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The effect of fish morphology and behaviour on the efficiency of gill nets, their selectivity and by-catch: two examples from southern Brazil

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ABSTRACT

The catchability of fish and their size selection by gill nets are either affected by factors that are related to the characteristics of the net or to characteristics of the fish. The pelagic bluefish *Pomatomus saltatrix* and the demersal striped weakfish *Cynoscion guatucupa* are exploited in southern Brazil by surface and bottom gill nets, respectively. Catch rates are efficient for both species when body girth is equal to, or slightly greater than, the mesh perimeter (180 mm); i.e. a ratio of girth at capture to mesh perimeter equivalent to 1.0 and 1.1. However, fish are still caught even when this ratio is as high as 1.3 and 1.4 but such captures can be related to both the elastic properties of the nylon netting and to the compression capacity of the fish's body. Bluefish have a capacity of body compression to ease passage through the netting; superior to that of the striped weakfish. When estimating gill net selectivity the behaviour and body shape of the species should be taken into account. Both bluefish and striped weakfish have similar girths along their body length and each of the two species is a by-catch within the targeted fishery of the other species.

Keywords: bluefish; by-catch; gill net; selectivity; striped weakfish

INTRODUCTION

Compared to other fishing gears, gill nets are highly size selective and, for a given mesh size, age or length class have differential fishing mortality because catches decrease sharply for fish either smaller or larger than the modal size class retained (Regier 1969).

Apart from fish size, Hamley (1975) lists a number of factors affecting the gill net selectivity such as the reaction of fish to nets (behaviour patterns), the type of netting construction adopted, its hanging ratio and the visibility, elasticity and thickness of meshes.

In southern Brazil, the gill net exploitation of the bluefish *Pomatomus saltatrix* (up to 72% of species annual total landings) and the striped weakfish *Cynoscion guatucupa* (up to 32% of species annual total landings) occur during the winter months (June to September). The fleet operation comprises the area between Conceição and Chuy, mainly in depths between 10 and 40m (Lucena & Reis 1998) (Figure 1).

The coastal gill net fleet is composed of around 100 boats of 16m average length (Boffo & Reis 1997) which use a surface drift gill net of 1800m in length (18m high) and a stretched mesh size of 90mm for bluefish; whilst striped weakfish are caught by a bottom net of 6500m in length (3m high) and a mesh size of 90mm (Lucena & Reis 1998). However, the bluefish and the striped weakfish are not commercially exploited independently. Each of the two species is a by-catch within the targeted gill net fishery of the other which make them technically dependent.

The paper attempts to address the main factors relating to fish body shape and behaviour, which affects the gill net's efficiency and selectivity. Furthermore, the causes and consequences of the technical interactions arising from the exploitation of the bluefish and striped weakfish are discussed.

MATERIAL AND METHODS

Sampling data

During routine visits to the landing sites of the commercial fishery the total length (TL) of 8,629 bluefish and 5,889 striped weakfish derived from gill net landings were measured to the nearest centimetre. Length compositions were evaluated by the targeted and non-targeted catch composition in the gill net fishery. For the bluefish the species length distribution in the targeted fishery was compared to the length distribution in the non-targeted fishery (striped weakfish targeted fishery). The same was applied for striped weakfish.

Body shape and the process of gill netting

Because the bluefish is recorded as by-catch in the target striped weakfish gill net fishery and vice-versa, similarities in the body shape of both the bluefish and the striped weakfish were investigated. For this purpose, within the routine visits to the landing sites, during one year's fishing season, at a weekly interval, 20 Kg of bluefish and 20 Kg of striped weakfish were randomly select from vessels' landings. In the laboratory, all girth measurements were made to the nearest millimetre with a loop of non-stretchable synthetic twine. Girth measurements were recorded at eight positions along the species' body: orbital (Orb), preopercular (Pop), opercular (Op), pectoral fin (Pect), first dorsal fin (D1), second dorsal fin (D2), anal fin (Anal) and caudal peduncle (CP). Girths were measured on 364 bluefish (TL varying from 290 to 711mm) and 402 striped weakfish (TL varying from 312 to 591mm) (Figure 2).

The species' body shape was described by plotting the girth at each of the eight predetermined positions against the distance from the snout to the respective position (McCombie & Berst 1969). Girths and distances measured from the snout were expressed as proportions of total length and averages for each position were determined. To analyse the catching methods, the relative frequencies of the fish caught against the ratio G/P (maximum girth/mesh perimeter) and against the ratio Gc/P (girth at the position where the fish were caught/mesh perimeter), discriminated by points of enmeshing were plotted based on the methodology described by McCombie & Berst (1969).

