SCS/DEV/79/19

SOUTH CHINA SEA FISHERIES
DEVELOPMENT AND COORDINATING
PROGRAMME

executing agency:
FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS

THE SOUTH CHINA SEA FISHERIES
stock assessment in multispecies fisheries

UNITED NATIONS DEVELOPMENT PROGRAMME

STOCK ASSESSMENT IN MULTISPECIES FISHERIES, WITH SPECIAL REFERENCE TO THE TRAWL FISHERY IN THE GULF OF THAILAND

by

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This study, prepared on behalf of the South China Sea Programme, was based on field visits in the region in 1976.

SOUTH CHINA SEA FISHERIES DEVELOPMENT AND COORDINATING PROGRAMME
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Manila, Philippines
June 1979

The South China Sea Fisheries Development and Coordinating Programme is a regional project of the Food and Agriculture Organization of the United Nations carried out with the cooperation and funding support of the United Nations Development Programme.

ISBN 92-852-1011-2

ACKNOWLEDGMENTS

I would like to take this opportunity to express my gratitude to the staffs of the Fisheries Department, FAO, Rome, the South China Sea Fisheries Development and Coordinating Programme, and of the Fisheries Departments of the Philippines, Sri Lanka and Thailand for their help and hospitality. In particular, I would like to thank the staff of the Fisheries Laboratory at Bangkok for the kind way in which they made their data freely available to me. Without their sustained sampling effort, this report would be of only academic interest.

Distribution:

Members of the Indo-Pacific
Fisheries Commission
FAO Department of Fisheries
Other interested nations and
international organizations

Bibliographic Entry:

Pope, John (1979)
SCS/DEV/79/19: 106p.
Stock assessment in multispecies fisheries, with special reference to the trawl fishery in the Gulf of Thailand.

Stock assessment, demersal fish Southeast Asia, multispecies fisheries.

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1. Introduction

This report has two main objectives. To develop multispecies fishery theory to make it more appropriate to tropical fisheries; and to apply this as far as possible to the demersal fisheries of the Gulf of Thailand. The first two sections describe and develop the model with particular attention being given to the use of trawl survey data for assessment purposes. Various algorithms for managing fisheries using this form of data are developed. The third and fourth sections are concerned with assessment of the Gulf of Thailand trawl fisheries based on the statistical analysis of the groundfish survey. This indicates that considerable simplifications of the yield/effort relationship may be made due to the considerable degree of correlation between the biomasses of the various stocks. Preliminary analysis of diferring catch rates in different areas and depth and by different gear and vessel types are also made.

In addition, some consideration is given to the problems of examining economic yield and of using biological sampling data to improve assessments. Recommendations for further work in the area are made.

2. Why multispecies fisheries present a problem for the management of fisheries

The theory of fisheries management was large developed for use in temperate and arctic regions. In these regions, it is common for comparatively few species to predominate in the catch. Consequently, the theory largely developed to account for the reaction of one species to fishing pressure. This simple approach may however be upset by three problems:

(a) Technological interactions. This simply means that in fishing for one species (Species A), a second species (Species B) is also caught in appreciable amounts. Thus, it is not proper to consider the problem of managing species A without considering the consequential effects such management may have on species B.

(b) Interspecific interactions. This simply means that the stock level of species A affects the stock level of species B. This might be caused by predation or by competition. Clearly, this is a complicated subject since such interactions might take place at various points in the life history of the two species. For example, species A might eat the eggs of species B. Similarly, adults of species B might eat adults of species A. If such interactions take place, they might upset single species management.

(c) Data required for management. For single species management, quite extensive data sets are required. The collection of these data is a major problem for developed countries having concentrated fisheries on comparatively few species. For developing countries in the tropical area, the collection of suitable data (e.g. age/length keys) for more than a few species of fish is likely to prove almost impossible. This would be due to the multitude of species forming the catch and the diffuse nature of the landings of sustenance fishermen. Consequently, single species management is likely to prove unattainable in any general sense in the tropics even supposing it to be desirable.

Problems (a) and (b) suggest the need for a theory of fisheries which takes account of technological and interspecific interactions while problem (c) virtually dictates that any theory that is to have practical uses must be extremely simple and undemanding of data.

If as stated in the last paragraph the problems of data collection largely prevent single species assessments being made, then it is still more true that these problems prevent multispecies assessments based on detailed knowledge of interactions between various species at various ages. Clearly. the only models which have any practical chance of use will be the simplest models requiring the minimum of data for their use.

The following subsections develop such a theory. This was developed more or less independently by several authors but to avoid overcomplications, it is presented as it occurred to the author without citing the literature. The bibliography does, however, give some of the more useful papers on the subject. In order to minimize the mathematics in the development, the exposition given here is usually confined to two species. This enables the theory to be presented graphically for the benefit of non-mathematicians. It can, however, be generalized to any number of species and this is indicated in the text. Again the bibliography should be consulted by anyone concerned with the more general formulation of the theory.

2.1 The simplest approach to multispecies assessment

The simplest model of all is to assume that the overall yield is governed by overall effort in such a way that Schaefer's yield model holds. Thus the model is fitted by plotting total catch per effort against fishing effort. Such a model requires as a minimum, the input of a time series of catch per effort and of fishing effort. Catch per effort is most often available from the results of research surveys. This use of research vessel survey results underlines the value of such investigations. Effort might be assessed directly in terms of the numbers of and fishing power of the boats fishing. Alternatively, it might be taken as the total catch divided by the total catch per effort. The Malacca Strait Workshop makes excellent use of this latter approach.

The overall Schaefer approach has been used in other areas. For example, the North East Pacific by Hongskul, Georges Bank by Brown et al. and Labrador-Northern Newfoundland by Pinhorn. In the main, these methods give a smoother fit of the catch per effort data to the effort data than a detailed knowledge of the component stocks would have suggested. One explanation of this might be that by taking all stocks together, the interactions between species are perhaps taken care of. Another possible explanation is that fishermen react to adverse changes in one stock by switching fishing to other resources. Thus the overall catch rate might be smoothed to some extent. It might, therefore, be argued that such total yield curves are more of an artifact of the fishing pattern than a clear indication of the total yield that the system could deliver.

In order to investigate these problems, the theory shown in sections 2.2 to 2.5 was developed. This indicates that in certain conditions, the total yield/total effort model is a reasonable way of managing a multispecies fishery.

To sum up, the simplest theory of multispecies fisheries assumes that the overall yield (Y) in a steady state is related to the overall fishing effort (f) by the equation

$$Y = af - bf^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1.1$$

where (a) and (b) are constants. In other words, it assumes that a Schaefer model applies to all stocks combined. Alternatively

$$Y = Ap - Bp^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1.2$$

where (p) is the overall biomass or an estimator of it such as the overall catch per hour of some research vessel survey. The formulation supposes a steady state such that

$$A + Bp = kf \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1.3$$

where (k) is the catchability coefficient and (A) and (B) are constants as in 2.1.2. This form of the model is usually used to fit the parameters using a linear regression of (P) on (f).

Figure 2.1 shows the forms of these three formulae. It is apparent that the maximum yield occurs when $f = a/2b$ and when

$$P = A/2B$$

it is also apparent that the maximum occurs when $p = \frac{1}{2}p(o)$ where p(o) is the value of (p) when there is no fishing. p(o) is sometimes called the virgin stock biomass. A further useful result is that the maximum yield is given by

$$Ymax = \tfrac{1}{2}Ap(o) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1.4$$

An alternative to the Schaefer model shown above is to suppose that

$$A - B \log_e p = kf \quad \ldots\ldots\ldots\ldots\ldots \quad 2.1.5$$

Thus the yield is given by

$$Y = Ap - Bp \log_e p \quad \ldots\ldots\ldots\ldots\ldots \quad 2.1.6$$

and the maximum occurs when

$$p = p(o)/e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1.7$$

Thus since e 2.718, this is at about one-third of the virgin stock size. This form leads to an asymmetric relationship between fishing effort and yield which may be more appropriate in some circumstances. If, however, there is little to choose between the two models, the former is perhaps preferable both for its mathematical simplicity and because it leads to a more conservative form of management. Because of the simplicity of the Schaefer form of yield model, it will be used to develop the theory further in the following sections.

2.2 Modelling technological interactions

Let us consider the fishing effort or fishing mortality on two or more species. If technological interactions occur then fishing for species p will produce a fishing mortality on species q. Similarly, fishing for species q may produce a fishing mortality on species p. This is best described using diagrams. Fig. 2.2a shows a coordinate system of the fishing mortality of p and q. Thus, any point on such a grid will correspond to a pair of values of F(p), F(q). For example, point X is at F(p) = 0.9 and F(q) = 0.5.

If in fishing for species p, species q were also caught with a catchability coefficient of half that which applied to species p, then the values of F(p), F(q) generated would have to be on the line OA in Fig. 2.2b. Similarly, if in fishing for species q, species p were also caught with a catchability coefficient of half that which applied to species q, then the values of F(p), F(q) would lie on the line OB.

It is fairly obvious that any value of F(p), F(q) which lies on or between the lines OA, OB could be achieved by a suitable combination of directed fishing for species p and species q. For example, F(p) = 0.8, F(q) = 0.7 could be achieved by a directed fishery for species p of 0.6 and a directed fishery for species q of 0.4. Figure 2.2c shows how this value would be obtained.

Equally obvious is the fact that values of F(p), F(q) which lie outside of the lines OA, OB could not be achieved except by using a negative directed fishery for one or other species. For example, F(p) = 0.5, F(q) = 0.1 would require a directed fishery of 0.6 for stock p and a directed fishery of -0.2 for stock q. Since negative fisheries (presumably rearing fish and releasing them at sea) are not practicable, this combination of F(p), F(q) is not achievable with the two directed fisheries shown. Clearly if there were some fishery which had less technological interactions between species p and species q, then this point might be achievable. For example, if a fishery for species p had a catchability coefficient for species q of one-fifth of that applied to species p, then clearly this point (0.5, 0.1) could be achieved.

This explanation of how technological interactions affect the level of fishing mortalities that can be simultaneously attained may be over-simple. It does, however, serve to point out that there are likely to be some combinations of fishing mortality which in practice cannot be attained. In the context of tropical demersal fisheries, it is quite possible that the intrinsic technological interactions between species are quite high and that, therefore, the lines OA, OB might lie close together (see Fig. 2.3a). Alternatively, the multiplicity of species in such fisheries might well persuade the fishermen to have some objective like maximizing his total catch of all species rather than his catch of one or more preferred species. In this case, the lines OA, OB might become merged as a single nonspecific fishery (see Fig. 2.3b). Whichever is the case, the fishing mortalities on the two stocks which may be achieved will effectively be constrained to a narrow wedge of values such as in the examples shown in Fig. 2.3a and 2.3b $F(p) \triangleq F(q)$. More generally

$$\frac{F(p)}{k(p)} \triangleq \frac{F(q)}{k(q)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.2.1$$

where k(p), k(q) are the respective catchabilities.

If such a relationship as 2.2.1 is the case for a multispecies fishery, then it has very definite implications for the yield of the fishery. This will be considered in a later subsection.

Even if this relationship between the fishing mortalities of the two species is generally true, it is possible that subsequent developments in gear design (e.g. higher headline) might change the ratio of the catchability of the two species in the future. Any such modifications in ratio of the catchability of the two species may give scope for increasing the overall yield and thus will be well worth examining. The effect such changes have on the overall yield will be taken up in subsection 2.4.

2.3 Multispecies Schaefer models

In subsection 2.1, the total biomass was treated as though it obeyed a Schaefer model. Let us now consider a two-species model where the two component species each follow a separate Schaefer model.

For example, let us suppose that species p has a yield equation of

$$Y(p) = 200\, F(p)\, (1 - 0.5\, F(p)) \quad \ldots\ldots \quad 2.3.1$$

where Y(p), F(p) are the yield and fishing mortality of stock p.

Clearly, stock p gives a maximum yield when

$F(p) = 1.0$ and at that value

$Y(p) = 100$ units

Similarly, let us suppose that species q has a yield curve

$$Y(q) = 100\ F(q)\ (1 - F(q)) \ \ldots\ldots \qquad 2.3.2$$

where Y(q), F(q) are the yield and fishing mortality of stock q. Clearly, stock p gives a maximum yield when

$F(q) = 0.5$

and at this value

$Y(p) = 25$ units

Figures 2.4a and 2.4b show these two yield curves.

Let us now consider the total yield of the system. We can do this by adding Y(p) and Y(q) to get Y the total yield. Thus,

$$Y = 200\ F(p) + 100\ F(q) - 100\ (F(p))^2 - 100\ (F(q))^2 \ \ldots \qquad 2.3.3$$

as can be seen from Fig. 2.5. This gives a yield function that has a maximum at $F(p) = 1.0$, $F(q) = 0.5$ where $Y = 125$. The contours of equal yield form circles about this point. The circles of larger radius correspond to lower levels of joint yield.

The circular contour lines of course break down if $F(p) \geq 2.0$ or if F(q) 1.0. This is because at these levels of fishing mortality, stock p and stock q respectively become zero and the parabolic relationship between yield and fishing mortality breaks down.

The reason that the contours of equal yield are circles is because the coefficients of $(F(p))^2$ and $(F(q))^2$ in equation 2.3.3 are the same (equal 100). This of course is due to the choice of the parameters of the two yield curves (2.3.1, 2.3.2). In general, these coefficients would not be the same so the contours of equal yield would form concentric ellipses with their major and minor axes along the directions of the fishing mortality axis. In this case, however, we could always scale F(p) or F(q) to make the contours of equal yield into circles. Thus talking about circular contours is perfectly general.

2.4 Combining multispecies Schaefer models with technological interactions

If we combine the ideas of subsections 2.2 and 2.3, we can see how technological interactions may affect the level of yield available.

Firstly, let us combine Fig. 2.2b with Fig. 2.5 as this is shown in Fig. 2.6. We can see that the overall maximum yield lies just within the sector AOB; thus, we can actually attain the F(p), F(q) required to give the overall maximum yield. This point (1.0, 0.5) in fact lies on the line OA. Hence, we would attain this by having a directed fishery for stock p of 1.0 and no directed fishery for stock q. If in fact there was only a directed fishery for stock q, then the overall maximum yield would not be obtained since the highest value of the total yield along OB is something between 75 and 100 units.

Similarly, if the situation described in Fig. 2.3b occurred and $F(p) \doteq F(q)$, then the overall maximum yield would not be attained since the highest value of the total yield along line OC (Fig. 2.6) is at about 110 units.

If we imagine different levels of fishing along lines such as AO, OB and OC, then we can build up a yield curve for each case. Figure 2.7 shows the yield curves that would result from fisheries along these three lines. It can be seen that within the area of validity of the circular contours of yield, these form parabolas. The maximum yields of these three curves are, however, different and so are the levels of fishing mortality which would achieve them.

It is fairly obvious that any straight section through the overall yield contours would result in a parabolic yield curve but, it is also obvious that in general, the maximum of such a yield curve would not be the overall maximum yield attainable. Neither would the level of fishing effort which achieved the curve maximum necessarily be the correct level of fishing effort to attain the overall maximum.

This helps us to understand both why the overall Schaefer analysis shown in subsection 2.1 might occur and also why it might probably not lead to the overall maximum being achieved.

Clearly, if the fishing effort is such as to cause the fishing mortality on the various species to remain in the same ratios, then the situation is as described for the line OC above. The resulting yield curve has a maximum and appears to be a parabola but it will not in general pass through the overall maximum of the system.

One criticism levelled at the preceding theory was that it did not consider the possibility of interspecific interactions. Perhaps they would result in the overall yield-curve approach being valid. This question is considered in the next subsection. In both this subsection and in the next subsection, the multispecies model has been presented for the case of two species. The conclusions can however be generalized to any number of species.

2.5 Interspecific interactions

In section 2.3, we consider the two yield curves

$$Y(p) = 200\ F(p) - 100\ (F(p))^2$$

and $$Y(q) = 100\ F(q) - 100\ (F(q))^2$$

We could write such curves more generally as:

$$Y(p) = A_1F(p) - B_1\ (F(p))^2 \quad \ldots\ldots\ldots\ldots\ 2.5.1$$

$$Y(q) = A_2F(p) - B_2\ (F(q))^2 \quad \ldots\ldots\ldots\ldots\ 2.5.2$$

Alternatively, we could write the yield in terms of the two populations as:

$$Y(p) = a_1p - b_1p^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 2.5.3$$

$$Y(q) = a_2q - b_2q^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 2.5.4$$

The simplest fashion in which interspecific interactions can be introduced is to include an extra term in each equation as follows:

$$Y(p) = a_1p - b_1p^2 - c_1pq \quad \ldots\ldots\ldots\ldots\ 2.5.5$$

$$Y(q) = a_2q - b_2q^2 - c_2pq \quad \ldots\ldots\ldots\ldots\ 2.5.6$$

This gives equivalent steady state equations of:

$$a_1 - b_1p - c_1q - F(p) = 0 \quad \ldots\ldots\ldots\ldots\ 2.5.7$$

$$a_2 - b_2q - c_2p - F(q) = 0 \quad \ldots\ldots\ldots\ldots\ 2.5.8$$

If we combine equations 2.5.5 and 2.5.6 to give total yield Y, we have:

$$Y = a_1p + a_2q - b_1p^2 - b_2q^2 - (c_1 + c_2)\ pq \ \ldots\ 2.5.9$$

This equation represents contours of equal yield that form concentric ellipses with their major and minor axes inclined to the axes of either F(p), F(q) or p, q.

This situation is probably best explained using diagrams. Let us consider the case when the equations given below describe the yield of the two species:

$$Y(p) = .43p - 0.000143p^2 - 0.0000143pq \ \ldots\ 2.5.10$$

$$Y(q) = 1.10q - 0.001q^2 - 0.00005pq \ \ldots\ldots\ 2.5.11$$

Then Fig. 2.8 shows the form of the contours of equal yield when they are plotted against F(p), F(q). As it can be seen from the diagram, the contours are concentric ellipses. Since the interaction terms in equations 2.5.10 and 2.5.11 were smaller than the other terms, they do not have a great effect and the axes of the ellipses are nearly parallel to the F(p), F(q) axes. The point of maximum yield is at the centre of the ellipses and is equal to 576 units. The lines $p = 0$, $q = 0$ are where one or other stock becomes zero. As before, therefore, the elliptical contours break down when this happens.

Let us see what happens if we make the competition terms greater, for example, consider the equation:

$$Y(p) = 0.43p - 0.000143p^2 - 0.000118pq \quad \ldots \quad 2.5.12$$

$$Y(q) = 1.10q - 0.001q^2 - 0.000266pq \quad \ldots\ldots \quad 2.5.13$$

Clearly, these equations only differ from 2.5.10, 2.5.11 in the last term. Fig. 2.9 shows the effect that this change has. The major and minor axes of the ellipse have rotated and the value of the maximum is lower at 415. The position of the maximum is also changed from about (0.24, 0.52) to (0.25, 0.48). The only obvious change is that the region in which the elliptical yield curves are valid is sharply reduced. This means that the chance of one or other stock being pushed out is increased. Another possible situation is where the interaction terms are of opposite sign, for example, modifying 2.5.12 to read:

$$Y(p) = 0.43p - 0.000143p^2 + 0.000118pq \quad \ldots \quad 2.5.14$$

and with 2.5.13 remaining the same, we would have a description of prey-predator system with stock p tending to increase when stock q is high and to decrease when stock q is low. Fig. 2.10 shows what effect this change has on the contours of equal yield. It is obvious that the maximum yield is higher than in the previous case and is at a still lower value of F(q) and still higher value of F(p). This is not surprising as we would expect to get more yield by fishing down the predator and leaving the prey less affected by fishing. It is also noticeable that the line $p = 0$ is altered and makes for a far larger area of elliptical yield contours.

This then gives some idea of how interspecific interactions affect the theory developed in the previous sections. It is clear that whether interactions are present or not, the contours of equal yield form ellipses centred on the maximum yield of the system. The chief conclusion we may draw, therefore, is that as long as no stock becomes zero, any fishery which develops with the fishing mortalities on its various component stocks in equal proportion will have a parabolic yield curve i.e. in terms of the figures, if fishing mortality moves along a straight line through the origin, the yield curve is parabolic. This can readily be shown by mathematical analysis to be true, however many species are present, provided that the multispecies Schaefer model holds true. Consequently, the yield curve resulting from such a fishery will have a parabolic form. However, unless the various fishing mortalities are in the ratio which will take them through the joint maximum sustainable yield, the yield curve observed will underestimate the maximum yield available. Furthermore, the level of fishing effort required to achieve this maximum on the observed curve will not in general be the same as would be required to achieve the overall maximum yield.

It is worth bearing in mind that the equations developed in this section form the simplest hypothesis which describes interspecific interactions. It might be considered as a first approximation to what actually occurs in the sea. While it may seem crude, it might well explain the main consequences of fisheries in interactive fisheries. It consequently would seem a useful theory to illuminate the management of multispecies fisheries that occur in tropical areas. The problems of applying this model to tropical fisheries is considered in the next section.

3. The application of the multispecies theory to tropical mixed fisheries

Problems in applying the mixed fishery model of the previous section to many actual fisheries arise from the large numbers of species involved. This means that the model will potentially contain many parameters and these will be difficult or impossible to assess with our current information. Because of these problems, we will need to seek for ways in which the theory can assist us in management at the present time given our present lack of knowledge of the fine detail of the parameters of the model. We must also consider how we might seek to improve our knowledge.

3.1 Problems with estimating the model parameters

In the previous section, the multispecies fishery model was described in terms of a two-species problem. In this problem, we had the 6 parameters:

$$a_1, a_2, b_1, b_2, c_1, c_2$$

and in general, we would also need to know the catchability of each stock k_1, k_2. Thus we need to estimate 8 parameters even in this simple case. If we had n stocks of fish, then we would have

$$a, \ldots\ldots\ldots\ldots\ldots\ldots \; a_n$$

giving n a's.

Also, we would have an array of b's and c's

$$\begin{array}{llll} b_1, & c_{12}, & \ldots\ldots\ldots\ldots & -, c_n \\ -, & -, & \ldots\ldots\ldots\ldots & - \\ -, & -, & \ldots\ldots\ldots\ldots & - \\ c_{n1}, & -, & \ldots\ldots\ldots\ldots & c_n \; n-1, b_n \end{array}$$

giving n x n b's and c's.

If we needed the k's, then they would be another n parameters. Thus we would need to estimate $n^2 + 2n$ parameters or $(n + 1)^2 - 1$. Clearly, this becomes difficult if n is large. Table 3.1 shows the number of potential parameters at various levels of n. It is quite clear from this table that as n increases so, the number of parameters in the model becomes extremely high.

To emphasize how difficult we will find it to estimate the parameters of such a model, we need only to consider the difficulties of estimating the 6 or 8 parameters of the two-stock model. Let us simplify this by assuming that we have directly estimated fishing mortality and that we know the catchability of the fishing effort for the two stocks. Thus, we have the two equations:

$$a_1 - b_1p - c_1q - F(p) = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad 2.5.7$$

$$a_2 - b_2q - c_2p - F(q) = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad 2.5.8$$

in which we know p, q and F(p), F(q) for each of a series of years and need to estimate a_1, a_2 b_1, b_2, c_1, and c_2.

We will probably seek to estimate these using multiple regressions of:

F(p), p and q

and of

F(q), p and q

One problem arises because in all probability

F(p), F(q), p, q

will be highly correlated.

For example, if they were perfectly correlated so that the following relationships hold:

$$p = sF(p) + t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.1.1$$

$$q = uF(p) + v \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.1.2$$

Where s, t, u, v are constants, then 2.5.7 becomes

$$a_1 - b_1sF(p) - b_1t - c_1uF(p) - c_1v = F(p) \qquad 3.1.3$$

Hence, the only constraints on a_1, b_1 and c_1 are:

$a_1 - b_1 t - c_1 v = 0$ 3.1.4

$b_1 s + c_1 u = -1$ 3.1.5

Clearly, there are an infinite number of combinations of a_1, b_1, c_1, which would satisfy these relations. If F(p), F(q), p, q are closely but less than perfectly correlated, then there may be only one combination of a, b, c that exactly fits, but there will be a wide range that fits so closely that they could not be distinguished in practice. A close correlation must be expected if there is in reality only one fishing effort which generates the fishing mortality on all the various component stocks of the fishery in accordance with stock specific catchability coefficients. This is the situation described in subsection 2.2 in the discussion of Fig. 2.4b. Such a situation of one basic fishing effort catching all species might be expected in a tropical multispecies fishery. This would be because the multiplicity of species might make it impossible for fishing to concentrate economically on any one individual species which by itself represents no more than a minor proportion of the catch.

To conclude, therefore, the problems outlined in this subsection suggest that given the numbers of species involved and given the likely pattern of development of fishing mortality in a tropical multispecies fishery, it is unlikely that we will be able to estimate the model parameters with any confidence. The question, therefore, must be asked: How can we set about managing such a system without a knowledge of these parameters?

3.2 How should we maximize the yield if one effective fishing effort is applied to all stocks?

The situation where there is only one effective fishing effort for all of the stocks is an interesting case. As it was explained in the previous subsection, such an effort would generate fishing mortalities on each stock in accordance with catchability coefficients (k's) which would stay in the same proportion through time. We might expect to see such a fishing effort when fishermen fished indiscriminately for many species.

It was explained in the previous subsection that such an effort would cause considerable correlation between the fishing mortalities of the various species and hence between the population sizes of the various species. This situation makes the estimation of the model parameters difficult or impossible. On the other hand, it allows us to infer something from the general forms of the theory. First, since such an effort would cause the fishing mortalities to develop in the same ratio, it would cause the contours of equal yield to be cut in a straight line (see subsections 2.4 and 2.5). Consequently, we know that if the model is true then:

(1) The relationship between overall yield along this line is parabolic provided no stock becomes zero.

(2) The maximum of this curve is not necessarily the overall maximum of the system.

(3) Provided no stock becomes zero, we may expect to see close correlations between the stock biomasses of the various species.

Thus, if we have one overall effort, then the yield curve obtained for all species will behave like a Schaefer-yield curve on one species. Since we are constrained to this line by the nature of the fishing effort, then point (2) above may not unduly worry us. Alternatively, we might regard this maximum as a first step to attain in managing the system and then seek ways of changing the relative impact of the effort on various species to move closer to the overall maximum. Point (3) above suggests that if the effort is applied indiscriminately to all stocks, then we should expect to see close correlations between the various stocks. If such correlations occur, this will be a useful indication as to the nature of the fishing effort and the applicability of the overall Schaefer model (see subsection 2.1). This begs the question: What measure of overall population size should be used? One way to ask this question is to ask: What measure of overall population is at half its virgin stock level when the yield is at a maximum? The answer is the function:

$$k_1p_1 + k_2p_2 + k_3p_3 \ldots k_np_n \quad \ldots\ldots\ldots\ldots\ldots \quad 3.2.1$$

where k_1 to k_n are the respective catchabilities of various stocks and p_1 to p_n are the stock sizes. The proof of this is rather complicated and is contained in the annex to this subsection.

Now, k_ip_i is the catch per effort of the i'th stock in the fishery. Therefore, 3.2.1 is simply the sum of the catches per unit effort for all species. As long as the k's are in the same ratio for both the commercial fleet and a groundfish survey, the sum of the groundfish survey indices of abundance of the various stocks may be used as a population estimate for the overall Schaefer curve. If there are systematic differences in catchability between the groundfish survey and the commercial fleet, these could of course be allowed for provided they are known.

The form of 3.2.1 thus means that the practice of assessing multispecies fisheries using overall yield curves of a Schaefer type is consistent with the model developed in section 2. Also, it shows that the use of research vessel overall estimates of abundance in place of estimates of overall population is a reasonable procedure. However, these procedures are only reasonable so long as:

(a) The catchabilities are in constant ratio between species through time.

(b) The catchabilities of the research trawler for various species are in the same proportion as the catchabilities of the commercial fleet.

Mathematical Annex

The derivation of 3.2.1 is as follows. From 2.5.7 and 2.5.8, we have the steady state equations for an interactive two-stock model

$$a_1 - b_1p - c_1q - F(p) = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad 2.5.7$$

and

$$a_2 - b_2q - c_2p - F(q) = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad 2.5.8$$

Thus the yield Y is given by:

$$Y = a_1p - b_1p^2 - c_1pq + a_2q - b_2q^2 - c_2pq$$

If the effort f is common to both stocks p and q such that

$$F(p) = k_1f$$

and

$$F(q) = k_2f$$

then

$$\frac{F(p)}{k_1} = \frac{F(q)}{k_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.2.3$$

We may thus conclude from 2.5.7 and 2.5.8 that

$$(a_1 - b_1p - c_1q)/k_1 = (a_2 - b_2q - c_2p)k_2 \qquad 3.2.4$$

Thus p and q have a linear relationship. In these circumstances, there will be some value of F(p), F(q), p and q such that the yield is maximized. We will designate this maximum by using a hat symbol as follows:

$$\hat{F}(p),\ \hat{F}(q),\ \hat{f},\ \hat{p},\ \hat{q}$$

The mathematics is simplified by writing the equations in the form of general homogeneous coordinates. This means we include an extra variable r in our equations such that all terms are of the second order. We may think of r being always equal to 1 in the applications that concern us. Thus 3.2.2 becomes:

$$0 = -Yr^2 + a_1pr - b_1p^2 - c_1pq + a_2qr - b_2q^2 - c_2pq$$

$$= f(p,\ q,\ r) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.2.4$$

The tangent to the ellipse f(p, q, r) at p, q, r, is given by:

$$\left(\frac{\partial f(p,\ q,\ r)}{\partial r}\right)_{max} r + \left(\frac{\partial f(p,\ q_1,\ r)}{\partial p}\right)_{max} p$$

$$+ \left(\frac{\partial f(p,\ q_1,\ r)}{\partial f}\right)_{max} q = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad 3.2.5$$

Thus we have the following equation:

$$- 2\hat{Y}\hat{r}r + a_1\hat{p}r + a_2\hat{q}r$$
$$+ a_1\hat{r}p - 2b_1\hat{p}p - (c_1 + c_2)\hat{q}p$$
$$+ a_2\hat{r}q - 2b_2\hat{q}q - (c_1 + c_2)\hat{p}q = 0 \quad \ldots\ldots\ 3.2.6$$

This may be rearranged as followings:

$$+ \hat{p}\ \{a_1 r - b_1 p - c_1 q\}$$
$$+ \hat{q}\ \{a_2 r - b_2 q - c_2 p\}$$
$$+ p\ \{a_1\hat{r} - b_1\hat{p} - c_1\hat{q}\}$$
$$+ q\ \{a_2\hat{r} - b_2\hat{q} - c_2\hat{p}\} = 2\hat{Y}\hat{r}r \quad \ldots\ldots\ldots\ldots\ 3.2.7$$

This line is tangential to the ellipse which gives the greatest yield for the system subject to the constraint $\frac{F(p)}{k_1} = \frac{F(q)}{k_2}$. Consequently, it must be the same as the line 3.2.4. Thus in particular, it must pass through the values of p, q, r where the ° superscript denotes the virgin-stock size. If we insert this point in 3.2.7, we obtain:

$$\hat{p}\ \{a_1\overset{o}{r} - b_1\overset{o}{p} - c_1\overset{o}{q}\} + \hat{q}\ \{a_2\overset{o}{r} - b_2\overset{o}{q} - c_2\overset{o}{p}\}$$
$$+ \overset{o}{p}\ \{a_1\hat{r} - b_1\hat{p} - c_1\hat{q}\} + \overset{o}{q}\ \{a_2\hat{r} - b_2\hat{q} - c_2\hat{p}\} = 2\hat{Y}\hat{r}\overset{o}{r} \quad 3.2.8$$

If we rewrite 2.5.7 and 2.5.8 in homogeneous coordinates, then we have:

$$a_1 r - b_1 p - c_1 q = F(p)r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 3.2.9$$
$$a_2 r - b_2 q - c_2 p = F(q)r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 3.2.10$$

Thus the terms in brackets in 3.2.8 may be replaced by F(p)r and F(q)r.

However, $F(\overset{o}{p}) = F(\overset{o}{q}) = 0$ thus

$$\frac{F(\hat{p})}{k_1} = \frac{F(\hat{q})}{k_2} = \hat{f}$$

Also, we know that $\hat{Y}\hat{r} = \hat{p}F(\hat{p}) + \hat{q}F(\hat{q})$

$$\overset{o}{p}\ \{F(\hat{p})\hat{r}\} + \overset{o}{q}\ \{F(\hat{q})\hat{r}\} = 2\ (\hat{p}F(\hat{p}) + \hat{q}F(\hat{q}))\overset{o}{r}$$

Writing F(p and F(q) in terms of f thus gives:

$$\overset{o}{p}\left(\frac{(k_1\hat{f}}{r_o} + \frac{qk_1\hat{f})}{r_o}\right) = 2\left(\frac{(\hat{p}k_1\hat{f}}{\hat{r}} + \frac{\hat{q}k_2\hat{f})}{\hat{r}}\right)$$

Eliminating f and recalling that r = 1, we have

$$\overset{o}{p}k_1 + \overset{o}{q}k_2 = 2(\hat{p}k_1 + \hat{q}k_2)$$

Thus we have shown that $pk_1 + qk_2$ has half the value at the attainable maximum that it had in the virgin-stock state.

