

SHRIMP TRAWL DESIGN IMPROVEMENTS SUGGESTED FOR MEXICAN FISHERIES.

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ABSTRACT

In this paper the current shrimp trawl net designs used in Iceland are examined and the method of design is analysed. Various selectivity devices used in the world fisheries are reviewed in order to find a way to keep shrimp catch high and bycatch or discards low. The general situation in the Mexican shrimp fisheries is analysed and a new shrimp trawl net with selectivity devices is suggested.

TABLE OF CONTENTS

1	INTRODUCTION.....	3
1.1	The trawl as the fishing gear	5
1.2	Type of rigging used for trawling	7
1.3	The performance of the gear	8
1.4	Target species, bycatch and discards.....	8
1.5	Types of shrimp trawl nets used in Mexico.....	10
1.6	Rresearch on selectivity and modification of the fishing gear	14
1.6.1	The selectivity of the shrimp trawls.....	14
1.6.2	Improvement on fishing devices and modified equipment for selectivity and avoidance of bycatch	17
2	AN OVERVIEW OF TRAWL DESIGN AND USE OF SELECTIVITY DEVICES IN SHRIMP FISHERIES	20
2.1	The trawl design method	20
2.2	The 16 steps approach in designing a trawl.....	22
2.3	The performance of Bycatch Reduction Devices for shrimp trawls	30
2.4	Types of Icelandic shrimp trawls developed in the past years	31
3	SUGGESTIONS FOR MODIFICATION OF SHRIMP TRAWLS IN MEXICAN FISHERIES.....	39
4	DISCUSSION	49
	ACKNOWLEDGEMENTS	50
	REFERENCES.....	51
	APPENDIX 1 :THE MEXICAN FISHERIES DATA: MAIN FISHING PORTS, NUMBER OF FISHING VESSELS, TOTAL FISH PRODUCTION.	54

1 INTRODUCTION

Fishing activities are very important in Mexico; they have been contributing to the economy for many years and their benefits help for the development of the country. The shrimp fisheries are one of the important activities that take place in both the Pacific Ocean and in the Gulf of México. As a natural resource it will be important to preserve it for a long time, therefore the responsible fisheries management is a matter of great importance.

Mexico has a coastline by the Pacific Ocean shore of 8475 km and 3294 km by the Atlantic Ocean where the Gulf of Mexico is localised and the Caribbean Seas are surrounding the Yucatan peninsula. There are 62 fishing ports along these coasts. Of a total population of more than 95 millions more than 235 thousands are employed in the fishing activities and 23 thousands work in the aquaculture sector. The number of registered fishing vessels increased from 33,000 in 1980 to more than 100,000 in 1998. Of these 100,000 boats 2000 are fishing in open seas and the rest are operating inshore and on inland waters.

Since 1986 the total fish production has been between 1.4 - 1.5 billion tons but in 1998 it decreased to 1.2 billion tons (Appendix 1). About 36% of the total fishing production comes from the Pacific Ocean. The three most important states of the Northwest coast are Baja California, Sonora and Sinaloa. The Gulf of Mexico and Caribbean seas are producing 43% and about 21% come from the inland waters. The main species are sardine, tuna, mojarra (fish specie) and shrimp.

The shrimp production has been less than 100 thousand tons with an average of about 76 thousand tons between 1986 and 1998. The importance of this resource is great because of its high value. The value of shrimp in 1998 was 66 % of the total value of the four main species. The shrimp fishing vessels use bottom trawls and the fishing season lasts from September to April or May (fishing stops at the beginning of the spawning season) with close to 2000 boats, (SEMARNAP 1998).

This shrimp subsector of the Mexican fisheries is well dispersed geographically. A number of people living in the coastal area benefits from these fisheries. The main problem is the increasing number of the small fishing boats and the fishing pressure on the shrimp and coastal fisheries resources. It is important to observe some measures in order to fish in a sustainable way and to contribute to the preservation of the marine ecosystem.

Shrimp fisheries take place all over the world but mainly in deep cold waters and in the tropics. The main ecosystem is affected by the shrimp fisheries through the by catch. Species other than shrimp that are caught in shrimp trawls are often discarded as “unwanted species” and these species die but sometimes other animals like birds and marine mammals can utilise the discards as diet.

The small scale fishery is a fisheries subsector mentioned in the 1995 FAO Code of conduct for responsible fisheries. It contributes to direct human consumption and constitutes more than a quarter of world catch. Shrimp fisheries are a part of them. There are various items that need to be taken into consideration in exploitation of shrimp; one is the equipment that is used. The bottom trawls used in shrimp fisheries

are of special kind but with certain characteristics depending on the area where they are used. Some of the developed gears used in cold waters have technical innovations that the gears used in tropical waters do not have.

From the global situation of marine fish stocks, Garcia and De Leyva (2001) present in earlier reviews that the most pressured species were redfish, hake, Antarctic cod, lobster, prawns and shrimps, and cod. This information must be taken into consideration in improving the fishing gears. It is important to listen to the warnings. Mathew (2001) refers to the action of the large-scale subsector that is applying non-selective fishing gear in demersal fisheries that have negative impact on fish stocks. The importance of the small-scale fisheries is recognised by the economic activity it brings to coastal communities, especially in remote areas where fishing creates employment, produces revenues and alleviates poverty. One of the most important things of this activity is valuable foreign exchange that the country earns. Since large-scale, industrial fisheries tend to promote biological overfishing, one can argue that from an economic, social and ecological perspective, small-scale fisheries are better.

"Although the size of the gear still remains small in comparison with gears used in large-scale fishing, those used in the small-scale subsector are nevertheless growing in size. These are also becoming less and less selective" (Mathew 2001, p. 9). The impact of fishing gear selectivity on live marine resources is not well defined. It is not easy to ask people to alleviate overcrowding fisheries by leaving it if there is no alternative employment provided by the state.

One of the most commonly used fishing methods is trawling, which catches all kinds of marine organisms and involves a range of gear sizes. Smaller trawls are usually used for shrimp and the biggest trawls are used for pelagic fisheries.

This project considers the possibility of changing some of the adverse effects of fishing on the ecosystem by altering the shrimp trawl and adapting some technical advantages.

New rules have been established for shrimp fishing in order to protect the shrimp stocks and to assure sustainability as stated in Texas Park Wildlife Commission adopted on August 31, 2000 (Lightfoot 2000).

One of these regulations, which takes effect on September 1, 2000, requires the use of a turtle excluder in all trawls in the Gulf of Mexico with few exceptions. It seems that the regulations on the protection of the resources will be adopted soon in many countries.

The objective of the present project is to design a shrimp trawl for Mexican fisheries to be tried in September 2002 and suggest the selective devices that can be used to increase its selectivity to diminish the problem of discards.

In order to reach this objective the following steps must be taken:

- a) Analysis of the current status of the shrimp fisheries in México.
- b) Review research on selectivity devices inserted in trawl gears to find out the best solution for selectivity, bycatch reduction, etc.
- c) Examine the designing methods currently used in Iceland.

- d) Develop a method for adapting fishing gear to specific situations.
- e) Design a trawl susceptible for Mexican shrimp fisheries.

A brief description of a trawl as gear equipment and the type of rigging are presented to help the understanding of the fishing action. Data on the target species and the unwanted catch is also presented in relation to some of the places and areas where shrimp fisheries are important.

The fishing gear used in Mexico is presented as the starting point for designing a new trawl. The technical innovations adopted by the fishing technology sector in order to increase the capacity to catch are described. New devices inserted into the gears to reduce the adverse environmental impact of fishing are described to consider and evaluate the selectivity of the shrimp trawls. The results from the use of these devices are analysed to find the most suitable device to increase the selectivity in the new trawl.

1.1 The trawl as the fishing gear

Fishing gear is a name for all auxiliary gear that can be use for catching, trapping or getting any aquatic organism, animals or vegetal. From the various technical classifications of the principal types of fishing gears it can be found that it is possible to use the trawl net for shrimp fisheries. It is towed on the sea bed where the shrimps are hiding in the sand or mud. From this action the gear gets the name of bottom trawl and this is considered an active gear because it needs to be towed to catch fish. According to Sainsbury (1996), the modern bottom trawl net is basically a large bag made of netting which is drawn along the sea bed to scoop up fish on or near the bottom.

A specific description of the trawl depends on the target species. A shrimp trawl is cone-shaped; the end forward is wide and serves as the mouth. The front part of the net body is tapered to the closed codend. The codend will concentrate most of the target organism that enter through the opening of the trawl. It has a mesh size that permits only the smaller organism to escape. "The cod end is a funnel of netting closed at the rear end by a rope looped through the meshes or through rings and tied with a special codend knot which is secure when pulled tight, but easily released to dump the catch when under pressure from the weight of a full bag. At about midlength is the splitting strap, an endless rope fitted loosely through steel rings attached around the outside of the netting so that when pulled tight the net is brunched together at that point. Spliced into the splitting strap is the bullrope (pork line) which is run loosely along the length of the net to be tied at the headrope. The use of this splitting strap and various other working lines for net handling depends on the vessel design and operating procedures" (Sainsbury 1996, p. 36).

On either side of the mouth there are tapered sections of net, which form the wings. To frame the net, in the upper side of the mouth and running from one wing, taking as the centre the upper side of the mouth and to the other wing there is a strong headline called "headrope or floatline" because of floats fixed to it, and at the lower side of the mouth, running similarly, there is a stronger fishing line called "footrope or groundrope" because it is in contact with the bottom and normally its weight is increased using a steel chain. The net takes an oval shape at the entrance. The wings

in the front increase the sweep area and herd the shrimp in the net's path down to the body and hence to the codend. The headline is shorter than the fishing line and the upper side of the net overhangs the fishing line to ensure that any shrimp jumping out from the sand is retained in the net and therefore can not escape upwards. The vertical opening of the mouth is maintained by the floats on the headline and the weight of the chain on the fishing line and the water pressure generated from towing. To keep the mouth of the net horizontally open while the net is towed otter boards (doors) are used.

The netting material used for this type of nets is the strong and elastic polyamide (PA) but the fishing industry is changing to different materials such as polyethylene (PE), combined twine using PE and PA and to the new stronger fibres as "dynema" or "spectra". The legal mesh size for shrimp trawl nets in Mexico fisheries is 57 mm, (mandatory in Mexico's commercial shrimp fisheries since August 1978. Diario Oficial de la Federación 1978). Fisherman are using from 57 to 45 mm mesh size in order to retain the small "pink" shrimp but inspections are made to ensure fishermen comply with the regulations. For the headline and fishing line a "combination" rope is used which is constructed from wires and natural fibres with great flexibility. The natural fibres are being replaced by synthetics such as PE.

The nets can be made of two or four seams. The four seams are similar in pairs, the side panels are exactly the same but the upper panel is different from the lower panel by the first section. This feature in the bottom trawls is called "square" and forms the peak of the trawl. The size of the trawl nets depends on the engine power of the vessels and varies from 23 to 33 meters headline length (Figure 1).

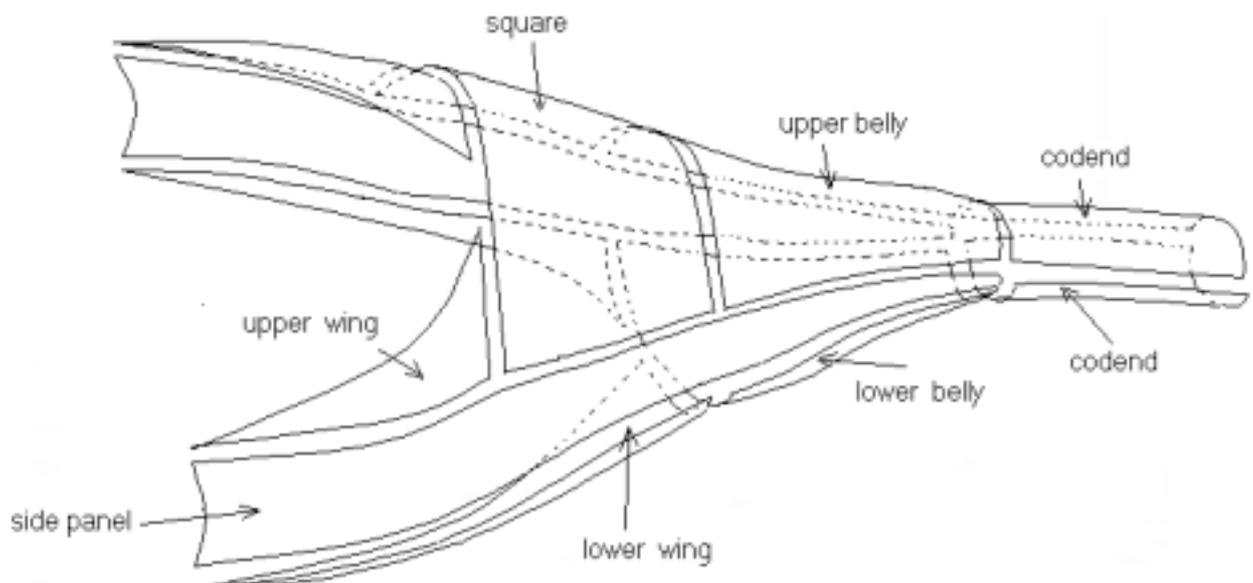


Figure 1: Schematic presentation of the different sections of a shrimp trawl net made of four panels equals by pairs in the Mexican fisheries.

1.2 Type of rigging used for trawling

The rigging method used in Mexico is named twin-rig or double-rig shrimp trawling. One vessel tows two otter trawls from the ends of outrigger booms. One single net is towed on each side with only one warp and both nets are normally of the same size and characteristics. Commonly a small trynet is operated with a third warp from a small boom by the side near the stern of the vessel (Figure 2).

According to Sainsbury (1996), this method was developed in the Gulf of Mexico during mid 1950s and by 1958 it became the main trawling method used in the offshore fishery in that area. Since then, thousands of vessels have been built and the method has spread world-wide, being adapted to suit different conditions and applications, usually in depths of up to 150 m (82 fathoms). The rectangular doors are wood and steel structures with a thick steel shoe. They are connected directly from the after end of the door to the headline and the fishingline of the net. The towing brackets are made of steel chain and fitted to the inner face providing a towing point. To each otter board a bridle is connected and they joined together with the steel warp leading up to the towing vessel. The length of the bridles is from 64 to 100 m for 23 to 33 m headline nets. Finally there is a tickler-chain connected between the doors which is one or two feet shorter than the fishing line to disturb the shrimps up from the bottom so they can be caught.

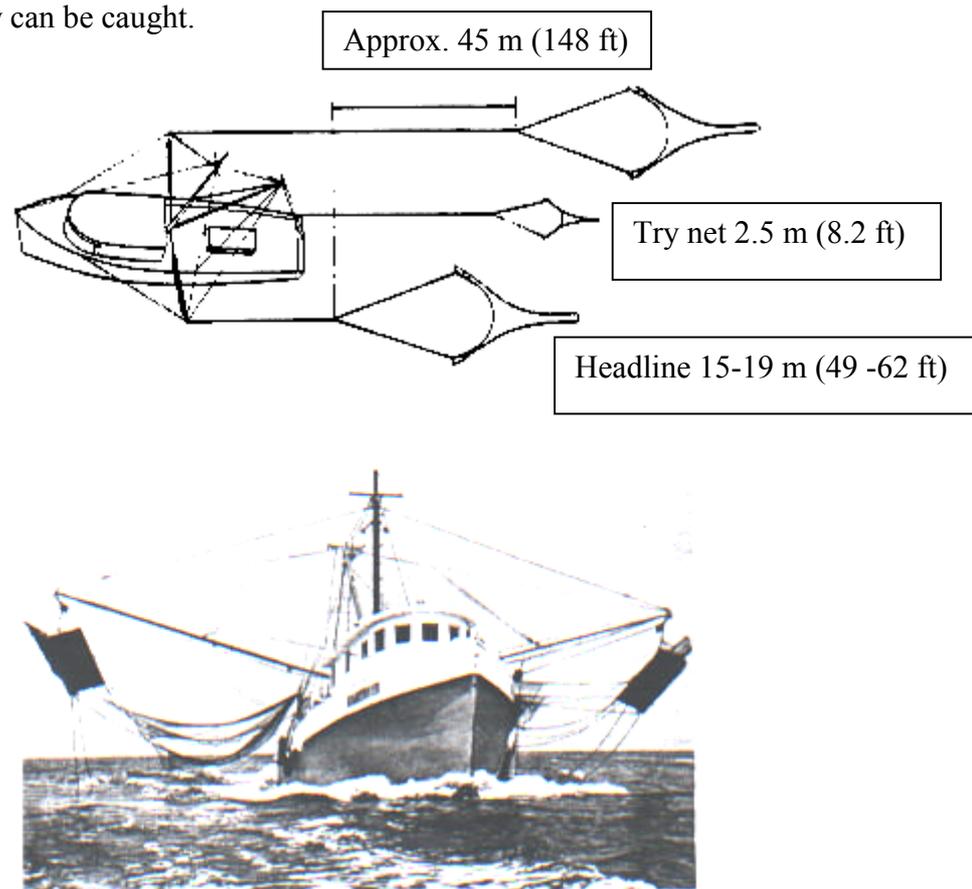


Figure 2: Twin rig trawling or "Gulf of México double rig trawling" using otter boards. (Sainsbury 1996).