The by-catch of the targeted bluefish and striped weakfish is obtained from catch records from coastal landing sites collected directly from fleet managers for the period 1994-1997. These comprised the specific catch of 1050 trips operated by 25 different gill net boats.

The influence of the body compressibility and the elasticity of the netting in the estimation of gill net selectivity

Of the methods used to estimate gill net selectivity, those inferring retention from girth measurements (e.g. Sechin 1969a,b, Kawamura 1972) can be applied in situations where data can be obtained at only a limited number of different mesh sizes or more extremely, at only one mesh size. Although use of this methodology is the only option for such a situation, their purely theoretical basis is often their main weakness (Reis 1992).

The method 'Inference from Girth Measurements' (Sechin 1969a,b) is derived assuming that all fish are fully selected whose maximum girth is greater than the mesh perimeter (but whose head girth is smaller); and girths among any one length class of fish are distributed normally. The girth at the region of the opercular determines the maximum size of fish held and the maximum body girth determines the minimum size of fish held.

The length distribution probability of fish small enough to enter a mesh beyond head girth and that of fish too large to pass through the mesh ($G_h \leq 2M \leq G_{max}$) is:

$$S_j = \phi \{(2M - G_{hj}) / \sigma_{hj}\} [1 - \phi\{(2M - G_{maxj}) / \sigma_{maxj}\}]$$

where S_j is the probability of retention of fish of size-class j, G_{hj} is the mean head girth for fish of size-class j, σ_{hj} is the standard deviation of head girth of size-class j, G_{maxj} is the mean maximum girth for fish of size-class j, σ_{maxj} is the standard deviation of maximum girth of size-class j, 2M is the mesh perimeter and ϕ is the cumulative distribution function of the standard Normal distribution. The analyses were performed for both species with a 90mm mesh net; corresponding to 180mm at the perimeter (2M).

However, this approach ignores that fish behaviour and elasticity of the twine may have influence on the smaller and/or larger fish retained. The perimeter/girth ratio or K value (denoted K_h and K_{max}), which quantifies the compressibility at retention girth and the elasticity of the twine, can be estimated from individual measurements on girth at the meshing mark and incorporated in the theoretical selectivity curve (Kawamura 1972, Pet et al. 1995) which becomes:

$$S_j = \phi \{(2M - K_h G_{hj}) / \sigma_{hj} \} [1 - \phi\{(2M - K_{max} G_{maxj}) / \sigma_{maxj} \}]$$

where K_h is the mesh perimeter/retention girth ratio in the opercular position and K_{max} is mesh perimeter/retention girth ratio in the maximum position (first dorsal fin).

For this study, K's values were obtained from the actual measures of the retention girth (head and maximum). The retention girth was recorded at the landing sites in 280 bluefish and 517 striped weakfish at the mark left by the mesh.

RESULTS

Gill netting technical interaction

The bluefish caught by a targeted and non-targeted fishery are very similar in length. This also applies to the striped weakfish (Table 1).

Gill net by-catch

The by-catch of the targeted bluefish gill netting varied among sampled years. The higher proportion of by-catch is due to the menhaden *Brevoortia pectinata*, the amberjack *Parona signata* and the striped weakfish, which constitute an average 17% (by weight) of the total catch (Table 2a). The annual variability in the by-catch of the targeted striped weakfish gill netting is also reported in Table 2b. This fishery is, compared to the targeted bluefish fishery, more species-diverse and, the argentine croaker *U. canosai*, the codling *U. brasiliensis*, the bluefish, elasmobranchs and the white croaker *M. furnieri* comprise 21% of the total catch.

Body shape and the process of gill netting

The body shapes of the bluefish and the striped weakfish are similar. For both species, the maximum girth is located near the first dorsal fin and girths at the opercular and the pectoral fins are similar but slightly smaller than the maximum girth (Figure 3). Girths at the second dorsal fin for both species are similar to those at the first dorsal fin, but the striped weakfish body becomes slimmer in its terminal portion when compared to the bluefish.

Concerning the catching process, bluefish were mainly enmeshed in the opercular and pectoral fin region (57.8%), with 26.8% caught at the first dorsal fin and 11.1% caught at the preopercular region (Table 3). Only 4.3 % of bluefish are caught at the second dorsal fin. striped weakfish were also mainly enmeshed in the opercular and pectoral fin region (71.8%), with a larger proportion caught by the preopercular region (22.2%) and relatively few at the first dorsal fin (5.2%). Less than 1% of *C. guatucupa* is caught at the orbital region. Smaller fish are often caught near the maximum girth region and the larger fish caught near the head.