3.3 How should we seek to attain the overall maximum yield? (Given groundfish survey data only.)

If we knew all the parameters of the model, then finding the maximum yield would simply be a question of solving the following equations for the populations of the various stocks (P_i) ($i = 1$ __ r).

The equations are:

$$\frac{\partial Y}{\partial p_1} = 0, \frac{\partial Y}{\partial p_2} = 0 \quad .... \quad \frac{\partial Y}{\partial p_2} = 0$$

These equations simply say that the rate of change of Y with respect to any population size is zero. For example, the two-stock model gives:

$$\frac{\partial Y}{\partial p} = a_1 - 2b_1p - (c_1 + c_2)\,q = 0 \quad .... \quad 3.3.1$$

$$\frac{\partial Y}{\partial q} = a_2 - 2b_2q - (c_1 + c_2)\,p = 0 \quad .... \quad 3.3.2$$

These two equations are solved for the value of p and q which will give the maximum.

This will be where:

$$p = \frac{a_1 2b_2 - a_2(c_1 + c_2)}{4b_1b_2 - (c_1 + c_2)^2} \quad .... \quad 3.3.3$$

$$q = \frac{a_2 2b_1 - a_1(c_1 + c_2)}{4b_1b_2 - (c_1 + c_2)^2} \quad .... \quad 3.3.4$$

It is clear from this that the position of the maximum is very much determined by the parameters a, b, c. Consequently, if we do not know these parameters, we will be unable to say at what levels of the various populations the maximum occurs. This will certainly be the case if the only data available come from groundfish surveys. What then should we do? If we assume that the fishing effort does not constrain us in the way described in the previous subsection, then potentially we may be able to manage the fishery so as to achieve certain desired population biomasses. If this is the case, then it will be interesting to see the effect of reducing the biomass of each stock to half its virgin biomass. Obviously, if there were no interactions, this would achieve the overall maximum yield of the system. If there are interactions, however, how would this affect the result? Would the yield at the half virgin-stock size level be a substantial proportion of the overall maximum yield or would it be a small fraction? For the two-stock model, the ratio of the yield when p and q are half their unexploited levels to the overall yield is

$$1 - \frac{(c_1 - c_2)^2}{4b_1b_1 - 4c_1c_1} : 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.3.5$$

Obviously, if the interaction terms (c_1, c_2) are of the same size, then the yield ratio will be 1:1. Equally obviously, if the interaction terms c_1, c_2 are small with respect to b_1, b_2 then the ratio of the two yields will almost be 1:1.

The ratio will only be much smaller if c_1 and c_2 were of opposite sign. This can be seen from the Fig. 3.1, 3.2 and 3.3. These show the same yield contours as were discussed in subsection 2.5. The point half-way along the line between F(p) = F(q) = 0 and p = q = 0 is the value of F(p), F(q) which would give $p = \frac{1}{2}p_o$, $q = \frac{1}{2}q_o$ where p_o, q_o are the population sizes when there is no fishing.

Fig. 3.1 shows the case where interactions are small. The yield at $\frac{1}{2}p_o$, $\frac{1}{2}q_o$ is virtually the same as the overall yield. Fig. 3.2 shows the interactions are larger but the yield at $\frac{1}{2}p_o$, $\frac{1}{2}q_o$ is still close to the maximum 400 : 415. Only in Fig. 3.3 is there a substantial penalty for adopting the $\frac{1}{2}p_o$, $\frac{1}{2}q_o$ position. In this case, the yield is in a ratio at 400 : 523 to the overall maximum. This case is where the interaction terms are of the same numerical size as for Fig. 3.2 but of opposite sign. This is the case that the formula 3.3.5 predicted would be worst. This case where the interaction signs are of opposite sign is similar to the classical Lotka Volterra prey-predator model. Thus, if we reduce the predator stock, we might expect to see an increase in the prey species assuming we are not reducing it heavily at the same time. If we see such an increase, we may be wise to tend to reduce the predator rather beyond the half virgin-stock size and the prey species rather less. This would only be done, however, on an experimental basis. In any case, it would probably be better not to reduce the predator much beyond half of the virgin-stock biomass.

Formula 3.3.5 gives the ratio for the two-stock model. More generally, if we have n stocks then we may imagine a (1 x n) matrix of the a's called A, an (n x n) matrix of b's called B and an (n x n) matrix of the c's called C. This last matrix will have zero value-diagonal terms. The ratio of the yield when each species is at half its virgin biomass to yield at the overall maximum is given by the ratio of the two quadratic forms:

$$\tfrac{1}{4}(A)^T(B + C)^{-1}(A) : \tfrac{1}{2}(A)^T(B + C + (B + C)^T)^{-1}(A) \qquad 3.3.6$$

As before, if the c's are small compared to the b's or if $C = C^T$ (equal interaction terms), then the half virgin biomass position will give practically the global maximum yield.

In conclusion, therefore, it would seem that to try to achieve biomasses for each species which are half the level of their unexploited biomass is a reasonable first approximation to the maximum yield. It, therefore, forms a very useful rule of thumb for managing multispecies fisheries where the parameter values are unknown. It is least satisfactory if there is a marked prey-predator type interaction. Such a relationship might be suspected either from the increase in one species consequent on the reduction of others or on general biological grounds (e.g. whales eat krill). If this were the case, then the rule might be modified to reduce the predator stock somewhat beyond the half virgin-stock size level while reducing the prey stock by a lesser proportion. This rule of thumb supposes an ability to achieve the half virgin-stock size level for each separate species. Clearly, in a tropical multispecies fishery, this may not be possible since the management strategy needed to achieve this might be hopelessly complex. Nevertheless, the rule of thumb would help in deciding which segments of the commercial fleet to encourage and which to discourage. For example, if the inshore fleet of sustenance fishermen catch proportionally more of lightly exploited species and proportionally less of heavily exploited species than an off-shore trawl fleet, they should be encouraged to increase their share of the catch (if maximization of physical yield is the objective).

A further good feature of this rule is that it makes biological sense since it imposes fishing mortalities on the stocks in the ratio of the stock specific a's. These terms in the equation could be regarded as the intrinsic rates of growth of each stock. Thus the rule tends to exploit fast growing stocks at a high rate while exploiting slow growing stocks more gently.

Another interesting feature of this rule is that the yield at the half virgin-stock biomass (p_i) position is given by the formula:

$$\tfrac{1}{2}\overset{o}{p}_1 a_1 + \tfrac{1}{2}\overset{o}{p}_2 a_2 + \ldots + \tfrac{1}{2}\overset{o}{p}_r a_r \quad \ldots\ldots\ldots\ldots\ldots \quad 3.3.7$$

If we know the p's (from a groundfish survey and a knowledge of the catchabilities) and if we know the a's then we can estimate the yield when all stocks are at half their virgin biomass. While the a's are not known as such, their values might be guessed either from known examples of such species or on general biological grounds. The derivation of 3.3.7 is given in the mathematical annex.

3.4 How should we seek to maximize yield if we have a time series of both groundfish survey data and data on the the commercial catch of each species?

If both groundfish survey indices of abundance and total commercial catches are available, then we have more information to guide us toward the overall maximum of the system and hence, more possible ways of tackling the yield maximization problem.

As a first step, we can divide each annual species catch by its groundfish survey index of abundance. We will thus obtain an estimate of fishing effort for each species each year. Our next step should be to inspect the intercorrelation of the population biomasses of all species groups. It would also be worth doing this for the various species fishing efforts. Probably, the best way to do this is to use principle component analysis as this will indicate whether or not there is a strong general trend in the biomasses or in the fishing efforts of the various species. It will also indicate any secondary trends. For example, demersal fish might have a general trend in their abundance while pelagic species caught in the groundfish survey might show a different general trend. If the principle component analysis revealed the same general trends for all of the species, then we are very much in the situation described in subsection 3.2. In this case, the maximum yield given by a yield curve based on the total catch and the total effort will be the maximum that can be attained. This will be the case unless it is possible to disrupt the trend between the species. This might be done by the introduction of fishing gears or regulations which change the species mix of the commercial catch.

If the trends observed in the various species biomasses are less apparent, then it may be possible to evaluate some of the model parameters. We are most likely to be able to discover the parameters of the model relating to species whose fishing effort is largely uncorrelated and it is, therefore, possible that we may be able to isolate some of the more important interactions between species for which this is the case. Where there is no correlation between the various species biomasses, the proper approach is to apply the Schaefer model to each species separately.

If as is probable we are unable to estimate satisfactorily the model parameters to any marked degree, we will probably proceed by trying to achieve something like the half virgin-stock biomass position explained in subsection 3.3. If our groundfish survey has estimates of the virgin-stock biomass, then this value is already defined. If the groundfish survey series starts after the fisheries developed, then estimates of the virgin-stock biomass may still be achieved by plotting the groundfish survey estimates of abundance of each species against the species specific fishing effort estimates.

The virgin-stock size is of course estimated by extrapolating back to where fishing effort is zero. In general of course, we would expect the catch rate to fall with increasing effort but it is possible that we would observe a rising or level trend for some species. This is entirely consistent with the model as it would indicate that the reduction in the biomasses of other species is releasing the pressure of competition or predation on the species that is increasing. This is a particularly interesting situation as it indicates that there are strong competition or predation links between this species and some other. When these links are strong, the half virgin biomass solution is potentially least satisfactory as an approximation to the overall maximum yield. An appropriate management strategy would probably be to attempt to bring those species whose biomass had fallen with increasing effort to a situation where their biomass was half its virgin-stock level; meanwhile, slowly increasing effort on the stocks whose biomass had risen. This a trend which might be expected to occur naturally as fishermen may be expected to modify their fishing practices to catch more of a species which has an increased biomass while concentrating less on species with biomasses that have markedly declined. Whether these changes occur naturally or whether they are brought about as a result of deliberate management policies, the yields that result should be carefully monitored. By doing this, those combinations of biomass and of fishing effort which maximize the yield will be revealed. Those may indicate that extending the change of biomasses to their half virgin biomass position may be counter productive and may indicate a combination of fishing effort and stock size which gives a better yield.

The strategy suggested in the previous paragraph might also be used if only the total catch of all species were available. In this case in moving toward the half virgin-stock size position, we would monitor the overall yield. If this appeared to decrease as we approach the half virgin-stock sizes of most species, then we would conclude that we would do better at some previously explored levels of stock size and try to adjust the fishing to achieve these. The concept of managing a fishery by what amounts to a rule of thumb may not seem very attractive from a theoretical standpoint, but in practice, it may be all we can do. The situation of trying to maximize overall yield when the model parameters are unknown is analogous to trying to climb a hill in a mist without a map. We could do this if we have some form of position-finding equipment (Decca for example) and an altimeter. We might climb the hill by moving at random. If we found we had moved higher, then we would carry on; if we found we were lower, we would retrace our tracks back to the highest known point and try again. Clearly we would eventually reach the top provided there was only one peak, but equally clearly it would take a long time. If we climbed the hill in this way, then we would be wise to make a contour map as we went along, as this might give us some idea of the general shape of the hill and thus the likely position of the maximum. In this analogy, we might think of the altimeter as being the total yield of the fishery and the position-finding gear as the groundfish survey estimates of abundance.

In the absence of other information, we could use a similar strategy to maximize yield. We would expect this to take a long time, but we may be able to improve our movement toward the overall maximum yield by making use of other information. The model gives us some idea of the possible general shape of the hill and we may also have some biological information which will illuminate the theory. For example, if we have a prey-predator system, we would expect to find the maximum yield where the reduction in biomass of the predator was greater than that of the prey species. If we have two species which seem to compete strongly, then changes in the one species may cause compensatory changes in the other species. This points out that general biological knowledge about the various species may be valuable even if it is unquantified.

Hill-climbing problems have been studied by mathematicians at some length because they are used to evaluate the maxima and minima of difficult functions. They have discovered various algorithms for approaching the maximum. Many of these of course are inapplicable because they require extra information which we do not have. In particular, they often use the gradient in the algorithm. There are, however, some algorithms which do not require this knowledge and these might be valuable. A book by L.C.W. Dixon (Nonlinear Optimisation) gives many of the better algorithms, and in particular, the PARTAN techniques and direct search techniques may be of some interest.

Regarding fisheries management with insufficient information as a hill-climbing problem is a useful idea since the objectives of a mathematical hill-climbing algorithm and of a fisheries manager are rather similar. Both wish to get to the maximum of the system as quickly as possible by the most direct path. Both wish to avoid undue back tracking since to the computer programmer, this represents wasted time while to the fisheries manager, it represents the need to cut back existing fishing effort. The need for such cut-backs will seldom be compatible with an efficient development of a fishery. An example of a modified PARTAN method is shown in the mathematical appendix. In using a hill-climbing approach to the management of fisheries, we must remember that our hill is rather variable with time. The yield to be obtained at certain stock biomasses and fishing mortalities will not always be the same. In particular, if we increase fishing mortality, then the yield in the next year may be untypically high since it will be partly based on the higher stock sizes which occurred at the previous lower mortality position. In our analogy, the hill is made of jelly and we may have to stop at each point to allow it to stop wobbling before we can decide whether or not we are better off than we were previously. In a tropical mixed fishery, the indications are that the system is rather less variable than has been experienced in temperate regions. This coupled with the faster turnover time of the stocks may help to reduce this problem of variability of steady state yield with time.

Mathematical Annex

A modified PARTAN technique for maximizing the yield from a multispecies fishery. The following discussion assumes that either problems of accumulated biomass do not affect tropical fisheries to the same extent as in temperate fisheries or that each of the effort levels is held for a number of years to allow the fishery to stabilize. Let us suppose that we have a two-stock fishery which in fact has contours of equal yield as in Fig. 2.1. The configuration of the contours and the position of the maximum is, however, unknown to us. Figure 3.4 shows a strategy we might adopt to reach the maximum. Initially, a demersal trawl fishery develops which produces fishing mortalities on the two stocks so that F(p) : F(g) is approximately 2 : 1. After several years, the overall yield curve relating to this effort is analysed and this indicates that the maximum yield of 400 units occurs at point A on the figure. As can be seen at this point, the line OA is tangential to the ellipse of constant yield (400). The fishery so far has mainly concentrated on stock p which is a demersal species. It has had less effect on stock q which is found more in midwater. At this time, therefore, it is decided to stabilize the trawl fishery at the level corresponding to A. A midwater trawl fishery is set up and this tends to change F(p) and F(q) in the ratio of about 1 : 4. Thus the midwater trawl fishery develops the fishing mortalities along the line AB. A yield curve based on yields on the line AB is calculated and this indicates a maximum of 500 at B. The midwater trawl fishery is, therefore, stabilized at B. Since the biomass of stock p at this point is much reduced, it is decided to reduce the demersal trawl fishing effort. This is done and the fishing mortality on both stocks declines along the line BC. An analysis of the yield along the line BC indicates that the maximum 550 occurs at C. The line BC is thus tangential at C to the ellipse which gives a constant yield of 550. Moreover, BC is parallel to OA and from the general properties of concentric ellipses, it is known that the maximum lies on the line joining AC since these points are the points of contact of parallel tangents. Hence the name of the technique (parallel tangents). The management would thus proceed by moving along the extension of the line AC until the maximum was found at D.

It can be seen that the parallel tangents technique has let to a full development of the fishery with not too many twists and turns. This has been described for two species but a similar approach could be used if more species were present. The idea is particularly interesting in that even where a fishery has many species, there may still only be two or three different types of fishing fleet (onshore/offshore) or fishing gear (pelagic/demersal) that produce markedly different catch rates for different species.

4. Applying the multispecies fisheries model to the demersal fisheries of the Gulf of Thailand and other regions in the South China Sea

The Gulf of Thailand fisheries have developed rapidly since about 1960 and form one of the better documented of the tropical multispecies fisheries. Numerous authors have pointed out that fishing intensity has exceeded the optimum level since about 1966-67. From the point of view of the application of the multispecies fishery model, the most attractive feature of this region is the research vessel survey conducted by the Kingdom of Thailand. This was initiated in 1961 and 1963 and carried on continuously since 1966. Moreover, it has been carried out in a consistent fashion through the entire series. Tiews (1967) gives an account of the initial years of the survey and Ritragsa (1968, 1969, 1970) gives detailed accounts of the survey results in 1966, 1967, 1968. An overview of the survey results to 1972 may be seen in Ritragsa 1974. This survey gives an excellent idea of the changes in the biomass of the various species groups reported on. The survey also yields considerable information on the relative distribution of the various species groups and also some information on length distribution.

Unfortunately, other information from the Gulf of Thailand is in a less satisfactory condition. In particular, the commercial catch data from the area are doubtful for most years and in general are not differentiated into useful species groups. Sample survey results are, however, available for 1972 which break down the catch into useful species groupings. The annual total catch series is available but these results are confused by having catches from other regions being reported as coming from the Gulf of Thailand. Estimates of total catch have been made to try to correct this effect but essentially these are tied to the expected relationship of catch per effort and catch. They are, therefore, probably not exact.

Because of the limitations of the catch data, it will not be possible to apply all the methods of section 3 but it will be possible to consider the nature of the Gulf of Thailand fisheries and indicate in what directions management should seek to change the fisheries if maximum yield is the objective. Indeed it is encouraging to see how far a multispecies assessment can be extended with only research vessel survey data and total catch data.

4.1 Consideration of the stock areas in the Gulf of Thailand

The regions of the Gulf of Thailand covered by the groundfish surveys are those areas of the Gulf adjacent to the coast of the Kingdom of Thailand to a depth of about 50 m. There is, therefore, no particular reason to suppose that this area encloses a unit stock of fish of each species. Indeed a study of the trends in total catch rate given in Ritragsa (1974) shows that the various regions of the Gulf (Fig. 4.1) into which groundfish survey results are stratified show differences in their rate of decline. Fig. 4.2 shows the rate of decline of average total catch per hour in a selection of these areas. It is apparent that the decline has not occurred at the same rate in all regions. Similar conclusions apply to the average total catch per hour in the various depth strata of the survey (Fig. 4.3). These indicate a slower rate of decline in the deepest strata. Fig. 4.4 and 4.5 indicate the catch rate per hour of Carangidae and Leiognathidae for various regions from 1963 to 1972. These again indicate that changes in catch rate have differed through the survey area. In the case of the Carangidae, there is some indication that adjacent regions behave in a more similar fashion. Thus in areas I to IV, this group of species declined rapidly from a high level in 1963. In regions V to IX, the biomass showed a tendency to increase in the earlier years of the survey. This tendency for adjacent areas to have a more similar trend is illustrated by the matrix of correlation coefficients of the average catch rate of good fish in the areas for 1963, 1966-72. This is shown in Table 4.1. It can be seen that in general, adjacent areas are highly correlated while correlations with more distant areas tend to become lower (though still respectable). Area 5 is the only serious exception to this rule. A similar correlation coefficient matrix is shown for scrap fish in Table 4.2. The results of this are more cryptic and the correlations are in general lower.

It is difficult to decide from these results which areas might form the best stock boundaries. The general indication from the results is that the area of stocks are smaller than the total area of the survey. Consequently, overall management of the entire region might allow local stocks to be overfished when the average level of exploitation was at about the optimal level. This might happen particularly in waters adjacent to the larger markets (particularly in the inner Gulf area). On the other hand, a broadly similar trend has occurred throughout the region and it might be argued that the natural tendency of fishermen to seek the highest catch rates would counteract any tendency to local overexploitation.

Bearing these points in mind, subsequent analyses have been made most comprehensively for the whole region covered by the Gulf of Thailand Groundfish Survey but some results are also shown for the area strata.

4.2 Is an overall yield model appropriate to the fisheries of the Gulf of Thailand?

Any fisheries model can of course only be tested by comparing the accuracy of the predictions it makes with those of other models. Obviously, we do not yet have the information available which would enable us to test the general applicability of the model to the Gulf of Thailand fisheries. One test we could however make is of the assumptions required if a simple total catch, total effort, yield curve approach is to be valid. As was explained in subsection 3.2, these are:

(1) that the catch rate of the various species groups should have a similar general trend;

(2) that no species group should become zero;

(3) that the trawl survey catches the various fish species in the same proportion as the commercial fleet.

The validity of (1) and (2) above may be judged from the results of the Groundfish Survey; (3) will require commercial species catch data for its validity to be examined.

If (1) is true, then if we correlate the catch rates of the various species through time either within areas or over the whole Gulf of Thailand, we might expect to find high correlations. Tables 4.4 to 4.13 show the correlation coefficients for the 16 species groups for which data were available in each year of the survey. Table 4.3 shows the key to these tables giving the Latin and common names of the species groups included. It is apparent that a generally high level of correlation exists between the overall catch rate of the various species both overall and in each area of the Gulf of Thailand. The exceptions to this rule are Priacanthus spp. (5), Lutjanidae (7), Scomberomorus spp. (12) and the crabs (14). The latter group together with the squids (13) are unusual in that they have negative correlations with the majority of other species. Thus, tables 4.4 to 4.13 indicate a system where catch rates of one species have the same general trend as catch rates of another. This state of affairs could be brought about by a common fishing effort and perhaps by the action of interspecific interactions. For example, the rise in the catch rate of squid through time might well be a result of one or more of its predators being reduced in number.

One way of assessing the overall correlation between all the species is to perform a principle component analysis. This technique discovers the direction of the greatest variance of the data (main trend) and then the orthogonal direction with the next most important component of variance and so on. Thus the first principle component may be viewed as the main trend of the data and its size (eigen value) is the measure of how much variance it accounts for. Table 4.14 shows the percentage of the variance accounted for by the first and second principle components of the yearly species catch rate data derived from the Gulf of Thailand Groundfish Survey. This table indicates that certainly for all areas combined, there is a general trend amongst the majority of the species involved. This observation that a general trend is most pronounced when all areas are combined is most interesting in the light of the discussion of stock areas in subsection 4.1. The result could suggest that differences in the trends in different areas seen in subsection 4.1 are reflections of changes in behaviour of the fish from year to year with the peaks of abundance occurring in different areas in different years. For example, the different trends in the Carangidae in areas I-IV to areas V-IX (see Fig. 4.4) might be caused by these fish aggregating mainly in areas I-IV in the earlier years but tending to be found more in areas V to IX in the latter years. If this were the explanation, then we have observed a general trend between the overall catch rate of the majority of species. In this case, condition (1) holds reasonably well and it would seem satisfactory to calculate an overall yield curve. This has been done by various authors (e.g. Isarankura, 1970) who are familiar with the details of the Thailand catch statistics for the Gulf area.

The yield curve shown in Fig. 4.6 is that given in the Fisheries of the Kingdom of Thailand, 1976. It indicates a maximum yield of 450 000 t for the demersal resources of the Gulf of Thailand. It is interesting to note that the shape of this yield curve is of the shape resulting from the exponential form of the relationship between catch per effort and effort. This could be due to this formulation being appropriate. Alternatively, it could be due to the species specific catchability having changed with time as is perhaps indicated by the existence of a second principle component with a significant proportion of the variance. The further interpretation of the principle component analysis will be made in subsection 4.3.

The conclusion from this subsection is that the yield curve shown in Fig. 4.6 is based on stock estimates which have a substantial linear trend. It may thus be regarded as a reasonably straight section of the multispecies yield isopleth ellipsoid and consequently, the maximum yield it indicates will be the maximum that can be obtained with the current fishing practices. The maximum shown, however, might change if the catchabilities the commercial fleet has for the various species groups could be changed. This might be achieved in a variety of ways. Some possibilities are discussed in subsection 4.4.

4.3 Further interpretation of the principle component analysis of the Gulf of Thailand trawl survey data and an interpretation of multispecies yield in the light of its results

The principle component analysis of the annual species catch rates from the trawl survey reveals several important features of the fishery system in the area. The first feature is that over the whole area, the first and second components account for 83 percent of the variance. This has been discussed briefly in the previous subsection. The level of correlation indicated by this result is striking and it is probable that much of the remaining 17 percent of variance results from random effects. If this were so, then the differences in the results from the various areas (Table 4.14) are roughly compatible with their having more random effects because results for individual areas are based on smaller samples than the overall result.

In fact, the first two principle components do explain nearly all of the non-random processes in the catch data and they provide a very valuable way of mapping the events occurring in the Gulf of Thailand. This is because they enable us to draw these events in 2 dimensions rather than being faced with changes in 16 separate variables.

Let us first consider what the two components represent. Table 4.15 shows what is called the first eigen vector of the analysis. This is shown for all areas combined and for each separate area. The value given for each species group is the extent that it contributes to the first principle component. Table 4.16 shows the second eigen vector of the analyses. Again, these are both for all areas combined and for each area separately. The interpretation of the principle component analysis can sometimes be difficult but in this instance, the results are remarkably clear. For most species, their contribution to the first component of all areas is 0.27, 0.28 or 0.29; the exceptions to this being Priacanthus (5), Lutjanidae (7) and Scomberomorus (12) which have components of 0.13, 0.15 and 0.04. Thus, Priacanthus and Lutjanidae have only half the impact on the first principle component that other species do while Scomberomorus has hardly any effect at all. The other exceptions are squid (13) and crabs (14) which have a negative component. This indicates that, as other species become less abundant, these become more abundant. This was of course recorded in the negative correlation coefficients shown in Table 4.4. The first eigen vectors for the areas taken separately are rather similar to those of all areas combined. They are of course more variable, as we would expect but, in the main, they are formed in very much the same way. We may regard the first principle component as being composed of all the finfish in fairly equal portions with the three exceptions of Priacanthus, Lutjanidae and Scomberomorus. It also reflects the opposite trend in the squids and the crabs.

The second principle component for all areas combined has large contributions from Priacanthus (0.47), Lutjanidae (0.48) and Scomberomorus (0.57). The contribution of the other fish species is comparatively slight. The crabs make a negative contribution (-0.24) to this eigen vector. Looking at the results for the second eigen vector for the separate areas, the first impression is of a more confused situation. Lutjanidae figures prominently however in most of them while Priacanthus and Scomberomorus frequently have a considerable component. The situation is further clarified by consulting the first eigen vector. In general, when a species group has a low value in the first eigen vector, it has a higher value in the second eigen vector. As an example of this, sharks (species 1) have a low first eigen vector in area 3 (0.12) and a high second eigen vector in area 3 (0.35).

Thus in general, the first and second eigen vectors or principle components reflect the changes in catch rate in most of the species whether looked at for all areas combined or for separate areas. The precise composition of the two components does, however, change between the areas.

The composition of the first and second components are clarified by the graphs of overall annual catch rates for the two species shown on Fig. 4.7, 4.8 and 4.9. Fig. 4.7 shows the species groups which occurred in the first eigen vector. For clarity, the graphs are drawn on semi-logarithmic paper and the catch rates of the upper five graphs are increased by an order of magnitude to avoid confusion. All these species groups indicate a generally unrelieved decline with time. The species with negative components to the first eigen vector, squid and crabs, are shown in Fig. 4.8. They show a fairly steady though undramatic increase through time. This, of course, is the reverse of the species groups in the previous graphs. Fig. 4.9 shows the three species which predominate in the second principle component. These species have tended to increase in the earlier years and decrease in the latter years of the sequence.

We thus see that the first principle component reflects the general decline of demersal biomass and the increase of squid and crabs. This general decline presumably results from the application of general and indiscriminate fishing effort in increasing amounts. The increase in the squid and crabs presumably results from a decrease in predation on them. The second component reflects the change in those species which have not declined initially. These are predominantly the snappers and Scomberomorus. That the latter, a pelagic species, should not follow the decline of the demersal species is not perhaps surprising. The second eigen vector also contains elements of the main species groups though in lesser proportion than the snappers and Scomberomorus. It seems probable that the second principle component reflects some change in the catchabilities of the various species through time. Alternatively, it might reflect the effect of some time lag in the system which might prevent species reacting in a precisely linear fashion to increasing fishing effort.

Figures 4.10 to 4.15 show the plots of the values first and second principle components each year for all areas combined and for areas I, III, V, VII and IX. All of these except area IX show an almost unrelieved decrease in the value of the first principle component while the value of the second principle component first increases and then decreases. The differences observed in area IX almost certainly stem from this area having a fishery which developed more slowly. All areas show the same characteristic dog leg (V shape) in the loci of the annual first and second principle components.

Concentrating on Fig. 4.10, we see that these two components condense almost everything shown in the graphs of the individual species. Thus we may use this figure as a map of what has happened to catch rates in the Gulf of Thailand in this time period. This is shown in Fig. 4.16 which shows the first and second principle components each year and the total yield of the trawl fishery. Tentative contours of equal yield have been sketched in and these seem to indicate that with the relationships between the species so far observed, yield would be maximized by values of the first principle component higher than its current value; in other words, by a cutback in fishing to allow an increase in the biomass of species figuring in that component. The other point shown is the value of the two principle components would have, if all stocks were at half their 1963 biomass. This is the point which the theory in section 3.3 suggests would tend to give a substantial proportion of the total overall maximum yield. In practice, of course, this point would not lie in the plane of the two principle components since it would require not only the fish species to have half their virgin biomass (taking 1963 stock levels as the virgin stock) but also the squid and crabs. These increase when the other components of the first principle component decrease. Thus the half virgin biomass stock point (assuming 1963 stock levels to be approximately the virgin stock) would not lie in the line of either the first or second principle components. Fairly obviously, the value of the second component has a smaller effect on yield because it does not contain a great number of important species. Increasing the value of the first principle component back to half its 1963 level will increase the yield, but the indications are that the increase would not be large. If the pattern of fishing could be changed to alter the catchabilities of the various stocks and thus get the stock levels out of the plane of the first and second principle components, it is possible that the yield could be further enhanced.

In order to improve the catch rate with little change in yield, the first move should be to decrease fishing effort to about a half of its current value. This might best be done by an increase in mesh size. There would seem to be perhaps some potential for increasing fishing on squid. It would probably be best however not to decrease this stock below the 1963 level until the resulting yield changes could be assessed. Any other increases in yield would have to be looked for in the pelagic species. It is possible that the decrease in the demersal biomass may have caused consequential increases in the pelagic biomass.

Similar principle component results are found on the Indian Ocean coast of Thailand. A principle component analysis was applied to the six years and ten species recorded in the report of the Workshop on the Fishery Resources of the Malacca Strait. The percentage of the variance explained by the first principle component was 73 percent while the percentage explained by the first and second was 87 percent. Table 4.17 shows the resulting eigen vectors. Again the first eigen vector has remarkably similar values for each species except the last two. Priacanthus tayenus again has a trend different to that of the majority of groundfish. Another similarity is that with the Gulf of Thailand result. The second eigen vector has high values for those species. (Trichiurus dorab in this case) which have low values in the first eigen vector.

This result suggests that principle component analysis is a useful way of condensing the information in tropical multispecies fisheries at least in the phase where increases in fishing effort are causing rapid changes in catch rates. It also seems to suggest that tropical multispecies fish stocks (at least those of the coast of Thailand) tend to support fishing effort which does not discriminate very much which fish it catches. Therefore, the tendency is for fishing mortality to increase in fairly constant proportions on all species groups. The conditions for overall yield curves (see section 3.2) are, therefore, broadly satisfied. The fishermen do not seem to direct their fishing effort at any particular species groups but whether this results from economic pressures or from the intrinsically mixed nature of the tropical demersal fish species is not clear.

4.4 Can mortality be estimated from biological sampling in tropical fisheries?

Since in the Gulf of Thailand commercial catch statistics for each species are not available, it is not possible to estimate species or species group fishing effort directly. This begs the question: Can we circumvent this deficiency by estimation of fishing mortality from the length or age structure of the fish? The only length data available on an annual basis are the length measurements taken on the groundfish survey. The only age data would be given by the Petersen Method that is by observing the modes in the length distribution from these data.

One problem with these data is that their collection in the past has been rather a secondary consideration compared to the estimation of weight caught of each species in each haul. This order of priority is of course entirely proper because the estimates of abundance are the most valuable output of the survey but it has tended to mean that the length data may have been collected in a somewhat less systematic fashion. In some circumstances, this might lead to a biased result. Table 4.18 shows information on the length distribution of Priacanthus tayenus in area I for 1972 for each haul for which it was measured. In all, it was measured from 17 hauls and the weight sampled accounted for 30 percent of the total Priacanthus catch of this area. No samples were taken in the shallower depth range and this might have been a potential source of bias. This would be the case for example if fish in the shallower water were the young of the species. The median length in the samples does show a slight tendency for larger fish to be found in deeper water.

This problem of possible bias is also posed by the annually accumulated catch data. Table 4.19, for example, shows the catch of L. lineolatus in area III. This was sampled in 1969 and 1972-74. The fact that the mean and the mode of the distributions of this species decline with time is of course not surprising. This could be accounted for by the decline in the numbers of older fish caused by higher levels of fishing. It is, however, disturbing to find that the distribution in 1974 is of sizes which are generally smaller than any seen in previous years. This suggests that smaller fish previously not measured in past years may have been measured in 1974. Of course if this is the case, it would result in biased length distributions and cast doubts on any estimates of mortality calculated from length distributions. A further problem with the length distributions is that while they are made for individual species, much of the catch weights are recorded in species groups. Thus a knowledge of the relative mortality in Caranx leptolepis for example will be difficult to interpret in terms of the general fishing effort on Caranx species.

