Gear selectivity for three by-catch species in the shallow-water shrimp trawl fishery at the Sofala Bank, Mozambique

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ABSTRACT

The reduction of shrimp by-catch when fishing with shrimp trawlers can constitute a strategy to minimise discards. A research cruise was conducted in February 1995 in shallow waters off Sofala Bank, Mozambique to investigate the sorting (selection) efficiency of cod-ends (55mm and 60mm meshes) compared to the top-grid (14mm space bar) systems using covered cod-end method. The selectivity parameters were obtained for *Otolithes ruber, Johnius dussumieri* and *Thryssa vitrirostris* through the maximum likelihood estimate (MLE) method, using logit function and pooled samples through the variance component model (VCM) . The top-grid was mounted at a theoretical angle of 33°, one metre aft of the retriever strap, in a downward direction. The overall shrimp to by-catch ratio was 1:1.7. On average, the cod-end selection system gave a smaller $L_{50\%}$ and wider selection range than the top-grid for all three species. According to the study, the top-grid had better selection properties than the cod-ends relative to the species mentioned above. Differences in the selectivity of 55mm, 60mm meshes and 55mm mesh combined with grid are discussed as well as cod-end and grid selection systems.

INTRODUCTION

The discard by shrimp trawlers in tropical shallow waters is particularly extensive with shrimp to by-catch ratios ranging from 1:3.3 to 1:19.4 (e.g. Mahika, 1992; Nkondokaya, 1992; Evans and Wahju, 1996; Baio, 1996; Alverson, 1998; Brewer et al., 1998). The high discard gives a negative image of this sector of the fishing industry. The issue of selectivity of shrimp fishing gear is therefore of special importance as it constitutes the most important tactic to reduce the problem (Thorsteinsson, 1992; Broadhurst and Kennelly, 1994; Anon, 1996a; Rogers et al., 1997; Brewer et al., 1998; Kennelly et al., 1998). It is against this background that the present study of by-catch in the shrimp fishery in Mozambique was conducted.

Presently the shrimp resource is the most economically important in Mozambique in terms of annual export earnings and value of the fish exports. Nevertheless, there are enormous quantities of non-target species and sizes (by-catch) caught during shrimp fishery. Therefore, it is quite difficult to regulate selectivity for all species through the minimum mesh size of the cod-ends.

Two species, *Penaeus indicus* (Indian white prawn) and *Metapenaeus monoceros* (speckled shrimp) are the most abundant in Mozambican catches and account for more than 80% of the total yearly shrimp catches. Other species are *Penaeus japonicus* (kuruma prawn), *Penaeus monodon* (giant tiger prawn) and *Penaeus latisulcatus* (western king prawn). *Caridea* species also appear in the catches in small proportions (Brinca and Sousa, 1984). The most abundant fish species in the shrimp fishery are *Sardinella*, *Thryssa*, *Otolithes*, *Johnius* and *Thrichiurus* (Gislason, 1985; Bianchi, 1992; Pacule and Baltazar, 1995).

Although studies conducted before 1992 in Mozambique, were not focused on size selectivity, attempts to understand and reduce the problem date from the early 1980s. Studies were carried out to determine species composition and estimate the by-catch proportions. Pelgröm and Sulemane (1982) refer to a shrimp to by-catch ratio of 1:3 (catch rates greater than 50kg/h), Gislason (1985) found 1:3.8, Anon (1994b) found 1:5 with 89% of the by-catch discarded, and Pacule and Baltazar (1995) found 1:4.3.

There has been a need to improve the size selectivity for shrimps in the industrial shallow water fishery as emphasised in 1991 (Sætersdal, 1995). As a follow up of the selectivity experiments in shallow water prawn-trawls in Tanzania (Mahika, 1992), a similar study was conducted for industrial shallow water shrimps in Mozambique in 1993 (Isaksen and Larsen, 1993). The latter experiment showed improvement on size selection of shrimps using a top grid with 14mm bar spacing mounted in a 55mm cod-end compared to a 60mm cod-end.

Apart from these studies, the minimum legal mesh size was increased from 45 to 60mm in 1994. This increase prompted the claim from the fishing industry that they were losing at least 20 to 30% of the catches of marketable shrimp when using a 60mm cod-end mesh size (Isaksen et al., 1995). For this reason, and based on previous tests, an experiment on selection of shrimp using: (a) 55mm mesh cod-end; (b) 60mm mesh cod-end, and (c) 55mm meshed cod-end with a 14mm grid bar spacing was done in 1995. The top-grid gave better results in sorting out small-sized shrimp and at the same time retaining marketable sizes better than the cod-ends tested (Isaksen et al., 1995). To avoid making use of grid compulsory, the State Secretariat of Fisheries (SEP) approved the use of 55mm mesh as the minimum legal mesh size (Anon, 1996b). No analysis of the selectivity of by-catch species was done as part of this experiment.

Fish is the major part of the catches and the high by-catch taken in the course of shrimp fishing causes concern (Anon 1994a). However, there are logistical (e.g. limited chill or cold storage capacity), economic (e.g. low price paid for by-catch) and other factors that make the handling of non-target species difficult for the fishing industry (Suluda, 1997). Nevertheless, the by-catch species have significant importance to the country in terms of human consumption (Anon, 1994a). Therefore, it is important to determine how different mesh sizes and the use of selective devices (grid) affect the selection of the more frequently occurring by-catch species (*Otolithes ruber, Johnius dussumieri* and *Thryssa vitrirostris*).

The present study was aimed at performing an analysis of by-catch data collected during the selectivity experiments in 1995. The more specific objectives are first, to quantify the by-catch composition; second, to investigate the cod-end mesh selectivity for 55mm and 60mm meshes; and third, to study the efficiency of the sorting grid as an excluder device for non-target species.

