FISHERIES TRAINING PROGRAMME
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Final Project 2001

AN ALTERNATIVE DESIGN OF TRAWLS FOR OFFSHORE FISHING IN VIETNAM

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ABSTRACT

This study deals with designing an alternative fishing gear for Vietnamese fisheries. It looks at both pair trawl and single trawl with doors for fishing in Vietnam seawater at depth 100 – 300 m. The study used a combination of knowledge pertaining to similarity method and experimental method in trawl designing. Although there is no exact design theory, similarity method gives a sound knowledge for designing trawl net better than experimental knitting method, which is commonly used by Vietnamese fishermen. As the designer has to be creative in each particular case, and the effectiveness of fishing gear so developed depends heavily on the knowledge acquired from fishermen and on information on bottom conditions and fish behaviour, This study could be used as an effort of trial and balance for further work in this direction. It leads to rational decisions regarding future development of suitable trawls for Vietnamese deep-sea fishery.

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1. INTRODUCTION

Vietnam is a coastal nation in South East Asia. Throughout the process of founding, defending and building the country, the sea has, and will, play a very great role. Therefore, the development and exploitation of natural resources along with the protection of the sea environment have become a long-term strategic objective of the country's process of socio-economic development.

Besides the marine resources, Vietnam also has an abundant potential in freshwater and brackish water resources and natural conditions are suitable for promoting the cultivation of freshwater, brackish water and marine species, contributing to the increase of income, the improvement of people's living standard and enriching the country.

1.1 Natural conditions

Vietnam has a 3,260 km coastline stretching from Mong Cai to Ha Tien and running through 13 latitudes from 8^0 23' North to $21^0$39' North. The area of inland territorial is 329,566 km^2 and that of Exclusive Economic Zone is over 1 million km^2, three times bigger than the mainland area.

In the sea areas of Vietnam there are more than 4,000 islands. Among the large ones is Co To, Bach Long Vi, Cat Ba, Hon Me, Phu Qui, Con Dao, and Phu Quoc islands, all of which are inhabited. These islands have great potential for developing tourism and they have been and will be built into a line of bases to provide logistic services to tranship products for the marine fishing fleet, and provide shelter for fishing vessels during the stormy season. Most of the islands are in the region from Mong Cai to Do Son (with more than 3,000 big and small islands, which make the Ha Long Bay become a world's famous spot).

In the sea area there are many bays, lagoons, swamps, estuaries such as the Ha Long Bay, The Bai Tu Long Bay, the Cam Ranh Bay, and the Tam Giang Lagoon and over 400,000 hectare of mangrove forests which are potential areas for developing communication, tourism and at the same time favourable places for developing aquaculture and providing shelter to fishing vessels.

The sea area of the country is divided into four smaller ones, namely the North Sea area, the Central sea area, the East and the West, (Figure 1). The East and West areas have no places with great depth since the slope of the bottom base is small. More than 50% of the sea area has a depth of less than 50 m. The Central area is vastly different and bears the characteristic of a deep sea. The bottom base slopes down sharply. In many places the 100 m isodepth line is only 10 nautical miles away from the shore. That is the region where the country lies furthest to the east and is bordering the deep-sea area. This is the reason for dividing the limit between the inshore fishing activities and the distant waters fishing activities. This limit is 50m for the Central sea area and 30m for other areas. Depending on two seasons in the year the marine capture fisheries is also divided into two seasons with different characteristics, namely the south season (from March to September) and the north season (from October to February).

Figure 1: Map of Vietnam.

1.2 Characteristics of marine resources

According to the Vietnam Ministry of Fisheries (Fistenet 2001) there are more than 2000 fish species in Vietnam waters, where about 130 species have economic value. According to the latest evaluation, the marine fish stock biomass in the whole sea area is 4.2 million tons; TAC is estimated 1.7 million tons, including 850,000 tons of demersal fish, 700,000 tons of small pelagic fish and 120,000 tons of pelagic fish.

Besides marine fish, there are also many natural resources namely more than 1,600 species of crustaceans with an annual allowable catch of 50,000 – 60,000 tons, in which marine shrimps, lobsters, slipper lobsters, crabs and mud crabs are high valued species. Of about 2,500 species of molluscs, squids, cuttlefish have significant economic value and annual allowable catch is 60,000 –70,000 tons. Each year a volume of 45,000 – 50,000 tons of high valued seaweed such as *Gracilaria verrucosa* and *Sargassum* can be harvested. In addition, there are also many precious species such as abalones, sea turtles, and sea birds. Shark fins, fish bladders and mother pearls can also be utilized.

Dominated by the feature of a tropical sea area, the resources of marine products of the country have a diversified composition of species with small sized individuals and the high speed of reproduction. The monsoon regime creates the basic change in oceanographic condition leading to the change of fish distribution. Fish live scattered in small schools. The ratio of small schools of fish with size under 5 * 20 m accounts for up to 82% of the total number of fish schools, the schools of medium size (10 * 20 m) occupy 15%, while the big schools (from 20 * 50 m upward) occupy only 0.7% and the largest schools (20 * 500 m) occupy 0.1%. The number of schools bearing ecological characteristics of the coastal area occupies 68%, and the schools bearing oceanic characteristics occupy 32%.

The distribution of fish stocks and the capacity of exploiting demersal fish are mainly in the sea area of below 50 m (56.2%), followed by the areas 51 – 100 m (23.4%). According to statistics, the TAC of marine pelagic and demersal fish in the regions near the coast can be maintained at 600,000 tons. If other marine species are included, the TAC is 700,000 tons a year, lower than the catch in this region in past years. Meanwhile, resources in offshore waters are under- exploited.

Fish resources are also different depending on the region and the depth. The South – East Sea gives the greatest TAC, accounting for 49.7% of the exploitation, followed by the Tonkin gulf 16.3%, the Central area 14.3%, and the South Western area 11.9%, oceanic pelagic 7.1% (Table 1).

Table 1: Vietnam marine stock and fishing capacity, (Fistenet 2001c).

Sea area	Kind of fish	Depth	Fish stock tons	Fish stock %	TAC tons	TAC %
The Tonkin Gulf	Small Pelagic		390,000	57	156,000	57
	Demersal	< 50 m	39,200	6	15,700	6
	Demersal	> 50m	252,000	37	100,800	37
	Total		681,200		272,500	
The Central Region	Small Pelagic		500,000	82	200,000	82
	Demersal	< 50 m	18,500	3	7,400	3
	Demersal	> 50m	87,900	14	35,200	15
	Total		606,400		242,600	
The South Eastern	Small Pelagic		524,000	25	209,600	25
	Demersal	< 50 m	349,200	17	139,800	17
	Demersal	> 50m	1,202,700	58	481,100	58
	Total		2,075,900		830,500	
The South western	Small Pelagic		316,000	62	126,000	62
	Demersal	< 50 m	190,700	38	76,300	38
	Total		506,700		202,300	
Floating knoll	Small Pelagic		10,000	100	2,500	100
The whole Sea area	Deep sea Pelagic fish (*)		300,000		120,000	
Total	Small Pelagic		1,730,000	41	694,100	41
	Demersal	< 50 m	597,600	14	239,200	14
	Demersal	> 50m	1,542,600	37	617,100	37
	Deep sea Pelagic fish (*)		300,000	7	120,000	7
	Total		4,180,200	100	1,672,900	100

(*). Data presumed according to total catch of the countries in this area.

1.3 The Vietnam fisheries from 1990 to 2000

1.3.1 Fishing fleet

As a result of the economic reforms led by structural adjustments in late 1980s large fishing vessels came into fishing operation and increased the total number of fishing vessels considerably. In 1990, there were 72,723 fishing vessels including artisanal fishing crafts such as rafts and wooden boats. By 1996 the total number of fishing vessels was 97,700. By 2000 it was 78,535 as small-scale traditional crafts were withdrawn from fishing (Figure 2).

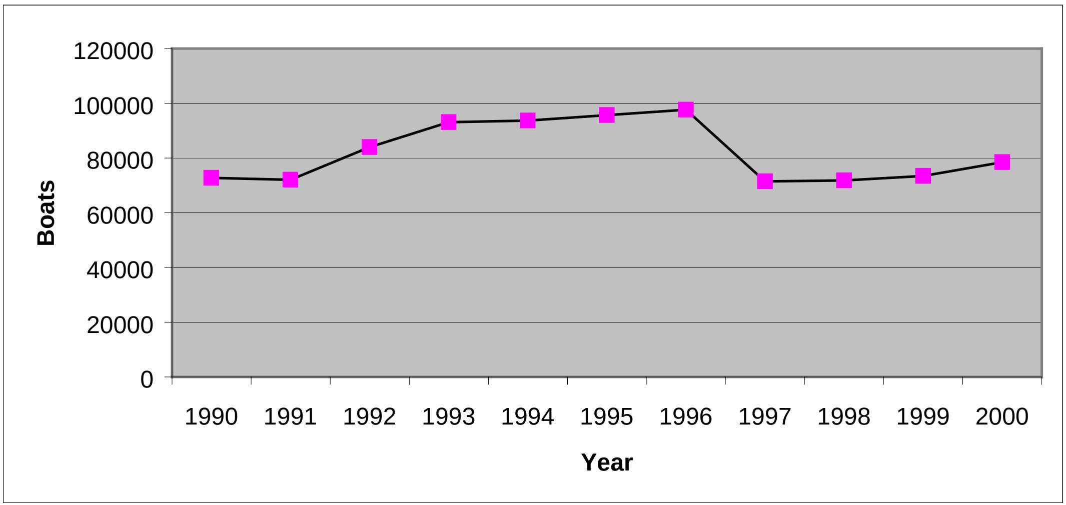


Figure 2: Altering of Fishing fleet in Vietnam from 1990 to 2000 (Fistenet 2001d).