Bearing these problems in mind, some of the length distributions from the survey were examined in order to try to estimate mortalities. Figures 4.17 to 4.21 show the available length distributions for various areas of the following species. These are Saurida cancellatus, Caranx leptolepis, Nemipterus japonicus, Caranx rumenopthalmus and Priacanthus tayenus. These are drawn on semi-logarithmic paper and the results for each year are multiplied by suitable orders of magnitude for clarity. The first three species all show what appears to be a catch-curve structure with a fairly evenly declining right-hand limb. If we assume that recruitment is constant through time and that growth is linear, then the slope of the line will indicate the level of mortality the stock has been enduring. The right-hand limbs are drawn as straight lines by eye. The general impression is that there is little systematic change in slope with time. This is surprising when the considerable decline through time in biomasses of the various species groups these species belong to is considered. Therefore, either increased fishing mortality has been matched by decreased natural mortality for these species or we must conclude that these catch curves do not measure mortality. It could be that the slope of the right-hand limb is more a result of changes in recruitment within the year.

The other two species show evidence of cohorts of fish but whether these are annual cohorts is uncertain. Wetchagarun (1971) shows that several batches of Priacanthus tayenus may occur within a year and it, therefore, seems doubtful that the bumps represent annual cohorts. Given such data for several periods of the year, it might be possible to estimate mortality from the relative abundances of the various years. Tentative splits of the length distribution were made and mortality was estimated from these as shown in Table 4.20. While these mortalities seem reasonable, it is uncertain whether or not they are annual mortalities.

In conclusion, it seems that the estimation of mortality for species is difficult and that the results obtained are ambiguous. At present, such estimates cannot, therefore, be used to estimate levels of fishing. Consequently, it is not possible to make good the lack of fishing effort estimates caused by the lack of commercial species group catch data.

The collection of length and other biological material on the survey should, however, be continued. It would be wise to do this in a fashion which did not lead to bias, for example, by deciding in advance and at random which hauls in an area and depth strata would be sampled for particular species. It would be useful if the length sampling could be related to the catch rate of the species group. This would perhaps be best achieved by taking length samples of all species present of a particular species group at the preselected stations. This would be useful as the weights of the various samples would enable the species group catch rate to be split into species catch rates. It would also enable the catch of a species group to be classified on a size basis which might be valuable in considering mesh assessments.

4.5 Economic considerations

The model described in sections 2 and 3 is of course concerned with the maximization of yield. It could, however, very easily be modified to consider economic yield provided that the value of fish remains fairly constant and the cost of fishing effort is a linear or quadratic function. In this case, the equations for yield would become

$$Y_E = Y_1\nu_1 + Y_2\nu_2 - C_1f_1 - C_2f_2$$

where Y_E is the economic yield Y_1, Y_2 are the physical yields for species p and q. C_1 and C_2 are the costs of fishing effort on species p (f_1) and species q (f_2). The effect of these modifications would not change the basic structure of the problem since the contours of constant Y_E would still remain ellipses. The effect of including the cost of fishing would be to move the overall maximum yield nearer to the origin of the fishing mortality axis.

In the Gulf of Thailand, the constant value of catch condition would seem to apply reasonably well. Table 4.21 shows the values of various types of fish given by the Thailand fish marketing organization as reported in the annual fishery statistics. It is apparent that there has been comparatively little change in the value of fish through the period despite the considerable changes in abundance observed in the Gulf of Thailand. This could be because the market may have been stabilized by landings from areas outside the Gulf of Thailand. Thus, the model of sections 2 and 3 will hold for economic yield provided that the cost of a unit of fishing effort is constant. This is quite probable and indeed, even if the cost of fishing were a quadratic function of the fishing mortality, the parabolic form of the economic yield equation would still hold. Thus, it should be possible to give estimates of maximum economic yield when it is possible to give estimates of physical yield. The only extra information required is the cost of fishing.

5. The scope for changing the catchabilities ratios of species groups in the Gulf of Thailand

If the close relationship between catch rates of the various demersal fish shown in the previous section is maintained, then the maximum yield given by an overall Schaefer curve defines the maximum yield that can be obtained. If the relationship between the catch rates can be changed, then the overall yield characteristics of the system may be altered. It is worthwhile, therefore, to investigate what potential there might be for changing the pattern of fishing. This can be examined in several ways. The most obvious of these being:

(1) Are there any systematic differences in the catch rates of various species in various areas or depth?

(2) Are there any systematic differences between the relative catch rates of various species caught by different gears or vessel types?

These problems are examined in the following subsections. It is, however, only possible with the data available to the consultant to suggest methods of analysis.

The way to proceed is by isolating possible ways in which different proportions of the various demersal species could be caught. It may then be possible to comment on the most satisfactory (from the point of maximization of yield) ways of altering the fishing effort in the region. Consequently, this kind of information is a valuable background for management. With the present status of stocks in the Gulf of Thailand, however, such fine tuning of the catchabilities is far less important than obtaining a general decrease in fishing mortality on the majority of species!

5.1 Differences in the catchabilities of the various species groups in various areas of the Gulf of Thailand

The groundfish survey data can be inspected for relationships between the catch rates of the species groups in various areas. This has been done comprehensively by Ritragsa for the surveys of 1966, 1967 and 1968. This work indicates that some species are found more frequently in some depth and areas than others. Table 5.1 shows the catch rates of various species groups in the various areas of the survey averaged over all years. This does show some differences between the catch composition of some areas. Consequently, there might be some possibility of changing catchability coefficients by area regulation.

For a comparatively small number of fish species groups, the catch rate is readily available both by area and by depth for all years of the survey. Table 5.2 shows the average catch in the two depth ranges 20-30 m and 31-44 m in each of the areas and in each year from 1966 to 1975 for skates and rays. The averages are for fish in these depths, areas and years, and so are somewhat different from the area results in Table 5.1 which gives all areas and all lengths. As analysis of variance was performed to indicate which differences were significant. This showed significant differences between areas, between depth and significant depth x area, area x year interactions. The depth x area interactions were a result of finding more skate and rays in the deeper stratum in areas I, III, IV, V, VI, IX but less in the deeper stratum of areas II, VII and VIII. Differences in area depth effects should be interpreted with caution as the different areas are surveyed at different times of year. Table 5.3 shows the times of year the survey was conducted in the various areas. Thus it is possible that the differences with area are the result of a seasonal differences rather than an area difference. This caution should be applied particularly to the area x depth interaction term.

Table 5.4 shows the significance levels of the analysis of variance for the other species groups for which suitable data were available. The stars indicate the level of significance. The most interesting differences were that <u>Priacanthus</u>, <u>Saurida</u>, and <u>Nemipterus</u> all had significantly greater catch rates in the greater than the lesser depth. The ratio of the catch rate in 20-30 m to that in 31-44 m was for these three species groups; 1 : 2.05, 1 : 1.44 and 1 : 1.72 respectively. Conversely, <u>Loligo</u> had significantly higher catch rates in the shallower depth (1.08 : 1.0). All species showed significantly different catch rates in the various areas and years, and all but <u>Priacanthus</u> and <u>Loligo</u> showed significant depth area interactions. It consequently seems possible that some modification of catchability might be achieved by encouraging fishing in certain areas and depths, and discouraging it in others. In which areas to encourage fishing would of course be best decided by local scientists who will have the best information on the biological features of the areas (e.g. spawning grounds). The choice might also critically depend on policy decisions as to what sectors of the fleet the Government of Thailand wish to encourage on socio-economic grounds. In either case, the trawl survey data could be examined to suggest the most useful divisions. Obviously, the most recent year's results would be the most appropriate to use for this study.

Another way we might look at the trawl data is to examine the haul-by-haul data for a year to see what species are found together and which are found separately. The easiest way to do this is to calculate the correlation matrix for all species groups and to see which species have a significant correlation and which do not. If a correlation is positive, it suggests that where the one species is found in abundance, the other species is likely to be more abundant.

This was performed for all the species groups of good fish on the haul-by-haul data for 1967. The resulting table is too extensive (39 x 39) to show conveniently but, all but a few species pairs gave low correlations. In all, out of 741 possible correlation coefficients, only 57 (8%) were greater than 0.20. This is only a few more than the 5% we might have expected to have seen by chance. Interestingly, only one correlation in the 57 was negative. This was the correlation (-0.23) between Scolopsis spp. and Sepia spp. Only 4 correlation coefficients were greater than 0.50. These were Chirocentrus spp. with Cynoglossidae (0.69) and crabs (0.92), Plectorhynchidae with Lethnnidae (0.69) and Cynoglossidae with crabs (0.73). Thus for the majority of species groups, it seems that there is little or no correlation between species abundance taking the Gulf of Thailand as a whole. Calculating a similar correlation matrix for some of the areas separately did yield rather higher correlations, for example, in area VIII. There were 151 (20%) correlations of more than 0.20. Of these, 32 were negative. Only 18 of the correlation coefficients were greater than 0.50 and of these, only 2 were negative. These were Rastrelliger kanagurta with Bothidae (-0.50) and Sepia spp. (-0.50). It would seem that, in the main, such correlations as exist between the abundance of species are positive rather than negative. For the majority of species groups, there would seem to be little tendency for the abundance on one species to affect the abundance of other species. Thus we might conclude that concentrating fishing on one species group would in general yield average or better than average catch rates of the other species groups. Thus, such a concentration would not in general change the relative catchability coefficients of other species groups very much, although it would presumably increase the relative catchability of the south species.

These correlations might be criticized in that they include the results of those hauls where neither species was caught in the correlation coefficient. These points might enhance positive correlations while helping to suppress negative correlations. Consequently, correlations were made with these points omitted. Table 5.5 shows such a correlation matrix for the 16 species groups examined in section 4. These are again based on haul-by-haul data from 1967 for all areas covered in the Gulf of Thailand trawl survey. The table shows that 29 (12%) of the correlation coefficients are greater than 0.20 of which 2 are negative. Thus, leaving out hauls where neither species is caught does not greatly affect our view of the likely aggregation of species. Table 5.6 shows similar results for area I. Again, correlations are generally low between species groups. Another way in which such data could be interpreted is by drawing up a table of high, medium and low catch rates of pairs of species. Table 5.7 shows such information for sharks and rays in area IX. This indicates that the highs of these two stocks tend to occur separately. Tables like this would indicate more clearly than correlations where fishing effort might be applied differentially to separate stocks. Whether such differences would allow fisheries management to generate different catchabilities would depend on how such differences occurred. If they were associated with distinctive bottom types or broad depths or areas, then it might be possible to use closed areas to generate changes in catchability. If they occurred more or less at random, then the only way the differences in catch rate could be used to generate different catchabilities for the species concerned would be to make it profitable for the fishermen to catch those species groups for which we might hope to increase the relative catchability and to make it unprofitable to catch other species. This might be done by a system of species levies and species premiums, for example, by increasing the general cost of fishing while paying a premium on landings of squid. Clearly at present in the Gulf of Thailand, fine tuning of the catchability coefficients is a less important problem than generally reducing fishing effort.

5.2 Differences in the catchabilities generated by different fishing gears in the Gulf of Thailand

The most obvious method of changing the catchability is by the use of different fishing gears. There has already been a shift toward higher headline trawls to catch squid in the commercial fleet according to the Thai Fisheries Department. This is the kind of change which might be expected to generate changes in the relative catchability of squid to other demersal species. Another obvious change in gear would be the adoption of larger mesh sizes in the nets of commercial fleet. This would tend to reduce all catchabilities but those of the smaller species would probably be reduced most. The report of R. Jones (1976) is concerned with this problem and should be referred to for further information on the likely effects of mesh changes. In addition to these specific changes in gear, the type of fishing vessel and in particular its size may very well affect the catchabilities obtained for various species. This suggests that comparisons of the catch rates of various species for the various vessel sizes and types should be conducted. This should be done in some detail and the report of and on the catches of baby trawlers in Thai waters is an example of how this might be carried out.

Some information on these catch rates is obtained from the sample survey result for the Marine Fishery Statistics 1972. Table 5.8 shows the catch rates of scrap fish expressed as a percentage of total catch for various gears and vessel sizes. It also shows the catch rate of each species group of good fish expressed as a percentage of the good fish total catch. It can be seen that there are systematic differences. The most obvious difference is the far greater catch rate of crustacea by the smaller vessels. The larger vessels catch a greater proportion of fish such as Nemipterus spp., Saurida, Lutjanidae and Priacanthus. Thus, the catchability ratios between these species and the crustacea and molluscs could be altered by encouraging particular sizes of vessels at the expense of other sizes.

As with the different area catch rates, the differences in the catchabilities generated by various vessel types might be used to alter the species balance in the fishery but such fine tuning of the system is less important at present than the problem of reducing fishing effort by a considerable amount.

6. General suggestions for research

The results of this report suggest that tropical multispecies fisheries can be assessed given the following input data:

(1) A time series of research vessel surveys of the resources;

(2) Annual catch data by species group for each significant section of the fishing fleet.

These two ingredients are both essential for a reasonable understanding of the multispecies fishery to be obtained. Consequently, national administrators of countries in the South China Sea area would be well advised to provide the infrastructure required to obtain these results. Both activities require personnel trained in the identification of the fish species found in the region. This training requires some time to acquire and it would consequently be wise to ensure that such personnel have sufficiently good pay and conditions to encourage them to remain in the organizations for long periods. This is particularly important in the case of trawl surveys where the continuity from year to year is very important.

Countries contemplating setting up trawl surveys may well find it advisable to seek assistance in the design and operation of the survey in the first few years. FAO should certainly consider making consultancies available for this purpose. In many cases, this expertise would most likely be found within the Southeast Asia area. Estimation of the annual catch of significant species groups by the main vessel types is probably best done using a sample survey method. The approach set out by Chakraborty (1976) for the Fishery Statistics of the Philippines is an excellent example to follow.

6.1 Thailand

Thailand should continue the trawl survey as a routine part of its assessment programme. Any changes in technique should only be made if they allow adequate comparison of results with past years' results. The collection of commercial catch statistics should be improved where possible. The collection of biological data during trawl surveys is valuable and should be done in as systematic a fashion as possible. In particular, length distribution data should be collected on a routine basis. This might mean assigning priorities to certain species groups or perhaps measuring all fish of particular species on predetermined stations. This would counteract any tendency to measure fish when a reasonable sized sample occurred which in practice might be when mostly smaller fish were caught.

Such systematic catch data could be very useful in considering within species interactions and the effects of mesh changes.

6.2 Philippines

The chief need is for the Philippines to set up routine monitoring surveys to obtain estimates of the biomass of significant species groups on a year to year basis. This will require some improvements in the infrastructure of the Bureau of Fisheries to enable staff of a sufficiently high calibre to be recruited and retained. It will also require suitable research vessels to be made available or the long-term chartering of commercial vessels. These requirements will obviously be expensive but the ability to assess the national fish resources should be the prime objective of the Bureau. Such expenditure would be directly linked to solving this problem. It would probably be helpful if a consultant were hired to help in the design and running of such a survey for the first few years.

7. Conclusions

The model set out in section 2 is the simplest way of considering yield changes in a multispecies fishery taking account of both technological and interspecific interactions. The simplicity of the model has the attraction of making the action of these effects easy to appreciate.

An important conclusion from the model is that in such a multispecies situation, any development of fishing effort which induces fishing mortalities on the component stocks which bear a constant ratio to each other will produce a parabolic yield curve. The local maximum of this yield curve will not, however, necessarily be the maximum overall that the system could produce if the ratios of fishing mortalities on different stocks are varied. Nor need the effort level which corresponds to the local maximum necessarily correspond to that needed to produce the overall maximum yield. One obvious problem with this model as with any model trying to explain a complex system is the need for estimating a considerable number of parameters. In a real life situation, this may not be possible with the available data, but the problems of managing the resource will nevertheless remain. The problem is thus to give management advice from a slender data base. Fortunately, the model can be used to examine the likely effects of various management algorithms (rules of thumb!). In particular, algorithms concerned with making use of the biomass estimates of the various species for assessment purposes are developed. These suggest that management rules based on trying to attain the half virgin biomass value for each species (species group) will form a sensible and robust basis for management. Another possibility is to use the species biomass series from a ground fish survey to examine whether or not they have followed similar trends. If they do, this suggests that trends in fishing effort have been similar through time and that a Schaefer curve may be applied to all species.

The Gulf of Thailand fisheries are examined along lines suggested by the model. Statistical analysis shows that the majority of species groups in this area have shown a similar trend in biomass through the period of the trawl survey. Thus as a first approximation, an overall yield curve may be drawn. A closer examination of biomass trends isolated a second orthogonal trend which together with the primary trend explained the major part of the variance in biomass in the trawl survey results. This enables a tentative two-dimensional yield isopleth diagram to be constructed. It was concluded from this that little opportunity of greatly increasing the yield existed under the current fishery regime. Some increase, however, should be possible by reducing fishing effort. More detailed analysis of these results is hampered due to the lack of commercial statistics giving the total catch for each species group from the area covered by the survey. It is suggested that priority is given to producing these statistics. Since commercial fishery statistics are not available which would enable estimates of mortality to be made, the possibility of estimating mortality from length samples is examined. It is concluded that currently this approach is unlikely to supply useful estimates of mortality for the various species.

Apart from the physical yield of the Gulf of Thailand, it is possible for the economic yield to be examined by the model since the essential requirements - constant relative values for the various species groups - seemed to be substantially true. For this analysis to be made, cost of fishing will be required.

Since it appears that the yield of demersal species in the Gulf of Thailand could not be substantially increased under the current fishing regime, the possibilities of modifying the regime by altering the effect of fishing mortalities on different species groups are considered.

In particular, the effects on the catch rate of various species groups of changes in the pattern of fishing by depth and area, or in gear and vessel type, were examined so far as possible with the data available to the consultant. The detailed results of this examination are shown in section 5. These are, however, rather tentative and are intended to illustrate what might be done with available data rather than to present a full analysis. This would more appropriately be made by local scientists who will have a greater knowledge of the factors involved. Various suggestions for further work are made in the report.

Perhaps the most important conclusion is that it is possible to make some reasonable attempts at assessing tropical multispecies fisheries if time series of commercial catch data (preferably by species group) and indices of abundance (preferably from research vessel survey) are available.

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Table 3.1 Number of potential parameters at various levels of n

Number of stocks (n)	1	2	3	4	5	10	20	30
Potential number of parameters in model	3	8	15	24	35	120	440	960

Table 4.1 Correlation coefficient matrix of catch per hour of good fish in each area strata of the Gulf of Thailand trawl survey - 1963, 1966-72. (Data from Ritragsa, 1974)

		Areas								
		1	2	3	4	5	6	7	8	9
Areas	1	1.00	0.96	0.98	0.96	0.86	0.83	0.89	0.73	0.67
	2	0.96	1.00	0.97	0.95	0.75	0.88	0.88	0.65	0.60
	3	0.98	0.97	1.00	0.97	0.83	0.83	0.85	0.74	0.70
	4	0.96	0.95	0.97	1.00	0.79	0.80	0.89	0.68	0.62
	5	0.86	0.75	0.83	0.79	1.00	0.63	0.80	0.83	0.85
	6	0.83	0.88	0.83	0.80	0.63	1.00	0.80	0.77	0.69
	7	0.89	0.88	0.85	0.89	0.80	0.80	1.00	0.71	0.68
	8	0.73	0.65	0.74	0.68	0.83	0.77	0.71	1.00	0.97
	9	0.67	0.60	0.70	0.62	0.85	0.69	0.68	0.97	1.00

Table 4.2 Correlation coefficient matrix of catch per hour of scrap fish in each area strata of the Gulf of Thailand trawl survey - 1963, 1966-72. (Data from Ritragsa, 1974).

		Areas								
		1	2	3	4	5	6	7	8	9
Areas	1	1.00	0.33	0.34	0.65	0.58	0.48	0.57	0.36	0.53
	2	0.33	1.00	0.44	0.24	0.28	0.32	0.43	0.41	0.17
	3	0.34	0.44	1.00	0.82	0.40	0.85	0.43	0.70	0.82
	4	0.65	0.24	0.82	1.00	0.70	0.82	0.57	0.52	0.82
	5	0.58	0.28	0.40	0.70	1.00	0.69	0.76	0.47	0.53
	6	0.48	0.32	0.85	0.82	0.69	1.00	0.55	0.72	0.82
	7	0.57	0.43	0.43	0.57	0.76	0.55	1.00	0.69	0.67
	8	0.36	0.41	0.70	0.52	0.47	0.72	0.69	1.00	0.85
	9	0.53	0.17	0.82	0.82	0.53	0.82	0.67	0.85	1.00

Table 4.3 Key to Tables 4.4 to 4.13, 4.15, 4.16, 5.5 and 5.6

Number	Species Group	Common Name
1	Sharks	Sharks
2	Rays	Rays
3	*Saurida* spp.	Lizard fish
4	Tachysuridae	Cat fish
5	*Priacanthus* spp.	Big eye
6	Carangidae	Trevally
7	Lutianidae	Snapper
8	*Nemipterus* spp.	Threadfin bream
9	Gerridae + Leiognathidae	Slipmouth
10	*Scolopsis* spp.	Monocle bream
11	Mullidae	Goat fish
12	*Scomberomorus* spp.	Mackerel
13	*Sepia* + *Loligo* spp.	Squid
14	Crabs	Crabs
15	Other good fish	Other groundfish
16	Scrap fish	Scrap fish

Table 4.4 Correlation coefficient matrix - All areas

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.9	.8	.9	.3	.8	.7	.9	.8	.9	.9	.1	-.6	-.5	.8	.7
2	.9	1.0	.8	1.9	.2	.9	.4	.9	.9	.9	.8	.0	-.7	-.4	.9	.9
3	.8	.8	1.0	.9	.5	1.0	.4	.8	.9	.9	.9	.2	-.6	-.3	.9	.9
4	.9	1.0	.9	1.0	.3	.9	.3	.9	1.0	.9	.9	.0	-.7	-.5	1.0	1.0
5	.3	.2	.5	.3	1.0	.5	.5	.3	.3	.4	.5	.5	-.1	-.4	.4	.2
6	.8	.9	1.0	.9	.5	1.0	.5	.9	.9	1.0	.9	.3	-.6	-.5	1.0	.9
7	.7	.4	.4	.3	.5	.5	1.0	.6	.2	.5	.5	.6	-.2	-.5	.3	.2
8	.9	.9	.8	.9	.3	.9	.6	1.0	.8	.9	.9	.0	-.7	-.4	.9	.8
9	.8	.9	.9	1.0	.3	.9	.2	.8	1.0	.9	.9	.0	-.7	-.5	1.0	1.0
10	.9	.9	.9	.9	.4	1.0	.5	.9	.9	1.0	.9	.2	-.6	-.4	.9	.9
11	.9	.8	.9	.9	.5	.9	.5	.9	.9	.9	1.0	.2	-.6	-.6	1.0	.8
12	.1	.0	.2	.0	.5	.3	.6	.0	.0	.2	.2	1.0	.2	-.3	.0	.0
13	-.6	-.7	-.6	-.7	-.1	-.6	-.2	-.7	-.7	-.6	-.6	.2	1.0	.6	-.7	.6
14	-.5	-.4	-.3	-.5	-.4	-.5	-.5	-.4	-.5	-.4	-.6	-.3	.6	1.0	-.5	-.3
15	.8	.9	.9	1.0	.4	1.0	.3	.9	1.0	.9	1.0	.0	-.7	-.5	1.0	.9
16	.7	.9	.9	1.0	.2	.9	.2	.8	1.0	.9	.8	.0	-.6	-.3	.9	1.0

* See Table 4.3 for key to species numbers

Table 4.5 Correlation matrix - Area 1

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.7	.8	.6	.4	.8	.1	.8	.7	.6	.8	.4	-.4	.4	.8	-.0
2	.7	1.0	.9	1.0	.5	.9	.5	.9	.9	.9	.9	-.1	-.5	.5	.9	.3
3	.8	.9	1.0	.8	.5	1.0	.2	1.0	1.0	.8	1.0	.2	-.3	.7	1.0	.3
4	.6	1.0	.8	1.0	.6	.8	.7	.8	.8	.9	.7	-.1	-.5	.3	.8	.3
5	.4	.5	.5	.6	1.0	.6	.5	.5	.5	.6	.5	.3	-.5	.3	.4	.1
6	.8	.9	1.0	.8	.6	1.0	.2	1.0	1.0	.9	1.0	.1	-.3	.6	1.0	.2
7	.1	.5	.2	.7	.5	.2	1.0	.2	.2	.6	.1	-.3	-.6	-.3	.2	.2
8	.8	.9	1.0	.8	.5	1.0	.2	1.0	1.0	.8	1.0	.1	-.3	.7	1.0	.3
9	.7	.9	1.0	.8	.5	1.0	.2	1.0	1.0	.8	1.0	-.0	-.2	.6	1.0	.2
10	.6	.9	.8	.9	.6	.9	.6	.8	.8	1.0	.8	.1	-.6	.3	.8	.1
11	.8	.9	1.0	.7	.5	1.0	.1	1.0	1.0	.8	1.0	.1	-.3	.7	1.0	.2
12	.4	-.1	.2	-.1	.3	.1	-.3	.1	-.0	.1	.1	1.0	-.4	.2	-.0	-.4
13	-.4	-.5	-.3	-.5	-.5	-.3	-.6	-.3	-.2	-.6	-.3	-.4	1.0	.1	-.2	-.2
14	.4	.5	.7	.3	.3	.6	-.3	.7	.6	.3	.7	.2	.1	1.0	.6	.3
15	.8	.9	1.0	.8	.4	1.0	.2	1.0	1.0	.8	1.0	-.0	-.2	.6	1.0	.2
16	-.0	.3	.3	.3	.1	.2	.2	.3	.2	.1	.2	-.4	-.2	.3	.2	1.0

* See Table 4.3 for key to species numbers

Table 4.6 Correlation matrix - Area 2

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.8	.7	.7	.2	.8	-.1	.7	.8	.7	.7	.3	-.3	.1	.7	.4
2	.8	1.0	.9	.9	.1	.9	-.1	.9	1.0	1.0	.9	.2	-.5	.4	.9	.5
3	.7	.9	1.0	1.0	.3	1.0	.1	1.0	1.0	1.0	1.0	.1	-.4	.6	1.0	.6
4	.7	.9	1.0	1.0	.2	1.0	-.1	1.0	1.0	1.0	1.0	.0	-.4	.6	1.0	.6
5	.2	.1	.3	.2	1.0	.2	.4	.3	.2	.2	.1	.3	.6	-.2	.3	.2
6	.8	.9	1.0	1.0	.2	1.0	-.0	1.0	1.0	1.0	1.0	.2	-.4	.4	1.0	.5
7	-.1	-.1	.1	-.1	.4	-.0	1.0	.1	-.0	-.0	-.0	.2	.4	-.3	-.0	.0
8	.7	.9	1.0	1.0	.3	1.0	.1	1.0	1.0	1.0	1.0	.1	-.4	.5	1.0	.6
9	.8	1.0	1.0	1.0	.2	1.0	-.0	1.0	1.0	1.0	1.0	.2	-.4	.5	1.0	.5
10	.7	1.0	1.0	1.0	.2	1.0	-.0	1.0	1.0	1.0	1.0	.1	-.5	.5	1.0	.6
11	.7	.9	1.0	1.0	.1	1.0	-.0	1.0	1.0	1.0	1.0	.1	-.4	.6	1.0	.5
12	.3	.2	.1	.0	.3	.2	.2	.1	.2	.1	.1	1.0	.2	.0	.1	.5
13	-.3	-.5	-.4	-.4	.6	-.4	.4	-.4	-.4	-.5	-.4	.2	1.0	-.5	-.4	-.1
14	.1	.4	.6	.6	-.2	.4	-.3	.5	.5	.5	.6	.0	-.5	1.0	.6	.7
15	.7	.9	1.0	1.0	.3	1.0	-.0	1.0	1.0	1.0	1.0	.1	-.4	.6	1.0	.6
16	.4	.5	.6	.6	.2	.5	.0	.6	.5	.6	.5	.5	-.1	.7	.6	1.0

* See Table 4.3 for key to species numbers

Table 4.7 Correlation matrix - Area 3

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.4	.6	.1	.1	.4	.2	.6	.2	.5	.2	.4	.4	-.3	.2	.3
2	.4	1.0	.8	.9	.9	1.0	-.1	.8	1.0	1.0	1.0	-.4	.1	.0	.9	.9
3	.6	.8	1.0	.6	.7	.8	-.0	.8	.7	.8	.7	-.1	.4	.0	.6	.7
4	.1	.9	.6	1.0	1.0	.9	-.0	.7	1.0	.9	1.0	-.5	.1	.1	1.0	.9
5	.1	.9	.7	1.0	1.0	.9	-.1	.8	1.0	.9	1.0	-.5	.2	.1	.9	.9
6	.4	1.0	.8	.9	.9	1.0	.2	.8	.9	1.0	1.0	-.3	.2	-.1	1.0	1.0
7	.2	-.1	-.0	-.0	-.1	.2	1.0	.3	-.1	.1	-.1	.5	.3	-.6	.2	.3
8	.6	.8	.8	.7	.8	.8	.3	1.0	.7	.9	.7	.1	.5	-.4	.8	.8
9	.2	1.0	.7	1.0	1.0	.9	-.1	.7	1.0	.9	1.0	-.5	.1	.1	.9	.9
10	.5	1.0	.8	.9	.9	1.0	.1	.9	.9	1.0	.9	-.3	.3	-.1	.9	.9
11	.2	1.0	.7	1.0	1.0	1.0	-.1	.7	1.0	.9	1.0	-.5	.1	.1	1.0	.9
12	.4	-.4	-.1	-.5	-.5	-.3	.5	.1	-.5	-.3	-.5	1.0	.5	-.4	-.3	-.2
13	.4	.1	.4	.1	.2	.2	.3	.5	.1	.3	.1	.5	1.0	-.3	.2	.3
14	-.3	.0	.0	.1	.1	-.1	-.6	-.4	.1	-.1	.1	-.4	-.3	1.0	-.0	-.0
15	.2	.9	.6	1.0	.9	1.0	.2	.8	.9	.9	1.0	-.3	.2	-.0	1.0	1.0
16	.3	.9	.7	.9	.9	1.0	.3	.8	.9	.9	.9	-.2	.3	-.0	1.0	1.0

* See Table 4.3 for key to species numbers

Table 4.8 Correlation matrix - Area 4

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.7	.9	1.0	.4	.9	.7	.9	.9	.3	.9	-.1	-.4	-.7	.9	.9
2	.7	1.0	.5	.5	.1	.4	1.0	.8	.3	.8	.5	-.3	-.4	-.6	.5	.7
3	.9	.5	1.0	.8	.4	.9	.6	.8	.7	.4	.8	.2	-.1	-.4	.8	.7
4	1.0	.5	.8	1.0	.3	1.0	.5	.9	.9	.2	.9	-.1	-.4	-.6	1.0	.9
5	.4	.1	.4	.3	1.0	.3	.2	.2	.3	-.2	.2	.4	-.0	-.4	.3	.2
6	.9	.4	.9	1.0	.3	1.0	.4	.8	.9	.1	.9	-.1	-.4	-.6	1.0	.8
7	.7	1.0	.6	.5	.2	.4	1.0	.8	.3	.8	.4	-.1	-.2	-.5	.4	.7
8	.9	.8	.8	.9	.2	.8	.8	1.0	.7	.5	.8	-.3	-.4	-.6	.8	.9
9	.9	.3	.7	.9	.3	.9	.3	.7	1.0	-.1	.9	-.2	-.5	-.6	1.0	.8
10	.3	.8	.4	.2	-.2	.1	.8	.5	-.1	1.0	.1	-.1	.0	-.1	.1	.4
11	.9	.5	.8	.9	.2	.9	.4	.8	.9	.1	1.0	-.3	-.4	-.6	.9	.8
12	-.1	-.3	.2	-.1	.4	-.1	-.1	-.3	-.2	-.1	-.3	1.0	.5	.2	-.2	-.4
13	-.4	-.4	-.1	-.4	-.0	-.4	-.2	-.4	-.5	.0	-.4	.5	1.0	.6	-.5	-.3
14	-.7	-.6	-.4	-.6	-.4	-.6	-.5	-.6	-.6	-.1	-.6	.2	.6	1.0	-.7	-.5
15	.9	.5	.8	1.0	.3	1.0	.4	.8	1.0	.1	.9	-.2	-.5	-.7	1.0	.8
16	.9	.7	.7	.9	.2	.8	.7	.9	.8	.4	.8	-.4	-.3	-.5	.8	1.0