MATERIALS AND METHODS

The commercial shrimp trawler *ARPEM IV* was used for the investigation. The vessel was equipped with two 11.5m outriggers (Figure 1) and was able to tow two identical trawls simultaneously (Isaksen et al., 1995).

The fishing trials were done along the Sofala Bank, (19°20' S, 35°40' E) and along the banks further north to the area outside Angoche (16°10' S, 39°50' E) (Figure 2). The depth range was between 10 and 26m. All hauls were made during daytime hours. Tow duration varied between 2 and 3 hours per haul and the towing speed was 3.2 knots.

The trawls used were of the 'semi ballon-type', built as 4-panel trawls. A pair of wooden otter-boards were connected to each of the trawls through bridles, and to the towing warp by a 60m crowfoot. The normal warp length to depth-ratio used during the study was:

warp-length = 3 x depth (fathoms) + 25 fathoms (1 fathom = 1.82m).

Studies were carried out applying cod-ends with 55 and 60mm mesh sizes. They had a circumference of 200 meshes and a length of approximately 5m. Both cod-ends were made of polyamid (PA). A shark protection net made of polyethylene (PE) was mounted around the cod-end. The protection net had a mesh size of 70mm and a circumference of 150 meshes. It covered the whole cod-end, and ended about 70cm aft of the cod-end knot ('zipper'). It was open at the aft end.

The 'twin trawl method', whereby the two identical trawls are fished with the same cod-end mesh size, but with a small-meshed cover over one of the cod-ends, was used to investigate cod-end selectivity (Anon, 1996c). The cover had a mesh size of 37mm and a circumference of 480 meshes, giving a stretched circumference of approximately 1.5 that of the cod-end (Pope et al., 1975). The length of the cover was 6.65m and it was attached 4.65m in front of the aft end (zipper). The same cover was used for both the 55 and 60mm cod-ends and attached the same way. The shark protection net was fitted outside the cover.

The top-grid experiments were carried out with a grid with 14mm bar-spacing. The grid-section was installed about 1m aft of the retriever strap, and mounted at a theoretical

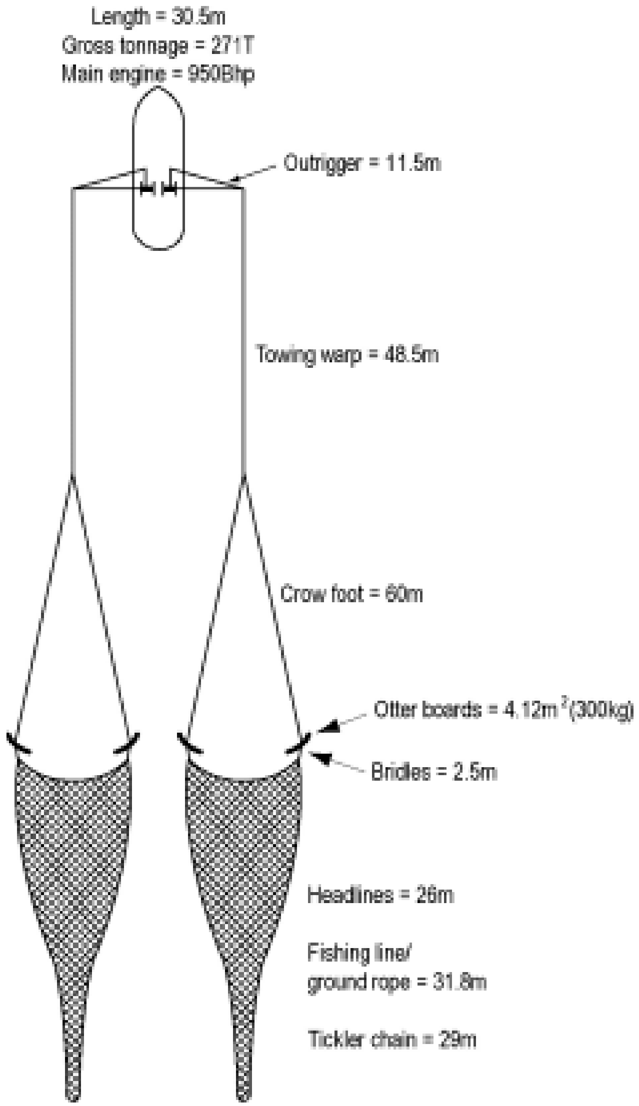

Figure 1. Schematic diagram of a shallow water shrimp trawler at the Sofala Bank, Mozambique

angle of 33° (Figure 3). The grid was made of sea-water resistant aluminum and had a length and width of 1.5 and 0.9m, respectively (Isaksen and Larsen, 1993). It weighed approximately 11kg in water. To make the top-grid neutral or slightly buoyant, 4 x 200mm plastic floats were attached to the upper and foremost part of the grid. A fine-meshed top-cover (control bag) 12.5m long and made of stretched 37mm mesh netting (Isaksen and Larsen, 1993) was placed over the escape area of the grid to collect the shrimp and fish escaping through the grid (Figure 4). A shark protection net was mounted over the aft end of the cover. The grid was used in combination with a 55mm meshed cod-end with

