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Gill-Net Selectivity of Bass and White Croaker Using Commercial Catch Data

by

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ABSTRACT

The object of this study was to determine a method of estimating the selectivity of gill nets for which catch data are available for only a few mesh sizes. For bass, a model inferring retention from girth measurements of fish and mesh dimension, but which is independent of catch data, resulted in wide selectivity curves, which could not be used to predict mesh size which would most efficiently catch fish in a particular range. Methods utilising observed frequency distributions of the ratio between mesh perimeter and fish length or girth provided good fits between the catch and selectivity curves for the mesh sizes most used in a bass (*Dicentrarchus labrax*) fishery. For white croaker (*Micropogonias furnieri*), only one approach can be adequately applied to data obtained from only one mesh size which depends on the inference of selectivity from girth measurements. The results were unsatisfactory because the selectivity curve underestimates the catch, the catch curve does not fall within the probability of capture and because these methods ignore any fishing trial with mesh size that should theoretically be selective on certain length ranges. The role and usefulness of the selectivity models in the management of gill-net fisheries is discussed.

1. INTRODUCTION

Commercial fishermen use the most suitable mesh sizes to catch the most abundant or economically valuable size classes of the available fish species, and only a few different mesh sizes are employed to catch a particular species. For practical reasons, therefore, a method of estimating gill net selectivity is required which is capable of using length distributions of commercial catches from only a few mesh sizes.

The objective of this study was to determine which analytical techniques can best be

Gear Selectivity/Technical Interactions Symposium used with commercial data to provide a scientific basis for advice on mesh size regulations. This was developed using as data set:

a) the length composition of bass (*Dicentrarchus labrax* L.) caught with gill nets of 4 different mesh sizes on the English and Welsh coasts, and applied to

b) the size frequency distributions of white croaker (*M. furnieri*) of the southern Brazilian coast caught with gillnets of only one mesh size.

2. MATERIAL

Data on the length frequency distributions of bass and white croaker were obtained from commercial gill-net fisheries. They were pooled by mesh size for the whole sampling period for each species, which reduces the influence that characteristic size distributions of particular year classes might have on the retention curves.

For bass, length frequency distributions were obtained from catches taken by inshore monofilament gill-net fisheries in English and Welsh coastal waters, during a study of the bass fishery in 1981-1984 (Pawson and Pickett, 1987). Although a wide range of mesh sizes was used throughout this multi-species fishery, only the samples of bass taken in nets with a stretched mesh size of 70, 82, 89 and 92 mm were considered to contain sufficient data for the analysis (n=95, 549, 580 and 274 fish respectively). Girth and length measurements of bass were obtained from biological samples of angling and gillnet catches.

For white croaker, length frequency distributions were obtained from catches taken by monofilament gill-net fisheries in coastal waters of southern Brazil in 1988-89 and 1991. A total of 3382 fish caught with a stretched mesh size of 140 mm were sampled for length during the 3-year period. Girth and length measurements of white croaker were obtained from samples of commercial trawl and coastal gill net catches, and from experimental catches with gill nets in the estuary of the Patos Lagoon (Reis, 1993).

3. METHODS

In order to transfer from girth to length, an overall relationship between maximum girth (G_{max}) and total length (L), of the form $G_{max}=a+bL$, was determined for bass and for white croaker, and between head girth (G_h) and total length for white croaker. Length frequency distributions of gill-net catches of bass and of white croaker were used in some of the chosen selectivity methods and to validate the resulting selectivity curves.

Reviews of selectivity models (see Regier and Robson, 1966; Hamley, 1975) indicated that two approaches are most applicable in situations where data from only a small number of commercially used mesh sizes are available. Therefore, in the case of bass, inference from girth measurements (Sechin, 1969a, 1969b) and the indirect methods of McCombie and Fry (1960) and Kitahara (1968) were used to estimate selectivity.

On the other hand, only one approach can be adequately applied to data obtained from only one mesh size. This depends on the inference of selectivity from girth measurements, and the procedures developed by Sechin (1969a, 1969b) and Kawamura (1972) were used for white croaker.

3.1. Inference from Girth Measurements

This method allows selectivity to be predicted from measurements of a species' maximum and head girths, provided that wedging and gilling are the main ways of capture, and the analysis is independent of size distribution data for gill-net catches. Sechin (1969a, 1969b) and Kawamura (1972) derived theoretical selectivity curves based on the following assumptions:

a) all fish are fully selected whose maximum girth is greater but head girth is smaller than the mesh perimeter; b) girths among any length class of fish are distributed normally with a common variance for all length classes.

Following Sechin (1969a), the length distribution of fish small enough to enter a mesh beyond the operculum is

$P(G_h < 2M) = \Phi((2M - G_h)\theta_h^{-1})$

and that of fish too large to pass through the mesh is

$P(2M < G_{max}) = \Phi((2M - G_{max})\theta_{max}^{-1})$ where

G_h is the mean head girth in the jth length interval, θ_h is the standard deviation of head girth, G_{max} is the mean maximum girth in the jth length interval, θ_{max} is the standard deviation of maximum girth, 2M is the mesh perimeter (M= mesh size when stretched between two opposite knots), and Φ is the cumulative standardised normal distribution function.

The length distribution of fish that are caught if they swim into the net, i.e., fish for which $G_h < 2M < G_{max}$, is

$S_j = \Phi((2M - G_h)\theta_h^{-1})[1 - ((2M - G_{max})\theta_{max}^{-1})]$ where

S_j is selectivity

Sechin (1969a, 1969b) added to this formula coefficients to account for compression of girth and variation in mesh size but, in view of the lack of relevant information, the formula presented above was used in this study for both bass and white croaker.

Kawamura (1972) expressed girth as function of length, and defined critical values of maximum and head girth between which fish would be retained by the net. These are:

$G_{mc} = 2\varnothing / k_m$ and $G_{oc} = 2\varnothing / k_o$ where

G_{mc}- critical value for maximum girth

k_m- the average degree of body compression at maximum girth, expressed as $k = 2\varnothing / G_{mc}$

G_{oc}- critical value for head girth

k_o- the average degree of body compression at head girth, expressed as $k=2\varnothing/G_{oc}$

$2\varnothing$- mesh perimeter.

For **bass**, two methods of estimating G_{max}, for each length class were considered. The first was simply to calculate the average of observed values, but there were insufficient data for some important length classes for this to be practicable. The second method assumed that G_{max} has an overall relationship with L. As there were very few data for G_h, this was assumed to be a fixed proportion of G_{max}.

Selectivity curves were estimated for mesh sizes for which catch data were available, and at two 4 mm increments above these, to examine the relationship between selectivity and catch curves. These calculations also provided information with which to judge the most "efficient" mesh size (i.e. that which maximises the proportion of those fish encountering the net which are retained) for the length ranges that predominate in the catch.