For both species, there are a number of values of the ratio Gmax/P greater than or equal to 1.3 (24.6 % and 34.4% for the bluefish and striped weakfish, respectively) and no values less than 1.0 (Figure 4, left-hand graphs). When considering the girth where fish were actually caught (Gc/P), for both species the modal value was 1.1, except for fish caught at the preopercular region and orbital (in the case of the striped weakfish), where the modal value was 1.0 (Figure 4, right-hand graphs). The average girth where fish were caught is 195mm for both the bluefish and striped weakfish with a mesh perimeter of 180mm.

The influence of the body compressibility and elasticity of the netting in the estimation of gill net selectivity

For both species, the retention curves estimated are distinct in shape and mode depending on the inclusion/exclusion of the K factors. When compared to the length frequency distribution of catches for the single mesh size, the theoretical retention curves without the K factors are to the left of the modal catch (Figure 5).

Both the average K_h and K_{max} are greater for the striped weakfish, 0.971 (σ = 0.049) and 0.906 (σ = 0.045), than for the bluefish, 0.954 (σ = 0.064) and 0.881 (σ = 0.052), and for both species K_h is greater than K_{max}.

DISCUSSION

In some fisheries, the gear comes into contact with stocks of different species, and a mixed catch results due to the exploitation of technologically interdependent species (Anderson 1986). The effect of incidental catches in non-targeted species is of increasing concern (Hudson & Mace 1996). As a wide variety of fish species occupy the same habitat, fishers are generally unable to catch individual species without some unintended catch of other species (Pascoe 2000a). Gill net's by-catch is proportionally less in weight and in bio-diversity when compared to trawlers, but the gear is highly selective for certain size-classes of fish.

For a given mesh size, the similarity between body shape determines which species are potential by-catch in a targeted gill-net fishery (McCombie & Berst 1969, Reis & Pawson 1999). In southern Brazil, the bluefish and the striped weakfish have a similar body shape, both are fusiform and lacking protuberances and spines. Their girths are similar along their body length, except for the terminal portion where the striped weakfish are slimmer than the bluefish. Thus, both species are caught in the others targeted fishery. There is no difference between the length composition in both targeted and non-targeted fisheries for both species. We can consider that in terms of size-classes exploited, the effects of the targeted and non-targeted fisheries are similar for both the bluefish and the striped weakfish.

For both species, in targeted or non-targeted fisheries, catch seems to be most efficient when the girth is equal to or slightly greater than the mesh perimeter; i.e. girth at capture/mesh perimeter ratio equivalent to 1.0 and 1.1, but they were also caught when this ratio was as high as 1.3 and 1.4. Such capture can be related to the elastic properties of the nylon netting as well as to the compression capacity of the fish's body.

The amount of by-catch may be influenced by the targeted species abundance and accessibility. Maximum and minimum percentage of by-catches are often recorded together with lower and higher catches of the targeted species respectively. Bluefish, for example, recorded the minimum percentage of by-catch in 1995, when it was recorded a maximum in specific catches (IBAMA, unpub.). The opposite trend was reported for 1997. It seems that netting is mostly (and quickly) saturated with the target species, when it is accessible and abundant. In contrast, other non-target species catches are significant when the target is not abundant.

The analysis of a by-catch could be approached from an economic perspective. For non-commercial by-catches, the discard is a fairly straightforward decision as there is no associated benefits with landing the species (Pascoe 2000a). For commercial by-catch, the decision on discards will depend on the expected price received, the cost of landing and the opportunity cost of storing fish on-board (Pascoe 2000a). On the other hand, the costs of capturing incidental catches are negligible (Pascoe 2000b), and in accordance to cost-benefit analysis, fishers may decide to land the unwanted catches. In these cases by-catch should be accounted into the gross revenue of a fishery, otherwise the fleet profit will be under-estimated. The unwanted catches of gill nets are for most cases commercialised because, the select numbers of species are most valuable and, due to the gear selectivity, under the law and within market consumption sizes.