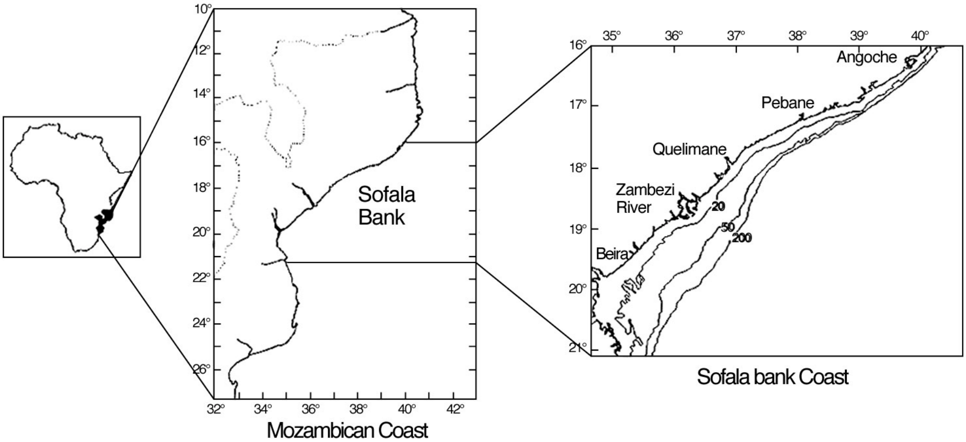

Figure 2. Map of the study area — Sofala Bank coast

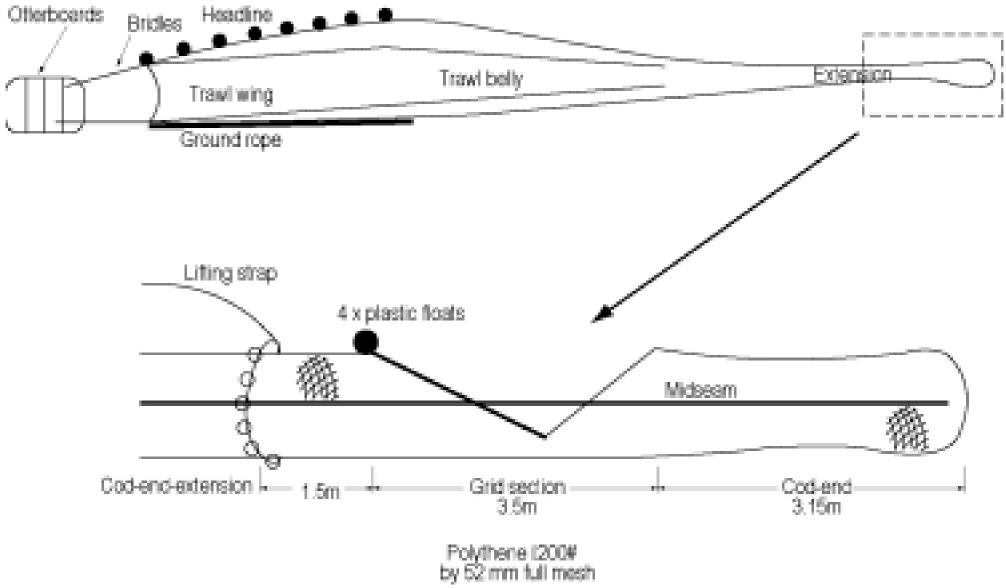

Figure 3. Attachment of the grid-section to the trawl. Side-view of the trawl and the grid-section

shark protection net, but without cover. During operation, the catch is led towards the grid sorting surface; small-sized shrimps and fish are filtered through the grid and into the control bag, whereas larger shrimp and fish are guided along and under the grid and into the main cod (Figure 5).

Experimental set-up

Before the experiment started, four hauls were performed to test for possible differences in fishing power between the two trawls. During the experimental fishing four groups (I,

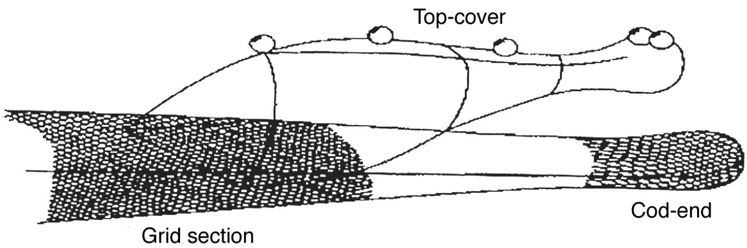

Figure 4. Attachment of the top-cover to the trawl over the grid. Side-view of the aft part of the trawl

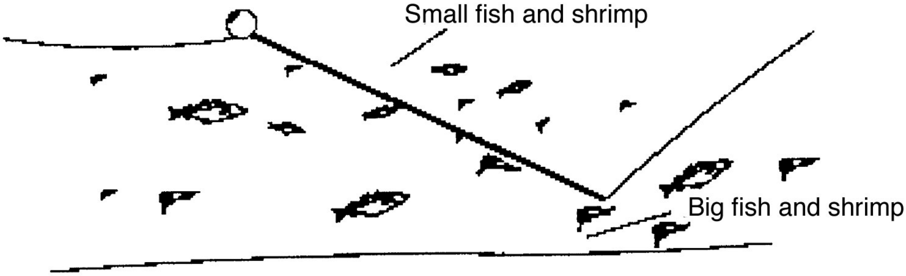

Figure 5. Illustration of the sorting principle using top-grid. The small fish and shrimp pass through the space between the bars of the grid and escape. The big shrimp and fish are guided into the cod-end

II, III and IV) of hauls were accomplished (Table 1). In group I (hauls 1 to 10), the port and starboard sides were both rigged with 55mm meshed cod-ends (54mm nominal mesh opening), but with a fine meshed cover around the starboard cod-end. The design of experimental group II (hauls 11 to 20) was identical to that of group I, but with a cod-end mesh size of 60mm. In group III (hauls 21 to 28), port side trawl was rigged with the grid-section (including the cover above the grid) and 55mm meshed cod-end. The starboard side was rigged with a 60mm meshed cod-end with a fine-meshed cover (Table 1). In group IV (hauls 29 to 32) the trawls were rigged as in commercial fishing with mesh sizes of 55 and 60mm on the port and starboard sides respectively.