For **white croaker**, overall relationships between G_{max} and L, and G_h and L were used to estimate girths for each length class. For Kawamura's (1972) method, values of k_m and k_o were calculated from individual values of maximum and head girth at each length class and then averaged for the whole data set.

3.2. Indirect Methods

The indirect methods utilise size distributions of catches taken by gill nets of specified mesh sizes. They rely on assumptions about the nature of selectivity curves and their relationship with the mesh sizes used, but require no knowledge of the fish population's size composition. Using girth or length data from gill net catches, selectivity is related to mesh size for a given fish length, and these estimates are then used to predict how selectivity changes with fish length for a given mesh size.

McCombie and Fry's Method (1960)

Length distribution data from the catches by mesh size were converted to fish girth-mesh perimeter (G/P) ratios and their frequencies calculated for each mesh size for each fish size class. The number of fish captured in each length class was plotted against log (G/P). The ordinates of these size-class curves were brought to the same scale by shifting the ordinate of each plot to compensate for numerically unequal size distributions in the fished population, on the assumption that all mesh sizes had the same relative total catching efficiency over their respective retention ranges. To draw the master plot, these adjusted frequencies were grouped in intervals of 0.01 log(G/P) and the interval means calculated. The theoretical frequency curve was then estimated by referring the mean and standard deviation, together with the modal frequency of the master plot, to a table of ordinates for the normal frequency distribution. The relative frequencies of each length class of fish, which each mesh size would be expected to capture, was then estimated. As with the girth inference method, selectivity curves were calculated for 2 mesh sizes larger than that of the original.

Kitahara's Method (1968)

The catch per unit effort (C_{ij}) of fish in any length class L_j taken by a net of mesh size M_i, is given by

$C_{ij}=S_j(M_i,L_j)qD_j$

where q is the catchability at the peak of the selection curve, and D_j is the population density of fish at L_j.

A plot of log C_{ij} against log (L_j/M_i), for different length classes of fish, produces a family of parallel curves that can be superimposed by vertical adjustment, as in the previous method. Theoretically, the degree of adjustment is proportional to the relative (log) abundance of fish in the length ranges selected by various mesh sizes. To obtain the master plot, means of log catch frequencies were obtained for intervals of 0.01 log(L/M).

Selectivity is estimated as a function of L/M, by taking the anti-logarithm of the master curve and letting the peak represent 100% relative efficiency. It is then possible to estimate the relative frequencies of the various length classes of fish which any mesh would be expected to capture.

The resulting curves were compared with the catch curves by mesh size, and again selectivity curves for two larger mesh sizes were determined.

4. RESULTS

4.1. BASS

Girth vs Length Relationship

Linear regressions of the girth and length data for catches of bass taken by angling and gill nets were fitted separately, and the relationships were found not to be significantly different. The fitted regression for the combined gill-net and angling data was as follows:

$G_{max} = 14.09 + 0.5127\ L$ ($n=775$ $r=0.96$) and

$\theta_{max} = 0.0366\ L$

In the absence of appropriate data, the mean head girth was taken as being $G_h = 0.75\ G_{max}$, (a reasonable approximation to the actual proportion of head girth in relation to maximum girth, Pickett, G. pers.comm.), with its standard deviation θ_h assumed to be equal to θ_{max}.

4.1.2. Selectivity Estimates

Girth Inference Method (Sechin, 1969a)

The selectivity curves calculated for 70, 82, 89 and 92 mm mesh sizes are unimodal, skewed to the left and with more length classes above than below the mode (Fig.1). As the mesh size increases, the modal lengths shift towards higher length classes and the selection ranges increase. The results indicate that the probability of catching bass is highest at the 28 cm length group with a 70 mm mesh size, at 34 cm with an 82 mm mesh size, 37 cm with 89 mm and 38 cm with 92 mm. Only with the 89 mm mesh size did the calculated selectivity curve approximate to the length frequency distribution of the respective catch, and it is apparent that the fishery's catch curves were consistently narrower and had larger modal lengths than those of the corresponding selectivity curves.

Indirect Methods

McCombie and Fry's Method (1960)

The girth-perimeter ratio frequencies were calculated for each size class from 32 cm to 44 cm, these being the size classes that contributed to catches taken by all four commercially used mesh sizes. With the logarithmic transformation of G/P, the curves with adjusted frequencies all appeared to have the same symmetrical shape and were easily superimposed. Their modes varied between 0.06 and 0.117, expressed as log(G/P). The mean and the standard deviation of the master plot (Fig.2) were found to be 0.074 and 0.0299, respectively, with the mode, at 0.07. This fitted theoretical distribution of log (G/P) agrees reasonably well with that observed.

The resulting selectivity curves are shown in Fig.3, which can be compared directly with Fig.1, obtained using the girth inference method. The predicted efficiency of the 70 mm net appears to be highest for fish in the 30 cm length group, that of 82 mm at 35 cm, that of 89 mm at 38 cm, and that of 92 mm net at 40 cm. Comparison with the catch curves for the corresponding mesh sizes shows that the two curves overlap quite closely for both the 82 mm and 89 mm nets, whilst the catch curves of the 70 mm and 92 mm nets are more closely matched by selectivity curves calculated for mesh sizes some 4-6 mm larger than those actually used.

Kitahara's Method (1968)

Log catch numbers were plotted against the log of fish length-mesh size for fish in the 32-44 cm length range. Values for those length classes in which catches were low (< 5 observations) were not included in the master plot (Fig.4), which has a peak at log (L/M)=0.335. The selectivity curve derived from the master plot has a maximum relative selection efficiency at (L/M)=2.14.

Fig.5 shows catch and selectivity curves obtained by Kitahara's method and is directly comparable with Figs. 1 and 3, obtained using Sechin's and McCombie and Fry's methods, respectively. The selectivity curves for the 82 mm and 89 mm mesh sizes reflect the corresponding catch curves, but the 70 mm and 92 mm nets are again predicted to be more selective at smaller length classes than for those length classes most prevalent in the respective catches.

4.2. WHITE CROAKER

Girth vs Length Relationship

The girth and length data sets from catches of croaker taken by trawls, coastal gill nets and experimental estuarine gill nets were fitted separately, and the relationship for the experimental data was found to be significantly different from those for coastal gill net and trawling, which were similar. The fitted regressions for the combined coastal gill net and trawling data were

$G_{max}=-1.93+6.07L$ (n=617 r=0.98)

and

$G_h=-7.14+5.43L$ (n=619 r=0.95)

Standard deviations of maximum girth (θ_{max}) and head girth (θ_h) increased with length and linear relationships with y-intercept=0 were

$\theta_{max}=0.251L$ (r=0.77)

and

$\theta_h=0.203L$ (r=0.78)

In this case, head girth was not considered to be the girth measured at the posterior end of the opercula. Girths at the end of opercula, base of pectoral fin and anterior end of the first dorsal fin, are located on approximately the same imaginary line coincident with maximum girth (Reis, 1993), and head girth was therefore measured at the pre-opercula region.