Sechin's methodology can incorporate coefficients to account for body compressibility at the retention point and elasticity of the netting - the K factors. These factors are inversely related to compressibility of the fish or elasticity of the mesh. It can be assumed equal to 1 (e.g. Reis & Pawson 1992), but for a number of species, this factor is often less than 1 and may vary according to the morphological and behaviour characteristics of the species (Clarke & King 1986, Ehrhardt & Die 1988, Pet et al. 1995). The K_h factor is greater than K_{max} due to the lesser compressible capacity of the opercular region than the maximum girth region (Clarke & King 1986, Pet et al. 1995). K-factors are smaller for bluefish than for striped weakfish suggesting that, bluefish a pelagic voracious predator (Lucena et al. 2000) has a great capacity of body compression to ease passage through the netting; superior to demersal habit species such as the striped weakfish although this fish also has a considerable body compression. The monofilament 0.5 mm twine utilised to manufacture the gill net used in the Brazilian coastal fishery (Lucena & Reis 1998) has elastic properties and in conjunction with fish behaviour, this enhances the chance of large specimens of bluefish and striped weakfish being caught in nets designed to catch smaller sized specimens.

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Table 1 – Average length in cm, standard deviation (sd) and sample size (n) for bluefish and striped weakfish caught by target and non-target fishery

	Bluefish	Striped weakfish
	Average (sd,n)	Average (sd,n)
On targeted fishery	41.7 (3.7, 7377)	43.9 (3.5, 3267)
On non-targeted fishery	42.5 (4.7, 2846)	43.8 (2.7, 143)

Table 2 - Gill net by-catch (in weight) by year for the targeted (a) bluefish, (b) striped weakfish

(a)

	1994	1995	1996	1997	average
Bluefish	*66.4*	*88.8*	*83.7*	*78.1*	*79.2*
by-catch	*33.6*	*11.2*	*16.3*	*21.9*	*20.8*
B. pectinata	22.1	8.2	3.1	0.0	8.3
P. signata	2.8	1.6	11.5	2.3	4.6
C. guatucupa	5.7	0.9	0.6	9.8	4.3
Mullet	0.0	0.0	0.0	3.8	1.0
U. brasiliensis	1.5	0.0	0.6	0.7	0.7
Menticirrhus americanus	0.1	0.0	0.1	2.0	0.6
M. furnieri	0.1	0.0	0.0	0.9	0.3
U. canosai	0.5	0.0	0.0	0.0	0.1
Elasmobranchs	0.2	0.1	0.0	0.6	0.2
Other species	0.6	0.3	0.4	1.7	0.8

(b)

	1994	1995	1996	1997	average
Striped weakfish	*64.5*	*78.8*	*78.7*	*78.0*	*75.0*
by-catch	*35.5*	*21.2*	*21.3*	*22.0*	*25.0*
U. canosai	7.5	5.7	2.4	5.5	5.3
U. brasiliensis	8.0	3.3	5.4	1.2	4.4
P. saltatrix	5.5	5.1	3.0	2.5	4.0
M. furnieri	3.3	2.0	3.4	4.0	3.2
Menticirrhus americanus	0.8	1.0	0.6	0.9	0.8
P. punctatus	1.5	0.5	0.0	0.8	0.7
P. siganta	0.4	0.3	1.0	0.3	0.5
Trichiurus lepturus	1.5	0.1	0.0	0.0	0.4
B. pectinata	0.7	0.7	0.0	0.1	0.4
M. ancylodon	0.5	0.3	0.1	0.5	0.3
Paralichthys	1.2	0.0	0.0	0.1	0.3
Elasmobranchs	4.3	1.9	4.9	5.3	4.1
Other species	0.3	0.2	0.3	0.7	0.4

Table 3 - Average, minimum and maximum values of total length (TL) and girths only at the catch position (Gc) for bluefish and striped weakfish caught in different body regions. Numbers caught by girth are denoted by n (with percentage % of sampled catch).

		Orb		Pop		Op		Pect		D1		D2	
		TL	Gc	TL	Gc	TL	Gc	TL	Gc	TL	Gc	TL	Gc
Bluefish	Min.	-	-	382	164	360	165	368	170	360	181	328	172
	Ave.	-	-	453	189	430	194	417	192	406	204	390	196
	Max.	-	-	506	213	471	213	465	215	485	246	420	210
	n	-	-	31		116		46		75		12	
	%	-	-	11.1		41.4		16.4		26.8		4.3	
Striped weakfish	Min	400	178	380	163	360	173	360	171	360	179	-	-
	Ave	537	179	465	185	445	199	418	197	401	199	410	197
	Max	550	182	530	207	520	173	480	171	450	179	-	-
	n	3		115		258		113		27		1	
	%	0.6		22.2		49.9		21.9		5.2		0.2	