1.3 The performance of the gear

The shrimp trawls are towed over the bottom at a speed of about two to three knots for two to four hours depending on which area or fishing ground is explored. It is a continuous sequence of setting out (shooting) the gear, towing the net and then, after a period of towing, the trawl is winched up beside the vessel. By boom operations the cod-end is hauled back and untied, and the catch released onto the vessel's deck, where the fish and shrimps are separated, washed and stored in the hold. If necessary the net is repaired and shot out again for the next tow.

“The try-net is a particular feature of this method. It is a small trawl equipped with miniature doors, which is used to sample the bottom for shrimp before the main trawls are set out, and to monitor the catch rates during a tow. Being light and easily handled, the try-net may be set, towed and lifted by one man. Usually it is left overboard during a tow and lifted regularly to ensure the vessel "stays on shrimp". It is an inexpensive means of locating shrimp and monitoring operations, which was developed when fish finding echo-sounders for shrimp detection were not available" (Sainsbury 1996, p. 98).

The net geometry is observed when it is in the surface of the sea before setting the necessary warp length and some adjustments can be made for the correct performance of the gear. After a few tows the whole gear is hauled back on to the deck of the vessel to observe the plate (steel shoe) of the otter boards and the chain from the fishingline to find out the performance of the gear.

Several videotapes of underwater observations have been made on this type of nets in order to find out the shape of the gear during the tow, however several changes are made to assure the best operation. Actually the shrimp fisheries are using electronic equipment as aids for navigation, such as Global Position Satellite (GPS) and plotters. To find the right fishing ground different echosounders are used, some of them with special features to help to find the shrimps. Electronic equipment for trawling is not in general use in Mexico shrimp fisheries because fishermen do not know how to use them and are wary of technological advances.

1.4 Target species, bycatch and discards

There are three characteristics to consider when estimating the use and efficiency of the trawls; the selectivity of the equipment, the bycatch and discard problems, and the resistance of the gear. The last one is related to the quantity of fuel used and the required size of the main engine. These characteristics are also related to the netting material used in the construction of the nets and with the rigging of the trawl.

For the selectivity of the net is important to use the right netting material, which also relates to the resistance or drag of the gear. Also there are several devices that have been developed and introduced in order to permit the escape of small size and the non-target species.

In some fishing operation it is easy to target a single species. That is possible when fishing species such as herring, mackerel and tuna. In temperate waters a few species are usually found, and when fishing for shrimp in cold waters there are not many

species mixed. This also happens in demersal fisheries. Most tropical fisheries however deal with various species, and shrimp fisheries in tropical waters produce large bycatch of fish resulting in large discards. This bycatch is composed of small fish and lots of other organisms, shellfish, plants, jellyfish, crustaceans, crabs, etc.

Target species have usually a minimum landing size for commercial purposes and the smallest ones are not desirable. When smaller fish is retained in the fishing gear it becomes the unwanted part of the catch and is usually discarded.

Trawling is a filtering operation where organisms that enter the gear are retained in the net, and only some of them may be able to escape, because of their size, their shape or their swimming ability. It is possible to control the characteristics of the catch by adapting the retention properties of the gear and the range of animals placed at risk of capture. When this is not possible the bycatch is present and so the discards.

Management of bycatch has become a very important issue in fisheries management. The innovations in trawl technology to reduce bycatch and thus discards work best when the species in question show markedly different reactions to them (Glass *et al.* 1999).

From an overview of global by-catch and discards, Cook (2001) claims that discards data in fisheries worldwide are incomplete. Furthermore, due to the nature of discarding data collection must be done at sea, which is expensive and usually imprecise. It has been estimated (Alverson *et al.* 1994) that discards are about 17.9 million metric tons annually. The most recent estimates of total discards suggest it to be in the lower end of this range, perhaps 20 million tons (FAO 1999). This means that about 25% of the total world catch of fish is discarded. This is a large biomass, and put in to the context that a large number of the world's fish stocks are already overexploited, this number puts the overexploitation rate to further extreme.

In the Northwest Pacific fisheries discards arise from a variety of fisheries, including crab, shrimp, mackerel, jack mackerel, cod and pollock fisheries. In the Northeast Atlantic most discards occur in traditional fish and flat fish fisheries, while in the Central Pacific, shrimp fisheries generate most discards. Thirteen of the twenty fisheries with highest discards in the world are for shrimp, and they produce about 33% of all discards and many of these take place in tropical regions, (FAO 1999).

When talking about fishing gears there is also a clear definition in the use of shrimp trawl and they are by far the most important gears in generation of discards. The main reason may be the small mesh size that is used in these fisheries but another reason is the large variety of fish that can be found in these areas.

The ecosystem is affected by the bycatch. Not only does the fish that is discarded die when thrown overboard but that particulate organic material will be eaten and decomposed by scavenger and microbes. That action will increase the number of scavengers and alter physical properties of the water (increase BOD and lower oxygen levels).

According to Cook (2001) the fisheries for small crustacean have already been noted for their large production of fish by-catch. Shrimp fisheries are implicated in high

mortalities of non- target fish species and are cited as the cause of the reduction of the croakers to very low levels.

By-catch of turtles is another big problem in shrimp fisheries. To reduce the risk of fishing turtles a special turtle excluder device (TED) has been developed and is in use in USA and México fisheries (Figure 3).

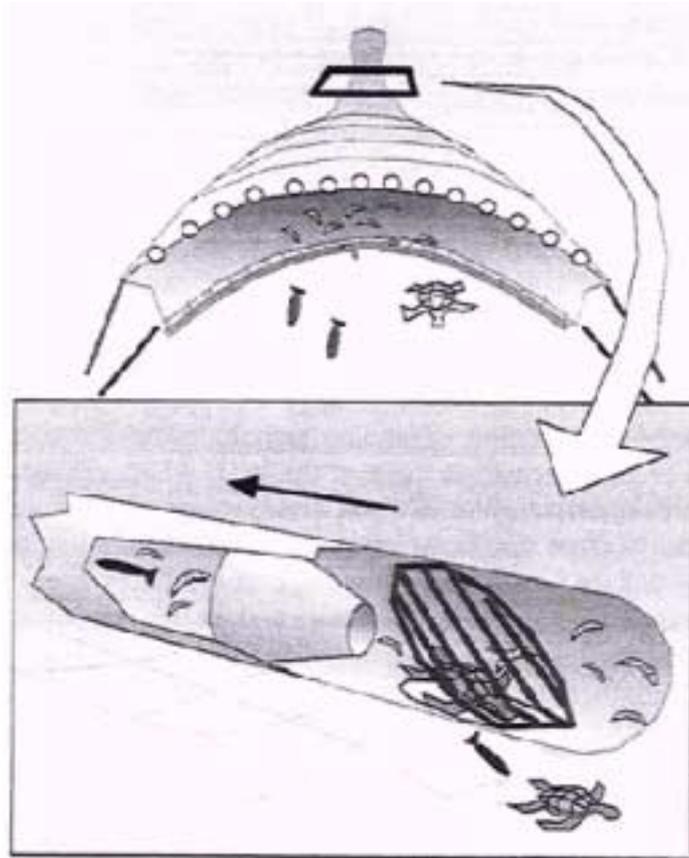


Figure 3: A turtle excluder device (TED) is a soft or rigid device inserted in front of the cod end to guide turtles out of the trawl, whereas most of the target shrimp will pass through the device into the cod end, (Valdemarsen and Suuronen 2001).

1.5 Types of shrimp trawl nets used in Mexico

The shrimp trawls used by the fishing fleet in the Pacific Ocean and Gulf of México coasts, have changed very little during the last decade, however the size and types of the shrimp trawls show great variation. With increased capacity and engine power of the fishing vessels, the size of gears has also increased. Different ideas of skippers, working in different fishing areas and under different situations have developed series of slightly modified trawl models with names such as “balon”, “texano”, “fantasma”, “semiportuguez”, “volador” (“balloon”, “Texan”, “phantom”, “simiportuguez”, “flying”, are the names in English respectively).

In general the Mexican shrimp trawls can be described by their construction on four panels by pairs, the side panels are similar in between. The upper and lower panel presents the main difference in the square enlargement of the upper section and the

increased length of the lower wings. They have wide side panels, wide body and short belly. Also the wings are short in comparison with other fishing nets.

The size of the trawls is characterised by the headline length. The smallest nets used in the “double-rigging” system, are 23 m, (75 feet) and the largest reach the 36 m, (120 feet). In the Gulf of Mexico fishing fleet “Multi-rigging” system is used for two nets on the side of the fishing vessel and nets as small as 16.76 m (55 feet) may be found.

Five different models of nets have been presented as the ones with high preference for use on the fishing vessels of Mazatlán, Sinaloa, México (Heredia 1999). They have 27 m (90 feet) headline length and the main shapes, data and characteristics are shown in Figures 4 and 5.

The whole body is made of 50.8 mm mesh size nylon polyamide (PA) netting material with 1.6 to 1.8 mm diameter of twisted twine, dyed with vegetal paint, treated by thermo-stabilisation and the application of tar as protection.

In the last decade, the use of the turtle excluder device (TED) added a piece of netting to the nets between the main body and the cod-end where the device is fixed (Figure 5). This extension is made of the same material, sometimes with smaller mesh size, 160 meshes wide and 80 meshes long. The TED is an ellipsoidal metallic frame, 1.070 m wide and 1.30 m long. It is fixed approximately in the middle of the net extension at a 45° angle (Figure 21) and with an exit window 0.890 m wide and 0.305 m long. That is equal to 30 meshes wide and 15 meshes long to let the turtle escape (Aguilar 1999). Finally, to cover and protect the cod-end, a netting material piece made of 100 mm mesh size and 4 mm diameter braided twine is fixed with polyethylene strands added which acts as a "chaffer".

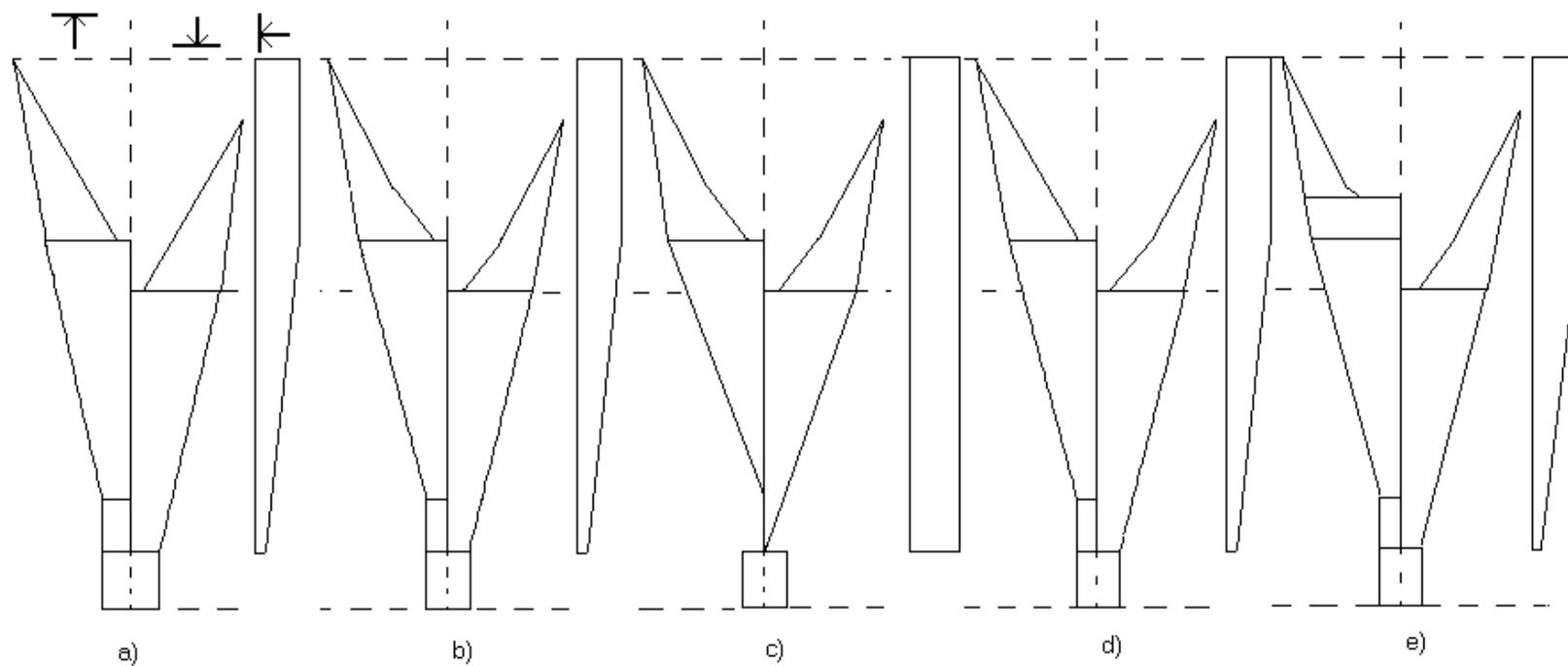


Figure 4: General shape of the main five Mexican shrimp trawls designs used in the Pacific Ocean coast; a) "Fantasma", b) "Volador", c) "Semiportuguez", d) "Mixto", and e) "Buzo".

1.6 Rresearch on selectivity and modification of the fishing gear

The fishing technology sector has adopted technical innovations to increase the capacity to catch fish and some newly developed devices inserted in the gears have also reduced the environmental impacts of fishing. The introduction of polyamide, polyester and polypropylene (synthetic fibres) in the 1950s, improved the fishing capacity of the fishing gears. Recently, new products as Dyneema fibre and polyethylene Ultra are reducing gear weight and hence the resistance, helping in reducing fuel consumption or increasing the gear sizes.

For the past few years, new technology has offered real advantages to the fishing industry: The advanced fibre technology called 'Gel Spinning Technology' has produced an extremely high strength and high modulus 'Super Fibre' known as Dyneema SK60, presenting many possibilities for various applications. It has the highest value of specific strength among commercialised organic strong fibres. A rope of 1 mm diameter can bear a load of up to 240 kg. Dyneema SK60 is lightweight (low specific gravity). It is the only super-fibre with a density below 1.0 (the fibre floats on water) and its specific gravity is 0.97, which is the lowest among super fibres. It has extremely high impact strength due to very high-energy absorption characteristics and offers high durability because it exhibits excellent flexibility and excellent abrasion and fatigue resistance. The easy fabrication of this fibre offers various textile applications since it is easily processed, (weaving, knitting, etc.), leading to a wide application for industrial use. The high light stability and chemical resistance in a wide pH range of Dyneema SK60 due to its chemical and highly crystallised structure leads to no degradation due to water absorption and thus it is the ideal material for ropes or nets used in marine and off-shore applications. Another advantage of the good light stability is that it can be used without special covering or coatings. Dyneema fibres also offer high strength retention by approximately 80% after 1500 hrs time exposure to light. (Toyobo 2001).

With this material it will be possible diminish the drag of the nets. Increasing the size of the trawl net raises the problem of a heavier trawl and, more importantly, higher water resistance. This increases the drag of the fishing gear so that the size of the net is limited by the size of the engine. Dyneema, the world's strongest fibre, makes it possible to build a larger net of a much lower weight. As Dyneema is stronger than for instance the normally used polyamide and polyolefine, the diameter of the ropes and lines can be kept down. This will reduce the drag of the net (DMS 2001).

To improve selectivity and hence mitigate the problem of by-catch it is possible to modify the fishing gear that is used in certain area. These various modifications are referred as technical measures. In the case of shrimp trawls that are considered one of the least selective gears it is important to mention the changes that have been made on the gear and the observed results. One of the changes is the increment of the holes in the net to allow unwanted species to escape.

1.6.1 *The selectivity of the shrimp trawls*

The selectivity of a trawl determines the quantity and the composition of fish retained. The selectivity can be interpreted as the percentage of fish with a given size that is retained. The length of the fish that is retained in the net is depended on the mesh size.

Normally the selectivity is measured in the codend however there is a possibility of an escape through the netting of the trawl therefore the selectivity in the body of the net is also the measure of the retention or escaping of the fish. Studies on selectivity of the Mexican shrimp trawls have been conducted by Heredia and Garcia (1986) and Galeana and Guevara (1986) concerning the escape of shrimp through the net of the body and in the codend. The results show minimum escape of commercial shrimp through the body of the net and a selectivity ratio less than the acceptable 50%. Larger mesh size in the body and in the codend of the nets was therefore recommended in order to improve selectivity.