4.2.2. Selectivity Estimates

Sechin's Method (1969a)

The selectivity curve calculated for 140 mm mesh size is unimodal and has a narrow range (Fig.6). The catch curve did not coincide with the selectivity curve of the 140 mm mesh, and showed an increased number of larger fish, but for both curves, the probability of catching white croaker appears to be highest at the 50 cm length group.

Kawamura's Method (1972)

A complete selectivity curve was not drawn due to the scarcity of points to generate a smooth line (Fig.6), but the estimated selection points show that the probability of catching croaker is estimated to be highest at the 55 cm length group. The catch curve fell well within the probability of capture for the large length ranges, but the selectivity points do not include the left arm of the length frequency distribution, which is the opposite of that indicated by Sechin's method.

5. DISCUSSION

5.1. BASS

Girth-length relationship estimated for bass, using data from angling catches (in which there is no selection by girth), did not differ significantly from that based on gill-net catches , and any difference in this relationship between fish caught by gill nets and the fish population in general is thought not to be a significant source of error. The shape of the fish's body can also explain some irregularity of selectivity curves (McCombie and Berst, 1969), though this does not seem to be the case for bass, for which selectivity curves are normally distributed.

5.1.1. Sechin's Method (1969a)

It was assumed that head girth was equal to 75% of the maximum girth and that the standard deviation by length was the same as that for maximum girth. Other, but still reasonable, values for the relationship between head girth and maximum girth and for the standard deviation of the head girth, were tested, but the resulting selectivity curves showed a much wider selection range of fish size than appeared in any of the catch curves.

The modal lengths of the catch were between 2% and 14% larger than those of the corresponding selectivity curves. However, it is probable that a measured mesh size underestimates that of the same net when it is fishing. A quickly swimming fish will force itself into a mesh by compressing its body and stretching the yarn of the net. An increase of 5-10% in the modelled mesh size resulted in overlapping catch and selectivity curves, and it is suggested that the formulae used here to estimate selectivity should allow for some degree of mesh stretching, which frequently occurs with monofilament nets (Potter, 1983). This effect could be investigated if catch data for nets of different material were available and the net characteristics were better known. Together with the excessive width of these selective curves, this suggests that, at least in the case of bass, this type of analysis should not be used to investigate catch efficiency or predict changes in yield with mesh size.

5.1.2. McCombie and Fry's Method (1960)

A gillnet will not catch fish by enmeshing as long as the fish's girth is less than the mesh perimeter, and retention is a consequence of maximum and head girth dimension and the elasticity of the fish's body and the net's mesh. As the maximum girth-mesh perimeter ratio exceeds unity, the efficiency of these monofilament gill nets in catching bass increased up to a maximum ratio of 1.17. Beyond that, the efficiency declined until it was negligible above a ratio of 1.32. This value of (G/P) at the position of maximum efficiency lies midway between that of 1.08, calculate for sockeye salmon (*Oncorhynchus nerka*) by Holt (1963), and 1.26, reported by McCombie and Fry (1960) for whitefish (*Coregonus clupeaformis*).

With this model, the selectivity curves of the 82 mm and 89 mm nets were similar to their respective catch curves, but the 70 and 92 mm mesh sizes were predicted to have catching efficiency maxima for bass which did not correspond to the modal sizes in the catch data. In practice, this result could be because during the fishing period, fish in the size range most readily selected were not so available as larger fish. There were fewer catch data for the 70 and 92 mm mesh sizes, suggesting that they are less frequently used than the 82 and 89 mm nets, which are more suited to the size range of bass available in the fishing area.

5.1.3. Kitahara's Method

Kitahara's (1968) master plot is usually determined by adjusting the plot of log catch vs log(L/M) for each length class (Fig.4) by an appropriate parallel shift. To minimise the subjectivity of superimposing curves in this way, we decided to use the mean of log catch by log (L/M) interval. This simple method of estimating selectivity is still rather subjective, because the results depend on how well the curves can be drawn by eye. Nevertheless, the relative frequencies of length group, predicted by Kitahara's method as being caught by a particular mesh size, are similar to those obtained with the method of McCombie and Fry.

5.1.4. Comparison between Girth/Mesh Perimeter Method and Indirect Methods

The selection ranges derived by Sechin's method are at least 50% larger than those derived by the methods of McCombie and Fry and Kitahara. In all cases, however, the length range of fish which are liable to be captured expands with increasing mesh size and the curves broaden. One of the fundamental assumptions of the indirect methods is that the selectivity curves of different mesh sizes are of the same shape, and this confirms that selection is by girth rather than by length.

Using Sechin's method, the peaks of selection efficiency occur at smaller length classes than those of McCombie and Fry and Kitahara, which predict the same modal lengths for particular mesh sizes. All three models, however, tend to generate selectivity curves for 70 and 92 mm mesh sizes that have peaks of efficiency at smaller fish lengths than the mode observed in the corresponding catch data. This could be a deficiency in these models, or it might indicate that, during the fishing period, fish in the size range most readily selected by these mesh sizes were not so available as larger fish. The 82 mm and the 89 mm nets, however, appeared to be operating within the most efficient part of their respective selection ranges, catching fish of 32-40 cm total length which were the main target for fishermen (Pawson and Pickett, 1987). It is therefore not surprising that the cumulative catches over 4 years and the selectivity curves for 82 and 89 mm are superimposed, because in these circumstances year-class-induced mortality is smoothed and catch curves begin to resemble selectivity curves.

To test whether the 82 mm and 89 mm mesh sizes were efficiently catching fish in length ranges thought to be representative of the available bass population, the selectivity curves were applied to a hypothetical length frequency distribution constructed to resemble successive year classes of equal original strengths. This was based on small-meshed trawl survey catch data for 2 and-3 group bass caught in a small-meshed trawl survey in September 1989 in the Solent (Pawson, in press). These length distributions were extrapolated over four age groups, at appropriate modal lengths and with allowance for instantaneous annual mortality of 0.5.

Figure 7 shows the length structure for this "population" and the resulting catch curves. It is apparent that Sechin's model is strongly influenced by the length distribution of available fish, most probably because it produces a wide selection range which spans the two adjacent age groups most likely to be caught in either 82 or 89 mm meshes. The results obtained with the models of McCombie and Fry and Kitahara, however, more closely replicate the catch curves actually obtained with these mesh sizes. In particular, they successfully predict the lengths and ages at which bass begin to recruit to gill nets. A shift in age of recruitment from 4 to 5 year olds, consequent on a change of mesh size from 82 mm (the gear most used in the Solent during the period of this study) to 89 mm, is apparent. Commercial fishermen are well aware of the benefits obtained by matching gill-net mesh sizes to length distribution of fish available to them. Mesh sizes were increased at approximately 6 mm increments each year as the extremely abundant 1976 year class of bass appeared as 3, 4 and 5 year olds in the inshore fisheries of southern England (M.G.Pawson, personal observations, 1980-82).

