0.389	0.247	0.532
		total	2,968	77	0.393	0.251	0.536
Gulf of Panama	1027	single	6,329	26	0.114	0.069	0.160
	1038	single	7,346	537	0.296	0.253	0.338
	1039	single	276	23	0.378	0.216	0.539
	8035	single	1,048	53	0.154	0.110	0.199
Galapagos Islands	1031	single	377	15	0.949	0.351	1.546
Outside CYRA	1057 and 1058	double	1,219	49	0.106	0.010	0.202
		total	1,265	52	0.106	0.011	0.201

Table 9. Data used for calculation of the regressions $\underline{Z_m''} = \underline{X_m} + \underline{\overline{f}_m}q$.

Area	Cruise	Months	$\overline{f}_m$	Z_m'	Z_m''
Revillagigedo Islands	1033	Apr. 60-Mar. 61	374.4	0.329	0.329
	1046	Jun. 65-May 66	467.2	0.288	0.301
	1047 and 1048	Feb. -Jul. 67	479.8	0.723	0.723
	1054	Jan. -Apr. 70	781.9	0.781	0.806
Mexico-Central America	56C5, 1008, and 1009	Nov. 56-Oct. 57	574.3	0.267	0.267
	1025	Feb. 59-Jan. 60	334.9	0.162	0.162
	1033	Mar. 60-Feb. 61	771.2	0.576	0.576
	1035 and 1036	Aug. 60-Jul. 61	816.7	0.282	0.282
	1055	Jan. -Apr. 70	2,475.7	0.640	0.658
	1056	Feb. -Apr. 70	2,375.4	1.702	1.716
	1058 and 1059	Jan. -May 71	1,749.9	0.581	0.606
	1063	Jan. -Apr. 72	2,109.6	0.614	0.639
	1066	Jan. -Apr. 72	2,109.6	0.693	0.718

Table 10. Estimates of the coefficients of catchability for tagged yellowfin.

Area	Cruise	Z_m''	$\overrightarrow{f}_m$	F_m	$q \times 10^3$
Revillagigedo Islands	1033	0.329	374.4	0.229	0.551
	1046	0.301	467.2	0.201	0.387
	1047 and 1048	0.723	479.8	0.623	1.168
	1054	0.806	781.9	0.706	0.813
Unweighted mean					0.730
Mexico-Central America	56C5, 1008, and 1009	0.267	574.3	0.167	0.262
	1025	0.162	334.9	0.062	0.166
	1033	0.576	771.2	0.476	0.555
	1035 and 1036	0.282	816.7	0.182	0.201
	1055	0.658	2,475.7	0.558	0.202
	1056	1.716	2,375.4	1.616	0.612
	1058 and 1059	0.606	1,749.9	0.506	0.260
	1063	0.639	2,109.6	0.539	0.230
	1065	0.718	2,109.6	0.618	0.264
Unweighted mean					0.306
Unweighted mean omitting outliners					0.226

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