In 1997 the Vietnamese Government has established a policy to develop offshore fishing. Since then there has been a great change in the fishing fleet with an increase in large boats and fewer small ones. The number of vessels fitted with engines from 90 hp and upward is about 6,000 units. This is the offshore fishing fleet. Of the other motorised vessels, 85% have engines that are 45 hp or less. In the category of 45 hp or more, 33% have GPS equipment, 21% have echo sounders, 63% have walkie– talkies, and 12.5% have long distance radio.

Most of the vessels lack communication facilities, safety buoys and navigational security facilities that are why they are only capable of operating in coastal areas.

Of the total number of vessels, transport and service vessels account for 0.7% in terms of quantity and 2.1% in capacity. However, during the process of carrying out the Government's policy to develop offshore fishing activities these numbers are changing rapidly. The technological standard of the fishing fleet is progressing day-by-day.

About 6,000 fishing boats can operate in offshore waters (90 hp and upward).
Average lengths are 16 – 30 m and loading capacity is 80 –100 MT.
Engines of up to 300 hp are usually truck engines, which must be overhauled annually.
Engines over 300 hp are usually marine diesel engines.
Private trawlers are made of wood. State or provincial companies own a few large trawlers made of steel.
The composition of the offshore fishing fleet according to engine size is shown in Figure 3. The boats with the largest engines (450-600 hp) are almost solely found in the East and West areas.

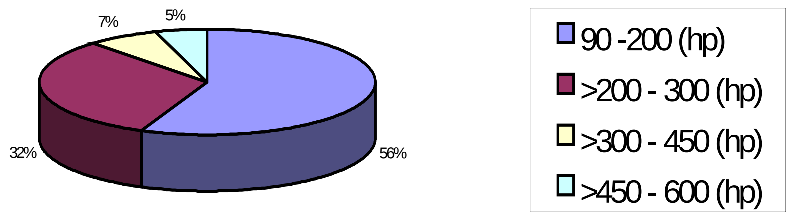


Figure 3: Offshore fishing fleet in 2001.

Deck equipment: Only larger boats are equipped with hydraulic wire winches for setting and retrieving trawls. Trawls are retrieved on boats manually; some of them were also equipped with hydraulically powered winches. Smaller boats are only fitted with hydraulic capstans.

Electronic equipment: Almost every boat 300 hp and upward were equipped by GPS, echo sounders, walkie-talkies and long distance radio.

1.3.2 Fishing gear

Most vessels engage in various fishing methods. In Northern provinces the fishing of demersal fish is 33 – 35 % and that pelagic fish is about 65%. In the Central provinces these figures are 31 – 32 % and 68 –69 %, respectively. In Southern provinces the ratio of demersal fish fishing and pelagic is equal (Figure 4).

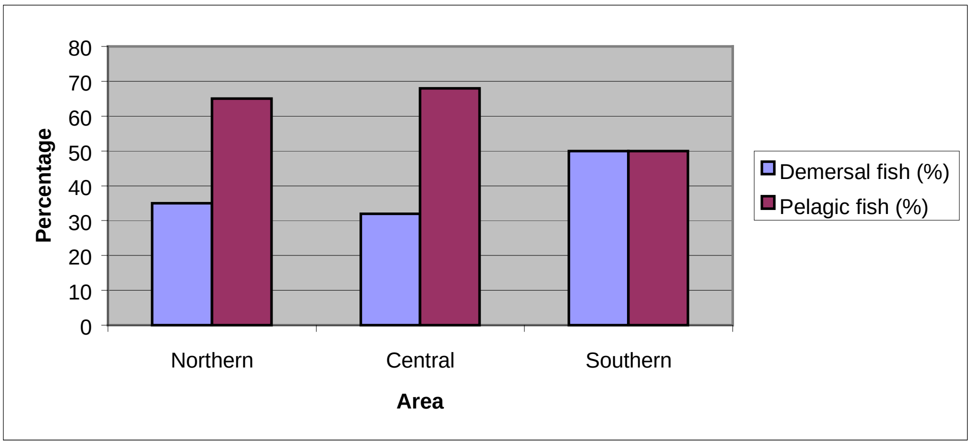


Figure 4: Ratio of catching methods between demersal and pelagic fish in Vietnam (Fistenet 2001e).

In the past years the trawling operation in sea areas at depth 50 –100 m has been limited due to the lack of large fishing vessels capable of fishing demersal fish in distant waters.
Many kinds of fishing gear is used in Vietnam. According to statistics, there are more than 20 fishing methods applied that are classified in 6 major fishing practices. Today the main fishing gear is trawlnet, purseine, longline, gillnet and liftnet (Figure 5). To

the category of "others", service boats which are providing support services such as carrying fuel and food for fishing boats engaged in fishing also have been included.

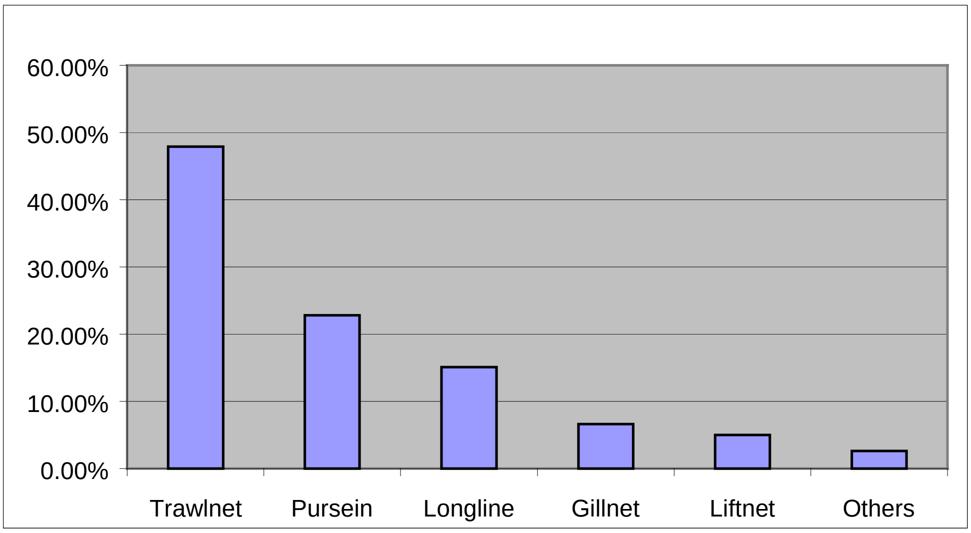


Figure 5: Fishing gear in offshore fishing of Vietnam (Fistenet 2001e)

Almost all fishing boats below 300 hp are pair trawling, from 300 hp to 450 hp the ratio between pair and single is 1:1 and over 450 hp there is only single trawling.

Almost all trawl nets were made by hand and every member in a fisherman's family takes part in netmaking. The quality of the trawl is depending on the experience of the fisherman and the construction material. At the present there is no any fish net manufacturing company owned by the private or public sector in Vietnam. Trawls were made of nylon imported from Japan, Taiwan and China.

1.3.3 Labour

Figure 6 shows the number of workers in the fishing industry from 1990 to 2000.

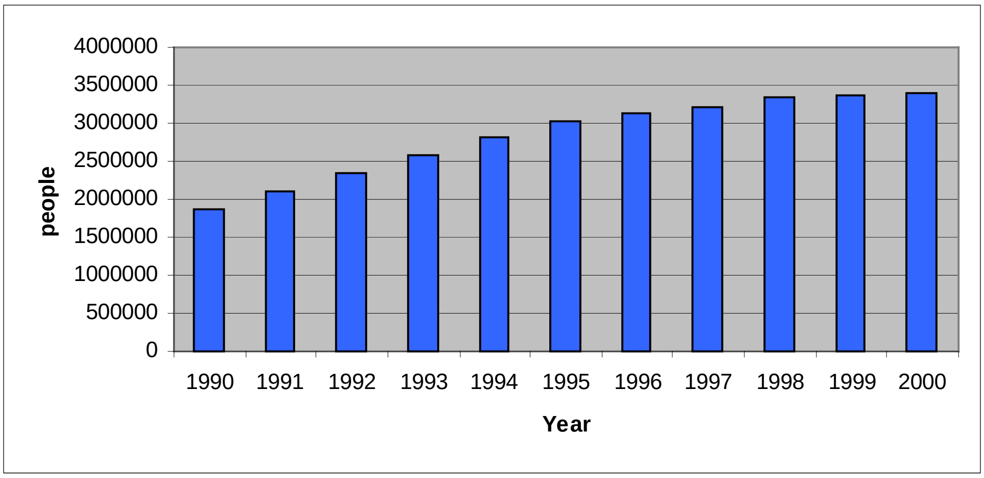


Figure 6: Labourers in the fisheries sector in Vietnam from 1990 to 2000 (Fistenet 2001e).

By the end of 2000 there were 3.4 million labourers in the fisheries sector. 484,000 persons were in fishing, 668.000 in aquaculture, 102,000 in processing, and 2,146,000 persons in services.

Of the 484,000 persons engaging in marine fishing 73% were in coastal fishing and 27% in offshore fishing. The fishing industry is actively promoting training in order to upgrade the skill of people engaging in fisheries activities helping them keep–up with the development of technology as well as mastering the operation of equipment installed in the offshore fishing fleet.

1.3.4 Total production

In 2000 total catch of marine fishes was 1,280,590 tons, with 860,590 tons inshore fishing and 420,000 tons offshore fishing (Figure 7).

The TAC for inshore fishing is 700,000 tons, and 973,900 tons for offshore fishing. One can see that over-exploitation takes place in the inshore fisheries and offshore species are under-exploited.