* See Table 4.3 for key to species numbers

Table 4.9 Correlation matrix - Area 5

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.5	.6	.7	.6	.1	.6	.6	.7	.6	.7	-.0	-.4	-.6	.4	.1
2	.5	1.0	.3	.3	.1	-.2	.7	.6	.2	.6	.2	-.1	-.6	-.3	.4	.5
3	.6	.3	1.0	.7	.7	.6	.6	.6	.6	.5	.5	.0	-.6	-.2	.7	-.0
4	.7	.3	.7	1.0	.5	.1	.3	.5	.9	.3	.8	-.1	-.5	-.6	.7	.3
5	.6	.1	.7	.5	1.0	.2	.5	.7	.5	.5	.6	-.1	-.6	-.5	.3	-.2
6	.1	-.2	.6	.1	.2	1.0	.4	.2	.0	.3	.1	.4	-.1	.1	.4	-.6
7	.6	.7	.6	.3	.5	.4	1.0	.8	.2	.8	.4	-.1	-.6	-.2	.4	-.1
8	.6	.6	.6	.5	.7	.2	.8	1.0	.5	.9	.7	-.4	-.7	-.4	.5	-.1
9	.7	.2	.6	.9	.5	.0	.2	.5	1.0	.4	.9	-.1	-.4	-.6	.7	.2
10	.6	.6	.5	.3	.5	.3	.8	.9	.4	1.0	.7	-.2	-.5	-.4	.5	-.3
11	.7	.2	.5	.8	.6	.1	.4	.7	.9	.7	1.0	-.1	-.5	-.7	.6	-.1
12	-.0	-.1	.0	-.1	-.1	.4	-.1	-.4	-.1	-.2	-.1	1.0	.0	-.2	.1	-.1
13	-.4	-.6	-.6	-.5	-.6	-.1	-.6	-.7	-.4	-.5	-.5	.0	1.0	.6	-.8	-.0
14	-.6	-.3	-.2	-.6	-.5	.1	-.2	-.4	-.6	-.4	-.7	-.2	.6	1.0	-.5	-.0
15	.4	.4	.7	.7	.3	.4	.4	.5	.7	.5	.6	.1	-.8	-.5	1.0	.0
16	.1	.5	-.0	.3	-.2	-.6	-.1	-.1	.2	-.3	-.1	-.1	-.0	-.0	.0	1.0

* See Table 4.3 for key to species numbers

Table 4.10 Correlation matrix - Area 6

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.7	.4	.7	-.3	.3	.3	.5	.7	.8	.9	.3	-.5	-.3	.8	.8
2	.7	1.0	-.2	.7	-.3	-.1	-.1	-.1	.8	.7	.7	-.2	-.4	-.5	.9	.9
3	.4	-.2	1.0	.2	.3	.6	.2	.2	.3	.4	.2	.3	-.0	-.0	-.0	-.1
4	.7	.7	.2	1.0	-.3	.6	.4	-.0	.8	.6	.7	.4	-.7	-.4	.8	.6
5	-.3	-.3	.3	-.3	1.0	.1	-.1	-.1	-.2	-.3	-.1	-.4	.7	.4	-.3	-.2
6	.3	-.1	.6	.6	.1	1.0	.5	.1	.3	.3	.1	.4	-.5	-.0	.2	-.1
7	.3	-.1	.2	.4	-.1	.5	1.0	.5	-.1	-.1	.4	.7	-.1	.4	.0	-.0
8	.5	-.1	.2	-.0	-.1	.1	.5	1.0	-.2	.0	.4	.5	-.0	.3	.0	.1
9	.7	.8	.3	.8	-.2	.3	-.1	-.2	1.0	.9	.6	.0	-.5	-.7	.9	.8
10	.8	.7	.4	.6	-.3	.3	-.1	.0	.9	1.0	.6	.0	-.5	-.6	.7	.7
11	.9	.7	.2	.7	-.1	.1	.4	.4	.6	.6	1.0	.3	-.2	-.1	.8	.8
12	.3	-.2	.3	.4	-.4	.4	.7	.5	.0	.0	.3	1.0	-.4	-.0	.0	-.0
13	-.5	-.4	-.0	-.7	.7	-.5	-.1	-.0	-.5	-.5	-.2	-.4	1.0	.5	-.6	-.2
14	-.3	-.5	-.0	-.4	.4	-.0	.4	.3	-.7	-.6	-.1	-.0	.5	1.0	-.5	-.5
15	.8	.9	-.0	.8	-.3	.2	.0	.0	.9	.7	.8	.0	-.6	-.5	1.0	.9
16	.8	.9	-.1	.6	-.2	-.1	-.0	.1	.8	.7	.8	-.0	-.2	-.5	.9	1.0

* See Table 4.3 for key to species numbers

Table 4.11 Correlation matrix - Area 7

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.3	-.5	.4	-.0	.6	.3	.2	.5	.1	.0	.5	-.3	-.5	.6	.0
2	.3	1.0	.3	.8	-.4	.3	.1	.1	.8	-.1	.7	-.2	-.5	-.6	.7	.8
3	-.5	.3	1.0	.1	-.0	-.1	-.2	-.2	.2	.0	.4	-.2	.0	.2	-.2	.6
4	.4	.8	.1	1.0	-.0	.4	.4	.3	.5	-.2	.7	.0	-.3	-.6	.9	.5
5	-.0	-.4	-.0	-.0	1.0	.1	.0	.2	-.4	.2	.0	-.0	.8	.2	-.3	-.4
6	.6	.3	-.1	.4	.1	1.0	.4	.3	.6	.5	-.1	.6	-.3	-.0	.5	.3
7	.3	.1	-.2	.4	.0	.4	1.0	.8	-.0	.4	-.2	.2	.1	.0	.3	.3
8	.2	.1	-.2	.3	.2	.3	.8	1.0	-.1	.6	.0	-.2	.2	.2	.3	.3
9	.5	.8	.2	.5	-.4	.6	-.0	-.1	1.0	.2	.5	.2	-.6	-.5	.6	.6
10	.1	-.1	.0	-.2	.2	.5	.4	.6	.2	1.0	-.3	.1	.2	.6	-.1	.3
11	.0	.7	.4	.7	.0	-.1	-.2	.0	.5	-.3	1.0	-.5	-.2	-.6	.5	.5
12	.5	-.2	-.2	.0	-.0	.6	.2	-.2	.2	.1	-.5	1.0	-.3	.1	.1	-.1
13	-.3	-.5	.0	-.3	.8	-.3	.1	.2	-.6	.2	-.2	-.3	1.0	.3	-.5	-.4
14	-.5	-.6	2	-.6	.2	-.0	.0	.2	-.5	.6	-.6	.1	.3	1.0	-.6	-.2
15	.6	.7	-.2	.9	-.3	.5	.3	.3	.6	-.1	.5	.1	-.5	-.6	1.0	.4
16	.0	.8	.6	.5	-.4	.3	.3	.3	.6	.3	.5	-.1	-.4	-.2	.1	1.0

* See Table 4.3 for key to species numbers

Table 4.12 Correlation matrix - Area 8

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.8	.6	.8	-.0	.5	.5	.8	.8	.0	.5	.6	-.6	-.4	.7	.4
2	.8	1.0	.6	.7	-.2	.2	.5	.9	1.0	.1	.4	.7	-.6	-.6	.6	.7
3	.6	.6	1.0	.6	.5	.4	.7	.8	.6	.2	.7	.7	-.5	-.4	.9	.7
4	.8	.7	.6	1.0	.2	.7	.7	.7	.7	.2	.8	.7	-.5	-.6	.6	.2
5	-.0	-.2	.5	.2	1.0	.6	.5	.1	-.2	.6	.5	-.0	.0	.3	.2	-.1
6	.5	.2	.4	.7	.6	1.0	.8	.4	.1	.7	.7	.5	-.1	-.3	.5	.1
7	.5	.5	.7	.7	.5	.8	1.0	.7	.4	.6	.9	.7	-.3	-.5	.8	.4
8	.8	.9	.8	.7	.1	.4	.7	1.0	.9	.2	.7	.8	-.6	-.7	.8	.7
9	.8	1.0	.6	.7	-.2	.1	.4	.9	1.0	-.1	.5	.7	-.7	-.7	.6	.6
10	.0	.1	.2	.2	.6	.7	.6	.2	-.1	1.0	.3	.1	.2	-.0	.2	.1
11	.5	.4	.7	.8	.5	.7	.9	.7	.5	.3	1.0	.6	-.5	-.5	.7	.2
12	.6	.7	.7	.7	-.0	.5	.7	.8	.7	.1	.6	1.0	-.5	-.7	.8	.8
13	-.6	-.6	-.5	-.5	.0	-.1	-.3	-.6	-.7	.2	-.5	-.5	1.0	.3	-.5	-.4
14	-.4	-.6	-.4	-.6	.3	-.3	-.5	-.7	-.7	-.0	-.5	-.7	.3	1.0	-.5	-.4
15	.7	.6	.9	.6	.2	.5	.8	.8	.6	.2	.7	.8	-.5	-.5	1.0	.7
16	.4	.7	.7	.2	-.1	.1	.4	.7	.6	.1	.2	.8	-.4	-.4	.7	1.0

* See Table 4.3 for key to species numbers

Table 4.13 Correlation matrix - Area 9

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	.4	.3	.3	.5	.5	.5	.6	.2	.5	.5	-.1	-.4	-.5	.7	.2
2	.4	1.0	-.1	1.0	-.3	.2	.0	.2	.9	.4	.2	-.1	-.5	-.6	.3	.9
3	.3	-.1	1.0	-.1	.4	.4	.4	.7	-.1	.7	.6	.2	-.3	-.3	.5	.1
4	.3	1.0	-.1	1.0	-.4	.1	-.1	.1	1.0	.3	.1	-.1	-.5	-.5	.3	.9
5	.5	-.3	.4	-.4	1.0	.4	.6	.5	-.4	.3	.5	-.1	.1	-.2	.6	-.3
6	.5	.2	.4	.1	.4	1.0	.9	.8	.0	.8	.9	.3	-.7	-.6	.8	.1
7	.5	.0	.4	-.1	.6	.9	1.0	.8	-.1	.8	.9	.3	-.6	-.6	.7	.0
8	.6	.2	.7	.1	.5	.8	.8	1.0	.1	.9	1.0	.3	-.7	-.7	.8	.3
9	.2	.9	-.1	1.0	-.4	.0	-.1	.1	1.0	.3	.1	-.2	-.5	-.6	.2	.9
10	.5	.4	.7	.3	.3	.8	.8	.9	.3	1.0	.9	.4	-.8	-.6	.8	.4
11	.5	.2	.6	.1	.5	.9	.9	1.0	.1	.9	1.0	.4	-.7	-.7	.7	.3
12	-.1	-.1	.2	-.1	-.1	.3	.3	.3	-.2	.4	.4	1.0	-.4	.3	.1	.2
13	-.4	-.5	-.3	-.5	.1	-.7	-.6	-.7	-.5	-.8	-.7	-.4	1.0	.7	-.6	-.5
14	-.5	-.6	-.3	-.5	-.2	-.6	-.6	-.7	-.6	-.6	-.7	.3	.7	1.0	-.5	-.5
15	.7	.3	.5	.3	.6	.8	.7	.8	.2	.8	.7	.1	-.6	-.5	1.0	.2
16	.2	.9	.1	.9	-.3	.1	.0	.3	.9	.4	.3	.2	-.5	-.5	.2	1.0

* See Table 4.3 for key to species numbers

Table 4.14 Percentage of the variance explained by the 1st and 2nd principle components. Gulf of Thailand groundfish survey - 1963, 1966-75

Area	1st component	1st + 2nd component
All areas	70%	83%
1	62%	76%
2	64%	78%
3	63%	81%
4	60%	75%
5	47%	61%
6	45%	64%
7	35%	55%
8	56%	75%
9	49%	74%

Table 4.15 1st eigen vector of principle component analysis carried out on the catch rates of 16 species groups reported by the Gulf of Thailand trawl survey - 1963, 1966-75.

Species*	All areas	1	2	3	4	5	6	7	8	9
1	.27	.25	.23	.12	.32	.30	.34	.24	.27	.24
2	.28	.30	.30	.31	.23	.20	.32	.39	.28	.17
3	.28	.31	.31	.25	.27	.28	.08	.05	.28	.21
4	.29	.28	.31	.30	.31	.29	.32	.35	.28	.15
5	.13	.20	.06	.30	.10	.27	-.14	-.17	.06	.13
6	.29	.31	.31	.31	.30	.11	.12	.22	.20	.31
7	.15	.12	-.02	.02	.22	.26	.06	.11	.28	.29
8	.28	.31	.31	.27	.31	.31	.05	.08	.32	.33
9	.28	.30	.31	.30	.28	.28	.34	.35	.27	.15
10	.29	.29	.31	.31	.10	.28	.31	-.01	.08	.34
11	.29	.31	.31	.31	.29	.31	.30	.26	.27	.33
12	.04	.03	.05	-.11	-.08	-.03	.10	.03	.29	.09
13	-.21	-.14	-.14	.08	-.15	-.28	-.23	-.27	-.21	-.30
14	-.16	.19	.18	.00	-.22	-.23	-.21	-.27	-.22	-.28
15	.29	.30	.31	.30	.31	.28	.35	.37	.30	.30
16	.27	.09	.19	.30	.29	-.00	.31	.31	.22	.18

* See Table 4.3 for the species key

Table 4.16 2nd eigen vector of principle component analysis carried out on the catch rates of 16 species groups reported by the Gulf of Thailand trawl survey - 1963, 1966-75

Species*	All Areas	1	2	3	4	5	6	7	8	9
1	.04	-.16	.08	.35	.03	-.10	.12	.29	-.11	-.01
2	-.14	.12	-.04	-.05	-.42	-.14	-.24	-.15	-.24	.41
3	.00	-.15	.06	.11	.01	.16	.27	-.25	.09	-.19
4	-.14	.28	-.01	-.13	.13	-.27	.12	.00	.08	.44
5	.47	.21	.54	-.11	.17	.08	.01	.15	.49	-.32
6	.06	-.09	.05	.03	.19	.56	.34	.39	.40	-.15
7	.48	.60	.46	.42	-.44	.26	.49	.39	.28	-.22
8	-.03	-.13	.06	.26	-.16	.09	.37	.36	-.09	-.14
9	-.16	-.09	.02	-.14	.30	-.26	-.13	-.02	-.30	.44
10	.03	.20	-.02	.05	-.59	.21	-.06	.38	.43	-.05
11	.05	-.17	-.02	-.12	.16	-.09	.11	-.30	.22	-.13
12	.57	-.20	.36	.49	.09	.17	.44	.30	-.07	-.09
13	.17	-.38	.51	.37	-.07	.01	-.08	.09	.21	-.11
14	-.24	-.38	-.26	-.41	-.07	.18	.26	.18	.13	-.13
15	-.08	-.12	.03	-.00	.19	.03	-.11	.09	.04	-.10
16	-.20	.12	.09	.05	-.09	-.54	-.17	-.04	-.18	.38

* See Table 4.3 for species key

Table 4.17 1st and 2nd eigen vectors obtained from a principle component analysis of catch along the Indian Ocean coast of Thailand from 1966-71

Leiognathidae	.35	-.18
Mullidae	.36	-.09
Sciaenidae	.36	.09
Tachysuridae	.37	.01
Caranx malabaricus	.36	-.04
Nemipteridae	.25	-.13
Sphyraenidae	.33	-.34
Synodontidae	.32	.25
Priacanthus tayenus	-.26	-.31
Trichiurus dorab	.08	.81

Data from Malacca Strait workshop report.

Table 4.18 Proportion of *Priacanthus tayenus* at various depths in Area I, 1972

Dept Range (m) of Stations	30-34	35-39	40-44	45-49	50-54	55-59
No. Stations	1	4	6	2	3	1
No. fish samples	98	241	425	125	247	25
No. fish $\leq$ 15 cm	38	78	122	29	61	2
% of fish $\leq$ 15 cm	39%	32%	29%	23%	25%	8%

Table 4.19 Length distribution of *L. lineolatus* in Area III

Length cm.	Year 1969	1972	1973	1974
8.0				8
8.5				21
9.0				52
9.5			1	33
10.0			2	12
10.5		1	5	3
11.0		6	39	1
11.5		4	51	
12.0		37	64	
12.5		59	61	
13.0		104	85	
13.5	2	132	70	
14.0	10	141	43	
14.5	8	87	34	
15.0	17	47	24	
15.5	19	35	14	
16.0	10	17	14	
16.5	10	12	7	
17.0	5	4	5	
17.5	0	4	3	
18.0	1	1	3	
18.5	1	0	2	
19.0	0	1		
19.5	0			
20.0	1			

Table 4.20 Estimation of total mortality from length distributions of Priacanthus tayenus in Area V of the Gulf of Thailand; assuming the modes seen on Fig. 4.21 represent distinct year classes

Number in length samples

Length Range		Years						
		66	67	68	69	70	73	74
A	≤ 8.0	30	306	107	36	626	1120	806
B	8.5-13.0	139	411	468	283	227	89	2226
C	13.5-18.0	2291	702	573	479	1069	1329	216
D	18.5-21.0	943	682	266	285	85	51	32
E	21.5 +	262	104	79	60	46	4	16

Numbers corrected by sampling intensity to number per haul

A	≤ 8.0	.84	19.12	17.36	2.79	48.59	36.73	45.78
B	8.5-13.0	3.90	25.68	47.78	21.94	17.62	2.92	126.40
C	13.5-18.0	64.24	43.86	58.50	37.13	82.98	43.58	12.27
D	18.5-21.0	26.44	42.80	27.16	22.09	6.60	1.67	1.82
E	21.5 +	7.35	6.50	8.07	4.65	3.57	.13	.91

Estimated total mortality assuming 1 yr lag for each length group

A	≤ 8.0							
B	8.5-13.0		-3.4	-.9	-.2	-1.8		-1.2
C	13.5-18.0		-2.4	-.8	.3	-1.3		-1.4
D	18.5-21.0		.4	.5	1.0	1.7		3.2
E	21.5 +		1.4	1.7	1.8	1.8		.6
Average D and E			.9	1.1	1.4	1.8		1.9

Table 4.21 Average price of fresh sea fishes auctioned at the fish marketing organisation of Thailand.

Species	66	67	71	72	73
Chub mackerel L)	)	)	5.5	7.0	9.0
M)	4.0)	4.0)	4.0	5.0	5.0
S)	)	)	2.5	4.5	3.0
Indian mackerel	-	-	4.0	4.5	4.5
Spanish mackerel	8.0	7.0	8.0	8.0	14.0
Bonito	3.5	2.5	2.5	3.0	4.0
Pampano (<u>Caranx</u>)	5.0	5.0	5.0	5.0	5.0
Pampano (<u>Megalaspis</u>)	3.0	2.5	2.0	3.5	3.0
Silvery Lacterid	12.0	10.5	20.0	22.0	18.0
Dorab	7.5	6.5	6.0	6.0	5.0
Hairtail	4.0	3.5	3.0	4.0	3.5
Barracuda	7.5	6.5	6.0	6.0	7.0
Yellowtail	11.0	10.0	9.0	8.0	[illegible]0.0
Black Pomfret	7.0	7.5	9.0	11.0	[illegible]2.0
Silver Pomfret	24.0	26.5	32.0	28.0	[illegible]0.0
Sea Bass	13.0	14.5	18.0	20.0	20.0
Snapper	10.0	9.0	9.0	10.0	12.0
Threadfin Bream	-	-	3.0	3.0	3.5
Monocle Bream	-	-	1.0	1.5	1.5
Lizard fish			2.0	2.0	2.5
Trigger fish			1.0	1.0	1.0
Threadfin			12.0	12.0	15.0
Ray			1.0	1.5	1.5
Marine Catfish			3.0	3.0	3.0
Jew fish			3.5	4.0	5.0
Shark			2.5	2.5	2.5
Big eye			2.0	2.0	2.0
Squid and Cuttlefish			4	5	8

Table 5.1 Average catch rate of various species groups (1963, 1966-75)

Species	All Areas	Area 1	2	3	4	5	6	7	8	9
Sharks	.91	.70	.87	.98	.99	.54	.37	1.01	1.07	1.35
Rays	3.93	1.15	1.08	3.54	2.50	1.43	3.68	6.94	9.84	6.51
Sauridae	4.62	6.09	2.82	2.55	6.01	7.52	4.57	3.26	3.53	4.32
Tachysuridae	1.84	1.08	.80	0.21	1.26	0.78	0.97	1.46	4.01	4.50
Priacanthus	4.98	6.03	4.11	4.14	5.81	7.25	2.52	3.51	5.08	7.02
Carangidae	7.49	7.16	5.07	8.98	9.93	5.84	7.70	4.67	8.93	7.61
Lutjanidae	2.03	2.91	1.27	1.64	1.57	1.59	1.10	1.60	2.19	4.36
Nemipterus	8.43	6.71	3.87	5.24	10.93	13.64	9.22	5.49	10.81	9.44
Gerridae + Leiognathus	16.09	20.56	8.05	2.53	4.84	14.20	27.56	23.74	21.81	18.15
Scolopsis	2.79	2.40	2.70	3.78	2.77	0.59	0.24	0.54	3.82	6.88
Mullidae	5.20	5.19	1.83	2.98	2.96	7.74	3.30	4.58	10.52	8.72
Scomberomorus	0.54	0.41	0.46	0.29	0.64	0.93	0.47	0.90	0.44	0.27
Sepia + Loligo	12.20	7.02	1.04	21.75	18.82	17.06	8.91	8.49	8.41	8.67
Crabs	0.98	0.60	0.95	1.01	1.18	1.16	2.24	0.72	0.53	0.60
Other good fish	11.66	10.84	6.65	7.93	11.42	11.82	17.33	14.18	14.92	12.68
Scrap fish	15.06	9.39	6.35	8.94	15.62	23.32	22.88	16.11	19.27	15.85

Table 5.2 Averages by strata and an analysis of variance for Rays and Skates caught in the Gulf of Thailand survey.

Depths m.		20-30	31-44							
		2.47	2.25							
Areas	1	2	3	4	5	6	7	8	9	
	.64	.61	2.06	2.70	.86	1.42	2.14	6.11	4.70	
Years	66	67	68	69	70	71	72	73	74	75
	8.07	4.27	2.00	2.20	1.71	1.30	.68	1.31	1.13	.92

Analysis of variance

Source of Variation	D.F.	S.Sq	M.Sq	F	Significance
Depths	1	2.13	3.12	-	-
Areas	8	578.42	72.30	15.12	xxx
Years	9	817.99	90.89	19.01	xxx
Depth x Areas	8	130.61	16.33	3.41	xx
Depth x Years	9	77.26	8.58	1.80	N.S.
Years x Areas	72	1030.29	14.31	2.99	xx
Residual	72	344.22	4.78	1.00	-

Table 5.3 Times of years the surveys were conducted in various areas of the Gulf of Thailand

Year	Areas								
	I	II	III	IV	V	VI	VII	VIII	IX
1963									
64									
65									
66	Dec	Nov-Dec	Nov	Jul-Aug	Sep	Jun-Sep	Jun	May	Apr-May
67	Dec	Nov-Dec	Nov	Aug-Sep	Sep/Oct-Nov	Sep	Jun	May	Apr-May
68	Dec	Nov-Dec	Nov	Jul-Aug	Sep	Aug-Sep	Jun	May-Jun	May
69	Dec	Nov-Dec	Nov	Jul-Aug	Sep	Aug	Jun	May-Jun	May
70	Dec	Nov-Dec	Nov	Aug	Sep	Sep	May-Jun	May	Apr-May
71	Dec	Nov-Dec	Oct-Nov	Sep	Aug-Sep	Aug	May-Jun	Apr-May	Apr
72	Dec	Nov-Dec	Oct-Nov	Sep-Oct	Aug-Sep	Aug	May-Jun	May	Apr-May
73	(Jan, Feb 74)	Dec-(Jan 74)	Nov-Dec	Oct-Nov	Jul-Aug	Jul	May-Jun	May	Apr-May
74	Dec	Nov	Oct-Nov	Sep	Jul-Sep	Jul	Jun	May,Jun	May
75									
76									

Table 5.4 Results of analysis of variance on catch rate of various species by depth, area and year

Cause	Species					
	Priacanthus	Saurida spp	Carangidae	Nemipterus	Loligo + Sepia	Leiognathus spp
Depths	xxx	xxx	N.S.	xxx	x	N.S.
Areas	xx	xxx	xxx	xxx	xxx	xxx
Years	xx	xxx	xxx	xxx	xxx	xxx
Depth x Areas	N.S.	x	xx	x	N.S.	x
Depth x Years	N.S.	x	N.S.	xxx	N.S.	N.S.
Years x Areas	N.S.	x	xx	xxx	xxx	xxx

Key: x significant P ≤ 0.05

xx very significant ≤ 0.01

xxx extremely significant ≤ 0.001

Table 5.5 Correlation matrix - All areas

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	-.1	.0	-.0	.1	.0	.0	.0	-.0	.1	.0	-.1	-.1	-.1	.1	.1
2	-.1	1.0	.0	.3	-.0	.2	-.0	-.0	.0	.1	.1	-.1	-.1	-.1	.1	.1
3	.0	.0	1.0	.1	.2	.1	.1	.5	.1	.2	.3	-.1	-.1	.2	.0	.1
4	-.0	.3	.1	1.0	.1	.2	-.1	.0	.2	.2	.2	-.1	-.2	-.1	.1	.0
5	.1	-.0	.2	.1	1.0	.1	.1	.2	.0	.3	.2	-.0	-.1	-.1	.0	.0
6	.0	.2	.1	.2	.1	1.0	.2	.1	.2	.2	.1	-.1	.1	-.0	.1	.2
7	.0	-.0	.1	-.1	.1	.2	1.0	.1	.0	.2	.1	-.1	-.0	-.1	.1	.1
8	.0	-.0	.5	.0	.2	.1	.1	1.0	.1	.2	.5	-.1	-.1	.1	.0	.1
9	-.0	.0	.1	.2	.0	.2	.0	.1	1.0	.1	.1	-.0	-.1	-.1	.0	-.0
10	.1	.1	.2	.2	.3	.2	.2	.2	.1	1.0	.1	-.2	-.2	-.1	.1	.1
11	.0	.1	.3	.2	.2	.1	.1	.5	.1	.1	1.0	-.1	-.1	-.1	.1	.0
12	-.1	-.1	-.1	-.2	-.0	-.1	.1	-.1	-.0	-.2	-.1	1.0	.1	-.1	.0	.0
13	-.1	-.1	-.1	-.2	-.1	.1	-.0	-.1	-.1	-.2	-.1	.1	1.0	-.0	-.1	-.0
14	-.1	-.1	.2	-.1	-.1	-.0	-.1	.1	-.1	-.1	-.1	-.1	-.0	1.0	-.0	.1
15	.1	.1	.0	.1	.0	.1	.1	.0	.0	.1	.1	.0	-.1	-.0	1.0	.3
16	.1	.1	.1	.0	.0	.2	.1	.1	-.0	.1	.0	.0	-.0	.1	.3	1.0

* See Table 4.3 for key to species numbers

Table 5.6 Correlation matrix - Area 1

Species No.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0	-.2	.0	-.1	.1	-.1	-.1	.1	-.0	.1	.1	-.2	-.2	-.1	.1	-.1
2	-.2	1.0	.0	-.2	-.1	-.1	-.1	.0	-.0	-.1	.1	-.2	.0	-.3	.0	-.1
3	.0	.1	1.0	.0	.3	-.0	-.0	0.6	-.1	.4	.6	-.2	-.1	-.0	.0	-.2
4	-.1	-.2	.0	1.0	.0	-.1	-.1	.1	.1	.1	.1	-.0	-.2	.0	-.1	.2
5	.1	-.1	.3	.0	1.0	.0	-.1	.6	-.0	.5	.3	-.1	-.1	.0	.3	-.1
6	-.1	-.1	-.0	-.1	.0	1.0	.8	-.0	.3	.0	.3	-.1	.2	-.1	.1	.4
7	-.1	-.1	-.0	-.1	-.1	.8	1.0	-.0	.2	.0	.3	-.1	.2	-.3	.1	.4
8	.1	.0	.6	.1	.6	-.0	-.0	1.0	-.0	.8	.5	-.1	-.2	.1	.1	-.2
9	-.0	-.0	-.1	.1	-.0	.3	.2	-.0	1.0	.0	.1	.0	.2	-.1	.0	.1
10	.1	-.1	.4	.1	.5	.0	.0	.8	.0	1.0	.3	-.1	-.2	.1	.2	-.1
11	.1	.1	.6	.1	.3	.3	.3	.5	.1	.3	1.0	-.2	-.2	.0	.1	-.1
12	-.2	-.2	-.2	-.0	-.1	-.1	-.1	-.1	.0	-.1	-.2	1.0	-.0	-.2	-.1	.0
13	-.0	.0	-.1	-.2	-.1	.2	.2	-.2	.2	-.2	-.2	-.0	1.0	-.0	.1	.1
14	-.1	-.3	-.0	.0	.0	-.1	-.3	.1	-.1	.1	.0	-.2	-.0	1.0	.1	.0
15	.1	.0	.0	-.1	.3	.1	.1	.1	.0	.2	.1	-.1	.1	.1	1.0	-.0
16	-.1	-.1	-.2	.2	-.1	.4	.4	-.2	.1	-.1	-.1	.0	.1	.0	-.0	1.0

* See Table 4.3 for key to species numbers

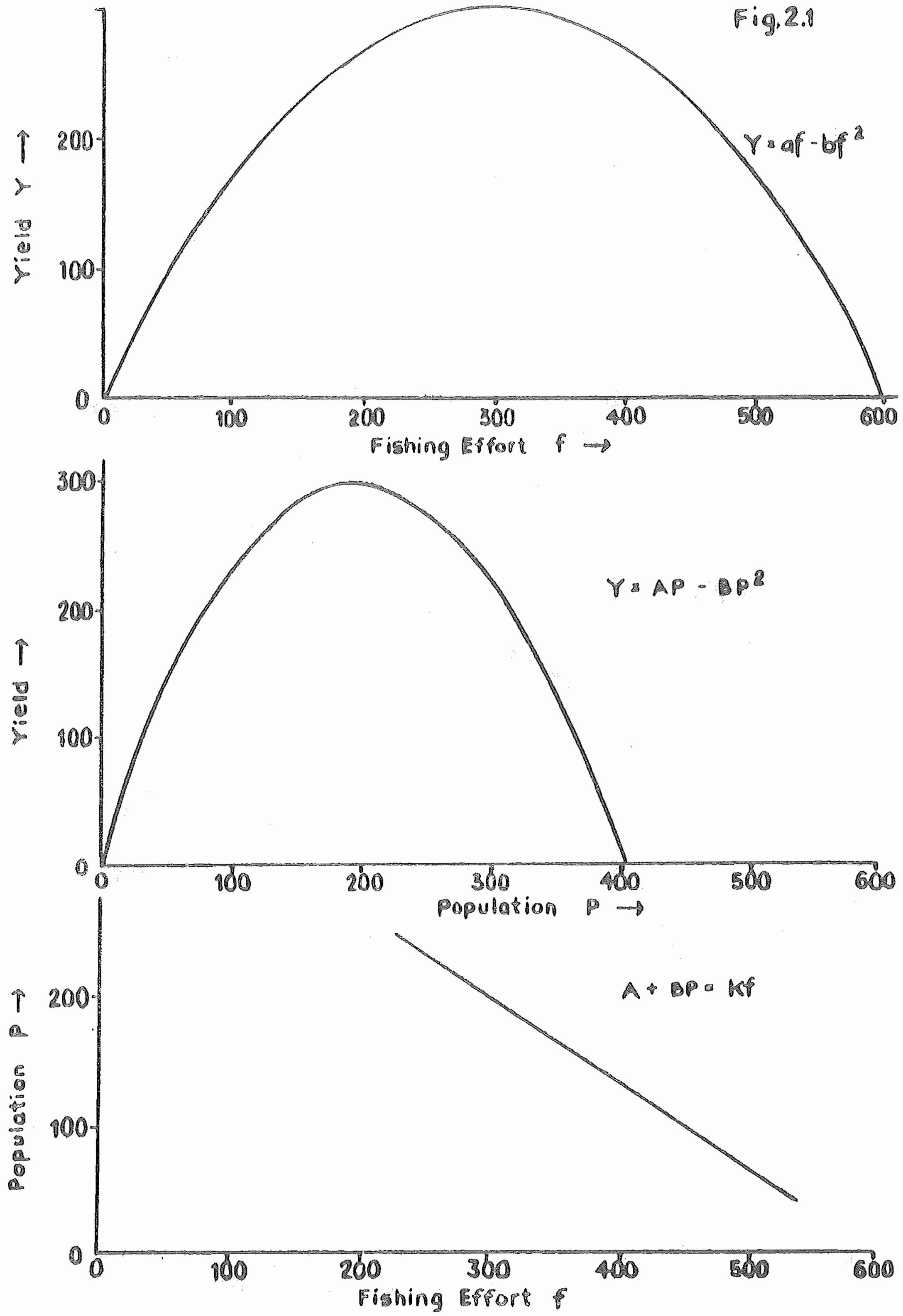
Table 5.7 Correlation of high, medium and low catch rates between Rays and Sharks in Area IX

Shark Catch rate / Ray Catch Rate	Low < 10 Kg hr	Medium 10-14 Kg hr	High > 40 Kg hr	
Low < 10 Kg hr	26	6	3	35
Medium 10-40 Kg hr	16	0	1	17
High > 40 Kg hr	6	0	0	6