Sometimes there is a need for enforced changes in the mesh size of gill nets. Recently, regulations for the UK bass fishery have been introduced in order to protect juveniles, which reach maturity at 4-6 years of age (34-40 cm) (Pawson and Pickett, 1991). The justification for a prohibition of mesh sizes under 89 mm in this fishery was based on observations that commercial catches with this mesh size contain less than 10% of bass under the EC minimum landing size of 36 cm (Pawson and Pickett, 1987). The results obtained using the methods of McCombie and Fry and Kitahara support this argument, and clearly indicate that nets of 89 mm and above are not efficient at catching bass smaller than 36 cm.

5.2. WHITE CROAKER

The comparison of girth measurements of fish caught by different fishing gear showed that an overall relationship between maximum girth and total length could be estimated for white croaker by considering data from trawling and gill net catches together. Fish originated from these gears are caught exclusively in marine waters and their girths significantly differed from those of fish caught in the estuary with experimental gill nets. Estuarine fish showed smaller girths at length than fish caught in marine waters. This indicates a lower condition of fish that stay in the estuary for long periods (Reis, 1993).

Head girth, measured at the posterior end of the opercula, and maximum girth are similar due to the characteristic anterior profile of the croaker. If there is no difference between head and maximum girths, fish tend not to be enmeshed because head girth is not smaller than the mesh perimeter. That is the reason why the head girth for white croaker is considered to be the girth measured at the pre-opercula.

5.2.1. Inference from Girth Measurements

Girth inference methods are, naturally, very sensitive to girth measurements. It was observed that the degree of difference between maximum and head girth strongly affects the estimated efficiencies of the selectivity curves, i.e., the larger the difference between head and maximum girth is, the wider will be the selection range of the resulting selectivity curves. On the other hand, when head girth and maximum girth are approximately the same (as are the girths at the end of operculum and at the anterior end of the first dorsal fin in white croaker), selectivity curves have a narrow range. Variances of girths increased with fish size. This result indicated that one assumption, that the girths have a common variance δ^2 for all length classes, adopted for the girth inference method was violated. In an attempt to test the effect of a common standard deviation on the resulting selectivity curves, averaged standard deviations for maximum and head girth were expressed as the average for pooled length classes. The resulting selectivity curve did not show any difference from the selectivity curve obtained when considering increasing variance for larger length classes (Fig.8). Although constant variance was supposed to be one of the assumptions required to be satisfied in using these methods, it was found that its practical effect is much less important than the relation between maximum and head girth.

Selectivity curves for 140 mm mesh size estimated both by Sechin's and Kawamura's method partially overlapped the catch curve and the selection range was smaller than the catch curve.

The narrow selectivity curve found for white croaker is probably a result of its body shape. Comparing to bass, their anterior profiles differ, white croaker appearing to be more stouter than bass. Maximum girth and head girth measures of white croaker differ only slightly, and Jensen (1986) found a narrow selection range for burbot (*Lota lota* L.), which is also probably related to the fish's cylindrical body shape.

In view of the characteristics of the coastal gill net fishery being studied, only girth inference methods could be used to estimate selectivity for white croaker. The results of using Sechin's or Kawamura's methods are not satisfactory, however, for the following reasons:

a) the selection range is narrower than the catch curve range, unlike the wider selectivity ranges for other species estimated by the same methods (Kawamura, 1972; Ehrhardt and Die, 1988);

b) the catch curve does not fall within the probability of capture;

c) although the purely theoretical approach allows selectivity to be estimated in almost any circumstances, providing girth measurements are available, it is not easy to accept the results as being completely trustworthy, because they ignore any fishing trial with mesh size that should theoretically be selective on certain length ranges.

6. GENERAL DISCUSSION

The relationship between the size distribution of fish in the catch and that in the population being fished can be affected at any stage of the capture process: the geographic distribution of the fish and the fishery must overlap in time and space, the fish must encounter the net, and finally be caught and retained. To minimise the effect of "patchy" fish distributions and variations in relative abundance of the year classes of bass (Pawson and Pickett, 1987) and white croaker accessible to the fishery, the data on fish length distributions in gill net catches were pooled for several years by mesh size. The procedure has the additional benefit of smoothing modality induced by year class size distributions, so that catch curves begin to resemble selectivity curves.

Girth-based methods for determining selectivity of gill nets require that fish are, in practice, caught by becoming enmeshed between the operculum and the fishes' maximum girth. However, fish which have become tangled in the net can sometimes account for a significant proportion of the catch and, in these circumstances, compound selectivity curves are required. Bass and white croaker were mostly enmeshed, which is corroborated by the fishery's catch curves, which are relatively narrow and unimodal for all mesh sizes. In this case, compound selectivity curves are considered to be an unnecessary complication.

Whilst selectivity curves can be used to provide an estimate of the relative numbers of each size group in the population from which the catch is taken, the index of efficiency discussed here indicates only that proportion of fish which one mesh size will capture relative to other meshes. It does not show directly what fraction of the available fish population any mesh size will catch (i.e., the net's absolute effectiveness).

Precise estimates of average girths for each length class are required for valid results, and the distribution of the girths should be that of the fished population and not of the gill net catches alone (M.Nicholson, pers.comm., 1990). When girth measurements are taken from fish caught by gill nets only, they will show reduced variance due to the nets' high selectivity for girth, leading to bias in the results.

Inference from Girth Measurements

The girth inference method's main advantages are that it can be used in the absence of catch data and its mathematical expression is simple, though more complex equations can be used depending on the information available (see, for example Sechin, 1969a, 1969b; Kawamura, 1972). The model assumes that the length distribution of fish caught by gill nets follows a normal function, but selectivity curves are generally skewed to the left, which suggests that models incorporating appropriate transformations are likely to be more satisfactory (Regier and Robson, 1966). Their application is limited to those species of fish which are normally caught by wedging or gilling. No account is taken of fish that are tangled in the nets. Their purely theoretical approach is their main weakness. Whilst this method does not require catch data for its application, catch curves should be available in order to validate the resulting selectivity curves.

Indirect Methods

Methods of estimating selectivity which indirectly use length or girth frequency data for actual catches can be used to predict a minimum mesh size which will support a regulation aimed at increasing the size at which fish recruit to a gill-net fishery. It is suggested, however, that these methods fail to describe properly the entire selection characteristics of gill nets and care should be taken in using them.

The methods of McCombie and Fry (1960) and Kitahara (1968) gave satisfactory results for bass, but it appears that only where adequate catch data are readily available for nets with mesh sizes selecting the most abundant length ranges in the local fish population, can models be developed which not only fit the catch curves but are validated by them. That is, a knowledge of the size distribution in the fished population is still important. Extrapolation to other, less well used, mesh sizes is made with less confidence, and these methods are unlikely to provide a robust basis for advice on mesh sizes intended to maximise yields in gill-net fisheries, for example.