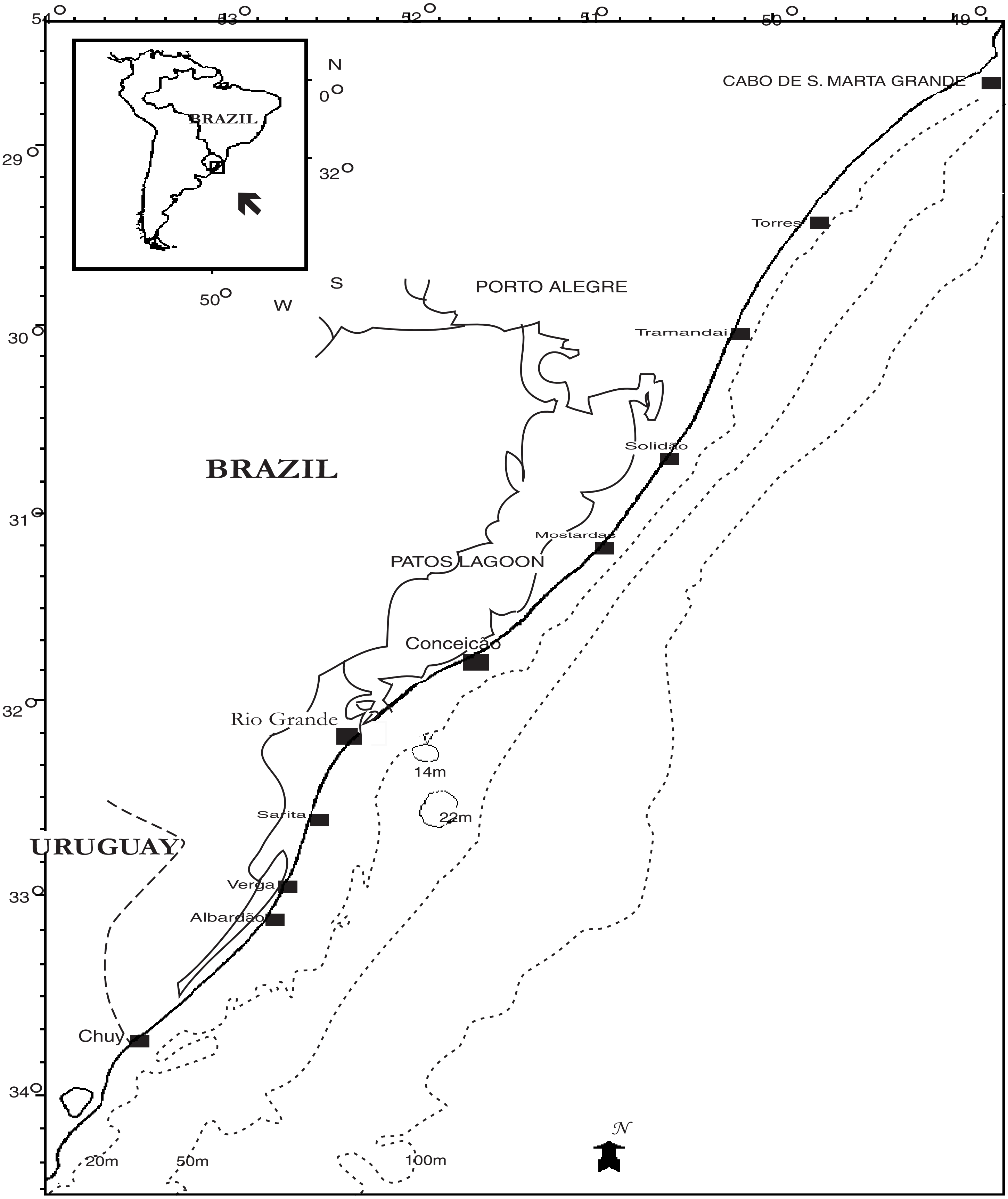
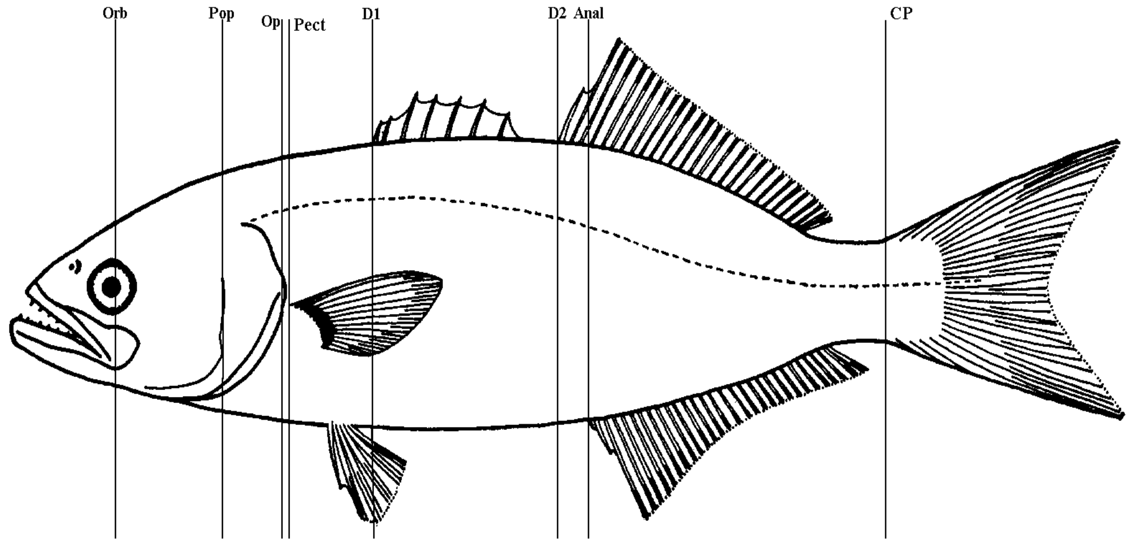