Table 5.8 Catch rates of scrap fish expressed as a percentage of total catch for various gears and vessel sizes

Species	Otter board trawl			Pair trawl			Beam trawl
	< 14m	14-18m	18-25m	< 14m	14-18m	> 18m	
Rastrelliger neglectus	.39	.67	2.52	.03	3.98	10.58	-
Rastrelliger kanagurta	.09	.15	.57	-	.91	2.40	-
CARANGIDAE	.88	1.14	2.93	.43	3.42	2.42	.17
POLYNEMIDAE	-	.26	.22	-	.20	.16	-
Parastromaleus niger	.31	.32	.40	.07	.40	.37	-
Pampus argentius	.15	.17	.17	.16	.12	.31	-
Lactarius lactarius	-	.21	.08	-	.10	.13	-
Sphyraena spp.	.15	.54	2.21	2.26	1.10	1.05	-
SCIAENIDAE	5.89	3.08	4.05	15.41	5.32	6.75	2.21
Nemipteru spp.	2.92	5.53	11.57	1.67	2.43	3.25	-
Scolopsis spp.	.51	1.38	2.31	1.47	.75	.36	-
Saurida spp.	.53	4.48	7.83	.36	2.90	5.42	-
Trichiurus haumela	.08	.87	1.30	-	.47	.89	1.12
LUTIANIDAE	.29	.90	2.38	-	.29	1.46	1.00
Priacanthus tayenus	1.85	4.86	7.75	-	2.86	4.45	-
Sillago spp.	.13	.15	-	.82	.80	.17	.14
TACHYSURIDAE	.84	1.28	2.45	5.37	1.67	4.06	1.64
TRYGONI	1.57	1.97	2.53	3.40	1.72	1.94	.69
SPHYRNIDAE, CARCHA, RHINIDAE ORECTOLOBIDAE	.98	1.00	1.67	2.52	1.13	2.08	.81
Miscellaneous fish	19.17	19.41	23.61	19.54	15.18	26.55	12.62
Crustaceans	50.00	35.11	7.77	13.06	2.44	1.66	67.49
Molluscs	13.29	16.52	15.68	33.44	51.79	24.27	12.10
Trash fish as % of TOTAL catch	66.48	69.32	73.41	68.22	51.89	49.83	28.66

Fig.2.1


Yield Y →
200
100
0
0
100
200
300
400
500
600
Fishing Effort f →
Y = af - bf²
300
200
100
0
Yield →
Y = AP - BP²
0
100
200
300
400
500
600
Population P →
Population P →
200
100
0
A + BP = Kf
0
100
200
300
400
500
600
Fishing Effort f

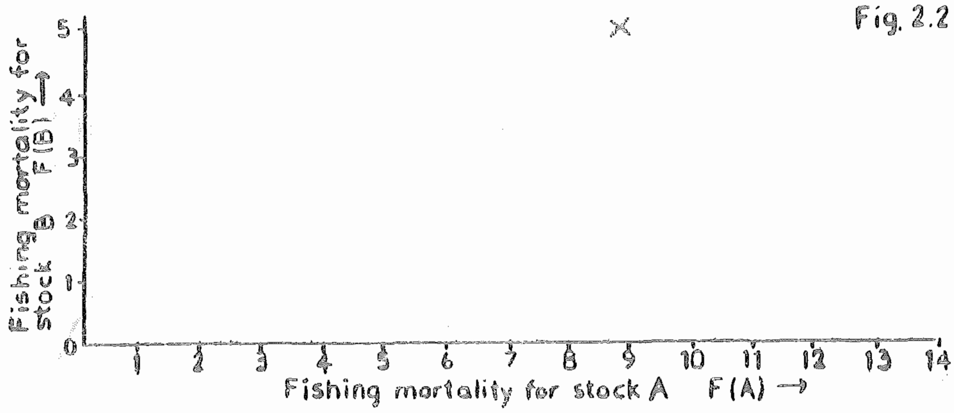


Fig. 2.2 a

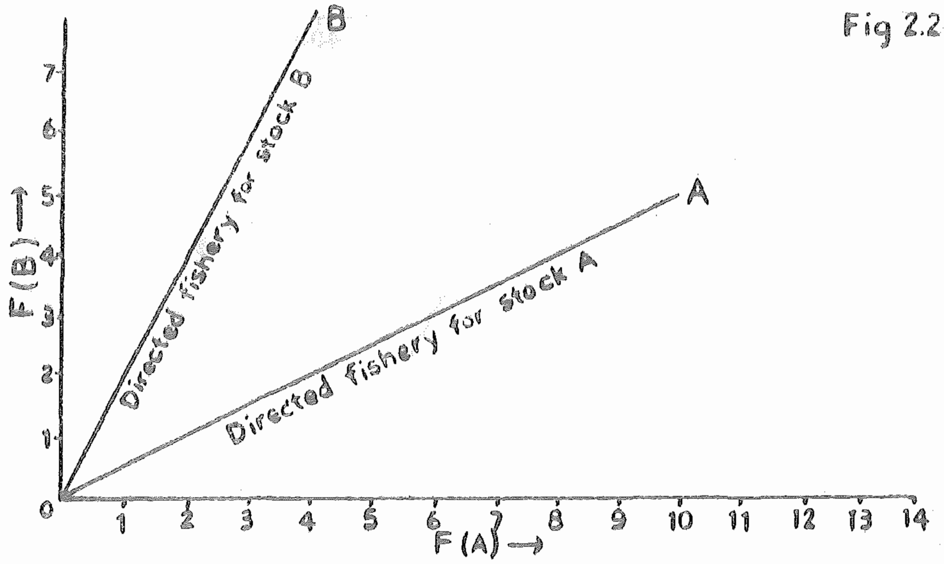


Fig 2.2 b

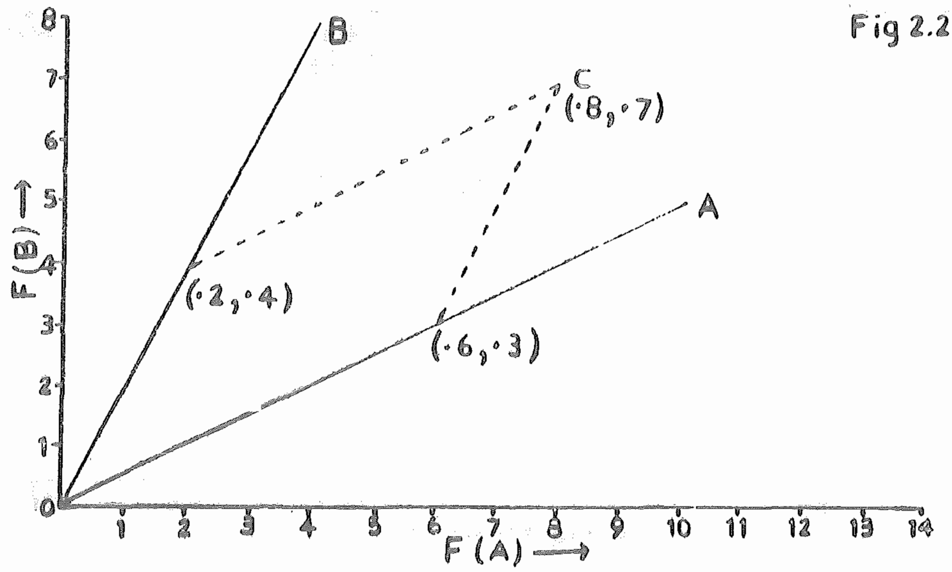


Fig 2.2 c

Fig. 2.3 a

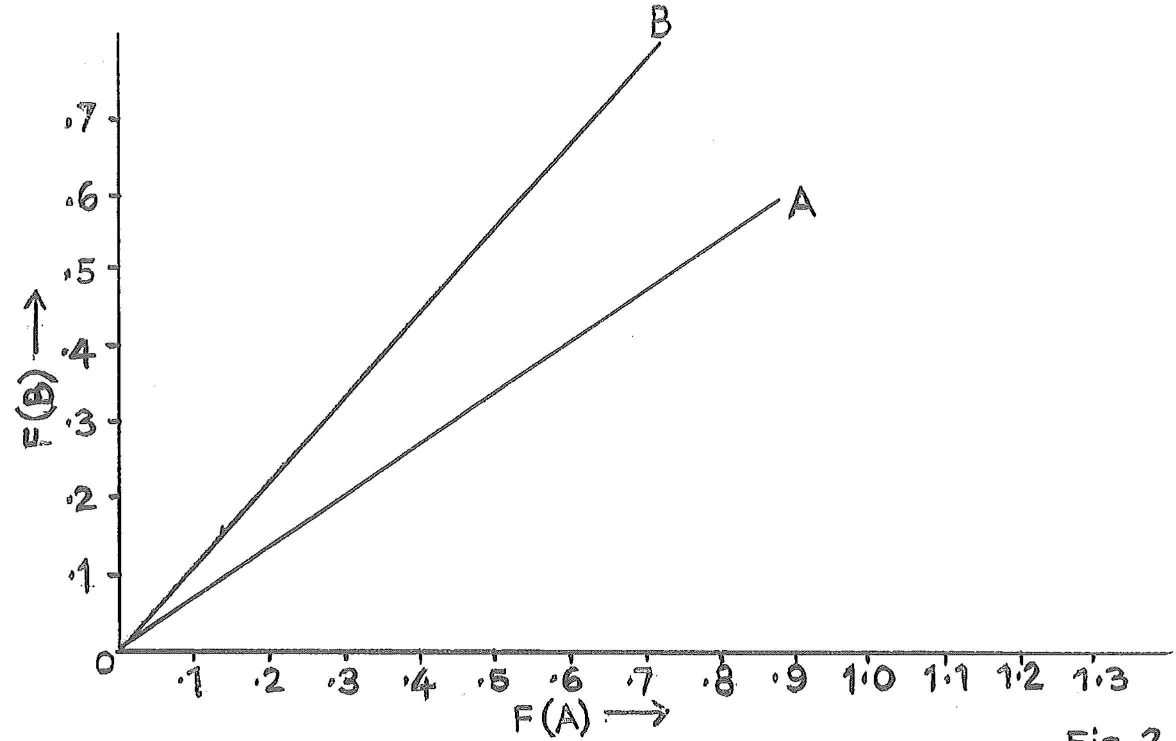


Fig 2.3b

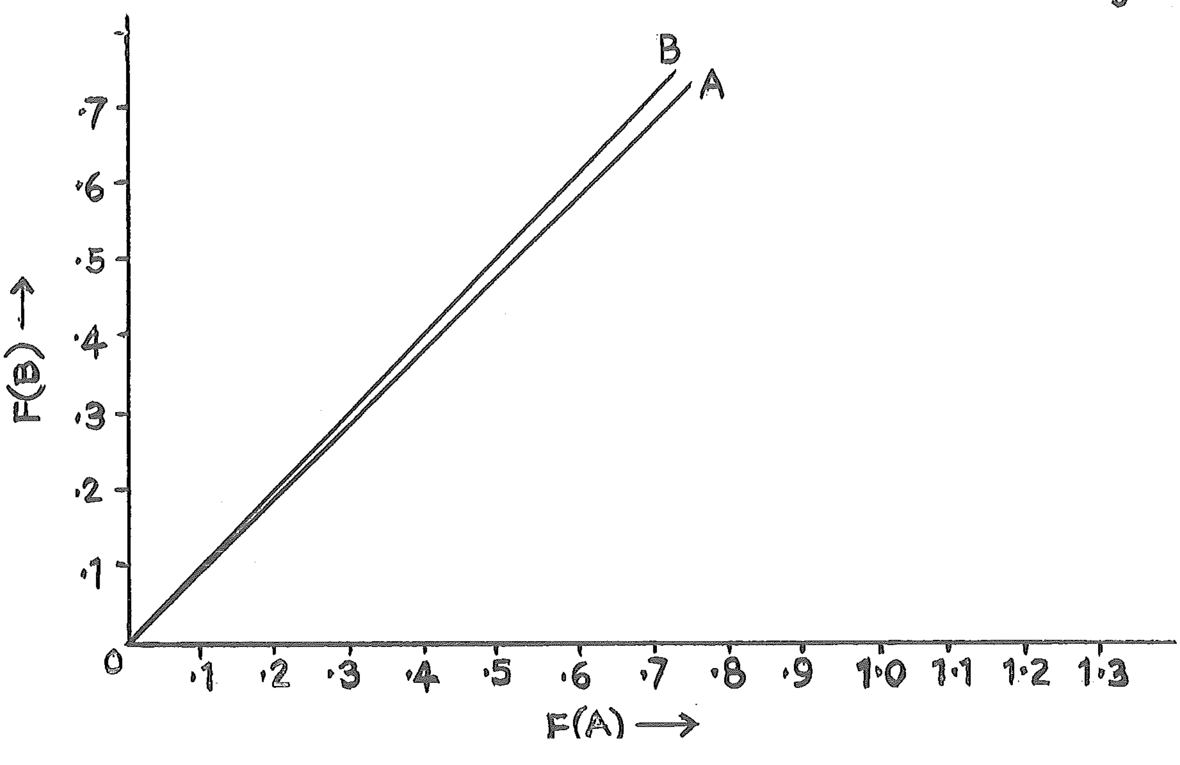


Fig.2.4a

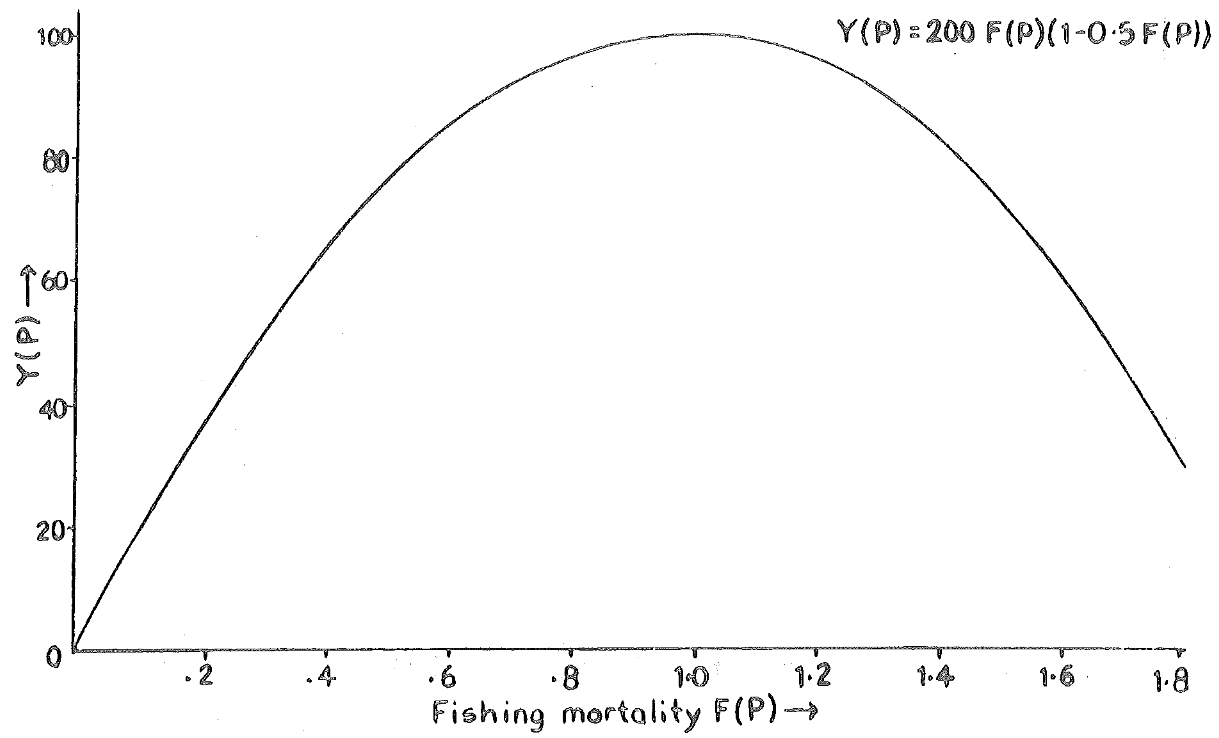


Fig 2.4b

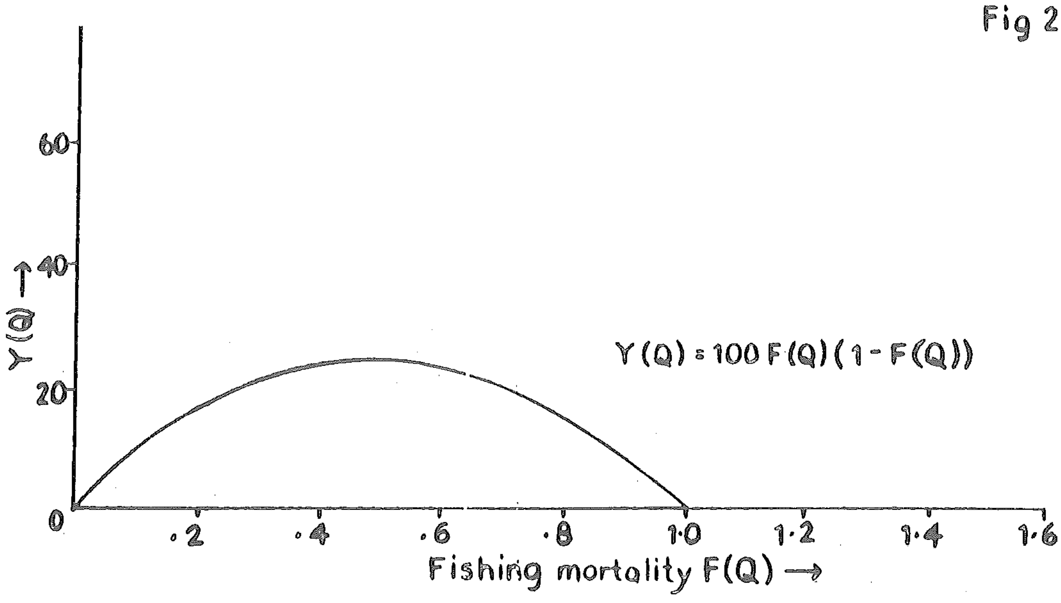


Fig. 2.5

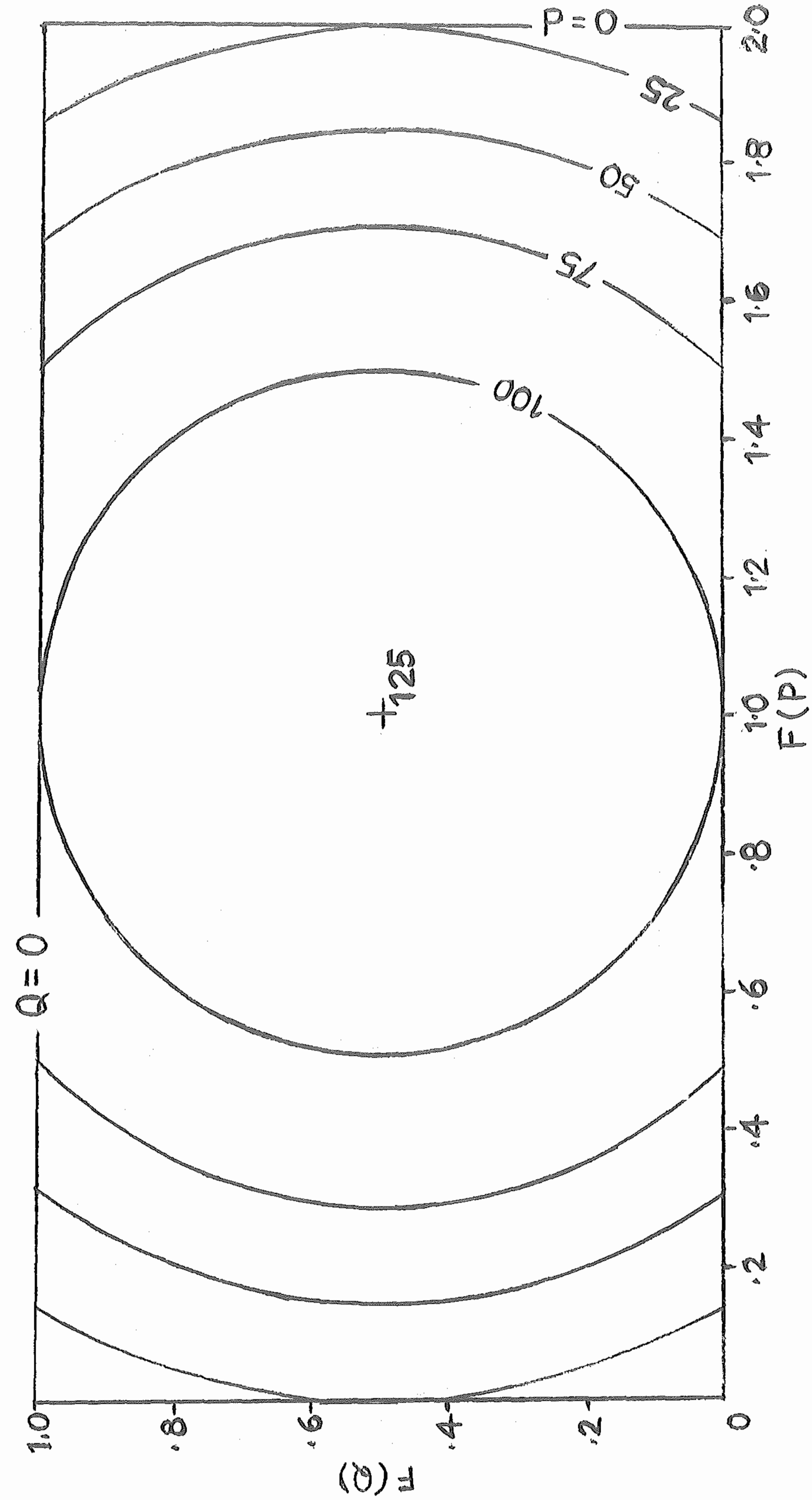


Fig. 2.6

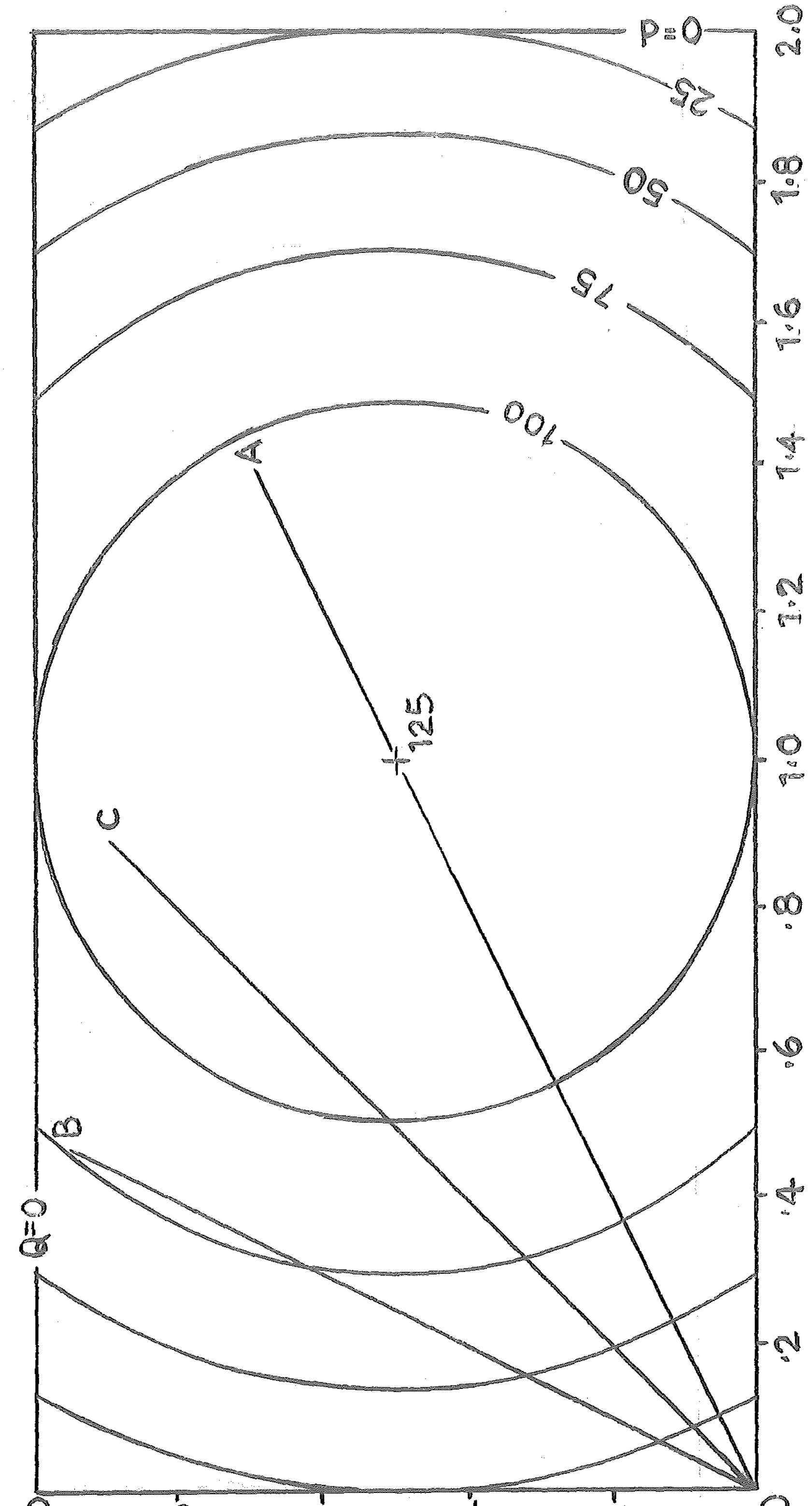
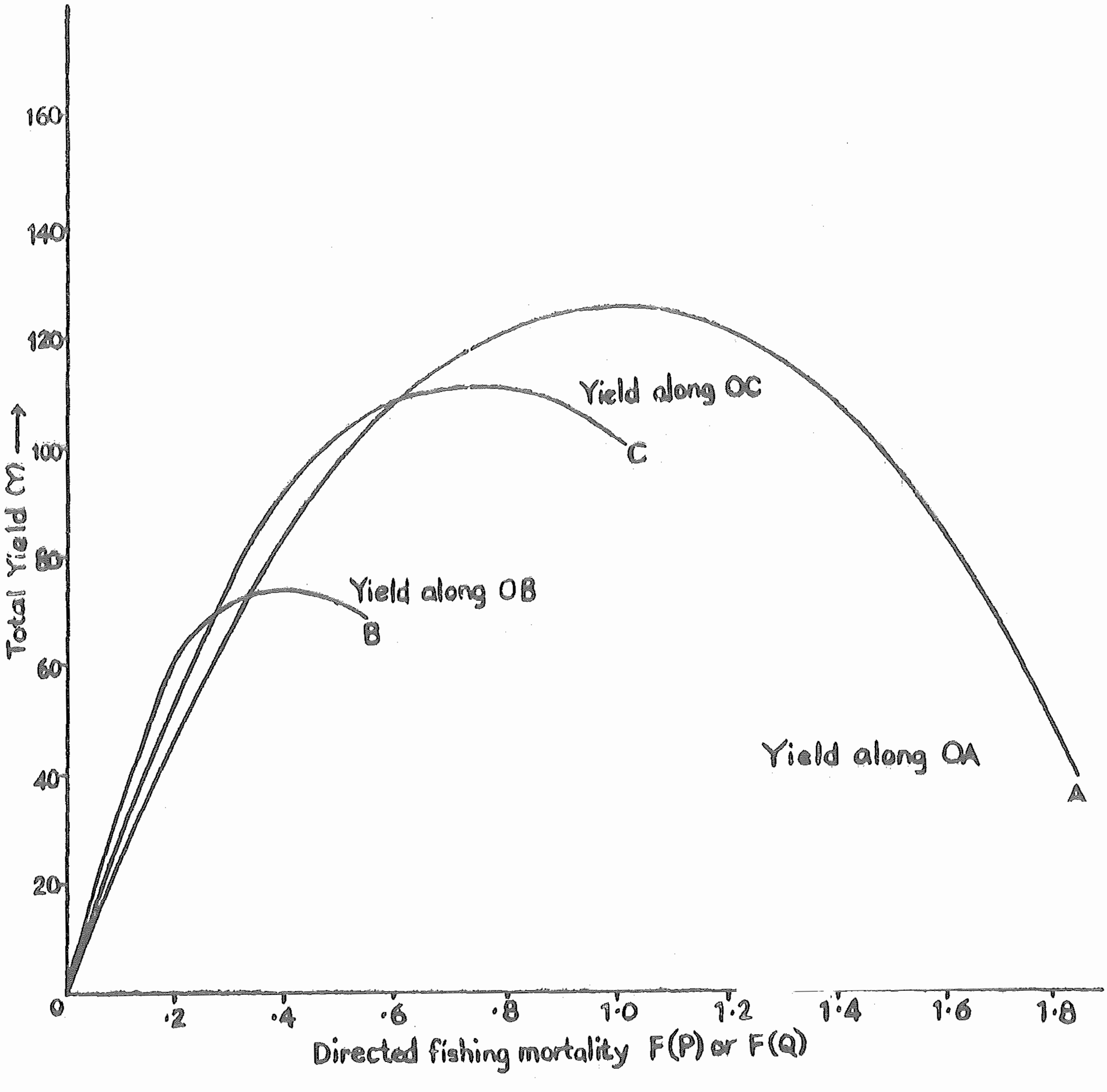


Fig. 2.7



Total Yield (Y) ⟶
160
140
120
100
80
60
40
20
0
·2
·4
·6
·8
1·0
1·2
1·4
1·6
1·8
Directed fishing mortality F(P) or F(Q)
Yield along OC
C
Yield along OB
B
Yield along OA
A

Fig. 2.8

Contours of equal yield
Weak interspecific competition

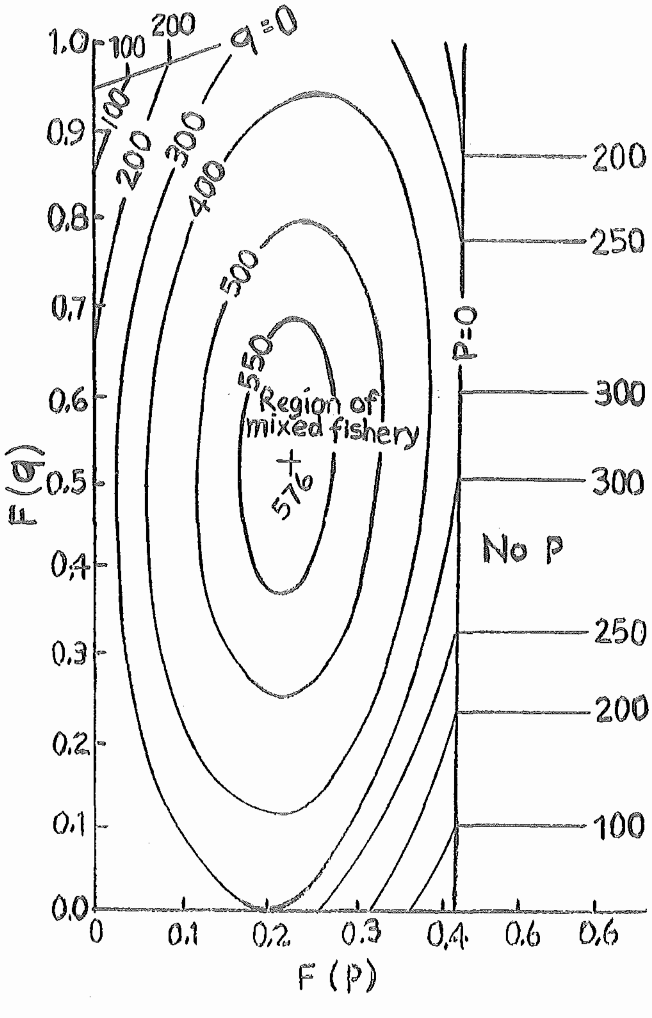


Fig. 2.9

Contours of equal yield for two species fishery
Stronger interspecific competition