Mesh size can be increased but in the case of the conventional diamond shaped meshes it will have little effect since the mesh will close when the tension from the tow is applied. An alternative to mesh size increases is the insertion of panels made with a net that is fixed in a diagonal position in the netting, so called “square mesh windows”. They are less susceptible to mesh closure and the place where they are located in the net has to be very well determined for success (Figure 6).

There are also a series of devices called grids, excluders, etc., which are placed somewhere in the cod-end of the trawl. The grid sorts the fish according to the size. These devices filter the organisms and divert the large ones to an exit hole, to another part of the net or to the codend itself. The Nordmore grid is based on a rigid filtering system developed in Norway in the late 1980s to reduce the capture of unwanted bycatch of juvenile finfish in northern deep water shrimp (*Pandalus borealis*) fisheries (Valdemarsen and Suuronen 2001) (Figure 7). This principle was first applied to eliminate fish and turtles in fisheries e.g. in Mexico and USA, although some commercial fishermen are reluctant to use the turtle excluder device (TED) due to the loss of shrimp catch that come with the use of the TED.

When considering the particular behaviour of the fish species the “separator panel” is utilised with good results (Figure 8). In this case, some species of fish or another species such as squids are swimming at different levels above the seabed and they swim upwards when a trawl is approaching. This behaviour permits the catch of some species and the avoidance of another unwanted species.

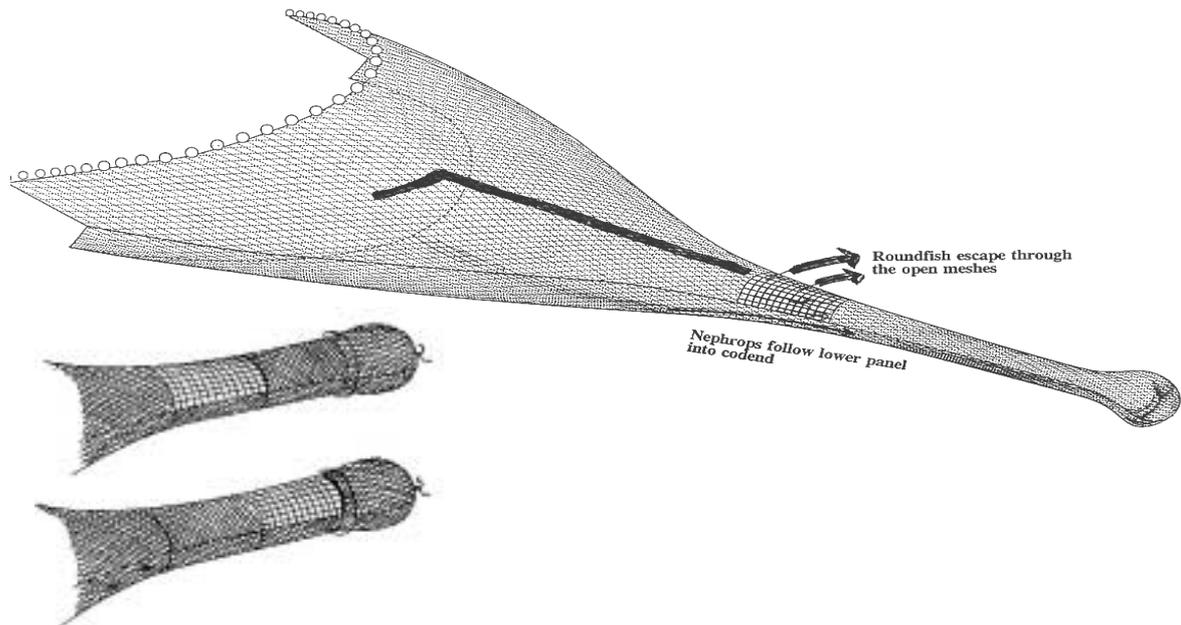


Figure 6: The "square mesh window" can be used at the end of the belly, ahead of the codend, as shown in the top scheme. This insertion will be effective in reducing the number of small fish retained in the codend. It can also be installed at the beginning of the codend (scheme in the middle) as used in a cold water shrimp (prawn) trawl and the third scheme is for the position in a round fish trawl (Collins and Pedersen 1992 and Sainsbury 1996).

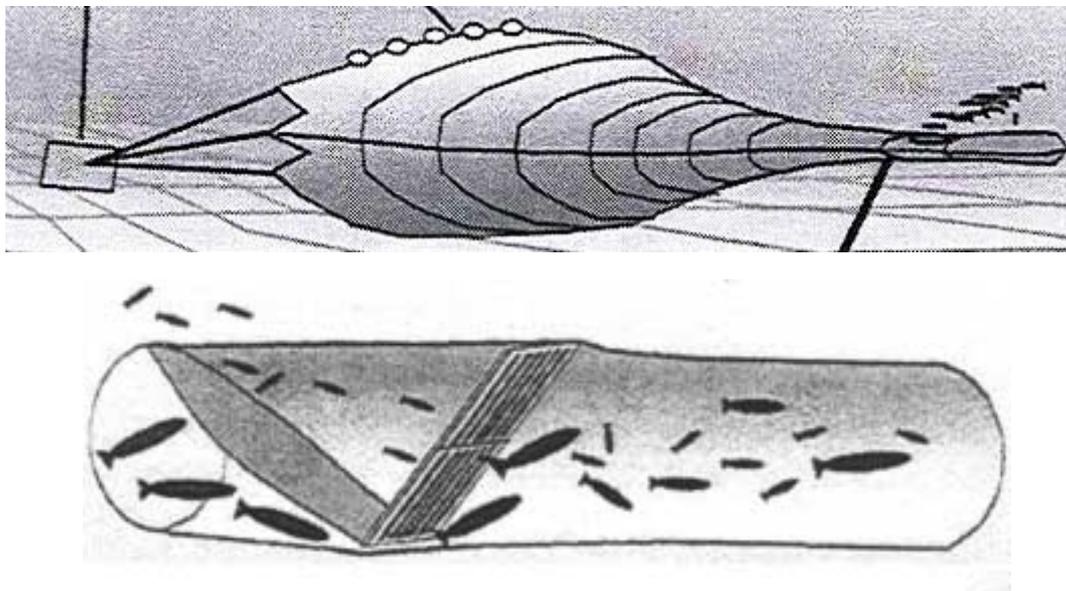


Figure 7: The Nordmore Grid effectively reduces the capture of unwanted bycatch of juvenile finfish in shrimp fisheries whilst simultaneously retaining the targeted shrimp (Valdemarsen and Suuronen 2001).

1.6.2 *Improvement on fishing devices and modified equipment for selectivity and avoidance of bycatch*

An example of the indirect effects of fishing can be seen as results of exploitation of target species on tropical reefs. While many studies show a dramatic reduction in the abundance of piscivores on reefs Kaiser *et al.* (2001) show that there is little evidence of a corresponding increase in the abundance of their prey. Their research also shows that the fishing gear disturbs soft sediment sending sediment plumes into the sea, remobilising previously buried organic and inorganic matter which may have an impact on the rate of biogeochemical cycling (Kaiser *et al.* 2001).

In Collins and Pedersen (1992) summary on data on modified nets, they exclude about forty articles concerning selectivity devices for shrimp and fish. As important examples, Venderville (1990) presents the use and selectivity of fishing gears, Valdemarsen and Mikalsen (1991) tested grid arrangements for shrimps and Thorsteinsson (1992) dealt with the use of square mesh cod ends. On the by-catch aspect, Roullot (1989) presents a study on the shrimp fisheries of Madagascar.

Separators of fish and shrimps are part of the equipment that has been incorporated into the trawl. They can be useful in the quota and discard problems for fish and in the selectivity of shrimp. The use of ground fish excluder and the small shrimp grid excluder has developed several prototypes that have been tested in the last fishing season. In Canadian waters there is a trial of shrimp excluder, which shows promising results (Fishing News International 2001).

According to Tokai, (1998) a 15.2% loss of shrimp was experienced when testing a grid separator for shrimps in small beam trawls. The usual Nordmore grid separator system consisting of a grid, a fish outlet, a funnel or flapper, which guides fish and shrimp against the grid. A very high shrimp loss (40%) was reported in tests without any guiding funnel or flapper. Similarly, a 3.6% mean loss of shrimp was reported for Georgia TEDs when funnels were used but 13.6% when funnels were not used (Tokai 1998).

The increment of the mesh size deals with selectivity, with characteristics of the netting material and with the total resistance of the net and engine power required towing. New netting material is being developed and produced for the fishing industry

Many fish species, such as Loligo squids, react to the approaching ground gear of the trawl by turning and swimming at the same speed as the net in the direction of the tow. This behaviour patterns results in a distribution of the squid in the upper and upper-lateral parts of the net. The squid then later fall back to the codend of the net while the major bycatch and discard species remain in the lower parts of the net passing into the belly. This behaviour suggests that a separator panel in the net (Figure 8) might be effective for separation of species (Glass *et al.* 1999).

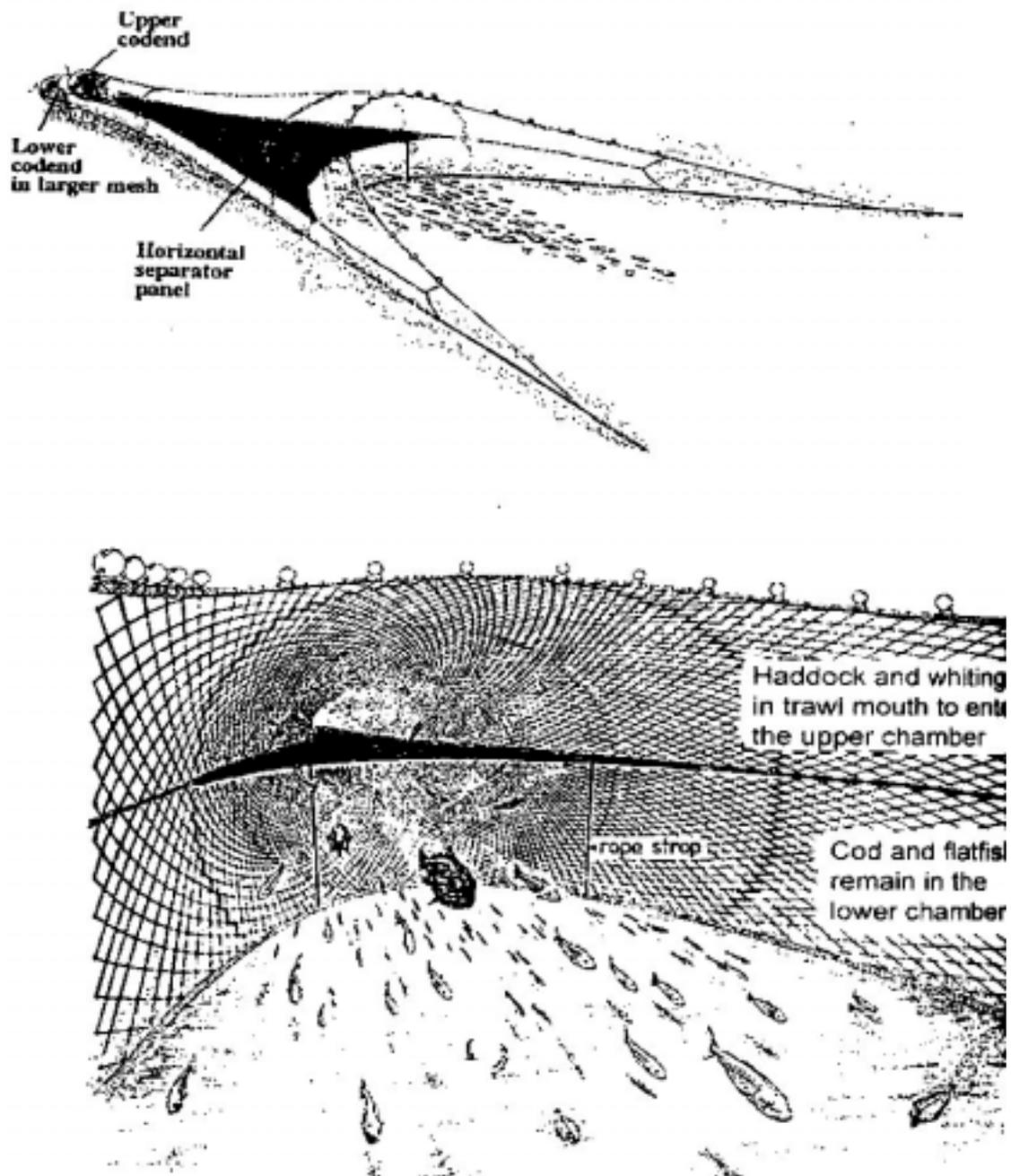


Figure 8: General view of the net with the experimental separator trawl showing the positioning of the horizontal panel, and explaining the effect of this type of trawl obtained from the behaviour of the different species (Glass *et al.* 1999).

Talking about the acceptance of modifications on fishing gears in different parts of the world, Tucker *et al.* (1997), presents the use of turtle excluder devices (TEDs) that have been tried on a voluntary basis in many Australian prawn (shrimp) fisheries to reduce sea turtle captures. They found that TEDs are being introduced with good acceptance.

Rogers *et al.* (1997), conducted trawling in three areas of coastal Louisiana to evaluate the effectiveness of Bycatch Reducing Devices (BRDs) in shrimp fisheries. Five devices showed a reduction in fish bycatch from 30-60% and shrimp loss from 18-35%.

Considering the use of bycatch reduction devices in the shrimp fishery of the Gulf of California, Mexico, Garcia-Caudillo *et al.* (1988) tested the exclusion rates of a square mesh/extended funnel (BRD) on the Sonora coast and in the upper Gulf of California, Mexico. They installed in a trouser trawl codend the Super Shooter TED, mandatory in Mexico's commercial shrimp fishery since April 1995 (Diario Oficial de la Federacion 1995) and in the other codend they used the BRD in addition to a TED. Results indicated that the codend with the BRD allowed a significant release of bycatch, although with a cost of some shrimp loss. Overall exclusion was 40.2%, fish exclusion was 37.4% and shrimp exclusion (loss) was 7.3%, and the exclusion of total bycatch was 43%, fish exclusion 38% and for shrimp the exclusion was slightly lower, 5%. An average shrimp vessel with 7% average shrimp loss due to the use of BRD would be 86% more efficient in terms of profit compared to where no BRD is used (Garcia-Caudillo *et al.* 1998).

When proving the reduction of bycatch, three different types of fish excluders were tested in the prawn fisheries in Washington. The Nordmore grid performance tends to be good in pink shrimp fisheries, average shrimp loss was 1 to 3% by weight and fish exclusion up to 95% for small fish and 100% for larger species. With a separator panel made entirely of netting, shrimp losses have been reported between 2 and 30% and fish exclusion 30-80% for small fish and it was considered inconvenient. With the fish eye inserted in the top panel of the aft part of the trawl, it was observed from video that the water flow down through the fish eye was holding the fish back in the codend and preventing escape. Many flatfish were seen escaping but there was no great effect in reducing bycatch of any other species.

The North Carolina Sea Grant (1999) is running a Fishery Resource Grant to help the North Carolina Division of Marine Fisheries (DMF) certify bycatch reduction devices (BRDs). For the Morrison/Parker soft TED/BRD, the reduction of weakfish in weight was 75% and reduction in number was 77%, shrimp catch had a reduction in weight of 27% and it resulted in too much shrimp loss for certification. The Oval BRD presented a weight reduction of weakfish of 17.2% and it was not eligible for certification. Researchers conclude that BRD certified in other areas may not be appropriate in North Carolina fisheries.

“Grids have been proven successful world-wide as bycatch reducers in shrimp fisheries but very little has been done in e.g. The North Sea shrimp fishery. Still research have shown that 95 mm square mesh escape window in front of a 35 mm shrimp cod end can reduce gadoids in shrimp fisheries (Madsen and Hansen 1999 p. 204).

When Madsen and Hansen (1999) used the grid, a section of square mesh 150 mm inside mesh size was attached to the top and sides of the frame of the escape hole and joined to the netting of the extension piece forming a guiding funnel back to the cod end. Later during the first sea trial some marketable round fish escaped through the 150 mm mesh size and therefore they replaced it with a nominal 110 mm full mesh (inside mesh size) knotless Ultra Cross netting for the second sea trials. The type of

net used on sea trials were shrimp trawls with 1450 meshes in circumference made by 40 mm meshes except from in the front wings where the mesh size were 80 mm. The grid codend trawl caught considerably more shrimp in the second experiment than the standard trawl. A possible explanation is that the grid trawl had a higher catching power, by having a wider or higher mouth opening or better bottom contact, because of the reduced catch weight or because the grid section increased the trawl length. In principle, the increase in the shrimp catch reduced the bycatch rate measured per kg of caught shrimp (Madsen and Hansen 1999).