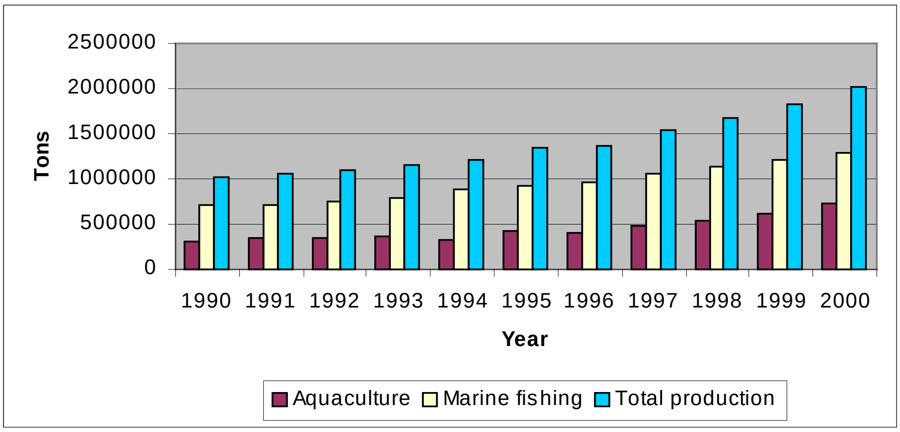


Figure 7: Total production of Vietnam fisheries from 1990 to 2000 (Fistenet 2001e).

1.3.5 Fishing ports

From 1996 to 2000 the Vietnam government has invested US$ 71.4 million in building fishing ports. There are 27 ports along the coastline and on some large islands. One of these ports was built with Japanese aid.

1.3.6 Total export value

From 1990-2000, exports earning from fisheries increased rapidly (Figure 8). There are three main reasons for this. The government policy affected diversion of the fishing industry towards offshore fishing providing necessary encouragements to the fishing companies. As a result, within the industry there had been a great renovation and recruitment of bigger vessels in to the total fishing fleet. On the other hand, this renovation endeavour placed a higher emphasis on the quality improvement aspect of the industry and it led to winning the export market.

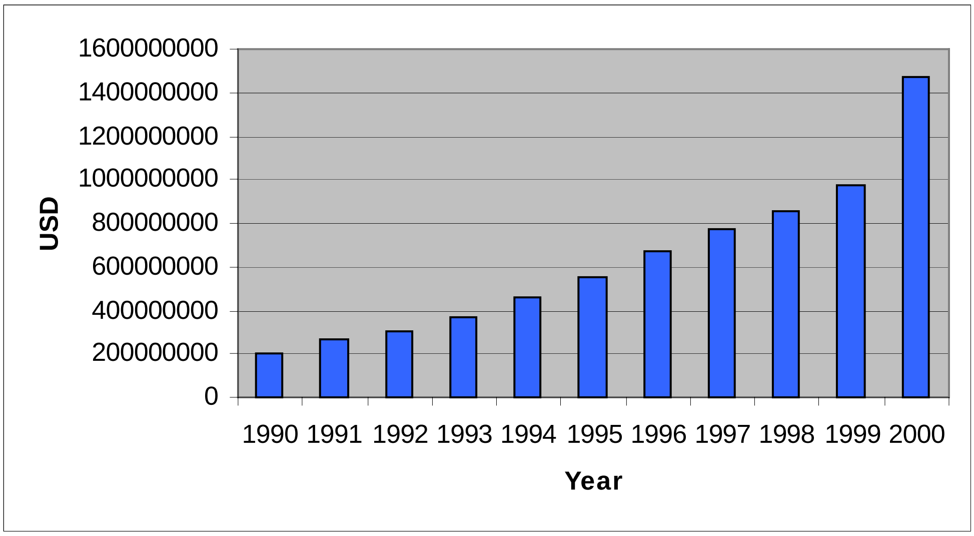


Figure 8: Total export value of Vietnam fisheries from 1990 to 2000 (Fistenet 2001d).

1.3.7 Target programs

Since 2000 the fisheries sector continues to carry out simultaneously three target programs:

- Aquacultures development
- Development of fisheries export
- Offshore fishing development

Successful implementation of these figures will be premises to establish development program in the period of 2001 – 2005. The objective is to make Vietnam become a major power of fisheries in the world by the year 2010.

Vietnam's fisheries ministry has estimated that total investment in the fisheries sector will surge to between $US 2.3 - 3.8 billion between now and 2010. Of this amount approximately $US 500 million will be need for offshore netting, $US 2.3 billion for aquaculture and 228 million for seafood processing (World fishing 2001).

1.4 Problems in Vietnamese fisheries

The Government of Vietnam has established offshore fishing program from 1997, but there are many difficult problems such as small fishing boats and old equipment, lack of experience and knowledge of deep-sea areas. As said earlier there is no fish net manufacturing company in Vietnam. Therefore, the fishing gear technology in Vietnam remains under-developed.

However, the trawl net is widely used in both coastal and offshore fishing. Of the total fishing fleet engaged in offshore fishing, 48% used trawl nets (Figure 5). But almost all of them are pair trawlers. Vietnamese fishers have experience in making pair trawl nets and how to use them. However, they have very limited knowledge relating to the single trawling and do not know how to design a single trawl net since there are no designers to help them.

Experience has shown that with smaller fishing boats pair trawling is more efficient, but with bigger fishing boats the best solution is not known.

Approximately 300 fishing boats from 450 to 600 hp were built during last three years, almost all of them are privately owned, and some public fishing boats will be built in near future (Fistenet 2001c). They need bottom trawls to operate.

In the South East region the TAC of demersal fish is 481,100 tons in waters deeper than 50 m (Table 1), that is 78% of TAC of demersal fish in all of Vietnam (in deep waters). In this area there are many species there are profitable to catch. At the present only about 50% of TAC is caught (around 200.000 tons per year).

With the fact that fishing gear in Vietnam is under-developed and the possibilities of increasing offshore fish by 50% the aim of this project is to look at possible design of trawls, both pair trawl and single trawl with doors for fishing in Vietnam waters at depth 100 –300 m. It will hopefully also help to develop offshore fishing programme in the future.

The objective of project is to design a bottom trawl, which can catch many species of demersal fish in South East Vietnam.

2. LITERATURE REVIEW

2.1 The trawl net

The trawl nets are cone-shaped nets (made from two, four or more panels) which are towed, by one or two boats, on the bottom or in midwater (bottom trawl and midwater trawl). The cone-shaped body ends in a bag or codend. The horizontal opening of the gear while it is towed is maintained by beams, otter boards (doors) or by the distance between the two towing vessels (pair trawling). Floats and weights and/or hydrodynamic devices provide for the vertical opening. Two parallel trawls might be rigged between two otter boards (twin trawls). The mesh size in the codend or special designed devices is used to regulate the size and species to be caught (FAO 2001).

2.2 Categories of bottom trawls

A bottom trawl is constructed like a cone-shaped net that is towed (by one or two boats) on the bottom. It consists of a body ending in a codend, which retains the catch. Normally the net has two lateral wings extending forward from the opening. The mouth of the trawl is framed by headline and groundrope. It is designed and rigged to catch species living on or near the bottom. Bottom contact with the gear is needed for successful operations. Three categories of bottom trawls can be distinguished based on how their horizontal opening is maintained: beam trawls, bottom otter trawls, and bottom pair trawls (Figure 9). Beam trawls are commonly designed without wings. (FAO 2001).

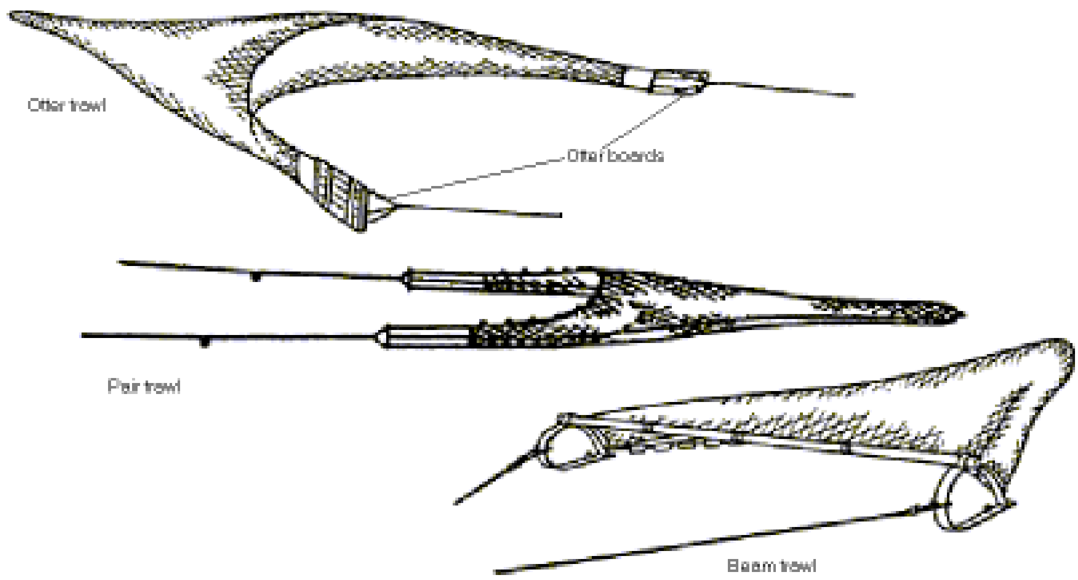


Figure 9: Three categories of bottom trawls (FAO 2001).

Bottom trawlers range in size from small, undecked boats, powered by outboard engines, up to 3000 GT (Gross Tons) with 8000 hp engines.

Bottom trawls are designed and rigged to have bottom contact during fishing. They are towed across the bottom at speed ranging from 1 to 7 knots (0.5-3.5 m/s), most frequently between 3 and 5 knots. Duration of a tow mainly depends on the expected density of fish (whether fish is aggregated or not) and bottom conditions lasting from a few minutes up to 10-12 hours, commonly 3-5 hours.
Bottom trawls can be operated in a very wide range of depths (from a few metres to 1500-2000 m), mainly at sea, but also, in some case inland water.

Bottom trawls interact physically with the bottom sediment, which might result in removal or damage of sedentary living organisms (including seaweed and corals) and in the case of uneven bottom displacement of stones or other larger objects. On flat sandy/muddy bottom the sediments might be whirled up into the water masses and suspended. The short and long-term impact on the bottom environment is poorly documented despite some scientific experiments. More research on possible impact of bottom trawling is urgently needed to evaluate the effect on the environment.