7. GENERAL CONCLUSION

Selectivity curves, expressed as relative retention efficiency by length class, when applied to population length frequency distributions, will seldom precisely replicate actual catch at length data. Retention is by girth and not by length, and the variance of girth, particularly in length classes longer and shorter than the mode, should be taken into account.

It is difficult to estimate selectivity when only data from one mesh size are available. The analytical investigation using bass data helped to identify the possible methods to estimate selectivity with data originated from few mesh sizes, and emphasised the need to validate selectivity estimates regardless of the method used. Estimates of selectivity of white croaker presented in this study, although not entirely satisfactory, are the only ones available. Many papers have been recently published on selectivity of gill nets (Jensen, 1986; Densen, 1987; Amarasinghe, 1988; Ehrhardt and Die, 1988; Winters and Wheeler, 1990; among others) but most of them are based in traditional approaches, which are not to be usable with data originating from only a few mesh sizes. Gill nets are frequently used in developing countries where infrastructure conditions are far from ideal, and methods of estimating selectivity that rely on experimental fishing to collect data are unlikely to be put into practice.

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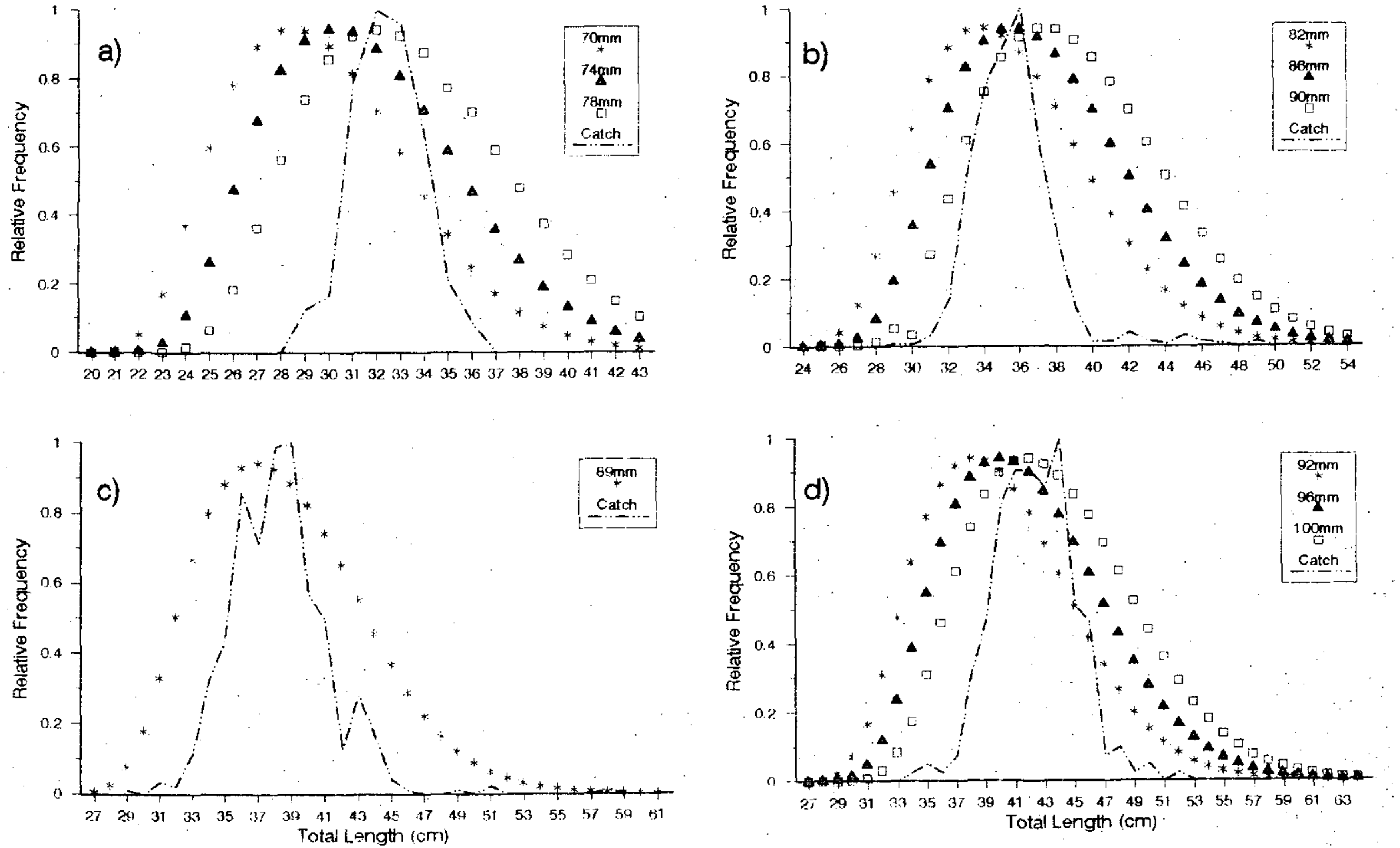
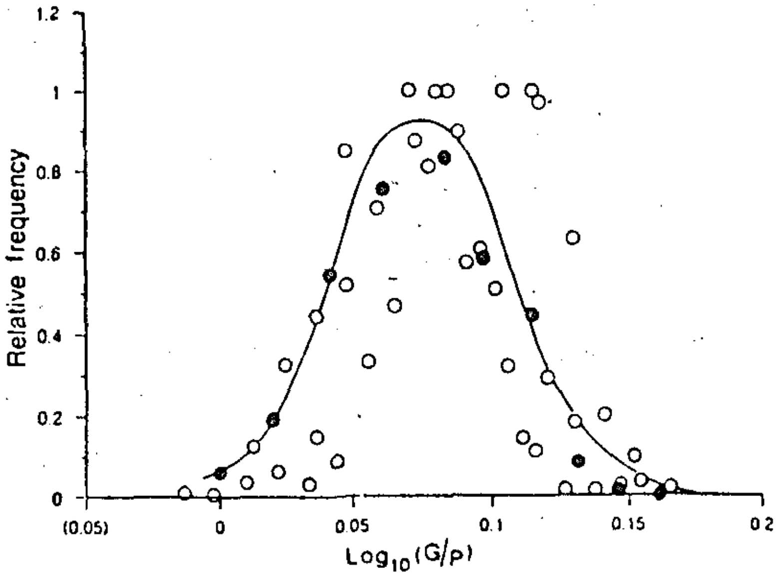
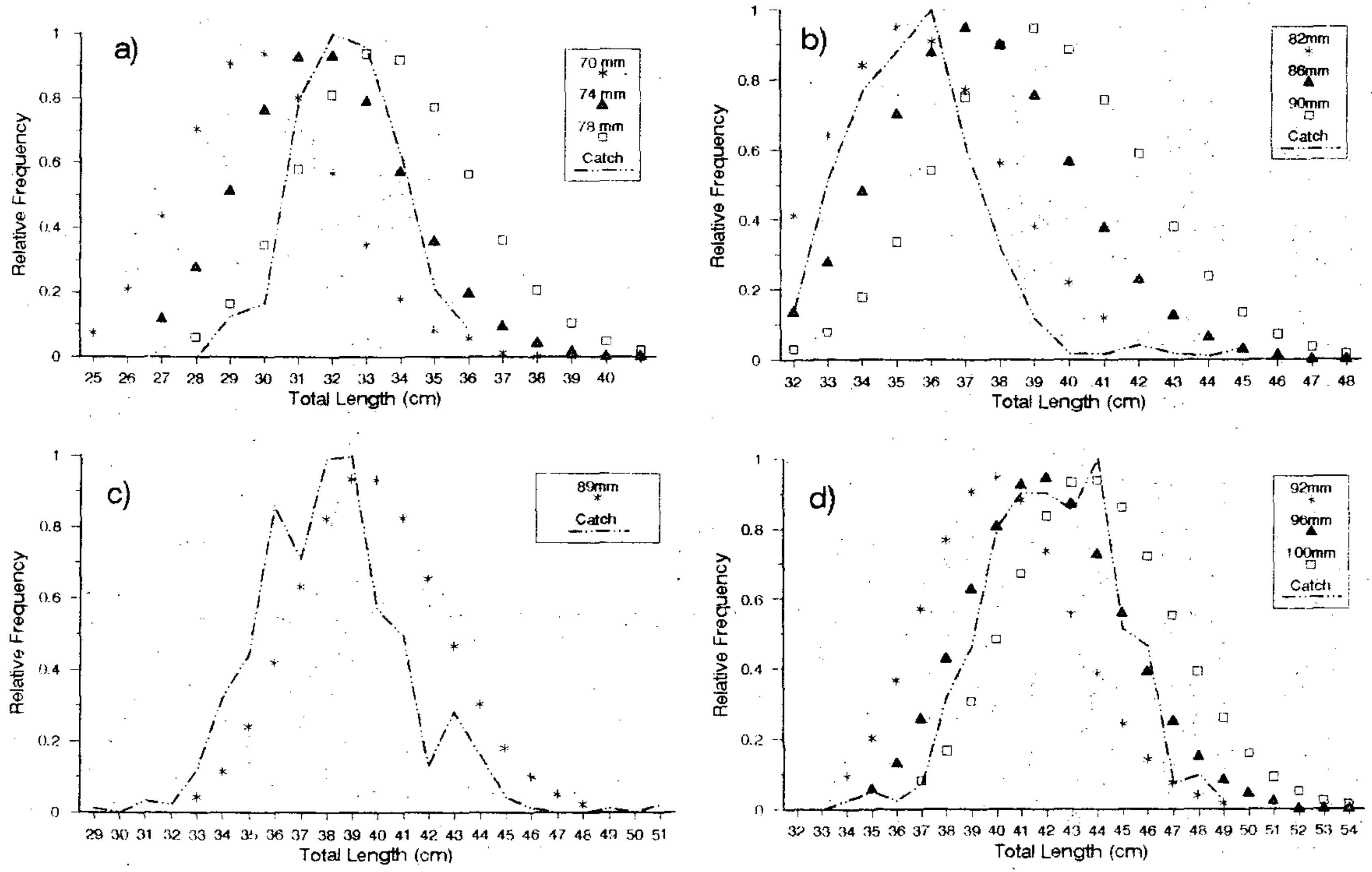