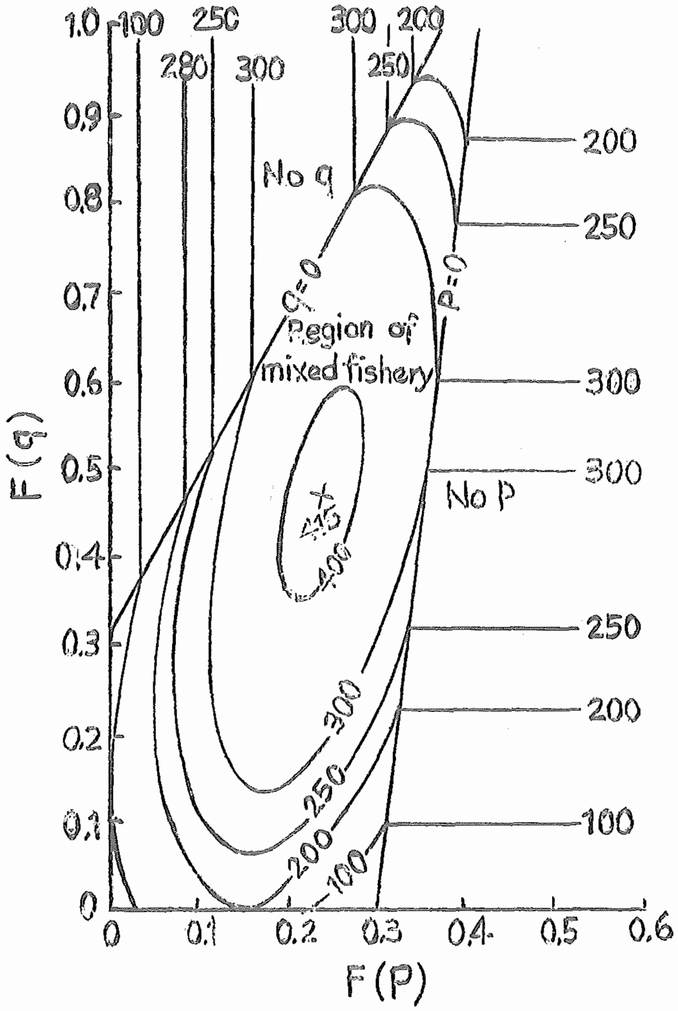


Fig. 2.10

Contours of equal yield for two species fishery
species p preys on species q

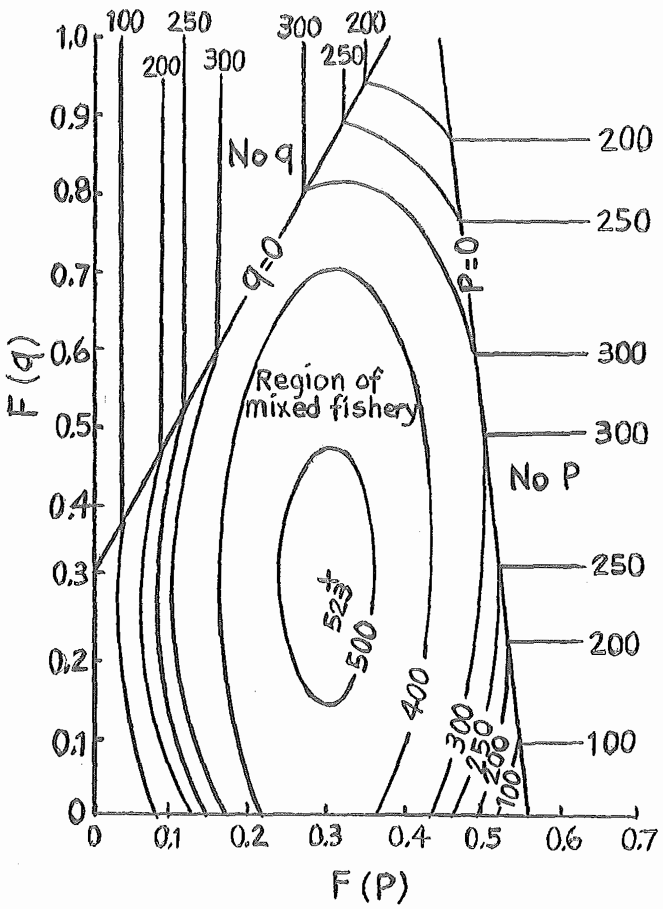


Fig. 3.1

Half virgin biomass position relative to contours of equal yield (Weak interactions)

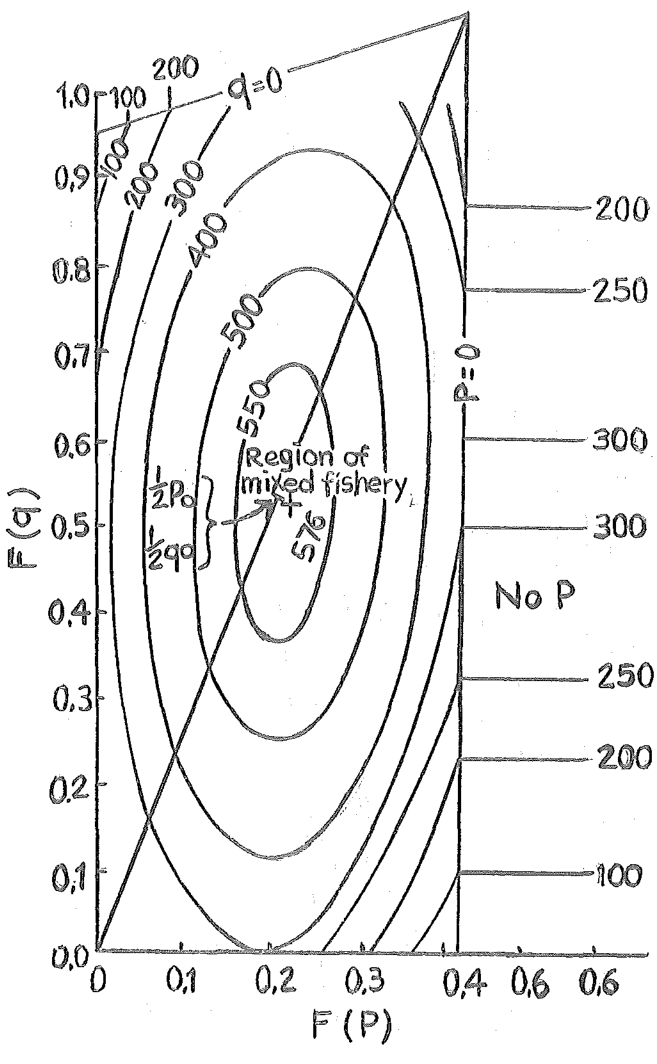


Fig. 3.2

Half virgin stock biomass position relative to contours of equal yield (stronger interactions)

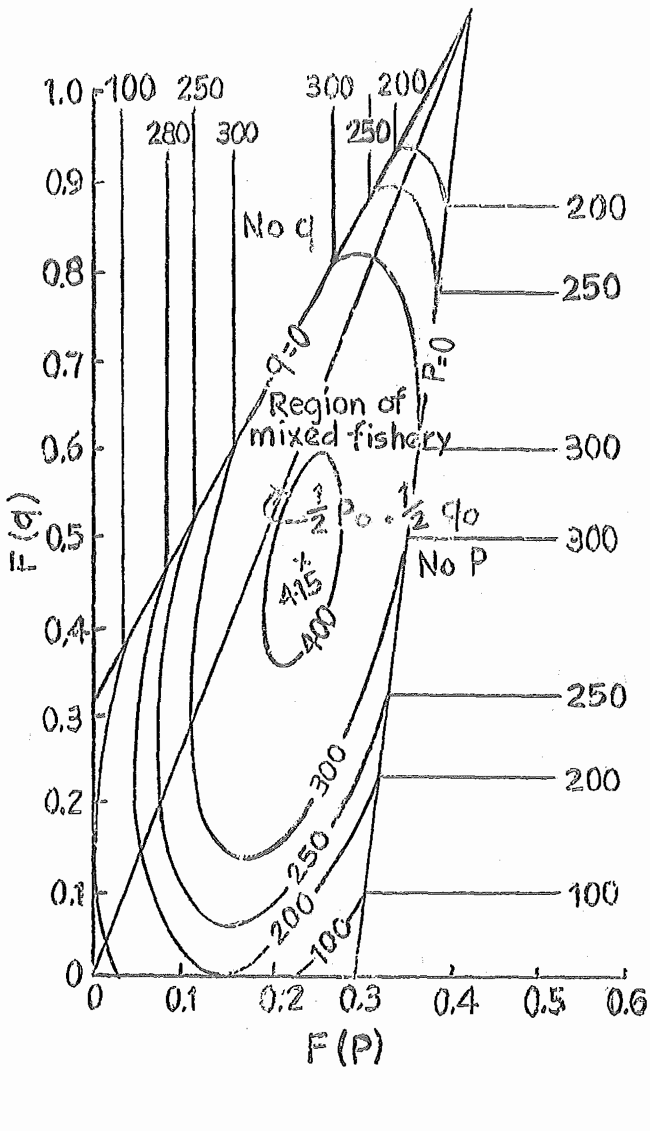


Fig. 3.3

Half virgin stock biomass position relative to contours of equal yield (prey preditor case)

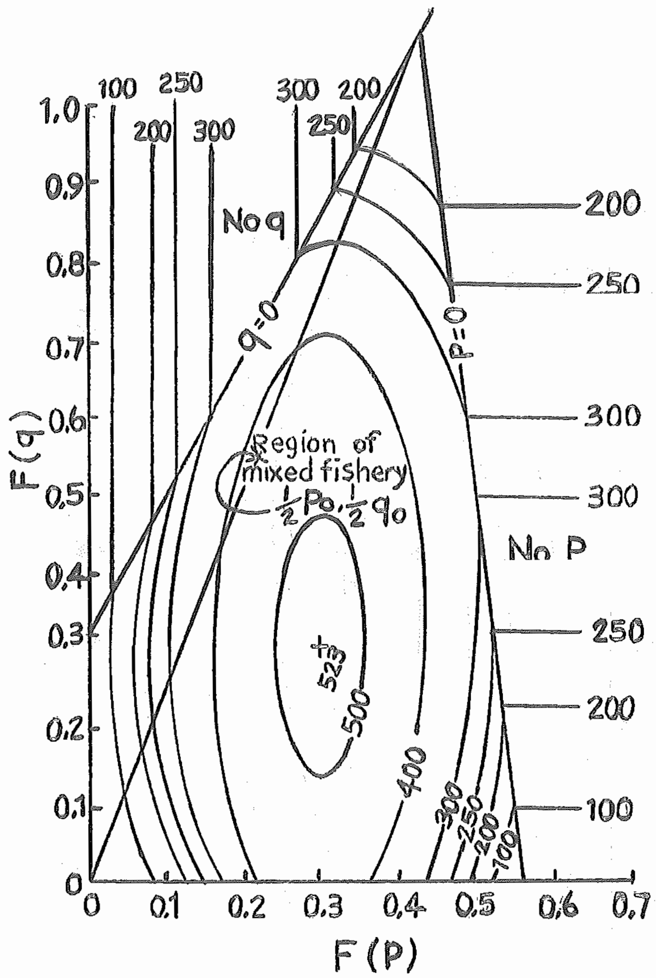


Fig. 3.4

Developing a multispecies fishery using a PARTAN approach

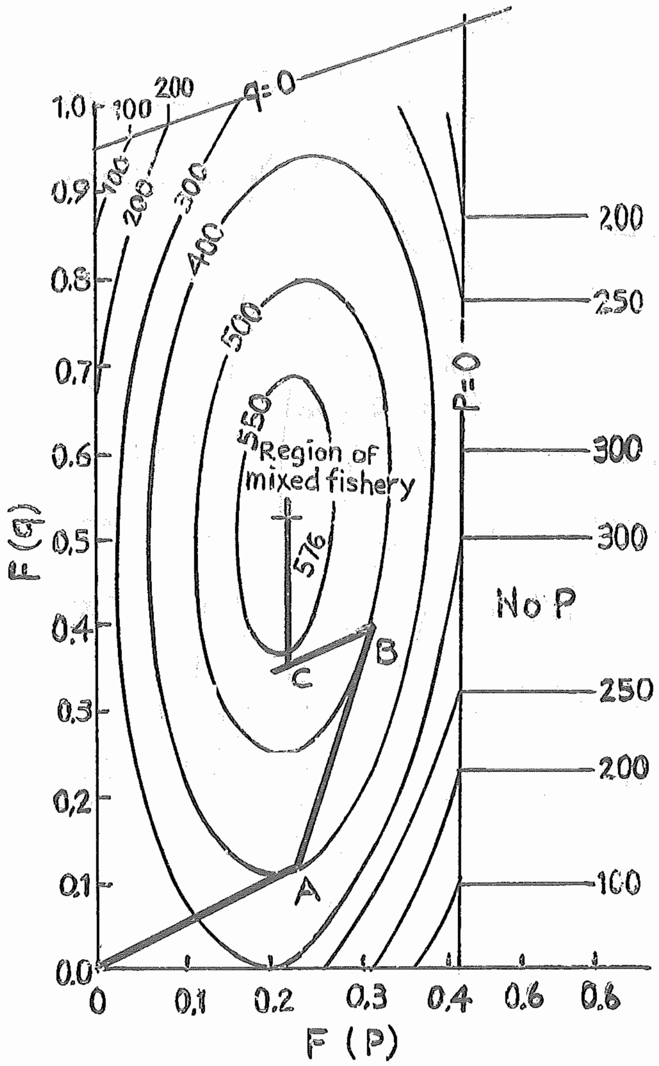
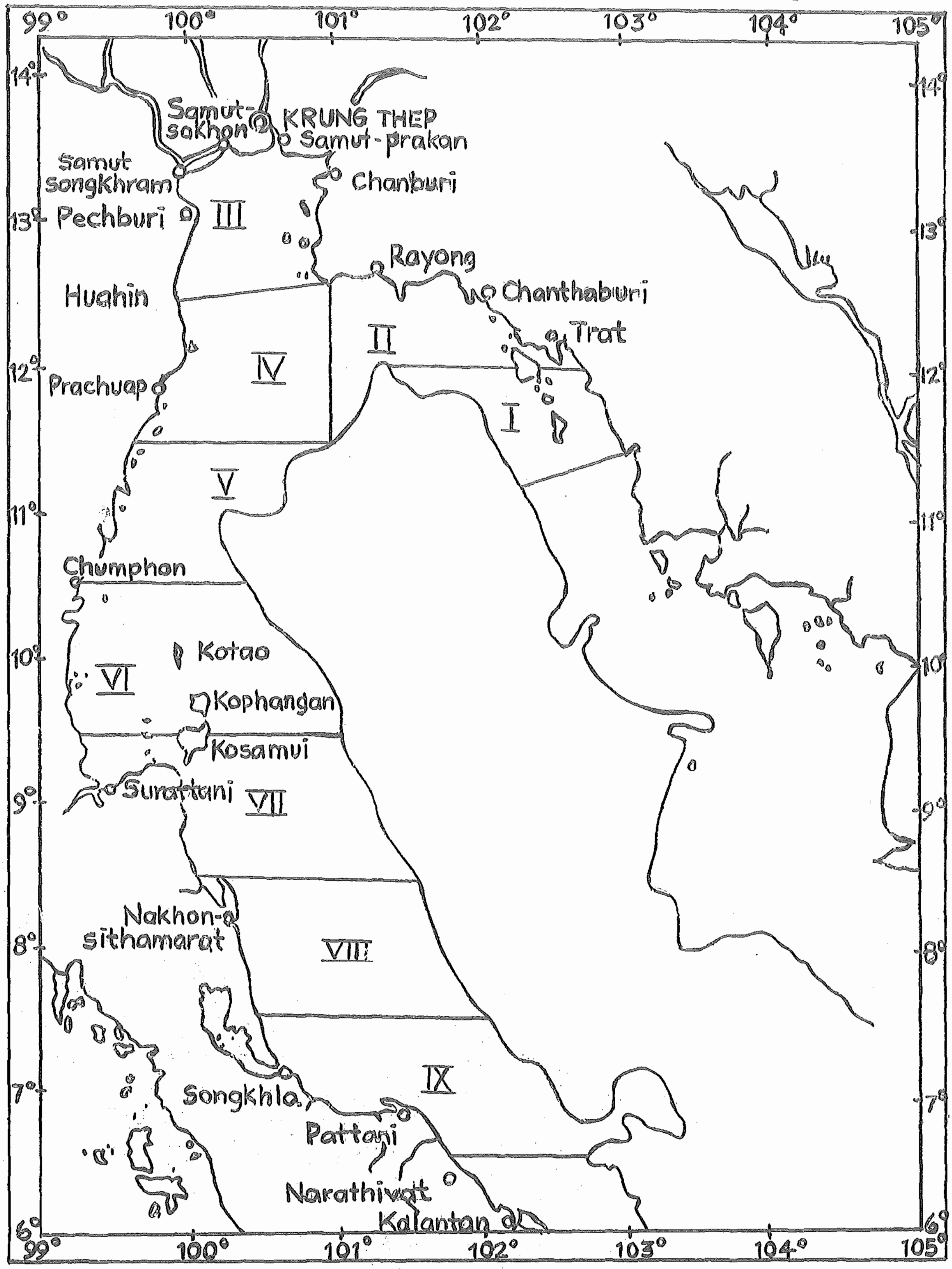


Fig. 4.1



Arbitrarily chosen statistical area for trawl fisheries surveys in the Gulf of Thailand.

Fig. 4.2

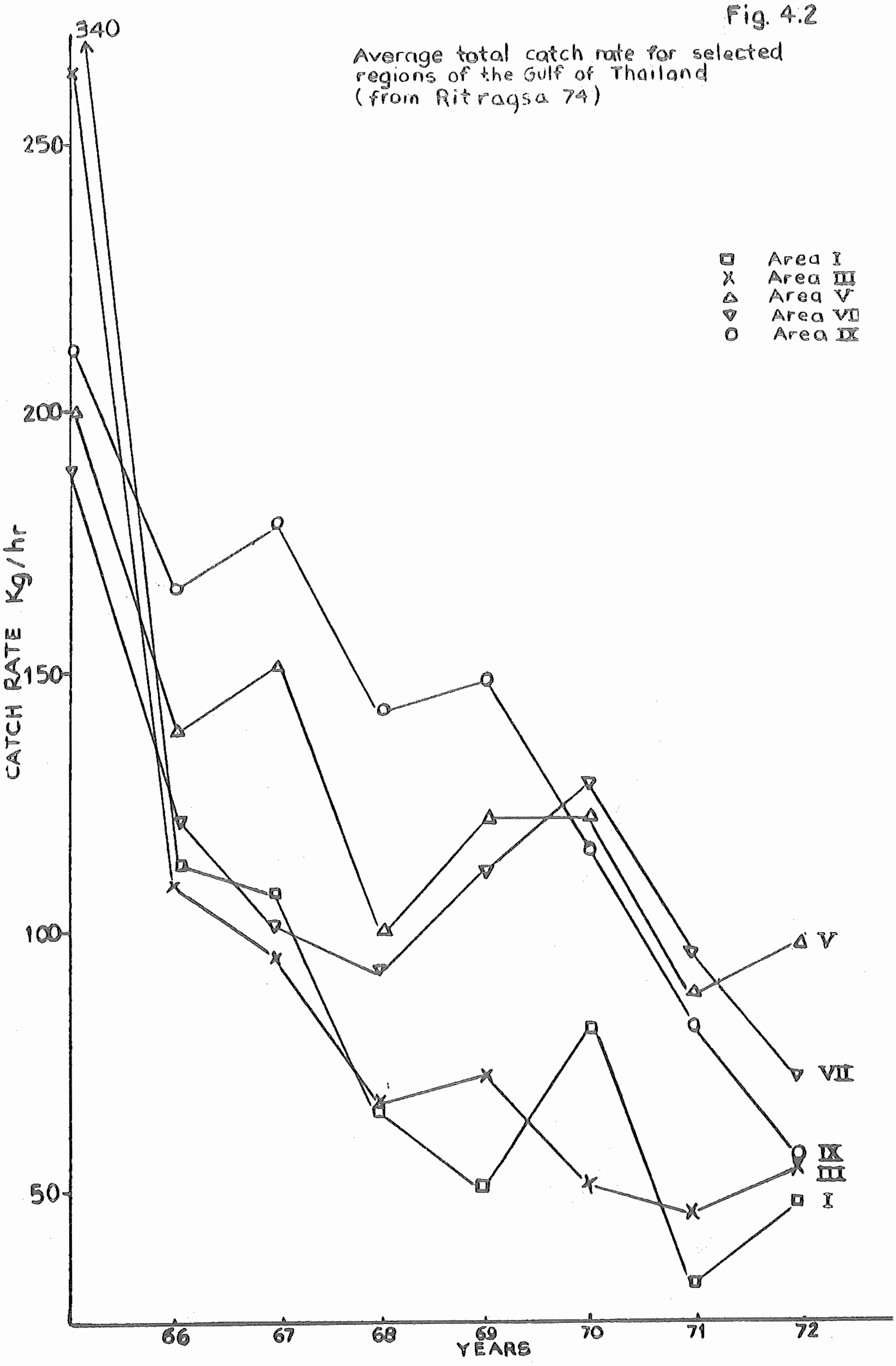

Average total catch rate for selected regions of the Gulf of Thailand (from Ritragsa 74)
340
250
200
150
100
50
CATCH RATE Kg/hr
66
67
68
69
70
71
72
YEARS
Area I
Area III
Area V
Area VII
Area IX
V
VII
IX
III
I

Fig. 4.3

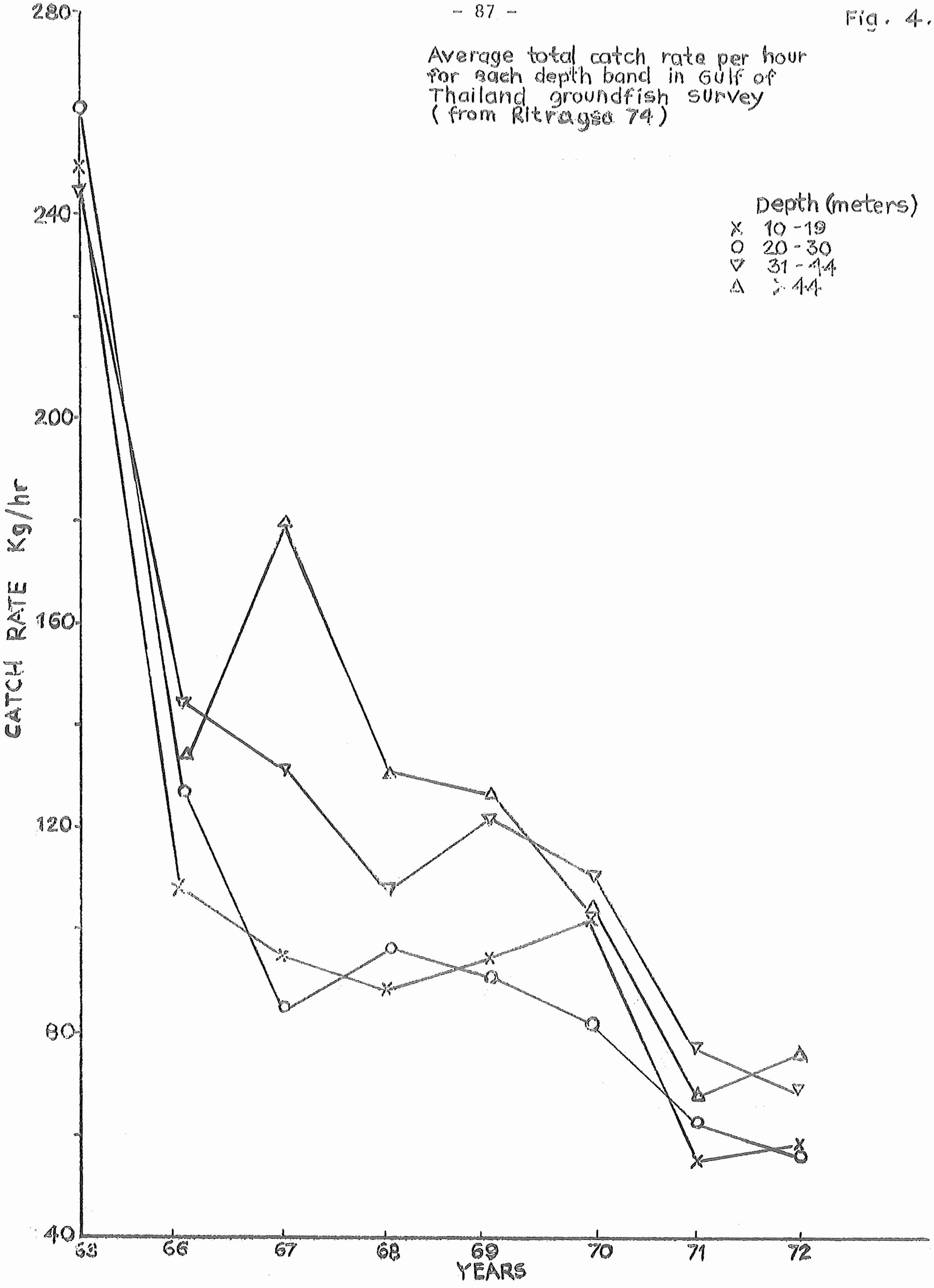
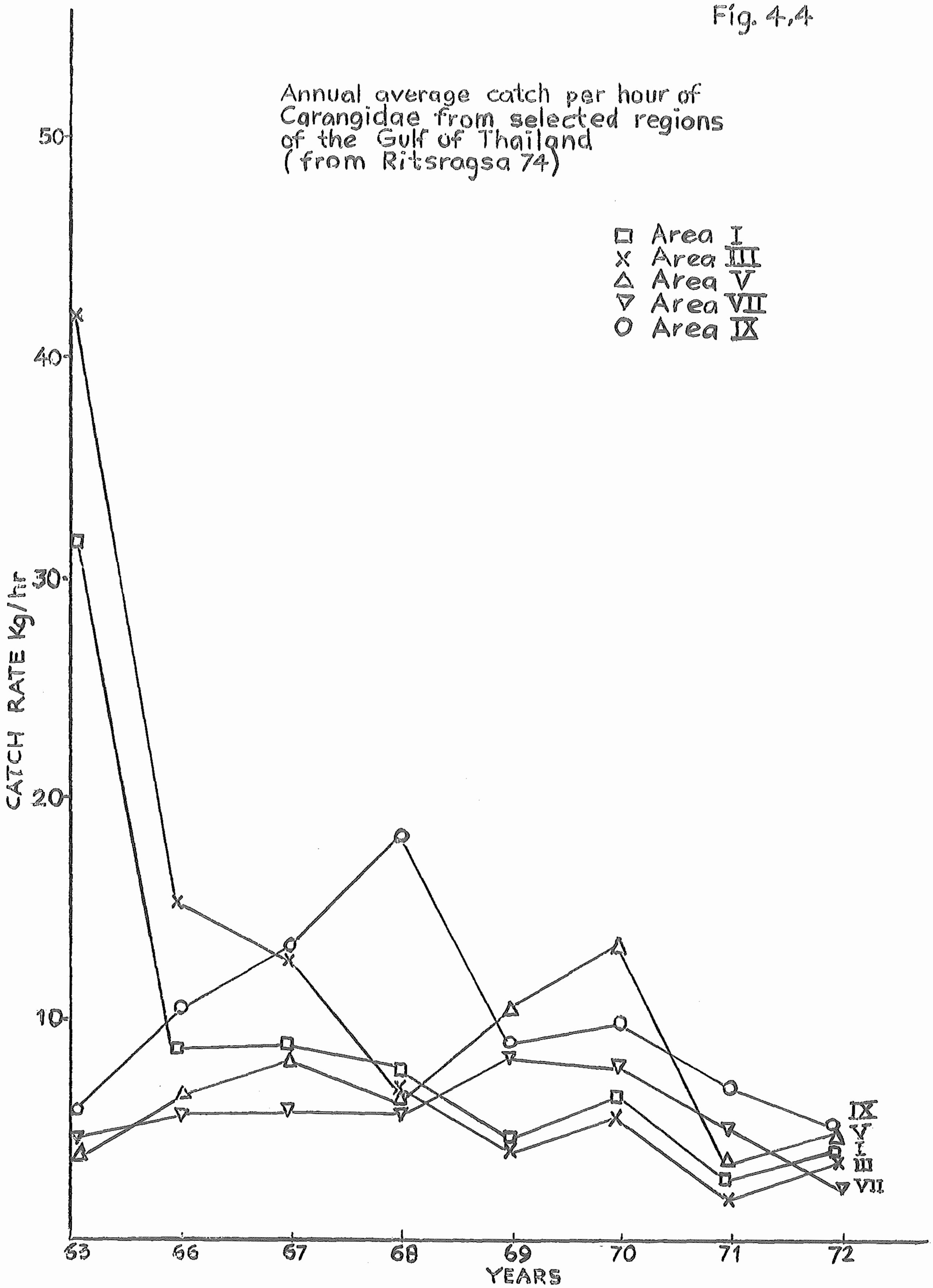

Average total catch rate per hour
for each depth band in Gulf of
Thailand groundfish survey
(from Ritragsa 74)
Depth (meters)
X 10 - 19
O 20 - 30
▽ 31 - 44
△ > 44
CATCH RATE Kg/hr
280
240
200
160
120
80
40
63
66
67
68
69
70
71
72
YEARS

Fig. 4.4


Annual average catch per hour of Carangidae from selected regions of the Gulf of Thailand (from Ritsragsa 74)
□ Area I
× Area III
△ Area V
▽ Area VII
○ Area IX
CATCH RATE Kg/hr
50
40
30
20
10
63
66
67
68
69
70
71
72
YEARS
IX
V
I
III
VII

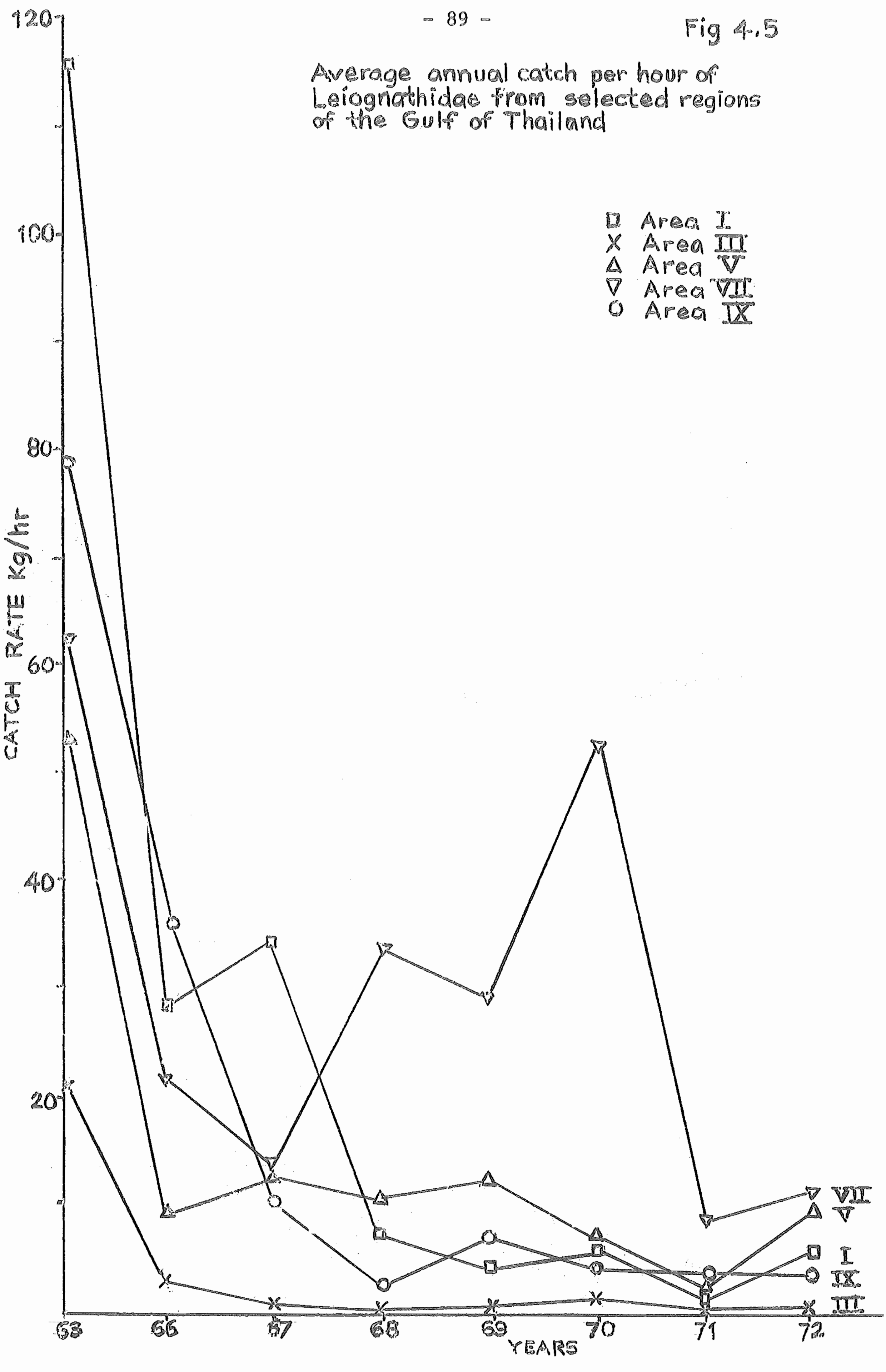


Fig 4.5
Average annual catch per hour of Leiognathidae from selected regions of the Gulf of Thailand
Area I
Area III
Area V
Area VII
Area IX
CATCH RATE Kg/hr
YEARS
120
100
80
60
40
20
63
66
67
68
69
70
71
72
VII
V
I
IX
III

Fig. 4.6

Relationship between catch and effort in the Gulf of Thailand trawl fishery.