Table 1. Set-up of the experimental fishing for testing selectivity during 1995 research survey on board *ARPEM IV* at the Sofala Bank

		Port side		Starboard side	
Group	Hauls	Cod-end mesh size (mm)	Cover (37mm)	Cod-end mesh size (mm)	Cover (37mm)
I	1–10	55	not used	55	used
II	11–20	60	not used	60	used
III	21–28	55+grid	used	60	used
IV	29–32	55	not used	60	not used

Sampling

For each haul the catch of cod-ends and cover(s) were kept separately. The catch of the cod-end or cover was weighed and a sub-sample of two boxes (approximately 40kg each) was sorted into species groups. The species identification was made using manuals by Anon (1984); Smith (1986) and Fisher et al. (1990). The weight and number of the species in the sub-samples were recorded, and for all specimens of *O. ruber*, *J. dussumieri* and *T. vitrirostris* total length was also measured. Overall catch in weight and number of a species were determined by raising the sub-sample figures by the ratio of total weight to sub-sample weight.

Data analysis

Weight-related data analysis

Due to variation in tow duration, catches were standardised into hourly values. The by-catch proportions by weight were calculated as:

$$BCP = \frac{\sum_{i=1}^{n} BC_i}{\sum_{i=1}^{n} TC_i} * 100 \qquad (1)$$

where BCP is the by-catch proportion; BC_i the by-catch weight in haul i; TC_i the total catch (shrimp and by-catch) in haul i; and n is the number of hauls. The confidence limits were obtained from bias and acceleration corrected (Bca) bootstrap estimates using 5000 iterations (Efron and Tibshirani, 1993). The calculation was done using the 'bootstrap' and 'limits.bca' functions in S-Plus (S-Plus ver. 4.5, Mathsoft Inc., Seattle, USA).

Variation in by-catch rates with respect to depth, time of the day and latitude were examined. The degree of association between proportion of shrimp and by-catch excluded and the total catch rates were analysed through simple linear regression analysis (Zar, 1984). To test for a possible masking effect (the effect whereby the cover around the cod-end prevents or deters fish from escaping through the meshes of the cod-end), the weight of shrimp and by-catch in the cod-ends on port and starboard sides were compared for the hauls of groups I and II (Table 1). The null-hypothesis of no difference was tested using a two-sample randomisation test for pairwise comparisons (Manly, 1991), using 5000 iterations.

Length-related data analysis

The length related data analysis involved the construction and comparison of length frequency distributions and the estimation of selectivity curves for the three species *O. ruber, J. dussumieri* and *T. vitrirostris*. The null-hypothesis of no difference in the length composition in the cod-end and cover was tested using a randomisation test. The difference between 55mm with grid and 60mm cod-end without grid was tested. The test was done with the actual (non-scaled) length measurements. P-values were based on 5000 permutations using the Kolmogorov-Smirnov test statistic which examines the largest absolute difference between the two cumulative frequency distributions (Zar, 1984).

Estimation of selectivity parameters

The estimated selectivity parameters were $L_{25\%}$, $L_{50\%}$ and $L_{75\%}$ (length of fish that has a 25%, 50% and 75% probability of being retained after entering the cod-end, respectively) and SR (selection range, i.e. the difference between $L_{25\%}$ and $L_{75\%}$). The selection factor, SF, is given by:

$$SF = \frac{50\% - retention - length}{Mesh - size - (Grid - bar - distance)} \qquad (2)$$

The cod-end and grid selectivity is represented here by reference to the 50% selection length and SR (Pope et al., 1975; Sparre and Venema, 1992; Anon, 1996c).

Covered cod-end method was used to obtain selectivity parameters of the three species by using the variance component analysis (VCA) option which accounts for the variability between hauls and the samples (hauls) are analysed individually (Fryer, 1991). The confidence bands for the estimates are also given.

Where a masking effect was present, selectivity was also calculated using the trouser trawl method (considering the pooled numbers of each side of the trawl separately, Anon, 1996c). The computer program CC Selectivity (1995 release, ConStat, 9800 Hjoerring, Denmark) was used to solve the maximum-likelihood equation, calculate the parameters including 95% confidence limit (Sokal and Rohlf, 1995) and fit the selectivity curves. The selection curves plotted in this paper were obtained using the maximum likelihood estimates (MLE) of the parameters from CC-selectivity applying the model (Anon, 1996c):

$$S_L = \qquad (3)$$

where S_L is the ratio between the number of fish of length 'L' in the cod-end and sum of number of fish of length 'L' in the cod-end plus in the cover; L is the length interval midpoint; S1 and S2 are constants [Paloheimo and Cadima, 1964; Hoydal et al., 1982 (referred by Sparre and Venema, 1992)].

RESULTS

Weight-related results

Catch composition

The overall total catch during the research cruise was 19,280kg of which 12,278kg was by-catch and 7002kg were shrimps (marketable shrimps). Of the by-catch 10,171kg was fish by-catch. A total of 70 species (plus organisms assigned to higher taxonomic groups) were identified, with a mean of 25 identified species per haul.

The most abundant shrimp species by weight was *P. indicus* (30.9%), but in number it was the group Caridea. In the fish by-catch, *Trichiurus lepturus, J. dussumieri, O. ruber, Pellona ditchela* and *T. vitrirostris* were among the five most abundant by weight (16.6, 7.5, 6.7, 6.3 and 4.8% of total catch respectively).

The estimated proportion of by-catch in the overall catch was 64% with 95% confidence limits from 46 to 74% of the total catch by weight. The by-catch proportion was highly variable between hauls. There was no clear indication of depth dependency on catch rates. No marked diel pattern in the shrimp catch rate related to the time at start of tow was observed.