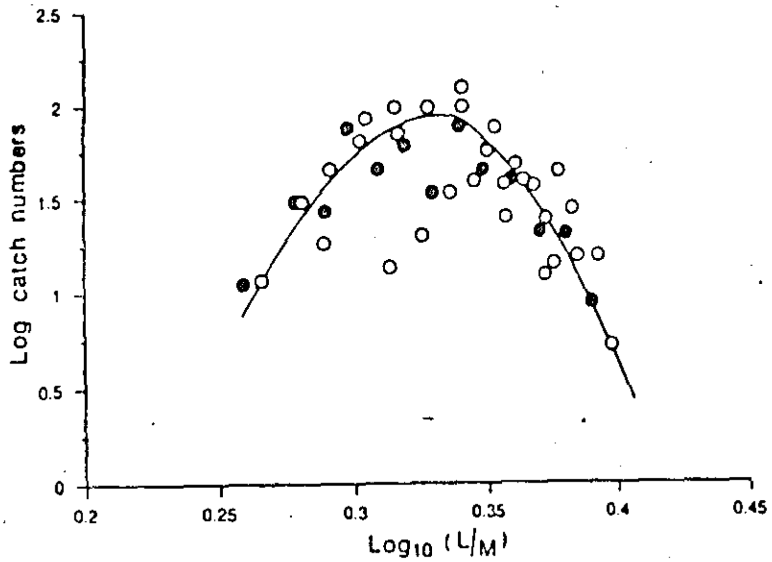
1- Selectivity curves for bass in monofilament gill nets calculated using a girth inference method and corresponding catch length frequency distributions for: (a) 70 mm mesh; (b) 82 mm mesh; (c) 89 mm mesh; (d) 92 mm mesh.