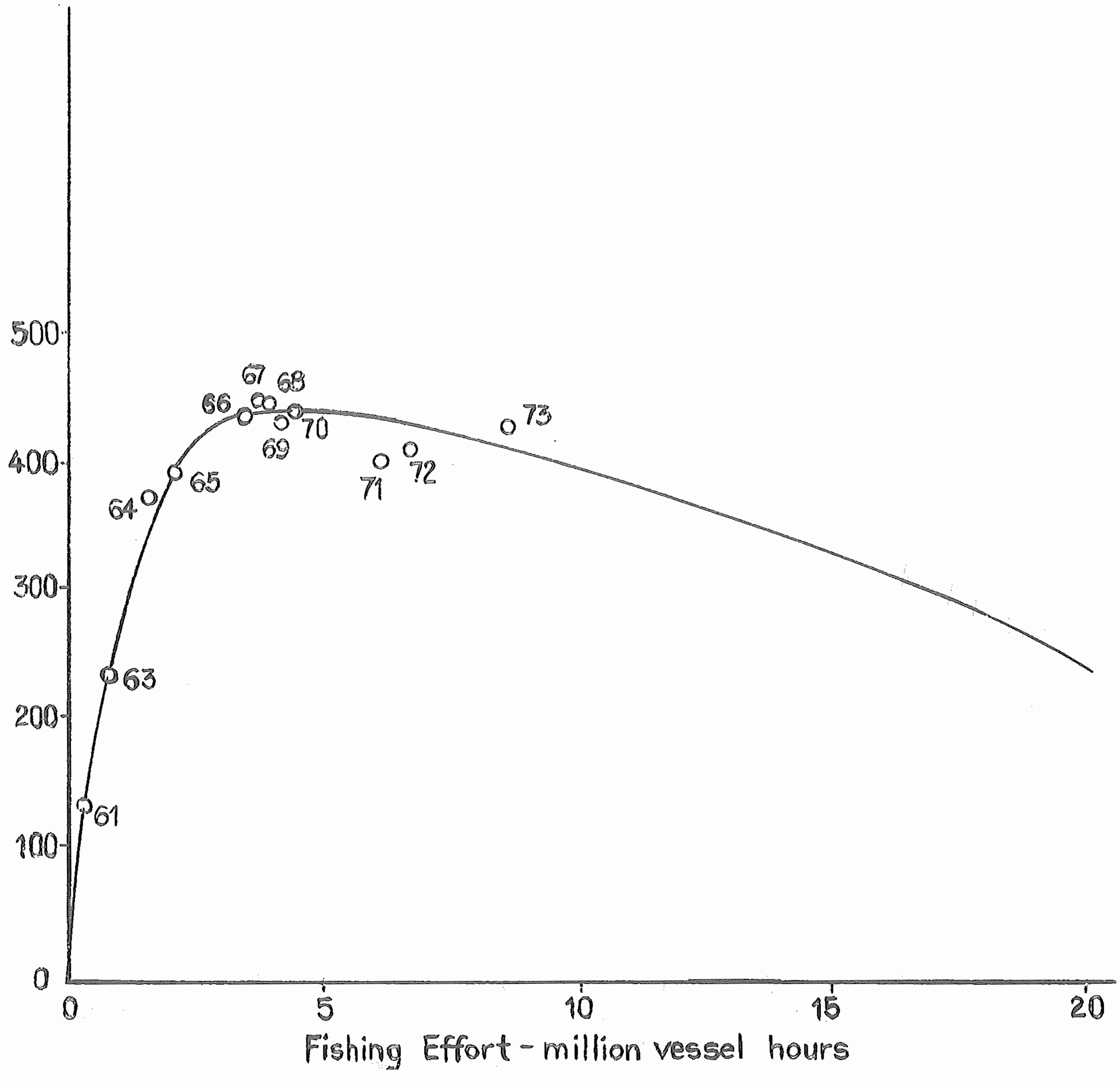
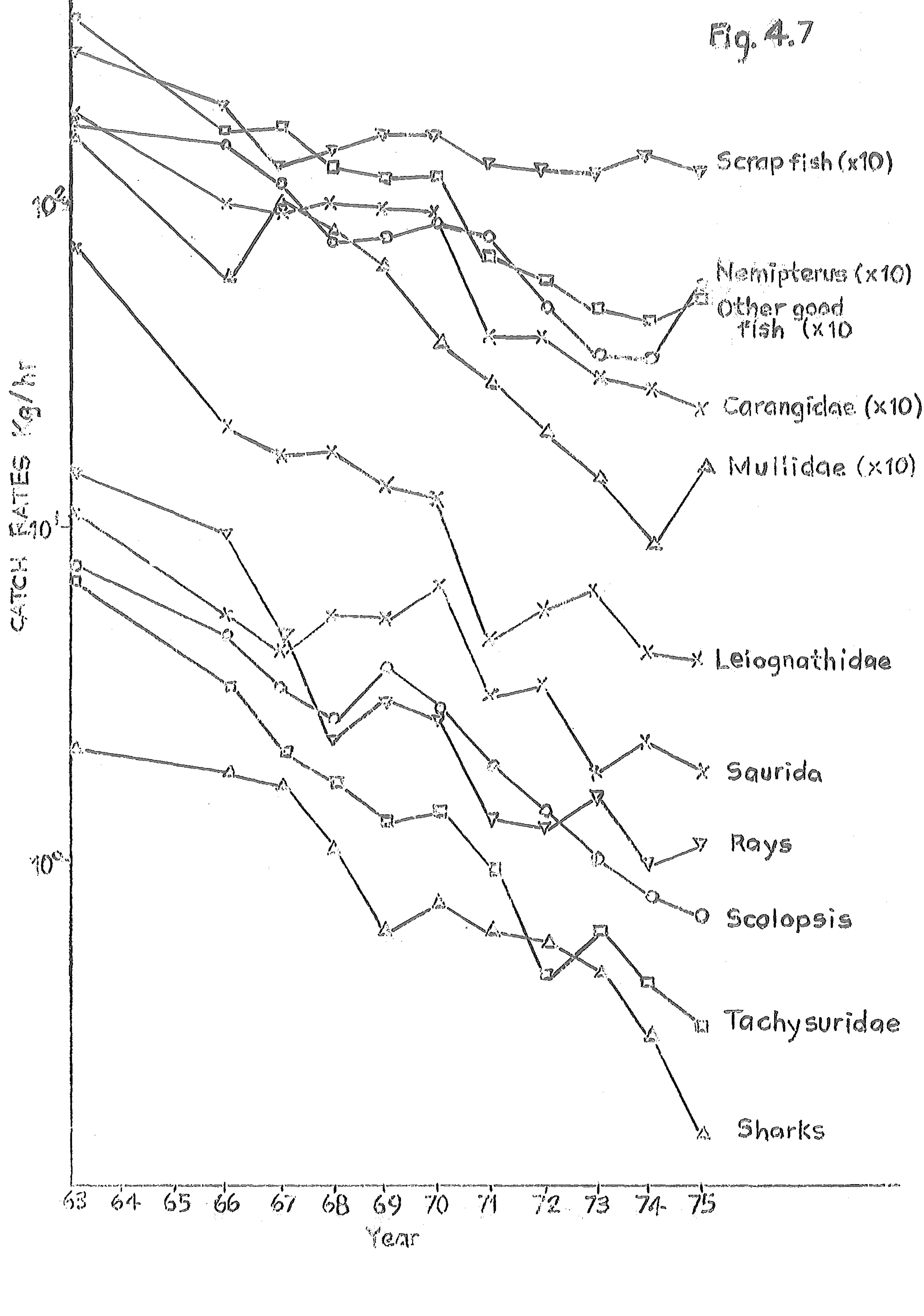


Fig. 4.7



Scrap fish (x10)
Nemipterus (x10)
Other good fish (x10
Carangidae (x10)
Mullidae (x10)
Leiognathidae
Saurida
Rays
Scolopsis
Tachysuridae
Sharks
CATCH RATES Kg/hr
10²
10¹
10⁰
63
64
65
66
67
68
69
70
71
72
73
74
75
Year

Fig. 4.8

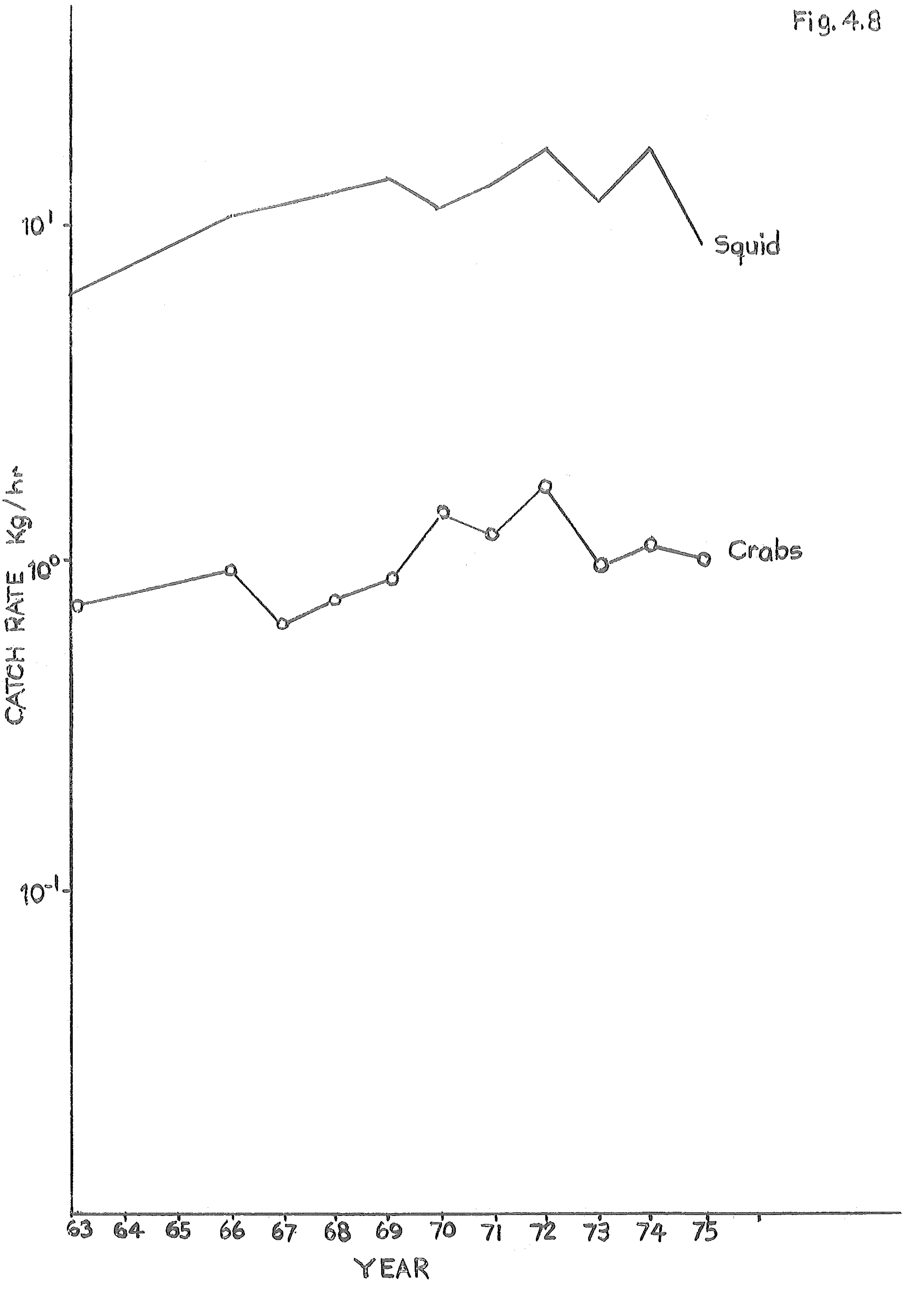
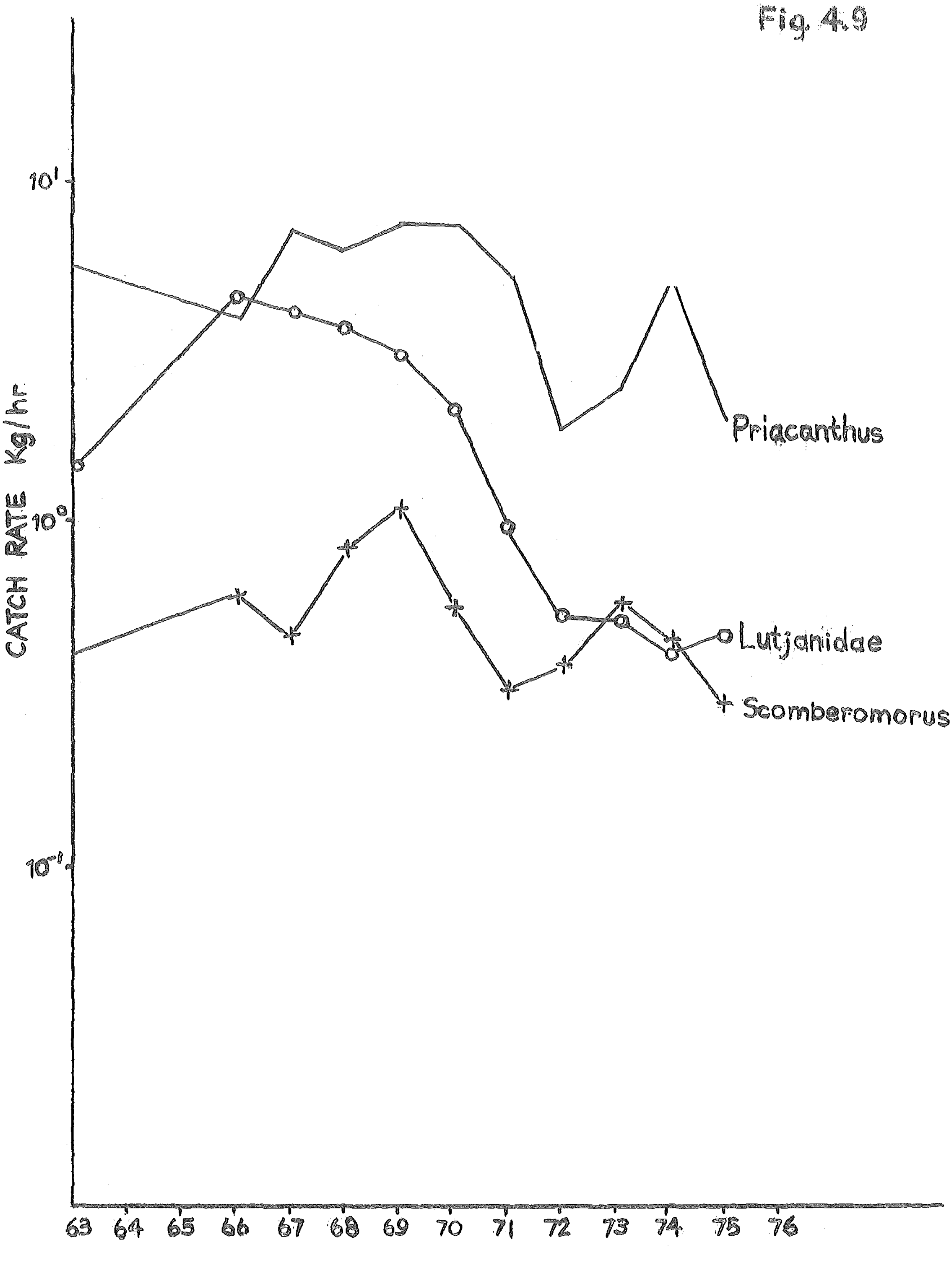

Squid
Crabs
10¹
10⁰
10⁻¹
CATCH RATE Kg/hr
63 64 65 66 67 68 69 70 71 72 73 74 75
YEAR

Fig. 4.9


CATCH RATE Kg/hr
10¹
10⁰
10⁻¹
Priacanthus
Lutjanidae
Scomberomorus
63 64 65 66 67 68 69 70 71 72 73 74 75 76

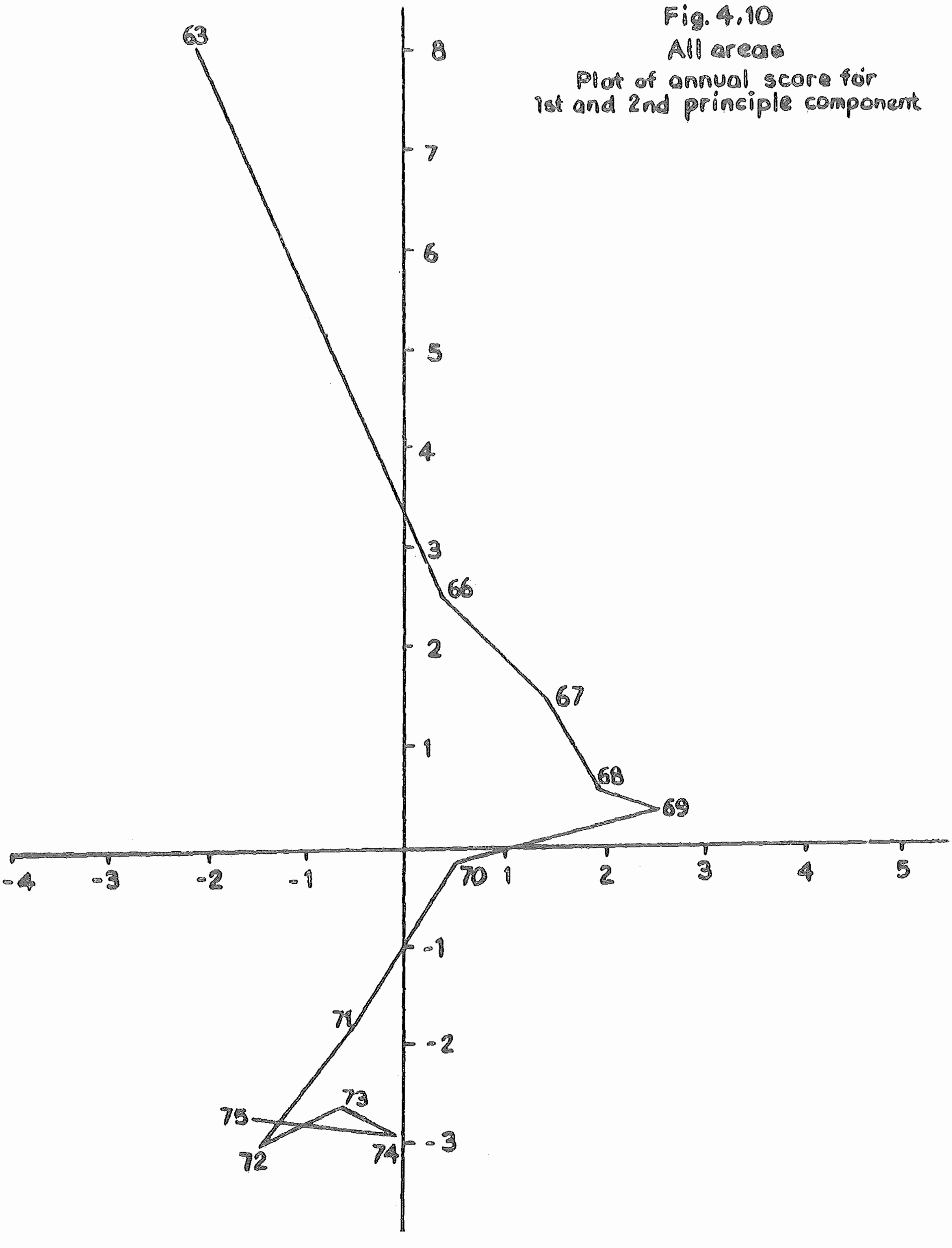


Fig. 4.10
All areas
Plot of annual score for
1st and 2nd principle component
63
66
67
68
69
70
71
72
73
74
75
8
7
6
5
4
3
2
1
-1
-2
-3
-4
-3
-2
-1
1
2
3
4
5

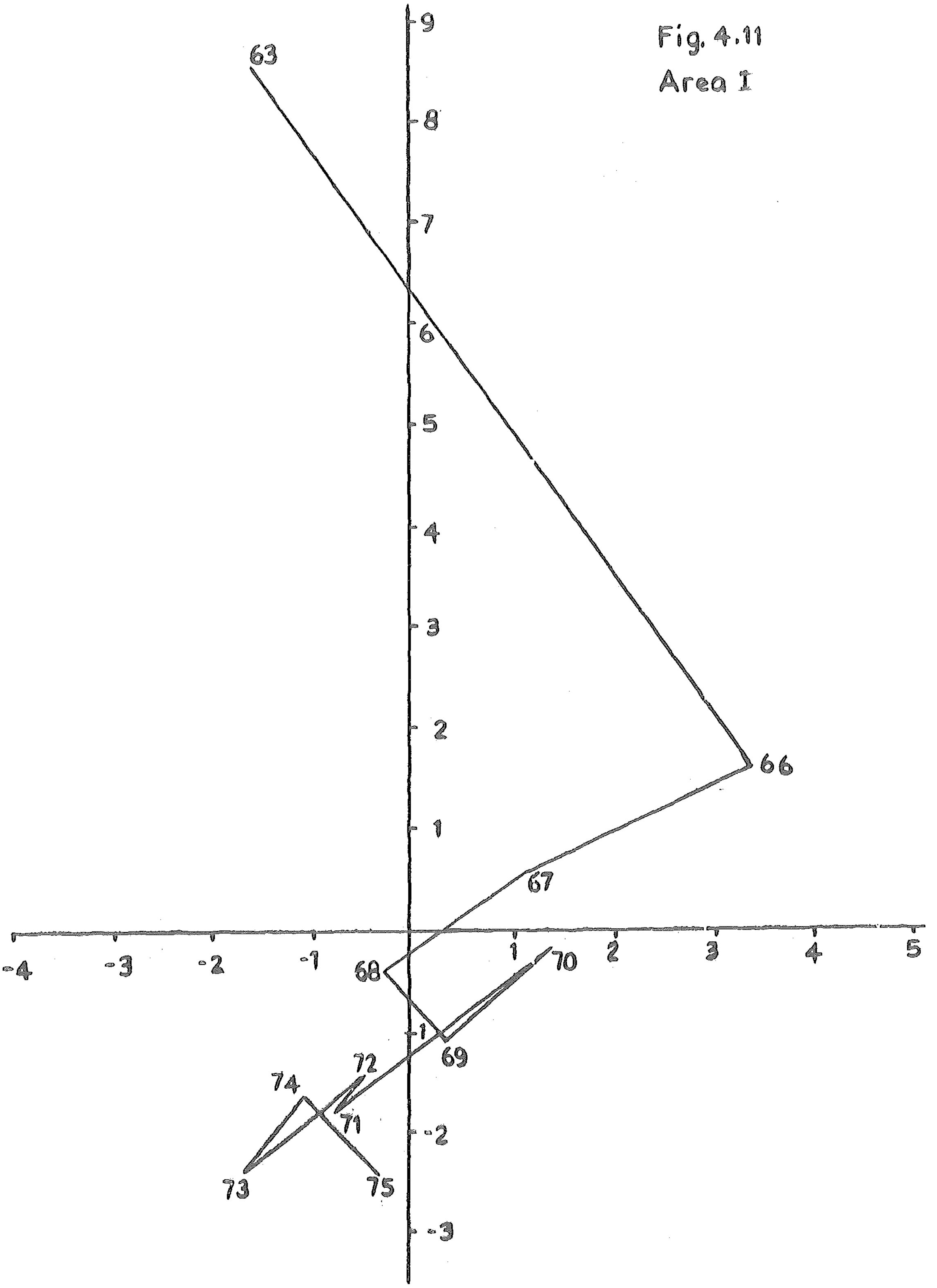


Fig. 4.11
Area I
9
8
7
6
5
4
3
2
1
-1
-2
-3
-4
-3
-2
-1
1
2
3
4
5
63
66
67
68
69
70
71
72
73
74
75

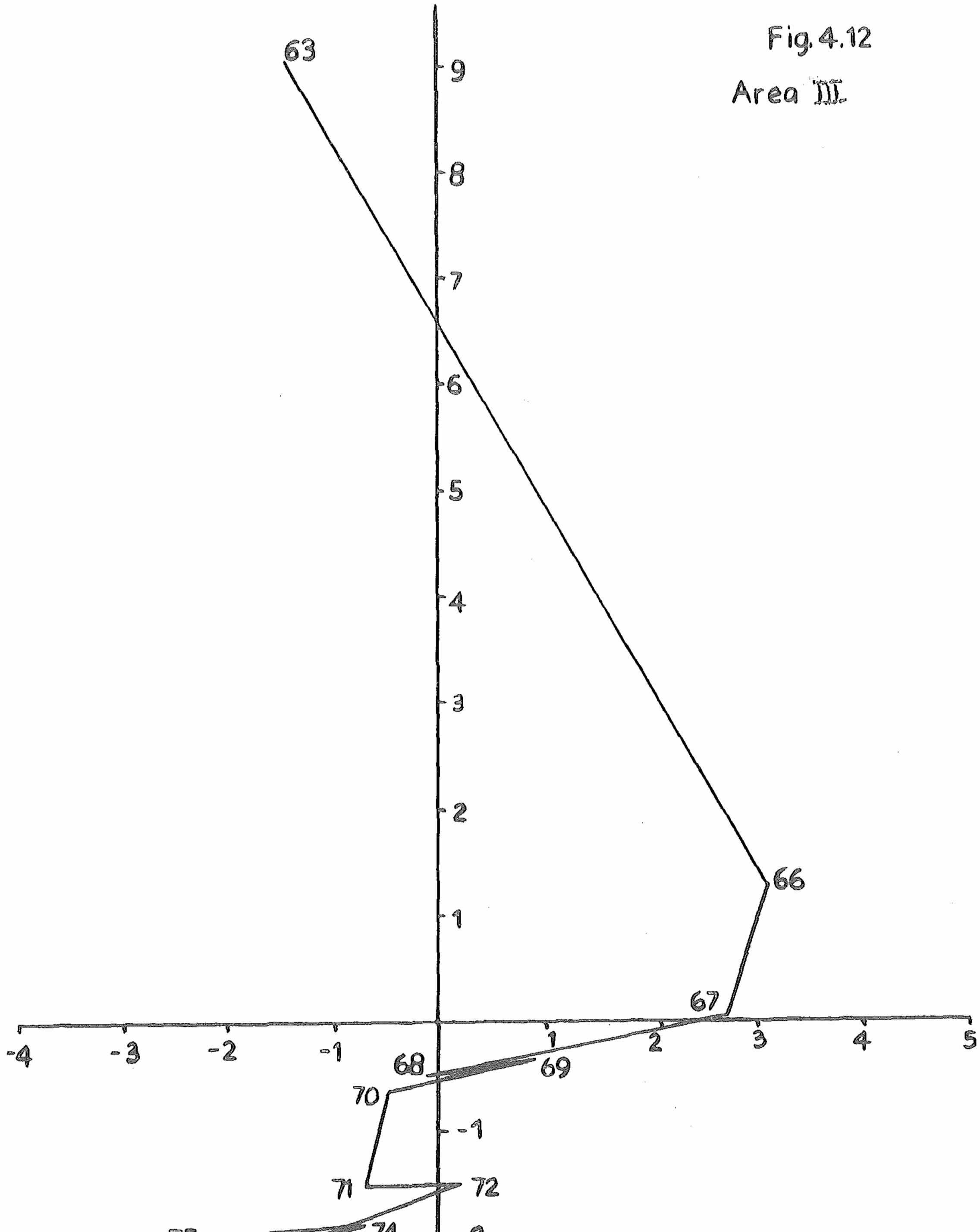


Fig. 4.12
Area III
63
66
67
68
69
70
71
72
73
74
75
9
8
7
6
5
4
3
2
1
-1
-2
-4
-3
-2
-1
1
2
3
4
5

