CATCH COMPARISON ANALYSIS BETWEEN CONVENTIONAL AND MODIFIED SHRIMP TWIN TRAWL IN CUBA

Roany Martínez Cabrera
Fisheries Research Center
Ministry of Fishery Industry of Cuba
roany@cip.telemar.cu

Supervisor
Dr. Ólafur Arnar Íngolfsson
Marine Research Institute
olafur@hafro.is

ABSTRACT

A shrimp trawl modified to reduce by-catch was analysed in terms of total catch and catch at length in the Santa Cruz del Sur shrimp fishery, Cuban South-eastern shelf. The modifications in the trawl design mainly focused on decreasing the vertical opening and increasing the horizontal opening together with the addition of a Fisheye by-catch reduction device in the upper part of the codend extension. A total of 99 comparative hauls during three cruises using the twin trawl method were completed with the modified trawl and a conventional trawl. Finfish catches were significantly reduced using the modified trawl but neither the number of Lane Snappers below length at maturation nor by-catch other than finfish was reduced. A significant difference in length distributions of shrimps between the trawl types was observed for the first and the third cruises. The modified trawl caught less undersized and damaged shrimp than the traditional trawl and mean shrimp lengths were higher for the modified trawl. A logistic regression revealed a length dependent split in favour of the modified trawl, with shrimps larger than 10 cm being caught to a greater extent. These results in addition to the significant difference in number of shrimps suggest that the modified trawl has a more favourable size selection of shrimps than the traditional trawl.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1   INTRODUCTION

Nearly 7 million tonnes of fish by-catch is estimated to be discarded globally by commercial fishermen every year. Industrial shrimp trawling in tropical waters is a leading offender in the capture of by-catch and accounts for about 27% of all global discards (Eayrs, 2007).

Despite decreasing captures in recent years, shrimp trawl fishery is the second most important commercial fishery in Cuba with around 48 vessels and an annual contribution of nearly 15 million dollars. Nearly 75% of the total fleet are directly related to the fishing activity and 25% are mother and factory vessels (Sosa, 2002). The most important commercial shrimp species in Cuba is *Farfantepenaeus notialis* which accounts for 98% of the national catches. This species has nocturnal behaviour; therefore fishing is carried out during the night. The distribution area for this species is located in the south-eastern Cuban shelf, basically in the Ana María and Guacanayabo gulfs (Baisre, 2004). The fishing ground is characterized by muddy-sandy bottoms with rock banks and an average of 15 m depth.

Finfish account for 85 % of the by-catch caught in the Cuban shrimp fishery. The past five years of analysis showed that 11 species account for nearly 90% of the finfish by-catch and that Yellow fin mojarra *(Gerres spp),* Lane snapper (*Lutjanus synagris*), Mojarra (*Diapterus* sp), Atlantic bumper (*Chloroscombrus chrysurus*) and Tomtate grunt (*Haemulon aerolineatum*) represented nearly 75% of this figure (ICES, 2008). Some important commercial species such as the Lane snapper are overexploited during juvenile stages, due to for example the low selectivity of the fishing gear (Font, 2002). After years of shrimp trawling exploitation, demersal fish communities tend to become more resistant but are comprised of species with less commercial value (Caddy and Mahon, 1995).

Since 2002, The Cuban Ministry of Fishing Industry has initiated a UNEP/GEF/FAO project aimed at the Reduction of Environmental Impact from Tropical Shrimp Trawling, through the Introduction of By-catch Reduction Technologies and Change of Management. Modifications in the trawl net design such as increase of horizontal and decrease of vertical openings as well as the use of "Fisheye" as By-catch Reduction Device (BRD) (FAO, 2003) have helped to reduce the effect on demersal fish communities including valuable species.

The modifications in shrimp-trawl nets are not only aimed at reducing by-catch, but may affect both by-catch and shrimp selectivity. Improving selectivity leads to a more efficient exploitation of the stock's growth potential and more shrimps may reach mature size and spawn. Furthermore, this smoothes fluctuation in recruitment and thus guarantees more even yields for the fishery (Machera *et al.* 2008). Also, from an economic perspective, bigger shrimp sizes are more favourable to companies and fishermen due to the higher price in the export markets.

To assess the performance of trawls before and after modifications in their design constitutes an important topic for the Cuban shrimp fishery today. For this reason, the main goal of the present study aims at a comparative analysis of conventional and modified shrimp trawls in terms of total catch and catch at length.

2   LITERATURE REVIEW

2.1   The shrimp fishery and by-catch

The second most valuable fishery for Cuba involves the exports of shrimps (Baisre, 2004). Pink shrimp is the principal species caught in this fishery. This species lives in shallow water, up to 3 nautical miles from the shore line. Adult individuals may reach a total length of 17 cm and have a short life cycle ranging from 12 to 18 months. The main recruitment period is from September to December when young sub-adult shrimps migrate in mass into the fishing grounds (Baisre *et al*., 1985). The distribution areas are predominately muddy-sandy bottoms at an average depth of 15 m. This species is caught by nocturnal trawling due to its active behaviour during the night. This industrial fishery is comprised of vessels which use flat twin trawls as fishing gears and operate on the Southeastern shelf of the country. The trawling fleet is comprised of 48 vessels, mainly ferro-cement vessels (17.9 m overall length) and few steel trawlers (22.9 and 25.2 m overall length) (Sosa, 2002).

Shrimp trawling is a relatively unselective fishing method and large volumes of by-catch are typically retained in the codend comprising several hundred species totally (Eayrs, 2007). In this fishery, as in many other multi species fisheries, unwanted species are often caught and discarded. In Cuba, shrimp

catches are dominated by a high biomass of diverse by-catch comprised mainly of 87 species, 66 genera and 46 families of finfish, crustacean and molluscs respectively. Most of these captures are landed and have represented around 13000 T annually in the past years. Approximately 12% are dedicated for human consumption and the rest for fish meal (Baisre, 2004).

The search for solutions to by-catch problems has intensified during the last two decades because of the increased global concern about biological overfishing and alterations in the structure of marine ecosystems (ICES, 2008). With the objective to reduce the environmental impact arising from commercial shrimp trawl fisheries in tropical countries, a FAO Reduction of By-catch in Tropical Shrimp Trawling (REBYC) project has been carried out since 2002 concentrating on the four tropical regions of the world. The overall goals have been focused on the capture and discarding of unwanted catch and by-catch species and the impact of shrimp-trawling on the bottom habitat. Up to the present, this project in Cuba has aimed at the design, construction and tests of a fishing technology less harmful to the environment on both experimental and commercial levels in Santa Cruz del Sur Fishing Enterprise (Southeastern region of Cuba). Important advantages are being verified. The first is to allow an escape of nearly 25% of by-catch, thus reducing the negative effect on fish populations and especially juvenile stages of Lane snapper. Secondly to increase the fishing gear selectivity to the catch of Pink shrimp with no detriment to the present observed levels and consequently an increase in the catch exportable value (ICES, 2008). The main changes in the Cuban shrimp trawl nets have focused on decreasing the vertical opening and increasing the horizontal opening with the addition of the fisheye (BRD) in the upper part of an extension in front of the codend.

In the last decade several experiments have revealed that special devices inserted either in the codend or in the aft part of the extension piece have improved the release of undersized fish and unwanted by-catch, by modifying only a small part of the gear in use (Wileman *et al*., 1996). The relative swimming speeds of the fish to be excluded and the location of the By-catch Reduction Device (BRD) in the trawl and/or its design with respect to relative water flow are common factors influencing the performance of many BRD in different trawl fisheries (Broadhurst, 2000; Heales *et al*., 2008; Brewer *et al*., 1998). Despite the wide variety of sorting devices, most can be classified under two broad categories according to the basic theory and methods used to facilitate the escape of by-catch: BRDs that separate species by behaviour, BRDs that separate species by size and of course, combinations of BRDs (Broadhurst, 2000).

2.2 Trawl Selectivity and catching comparison methods

The selectivity of fishing gears, as a measurement of the selection process, describes relative likelihoods that different sizes and species of fish will be caught by the gear (Wileman *et al*., 1996).