The major potential detrimental impact of bottom trawling on species can be the capture and removal from the ecosystem of small sized organism and non-target species, which frequently are discarded at sea. Using larger meshes in the codends and/or devices in the trawl that reduce capture of small and unwanted organisms can mitigate such impact (FAO 2001).

2.3 Development of trawl net

The dragged nets have been used to fish since Roman times. The Romans used a small bagnet to catch oysters of which mouth being held open by a wooden frame. The Wondyrchoun, which was so destructive to small fish in the fourteenth century, was a net 5.5 m (18 ft) long and 3 m (10 ft) wide. Its headrope nailed to a beam, which was raised above the bottom by frames at each end. The sole rope at the forward end of the bottom of the bag was weighted to keep it on the bottom (Sainsbury, 1996).

Beam Trawls: The first drawing of a beam trawl net reported is from 1635, and is still in use. The first American designed beam trawler was 26 m (85 ft) yawl built in Massachusetts in 1891, which was operated by an English crew. These early nets were all worked from sailing craft and this method of trawling reached its peak during nineteenth century (Sainsbury 1996).

Otter boards: The early otter trawl system also reported to be in use in 1885 and the doors of them were attached directly to the wings of the net, which appeared very similar to basic trawl today (Sainsbury 1996).

Pair trawling: The first major pair trawl fishery was developed by Spanish fishermen. They were working the east Atlantic shelf chiefly for one species – hake. These much sought after fish were found on the seabed from North Africa to west Scotland. Preferring the deeper waters, they were concentrated mostly around 100 fathoms line but were often as deep as 200 fathoms or more. It was possible to catch hake with an otter trawl but to operate one in such depths vessels needed a lot of power (Thomson 1978).

2.4 Fishing technology

Fishing technology, as a scientific discipline, was founded and developed in the 20^{th} century, mostly by Russian and Japanese scientists. It represents a generalization of practical experience accumulated by many generations of fishermen all over the world. The theories worked out by Professor Baranov (USSR) and by Professor Tauti (Japan), as well as subsequent investigations by other workers, contributed to a better understanding of fishing and related processes and of the interaction between fish, fishing gear and fishing vessel. Procedures have been worked out for objectively comparing fishing methods and gears to help select the most suitable ones and to permit a preliminary evaluation of the technical and economic feasibility of technological improvements and innovations.

The only knowledge that many good fishermen have is their experience and what they have learned from their fathers. They often distrust the results of theoretical investigation, particularly because they do not know how to take advantage of them. However, with the dynamic changes that have occurred in recent years in the world fisheries, improving the selection of fishing grounds, gears and methods, and involving sophisticated equipment such as monitoring instruments, large and powerful fishing gear and automatic machines, fishermen of a new type are needed, who are able to blend practical experience with theoretical knowledge (Fridman 1986).

This is the case in Vietnam. Fishing gear technology is undeveloped. Fishermen make fishnet themselves, so the quality of nets depends on the fishermen's experience.

3. METHODS

The method applied in this study is similarity method introduced by Fridman because this method can solve the relationship between trawl net, catching species, fishing ground and vessels. According to him, there are three numerical values for the similarity criteria Ne, Fr and Sr. In designing, one can use one or all of them. It depends on the information on net material, trawler, fishing ground, target species and its behaviour, and other technical requirements that the designer has. The most importance numerical value is Ne and it is used in this study. Fr and Sr can be ignored because a prototype and a new trawl are working in a similar medium and the value of Fr is so large so that its' influence is negligible.
The Ne criterion is chosen and is calculated:

$$SF*Sm/SC*S\rho*SV2*SL2*SD = 1 \quad (3.1)$$

Where SF is the force scaling factor
Sm is mesh size scaling factor
S_C is scaling factor of Reynolds number
S_ρ is operating medium scaling factor
S_V is velocity scaling factor
S_L is linear scaling factor
S_D is thickness scaling factor

Following this method a prototype net, catching species and vessel was chosen and the similarity factor and value of new design then calculated.

Studying also combined with experimental methods, which collected by Prado in Fishermen's workbook and fishing gear companies in Iceland and from another sources.

All of calculations in this study were done manually.

The prototype is a common kind of Vietnam trawl net, fishing in the same place with a new design but at less depth. The target species is cuttlefish; it is very high quality and good market. Total allowable catch is approximately 9000 tons and right now Vietnam does not have any kind of trawl net to catch cuttlefish.

DesignCAD Pro 2000 is used for drawing the trawl net and following systems specified by ISO and practised by FAO. The drawing specifies the linear dimensions of lines in metres, panel size in numbers of meshes, cutting rates, twine sizes in R-tex, extended mesh lengths in mm, etc.

Designing fishing gear is the process of preparing technical specifications and drawings for a fishing net to satisfy gear handling, technical, operational, economic and social requirements.

3.1 Design stages

The design of fishing gear and of any other associated equipment, machinery, instrument, etc, is divided into several stages, which may partly overlap in practice.

There 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.

The justification explains why a new or modified gear variant is needed, specifies the fishing conditions under which this variant is to be operated, including the knowledge and ability of the fishermen, and identifies economic and other gains.
The principal technical requirements of the new design are formulated according to:

1. The purpose of the gear;
2. The gear type and method of operation;
3. The performance characteristics of the gear;
4. The structural characteristics of the gear.

The efficiency of fishing gear depends very much on this technical formulation, because inappropriate characteristics can make the gear inefficient. If possible, an existing gear is selected as a prototype. Improvements are developed during this technical formulation, requiring a thorough knowledge of characteristics of the fish and the fishing conditions on the prospective fishing grounds. Then, the desired changes in the design and dimensions, rigging, materials, operational regime, etc. for the new design are tentatively suggested. The technical formulation should be mutually compatible. For example, the towing speed and trawl dimensions can be determined only if the power of the fishing vessel is known.

During the preparation of the tentative design, the compatibility of the structural and performance requirements should be verified and the expediency of developing several alternate variants of the design should be determined. For this purpose all available information on the design and operation of the prototype fishing gear is required for evaluating the different tentative variants of the design and rigging. If model tests are needed, they are carried out at this stage to determine the working shape and position of each gear, the speed, the location, magnitude and direction of force, etc. Also, it may be useful to conduct controlled experiments with the full-scale prototype gear. During this stage some necessary amendments and modifications to the original formulation can be made according to the constraints and limitations disclosed by the analytical calculations and the experimental results. During the stage of technical designing all the construction problems are solved, taking into account the availability of required netting materials, ropes, rigging and other equipment. For fishing gear developed for industrial production, structural details, list of materials and cost are specified.

Construction drawings containing all the necessary information for the manufacture and operation of the fishing gear are prepared at the next stage. The operational efficiency of the new gear is verified full scale under actual fishing conditions on the designated fishing grounds and, if the gear is accepted for commercial production, a full technical description and operation manual is prepared for delivery to the fishermen with the new gear.

The formulation of the technical requirements and the preparation of the tentative design are the most creative stages of the design process. At the stages the principal solutions are found. The subsequent stages consist of detailed technical specification, experimental work and gear evaluation, and material quantification and cost.

3.2 Analysis

While documenting the required characteristics of a new trawl, one must consider the behaviour of the fish the trawl is designed to catch, the technical characteristics of the fishing vessel from which the gear is going to be operated and the fishing conditions on the trawling grounds where the fishing system is to be used.

There is still no dependable mathematical model for describing the interaction between a trawl and the fish during the trawling process.

One way of taking specific fish behaviour into account is to base the new trawl design on characteristics of a well-known and proven trawl.

Another way is to try established designs from other areas or fisheries, or to apply new design ideas based on information on the behaviour of the desired fish obtained by such means as ecological research, direct visual observations or echo-sounding. The interaction between trawl and the fishing vessel can be rather precisely stated from calculations.

The various requirements for a new trawl may often not be compatible with one another. For example, the requirements for maximum fishing power and minimum hydrodynamic resistance at minimum cost contradict one another. Compromises must be made to handle such contradictions.

The formulation of technical requirements should involve a review of:

- Characteristics of fishing conditions, of the fishing grounds and of the species to be caught,
- Characteristics of the trawler or trawlers to be employed,
- Desired characteristics of possible trawl prototypes and criteria for selecting the most suitable,
- Characteristics of trawl operation such as speed, depth and tow duration,
- Special requirements of trawl performance such as for rough or smooth ground.

Finally, after these technical requirements are formulated, the main technical characteristics of the gear, such as principal dimensions, drag and sheer forces, buoyancy and ballast needed for the desired performance can be tentatively set.

3.2.1 Fishing ground

The Vietnam Sea is in the tropical region North-East monsoon, close to the equator, in the western Pacific, with two main wind seasons in the year and there is an definite difference in between North and South areas.

The meteorological and hydrological characteristics of the coastal zone show three shallow-water regions in the Vietnam seawater. In the Gulf of Tonkin, the South-eastern and South-western regions the seabed is suitable for bottom trawling (Fistenet 2001b).

Two major climatic seasons are in these areas depending on the winds: The North-East (November to March) and the South-West (May to September). The influence of the North-East monsoon is less in South-eastern area, but the South-West monsoon is a major influence. Typhoons moving from the east to the west or north-west are frequent in summer and greatly affect the meteorological conditions of the seas. Annually, there are 4-6 typhoons or tropical low pressures formed in the South China Sea, almost all of them come to Gulf of Tonkin and Central region, but less frequently to the South region.

South-eastern Vietnam is more than 40% of Vietnam seawater and 50% TAC of all Vietnam (Table1). This area also has 78% of demersal species (> 50m depth sea) (Table2).

Most of the South -eastern area has a flat, sandy and muddy bottom, which is well suited for operating bottom trawls, some places also have a little seaweed and corals (South of Spratly Islands). The average depth of deep-sea is 100 – 200 m.

Table 2: Stock estimates and TAC of demersal fish in Vietnam waters > 50 m (Fistenet 2001a).