Fig. 1 - The southern Brazilian coast



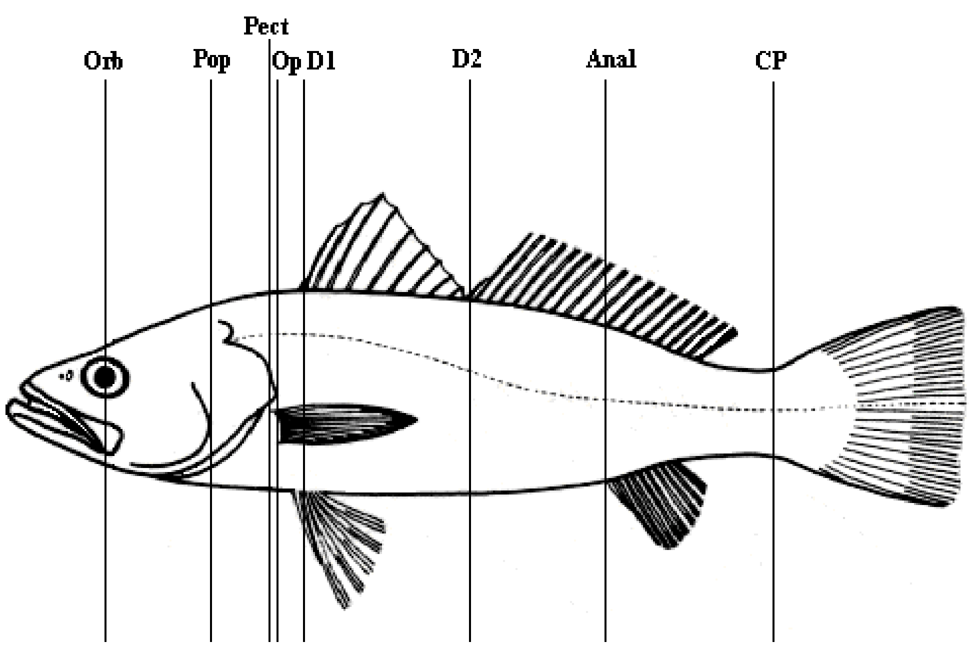


Fig. 2 – Relative measurements of girths in relation to the position on the fish's body for the bluefish and the striped weakfish.