In towed gears studies, considerable amounts of fish escape through the codend and this is where the main mesh selection is thought to occur. Most selectivity studies have been focused on this part of the trawl (Wileman *et al*., 1996). For codend selectivity analysis, the number of fish retained by the test codend and the total number that have entered the codend have to be known. In some experiments a cover around the test codend has been used (Grimaldo *et al*. 2008; Ragonese *et al*. 2001; Madsena *et al*. 2001). Another method uses two identical trawls, one fitted with a small mesh codend of equal overall dimensions to the test codend to match the test trawl as closely as possible giving an estimate of the numbers of fish that should have entered the test codend (Wileman *et al.,* 1996; Heals *et al.,* 2008).

The main advantage of the covered codend method is that the retention probabilities for each length class can be calculated directly, since the escaped fish are retained in the cover. However, the cover enclosing the codend or the grid may alter the water-flow around the codend (Wileman, 1996; Ingólfsson, 2006). The twin trawl method overcomes this problem but some added variations in the selectivity estimations may occur (Madsen and Holst, 2002; Ingólfsson, 2006; Herrmann *et al.,* 2007).

Statistical models, used to describe towed gears, typically model the contact selection curve r(l), which is defined by the (relative) probability that a fish of length (l) is captured given that it contacted the gear (Wileman *et al*., 1996, Millar and Fryer, 1999). A sigmoid-shape curve usually describes the codend selection and much used metrics are 50% retention length (L50) and selection range (SR) which is the difference in length of fish that have 0.25 and 0.75 retention probabilities, and is thus a measure of curve steepness, the lower the value, the sharper the selection (Ingólfsson, 2006).

One of the models used to determine the probabilities that a fish of length l is retained by the tested trawl, given it is caught in one of the two trawls can be modelled is the Generalized Linear Mixed

Model (GLMM). Using this model, controllable factors affecting fish selectivity, such as, mesh size, twine thickness, etc; and other uncontrollable factors like seasonal variations in girth, temperature, between- haul variations, etc, can be considered.

In towed fishing gears, the catch comparison experimental methods are used to analyse two trawls with different designs. In these methods, the control trawl is also selective and does not show a representative size distribution of the catch. The absence of a non-selective control gear means that it is not possible to estimate the absolute selectivity of the two codends, by which the proportions at length are determined (Holst and Revill, 2009). Examination of data from catch comparison experimental methods has been far less developed than that of selectivity experiments. This may likely be explained because data from these experiments do not permit a model-based analysis in the sense of estimating the underlying selective properties by which the data were generated (Holst and Revill, 2009). Kolmogorov-Smirnov test (K-S) is broadly used to analyse catch at length data from catch comparison experimental methods. This test permits comparison of size frequency distributions between different gear configurations (Nies, 2002; He *et al.,* 2007).

3   MATERIALS AND METHODS

The data analysed in this study consist of the catch results from three cruises under experimental and commercial conditions during 2006-2007.

3.1   Area of study

The experiments were carried out on fishing grounds of Santa Cruz del Sur Fishing Enterprise in the southern region of Cuba because of its significant contribution to national shrimp catches and uniformity of fishing gears and fleet (Figure 1).

In general, fishing grounds for shrimp fisheries are muddy-sandy bottoms with rock banks, an average of 15 m depth and have been delimited by grids of 5 nm^2 according to legislations established by Cuban Ministry of Fishing Industry for fishing enterprise operations (Sosa, 2002).

Figure 1. Study area corresponding to Santa Cruz del Sur fishing enterprise (coloured lines) on the Southeastern coast of Cuba.

3.2   Gear and Fisheye design

The fishing gear traditionally used since 1976 in Cuban shrimp fisheries is the flat twin trawl (Sosa, 2002). Net plans of the traditional trawl and the modified trawl tested are shown in Figure 4 and Figure 5 respectively.

The new trawl design has modifications mainly focused on decreasing the vertical opening contributing to catch less finfish distributed in higher levels of the water column and to increase

horizontal opening to compensate for the possible loss of shrimp over the lowered headline. Also, the modified trawl has 2 mm smaller mesh size than the traditional trawl (50 vs. 52 mm), except in the codend. A comparison of geometry of both traditional and modified trawls is shown in Table 1.

Table 1. Characteristics and technical parameters of the traditional and modified trawls (ICES, 2008).

Parameters	Traditional trawl	Modified trawl
Upper rope length (m)	9.0	10.4
Twine area (m^2)	155.0	129.6
Area of net mouth (m^2)	9.8	10.0
Horizontal opening (m)	6, 3	7.3
Vertical opening (m)	1,9	1,6
Net weight without codend (kg)	7,4	5.9
Resistance to trawl (Newton) *	1609.4	1415.3

* Calculated using formula proposed by Friedman (1986).

In addition, a fisheye designed to allow fish to voluntarily swim through an escape opening in the codend (FAO, 2003) was fixed to the upper central line of the extension (Figures. 2, 3, 4 and 5a). Figure 3 illustrates the fisheye located within the trawl net. The fisheye was made of stainless steel bars of 8 mm diameter, constructed with an ellipse shaped ring as base (50 maximum and 25 cm minimum diameter), with a 50 cm total length (Figure 2).

Figure 2. The fisheye bycatch reduction device (BRD).
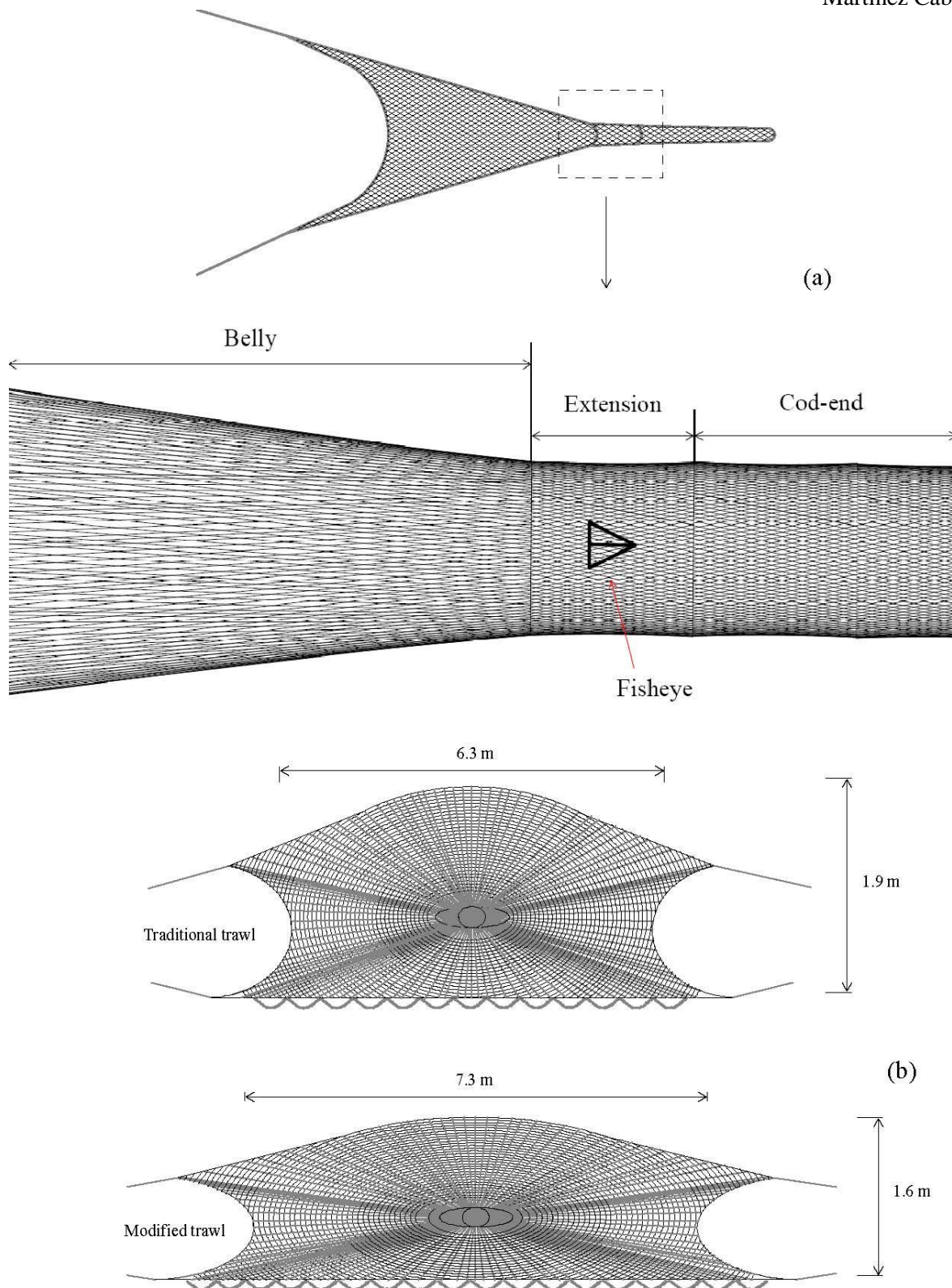
(a)