Gear performance when using cod-end cover

Based on a pair-wise comparison randomisation for both the 55 (Group I) and 60mm (Group II) cod-ends, the by-catch rates were significantly greater in covered trawls ($p = 0.03$ e;$p < 0.01$ respectively). The higher catch rate in the cod-end with cover indicates that there is a masking effect by the cover.

A comparison between the catch rates taken in 55mm with grid and 60mm (group III) showed no difference for either by-catch rates ($p = 0.14$) or shrimp catch rates ($p = 0.17$) as well as for shrimps in groups I and II ($p= 0.30$ and $p = 0.63$ respectively).

Catch proportion

No significant relationship was found between the by-catch rates excluded and the overall catch rates for a haul for the 55 and 60mm cod-ends for all three groups ($p > 0.05$). The same result was observed for shrimps except in group III ($r^2 = 0.52$; $p = 0.04$). These results showed that in most of the cases there was no correlation between proportion of shrimp or by-catch rates excluded and total catch rates within the ranges observed (86–113kg/h).

Length-related results

Masking effect

Significantly higher mean lengths of by-catch specimens caught in the main bag on the port-side (without cover) than those caught in the main bag on starboard side (with cover) were obtained for *O. ruber* in 55mm mesh ($p < 0.001$) and *J. dussumieri* in both 55mm and 60mm meshes ($p < 0.001$). This indicates a masking effect by the cover. *Thryssa vitrirostris* showed no difference in mean lengths between port side and starboard side ($p > 0.05$), and indicating the absence of a masking effect.

Mean lengths retained in main cod-end and cover

The randomisation test (Kolmogorov-Smirnov) indicated that all the three fish species had significantly greater mean lengths in the cod-end than in the cover for 55mm cod-end. For 60mm cod-ends, the lengths were also greater in the cod-end than the cover, but the differences were not significant for *O. ruber* (G II $p = 0.07$) and *T. vitrirostris* (G III $p = 0.70$). For *J. dussumieri*, all cases were significantly different. Based on randomisation test (Kolmogorov-Smirnov), the mean lengths for all three species in the 55mm cod-end with grid were significantly higher than those in the main bag of 60mm mesh (without grid) ($p<0.001$). Table 2 presents the selectivity parameters using both covered cod-end and trouser trawl methods to investigate the extent to which the methods influence the selection of cod-end and a combined cod-end and grid system.

Selectivity estimates from covered cod-end method

Based on the covered cod-end method, the fitted selection curve showed that the probability that *O. ruber* was retained by both 55mm and 60mm meshes increased very slowly with increasing length of fish, i.e. showed a wide selection range and poor model fit. It also showed a higher variability of selection between individual hauls. For the 60mm mesh cod-end most of the samples did not fit the model (Table 2; Figure 6). The selection curve for *J. dussumieri* is not shown since the results obtained were inappropriate (Table 2). The exclusion of the samples from the analysis can arise because of poor selectivity of the meshes caused by masking effect which is influenced by the shark protection and cover. This makes the selection a more-or-less random process.

Table 2. Size selection estimates by using the covered cod-end method (CCM) and trouser trawl method (TTM). Confidence intervals (95%) for the estimated parameters are also given

	Cod-end mesh size and grid (mm)					
	55 (G. I)		60 (G. II)		55 + grid *(G. III)	60 (G. III)
Selectivity parameters	CCM	TTM	CCM	TTM	TTM	CCM
Otolithes ruber						
$L_{25\%}$	8.4 ± 8.5	12.6 ± 3.0	8.2 ± 4.7	11.3 ± 2.5	11.8 ± 1.9	5.4 ±25
$L_{50\%}$	13.7 ± 5.0	14.9 ± 2.2	15.4 ± 6.0	12.8 ± 2.0	13.2 ± 1.1	12.1 ± 9.4
$L_{75\%}$	18.9 ± 6.5	17.2 ± 3.6	22.6 ± 9.0	14.3 ± 3.1	14.6 ± 2.0	18.9 ±12.2
SR	10.5 ± 4.4	4.5 ± 1.3	14.4 ± 6.2	3.0 ± 1.5	2.8 ± 0.9	13.5 ±11
SF	2.5	2.8	2.6	2.1	9.4	2.0
Johnius dussumieri						
$L_{25\%}$	6.3 ± 4.0	9.8 ± 2.0	7.5 ±13.2	13.3 ±18.0	11.1 ± 3.2	#
$L_{50\%}$	9.8 ± 1.9	11.3 ± 1.6	9.3 ± 6.7	15.4 ±26.2	12.7 ± 2.9	#
$L_{75\%}$	13.3 ± 4.1	12.8 ± 2.5	11.2 ± 4.0	17.6 ±35.5	14.2 ± 3.5	#
R	7.0 ± 1.0	3.0 ± 0.9	3.7 ± 3.2	4.3 ± 3.8	3.1 ± 1.2	#
SF	1.8	2.1	1.7	2.6	9.0	#
Thryssa vitrirostris						
$L_{25\%}$	1.5 ±10.5		8.1 ± 8.3			1.7 ± 7.1
$L_{50\%}$	8.7 ± 4.4		13.3 ± 6.1			5.6 ± 3.3
$L_{75\%}$	16.0 ±10.1		18.4 ± 8.0			9.5 ± 5.6
SR	14.4 ± 6.9		10.4 ± 4.5			7.8 ± 4.3
SF	1.6		2.2			0.9

inappropriate selection parameters; * port side (55mm mesh + grid) vs starboard side (60mm mesh).