Shrimp trawl bycatch is a significant source of fishery induced mortality for managed species. In 1990 the U.S. Congress passed amendments to the Magnuson Fishery Conservation and Management Act (16 U.S.C. 1854) which called for research programmes that included the design and evaluation of approaches for reducing shrimp trawl bycatch mortality. From the planning resolutions, between 1990 and 1996 145 bycatch reduction conceptual gear designs contributed by fishers, net shops, gear technicians, and biologists were evaluated. Sixteen of these designs were tested on co-operative commercial vessels by observers under south-east regional co-operative programme from the Gulf and South Atlantic Fisheries Foundation. As of results of these testing the fish eye and the extended funnel bycatch reduction device have been mandated in the the south-eastern Atlantic fishery and the fish eye and Jones/Davis by-catch reduction devices have been mandated for use in the Gulf of Mexico shrimp trawl fishery (Watson *et al.* 1999).

2 AN OVERVIEW OF TRAWL DESIGN AND USE OF SELECTIVETY DEVICES IN SHRIMP FISHERIES

2.1 The trawl design method

The approach for designing trawls can be both theoretical and practical. Either way certain points have to be considered; the observation of the behaviour of the nets or from the mechanical and technical point of view.

From the theoretical concepts it has been specified that, “The design of fishing gear is divided into several stages which may partly overlap in practice. They are: 1) Justification (definition of needs for the new gear); 2) Formulation of technical requirements to satisfy the new needs; 3) Preparation of a preliminary or conceptual design; 4) Development of a detailed technical design (specifications and details of materials); 5) Preparation of construction drawings” (Fridman 1986, p. 135).

When designing a bottom trawl for a specific fishing boat, several things must be considered:

- a) The main characteristics of the resource to be caught: one has to know the species to be harvested and its biological characteristics such as minimum length, shape, and behaviour (swimming reactions) and even life history. It is also important to know the fishing ground i.e. in what type of bottom the trawl will be towed on (rocky, sandy, muddy, etc.) and the environment (currents, sea state, depth, etc.).
- b) Definition of the characteristics of the vessel;

- The power of the main engine of the fishing vessel on nominal horse power (NHP), type of propulsion, including type and diameter of propeller, if they are using nozzles, etc.
- Type of vessel, size and gross tonnage, distribution of the fishing deck and the existing auxiliary deck machinery,
- When possible it is convenient to know the towing capacity of the vessel, bulled pull, in order to define the towing ability at various speeds.

c) Application of the practical commonly used rules and use of the technical data of the fishing materials:

For a new net design it is recommended to choose an existing trawl from a fishing vessel with good performance and good catches, and make the required modifications on the trawl design in order to suit the new vessel requirements. Then, biological characteristics should be used to establish the mesh size in the codend of the net, the fishing grounds determine the type of trawl according to the vertical and horizontal opening of the net required when towing and the characteristics of the vessel such as the power of the engine and the pulling capacity of the winch determine and limit the size of the net. Common use rules in designing are to use the fishing line length and/or the circumference of the mouth of the net as basic data to determine the size of a new trawl (Figure 9).

To establish the size of the trawl using the length of the fishing-line as basic data one must consider:

- a) The length of the fishing line depends on the size of the fishing deck of the trawler and the fishing operation for hauling the net in. Also this length depends on the length of the square section of the net, e.g. longer square is recommended for low vertical opening nets.
- b) The weight of the fishing line depends on the type of fishing ground, heavy and short fishing lines are used for rough grounds and light and long fishing lines for sandy and muddy fishing grounds.

Under special circumstances a diversion from the above guidelines is needed e.g. when using net drums for pulling and storage the net.

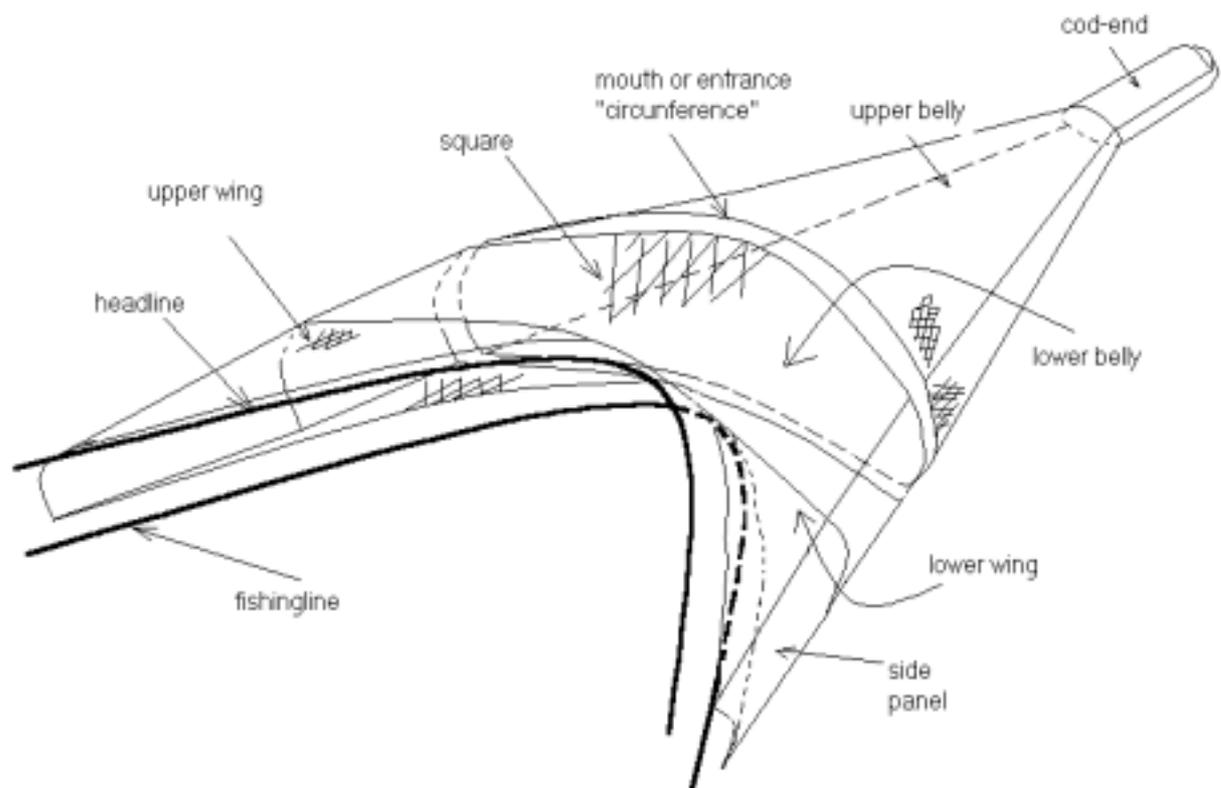


Figure 9: Scheme of the different parts of a shrimp trawl, the length of the fishing line and the circumference of the mouth or entrance of the net can be used as basic data in designing the trawl, to determine the size of a new trawl.

2.2 The 16 steps approach in designing a trawl

If the size of the new trawl is to be determined by using the circumference at the beginning of the belly section as a basic data, several designing steps have been defined (Palmasson and Hreinsson pers. comm.).

1) The circumference of the trawl

The size of the circumference of the trawl, known as “the mouth”, in number of meshes (NMC) (Figure 10), is equal to:

$$NMC = 2 (NHP) + 200 / 0.040$$

Where:

- NHP is the Nominal horsepower available from the engine of the vessel.
- 0.040 m (40 mm) is the basic mesh size for shrimp trawls to determine the number of meshes. Some designers will specify the mesh size.

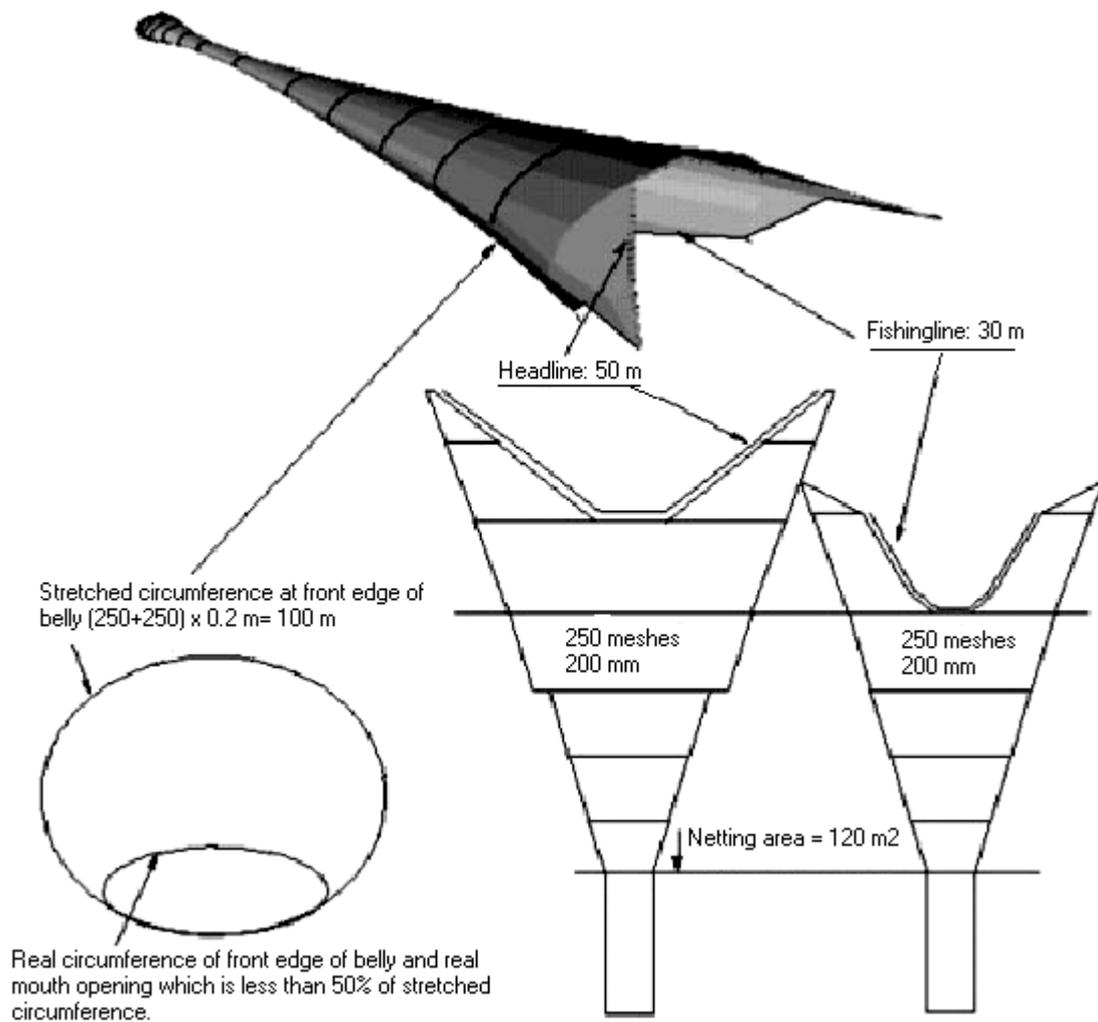


Figure 10: Schematic presentation of the circumference in the mouth or entrance of the trawl as considered by Netagerd Vestfjarda net designers.

2) The number of meshes in the belly panels

For nets made of four panels equals by pairs, the number of meshes of the belly section in the side panels (NMSP) is 14% of the number of meshes in the circumference (NMC):

$$\text{NMSP} = \text{NMC} (0.14)$$

The number of meshes of the belly section in the upper and lower panels (NMUP) is 36% of the number of meshes in the circumference (NMC):

$$\text{NMUP} = \text{NMC} (0.36)$$

The end of the belly will have the same numbers of meshes as the cod end used for the target specie. The width for the belly sections can also be related to the cutting ratio used, or to the convenient filter action for the target specie and with the total netting area because of the towing resistance of the net.

3) The length of the belly

The length of the belly (LB) for trawls used in the North Atlantic fishing fleet is usually 50 % of the circumference in meters. This length allows for the easy filtration of the water and prevents it in becoming a barrier that herds the fish when entering to the codend of the net. In four panel nets of this length, the side panels commonly end as a isosceles triangle.

$$LB = NMC (0.040) (0.50)$$

4) The netting

In order to determine the type of netting no plain rules apply. It is customary to use 1.8 mm twine diameter for the upper panel and 2.5 mm twine diameter for the lower panels when using PE as the netting material. Polyethylene (PE) or polyamide (PA) can be used depending on the kind of trawl. There is no specific information to support the use of one rather than the other. However, when using heavy material such as PA there is a need of compensation using more floats. Moreover, PA materials offer more strength and elongation than PE. When using PE, it will have to be thicker to be as strong and that will increase the towing resistance of the net and therefore the fuel consumption.

From experience it is known that:

- PE is more suitable than PA because it is easier to handle, if the net gets stuck on the bottom it will be easy to liberate it because its floats.
- It is easier to repair PE nets on board.
- PE is less expensive than PA.

For example “the breaking load for wet, knotted single twine made of PE with 1.42 mm diameter is 24 kg and for PA of 1.2 mm diameter is 29 kg” (Prado 1990, p. 24).

When determining the number of sections of the belly, the characteristics of the netting material from the factory should be considered. To use PE netting of 1.8 mm twine diameter and 42 mm mesh size the following characteristics can be used:

$$1500 \times 199.5 \times 1.8 \text{ mm} \times 42 \text{ mm} \times 72 \text{ kg}$$

Where:

- 1500 is the number of meshes in length of the bale from the factory
- 199.5 is the number of meshes in depth of the bale from the factory
- 1.8 mm is the twine diameter used to make the netting
- 42 mm is the mesh size of the netting
- 72 kg is the weight of the bale from the factory

5) The codend

The width of this section can be fixed between 150 and 200 meshes in circumference and for the length it is necessary to consider the fishing operations for lifting the cod end on board. The codend can be as short as 3 m and as long as 20 m.

6) The twine diameter

The diameter of the twine can be increased for the front part of the net and for the cod end in order to have stronger netting.

7) Protection of the codend

From experience the mesh size for this should be 150 mm and the same length as for the cod end.

8) The tapering and the cutting ratio

To determine the tapering of the net the cutting ratio for every section of the net is calculated and this determines the right size of each section.

To calculate the cutting ratio (Y) the following formula is used (Thorsteinsson 1992 and Gretarsson J. pers. comm.):

$$Y = M - m / 2 (m)$$

Where:

Y is the cutting ratio

M is the bigger number of meshes of the piece of net to cut = $2(Y)(m) + m$

m is the smaller number of meshes of the piece of net to cut = $M / 2(Y + 1)$

There are two situations to observe. Depending on the shape of the piece to cut out from a net section the cutting ratio (Y) can be expressed by (T & B) or (N & B), e.g. 1T2B, 1T4B or 1N2B, 2N5N, etc.

Where;

T is a transversal cut,

N is a side knot, and

B is a bar of the mesh.

- If there are T in the cutting ratio, M is the number of transversal knots or clean meshes and “m” is the number of side knots of the piece of net to cut.
- If there are N in the cutting ratio, M is the number of side knots and “m” is the number of transversal knots or clean meshes.

Examples:

1) To calculate the cutting ratio (Y) for a wing section with $M = 110$ and $m = 80$;

$$Y = M - m / 2(m) = 110 - 80 / 2(80) = 30/160 = 3/16 \Rightarrow 1/5 + 1/5 + 1/6$$

Therefore $Y = 2(1T5B) + 1T6b$, then repeat it again to the end of the cut.

2) To calculate the cutting ratio (Y) for an square or belly section with $M = 110$ and $m = 80$;

$$Y = M - m / 2(m) = 110 - 80 / 2(80) = 30/160 = 3/16 \Rightarrow 1/5 + 1/5 + 1/6$$

In this case $Y = 2(1N 5B) + 1N6b$, repeating again to the end of the cut.

9) The square section characteristics

From practice, the length used for square sections is 4 m with 45 mm mesh size and a cutting ratio of 1N4B. In this case the cutting ratio is expressed with N for side knots and B for a bar of the mesh.

It is recommended to choose a mesh size that is at least 50% larger than that of the belly. It is also recommended to listen to the skipper's ideas for better choice and acceptance of the final design. The length of the square section needs to be in reference to the type of net. For wide horizontal spread and low vertical opening in the mouth of the net, longer square is recommended to avoid the upper escape of herded fish.

10) The length of the side panel

The length of the side panel in the front part of the net depends on the type of net to be used. Sometimes the front section of this panel reaches only the length of the square and sometimes it can go a bit further or to the end of the wings. It also depends on the designer ideas.

11) The wing characteristics

For the upper wings the width on the base has a fixed ratio where 86% of the width of the square section in the upper border is used for the two wings (43% for each one), and the rest (14%) is for the central part (bosom). The length of the wing is based on the length of the deck of the stern trawler or the distance between gallops of a side trawler fishing boat. The cutting rate of the wings can be chosen according to the angle on the outside of the wing, the maximum angle recommended is 45 degrees and the inner side of the wing will need to be cut with bigger angle by using the transversal and bar cuts. When a drum net winch is used the length of the wings is determined from the volume capacity of the drum.