(b)

Figure 3. Diagrammatic representation showing a top view of the Fisheye in the trawl (a) and the mouth of the traditional and modified trawl in front view (b).
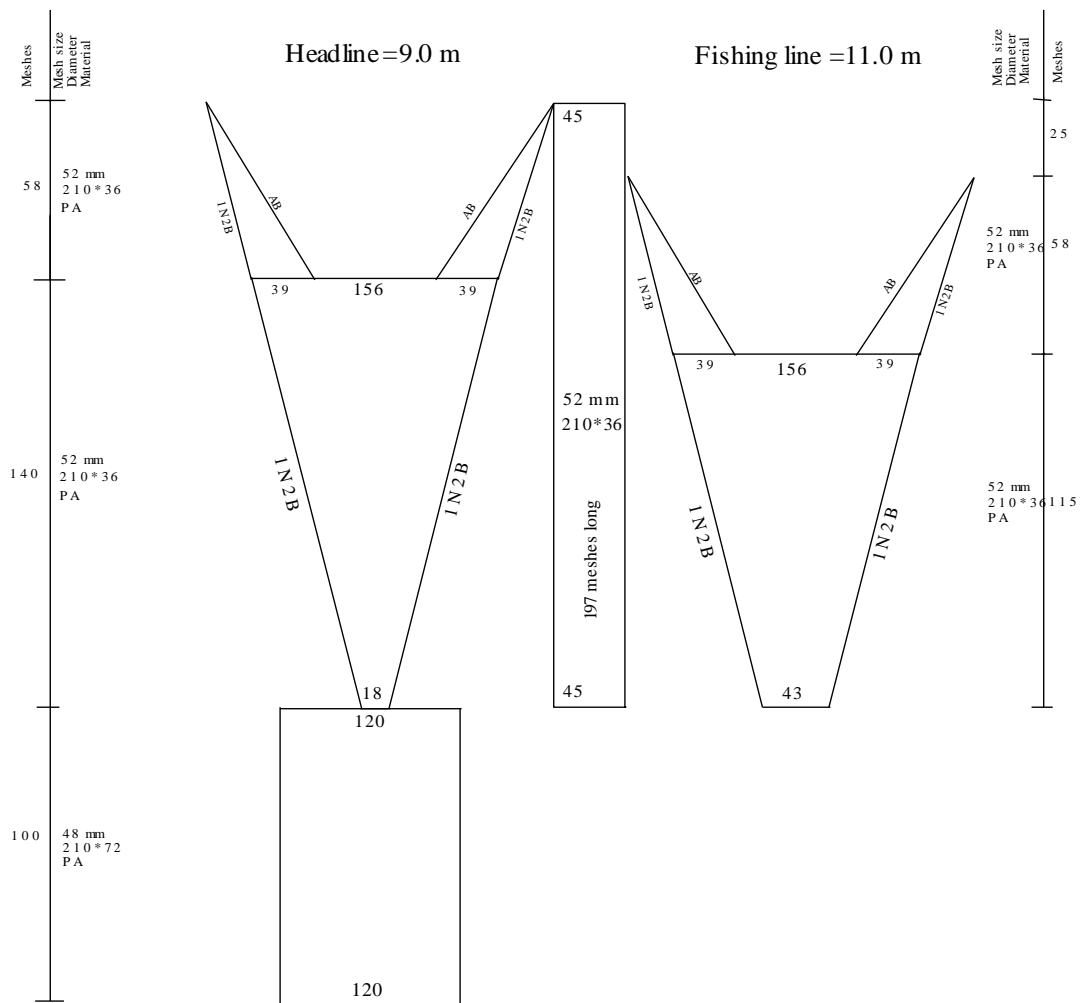
Figure 4. Net plan of the traditional trawl used as control during the comparative experiments in the Santa Cruz del Sur shrimp fishery in 2006 (drawn from information provided by the Fisheries Research Center of Cuba).
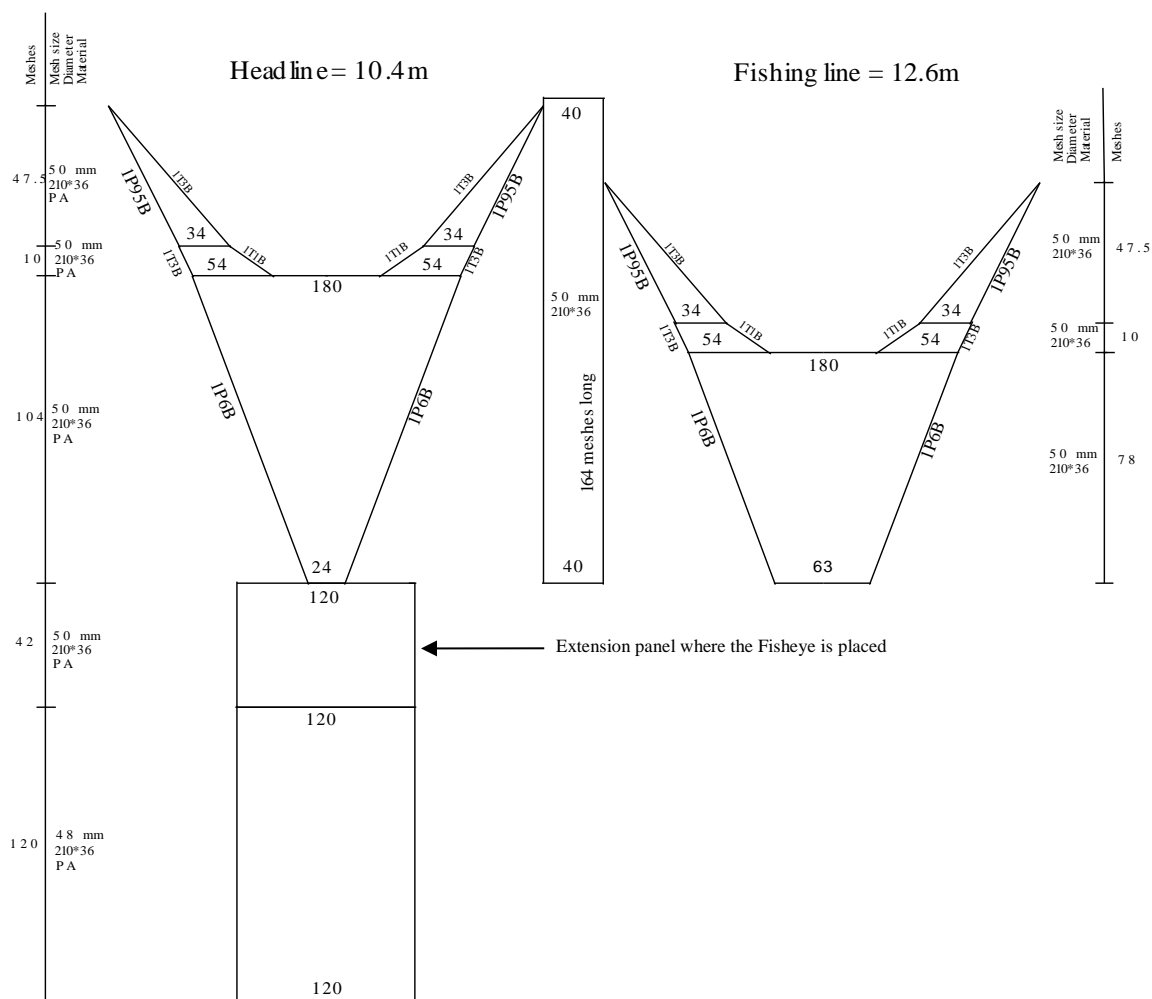
Figure 5. Net plan of the modified trawl tested during the comparative experiments in the Santa Cruz del Sur shrimp fishery in 2006 (drawn from information provided by the Fisheries Research Center of Cuba).