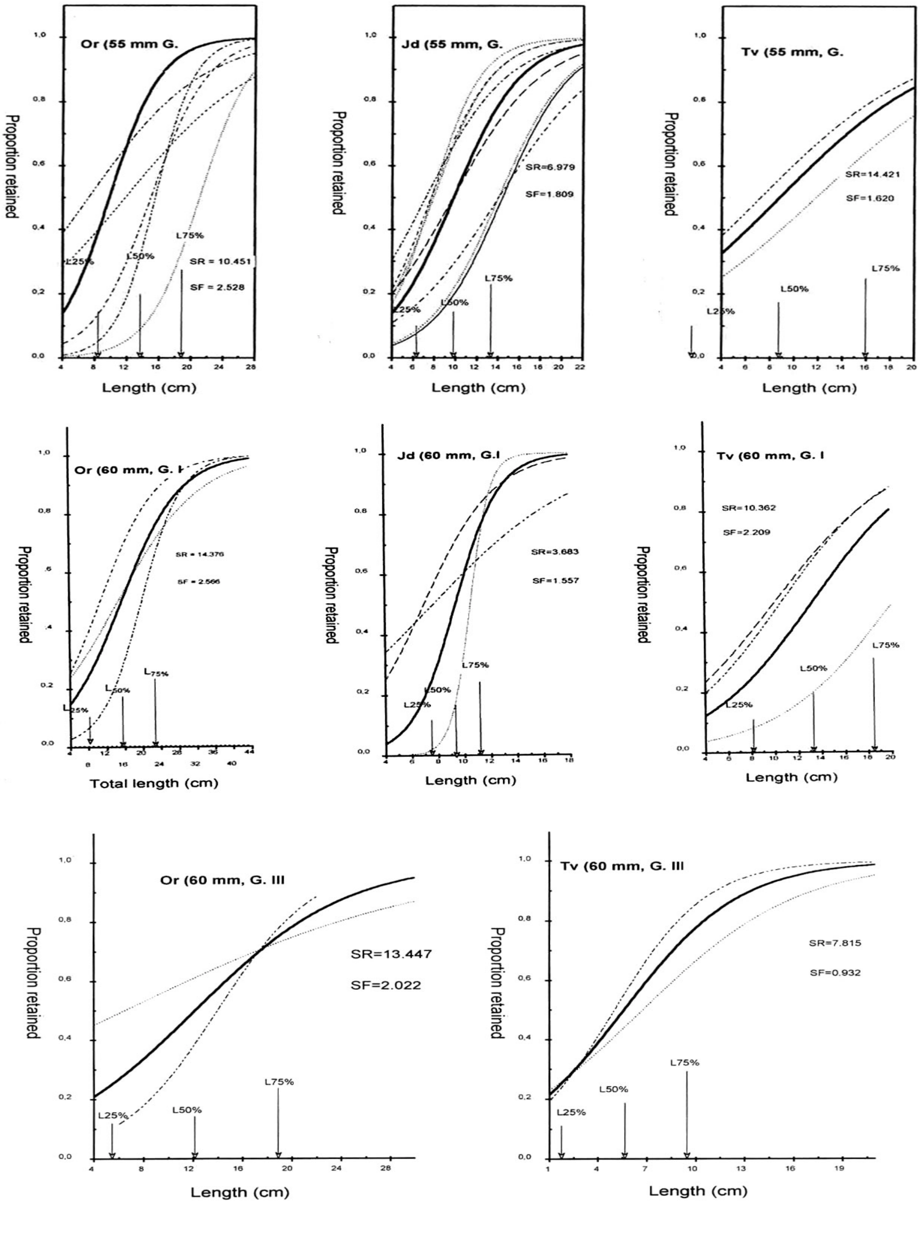

Figure 6. Length distributions of *Otolithes ruber* (Or), *Johnius dussumieri* (Jd) and *Thryssa vitrirostris* (Tv) using trawls with 55mm and 60mm mesh sizes. The selection curve for each haul (dashed line) and mean selection curve (solid line) given by the covered cod-end method are shown.