Region	Reserve (tons)	TAC (tons)	Percentage (%)
Tonkin Gulf	252,000	100,800	16
Central	87,900	35,200	6
South-East	1,202,700	481,100	78
Total	1,542,600	617,100	100

The current in the South-eastern region mainly two directions: From NE to SW (November to March) and from SW to NE (May to September). Surface currents and deeper currents are also similar.

The Mekong River is one of the longest rivers in the world; it opens into South China Sea at South-eastern area. Its waters teem with an abundance of plant and animal species and provide a lot of food and nutrients for marine species. The south-east region became a focal economic region for fisheries and rich in marine resources.

3.2.2 Fishing species and their behaviour

Trawls can be used to catch many species of demersal fish; cuttlefish, octopus, squid, etc. The emphasis of this study is to develop a trawl net specially aimed for catching cuttlefish (Figure 10) because, at present, there is no specific gear design used in Vietnam for cuttlefish and the export for this specie to Japan, Taiwan, USA and the EU countries is lucrative.

Figure 10: Cuttlefish.

Table 3 shows that in the South-eastern region, which this study focuses on, the potential quantity of harvest within the depth levels of 50- 200m is around 9000 tons. The current harvest level, however, is approximately 10% of the potential harvest.

In developing a trawl net to catch cuttlefish, it is essential to have as much information and understanding on the species behaviour as possible.

Cuttlefish belong to the class *Cephalopoda* and like all cephalopods; they have a large head that is ringed by tentacles. Cuttlefish are soft-bodied marine animals that can change both the colour and texture of their skin rapidly to provide natural camouflage. When threatened, a cuttlefish will squirt sepia ink into the water and hurry away using a form of jet propulsion.

Table 3: Stock estimates and potential exploitation of cuttlefish in Vietnamese waters (Fistenet 2001c).

Region	**Reserve and TAC (tons)**	**< 50 m**	**50 -100 m**	**100 – 200 m**	**> 200 m**	**Total**
The Tonkin Gulf	Reserve	1,500	400			1,900
	TAC	600	160			760
Central	Reserve	3,900	3,840	4,500	1,300	13,540
	Tac	1,560	1,530	1,800	520	5,410
South-East	Reserve	24,900	10,800	7,400	5,600	48,700
	TAC	9,970	**4,300**	**2,960**	**2,250**	**19,480**
	Total Reserve	**30,300**	**15,040**	**11,900**	**6,900**	**64,140**
	Total TAC	**12,130**	**5,990**	**4,760**	**2,770**	**25,650**
	Percentage (%)	**47**	**23**	**19**	**11**	**100**

The lifecycle of a cuttlefish spans only 18 – 24 months. They only spawn once in their lifetime and die shortly after spawning (Windspeed 2001).

Cuttlefish have very good eyesight. They have binocular vision as visual fields for both eyes overlap. Cuttlefish have W-shaped pupils that contain a lens that is similar to humans but focuses differently. To focus on close objects, the cuttlefish contracts the muscles around the eye, which pushes the lens forward, away from the retina. To focus on distant objects, the cuttlefish relaxes the muscles and draws the lens inward. Minute hairs along the cuttlefish head and tentacles detect low frequency vibrations enabling them to 'hear' and locate their prey.

Cuttlefish move by gently undulating their skirt-like fins. They glide smoothly through the water and can vary their depth easily. The cuttlefish bone is porous, gas-filled chambered shell which gives the cuttlefish natural buoyancy. To rise or sink in the water, the cuttlefish varies the proportion of liquid to air within the cuttlefish bone. For fast movement through the water, the cuttlefish uses a form of "jet propulsion". It draws water into the mantle cavity through the mantle opening and then contracts the mantle muscles which force the water back out through the siphon. The cuttlefish then shoot away. The siphon is flexible and can be swivelled into different directions in order to steer.

When a cuttlefish is threatened, it has three ways to escape:
1. It can sink to the bottom, rapidly pump water out through the siphon and then bury itself in the disturbed sand.
2. It can pump water out of the siphon and propel itself backwards.
3. It can pump a protein-based sepia ink out of the siphon and escape during the confusion. The sepia ink may be produced as mucus-bound blob or as a large cloud.

Cuttlefish usually grow to between 5 and 30 cm long, but the giant cuttlefish become much bigger. Cuttlefish are found in all oceans of the world, from warm, tropical water to cold, polar water. They are found in the wave-swept intertidal zone through the cold, dark abyss. Cuttlefish are, however, usually found in temperate and tropical waters. They prefer coastal waters but are also found in the open ocean. Some species of cuttlefish swim around in schools, like other fish whereas others more solitary and guard their own territory (Windspeed 2001).

3.2.3 Trawlers

The modern trawlers in Vietnam are powered with 450 to 600 hp engines. In this study, 600 hp trawlers, equipped with deck instruments and fish detection equipment are considered.

The majority of the vessels are made of wood and are privately owned. They are usually equipped with a Yanmar main engine; trawl winches, gilson winches, net drums and other auxiliary winches for gear and catch handling.

Vessel class: length is normally 20–30 m, width is 5–6 m and tonnage 80–100 MT.

3.2.4 Selecting the prototype

The basic procedure for using existing fishing experience in the design of fishing gear for new applications is to base the design on an existing and proven prototype. The prototype is chosen as having demonstrated performance characteristics similar to those required for the new application, meeting the technical specifications and satisfying the conceptual plans of the designer better than other known fishing gear. Some characteristics of prototype are transferred directly to the new design. With a good prototype, the selection of design parameters is simplified because most of them can be taken from the prototype, thus assuring suitability and avoiding large errors. Many general characteristics and even technical specifications of the new design may be selected arbitrarily. Consequently, two different persons may provide different solutions for the same technical assignment. Therefore, where possible, several solutions or design variants may be developed and the best ones selected.

When selecting the prototype for a new trawl design, special attention should be paid to the behaviour characteristics of the fish species to be caught. For example, long sweep lines (ground warps) are used on trawls for fast-swimming fish not only to reduce the angle of incidence of the sweeps to improve fish-herding but also to increase the width of the zone between the trawl doors for maximum volume of water fished. Shrimp trawls must have a wide mouth while the headline height is of no major consequence, and the body of a shrimp trawl can be much shorter than that for fast-swimming fish where the longer-tapered netting of the belly and batings cause less alarm and reduces escape from the trawl by fish swimming with the net.

Direct comparison of the design features of various trawls is rather difficult because a greater number of variables are involved and because many of them fluctuate during fishing. The dimensions of a trawl mouth opening cannot be estimated accurately from the trawl diagrams and drawings. Trawls of the same size may have very different mouth openings, whereas trawls of very different size may have similar mouth openings. A more effective method for comparing trawls when selecting a design prototype has been suggested. It consists of a comparison between relative structural dimensions rather than absolute dimensions. Relative structural dimensions are shown by ratios such as: N/L, A/L, B/L, C/L, D/L (Fridman 1986).

A: Extended netting length of lower wing (m)
B: Extended netting length of bellies (m)
C: Extended netting length of codend (m)
D: Width behind square (m)
L: Headline length (m)
N: Extended netting length of overall (m)

The reasons for these differences in empirical commercial practice should be determined and the effect of these variations in trawl proportions on the catching ability of the trawls established, with a view to improving trawl design. Thus, it is evident that comparing trawls by means of their relative design characteristics permits better clarification of their differences and peculiarities and permits better selection of the prototype. The best way to choose the prototype for a new trawl design is to compare several possible candidates, both with respect to technical parameters and in comparative fishing trials, to give fair judgement of both the technical performance and the comparative ability of the trawls.

In this study the prototype of single bottom trawl for a 450 hp trawler is chosen. This trawl design is conventional and widely used in Vietnam. This design is also used as pair trawl on smaller vessels in the range of 90-160 hp (Fistenet 2001d). Its basic parameters are shown in Table 4.

Table 4: Basic parameters of prototype trawl.

No	Parts	Material	Dimension
1	Headline ∅ = 26 mm	PE	33.5(m)
2	Footrope ∅ = 30 mm	PE	38.5(m)
3	Extended netting length of Lower wing	PE 380D/15	18.8(m)
4	Extended netting length of Square	PE 380D/15	3.4(m)
5	Extended netting length of Bellies	PE 380D/15	39.4(m)
6	Extended netting length of Codend	PE 700D/15	8.0(m)
7	Extended netting length of Overall		64.2(m)
8	Extended netting length of width behind Square		51.2(m)
	Total floats (buoyancy 3.7 kg/float)	27	
9	Towing speed (knots)	2.5	
10	Trawling depth (m)	30 - 80	
11	Fishing area	South East Vietnam	
12	Catching species	Cuttlefish and demersal fish	
13	Trawl door (2* 190 kg)	Wood and steel	2.2m * 1.2 m

3.3 Calculations

According to Fridman (1986) the basic technical characteristics of any fishing gear are its dimensions and shape, its drag as a function of speed and the magnitude of the forces imposed by various rigging components. These values are calculated for the new design from the prototype using the rules of similarity, regarding the main features of the new fishing gear and its prototype as being similar. The relationships between the technical characteristics of corresponding gear components are present as scales of similarity for linear dimensions, speed, forces, etc.

If the new design differs insignificantly in principle from the prototype, then its basic elements can be calculated directly from prototype data.

If the difference is significant, then a model test of new design may be considered. The technical characteristics obtained by testing the model are then used to calculate the basic components and technical characteristics of the new gear.

3.3.1 Calculation the mesh size of codend

The mesh opening in the codend, moc, should be such that the smallest commercial fish will not gill. This can be estimated from

$$moc \approx (2/3)*moG \qquad (3.2)$$

moG is the mesh opening of the gill designed to capture fish of the same species and size. The moG may be estimated from

$$moG = L/Km \qquad (3.3)$$

L is the length of the fish body from the tip of the snout to the base of the caudal fin and Km is an empirical coefficient depending on morphology of the fish and found by experimental fishing with gill net.

For narrow fish, Km = 5
For medium fish, Km = 3.5
For thick fish, Km = 2.5

The mesh size of the codend is also established by government rules. The minimum mesh size is 40 mm.