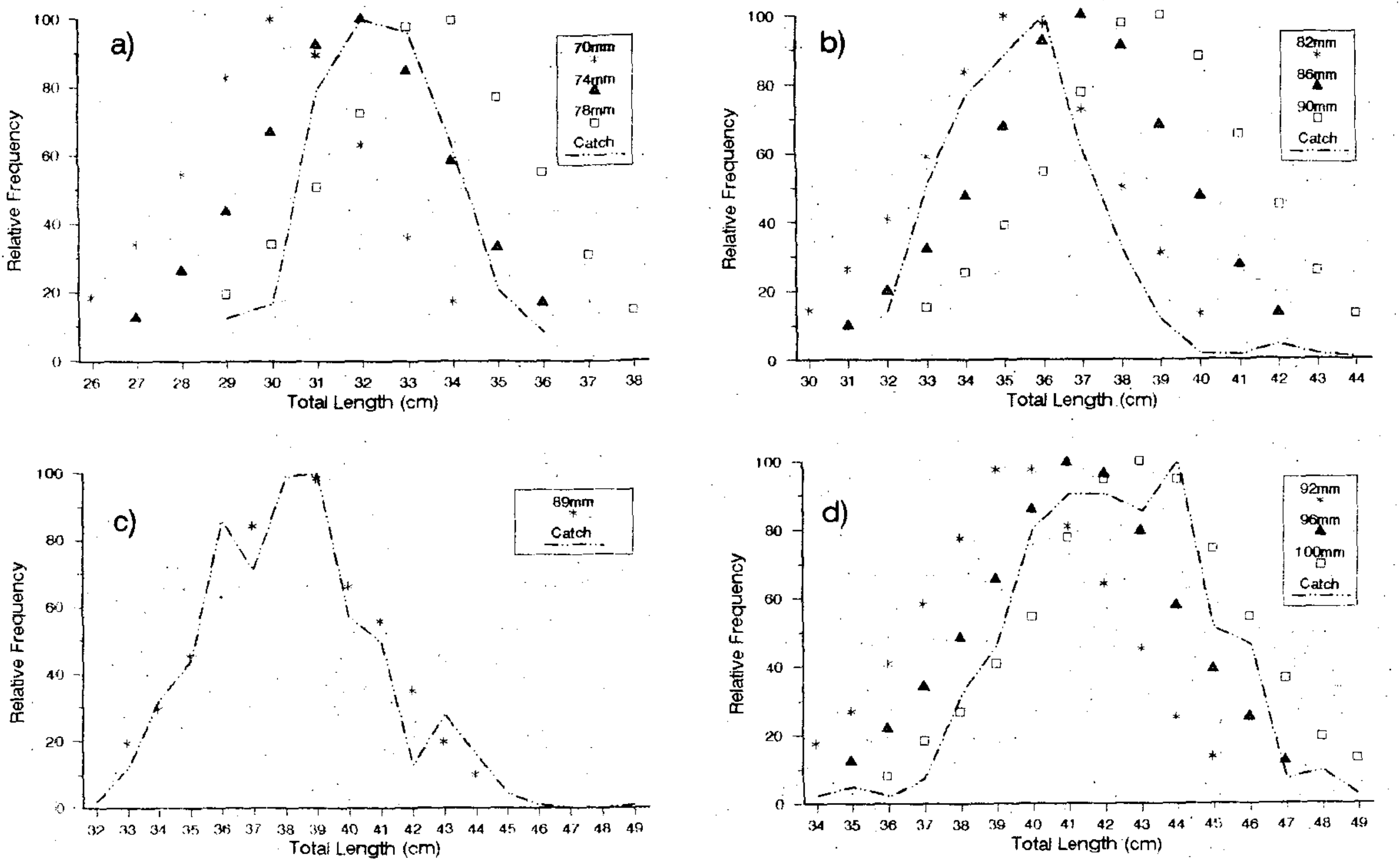
2- Theoretical frequency curve of the master plot of $\log_{10}$ (fish girth-mesh perimeter) for bass in monofilament gill nets:(●) denotes calculated means of adjusted log (G/P) frequencies; (O) denotes observed values.



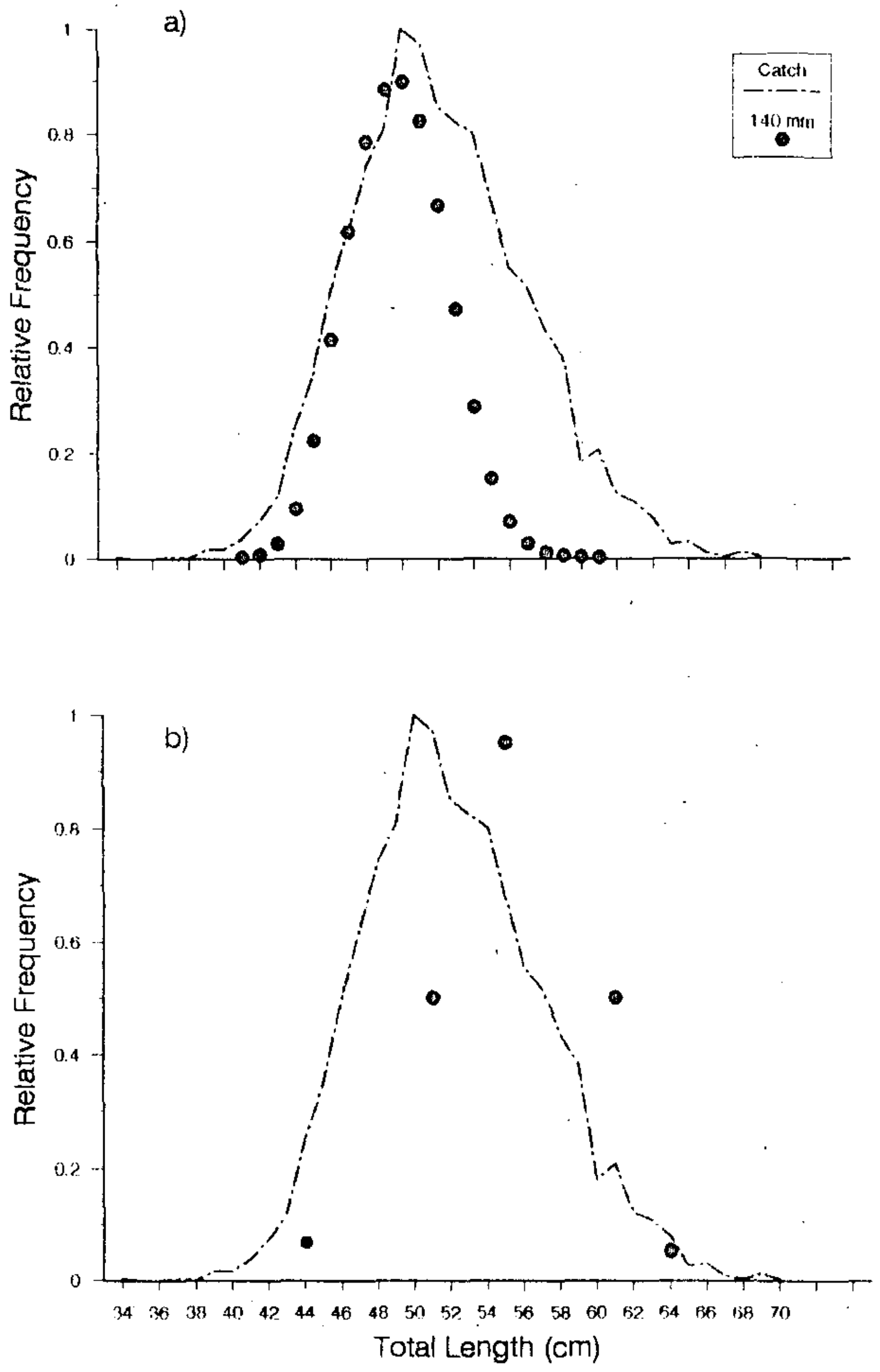
3- Selectivity curves for bass in monofilament gill nets based on the master plot shown in Fig.2; and corresponding catch curves for: (a) 70 mm mesh; (b) 82 mm mesh; (c) 89 mm mesh; (d) 92 mm mesh.