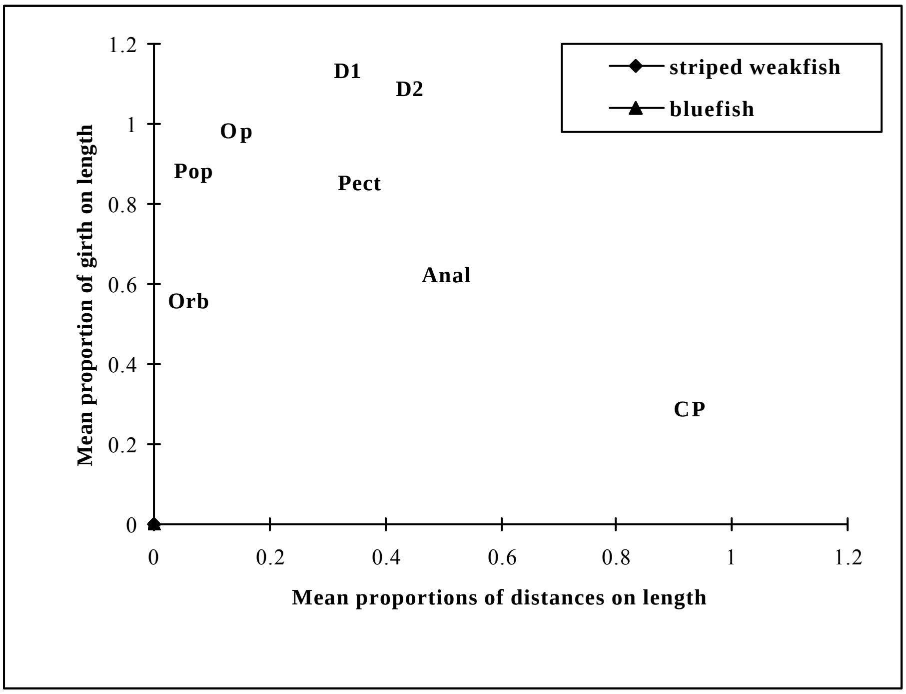


Fig. 3 - Relative measurements of girths in relation to the position on the fish's body for the bluefish and the striped weakfish.

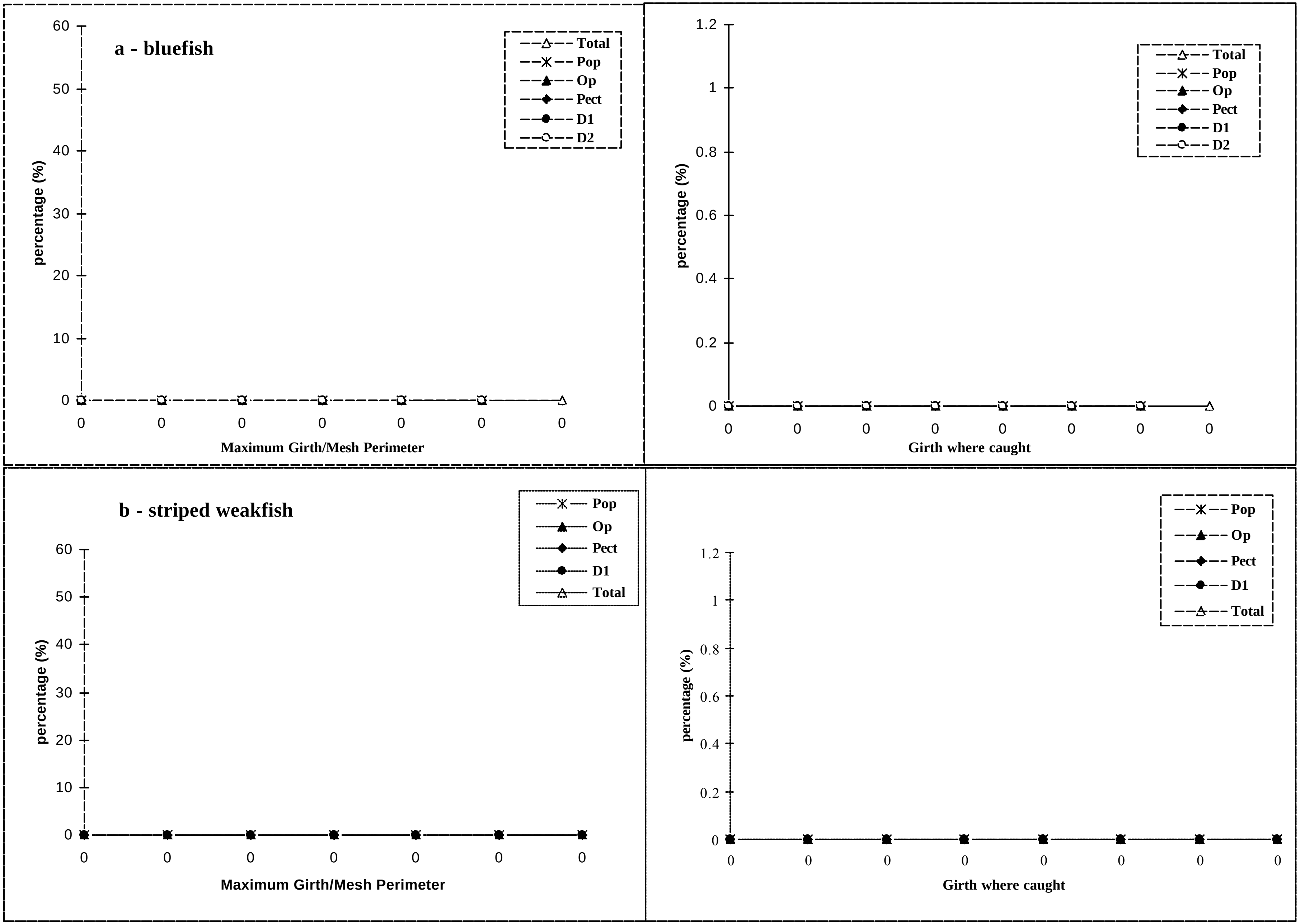


Fig. 4 - Position of girth and girth only at the point of enmeshing, for (a) bluefish and (b) striped weakfish.