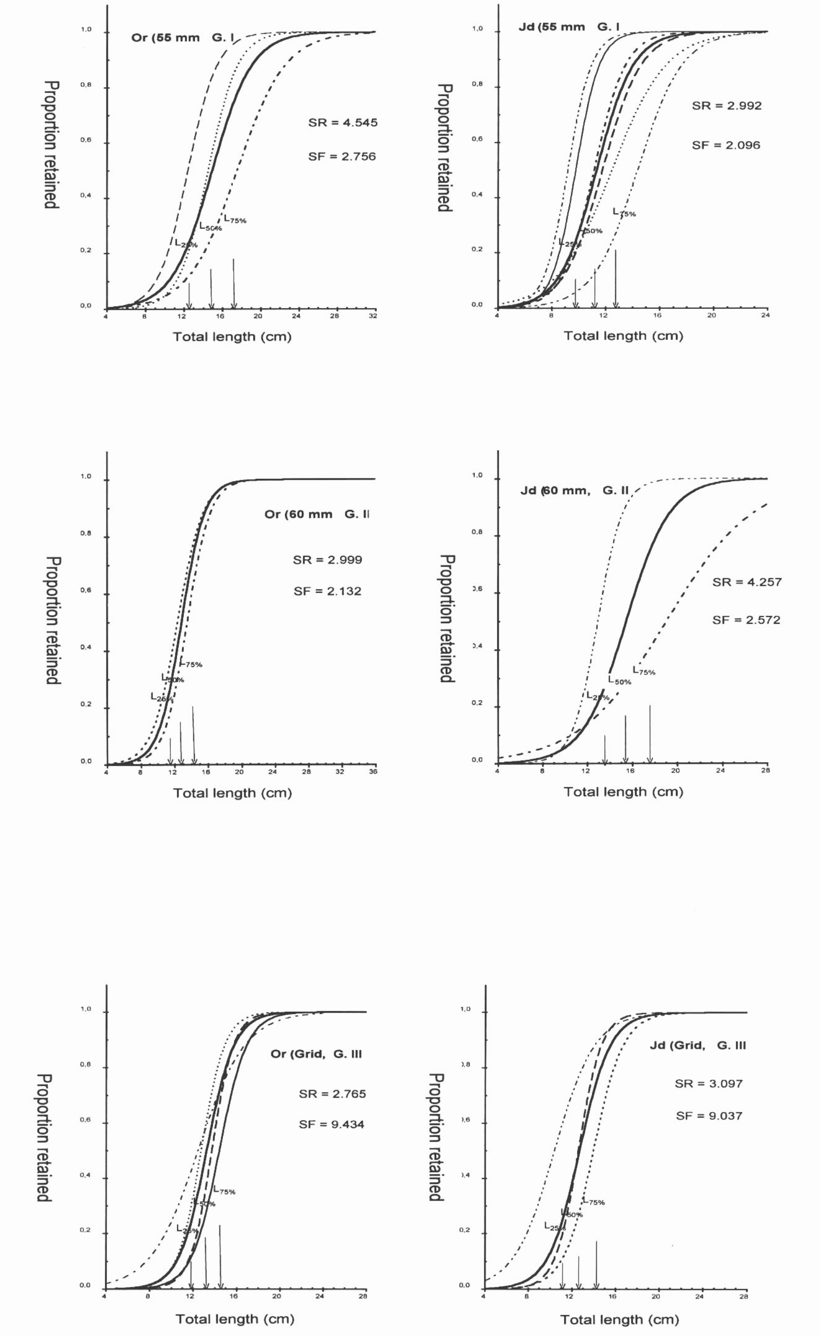

Figure 7. Length distributions and selection curve for each haul (dashed line) and mean selection curve (solid line) of *Otolithes ruber* (Or) and *Johnius dussumieri* (Jd) using cod-ends with 55mm and 60mm mesh sizes and 55mm mesh with grid by the trouser trawl method

Selectivity estimates from trouser trawl method

Otolithes ruber: The fitted selection curves had narrower selection ranges for the 55mm mesh cod-end combined with grid than for the 55mm without grid. However, the mean selection length was highest for the 55mm cod-end without grid (Table 2 and Figure 7). The $L_{50\%}$ for the 55mm cod-end was also higher than the mean selection length for the 60mm mesh cod-end.

Johnius dussumieri: The fitted selection curves (Figure 7) showed that the steepness of the curves for 55mm cod-end with and without grid is about the same. The mean selection length is higher in 55mm cod-end with grid (Table 2).

Since there was no masking effect for *Thryssa vitrirostris* there was no need of using trouser trawl method.

DISCUSSION

By-catch ratio

The overall shrimp to by-catch ratio found in this survey, 1:2.3, is towards the lower end of the range estimated previously for the commercial shrimp fishery in Mozambican waters, i.e. 1:3 (Pelgröm and Sulemane, 1982 [cited in Sparre and Venema, 1992], 1:3.3 for the years 1983–1984 (Gislason, 1985), 1:5 for the year 1993 (Anon, 1994b) and 1:4.3 for the years 1986–1990 (Pacule and Baltazar, 1995). Kennelly et al. (1998) concluded that the occurrence and quantity of different species in by-catches depend on the year, season and location in question. In this analysis the escaped specimens were considered, which is not possible on commercial rigging and there was relatively high shrimp catch rates in this cruise. Morever, the composition of by-catch may change as a consequence of river runoff according to tolerance for low salinity of some species. The exploitation patterns seem to play an important role on the sizes and species captured (some previous estimates were based on data from the commercial fleet using lower mesh size, 45mm up to 1994) (Silva et al., 1995).

Degree of association between shrimp or by-catch loss and catch size

One way to obtain an index of the efficiency of the selection device (cod-end or grid system) is to evaluate the relationship between retention and the size of the catches. The results showed no saturation of the cod-ends, in that the proportion retained was not correlated with catch size within the ranges observed (236–2320kg and 86–1113kg/h). However, an exception was found in 60mm mesh (G. III) that showed a positive relationship between shrimp catch rate excluded and total catch rate ($r^2 = 0.52$, $p = 0.04$). This could be due to small samples available.

Masking effect

The weight and length results from these experiments did indicate some masking effect of the cover when applied to 55mm and 60mm cod-ends. In this experiment, the cod-ends were surrounded by a shark protection net (an open cylinder) attached just behind the retriever strap and ending 70cm aft of the cod-end knot. The small-meshed cover was fitted inside this protection net. The selection process takes place in the cod-end, mainly at the escape zone (just in front where the catches accumulate). This net in combination with the cover can cause variation in the shape of the bag to such an extent that it can prevent fish from escaping through the meshes. Some additional factors that also could contribute to the existence of masking effect include: circumference of shark protection net used around the cod-end, double layer net and mesh size used (Isaksen et al., 1995). These factors may have influenced some individuals, preventing them from escaping towards the cover, and thus, remaining in the cod-end and contribute to reducing mean individual size. Consequently, selectivity parameters would be underestimated by using the covered cod-end method (Table 7). It has been recommended to increase the circumference of the shark protection net, increase mesh size and use single layer net to improve the mesh selectivity of the cod-ends (Isaksen et al., 1995).

Conversely, the shark protection net may not affect the selectivity of the grid. This is because the grid is placed in front of the cod-end (extension piece), where the selection takes place. However, the use of a shark protection net is absolutely necessary in order to keep the sharks from tearing apart the bag. Thus, the grid is expected to perform better than cod-end mesh selection since the selection of this device is not affected by the shark protection net.