For the side panel wings, the length should be the same as for the upper wing. Often the end of the wings is reduced to form a triangle. The mesh size in this panel will be increased in relation to the mesh size used for the belly i.e. 33% for the first section, 50% for the second section and 50% also for the forward-end of the panel.

For the lower wings the width of the base is 79% of the width of the first section of the belly (39.5% for each one) and the rest (21%) will be for the central part. The mesh size for the first section is also increased by 33% of the belly mesh, 50% for the second section and also for the forward-end of the wing.

12) The weight of the netting material

The weight of the netting material has to be considered for every section of the net. Then the sum of all the similar material needs to be determined. Finally the total weight of netting material is calculated using factory data and the following formula (Gretarsson 2001, pers. comm.):

$$W = (T_1 + T_2) / 2 / T * N_2 / N * W_s$$

Where:

- W = estimated weight of prepared net
- T₁ = number of upper clean meshes in the prepared net
- T₂ = number of lower clean meshes in the prepared net
- T = number of clean meshes in the stock net (bale of netting material)
- N₂ = number of side knots in the prepared net
- N = number of side knots in the stock net (bale of netting material)
- W_s = weight of the stock net

13) The characteristics of the footrope

The footrope characteristics depend on what is necessary for the type of fishing ground and what is suitable for the target species. For soft bottom (sandy or muddy) light footrope is required (over the main fishing line the rope cover and chain may be sufficient). For rough bottoms (hard and rocky) the heavy footrope is recommended. Heavy footrope can be made using rubber disks or steel bobbins. In the wing section of the footrope 14" diameter pieces are used and in the central section the 16" diameter pieces are recommended.

The weight of the footrope in the water is important for the towing resistance. Data from the suppliers can be used to determine the weight because of the various components of the footrope such as shackles, chains, connectors, etc. However, for a practical approach, the information presented by Prado (1990) to determine the weight of the groundrope or fishingline in the shrimp trawls can be used. In this section the recommendation is to consider the engine size of the trawler. For trawlers of 500 hp the weight of the footrope (W) in the air is:

$$W = P * 0.27$$

Where:

P is the engine power in hp.

14) The number of floats

When determining the number of floats in the headline, the main problem is to know how much flotation force is required. The minimum flotation force required should balance the footrope weight. The number of floats is determined according to the size (diameter) of each float and its individual floating force. The bigger floats should be used to reduce the towing resistance. When using heavy netting material, e.g. PA, more floats are required to compensate for increased weight of the gear. From experience the floating force is 90 % of the weight of the footrope.

Prado (1990) also recommends the headline buoyancy in relation to the engine power. The engine power is considered to determine the required buoyancy (B) for nets made of polyamide (PA nylon) according to the equation:

$$B = W (0.9) \text{ and/or } B = P * 0.20$$

Where:

P is the engine power in hp.

15) The rigging arrangement

The frame of the trawl is formed by the headline and the fishingline. In some cases as for Icelandic trawls the side panel wings are also framed by ropes. To complete the rigging arrangement for the trawl some observations from experience are usefully:

- a) The headline for small and light trawls for inshore fishing can be made of "combination ropes" and of steel wire for big and heavy trawls. The diameter is chosen by the strength of the material used. Some data presented by Prado (1990), can be used, combination wires of 16 mm diameter have a weight of 0.24 kg/m and a breaking strength of 2500 kg. Steel wire of 16 mm diameter has a breaking strength of 12300 kg.

To determine the length of the headline or fishing line to hang a piece of net the hanging ratio has to be considered. The hanging ratio (E) is commonly defined as:
 $E = L / L_0$

Where L is the length of the rope on which a net panel is mounted

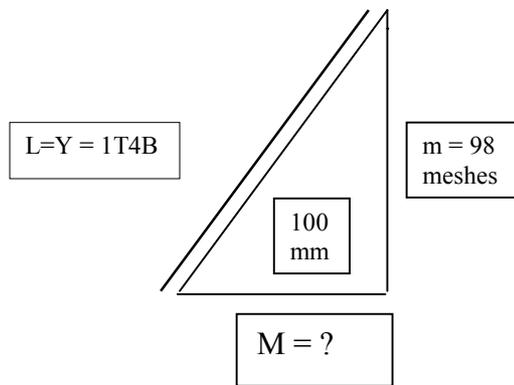
L_0 is the length of the stretched netting hung on the rope.

To a horizontal hanging ratio of 50 % an opening angle of 60° in the mesh is corresponding (Prado 1990).

This is the recommended angle to hang a trawl; however, there are two situations when hanging the trawl: the hanging of the bosom and the hanging of the wings. To hang the bosom the horizontal ratio $E = 0.50$ is used to determine the length of the wire to use and to hang the wings the vertical hanging ratio (E_v) is used. To calculate the vertical hanging ratio (E_v) the following formula is used:

$$E_v = \sqrt{1 - E^2}$$

e.g. to calculate the length of the headline to hang a wing 98 meshes long, 100 mm mesh size and a cutting ratio of 1T4B the following steps are considered:

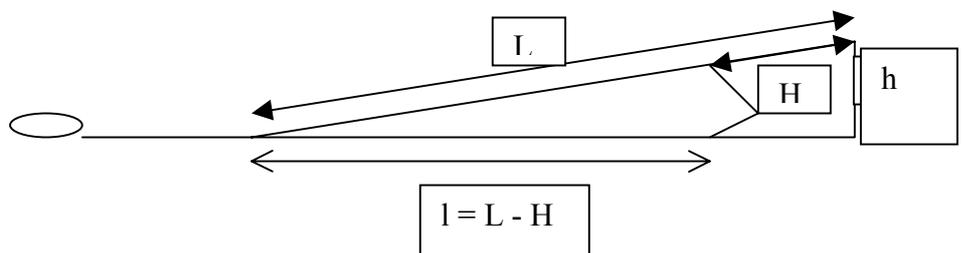


- L is related to the length of the wing, to the mesh size and to the cutting rate.
- Using the formula of the cutting ratio;
 - $M = 2(Y) (m) + (m) = 2(1/4) (98) + 98 = 147$ meshes
 - M is hung with $E = 0.50$, therefore $M = 147 (100) (0.50) = 7350$
 - m is hung with E_v
- $E_v = \sqrt{1 - E^2} = \sqrt{1 - (0.5)^2} = 0.866$

$$m = \text{Number of meshes long (Mesh size) } (E_v) = 98(100) (0.866) = 8486.8$$

$$L = Y = \sqrt{M^2 + m^2} = 11232 = 11.23 \text{ meters}$$

$$L \simeq h / \sin 7^\circ \simeq h * 8.2$$



b) The fishingline can be made from the same material as the headline, following the same criterion.

c) The bridles are made of steel wire. From experience the diameter used is 1 - 2 mm smaller than the diameter used for the towing warps. The length will be enough to ensure the vertical opening of the trawl. The triangle figure formed for the bridles connected to the net should have an angle of 7° and it can be used to calculate the total length (L) using the formula presented by Prado (1990):

Where:

h is the base of the triangle formed by the bridles and the vertical opening of the trawl, which can be determined from ecosounding measurements or estimated from the net data.

From this calculation the length of the bridle (l) is determined by the following formula:

$$l = L - H$$

Where:

L is the total length of the triangle above explained

H is the half of the headline

The bridle lengths are usually fixed for several fishing conditions, “To increase the vertical height: lengthen the upper bridle or shorten the lower bridle and to increase the ground contact: lengthen the lower bridle or shorten the upper bridle” (Prado 1990, p.80).

For shrimp trawl with twin rigging the bridles are used to allow the otter boards to open, “for trawlers of 500 hp the bridle length is 50 m and the booms length is 12 m”, (Prado 1990, p. 84).

d) The sweeps or second bridle used for herding the fish to the area of action of the trawl can be made of the same material and dimensions as the bridles. The total length of the bridles plus the sweeps is approximately equal to the distance between otter doors.

The tickler chain is connected to the trawl in order to dig out the shrimp before the net is passing over the seabed. It is commonly a foot shorter than the fishing line length.

16) The otter boards

The type, size and weight of the otter boards (doors) are important for the towing resistance and for the performance of the gear. Theories about performance, size and weight of otter boards are useful but the practical experience is generally used in determining the door dimensions.

Both the engine size and the size of the trawl (opening) need to be considered when selecting the doors. With increased size of doors the towing resistance is increased (also with increased twine area of the net). So, appropriate engine power is needed. Recommendations from the suppliers will help in making the right choice. “For shrimp otter boards made of wood for double rig in trawlers of 450 to 600 hp the recommended length is 3.3 m and the height is 1.1 to 1.3 m, with a weight of 300 kg”, (Prado 1990, p. 91).

2.3 The performance of Bycatch Reduction Devices for shrimp trawls

Many bycatch reduction devices (BRD) have been developed and tested (Table 1). Good performance is when shrimp losses are lower and fish loss (bycatch) is high. From Table 1 it can be observed that only six BRDs have presented fish loss greater than 50 %. Of these six BRDs only two presented shrimp loss less than 10 % which should be acceptable performance for BRDs.

Table 1: Main results from Bycatch Reduction Devices test dealing with the reduction or avoidance of unwanted species.

No.	BYCATCH REDUCTION DEVICE (BRD)	SHRIMP LOSS (%)	FISH LOSS (%)
1	Grid on Beam Trawl	15.2	NR
2	Nodmore Grid (without funnel)	40	NR
3	Georgia TED (with funnel)	3.6	NR
4	Georgia TED (without funnel)	13.6	NR
5	Authement Ledet 2	22	40
6	Extended funnel	16	36
7	Skirted extended funnel	21	25
8	No. 5 with modifications	16	22
9	No. 6 with modifications	5	44
10	No. 7 with modifications	19	38
11	CJ Kiffe	35	62
12	CJ Kiffe Second trials	22	50
13	Square mesh with Extended funnel and Super Shooter TED	7.3	37.4
14	No. 13 Modified	5	38
15	Nordmore Grid (Washington coast)	1 - 3	95 - 100
16	No. 15 plus separator panel	2 - 30	30 - 80
17	Morrison Parker Soft TED	27	75
18	Oval	NR	17.2
19	Square mesh window (95 mm)	NR	42 - 56
20	Square mesh window (150 mm)	NR	CSL

NR = Data not Reported

CSL = Commercial Size Loss (not acceptable)

The BRD has been tested on small beam shrimp trawls, in bottom trawls for demersal fish and shrimp in deep cold waters and for squids. These devices have been used in several parts of the world such as in Canadian waters, Japan, Norway, (North Sea shrimp fisheries), Gulf of California and Gulf of Mexico, (Mexican and North American fisheries), off the coasts of Washington, North Carolina, Texas, Gulf and South Atlantic fisheries.

The behaviour of the species plays an important role in the selectivity process of every BRD, but in most cases the behaviour is not known. The most suitable BRD for shrimp fisheries are the "Rigid TEDs". The Rigid TED presents low shrimp loss of 3.6 to 7.3% with "the guiding funnel" and "the square mesh window (95 mm)" presents high fish loss from 42 to 56% which improves the performance of the devices. The fish loss reported with rigid TEDs is 37.4% when square mesh windows and extended funnels are used.

The highest shrimp loss is reported (40%) when "grids" without funnel are used. On the other hand, when using grids, fish loss is also the highest up to 100%, so for the bycatch reduction and hence discards they are the most convenient, and again, the use of "square mesh windows" and "extended funnels" presents acceptable fish loss, from 37 to 56%.

Special attention should be given to the Nordmore Grid. The Nordmore Grid shows the lowest shrimp loss and the highest fish loss. The existence of shrimp must be confirmed, because as mentioned before, when grids without funnel were tested the highest shrimp loss was observed.

As a result from this analysis, it is recommended to make sure the use of "the guiding funnel" when using "Rigid TEDs" which is the case for the Mexican shrimp fisheries and as a complement the insertion of the "square mesh window" as a BRD is suggested to increase the fish loss and the quality of the shrimp catch of a new trawl.

2.4 Types of Icelandic shrimp trawls developed in the past years

Four shrimp trawls have been studied in Iceland and they were used as examples when designing the new trawl, they are:

- a) The Bastard 1000 trawl type from Hofdi net loft in Husavik,
- b) The 1200 Box trawl type,
- c) The 600 Box trawl type, and
- d) The Anmagsalik 3026, the last three from the net loft of Thorbjorn Fiskanes hf.

The technical drawings of the "Bastard 1000" trawl presented in Figure 11 shows the four panel equal by pairs, long belly, wide square section and long wings. This will create a big area in the mouth with big horizontal and vertical openings.

The "1200 Box trawl" has medium length belly of two seams and a front part of four seams equal by pairs, wide square section, very short wing and a wide side panel, this configuration gives to the trawl a higher vertical opening and a smaller horizontal opening (Figure 12).

The "600 Box trawl" has a similar shape as the 1200 Box trawl and is used for smaller trawlers, however, the different square characteristics allows relative bigger horizontal opening while the vertical opening is also high (Figure 13).

Finally the "Anmagsalik 3026 trawl" is for bigger trawlers of 1500 to 2000 hp has a long body made of four panels equal by pairs with short square and long wings. With this configuration a good round mouth will be observed when fishing in deeper waters (Figure 14).

The number presented in the trawl name define the number of meshes of circumference in the entrance or mouth of the trawl calculated with a basic mesh size of 40 mm as indicated in the trawl design method presented in section 2.1.

The structure of a trawl is a flexible enough to withstand the tension caused by acting forces during the fishing operation. Knowing this tension can help the designer to improve the performance of any trawl design, different shape in trawls produce different tension. By changing the shape of a trawl it is possible to change the tension

in the trawl. The acting forces or tension that will be present in the trawl no. 1 when working at sea are shown in Figure 15. This information is used to complete the final design of the new trawl.

From the Netagerd Vestfjarda company, eighth different shrimp trawl designs were found, which represent the main types of trawls that they offer to the fishing industry. The company tries to meet any requirement from the Icelandic fishing industry (Figure 16). This company produces shrimp trawls in many versions, but there are no mayor differences in those designs, all of them have four panels. The main variations are in the cutting rates of the wings and bellies, mesh size and twine diameters. The company has 40 years of experience in production of shrimp trawls.

The development of their products is based on close co-operation with the clients, and direct observations of full-scale shrimp trawls using remote controlled underwater vehicles fitted with television cameras and measurement devices. The accumulated knowledge and experience gained by this technique is unique among producers of shrimp trawls world-wide. Especially important is their knowledge regarding shrimp behaviour and reactions to fishing gear. They supply shrimp trawls for vessel ranging from 100 – 5000 hp, both for Pandalus and Peneaid species. In each case the gear is specially designed to meet the physical factors of the vessel, the fishing grounds, and the clients wishes. One of the newest designs called "Net Vest" has equal number of meshes in upper- and lower panels.

For the past years shrimp hunters have increased the horizontal opening of the trawls and reduced the headline-height. The older designs are all constructed to gain high headlines. Now the "normal" headline-height of a given shrimp trawl is 30% less than was considered normal only two years ago. This reduction was gained by changing the sweep rigging and by using relatively larger doors. This way of rigging does not fit the conventional designs and it was necessary to make new designs for this purpose. So far Netagerd Vestfjarda has produced this new design in sizes from 3000 – 3800 meshes.

The Skervøy–design is one of the oldest designs used in shrimp fishing today. This trawl was designed in Norway at least 25 years ago and has been very popular in deep-sea fishing for shrimp ever since. Its characteristic features are relatively deep side panels, the upper panel is larger than the lower one, and normally it has 3 wingtips and 3-bridle rigging. The most common sizes used range from 2000 – 3600 meshes.

The Bastard got its name during the 1970s when Norwegian shrimpers fishing in Greenland waters changed their Skervøy-designs in order to reduce the number of wing tips and sweeps to avoid problems with ice. The new version of this trawl was developed at Hvammstangi, and is very popular in the inshore fishing. The design allows large trawls on relatively short footropes. The most common sizes range from 1000 – 3000 meshes. The company is producing trawls for the Peneaid Shrimp Fishery in Mexico and Central - America. The trawls are characterised by wide and short bellies and relatively deep side panels. They have redesigned the conventional trawls, mainly by improving the cutting rates and panel shapes, and by inserting enforcements along the head- and fishing lines. The new designs have increased the catch rates considerably and lowered the average gear cost due to much more durable

designs. The material used is nylon, polyethylene, dyneema and magnet depending on the client's wishes but most of the trawls are now made of Hampidjan's new Magnet material, which allows to reduce the towing resistance and to lower the prices considerably. It can be observed that some changes in the main characteristics will give a different shape, develop different parameters and different performance is obtained.