3.3 Sea Trials

The modified trawl was compared to the traditional trawl under commercial regime during three cruises with 99 hauls in total. The first cruise took place in June-July 2006; the second in November-December 2006 and the third in December 2007. The average tow duration was 2½ hours and the towing speed was 3 knots. Between four and five tows per night were completed on board the FC 24 and Plástico 1 shrimp trawlers. The overall length of both vessels is 21 m and they are constructed of ferrocement and fibreglass respectively.

3.4 Experimental methods

Fishing trials were carried out towing both trawls simultaneously with the traditional trawl as control on one side and the modified trawl with a Fisheye device on the other.
The twin trawl method is particularly recommended for fisheries in which twin trawl is commonly used. This method is also utilized to estimate whole trawl selectivity and to conduct catch comparison trials. However, besides the usual variation in catches, there is also a random variation in catch between the two trawls and therefore a somewhat larger number of hauls are required to achieve the same precision of estimation as is attained by the covered codend (Wileman *et al.,* 1996).

3.5 Data Collection and analysis

For the cruise June-July 2006, shrimp and by-catch were sorted and measured for both the traditional and modified trawl after each tow. Shrimp catches were divided into two classes, small (<4.2cm) and damaged shrimp and large shrimp, and weighed to the nearest 0.2 kg. Shrimps were measured to the nearest mm from the orbital spine to the last abdominal segment from collected samples of approximately 1kg per tow. By-catch was divided into finfish and other by-catch and weighed to the nearest 0.2 kg. Among the finfish species, Lane Snapper was measured to the nearest mm of fork length. In the cruise of December 2007, total shrimp catches, samples of shrimp by classes and the finfish by-catch were measured. The cruise November-December 2006 (cruise 2), was confined to collecting samples of shrimps by classes for catch at length analysis (Table 2).

Table 2. The type of data collected from the traditional and modified trawl during the three cruises. S+L, means that shrimp was also separately measured in small (S) and large (L) sizes. x means measured variable.

	Number of hauls	Length frequency (shrimp)	Total catch (shrimp)	Total catch (bycatch)	Total catch (finfish)	Length frequency (Lane Snapper)
Cruise 1	44	x	S + L	X	X	x
Cruise 2	45	x				
Cruise 3	10	x	x		X	

Data of catches between the two trawls were analysed using a paired t-test.

The Kolmogorov-Smirnov (K-S) test was used to compare the size distributions between the traditional and modified trawl. For this test cumulative frequencies for each trawl were calculated. The test allows for testing differences in size distribution, regardless of catching efficiency (Steele *et al.,* 2002; Lawson, *et al.,* 2007).

Although experiments were replicated under non altered conditions of the gears and vessels along each cruise, there was an inter-haul variation, which was accounted for in the analysis to avoid misleading statistical inferences (Fryer, 1991; Millar and Fryer, 1999).

Shrimp catch proportions can be described by logistic curves, considering the probability that a shrimp of length l is retained by the modified trawl, given it is caught in one of the two trawls. This probability was modelled using a Generalized Linear Mixed Model (GLMM), where the between haul variation was accounted for by treating it as random effect and controlled changes (trawl design) modelled as fixed effect (Fryer, 1991; Millar and Fryer, 1999). Based on a method proposed by Holst and Revill in 2009, subsample fractions were also incorporated as offsets in the model to avoid underestimating the variances which may produce erroneous conclusions.

4   RESULTS

A total of 99 comparative hauls during three cruises using the twin trawl method were completed with a modified trawl with a Fisheye device and the trawl conventionally used in Cuban shrimp fishery. 44 hauls were executed in June-July 2006, 45 hauls in November-December 2006 and 10 in December 2007 (Table 2). In the three cruises, a total of 8.580 shrimps in the case of the experimental trawl and 8.473 shrimps in the traditional trawl were measured and considered for catch at length analysis. Total catch of shrimp and finfish were compared between the two trawls for the first and the third cruise. For June-July 2006, total by-catch was also analysed. Undersized and damaged shrimps were separately examined from the total shrimp catch in the first cruise. Also in this survey, catches of Lane Snapper were compared between traditional and modified trawl in terms of total catch and number of fish below the length at maturation (LM).

In general, finfish made up a considerable portion of the total by-catch in the analysed hauls. Despite variations between towing times, depths, and seasons of the year, the finfish by-catch mainly consisted of Lane snapper, Mojarra, Atlantic bumper and Tomtate grunt. Also skates and rays were present in most hauls but were not analysed separately.

4.1 Total catch comparison

4.1.1 Finfish

The traditional trawl caught more finfish than the modified trawl in 37 of 44 hauls conducted in the cruise June-July 2006. In Figure 6, catches per haul of finfish by-catch from the modified and the traditional trawl are shown.
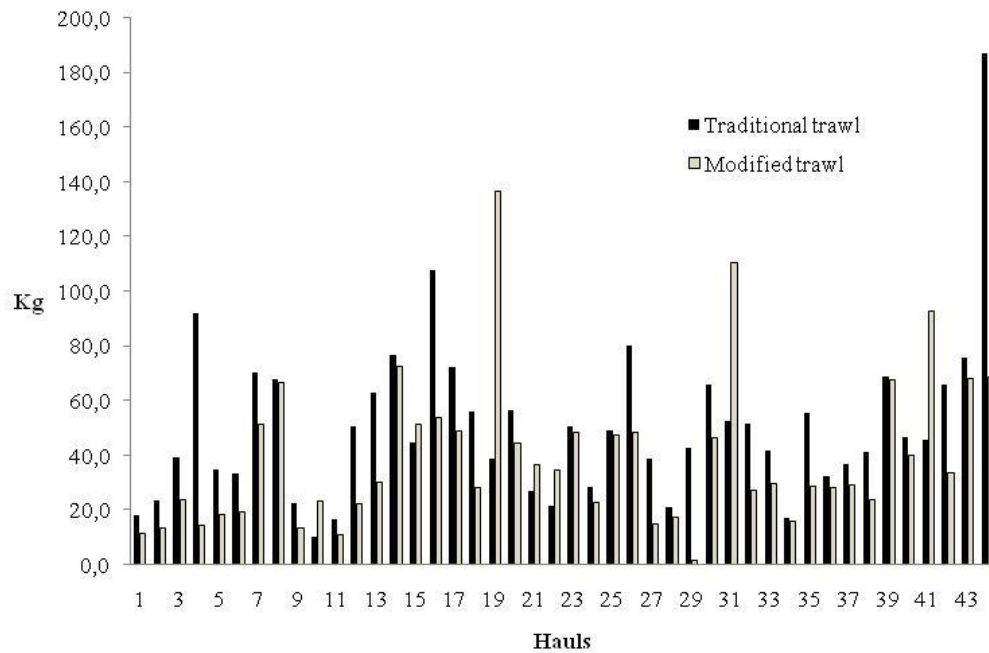

Figure 6. Catches in kg of finfish by-catch for the traditional and modified trawl during the 44 hauls in the cruise conducted in June-July 2006.