A similar masking effect was found by Isaksen et al. (1995) when analysing data for shrimp selectivity. Mahika (1992), without reference to the mesh size, and Baio (1996) using 43mm mesh size, did not find masking effect in the Tanzanian and Sierra Leonean waters respectively. This is probably because of associated differences in body shape of the species analysed, reflected in different behaviour and different trawl rigging (shark protection net was not used). No masking effect was obtained for *T. vitrirostris* in the present study. It may be due to its slim body shape and different visual response (Wardle, 1986), and the flexibility of the meshes made of polyamide with wide opening range. These aspects may contribute to allowing the species to better escape through the meshes.

Size selection estimates

Generally, the smaller the mesh, the smaller the fish that can be retained in the cod-end. The mean lengths obtained when the grid was used in combination with 55mm cod-end were significantly higher than those in the 60mm mesh for all three fish species studied ($p<0.001$). The expected result would be higher mean lengths in larger mesh (60mm). This did not happen probably due to the masking effect mentioned in previous sections. An indication of efficiency of the fishing gear selectivity based on size is the selection range (Anon, 1996c). The fixed spacing between bars grid usually have a sharper selection than cod-end meshes which usually are composed of meshes of variable sizes.

The covered cod-end method gave biased selection parameters and low precision of the estimates probably due to a masking effect. The trouser trawl method gave improved estimates of selection parameters and the more precise estimates. However, several hauls were excluded from the analysis because the data did not fit the model. The exclusion of samples from the analysis may have to do with poor selectivity of the meshes caused by the presence of the shark protection net and cover which makes the selection become more or less a random process, i.e. sub-samples were too small to adequatelly reflect size composition in catches. It seems that better results could be obtained with increased number of samples. The more precise estimates were obtained for *O. ruber* in 55mm cod-end without grid and *J. dussumieri* in 55mm cod-end with a grid.

The results suggest that the top-grid in combination with 55mm meshed cod-end had better selection properties to the species compared to both the 55mm without grid and the 60mm meshed cod-end.

No comparisons were made with other similar studies because of differences in cod-end mesh size, grid bar spacing and species examined as mentioned before in this section. However, the two durations reported by Mahika (1992) (2.75 hrs) and Baio (1996) (2–2.5 hrs with towing of speed 3–3.5 knots), are approximately equal to those used in this experiment (2–3 hrs and 3.2 knots). Thus, the selectivity parameters regarding the three species using a 14.0mm space bar should be regarded as first estimate.

Cod-end and grid sorting capacity

In shrimp fisheries in tropical areas, most fish by-catches comprise small specimens of about the same size as the target shrimp species. Therefore, it is difficult to sort out (exclude) the fish by-catch based on size selectivity by controlling cod-end mesh size (Brewer et al., 1998). The selectivity of the top-grid system is based on behaviour differences and physical characteristics of the grid, therefore intending to exclude more small specimens. Thus, the selection efficiency of a gear in this case is determined by lower retention of small fish. This principle was fulfilled by the 55mm mesh cod-end with top-grid, which excluded small fish while maintaining medium and bigger ones in the cod-end, which is in agreement with Isaksen et al. (1995). Escaped specimens (shrimp or fish) with lengths below their mature length can then grow bigger and be fished later. This can lead to reduction of fishing mortality of small sizes of fish (to some extent) and higher yield per recruit (i.e., more value). It is possible to regulate the grid bar distance as it is done for cod-ends to suit the management requirements. Thus, selective devices such as grids may help reduce by-catch. However, the reduction of by-catch may, to some extent contribute to an increase of biomass of shrimp predators, leading to increased mortality by predation on shrimps (Bianchi, 1992). Consequently, the biomass of shrimps may decline, on one hand. On the other hand, removing huge quantities of small shrimp and fish by-catch, may lead to changes in fish dominance structure or even depletion of some stocks (Jin, 1996).

Once the fishing industry faces time and space limitation to deal with by-catch, and the use of devices (grid) does not reduce the gear efficiency (Hall, 1995), the reduction of non-target animals (especially small-sized specimens) using grid or other gear configurations, e.g. square meshes (Broadhurst and Kennelly, 1994) would lead to smaller catches to be sorted on board, more clean catches of target species and consequently, longer tow times and lower fuel costs per unit of target species caught (Brewer et al., 1996).

CONCLUSIONS

This study analysed the selectivity for important by-catch species in the Mozambican shallow-water shrimp fishery. The analyses revealed that the rigging of the trawl with a shark protection net over the cod-end, most probably reduced the efficiency of cod-end mesh selection.

The cod-end mesh size selectivity parameters were not well estimated and the results were partly inconsistent. In addition to the masking by both cover and shark protection net, sample sizes were generally too low (probably due to poor selectivity of the meshes) to adequately reconstruct the length frequency distribution of the catches. Therefore, it is important to guarantee the absence of masking effect in order to obtain a good selectivity of the meshes.

The results from the experiments with a rigid grid showed that the grid in combination with a 55mm mesh cod-end gave higher mean length of the catches than the 60mm mesh cod-end. The grid also showed sharper selection curves. Moreover, the shark protection net does not affect the efficiency of grid selection.

Previous analysis of the shrimp data from the present selectivity experiment has shown that a 60mm cod-end mesh size leads to an unacceptably large shrimp loss (up to 30%). The present experiment has shown that cod-end mesh exclusion for by-catch species is low for both 55 and 60mm mesh cod-ends due to the use of shark protection nets. However, fishing without a shark protection net in the Mozambican shrimp fishery is not practical, since sharks would severely damage the cod-end during haul back with a subsequent loss of shrimp catch.

To reduce the high discard of by-catch (including undersized target species) it is recommended to carry out further selectivity experiments in the Mozambiqcan shallow-water shrimp fishery. Experiments should include more comprehensive trials with the rigid grid. The role of the shark protection net should also be further explored, and construction guidelines should be made in order to reduce its masking effect during commercial fishing.

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