Fig.4.13

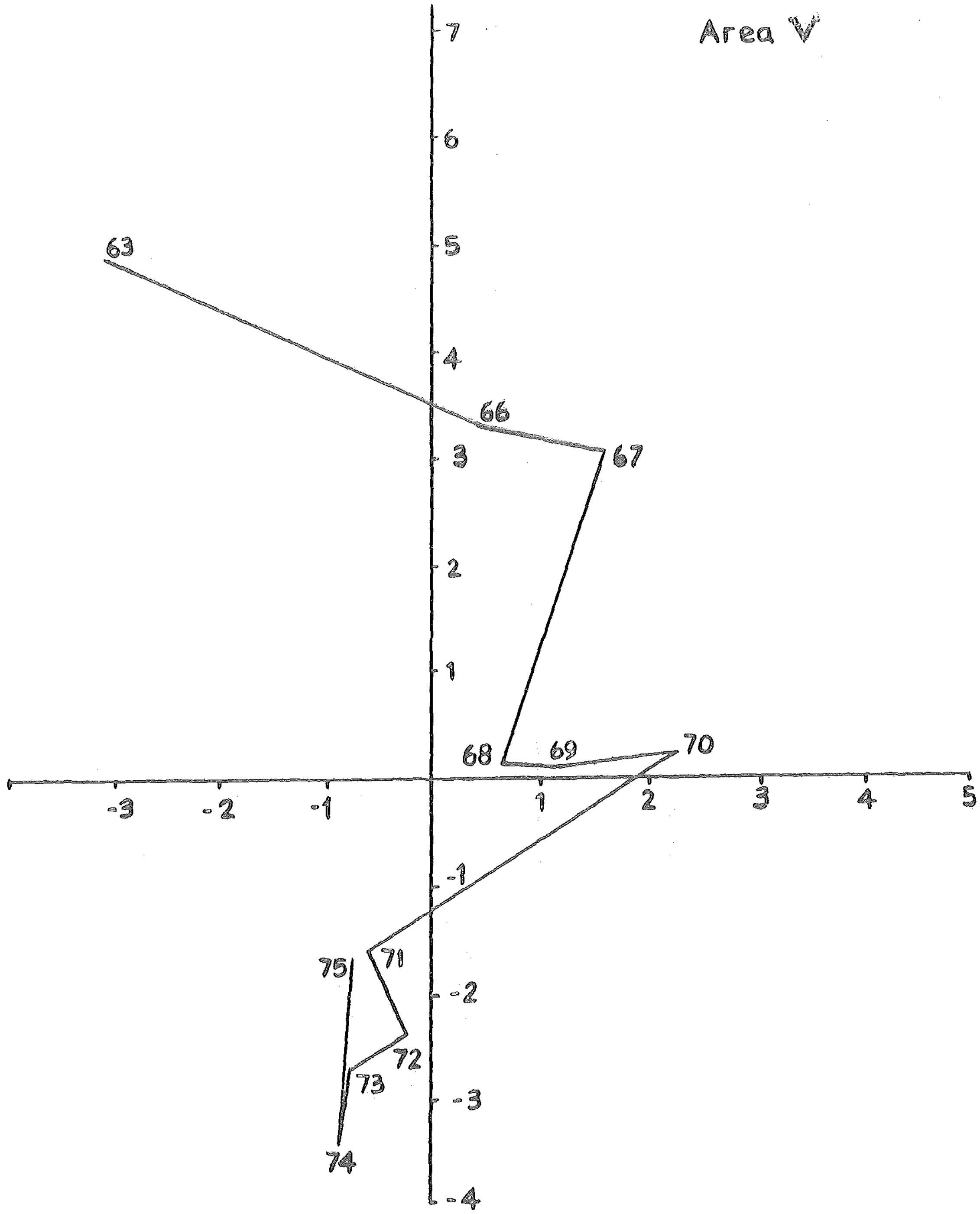


Fig. 4.14

Area VII

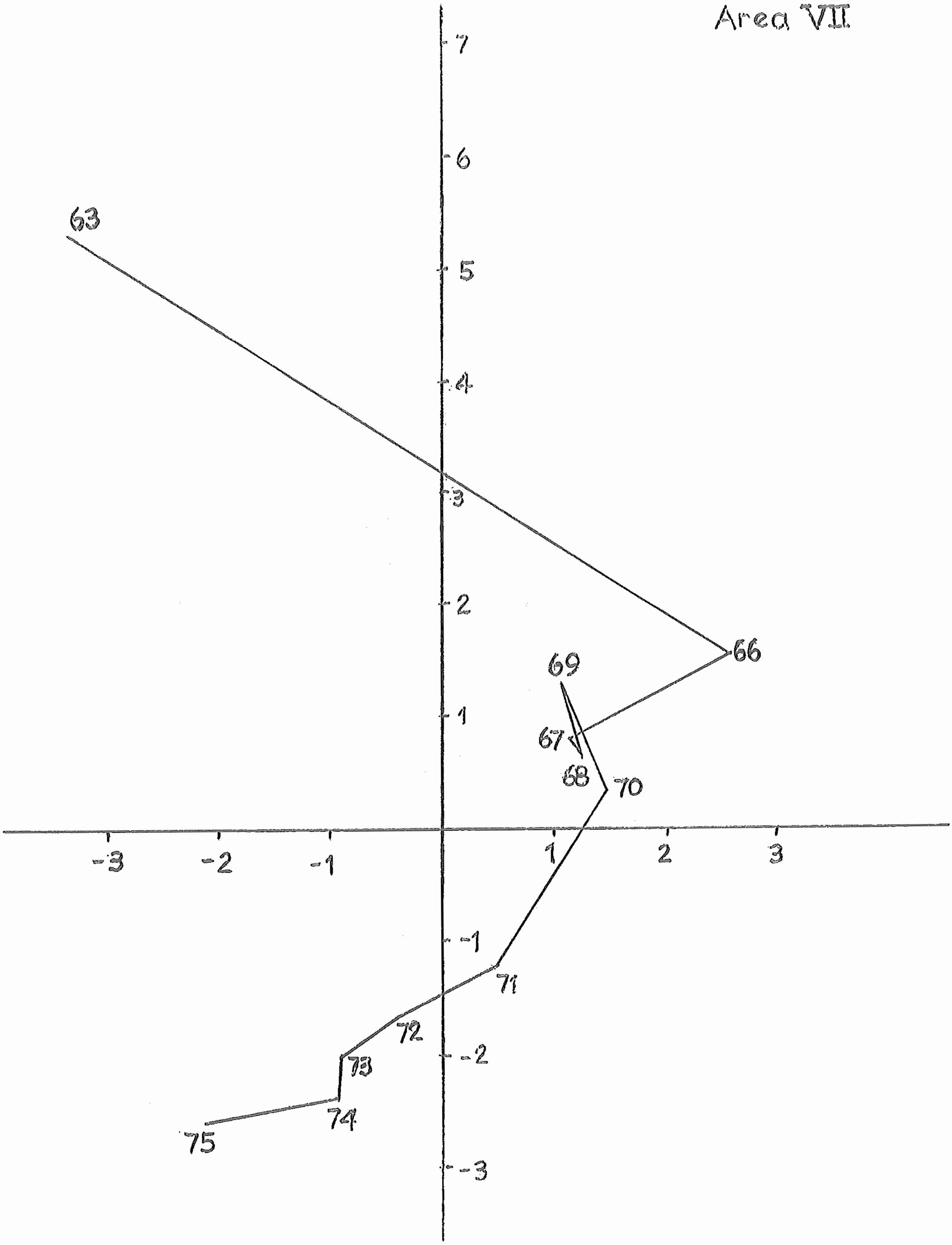
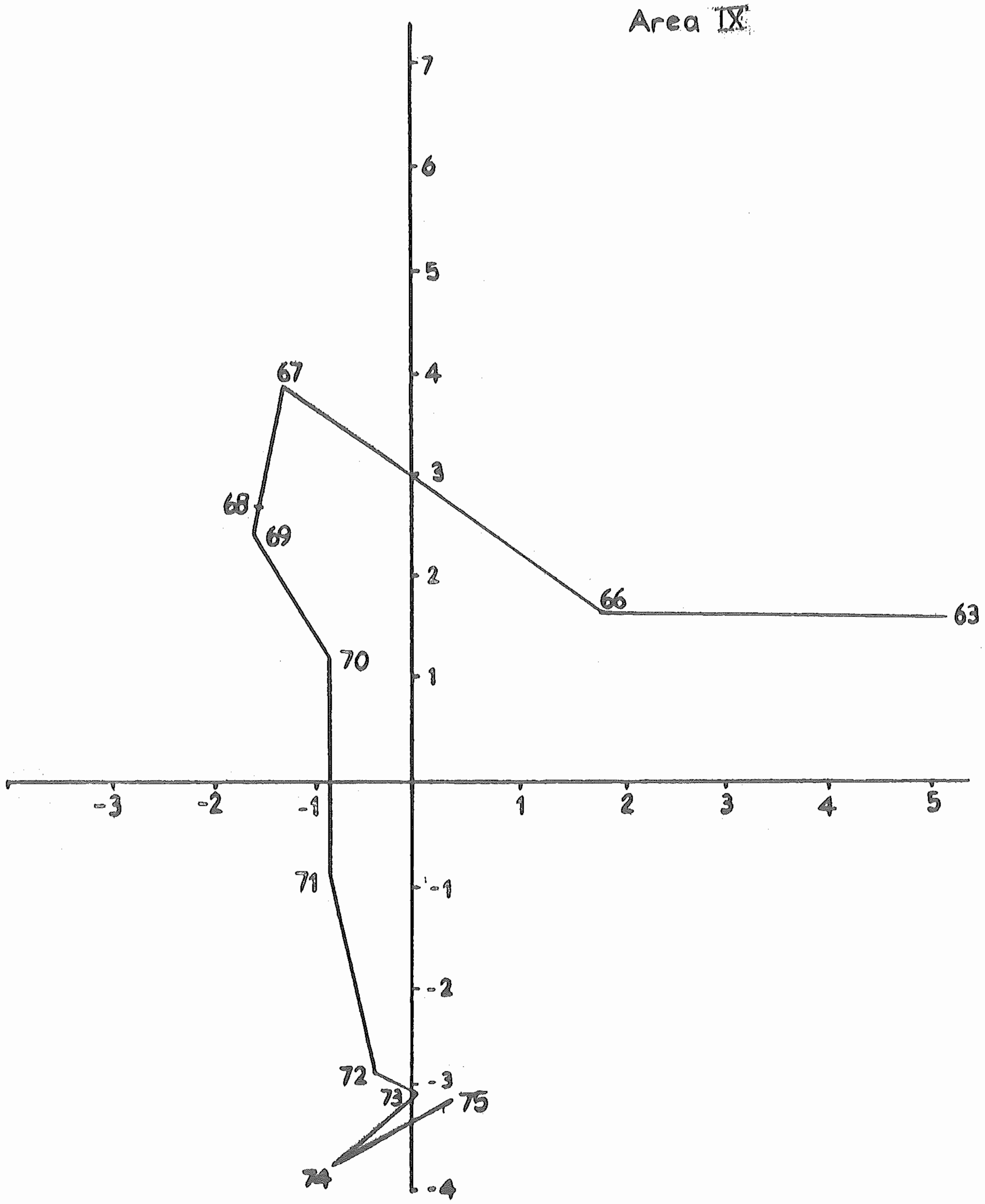


Fig. 4.15



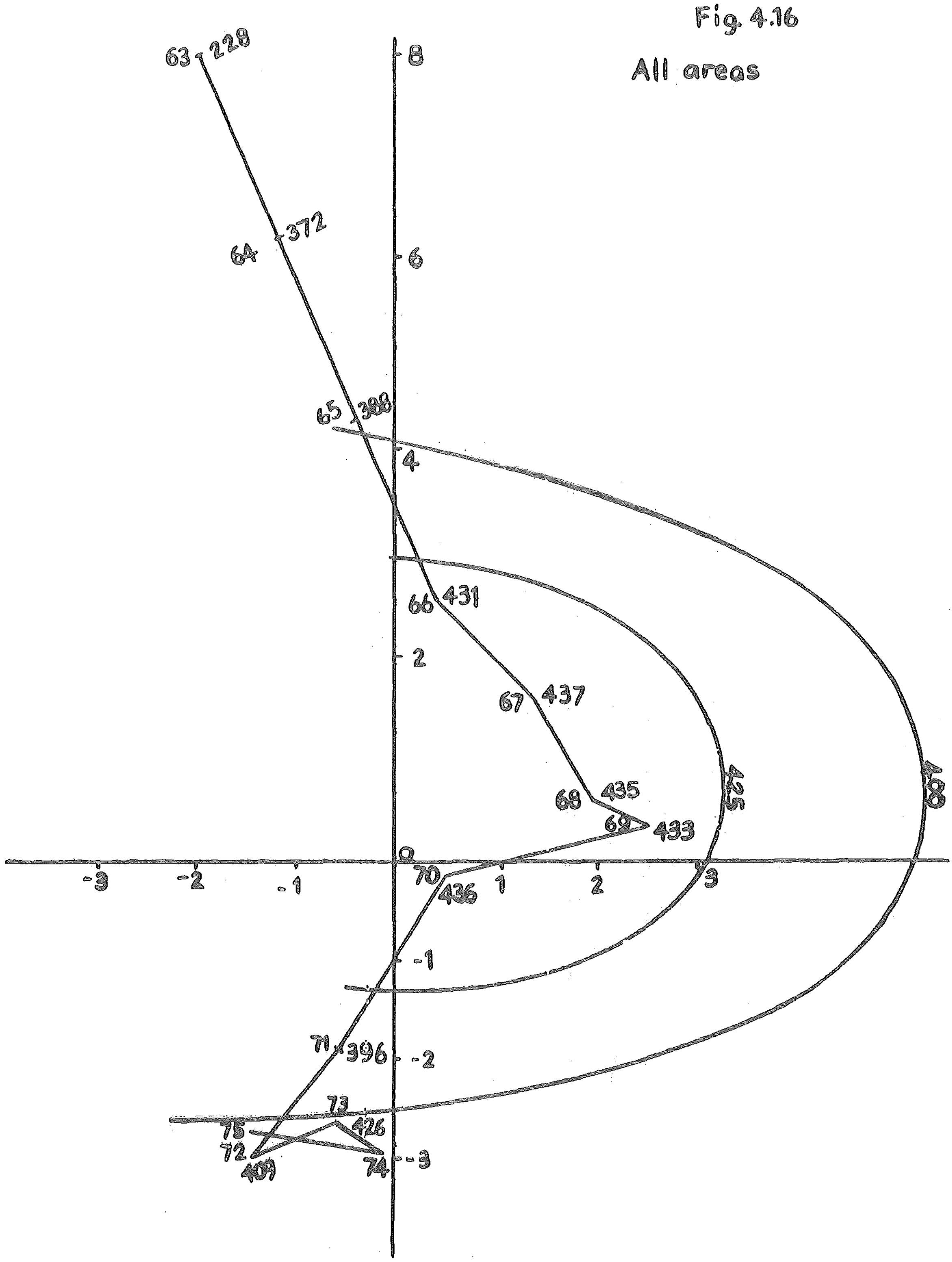
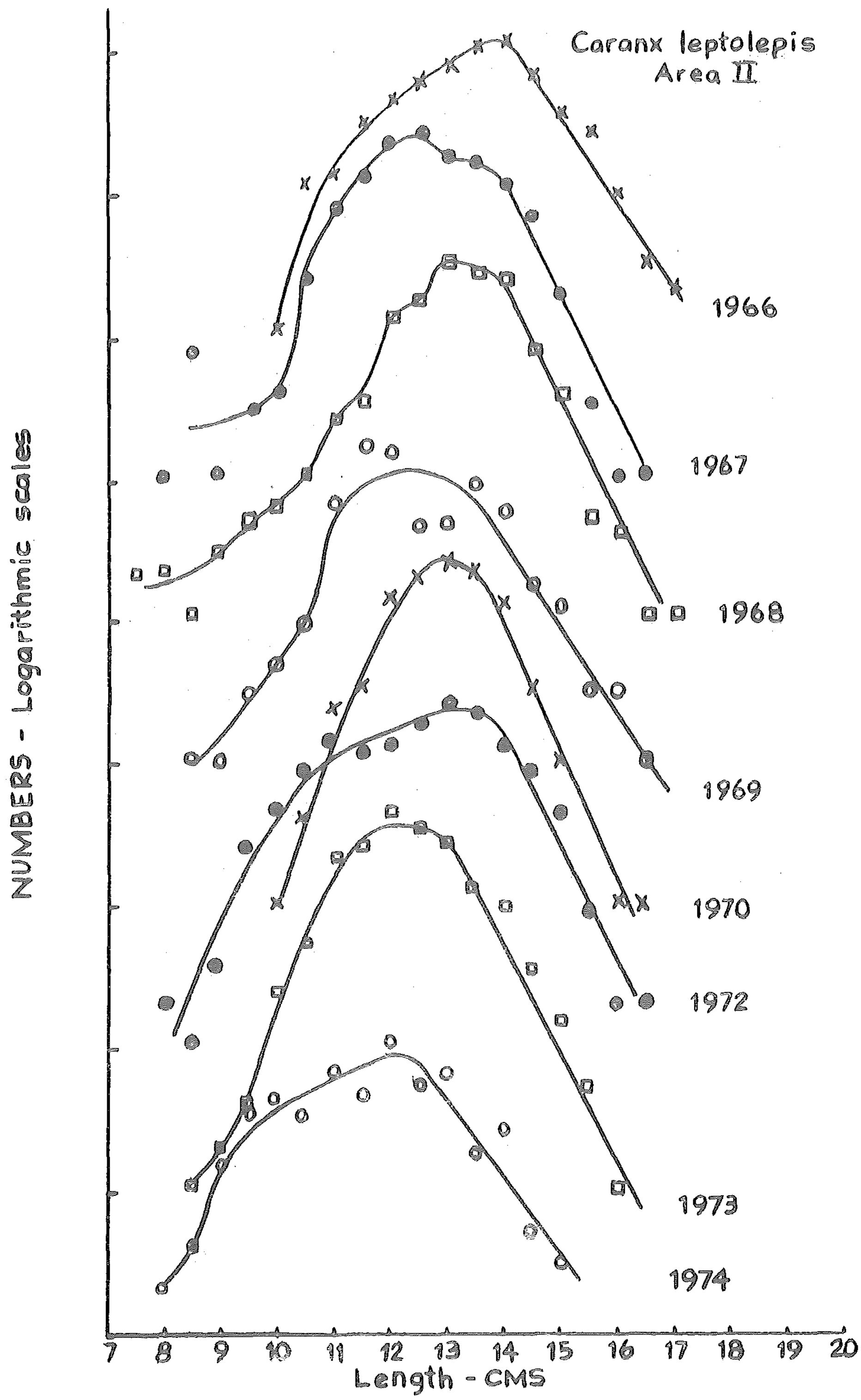


Fig. 4.16
All areas
63 228
64 372
65 388
66 431
67 437
68 435
69 433
70 436
71 396
72 409
73 426
74
75
425
480
8
6
4
2
0
-1
-2
-3
1
2
3
-3
-2
-1

Fig. 4.17


Caranx leptolepis
Area II
1966
1967
1968
1969
1970
1972
1973
1974
NUMBERS - Logarithmic scales
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Length - CMS

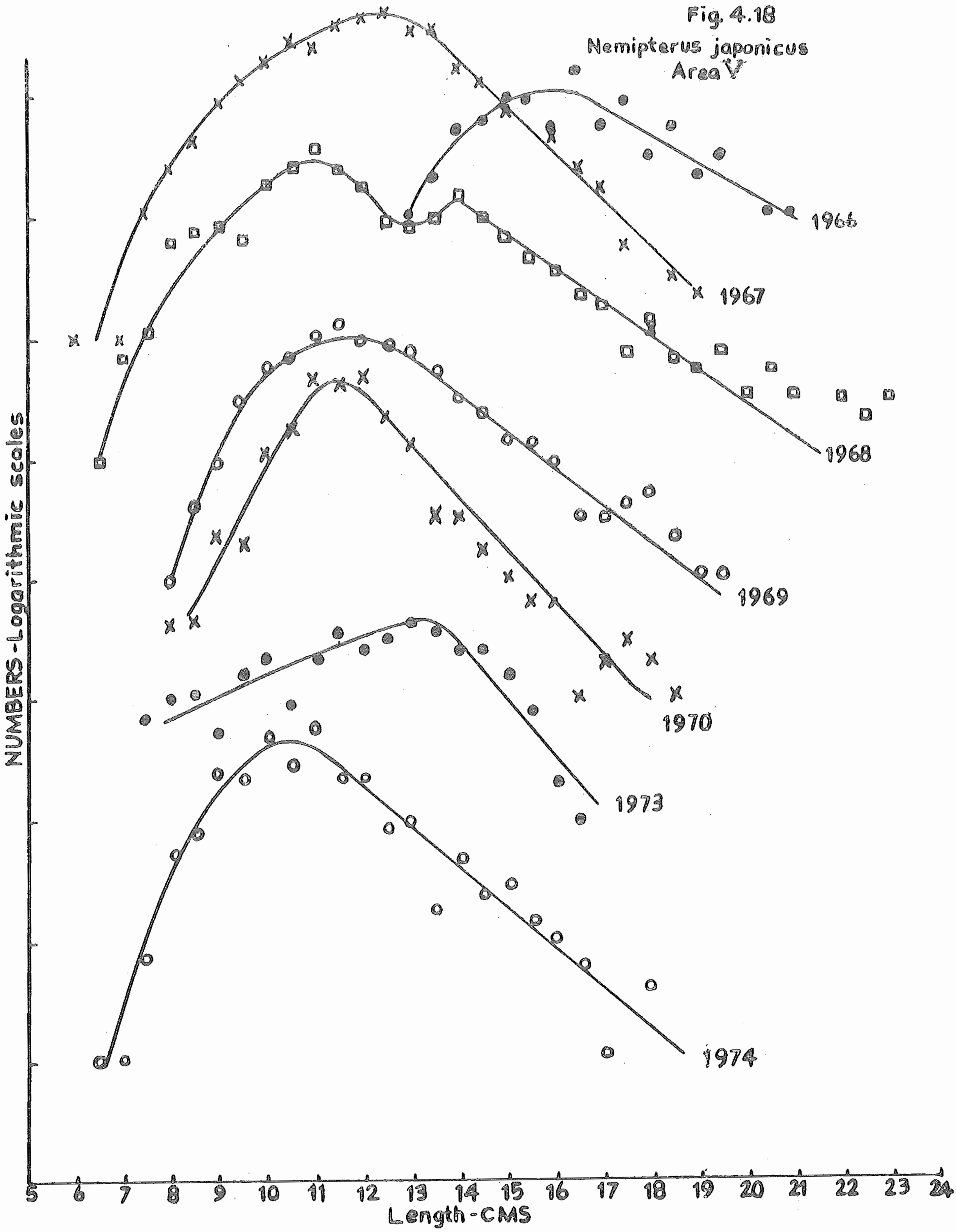


Fig. 4.18
Nemipterus japonicus
Area V
1966
1967
1968
1969
1970
1973
1974
NUMBERS-Logarithmic scales
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Length-CMS

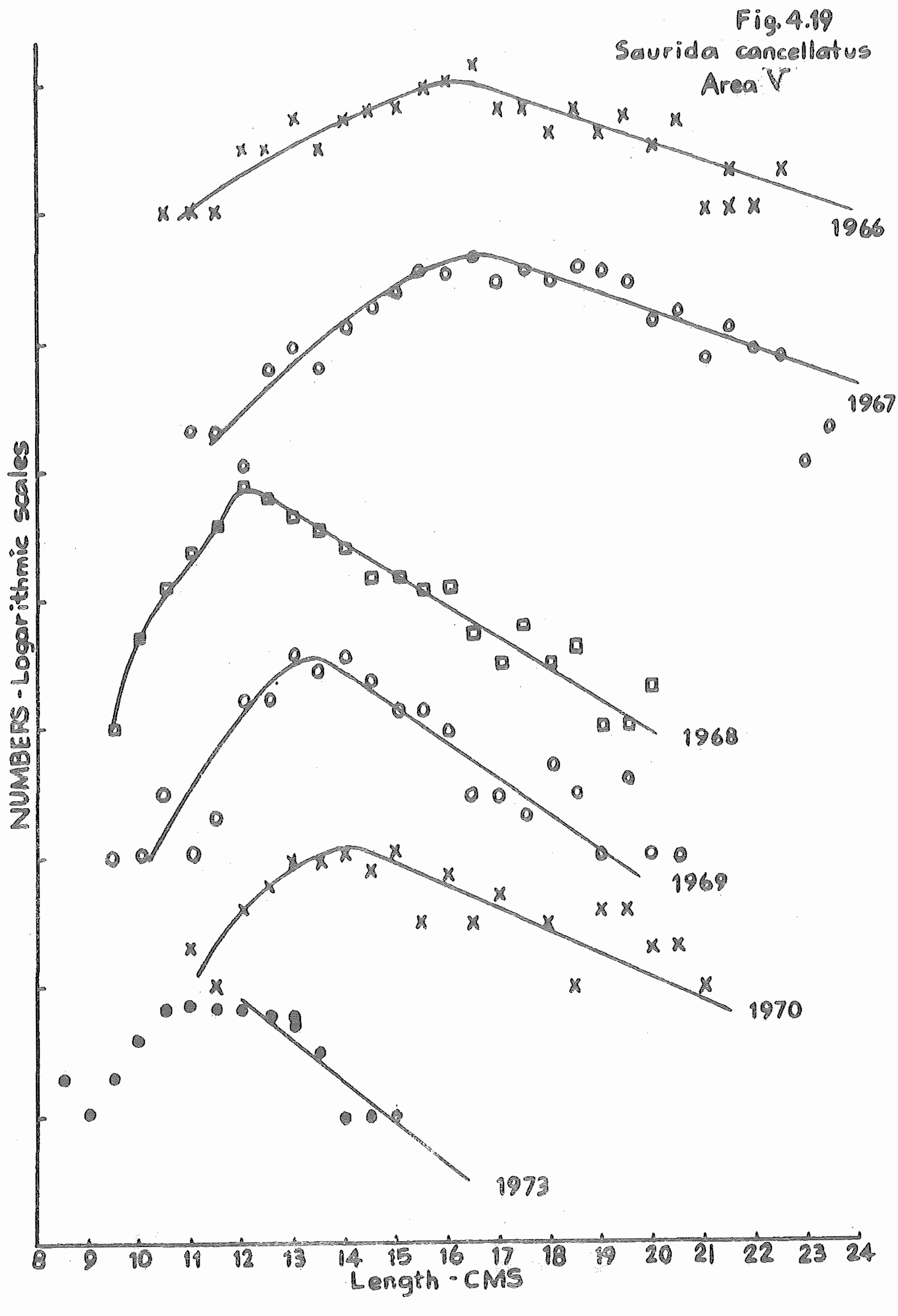


Fig. 4.19
Saurida cancellatus
Area V
1966
1967
1968
1969
1970
1973
NUMBERS - Logarithmic scales
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Length - CMS

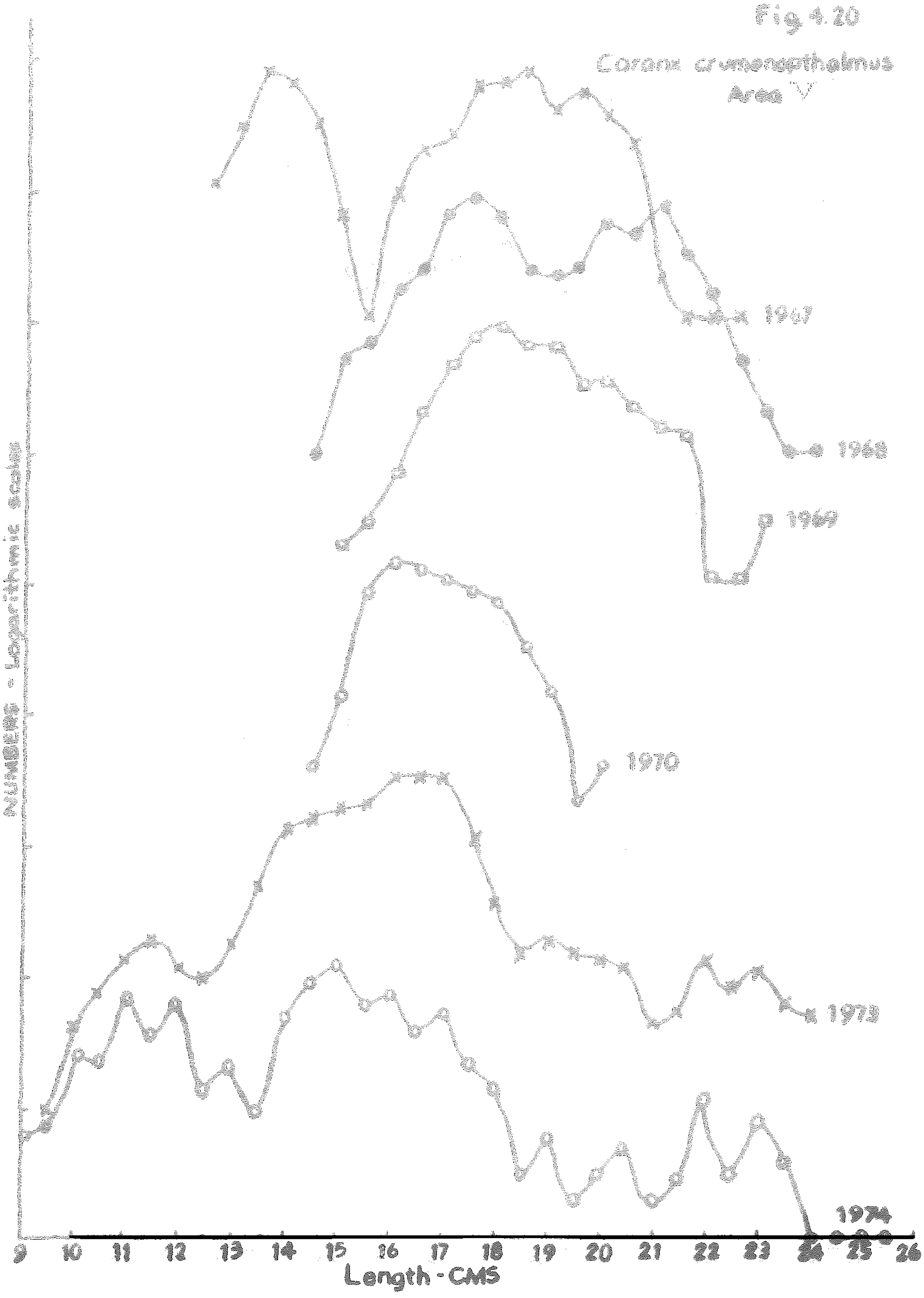


Fig. 4.20
Caranx crumenopthalmus
Area 'V'
1967
1968
1969
1970
1973
1974
NUMBERS - Logarithmic Scale
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
Length - CMS

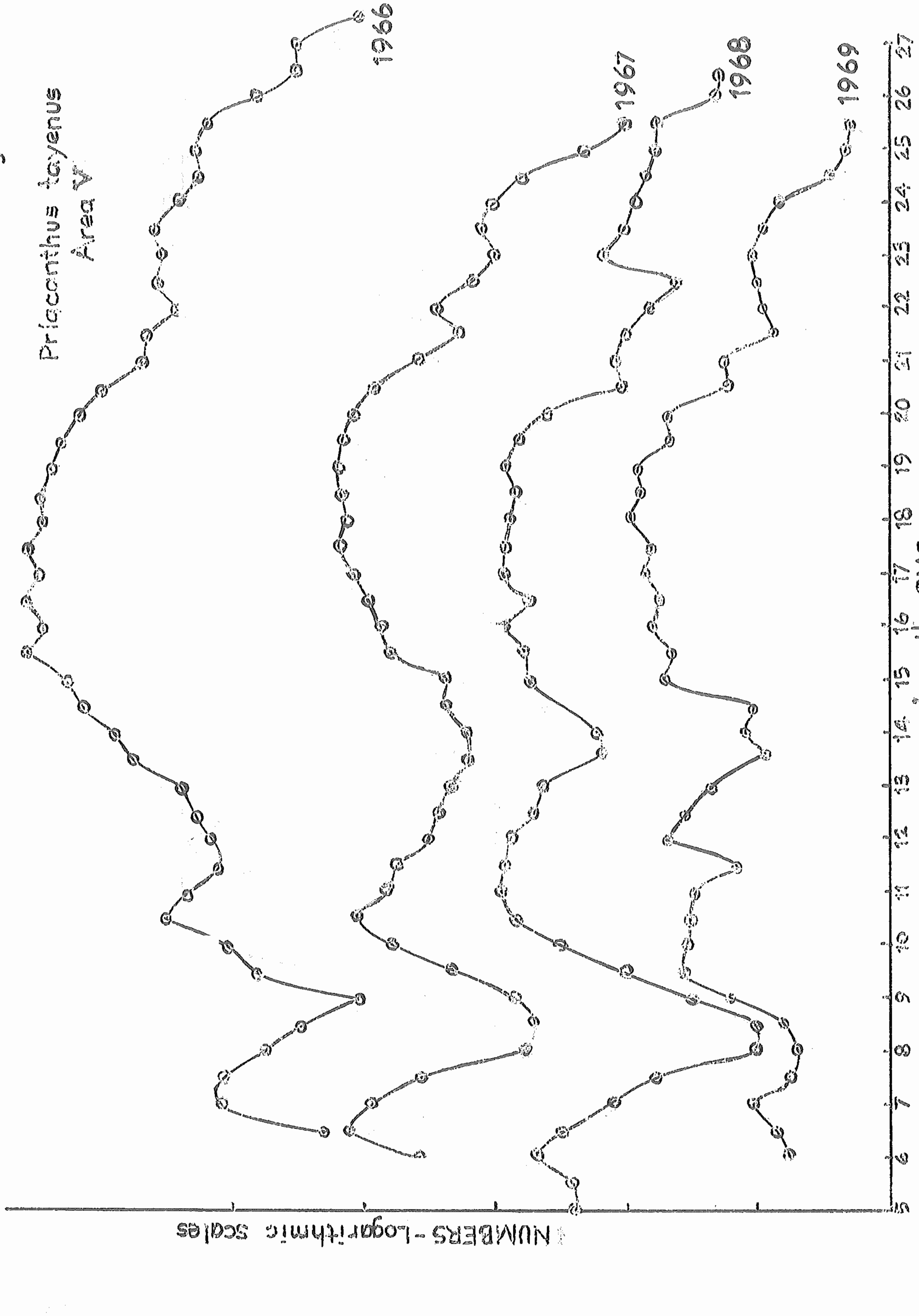
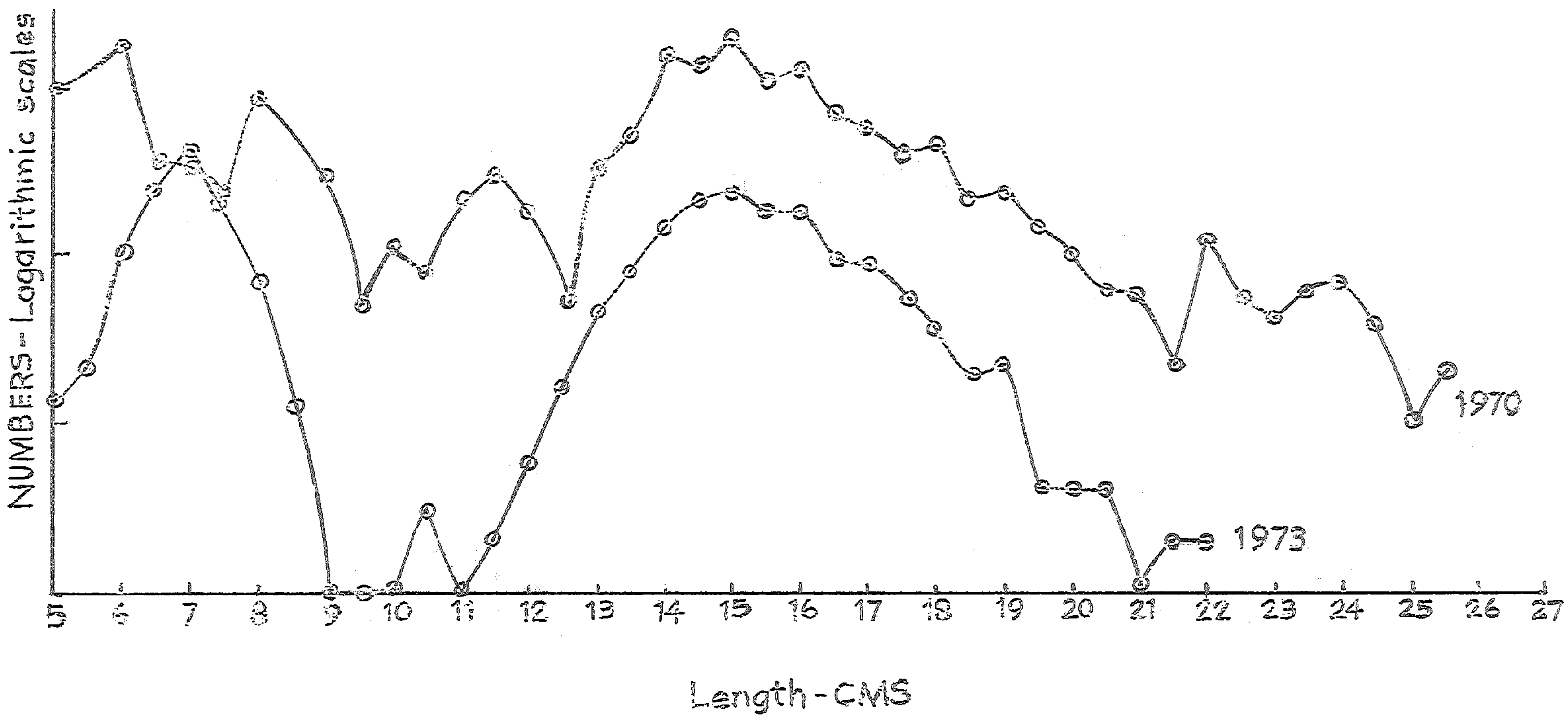


Fig.4.21
Priacanthus tayenus
Area V

Fig. 4.21 cont.


NUMBERS - Logarithmic scales
Length - CMS
1970
1973
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
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24
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27

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