There was a decrease in the finfish by-catch using the modified trawl when compared to the traditional trawl. The average catch of finfish by-catch for the traditional trawl was 51 kg per tow and 39.3 kg per tow for the modified trawl (Figure 7). This difference accounted for 22.9 % and was statistically significant (paired t-test, $p < 0.05$).
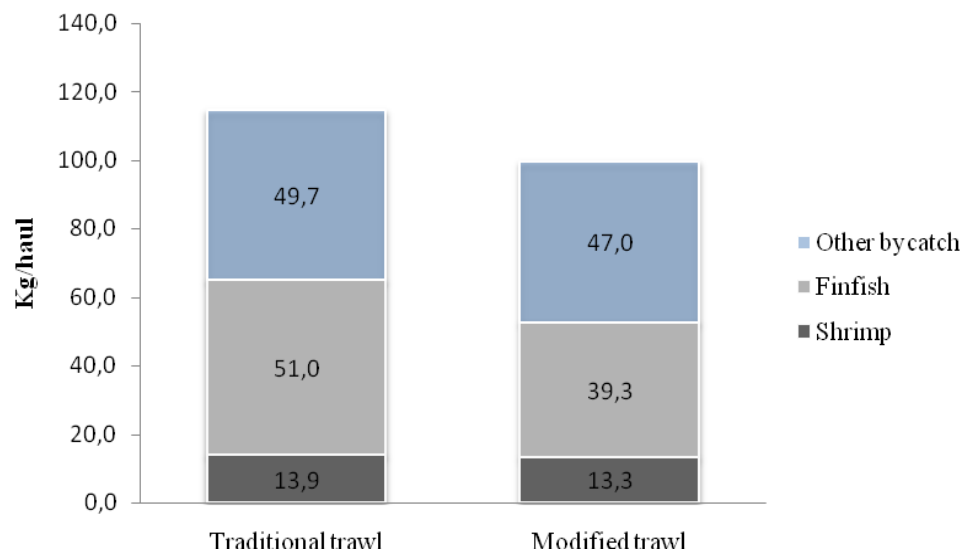

Figure 7. Average catches (kg/haul) by Shrimp, Finfish and Other by-catch groups for the traditional and modified trawl during the 44 hauls in June-July 2006 cruise.

The difference in number of Lane Snapper <15 cm (length at maturation) per haul between the two trawls is presented in Figure 8. In total 188 individuals <15cm were caught by the traditional trawl, but

180 by the modified trawl, with a difference not statistically significant (paired t-test, p=0.43). The high abundance of snappers in the modified trawl in hauls 6 and 34 is possibly related to the effect of scaling up the subsamples.
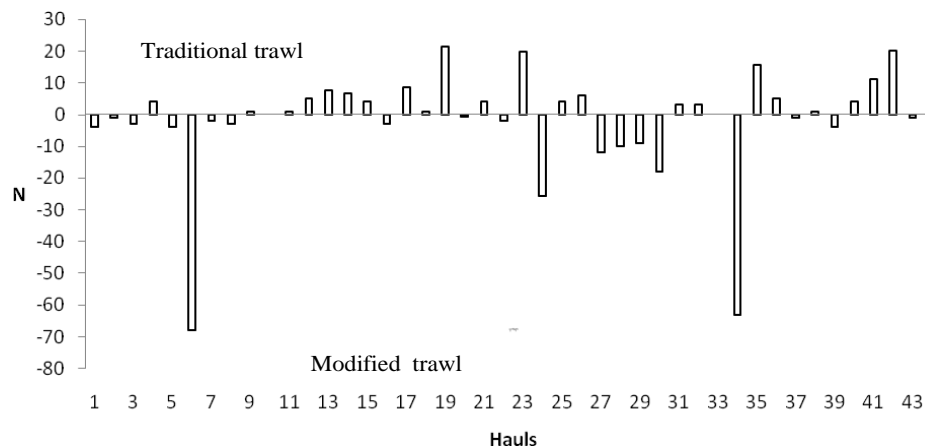

Figure 8. Differences in number of Snappers under LM between the two fishing gears analysed for the cruise June-July 2006.

Less finfish by-catch was observed in the December cruise in 2007 (Figure 9). The average catch of finfish in the traditional trawl was of 36.0 kg per tow and 29.5 kg per tow for the modified trawl. The statistical test applied to the ten paired catches between the two trawls showed significant difference (paired t-test, p<0.001).
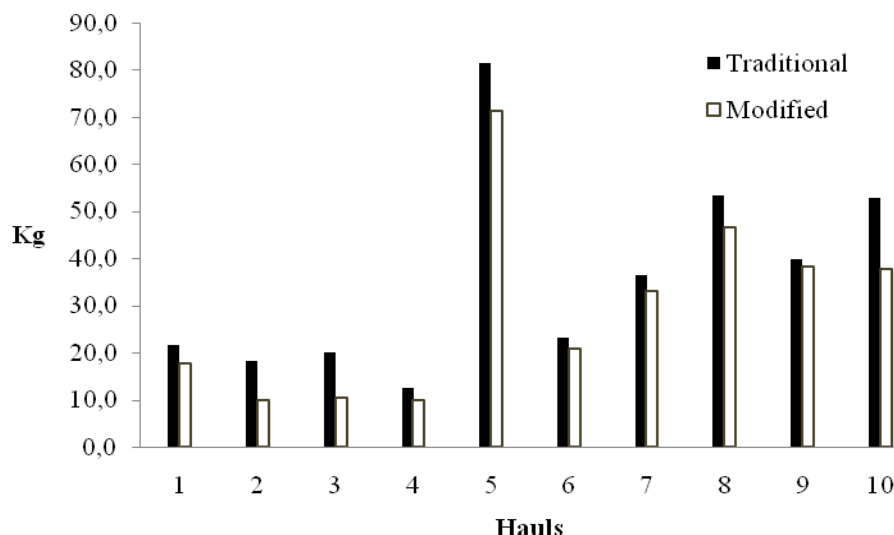

Figure 9. Catches in kg for finfish bycatch for the traditional and modified trawl during the 10 hauls in the cruise conducted in December 2007.

4.1.2 Other by-catch

This diversified group was mainly comprised of sponges, crustaceans, sea urchins (*Moyra sp*) and jellyfish (*Aurelia aurita*). The traditional trawl caught an average of 49.7 kg per tow of this by-catch and the modified trawl caught 47 kg per tow (Figure 7). The difference of 5.5 % between these values was not statistically significant (paired t-test, p = 0.53).

4.1.3 Shrimp

The shrimp catches from 44 hauls in the cruise in June-July 2006 were separately analysed in terms of large shrimps, small shrimps and total shrimps. In Figure 10 differences in kg between the traditional and modified trawl for the three groups are shown. Total shrimp difference per haul ranged from -0.3 kg to 1.38 kg with a median value of 0.88 kg. In general, the traditional trawl caught more shrimp than the modified one. Differences in large shrimps, however, show a range from -1.2 to 0.7 kg per haul

(median 0.1 kg), close to the x axis indicating that both trawls catch large shrimps similarly. The difference between the two trawls for small shrimps ranged from 0 to 1.25 kg and the median was 0.6 kg. The traditional trawl thus catches more small shrimp than the modified trawl with statistically significant difference (paired t-test, p< 0.01).
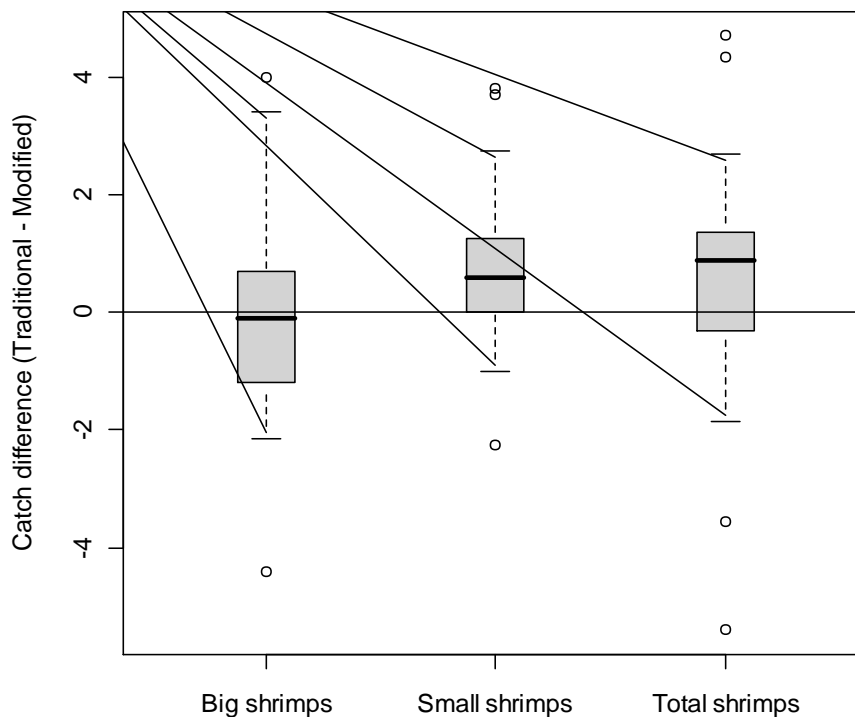

Figure 10. A Box-and-whisker plot showing differences in kg of large, small and total shrimp groups between the traditional (above X axis) and modified (under X axis) trawl per haul during June-July 2006.