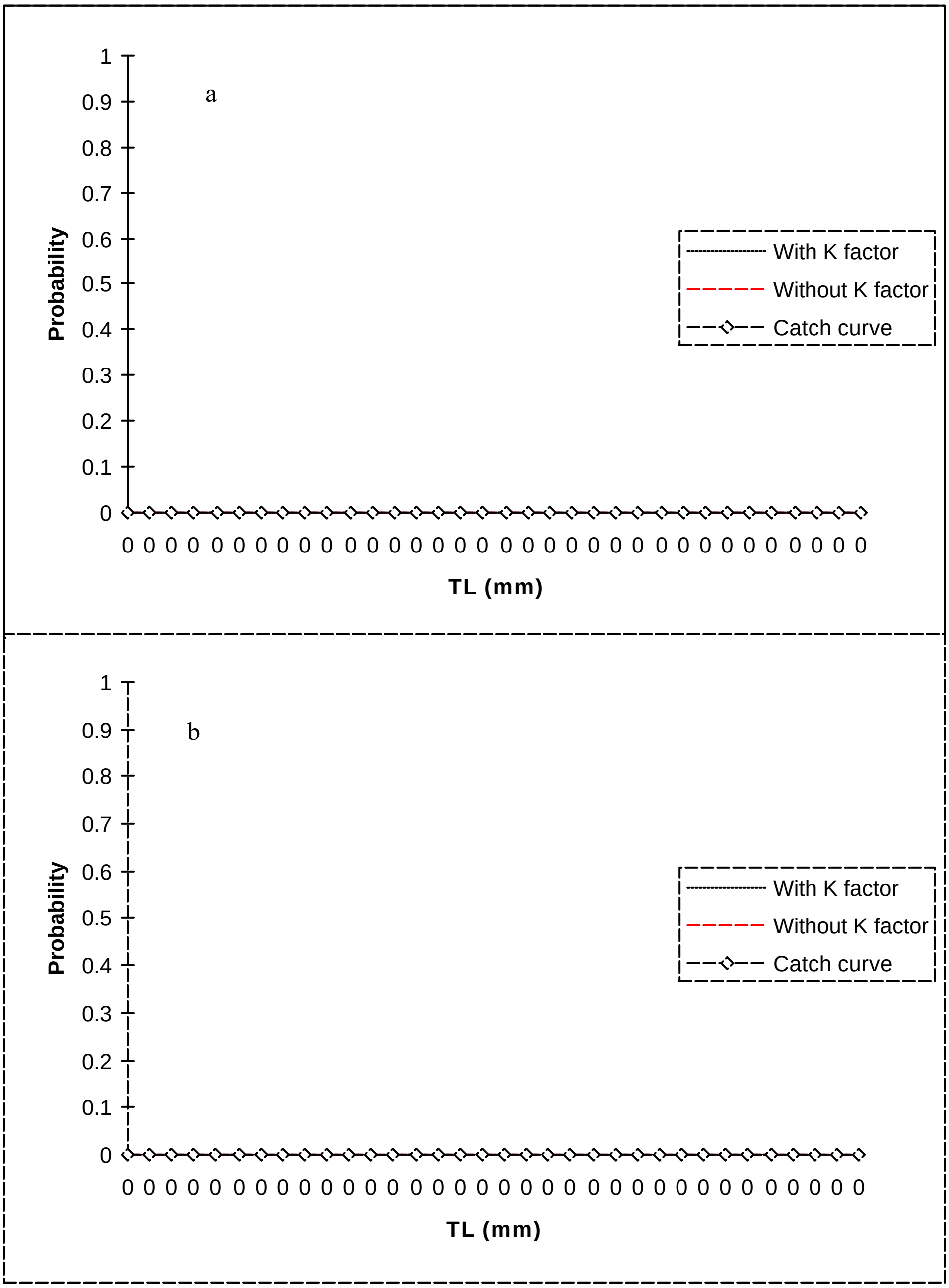


Fig. 5 - Retention curves for (a) bluefish and (b) striped weakfish calculated using Sechin's method with or without the K factors.