Fixing the mesh size of the codend at 40 mm, the smallest cuttlefish will not gill following (3.2) and (3.3):

$$40 \text{ mm} = (2/3) * moG \text{ then}$$
$$moG = 40*3/2 = 60 \text{ mm}$$

Smallest catching fish is $L = moG * Km = 60 \text{ mm} * 2.5$

$$L = 150 \text{ mm}$$

In the forward parts of the net (from wings through the bellies) the mesh size is as critical as in the codend. It is usually practical to base values from the prototype trawl. Recently, many trawls have been constructed with very large meshes in the fore parts. This allows both the towing speed and the area of the trawl mouth to be increased without significantly affecting the escape of fish from the net.

3.3.2 The available towing force of trawler

According to Fridman (1986) the following formula can be use for calculation of available towing force.

$$Ft \approx P * (KF - 0.7V) \qquad (3.4)$$

Ft is the towing pull (kgf)
P is the engine brake horsepower (hp)
V is towing speed (knot)
KF is an empirical towing force coefficient, which ranges from 10 for trawlers with conventional propellers to 15 for trawlers equipped with controllable pitch propellers in nozzles, leaving from 10 to 20% of the available towing force in reserve.

3.3.3 Towing speed

Towing speed should be proportional to the swimming speed of fish. Practical observations and special experiments have shown that there is an optimal trawling speed for each species of fish and trawl design, which provide the maximum catch. This optimal towing speed must be determined empirically by trawling under regular fishing conditions.

Optimal towing speed for catching cuttlefish is from 3.5 to 4.5 knots (Prado 1990). Common towing speeds of Vietnamese trawlers are 2.0 - 3.0 knots. In this study the choosen towing speed is 3.5 knots. This is considered the optimal towing speed for catching cuttlefish.

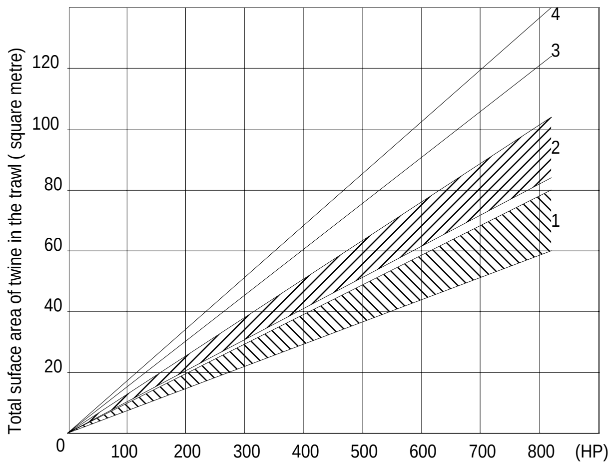
3.3.4 Calculation of twine surface areas

The engine power has to increase with increasing size of the fishing gear (figure 11). As the gear size increases then its resistance (drag) will increase and therefore a bigger engine is needed for effective towing. Formula 3.5 describes how the twine surface is calculates.

$$A_t = \frac{\left(\frac{M_1 + M_2}{2}\right) * N * 2 * \left(m * D_t\right)}{1000000} \qquad (3.5)$$

At: Project twine area (m^2)
Dt: Twine thickness (mm)
m: Mesh size (mm)
M1: Number of meshes at the top of the panel
M2: Number of meshes at the bottom of the panel
N: Number of meshes in the height of the panel

Choosing the right size trawl for the power of vessel



1. Two- panel bottom trawls
2. Four- panel bottom trawls
3. Single-boat mid-water trawls (mesh in wings up to 200 mm)
4. Single-boat mid-water trawls (wing meshes larger than 200 mm)

For Pair Trawling twine: surface area multiplied by 2.4 for Two- panel and 2.2 for four-panel.

Figure 11: The relation between gear size and vessel hp for a given group of vessels (Prado 1990).

3.3.5 Calculation the weight of netting

W = H * L* (Rtex/1000)*K (3.6)

Where W = estimated weight of netting (g)
H = number of rows of knots in the height of netting (2* number of meshes)
L = stretched length of netting (m)
K = knot correction factor to take into account the weight of the knots (Prado 1990)

3.3.6 Calculations for floats and sinkers

The total lift of floats of the new trawl Qfn can be defined as:

Qfn =Qfp:SF (3.7)

where Qfp is the total known lift of all floats of prototype.

Total number of floats Nf = Qfn / buoyancy of each float

Total weight of the footrope for the new trawl is:

Wn = Wp* SF (3.8)

where Wp is the total weight of the footrope on the prototype trawl

3.3.7 Calculations for trawl doors

Ln = SdL* Lp (3.9)
Hn = SdL* Hp (3.10)
Wn = SdL3* Wp (3.11)

The linear scale SdL can be defined as:

$$S_{dL} = \sqrt{\frac{F_n}{F_p}} \qquad (3.12)$$

Fn and Fp are available towing force of new and prototype trawls. It is calculated using formula (3.4).

3.3.8 Calculations of warp

The warp diameter can be determined by equation:

$$D_{\ln} = D_{lp}\sqrt{\frac{S_f . S_F}{S_{\sigma r}}} \qquad (3.13)$$

Where: Sf = fn/fp is the safety factors for the ropes of the new design and the prototype,
SF= Fn/Ep is the general scaling factors for forces,
Sσr = σrn/σrp is the scaling factor for breaking stress.

The length of warp to be paid out in relation to fishing depth can calculate following formula:

$$L_s = \sqrt{b^2 + \frac{2bT_0}{F_s}} \qquad (3.14)$$

Where: b is the fishing depth,
T_0 is the tension in the warp at the otter board,
F_s is the weight per meter of warp in water.

Length of warp is also determined by experiential method. According to Prado (1990) the length of warp for deep water is about 2.2 times the depth.

4. RESULTS

4.1 Value of similarity criteria

In this study only the Newton Criterion (3.4) will be used. Their values are shown in Table 5.

Table 5: Values of scale factors.

No	Scale factors	Single Trawl	Pair trawl
1	SC	1.00	1.00
2	SD	1.72	1.68
3	SF	1.22	2.44
4	SL	0.58	0.71
5	Sm	0.93	0.96
6	Sρ	1.00	1.00
7	SV	1.40	1.40

4.2 Netting area

Netting area of trawls is shown in Table 6. It is calculated from formula (3.5).

Table 6: Twine surface area of trawl nets.

Netting section name	Total	Prototype (m^2)	New Single trawl (m^2)	New Pair trawl (m^2)
Upper Wing tips	2(4)	3.77	0.83	1.15
Lower wing tips	2		1.19	1.65
Upper main Wings	2	3.21	3.09	6.24
Square	1	2.49	2.45	5.35
Upper force bellies	1(2)	9.79	3.98	7.44
Lower force bellies	1		5.71	10.69
Upper and lower second bellies	2	13.98	5.96	15.54
Upper and lower third bellies	2	12.73	4.54	14.45
Upper and lower fourth bellies	2	9.22	3.54	12.59
Upper and lower fifth bellies	2	4.08	10.88	20.48
Codend	2	7.42	18.43	18.43
Lower main wings	2	4.90	6.20	13.33
Total		71.59	66.82	127.34

(4) Upper and lower wing tip are similar in prototype trawl
(2) Upper and lower force bellies are similar in prototype trawl

4.3 Weight of nettings

The results of netting weight, calculated from formula (3.6) are shown in Table 7.

Table 7: Netting weight of trawls.

Netting section name	Total	Prototype (g)	New Single trawl (g)	New Pair trawl (g)
Upper Wing tips	2(4)	2537	706	974
Lower wing tips	2		2628	5303
Upper main Wings	2	2164	2087	4549
Square	1	1676	3381	6329
Upper force bellies	1(2)	6598	7291	13649
Lower force bellies	1		5292	13789
Upper and lower second bellies	2	9674	4368	13890
Upper and lower third bellies	2	9357	3669	13032
Upper and lower fourth bellies	2	7172	26010	48960
Upper and lower fifth bellies	2	3499	44064	44064
Codend	2	10969	7919	17019
Lower main wings	2	3299	1522	2100
Total		56945	108937	183658

(4). Upper and lower wing tip are similar in prototype trawl
(2). Upper and lower force bellies are similar in prototype trawl

4.4 Detail statistics of trawls

The details of the trawls are shown in Table 8.

Table 8: Details of trawls

Netting section name	Unit	Prototype	New Single trawl	New Pair trawl
Length of headline	m	33.2	27.4	43.3
Material and diameter of headline	mm	PE 26	PP 26	PP28
Footrope	m	38.0	32.6	52.4
Material and diameter of footrope	mm	PE 30	Comb 26	Comb26
Number of floats	∅=200 mm	27	33	40
Chain groundrope weight (sinkers)	Kg	100	122	148
Size of door	m2	2.2m*1.2m	2.4m*1.3m	
Weight of door	Kg	190	231	
Door material		Wood and steel	Wood and steel	
Netting material	Rtex PE	1265 and 686	1050 and 3400	1050 and 3400
Fishing area		South-East VN	South-East VN	South-East VN
Towing speed	Knot	2.5	3.5	3.5
Trawling depth	m	30 - 80	100 - 300	100 – 300
Catching species		Cuttlefish and demersal species	Cuttlefish and demersal species	Cuttlefish and demersal species

4.5 Drawing

4.5.1 Single trawl prototype

A drawing of the single trawl prototype is shown in Figure 12.