The average total catch of shrimps for the 44 hauls using the modified trawl was 13.3 kg per tow compared to 13.9 kg per tow for the traditional trawl, with a significant difference (paired t-test, p = 0.041). The average catch of the large shrimp was 9.9 kg per tow for the traditional trawl and 10.1 kg for the modified trawl, which is statistically not significant (paired t-test, p=0.50). The average catch of small shrimp (damaged and <4.2 cm) was 4 kg per tow for the traditional trawl and 3.2 kg per tow for the modified trawl with a significant difference (paired t-test, p< 0.01).

In December 2007 the average shrimp catch for the traditional trawl was 15.4 kg per tow but 17.6 kg per tow for the modified trawl (10 hauls) in the cruise. The difference between the average catches was statistical significant (paired t-test, p< 0.01). Here shrimps were not separated into small and large shrimp so catch at length analysis could help to clarify this result.

4.2   Catch comparison at length

4.2.1   Size distribution test

For shrimp, the cumulative catch at length plots for all cruises (Figure 11), show a consistent difference between the traditional and the modified trawl, where the modified trawl caught fewer small shrimps in all cases. This difference is statistically significant for the cruises in June-July 2006 and December 2007 (K-S test, Table 3). For the cruise in November-December 2006, the difference is not significant. For the three cruises the mean value is consistently higher in modified trawl compared to the traditional trawl.
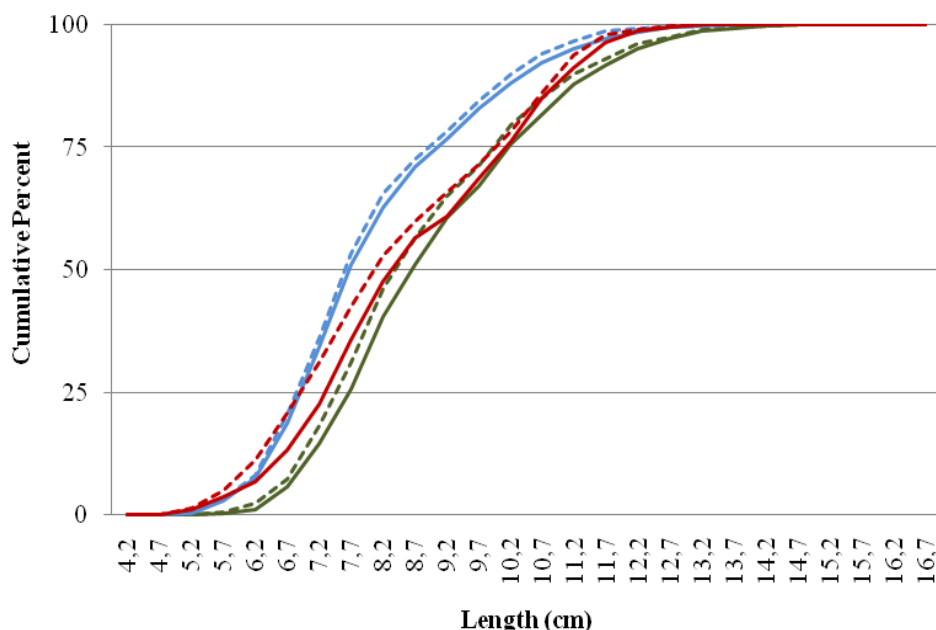
Figure 11. Curves of cumulative shrimp catch at length for the traditional and modified trawl for each cruise. June-July 2006 (red lines); November-December 2006 (bluelines); December 2007 (green lines). For all the cases, dashed lines represent the traditional trawl and solid lines the modified trawl.

Table 3. Results of K-S test for analysis of length frequency distributions of shrimps between traditional and modified trawl for the tree cruises. (D= maximum vertical deviation between the two curves; p= significance; x = mean).

	Jun.-Jul._2006		Nov.-Dec._2006		Dec._2007	
	Trad.	Mod.	Trad.	Mod.	Trad.	Mod.
$\overline{x}$ (cm)	9.01	9.24	8.20	8.31	8.62	8.88
D	0.0585		0.028		0.0852	
p	<0.001		0.1661		<0.001	

4.2.2 Logistic regression

To model the shrimp catches at lengths between the traditional and modified trawls a logistic regression was applied based on a GLMM. Haul to haul variation was modelled as random effects and length and cruises (1 and 3) as fixed effects. Sampling fractions were considered as offsets in the model. The "Cruise" factor was not statistically significant, Cruise 1 and 3 were therefore analysed together (54 hauls). Length of shrimp was a significant factor ($p<0.01$).

The result of the model was:

$$r(l) = \frac{e^{(-0.723 + 0.097L)}}{1 + e^{(-0.723 + 0.097L)}}$$

where r(l) describes the proportion of fish caught in the modified trawl.

L is length of shrimp.

Significantly more shrimps >10 cm were caught in the modified trawl (paired t-test, p< 0.01).The curve in Figure 12 indicates to the right of the interception with x axis, that bigger shrimps (> 10 cm) are caught by the modified trawl in greater extent compared to the traditional trawl.
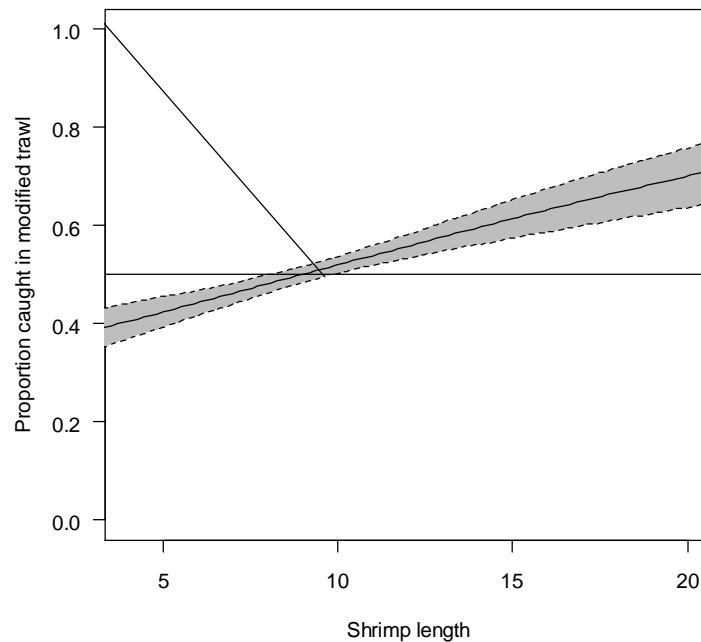

Figure 12. GLMM modelled proportions of shrimps caught in the modified trawl during the two cruises June-July 2006 and December 2007. Interpretation: the horizontal line indicates same catching efficiency of the two trawls, whereas values below the line indicates less than 50% of shrimps at that length were caught in the modified trawl and more than 50% were caught in the traditional trawl.

5   DISCUSSION

The modified trawl performed adequately in reducing the amount of by-catch, mainly finfish, as well as the group of small and damaged shrimps in the Santa Cruz del Sur shrimp fishery. Catch at length analysis showed favourable size selection of shrimp. Finfish by-catch was substantially reduced, but there was no significant difference for the Lane Snapper between the trawl types.

The trawls differed in two basic ways: 1) different trawl design, 2) Fisheye. In addition, there were small differences in mesh sizes (2 mm smaller mesh size in the modified trawl). Since the variables between trawl types were more than one during this comparative study, the causes of the observed differences cannot be verified. Based on calculations it is assumed that the modified trawl has wider horizontal opening (1m) and thus sweeps a larger area per equal length of haul than the traditional trawl. Taking this into account, this makes the modified trawl even more effective in avoiding the finfish by-catch compared to the traditional trawl. In view of the swept area, the shrimp catch of the modified trawl is, however, considerably lower than for the traditional trawl, with the higher headline.

Finfish catches, which accounted for more than half of the by-catch, were significantly reduced using the modified trawl in most hauls in the first cruise and in all hauls during the third cruise. The 30 cm reduction in vertical opening may result in finfish having more possibilities to avoid the trawl but the assumed increase in horizontal opening of the modified trawl should increase the number of fish encounters. During trawling, fish are herded together in the posterior section of the trawl and they become disorientated, resulting in increased swimming speeds and escape attempts (Watson 1989; Broadhurst, 2000). A fisheye creates an escape opening in the net, enabling mobile animals to detect and orient to the altered flow and potentially escape through the opening (Heals *et al.*, 2008). This

excluding device has proven to be successful for finfish by-catch in several shrimp trawl fisheries (Brewer *et al.,* 1998; Salini *et al.,* 2000; Eayrs, 2007; Heales *et al.,* 2008; Manjarres *et al.,* 2008). The most plausible explanation of a lower finfish by-catch is thus that the Fisheye installed in the codend extension of the modified trawl effectively lets out the finfish.

The modified trawl did not show a reduction in number of Lane snappers, neither totally nor below the LM. The escape of fish through By-catch Reduction Devices (BRD) is determined by several factors: their species-specific responses to various tactile and visual stimuli, their density, abundance and schooling behaviour in the trawl, physiology, behaviour and morphology (Broadhurst, 2000). Snappers do not seem to be very active in escape behaviour according to diver's observations in the Gulf of Mexico during trawling (Workman *et al.,* 1994). In that experiment, juvenile red snappers did little to escape as they were overtaken and captured by the trawl. Also in the same experiment, observations of snapper behaviour in relation to water flow indicated that they will actively exit through trawl excluder openings if water flow is reduced to between 0.2 and 0.5 m/sec, which is low compared to the towing speed used in the Cuban shrimp fishery (1.54 m/s).

Other by-catch was not reduced by using the modified trawl. The decreased vertical opening of the modified trawl is unlikely to affect catches of this group of small organisms, as some of these species are stationary (sponges), and the towing speed is faster than the locomotion speed of others (Sarmiento-Náfate *et al*., 2007). On the other hand, this result is probably also affected by the increase of the horizontal opening in the modified trawl which increased the swept area compared to the traditional trawl, and thus should have increased the possibilities to catch this group.

The total shrimp catch of the modified trawl was on average smaller than the average for the traditional trawl for the first cruise (13.3 vs. 13.9 kg). In the last cruise, however, more shrimp were caught on average by the modified trawl (17.6 vs. 15.4 kg). Judging from Fig. 11, the average size of shrimps encountered may have been larger during this last cruise than during the other two. As the modified trawl catches more of the large shrimps, this may explain the higher average catch in the modified trawl in December 2007. If lower catches of shrimp during the last three years, are caused by overfishing, and since the modified trawl catches less small shrimps, the general use of the modified trawl (assuming the same total catch), might not only increase and stabilize recruitment as suggested above, but with time the average size of shrimp should increase and with on average larger shrimps encountered, the superiority of the modified trawl, over the traditional one, would increase even more.

The modified trawl caught less small and damaged shrimps than the traditional trawl. When changing trawl design to reduce by-catch, retaining the catches of large shrimp is important because of the higher unit price. It is important that modifications of fishing gear do not cause a decrease in catches of large shrimp so the implementation won't be an economical hazard to the shrimp fishery. On the contrary, it may represent an increase of economic income as it results in better shrimp quality (ICES, 2008).

Mean shrimp lengths were in general higher for the modified trawl. This difference in length distributions between the trawl types was significant for the first and the third cruise. Additionally, the logistic regression analysis, exhibited a length dependent split in favour of the modified trawl, with shrimps larger than 10 cm being caught in greater extent. These results in addition to the significant difference in number of shrimps suggest that the modified trawl is more selective towards larger shrimps than the traditional trawl. Possible causes may be related to different behaviour of shrimp sizes in habitat selection. According to a study conducted by Meagera *et al.,* 2005, smaller shrimps perch on structures more than larger shrimps, which commonly shelter under structures or walk around structures (Primavera and Lebata, 2000). Also in this experiment large shrimps were mainly close to the substrate on low horizontal structures such as leaves. Contrary to this, smaller shrimps perched more often on narrow vertical structures than large shrimps. Taking into account this behaviour of shrimps, the reduced vertical opening of the modified trawl may offer more opportunities for small shrimps to avoid the net.

6   CONCLUSIONS

The amount of by-catch, especially of finfish, was effectively reduced by using a decreased vertical opening and the fisheye in the modified trawl.

The modifications did not reduce the amount of other by-catch.

The amount of small and damaged shrimps was successfully reduced by the modified trawl.

 The modified trawl was more selective to larger sizes of shrimps.

Despite the improved performance of the modified trawl, it is important in future studies to use an experimental setup with only one variable changed at the time in order to facilitate the interpretation of its effects.

7   RECOMMENDATIONS

Further experiments may be aimed at analysing the behaviour of the Lane Snapper in order to enhance its escape with modifications in the trawl design.

The need for underwater camera work in order to study the net performance and the fish escape behaviours is indicated.

The next steps in possible modifications of the trawl design could be focussed on:

- Decreasing even more the vertical opening to reduce finfish by-catch while preserving the shrimp catch.

- To substitute the fisheye by a square mesh panel with a larger escape area for the fish. This could also reduce the construction cost, compared to using the fisheye.

- To evaluate the possibilities of future tests of "The Nested Cylinder By-catch Reduction Device" (Parsons, 2007), designed to reduce the by-catch of juvenile red snapper in the Gulf of Mexico shrimp trawl fishery.

AKNOWLEDGMENTS

I am truly grateful to the people who have helped me carry out this project, especially my supervisor, Dr. Ólafur Arnar Ingólfsson, for his valuable advice, patience and dedication during the course of my work.

I would also like to thank the UNU-FTP staff, especially Mr. Thor Asgeirsson, Deputy Programme Director, who gave me the opportunity to participate in this program and for his generous guidance.

I cannot forget to acknowledge the support and experiences garnered during the lecture period of this training program, especially from Einar Hreinsson. Also, my sincere gratitude to Mr. Konrad Thorisson for his important comments and suggestions throughout the writing of this manuscript.

Special thanks to my fellow students: Mahadev Kokane, Kingsley M. Thengo, Kheng Makkhenh for sharing this experience and for bearing with me during difficult moments in the process.

I would like to thank the staff of the University Centre of the Westfjords for their welcome and support. I would also like to thank Andrea Cheatham Kasper for assisting me in reading through the manuscript.

Special thanks to Luis Font, Rafael Sánchez, Enrique Valdés and Dr. Gilma Delgado from the Fisheries Research Center of Cuba for supporting me and sharing their valuable comments.

Last but not least, thanks to my family and fiancé who have always been present.

LIST OF REFERENCES

Baisre, J. A., A. Pérez, M. H. Obregon y R. Cruz. 1985**.** Regulation of fishing effort in Cuban shelf fisheries: The case studies of shrimp, lane snapper and spiny lobster fisheries. Papers presented at the Expert Consultation on the regulation of fishing effort (fishing mortality). Conference on fisheries management and development. *FAO Fish.Rep* 298(3): 215–470.

Baisre, J. A. 2004. La pesca marítima en Cuba. Editorial Científico Técnica. 372 pp.

Brewer, D., N. Rawlinson, S. Eayrs, C. Burridge. 1998**.** An assessment of by catch reduction devices in a tropical Australian prawn trawl fishery. Fish. Res. 36: 195–215.

Broadhurst, M. K., S. J. Kennelly and S. Eayrs. 1999**.** Flow-related effects in prawn-trawl codends: potential for increasing the escape of unwanted fish through square-mesh. *Fish. Bull*. 97:1–8.

Broadhurst, M. K., 2000. Modifications to reduce bycatch in prawn trawls:a review and framework for development. *Rev. Fish Biol. Fish*. 10: 27–60.

Caddy J. F., R. Mahon 1995. Reference points for fisheries management. FAO Fisheries Technical Paper. 347. 83 pp.

Eayrs, S. 2007. A guide to bycatch reduction in tropical shrimp-trawl fisheries. Food and Agriculture Organization of the United Nations. Roma.

Eayrs, S., N. P. Hai, and J. Ley. 2007. Assessment of a juvenile and trash excluder device in a Vietnamese shrimp trawl fishery. *ICES Journal of Marine Science*. 64: 1598-1602.

FAO. 2003. Fisheries Topics: Technology. Fisheries technology. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 2006 15 09. [17 February 2009]. http://www.fao.org/fishery/topic/2800/

Friedman, A. L. 1986. Calculations for fishing gear designs. FAO by Fishing News Books, Ltd., London: 241pp.

Font, L. 2002. Progress Report to the Project Coordinator EP/GLO/201/GEF). [17 February 2009].http://www.fao.org/fishery/gefshrimp/2,7/en#Cuba

Fryer, R. J. 1991. A model of between-haul variation in selectivity. *ICES J. Mar. Sci*. 48: 281–290.

Grimaldo, E., R. B. Larsena, M. Sistiaga, N. Madsen, M. Breen. 2008. Selectivity and escape percentages during three phases of the towing process for codends fitted with different selection systems. *Fish. Res*. 95: 198-205.

He, P., D. Goethel, T. Smith. 2007. Design and Test of a Topless Shrimp Trawl to Reduce Pelagic Fish Bycatch in the Gulf of Main Pink Shrimp Fishery. *J. Northw. Atl. Fish. Sci*. 38: 13-21.

Heales, D.S, R. Gregor, J. Wakeford, Y. G. Wang, Yarrow, D. A. Milton. 2008**.** Tropical prawn bycatch of fish and seasnakes reduced by Yarrow Fisheye Bycatch Reduction Device. *Fish. Res*. 89: 76-78.

Herrmann B., R. P. Frandsen, R. Holst, F. G. O'Neill. 2007. Simulation-based investigation of the paired-gear method in cod-end selectivity studies. *Fish. Res*. 83: 175–184.

Holst, R.and A. Revill. 2009. A simple statistical method for catch comparison studies. *Fish. Res*. 95: 254–259

Ingólfsson, O. A. 2006. Size selectivity and escape mortality of gadoid fish in the Barents Sea trawl fishery. The degree philosophiae doctor (PhD). University of Bergen, Norway.

ICES. 2008. Report of the ICES-FAO Working Group on Fish Technology and Fish Behaviour (WGFTFB), 21-25 April 2008, Tórshavn, Faroe Islands. ICES CM
2008/FTC:02. 265 pp.

Lawson, D., J. DeAlteris, C. Parkins. 2007**.** An evaluation of the catch efficiency of a NMFS certified, standard turtle excluder device (ted) required in the mid-Atlantic summer flounder fishery. A Report to the Northeast Fisheries Science Center. National Marine isheries Service. 26 pp.

UNU-Fisheries Training Programme

Machera, C., O. Guyadera, C. Talidecc, M. Bertignacd. 2008. A cost–benefit analysis of improving trawl selectivity in the case of discards: The Nephrops norvegicus fishery in the Bay of Biscay. 92: 72-79.

Madsen N.and R. Holst. 2002. Assessment of the cover effect in trawl codend selectivity experiments. *Fish. Res*. 56: 289–301.

Madsena, N., K.E. Hansenb, T. Moth-Poulsen. 2001. The kite cover: a new concept for covered codend selectivity studies. *Fish. Res.* 49: 219-226.

Manjarres, L.M., L.O. Duarte, J. Altamar, F. Escobar, C. Garcia, F. Cuello. 2008. Effects of using bycatch reduction devices on the Colombian Caribbean Sea shrimp fishery. *Ciencias Marinas.* 34(2): 223-238.

Meagera, J. J., I. Williamson, N. R. Loneragan, and D. J. Vanceb. 2005. Habitat selection of juvenile banana prawns, Penaeus merguiensis de Man: Testing the roles of habitat structure, predators, light phase and prawn size. Journal of Experimental Marine Biology and Ecology 324: 89– 98.

Millar, R. B. and R. J. Fryer.1999. Estimating the size-selection curves of towed gears, traps, nets and hooks. *Reviews in Fish Biology and Fisheries* 9: 89–116.

Nies, T. 2002. Analysis of Catch-at-Length Data from the NMFS Industry Survey Trawl Study Conducted by the R/V Albatross IV and F/V Sea Breeze. Survey Trawl Workshop Working Paper.18 pp.

Primavera, J.H. and M.J. Lebata. 2000**.** Size and diel differences in activity patterns of Metapenaeus ensis, Penaeus latisulcatus and P. merguiensis. Mar. Behav. Physiol. 33 (3): 173– 185.

Parsons, G. R. 2007. WWF's International Smart Gear Competition. [17 February 2009]. http://www.smartgear.org/smartgear_winners/smartgear_winner_2007/

Ragonese, S., M. Zagra, L. Di Stefano, M.L. Bianchini. 2001. Effect of codend mesh size on the performance of the deep-water bottom trawl used in the red shrimp fishery in the Strait of Sicily (Mediterranean Sea). *Hydrobiologia* 449: 279–291.

Ragonese, S., M. L. Bianchini. 2006**.** Trawl selectivity trials on the deep-water rose shrimp (Parapenaeus longirostris) in Sicilian waters. *Hydrobiologia* 557:113–119

Salini, J., D. Brewer, M. Farmer, N. Rawlinson. 2000. Assessment and benefits of damage reduction in prawns due to use of different bycatch reduction devices in the Gulf of Carpentaria, Australia. *Fisheries Research* 45: 1-8.

Sarmiento-Náfate, S. H. A. Gil-López, D. Arroyo. 2007**.** Shrimp by-catch reduction using a short funnel net, in the Gulf of Tehuantepec, South Pacific, Mexico. *Rev. Biol. Trop.* 55 (3-4): 889-897.

Steidl R. J., J. P. Hayes, E. Schauber. 1997**.** Statistical Power Analysis in Wildlife Research. *The Journal of Wildlife Management* 61 (2): 270-279.

Sosa, M. 2002. Progress Report to the Project Coordinator EP/GLO/201/GEF). [Cited 17 February 2009].http://www.fao.org/fishery/gefshrimp/2,7/en#Cuba

Steele P., T. M. Bert, K. H. Johnston, S. Levett. 2002**.** Efficiency of bycatch reduction devices in small otter trawls used in the Florida shrimp fishery. *Fish. Bull.* 100: 338–350.

Watson, J.W. 1989. Fish behaviour and trawl design: Potential for selective trawl development. In: Campbell, C.M. (ed), Proceedings of the World Symposium on Fishing Gear and Fishing Vessels. Marine Institute, St Johns, NF, Canada, pp. 25–29.

Wileman, D.A., R. S. T. Ferro, R. Fonteyne, R.B. Millar. 1996. Manual of methods of measuring the selectivity of towed fishing gears. *ICES Cooperative Research Report*. 215, 126 pp.

Workman, I. K., D. G. Foster. 1994. Occurrence and Behavior of Juvenile Red Snapper, Lutjanus campechanus, on Commercial Shrimp Fishing Grounds in the Northeastern Gulf of Mexico. *Marine Fisheries Review.* 56 (2) 9.