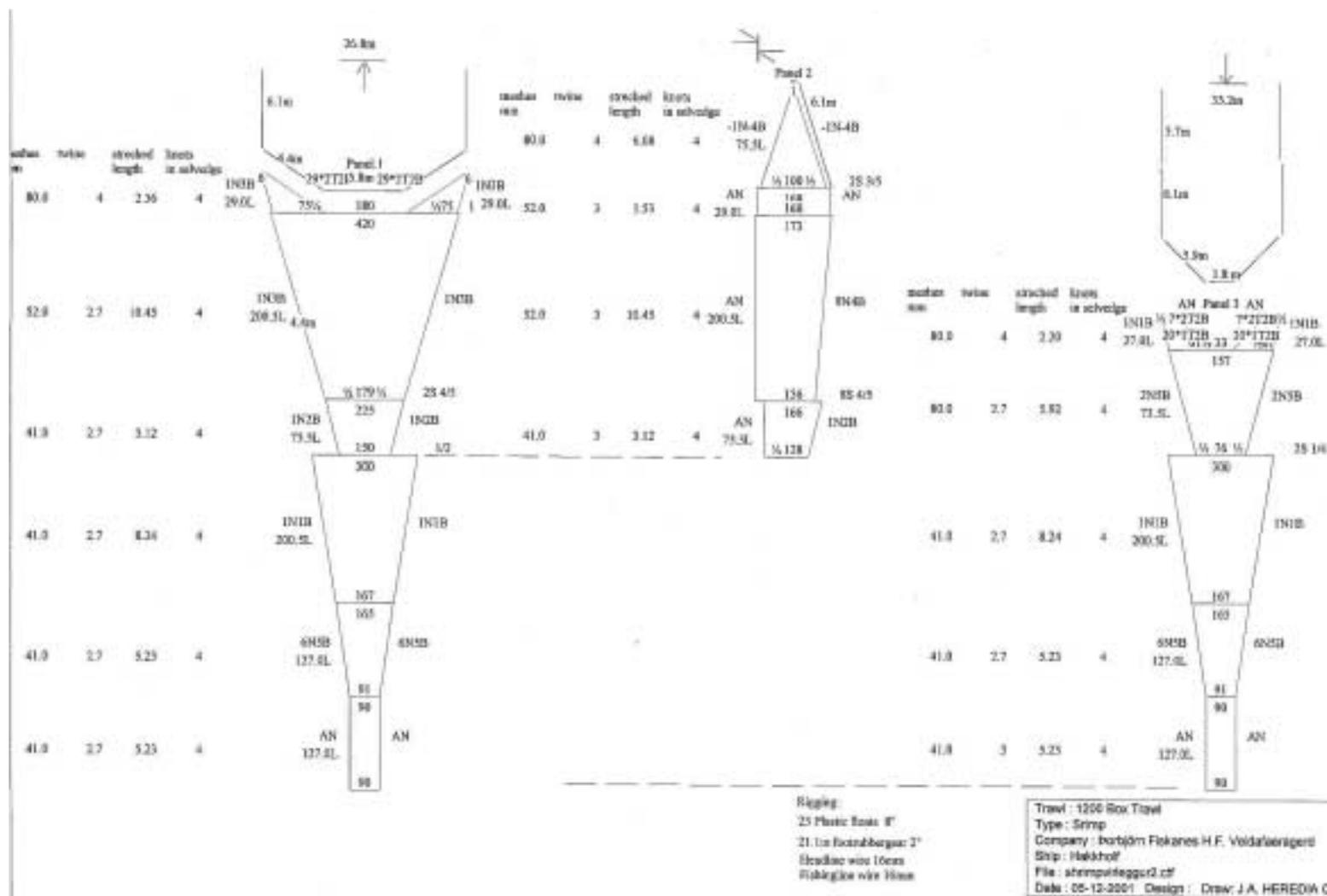
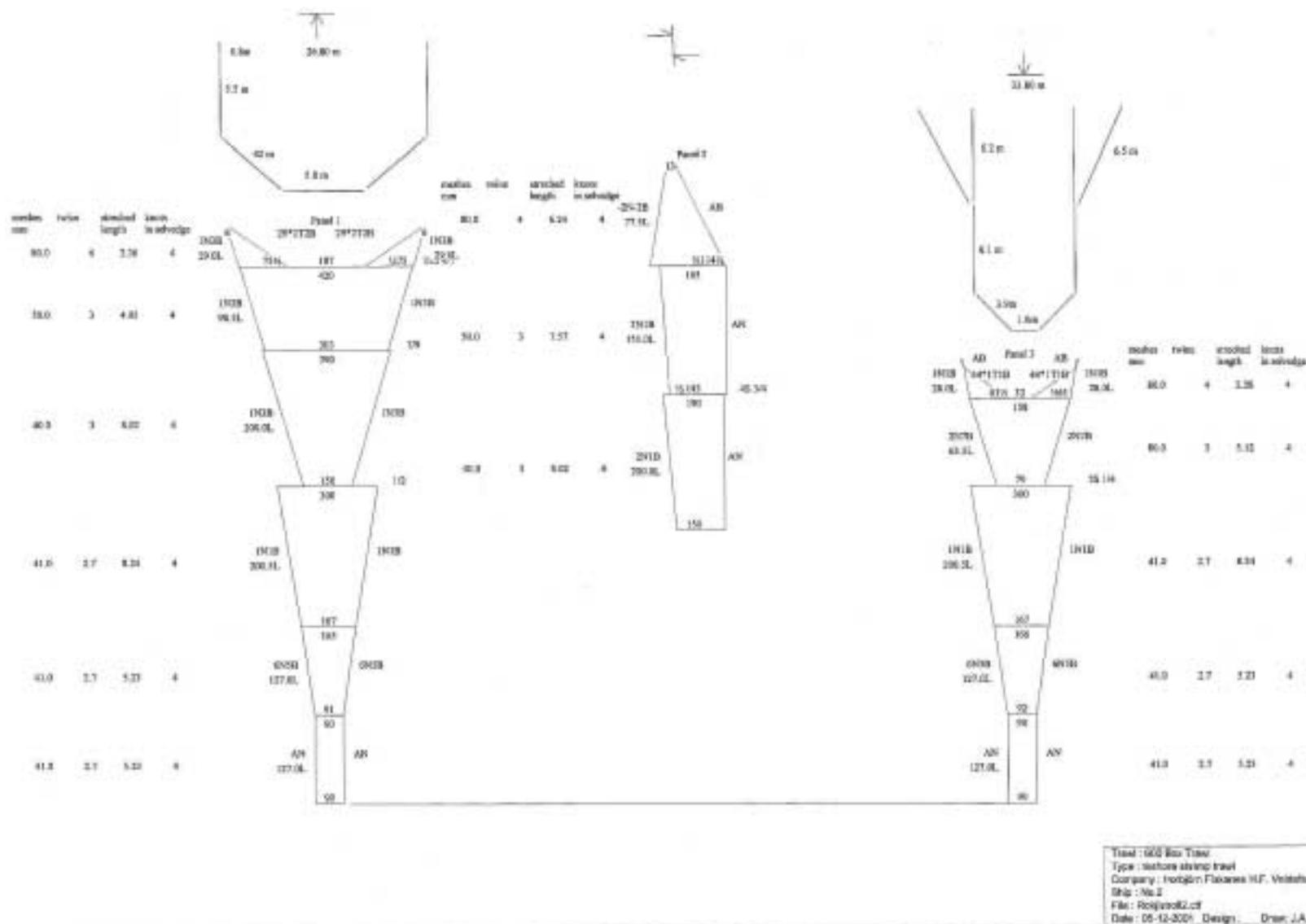


Figure 12: Shrimp trawl No 2, the "1200 Box trawl" is an Icelandic design from the net loft of Thorbjorn Fiskanes in Grindavik considered as an example for a new design.



Trawl: 600 Box Trawl
 Type: section drawing trawl
 Company: Thorbjorn Fiskanes HUF, Veltshengard
 Ship: No. 2
 File: R0131002.dwg
 Date: 05-12-2001 Design: Draw: J.A.HJERDIS

Figure 13: Srimp trawl No. 3 the "600 Box Trawl" is an Icelandic design from the net loft of Thorbjorn Fiskanes in Grindavik considered as an example for a new design.

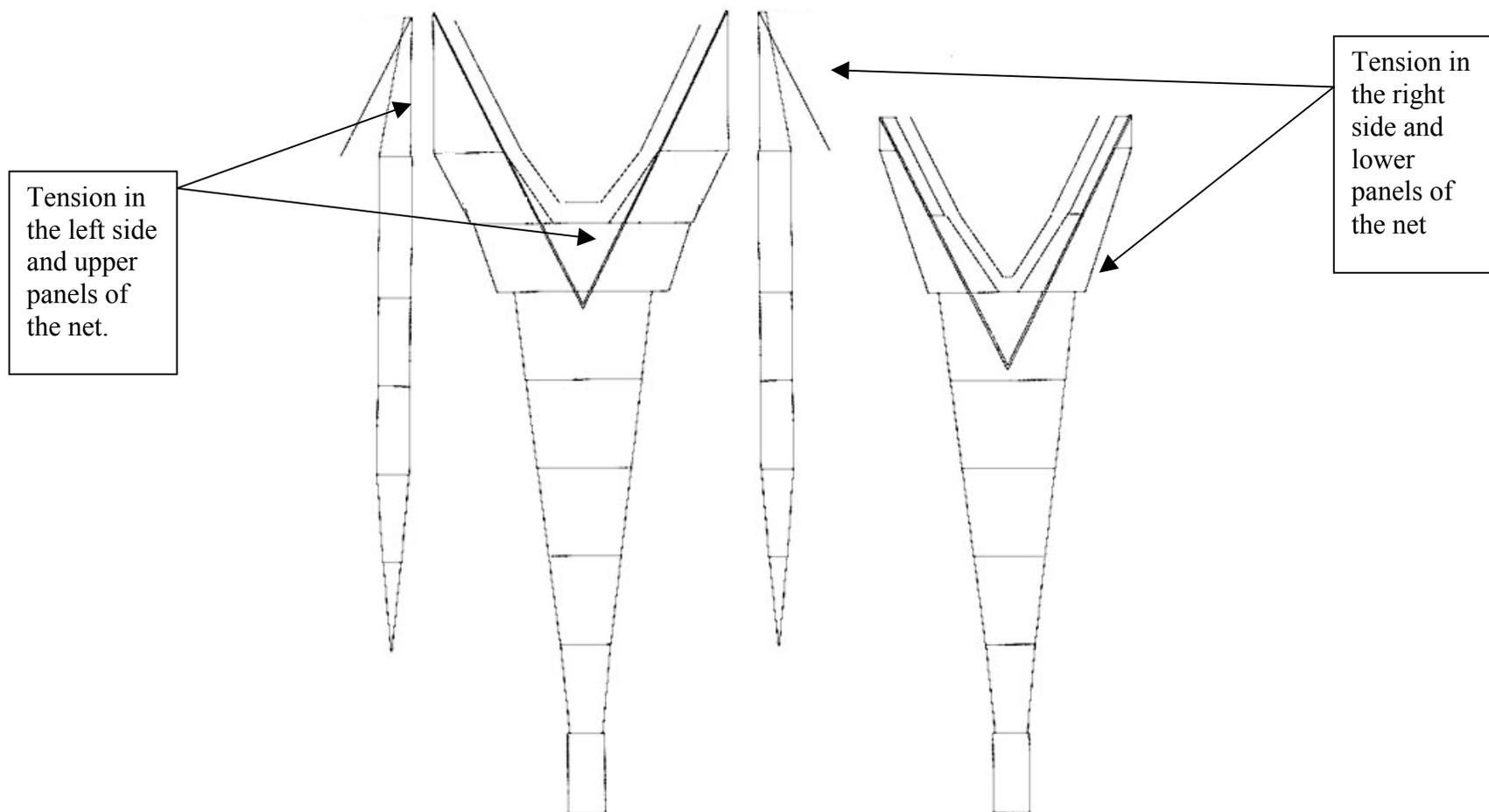


Figure 15: Schematic presentation of the acting forces in the Icelandic shrimp trawl no.1, as the tension the trawl will present.

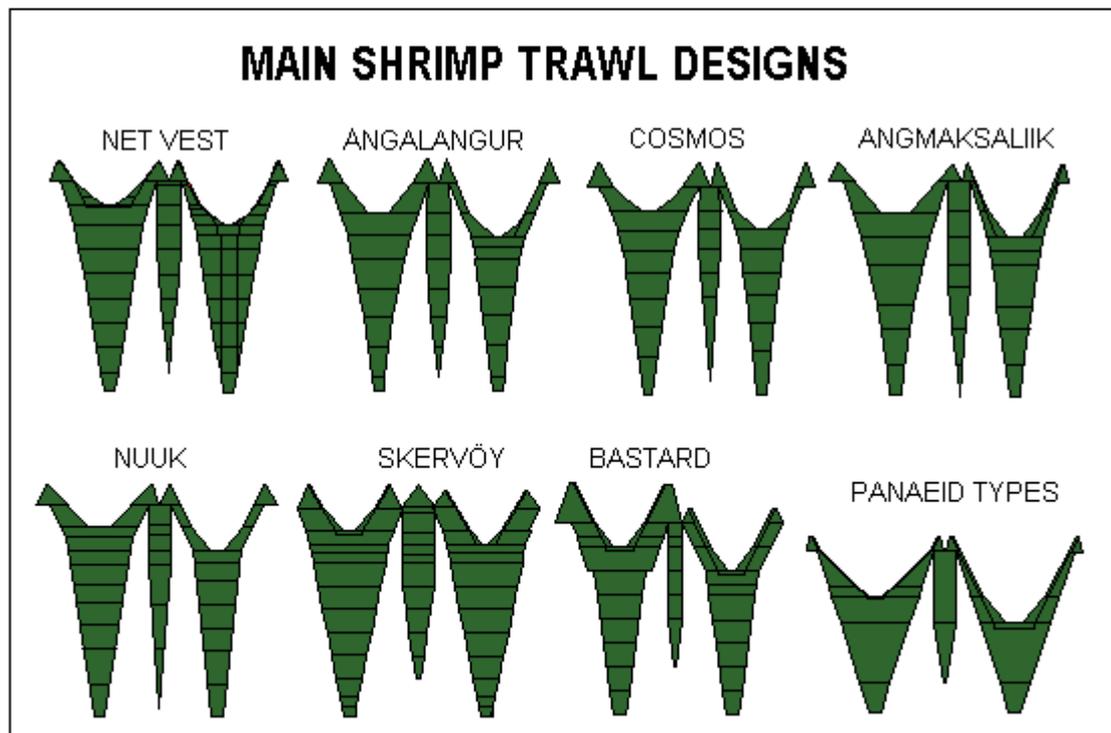


Figure 16: The Icelandic Netagerd Vestfjarða Ltd. is offering 8 different trawl designs in order to meet any requirement from the fishing fleet.

3 SUGGESTIONS FOR MODIFICATION OF SHRIMP TRAWLS IN MEXICAN FISHERIES

A new trawl has been designed for the Mexican shrimp fisheries following the "theoretic-practice method" presented earlier in this report. The justification for the design is that a new trawl is required to exploit the shrimp fishing grounds in México's Pacific Ocean coasts with the lowest possible bycatch. It has to meet the fishing vessels characteristics to operate efficiently and with the advantages of reducing the bycatch by its different characteristics in comparison with the ones that are actually in use. By reducing the bycatch, the drag or resistance of the gear will be diminish and less towing power will be required from the fishing vessels engine. This situation will help to reduce the fuel consumption for the fishing operations. The introduction of a Bycatch Reduction Device (BRD) will be suggested to increase the selectivity on fish species in order to avoid the problem of discards and it will also improve the quality of the final catch.

The resource:

The technical characteristic of the resource to catch are described as follow:

- The commercial size of the Penaeid species varies from 80 to 250 mm.
- The shape of the shrimp when swimming is long and thin, but when trying to escape it will take a shell rounded shape,
- The shrimp resource is in the sand in patches or swimming dispersed in the water above the seabed. Sometimes they can be found swimming in waters near the surface of the sea.

Fishing ground:

The type of fishing ground where this species lives is sandy, muddy or a combination of both. The sea currents are normally lower than two knots (approximately 1 m/sec), the state or condition of the sea to operate the fishing gear has to be lower than 3° in the Beaufort Scale, and the depth can vary from 10 to 100 m.