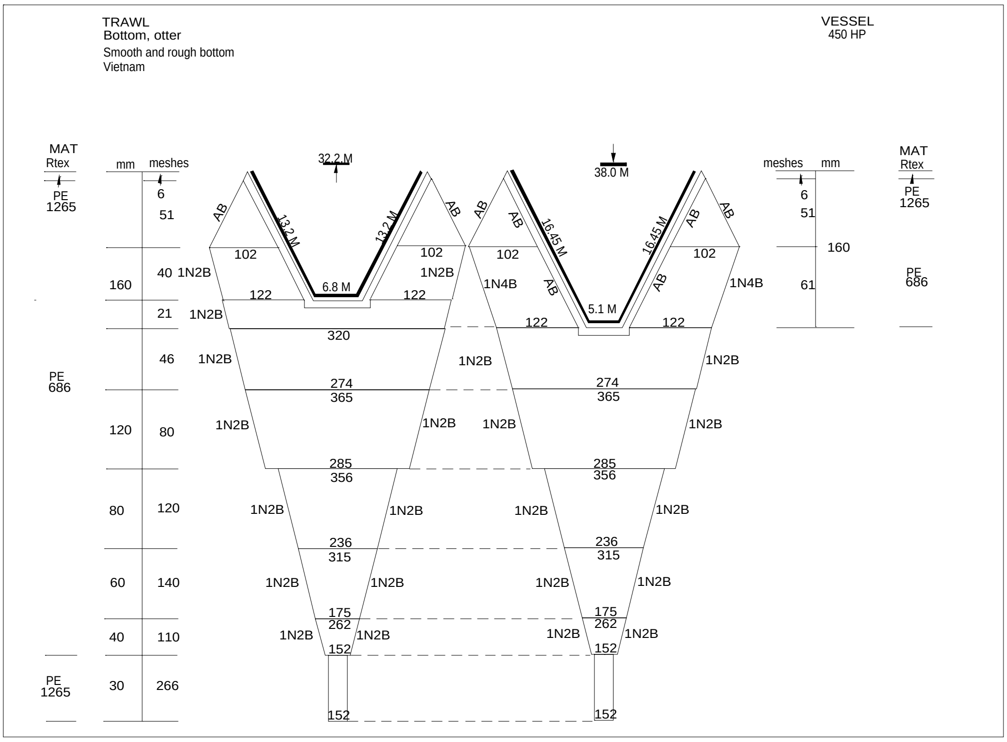


Figure 12: Vietnamese prototype trawl.

4.5.2 New design single trawl

A drawing of the new design for the single trawl is shown in Figure 13.

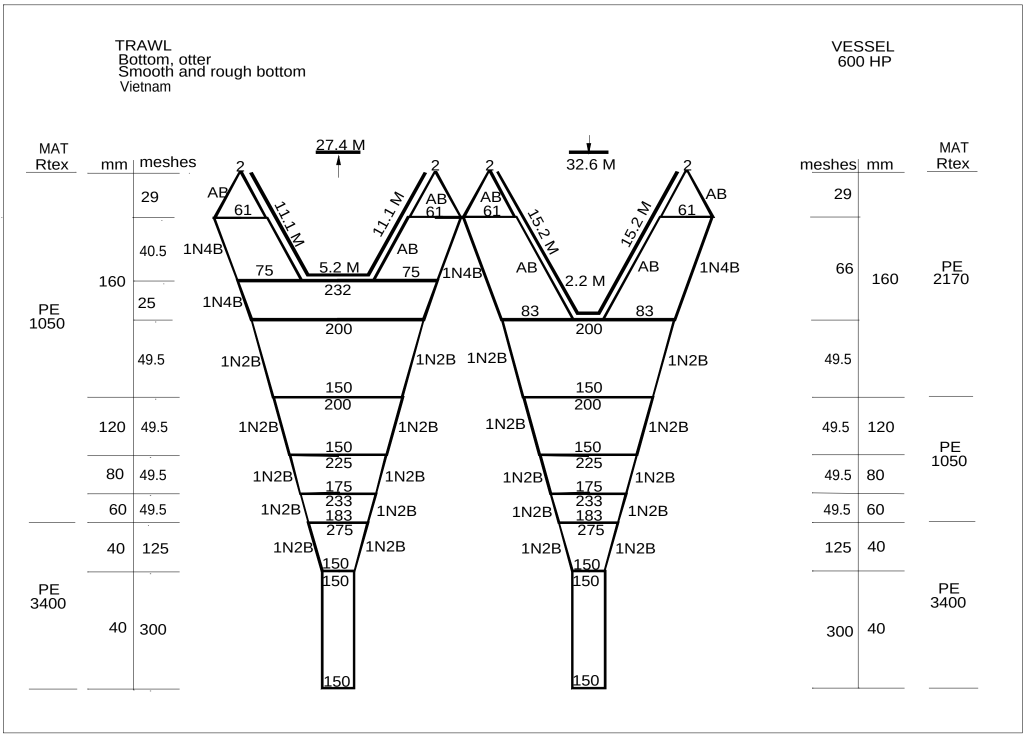


Figure 13: New design of single trawl.

4.5.3 New design pair trawl

A drawing of the new design for the pair trawl is shown in Figure14.

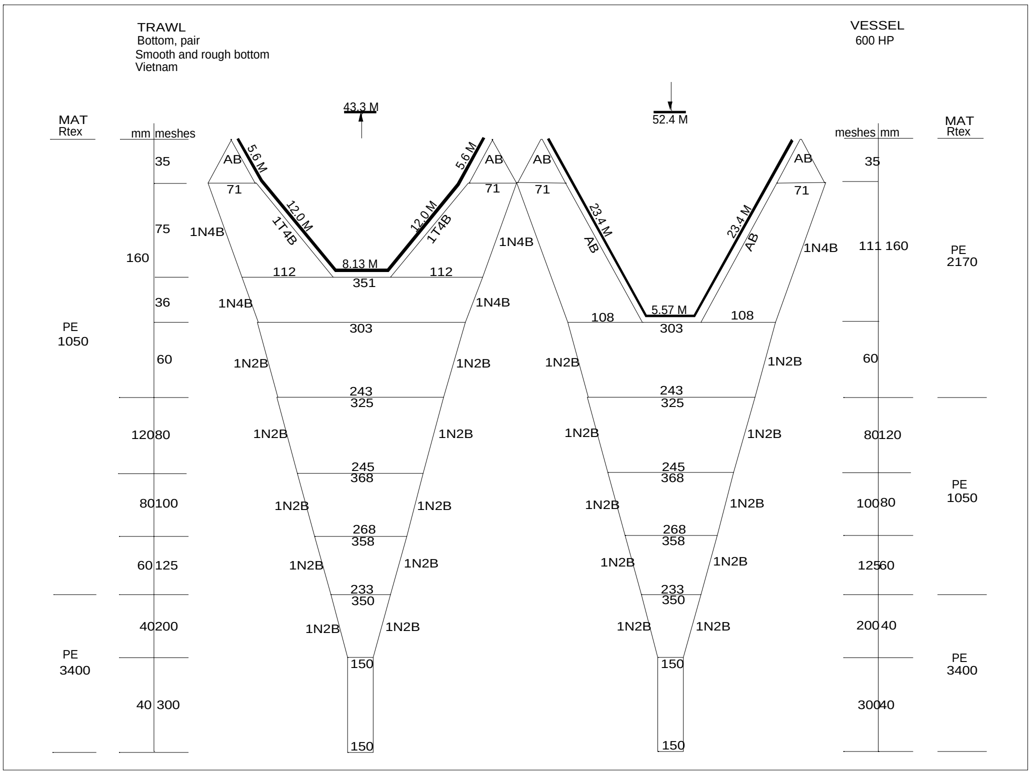


Figure 14: New design of pair trawl.

5. DISCUSSION

In fishing gear design one has to consider three aspects: the aimed pray, the physical conditions on the grounds, and the vessel to be used. According to Prado (1990), the proper trawl netting area for a 450 hp vessel should range between 30 and 50 m^2 (Figure 12). The Vietnamese are using around 70 m^2 on 450 hp vessels, claiming that bigger nets catch more. Larger netting area means higher towing resistance and less speed for a given engine. Therefore, it must be taken into account what speed is optimal for catching the aimed species, before the netting area is related to the vessel hp. Another important consideration is the twine diameter required for the physical operation of the gear and the bottom conditions. Relatively large net (in relation to hp) require thinner twine, which can lead to more time spent repairing, etc.

Bottom trawls are one of the principal fishing gears in Vietnam. They can be used for both inshore and offshore fishing. Hence Vietnam fishing authorities have paid special attention to further development of the trawling technique. The Vietnam fishermen have been using a simple method to make their own trawl nets. It is based on their experience and knowledge passed on by their fathers. The netting is hand knitted, and design skills are limited. The Vietnamese trawl fishery is monotonous, few designs used, and standard towing speed is used for all species.

The application of fishing gear science in the Vietnamese fishery is unsatisfactory at present. This study concerns the necessity of meeting real requirement of Vietnamese fisheries to design trawls for deep-sea fishing. This is an attempt to introduce an alternative method of designing a trawl to Vietnamese fishermen and to provide existing technical know-how in that field. For this purpose, the characteristics of a new trawl, the behaviour of the fish, the technical characteristics of the trawler, the fishing ground and bottom conditions are also documented.

The project also shows that Vietnam fishermen must change the manufacturing of the trawl net for offshore fishing, by using stock net and cutting it correctly and then joining them together. This method can give a good trawl at lower cost and it also does not take long to make.

Fishing conditions in South-east Vietnam allow fishermen use both single and pair trawls. It depends on their experience and the equipment they own. But it also depends on the available labour and Vietnamese social-economic policies, and which method gives a better profit.

6. CONCLUSION

Because there is no exact design theory, the designer has to be creative in each particular case, and the effectiveness of fishing gear depends heavily on the knowledge acquired from fishermen and on information on bottom conditions and fish behaviour. In the circumstances, the result of study was limited to the initial design calculations. This study could be used as platform for further work in this direction, leading to rational decisions regarding future development of suitable trawls for the planned Vietnamese deep-sea fishery. In addition it is evident that deep-sea fishing requires more sophisticated vessels with modern gear handling equipment, navigation and fish finding instruments.

ACKNOWLEDGEMENTS

I would like to thank the Programme Director of the United Nations University-Fisheries Training Programme, Dr. Tumi Tomasson, and the Deputy Programme Director, Mr. Thor Asgeirsson, for giving me an opportunity to be in this programme and also for their guidance and assistance. My thanks are due to the Director and staff of the Marine Research Institute for giving me a good learning environment and necessary facilities during my stay in Iceland. Also I extend my gratitude to all lecturers who enlightened me a great deal in diverse subjects.