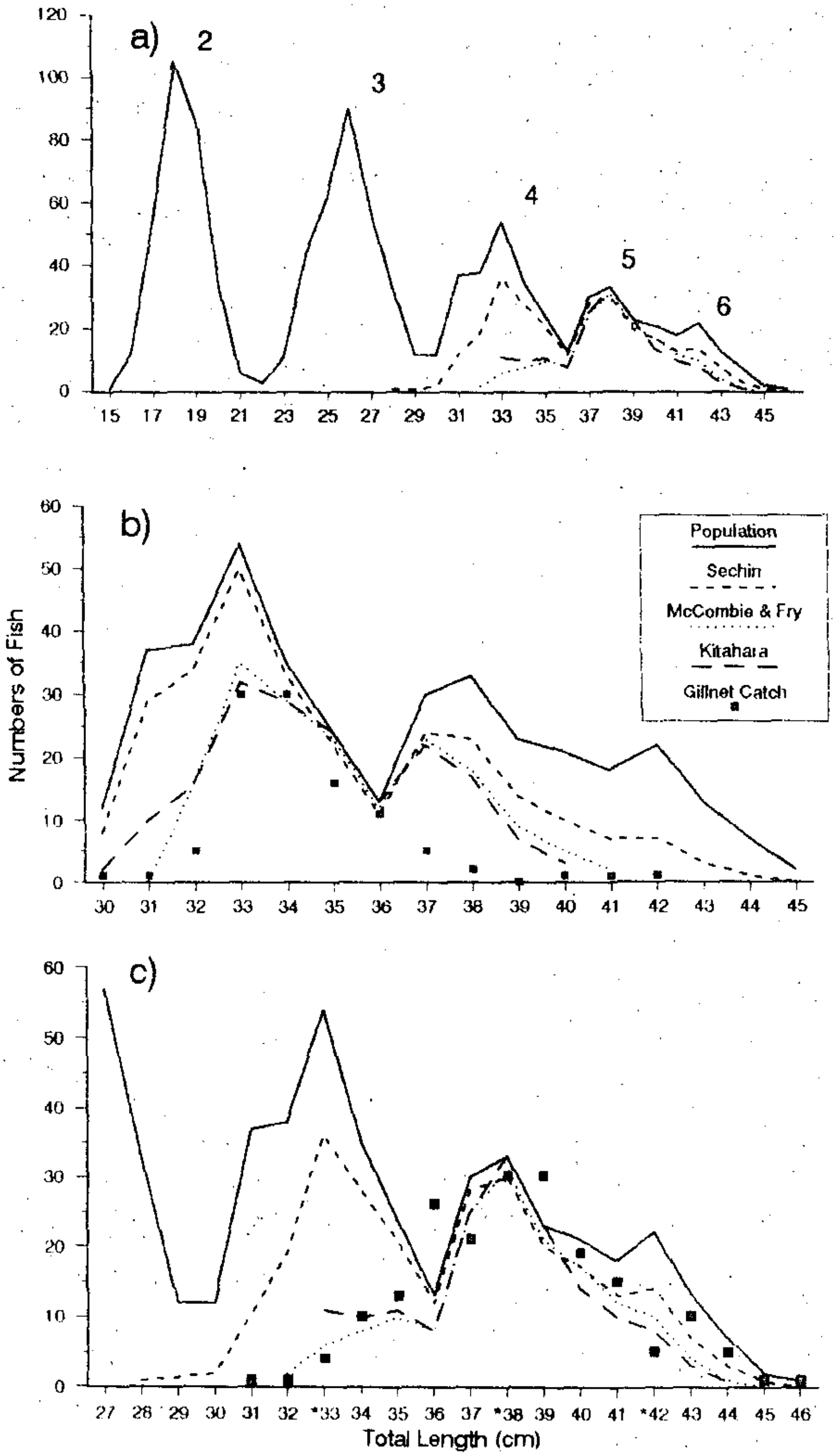
4- Theoretical frequency curve of the master plot of $\log_{10}$ (fish length-mesh perimeter) for bass in monofilament gill nets:(⊛) denotes calculated means of $\log_{10}$ catch frequencies; (○) denotes observed values.



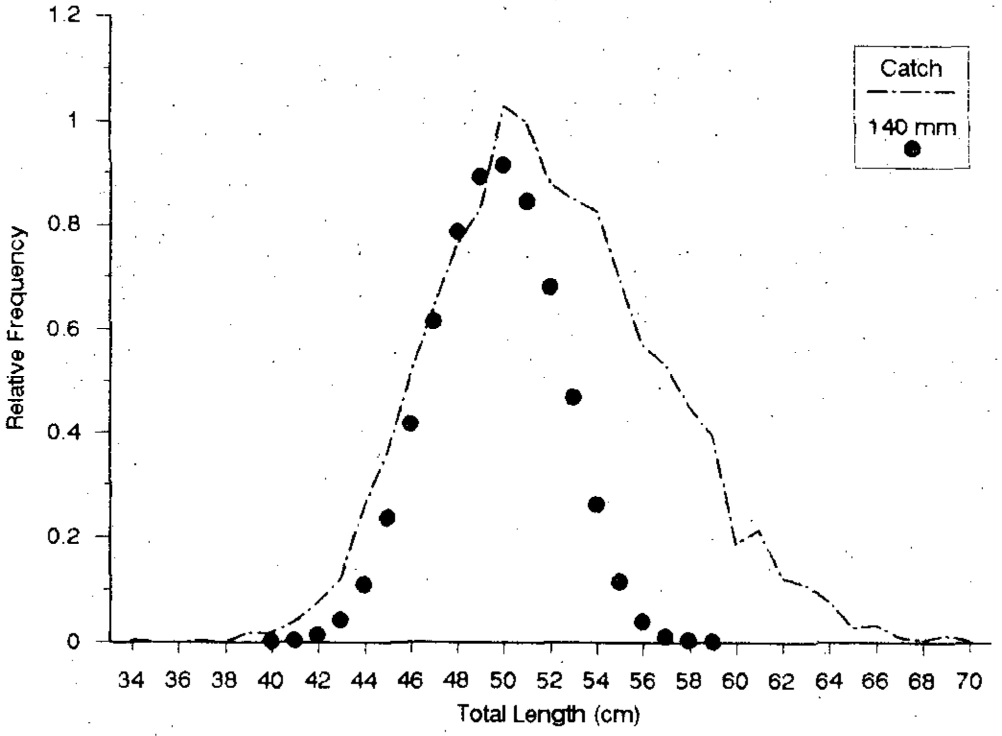
5- Selectivity curves for bass in monofilament gill nets based on the master plot shown in Fig.4, and corresponding catch curves for: (a) 70 mm mesh; (b) 82 mm mesh; (c) 89 mm mesh; (d) 92 mm mesh.



6- Selectivity curves for white croaker in monofilament gill nets using Sechin's and Kawamura's girth inference methods, and corresponding catch length frequency distribution for 140 mm mesh.



7- Hypothetical length frequency distribution of 2-6-year-old bass showing (a) retention curves for 82 mm mesh based on three selectivity models; (b) the same theoretical retention curves and actual commercial gill net catches for 82 mm mesh; (c) theoretical retention curves and actual commercial gill net catches for 89 mm mesh.



8- Selectivity curve of white croaker estimated using a constant standard deviation for maximum girth and head girth (Sechin's method).