The main characteristics of the fishing vessels to consider are:

- Average engine power of 500 hp
- Distance between boom ends - 30 m
- Length of the fishing deck - 6 to 8 m
- Propeller diameter - 60 inches (1.524 m)
- Nozzles (most vessels are using them)
- Average gross tonnage – 100 t

The application of the commonly used rules and the technical data of the fishing materials allowed preparation of the preliminary design with the following characteristics:

- The mesh size in the codend of the trawl is 44 mm and in the last section of the body a mesh size of 50 mm is chosen to meet the requirements of the Mexican shrimp fisheries.
- The type of trawl is for bottom contact in four panels equal by pairs, with an expected vertical opening of 3 m and horizontal opening of 13 to 15 m. The trawl otter boards (doors) will be fixed directly to the net without either sweeps or bridles.
- According to the rigging arrangement used, the twin rig, the engine power to consider in NHP (use of two nets, one by each side) is; $500/2 = 250$ hp and the pulling capacity of the winch as deck machinery reaches five tons on average without technical problems.
- The size of the trawl is determined by two methods: the fishing line length and the circumference of the mouth of the net. The fishing line length depends on the length of the square section determined for the net, which will be long, and of the headline for the new net, which will be approximately 30m. Therefore, the length of the fishing line will be approximately 40m. The fishing line will be lightweight because of the sandy fishing ground and a steel chain will be used to sink it. The size of the trawl can also be determined by the circumference of the mouth of the net. The number of 40mm meshes for the mouth circumference (NMC) is:

$$NMC = 2 (NHP) + 200 / 0.040 \text{ m} = 2(250) + 200 / 0.040 = 1075 \text{ meshes}$$

- The distribution of the number of meshes in the circumference (NMC) in the four belly panels determines the following data;
 - The number of meshes for the side panels (NMSP) is 14% of the NMC;
 $NMSP = NMC (0.14) = 1075 (0.14) = 150$ meshes
 - The number of meshes for the upper and lower panels (NMUP) is 36% of NMC;
 $NMUP = NCM (0.36) = 1075 (0.36) = 387$
 - The number of meshes at the end of the belly is 94 because there are 188 meshes in circumference of the codend.
- The length of the belly (LB), which can be equal to 50% of the circumference of the net in meters is determined by;
 $LB = 1075(0.040 \text{ m})(0.50) = 21.5 \text{ m}$
- The netting is of a twine diameter of 1.2 mm for the belly sections. The netting material used is polyamide (PA) because of the proven strength and abrasion resistance of this material and the availability in México's fishing industry. Considering the factory data for this material a mesh size of 50 mm and 200 meshes deep sections will be used.
- The circumference for the codend actually used in Mexican shrimp nets is 160 meshes of 44 mm mesh size. The length is 120 meshes. These characteristics meet the recommendations of the methodology used and for a good acceptance of the new design, the same method will be used.
- The netting for the front part of the net, the square section and wings is of a twine diameter of 1.6 mm and 2.0 mm for the codend.
- The protection for the codend is made of 150 mm mesh size PA netting material with a twine diameter of 4.0 mm. The width of this section is 45 meshes and the length is 35 meshes. Plastic strands are attached to this panel as a protection against abrasion.
- The net will be constructed with two belly sections of different mesh size, 50 mm for the second section (end) and 75 mm, (50% bigger) for the first belly section on each panel. The cutting ratio will be determined according to the length of each section.
- The square section has a length of 5.0 m, as recommended for low vertical opening trawls, the mesh size is 100 mm which is 100% bigger than the one used at the end of the belly. The cutting ratio is with one side knot and four bar (1N4B) and the number of meshes in the upper (front) side will be determined from the cutting ratio used.
- The length of the side panel front sections will have the length of the upper wings. The front end of the side panel wing is 36 meshes with 100 mm mesh size.

- The width of the base of the upper wings is 43% of the length of the upper front of the square section and the length will be determined to meet the length of the headline of the net. The inside and outside cutting ratios will be determined for the angle of 45 degrees that is used for a good performance of the net. The mesh size is 100 mm.
- The width of the base of the lower wings is 39.5% of the length of the first part of the lower belly; the mesh size is 75 mm. The length will be determined by the length of the square section and the cutting ratio applied to meet the shape of the net in the upper panel.
- The data for the weight of the netting material for each section is obtained from the technical drawing, the formula in the method and from the factory. This weight can help to estimate the cost and to make the final decision about what kind of netting material to use. This depends on the quality and the price. As an example of determining the weight, the belly sections made of PA 50 mm mesh size with a twine diameter of 1.2 mm, and the data from the net factory are used:

$$W = (T_1 + T_2) / 2 / T * N_2 / N * W_S = (157 + 91) / 2 / 2100 * 100 / 200 * 110 = 3.25 \text{ kg}$$

- The fishing line is made of combination rope (steel wires cover with henequen) 19mm in diameter and the length will be determined from the technical drawings. To keep the fishing line in bottom contact and digging in the sand, a steel chain is used as a sinker with 13 mm diameter link and weight of 2.92 kg/m. The length of the chain to use in the final fishing line depends on the required weight W:

$$W = P * 0.27 = 500(0.27) = 135 \text{ kg}$$

The required length of the chain is: $135/2.92 = 46 \text{ m}$.

- The tickler chain is made of steel chain with 10 mm diameter link and the length will be a foot shorter than the fishing line.
- The headline is also made of combination rope, 19 mm in diameter and a length determined from the technical drawings.
- The number of floats will be determined from the total flotation force (B):
 $B = W (0.9) = 135(0.9) = 121.50 \text{ kgf}$, or $B = P(0.2) = 500(0.2) = 100 \text{ kgf}$
 Which means, from 100 to 121.5 kgf.

The biggest floats available are the plastic, spherical ones with average diameter of 200 mm and a floatation force of 3.6 kgf. Therefore, the number of floats is:

$$NF = 100/3.6 = 28 \text{ or } NF = 121.5/3.6 = 34 ; \text{ from 28 to 34}$$

- Bridles and sweeps are not used because of the use of two nets with limited horizontal opening. The head and fishing lines will be attached directly to the otter door as mentioned before. For this rigging the otter boards are using bridle length of approximately 100 m which is twice that used several years ago.
- The otter door type is made of wood with a steel frame 10 feet (3.038 m) long and 5 feet (1.524 m) high and steel shoe one inch (0.0254 m) thick, 10 inches (0.254

m) wide, and 10.5 feet (3.19 m) long. These types of otter doors are used for the fishing fleet and new types have been tested without final approval.

The main characteristics can be seen in the preliminary technical drawing design of the new trawl (Figure 17). Some adjustments and changes were made for the final design according to the following observations:

- The shape of the trawl is similar to a box trawl with long wings
- The long belly will increase the surface of netting
- In order to maintain the four panels structure, the side panel is too slim and a lot of material would go to waste by the cuts
- A lot of material will also go to waste in the making of the lower wing because of the different cutting ratio.
- The tension observed for this design is acting in the border of the structure, which is good for the net, but it might limit the vertical opening (Figure 18).

For the final design the following changes were decided:

- The last belly sections will be shorter in the whole net
- The cutting rate for the new sections will be changed
- The upper wings will have a wider cut trying to get wider horizontal opening for the net
- The outside cut in the base of the lower wings will be the same as the cutting ratio of the square section.

These changes are included in the final design to get a new shape. The addition of the net section for the TED is considered and in general the characteristics of the final trawl are:

- Wide body
- Short belly
- Long wings
- Narrow lower wings
- Headline length of 30.5 m
- Fishing line of 38.6 m

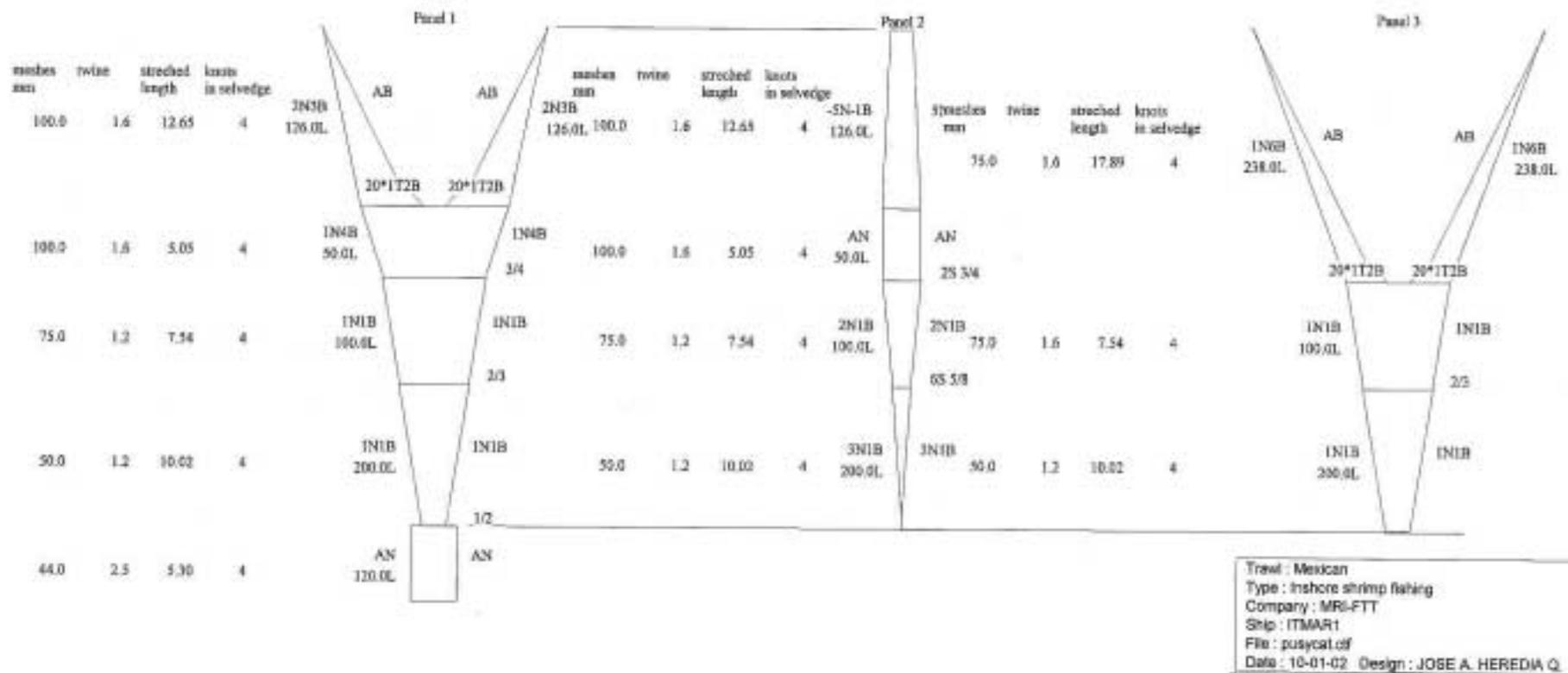


Figure 17: The preliminary design for the new trawl showing the main characteristics and shape.

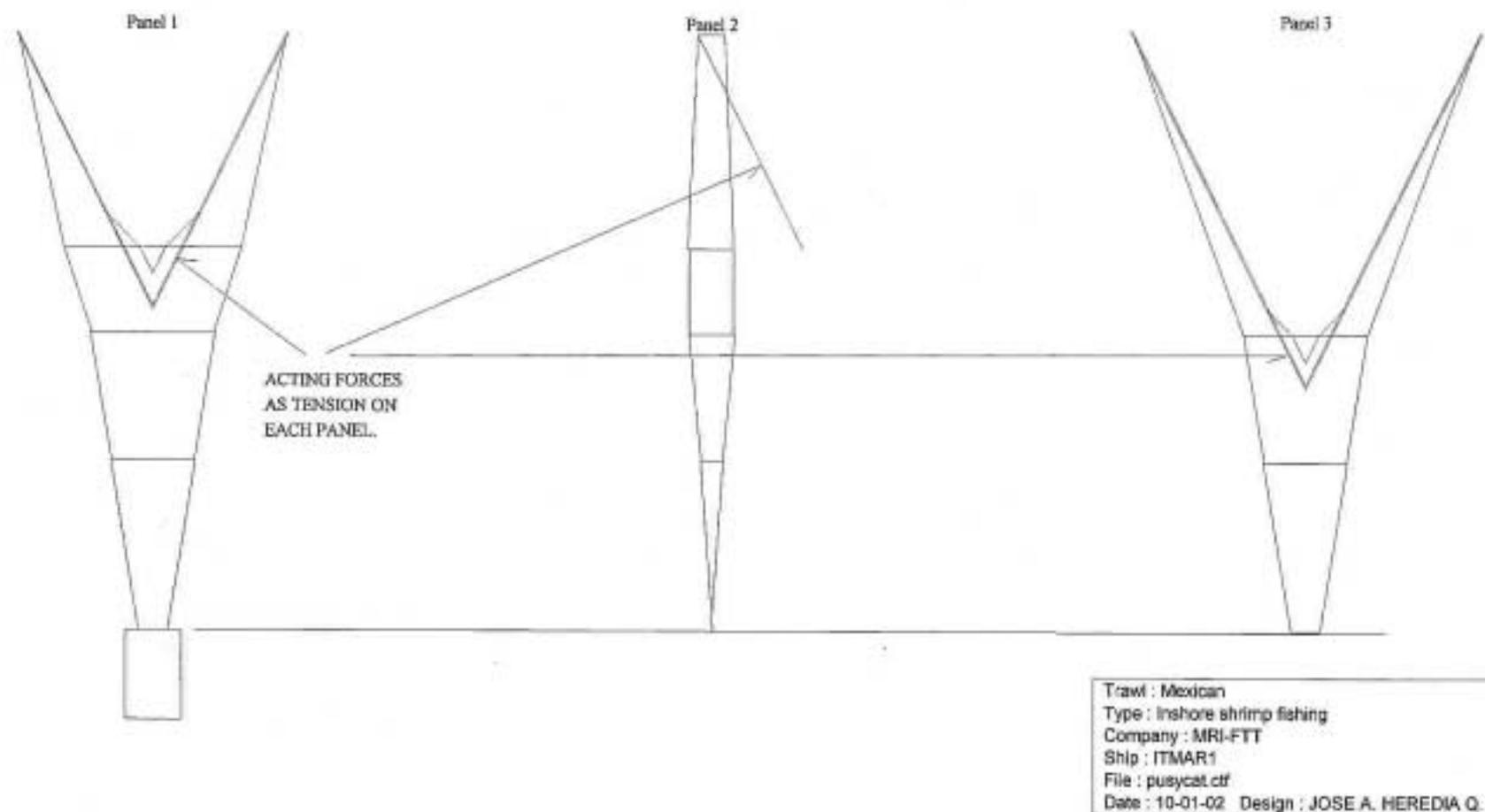


Figure 18: Schematic presentations of the tension forces acting in the preliminary design for the new trawl.

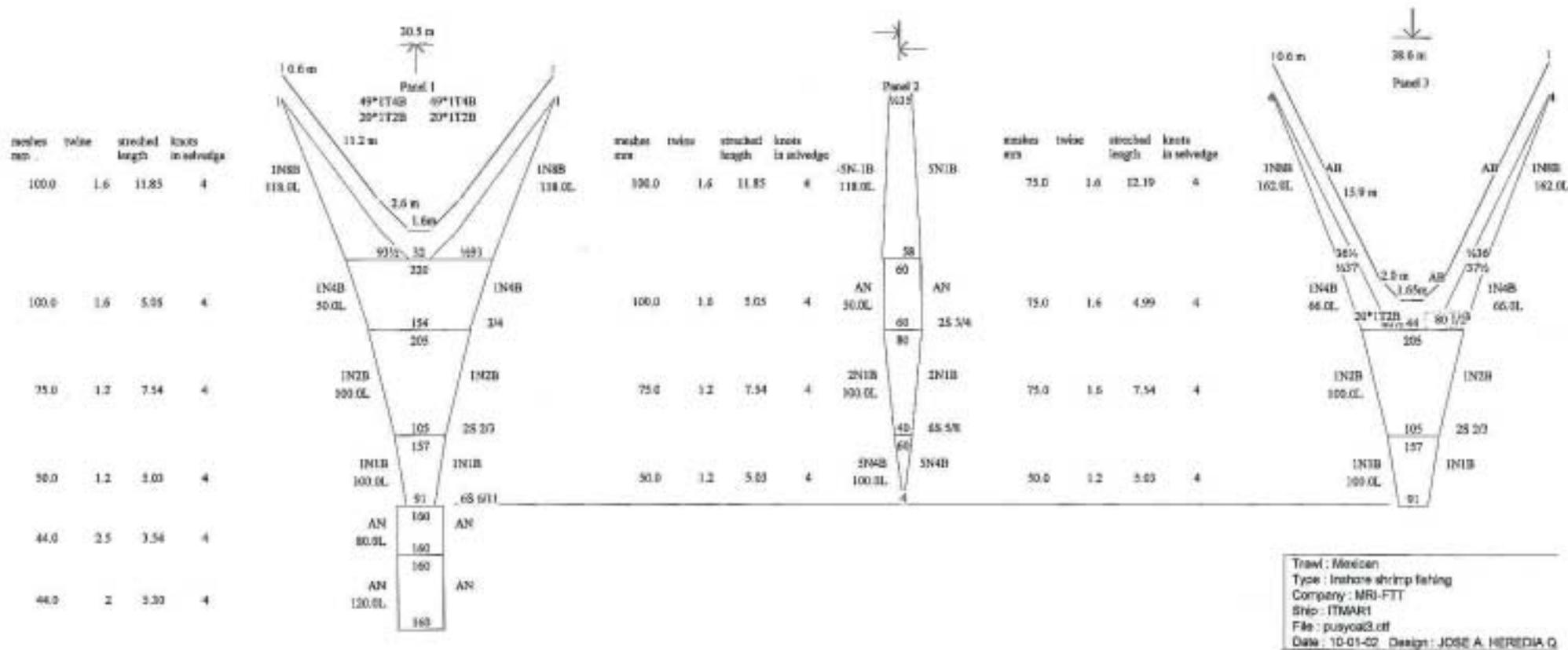


Figure 19: Technical drawing of the final design for the new trawl to be used in Mexican shrimp fisheries.