I am also thankful to my supervisors Mr. Jon Thordarson, Dean of Faculty of Fisheries Studies, University of Akureyri; Mr. Larus Palmason, the Fishing Gear Technology Department of the Sudurnes Comprehensive College; Mr. Einar Hreinsson. Technical Manager of Netagerd Vestfjarda hf.; Mr. Olgeir Haraldsson, Netagerd Fridriks Vilhjalmssonar hf. for giving me valuable assistance to make my study a success.

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Appendix 1

Twine suface area of prototype trawl

Netting section name	Total	M1	M2	(M1+M2)/2	N	m (mm)	D (mm)	A (m^2)
Upper and lower Wing tips	4	1	102	51.5	51	160	1.12	3.77
Upper main Wings	2	102	122	112	40	160	1.12	3.21
Square	1	341	320	330.5	21	160	1.12	2.49
Upper and lower force bellies	2	320	274	297	46	160	1.12	9.79
Upper and lower second bellies	2	365	285	325	80	120	1.12	13.98
Upper and lower third bellies	2	356	236	296	120	80	1.12	12.73
Upper and lower fourth bellies	2	315	175	245	140	60	1.12	9.22
Upper and lower fifth bellies	2	262	152	207	110	40	1.12	4.08
Codend	2	152	152	152	266	30	1.53	7.42
Lower main wings	2	102	122	112	61	160	1.12	4.90
Total								71.59

Twine surface area of new single trawl

Netting section name	Total	M1	M2	(M1+M2)/2	N	m (mm)	D (mm)	A (m^2)
Upper Wing tips	2	2	61	31.5	29	160	1.42	0.83
Upper main Wings	2	61	75	68	50	160	1.42	3.09
Square	1	232	200	216	25	160	1.42	2.45
Upper force bellies	1	200	150	175	50	160	1.42	3.98
Lower force bellies	1	200	150	175	50	160	2.04	5.71
Upper and lower second bellies	2	200	150	175	50	120	1.42	5.96
Upper and lower third bellies	2	225	175	200	50	80	1.42	4.54
Upper and lower fourth bellies	2	233	183	208	50	60	1.42	3.54
Upper and lower fifth bellies	2	275	150	212.5	125	40	2.56	10.88
Codend	2	150	150	150	300	40	2.56	18.43
lower main wings	2	61	83	72	66	160	2.04	6.20
Lower wing tips	2	2	61	31.5	29	160	2.04	1.19
Total								66.82

Twine surface area of new pair trawl

Netting section name	Total	M1	M2	(M1+M2)/2	N	m (mm)	D (mm)	A (m^2)
Upper Wing tips	2	1	71	36	35	160	1.42	1.15
Lower wing tips	2	1	71	36	35	160	2.04	1.65
Upper main Wings	2	71	112	91.5	75	160	1.42	6.24
Square	1	351	303	327	36	160	1.42	5.35
Upper force bellies	1	303	243	273	60	160	1.42	7.44
Lower force bellies	1	303	243	273	60	160	2.04	10.69
Upper and lower second bellies	2	325	245	285	80	120	1.42	15.54
Upper and lower third bellies	2	368	268	318	100	80	1.42	14.45
Upper and lower fourth bellies	2	358	233	295.5	125	60	1.42	12.59
Upper and lower fifth bellies	2	350	150	250	200	40	2.56	20.48
Codend	2	150	150	150	300	40	2.56	18.43
Lower main wings	2	71	113	92	111	160	2.04	13.33
Total								127.34

Appendix 2

Netting weight of prototype trawl

Netting section name	Total	(M1+M2)/2	N	m (mm)	Rows	L (M)	Rtex	K	W (g)
Upper and lower Wing tips	4	51.5	51	160	102	8.24	686	1.1	2537
Upper main Wings	2	112	40	160	80	17.92	686	1.1	2164
Square	1	330.5	21	160	42	52.88	686	1.1	1676
Upper and lower force bellies	2	297	46	160	92	47.52	686	1.1	6598
Upper and lower second bellies	2	325	80	120	160	39	686	1.13	9674
Upper and lower third bellies	2	296	120	80	240	23.68	686	1.2	9357
Upper and lower fourth bellies	2	245	140	60	280	14.7	686	1.27	7172
Upper and lower fifth bellies	2	207	110	40	220	8.28	686	1.4	3499
Codend	2	152	266	30	532	4.56	1256	1.8	10969
lower main wings	2	112	61	160	122	17.92	686	1.1	3299
Total									56945

Netting weight of new single trawl

Netting section name	Total	(M1+M2)/2	N	m (mm)	Rows	L (M)	Rtex	K	W (g)
Upper Wing tips	2	31.5	29	160	58	5.04	1050	1.15	706
Upper main Wings	2	68	50	160	100	10.88	1050	1.15	2628
Square	1	216	25	160	50	34.56	1050	1.15	2087
Upper force bellies	1	175	50	160	100	28	1050	1.15	3381
Lower force bellies	1	175	50	160	100	28	2170	1.2	7291
Upper and lower second bellies	2	175	50	120	100	21	1050	1.2	5292
Upper and lower third bellies	2	200	50	80	100	16	1050	1.3	4368
Upper and lower fourth bellies	2	208	50	60	100	12.48	1050	1.4	3669
Upper and lower fifth bellies	2	212.5	125	40	250	8.5	3400	1.8	26010
Codend	2	150	300	40	600	6	3400	1.8	44064
lower main wings	2	72	66	160	132	11.52	2170	1.2	7919
Lower wing tips	2	31.5	29	160	58	5.04	2170	1.2	1522
Total									108937

Netting weight of new pair trawl

Netting section name	Total	(M1+M2)/2	N	m (mm)	Rows	L (M)	Rtex	K	W (g)
Upper Wing tips	2	36	35	160	70	5.76	1050	1.15	974
Upper main Wings	2	91.5	75	160	150	14.64	1050	1.15	5303
Square	1	327	36	160	72	52.32	1050	1.15	4549
Upper force bellies	1	273	60	160	120	43.68	1050	1.15	6329
Lower force bellies	1	273	60	160	120	43.68	2170	1.2	13649
Upper and lower second bellies	2	285	80	120	160	34.2	1050	1.2	13789
Upper and lower third bellies	2	318	100	80	200	25.44	1050	1.3	13890
Upper and lower fourth bellies	2	295.5	125	60	250	17.73	1050	1.4	13032
Upper and lower fifth bellies	2	250	200	40	400	10	3400	1.8	48960
Codend	2	150	300	40	600	6	3400	1.8	44064
lower main wings	2	92	111	160	222	14.72	2170	1.2	17019
Lower wing tips	2	36	35	160	70	5.76	2170	1.2	2100
Total									183658

Appendix 3

Prototype trawl

Netting section name	Total	m (mm)	D (mm)	A (m^2)	m*A	Mean m (mm)	D*A	Mean D (mm)
Upper and lower Wing tips	4	160	1.12	3.77	603.2		4.22	
Upper main Wings	2	160	1.12	3.21	513.6		3.60	
Square	1	160	1.12	2.49	398.4		2.79	
Upper and lower force bellies	2	160	1.12	9.79	1566.4		10.96	
Upper and lower second bellies	2	120	1.12	13.98	1677.6		15.66	
Upper and lower third bellies	2	80	1.12	12.73	1018.4		14.26	
Upper and lower fourth bellies	2	60	1.12	9.22	553.2		10.33	
Upper and lower fifth bellies	2	40	1.12	4.08	163.2		4.57	
Codend	2	30	1.53	3.70	111		5.66	
lower main wings	2	160	1.12	4.90	784		5.49	
Total				67.87	7389	109	77.53	1.14

New single trawl

Netting section name	Total	m (mm)	D (mm)	A (m^2)	m*A	Mean m (mm)	D*A	Mean D (mm)
Upper and lower Wing tips	2	160	1.42	0.83	132.8		1.18	
Upper main Wings	2	160	1.42	3.09	494.4		4.39	
Square	1	160	1.42	2.45	392		3.48	
Upper force bellies	1	160	1.42	3.98	636.8		5.65	
Lower force bellies	1	160	2.04	5.71	913.6		11.65	
Upper and lower second bellies	2	120	1.42	5.96	715.2		8.46	
Upper and lower third bellies	2	80	1.42	4.54	363.2		6.45	
Upper and lower fourth bellies	2	60	1.42	3.54	212.4		5.03	
Upper and lower fifth bellies	2	40	2.56	10.88	435.2		27.85	
Codend	2	40	2.56	9.22	368.8		23.60	
lower main wings	2	160	2.04	6.20	992		12.65	
Lower wing tips	2	160	2.04	1.19	190.4		2.43	
Total				57.59	5846.8	101.52	112.81	1.96

New pair trawl

Netting section name	Total	m (mm)	D (mm)	A (m^2)	m*A	Mean m (mm)	D*A	Mean D (mm)
Upper Wing tips	2	160	1.42	1.15	184		1.63	
Upper main Wings	2	160	1.42	1.65	264		2.34	
Square	1	160	1.42	6.24	998.4		8.86	
Upper force bellies	1	160	1.42	5.35	856		7.60	
Lower force bellies	1	160	2.04	7.44	1190.4		15.18	
Upper and lower second bellies	2	120	1.42	10.69	1282.8		15.18	
Upper and lower third bellies	2	80	1.42	15.54	1243.2		22.07	
Upper and lower fourth bellies	2	60	1.42	14.45	867		20.52	
Upper and lower fifth bellies	2	40	2.56	12.59	503.6		32.23	
Codend	2	40	2.56	20.48	819.2		52.43	
lower main wings	2	160	2.04	18.43	2948.8		37.60	
Lower wing tips	2	160	2.04	13.33	2132.8		27.19	
Total				127.34	13290.2	104.37	242.83	1.91