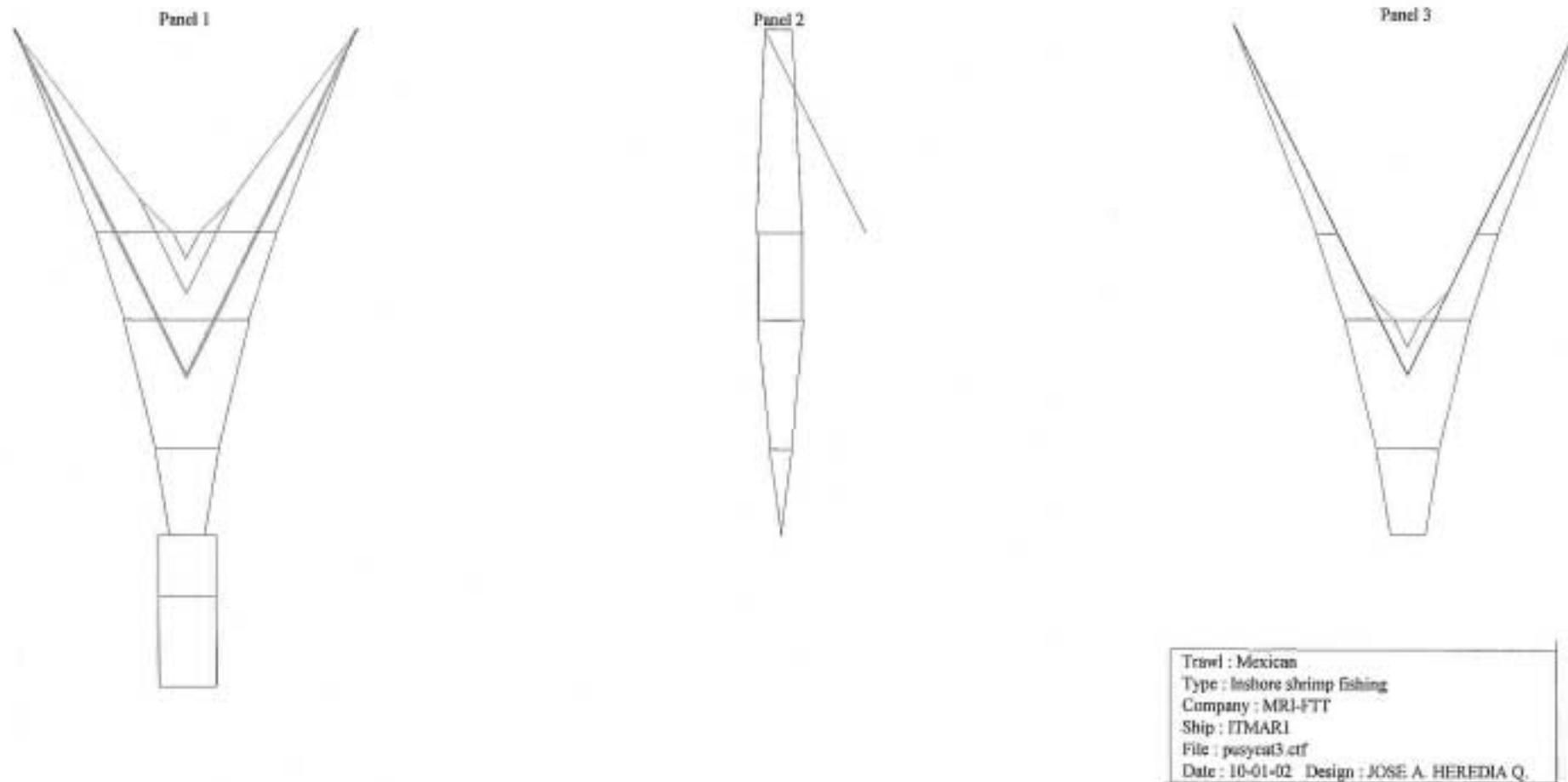


Figure 20: Schematic presentation of the tension acting forces in the final design of the shrimp trawl for Mexican fisheries.

The technical data is presented in Figure 19 and the acting forces or tension estimated for this new trawl are showed in Figure 20. In this scheme it is possible to observe the tension in the upper panel closer to the end of the belly. A higher vertical opening and wider horizontal opening is estimated for this trawl because of these changes.

To improve the selectivity of the trawl and reduce bycatch, the insertion of a “**square mesh window**” at the end of the upper belly section is suggested. The main characteristics are: 5 meshes wide, 8 meshes long, mesh size of 200 mm, twine diameter of 2.0 mm and knotless netting material. It have to be joined to 40 meshes wide and 32 meshes long in the centre at the end of the upper belly section which has a 50 mm mesh size.

The characteristics of the net extension, used to install the TED are 160 meshes in circumference, 80 meshes long, mesh size of 44 mm and the netting material is the same used for the codend. The characteristics and position of the guiding funnel are suggested and also the new position for the TED. The escape window for the TED is 28 meshes wide and 14 meshes long and positioned in the centre of the upper section of the extension (Figure 21).

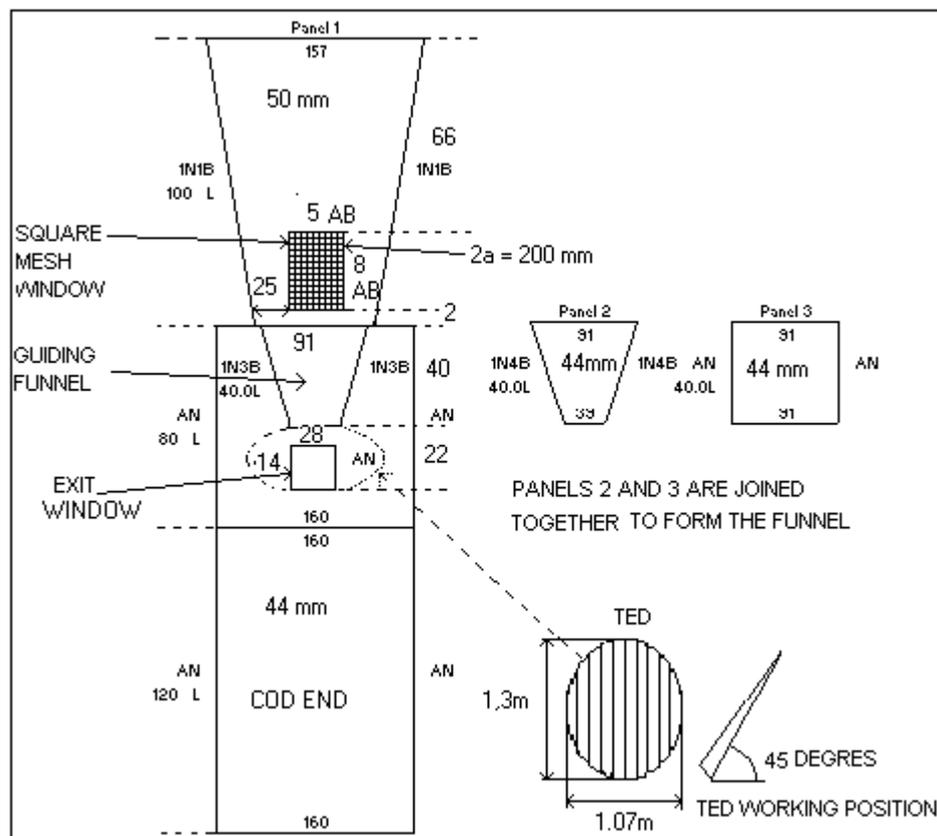


Figure 21: Scheme of the characteristics and position of the suggested "square mesh window" as a bycatch reduction device (BRD), of the net extension to fix the guiding funnel and the TED, of the guiding funnel, of the TED and of the “exit window” to allow the turtles to escape.

4 DISCUSSION

The modification of commercial fishing gears to make them more efficient is a very delicate matter. Problems of acceptance may occur when a new trawl is introduced in an established fishery (Valdemarsen and Suuronen 2001).

It should also be noted that some gear modifications may make gear more expensive to construct, and more difficult to operate and maintain. Moreover, catches of marketable fish may be reduced. Measures and techniques that increase cost and reduce earnings are unattractive to fishermen. There is little point in introducing totally unacceptable concepts or modifications, they will probably fail. The fishing effectiveness and practicality of new designs are important because an inefficient gear will not be used or will be "sabotaged," or may require so much additional fishing effort that overall impacts could actually be increased. Close co-operation between the fishing industry, scientists and other stakeholders will be necessary in the process of developing and introducing environmentally friendly fishing technology. This point of view is totally acceptable and the acceptance of the results of this project will depend on the efficiency of the new trawl.

In designing a trawl it is possible to follow the theoretical method established by several authors during the past decades such as the one developed by Fridman in 1986. It considers several stages such as the justification or definition of needs for the new gear and the formulation of technical requirements to satisfy the new needs. These methods also consider the mechanical properties of the gears as basic information to design fishing gears. Copying and adapting an existing net following this information and general information from the fishing practice is used to avoid future operational problems and ensure the efficiency of a new net.

Unfortunately the acceptance of a new net made under these conditions will require special considerations for the future user and special trials have to be carried out to demonstrate the operation and efficiency. In practice, the new fishing nets are designed with empirical knowledge of the fishing operations and situations. Normally, information from skippers is used for improvements and adaptations. This is happening in Mexico fishing industry and some effort has been made to introduce new ideas from the theory and develop new nets accepted by fishermen with good results.

The highest shrimp loss is reported (40%) when "grids" without funnel is used. On the other hand, when using grids, fish loss is also the highest, up to 100%. So for the bycatch reduction and hence discards they are the most suitable, and again, the use of "Square mesh windows" and "Extended funnels" presents a good performance by acceptable fish loss, from 36 to 56%.

Special attention should be given to the Nordmore Grid. The Nordmore Grid shows the lowest shrimp loss and the highest fish loss, the existence of shrimp must be confirmed, because as mentioned before, when grids without funnel were tested the highest shrimp loss was observed.

When looking for the Icelandic method of design it was found that most of the fishing gears used for the industry are designed taking the experience and results of the

practical situations into account and in most cases technical information is applied to improve the new designs. However, no written information was found about it. The importance of record this "Icelandic way" of designing is therefore of great importance.

In this work, an idea is presented as a method to design a new trawl. This method was developed from the interviews with designers in several companies, net lofts and the information from the teacher of "Fishing Gear Thecnology" at Sudurnes Comprehensive College and the University of Akureyri. The method is considered both theoretical and practical and the results of using it are presented as a new shrimp trawl design for the Mexican fisheries.

Several shrimp trawls already in use in Iceland have been considered as examples of nets to the design and construction of the new net presented. The new shrimp trawl is to introduce some new ideas of netting and construction and also the use of the bycatch devices to diminish the fish catches in order to avoid high discards from this fishery. That, on the other hand, affects the reduction of fuel consumption for operation and improves of the quality of the final shrimp catches.

Other considerations about the use of different components of the fishing gear such as metallic otter doors have to be made in close co-operation with technical designers and users. It is essential to develop environmental friendly fishing gear with the minimum economical risk.

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APPENDIX 1 :THE MEXICAN FISHERIES DATA: MAIN FISHING PORTS, NUMBER OF FISHING VESSELS, TOTAL FISH PRODUCTION.

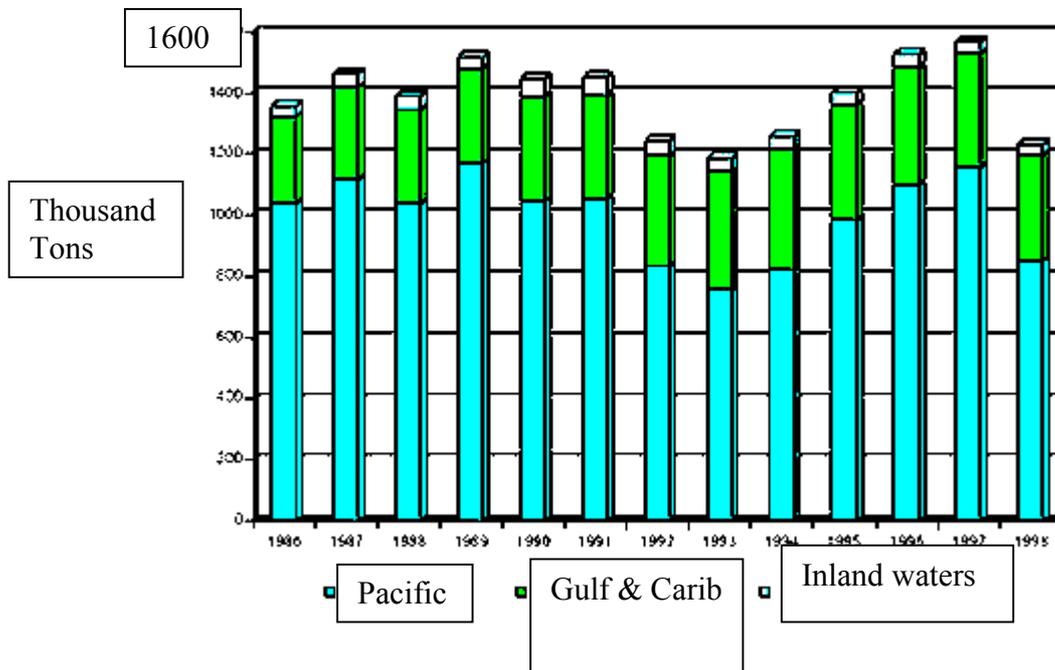
Mexico main fishing ports:



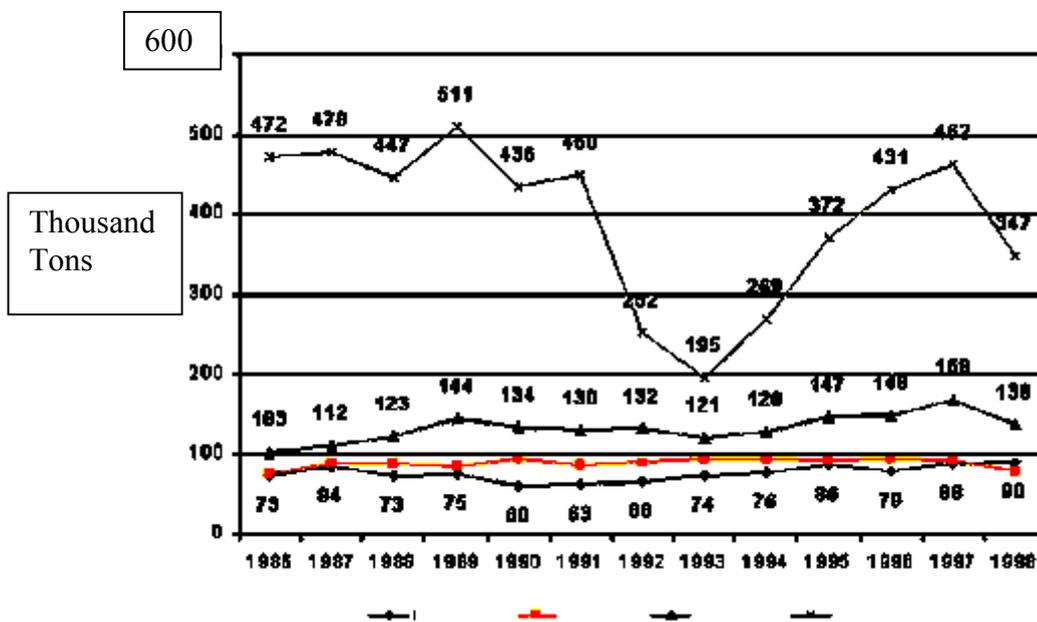
General economic data (1978)

- * Coast line shore : Pacific Ocean ; 8475 km,
Atlantic Ocean ; 3294 km (Gulf of Mexico & Caribbean
Seas included)
- * Fishing ports : 62
- * Population : 95 127 496
- * Employment ; on fisheries ; 235 345 and on Aquaculture ;
23 505

Fishing production:



Main fisheries exploited:



Main open seas fisheries by value:

- * Sardine and anchovy 2 %
- * Tuna 4 %
- * Shrimp 66 %
- * Several species of fish 28 %

Registered fishing vessels:

