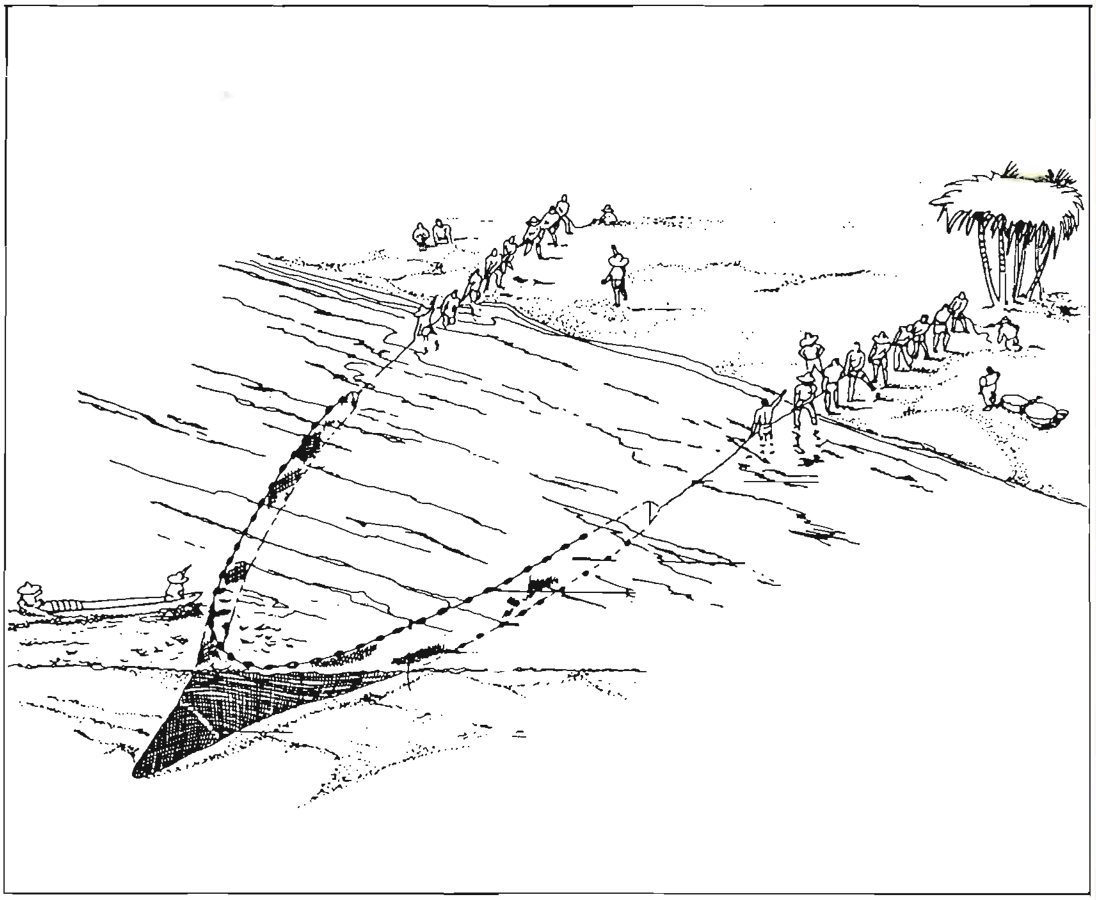
Tropical shrimp fisheries

Types of fishing gear used and their selectivity



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Tropical shrimp fisheries

Types of fishing gear used and their selectivity

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PREPARATION OF THIS DOCUMENT

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The selection of shrimp fishing gear has become a major factor in planning the exploitation of tropical shrimp. As this document will be used by persons responsible for fisheries planning, it is included in the series of technical documents which refers to the PRACTICES OF FISHERIES MANAGEMENT.

Distribution:

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ABSTRACT

Shrimp fisheries in tropical countries concern chiefly the members of the penaeid family. The industrial and small-scale sectors both fish the same resources at the same time using different fishing methods. They often compete with each other or with other fishery sectors.

This paper deals with the methods of production of these two sectors and includes descriptions of the main fishing methods used. Descriptions of the most popular trawls used in industrial fisheries and the selective devices which have recently been developed in an attempt to reduce fish catches are included. With regard to small-scale fisheries, where there is a wide variety of fishing methods, only the most commonly used methods are described.

As accurate information as possible is then given on selectivity and efficiency of different fishing gears.

The recommendations refer to fishing technology; certain lines of research are suggested and the need to develop an extension service is stressed.

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1. INTRODUCTION

Tropical shrimp fisheries have developed significantly over the last 30 years.

In most tropical regions, two different types of fisheries exploit the same resource: industrial and small-scale fisheries. Using very different fishing methods, they each claim a part of the resource. This gives rise to the problem of resource distribution and is a source of contention between the two sectors.

Such radical decisions as the banning of industrial trawlers in Malaysia, for example, (Panayotou, 1982; IPFC, 1982) show that there is an urgent need to find solutions with regard to management so that these two sectors can co-exist peacefully.

The introduction of fishing gear regulations and/or the development of selective shrimp fishing gear are only two of a number of available solutions to management.

Research into selective fishing gear has shown that, for species of temperate and cold zones, it was possible to develop gear that is just as efficient as the traditional type used by professionals. In June 1973, an expert consultation on selective shrimp trawls organized by FAO was followed by the publication of a document (FAO, 1973), which is still the authority on selective fishing gear but in which the question of tropical shrimp was not dealt with. Since 1973, models of selective gear for penaeid shrimps have been developed and tested and some are currently in use by commercial fishermen. These are described and illustrated.

In the present context of tropical shrimp fisheries, it was necessary to review the different production methods in use, their efficiency and selectivity. This document is not meant to provide an exhaustive list of fishing gear used in tropical shrimp fisheries, but it does deal with the main fishing methods. In accordance with the international convention, mesh measurements correspond to stretched mesh length (cf. Figure 39).

2. BACKGROUND

The species of shrimp fished in inter-tropical and sub-tropical regions belong chiefly to the penaeid family. The greater part of the catches brought ashore are made up of some 40 species (Garcia and LeReste, 1981).

Beginning in the fifties with the rapid expansion of fisheries in the Gulf of Mexico, industrial shrimp fishing later extended to Central America and then to northern South America (Jones and Dragovich, 1973; Venaille, 1979). In the sixties, fisheries expansion reached other tropical regions (e.g. Africa; Troadec, 1968). Spurred on by a high demand for shrimp, the small-scale shrimp fishery started to develop in the seventies. Shrimp fishing covers a large geographical area and the resource is subjected to high fishing pressure. For the developing countries, shrimp production is extremely important as a source of foreign currency, since the greater part of the landings is intended for export to the industrialized countries (Japan, USA and western Europe).

Biologically speaking, most penaeid shrimp have an amphibiotic life cycle which includes a juvenile phase in a coastal or estuarine zone, often marked by the influence of freshwater or brackish inland waters, and an adult phase in a deeper, marine zone. Sometimes, however, particularly in the Arabian Gulf fishery where brackish waters are rare, the nurseries are in marine waters, but nevertheless close to the coasts (FAO/UNDP 1982).

These two areas are fished in the following way:

- Industrial fishing is carried out in the sea, often offshore, and exploits chiefly the adult stock.

- Small-scale fishing is restricted to the coastal area, lagoons, estuaries and a coastal strip, the size of which depends on the region. Most often, it is the juvenile shrimp that is fished, but sometimes the adult as well.

Another feature of shrimp fisheries in tropical regions is that the life cycle of the shrimp is short and its availability to the fishery is estimated at a little over one year (Garcia and LeReste, 1981).

The problem facing shrimp fisheries involves the co-existence, on the one hand, between small-scale and industrial fisheries, which exploit the same resource at different stages of development and, on the other, between shrimp fisheries and other types of fisheries, especially fin-fish fisheries, since shrimp trawlers also catch a large quantity of small fish, some of which are juveniles.

2.1 Industrial fisheries

The industrial fishing fleet consists of boats capable of fishing offshore. The criteria used to define this sector are often boat size and horse-power. The figures most usually given are approximately 25 m overall length and 150 HP (in India 45-80 HP for small trawlers) (Garcia and LeReste, 1981). This definition is not satisfactory, however, considering that the small-scale sector has developed in certain regions with fishing units driven by engines exceeding 150 HP. For this reason, a definition including additional criteria such as type of organization and capital investment may be preferable (Bazigos, 1982). The industrial fleet is operated by companies, sometimes under contract to packing plants or to marketing and/or export companies.

Following the great strides made in the fifties, including a rapid expansion to new fisheries, industrial fisheries are now well established. Today, fishing of all stocks is approaching or has reached the maximum level, and it seems unlikely that new significant stocks will be discovered in the coming years (Rothschild and Gulland, 1982).

Industrial shrimp fisheries generally use bottom trawls. This is therefore a mono-specific, or at best a pauci-specific fishery, for several species of shrimp are often fished on the same fishing grounds. However, many species of demersal or semi-demersal fish are caught at the same time as shrimp. These are the by-catches, a varying proportion of which, depending on the region, are returned to the sea. The size of the by-catch may be considerable; it varies from one fishing ground to another - see Table 1 (Rothschild and Gulland, 1982).

With the increasing extension of national sovereignties through extended fisheries jurisdictions in the seventies, regulations were introduced with the aim of controlling the exploitation of the resources. For industrial shrimp fisheries, these regulations took the form of catch quotas and/or the demarcation of zones closed off to trawling and/or closed seasons (Cody, Rice and Bryan, 1978; IPFC, 1982; FAO/UNDP, 1982; FAO/UNDP 1982a; WECAFC, 1983), and/or the definition of the marketable size of landed shrimp (Cody, Rice and Bryan, 1978) and/or regulations concerning fishing gear, including netting and the number and size of trawls per vessel (see Section 5.2.2).

2.2 Small-scale fisheries

Conventional fishing methods are used in small-scale fisheries. The boats used are often small and are not mechanized; however, fishing may also be done by fishermen on foot or using fixed installations. The characteristic feature of this type of fishery is the low cost of production, but profits are also low since the stocks exploited are juveniles. The catches are smaller than those obtained offshore and the price lower ($1 against $4.5 per kilo in the Ivory Coast) (Griffin and Grant, 1982).

The fishery is often pluri-specific, as it is also directed to fish, or alternated by season.

Fishing methods vary widely. This depends not only on the zones exploited (coastal waters, coastal zones, estuaries, lagoons), but also on the wide variety of gear used, which is sometimes very primitive. It is not always selective, particularly as regards fin-fish juveniles.

Finally, fish are not fished solely for human consumption; some fisheries are directed to the cultured shrimp (post-larvae for fattening or breeding), particularly in Southeast Asia (Indonesia, Malaysia, Sri Lanka) (Angeles, 1978; Motoh, 1980, 1981), with trawls, trammel nets and traps (Pajot, 1989) towards the production of live bait for line or recreational fishing (in the USA: Tabb and Kenny, 1969; in India: Suseelan, 1975; in Sri Lanka (Pajot, 1989) and for fishing post-larvae on foot or employing stownets or pushnets (Indonesia, India, Bangladesh and Sri Lanka) (Pajot, 1989).

Table 1

Rough estimates of by-catch and discards in Penaeid shrimp fisheries[a]
(Reproduced from Interim Report of the Workshop on the Scientific Basis for the Management of Penaeid Shrimp by Rothschild and Gulland, 1982)

Country	Shrimp catches 1979 (tons)	Ratio shrimp: By-catch	By-catch (tons)	Discards (%)	Quantity discarded	Date of observations and references
China (d)	7,500	8:1-4:1	35-60,000	nil	nil	October 1962
Indonesia (Arafura Sea)	6,000	variable 3:1-1:1 (inshore)	ca.100,000	high	ca.100,000	1970s (Unar)
Indonesia (other areas)	157,000	20:1-30:1 (offshore)	115,000	< 2	< 2,000	
Australia	21,000	variable (b)	unknown	high	unknown	
Thailand	100,000	variable	750,000 (c)	small	small	
India	183,000	∿ 20:1	300-500,000	< 2	5,000	1970s (George)
Kuwait	1,600	10:1	15,800	95	15,000	1978 (Mattews)
Senegal	5,500	variable	80,000	ca.50	40,000	1970s (Garcia)
USA (Atlantic coast)	105,000	2.8:1	37,000	ca.100	37,000	1970s (Pelligran)
USA (Gulf coast)		9:1	600,000	ca.100	600,000	1970s (Pelligren)
Mexico (Pacific coast)	46,000	10:1-15:1	400-500,000	<95	400,000	1970s & 1980s (Ehrhardt)
Brazil & Guyana	21,500	10:1	215,000	high	200,000	1981 (Villegas & Dragovich)
***Total :**	658,600		2,700,000		1,399,000	

***Total:**
Total landings for all shrimp: 1,526,000
Total landings (excl. pandalids, sergestids, etc.): 1,230,000

(a) All these figures are rough estimates; these results have been included to give an idea of quantities and geographic variations.

(b) The by-catches are small for gregarious shrimp fisheries, but may be high for other fisheries.

(c) Considered equal to the volume of "non-specified marine fish", reported by Thailand in the Fishery Statistics Yearbook.

(d) Yellow Sea fishery.

3. METHODS OF PRODUCTION

3.1 Industrial fisheries

The industrial fleet consists of boats at least 15 m long, powered by engines of at least 150 HP. The boats usually have freezing or refrigerated holds (ice). The duration of the fishing trip varies depending on the size and means of storage used. For units using ice to preserve the catch, it is approximately five days, while for freezer vessels, it is often more than two weeks.

3.1.1 Vessels

Main characteristics: The most popular shrimp vessel is the double-rigged Gulf of Mexico trawler. It is between 22 and 23 m long, between 90 and 100 GRT, and is fitted with a 250 to 350 HP engine.

When fisheries were expanding, vessel size tended to increase. This was especially the case in the Arabian Gulf, where the length of the vessels reached 55 m (Bazigos, 1982). It appears that later preference was given to medium-size vessels of between 22 and 24 m.

In the fifties, the standard shrimp vessel in the Gulf of Mexico was a wooden boat 13.7 m (45 ft) long. In 1981, it was a vessel 22.9 m (75 ft) long. Between 1962 and 1967, tonnage increased, on average by 2.6 tons/year (Blomo, 1981).

On the Pacific coast of Mexico, trawlers are double-rigged, between 20 and 30 m long, and average engine power is 350 HP (Edwards, 1978).

On the northeastern coast of South America, boats are between 21.3 m (71 ft) and 22.9 m (75 ft) long. Foreign fleets (American and Japanese) are similar in size and design, with freezing capacity and are double-rigged. While size and power have increased slightly since 1973, when the boats were 22.25 m (73 ft) long and powered by 348 HP engines (Jones and Dragovich, 1973), characteristics have not changed (Jones and Dragovich, 1977; Dragovich, 1981; Dragovich and Coleman, 1983; Kasahara, 1983).

In West Africa, single-rigged trawlers (single trawl) (Troadec, 1968) began to be replaced in 1969 by double-rigged trawlers, powered by 150 to 250 HP engines. The popularity of the Gulf of Mexico shrimp trawler thus spread (Garcia, 1978; Garcia and LeReste, 1981).

During the period of fishery expansion in the Arabian Gulf, vessel size increased with the introduction of 55 m long shrimp trawlers (Bazigos, 1982). The boats currently in use in Kuwait have a tonnage of between 70 and 150 GRT, and are powered by 150 to 390 HP engines (Van Zalinge, El Musa and El Ghaffar, 1978).

In the Indian Ocean in 1978 the fleet consisted of Florida-type shrimp trawlers. The size of the trawlers and the storage methods used (freezing or icing - whether factory vessels or not) vary (Marcille, 1978). In India the present trend is to build small vessels in the 15-16 m range propulsed with 150-200 hp engines and with an endurance at sea of two to three weeks (Pajor, 1989).

Trawlers used in the Far East also measure between 21 and 30 m. The most popular type is 23 m long (FAO/SIDA, 1983), driven by engines of between 90 and 300 HP, equipped with freezing facilities (George, Suseelan and Balan, 1981).

In Australia, double-rigged shrimp trawlers began to replace single-rigged vessels in 1966. In recent years, tonnage and engine horse-power has tended to increase, but the wooden construction continues to be very popular, although the large and more recently constructed vessels tend to be built of steel. In 1981, average size was approximately 23 m (21 m at the waterline); since 1972, the policy has been to subsidize vessel construction and this has tended to favour an increase in the average size of the boats (Bowen and Hancock, 1982; Hughes, 1982; Glaister and McDonald, 1983).

From this brief review of the situation, it can be seen that shrimp trawlers used in industrial fisheries are relatively homogenous, both in size and design. The American Gulf of Mexico model has been widely adopted in all regions. These boats are between 20 and 30 m long; the most popular length is 23 m; engine horse-power has increased considerably from 150-200 HP (Kristjonsson, 1969) to 300-400 HP.

Deck equipment (Figure 1): The double-rigged shrimp trawler is fitted with a pair of outriggers, between 7 and 12 m long, fixed to the mast at a height varying between 1.5 and 2 m above the deck. In fishing position, the outriggers slope from horizontal at an angle of between 20^{o} and 30^{o}.

The deck is fitted with a twin drum winch for the two main trawls and a winch for a small try-net which is towed between the two main trawls. In more modern vessels there are independent winches for each rig.

There has been little change in the shape of the boats, except for the Australian trawlers which are more sturdily built, have more space inside and a larger free-board, as well as a raised bridge (Hughes, 1982).

Bridge equipment: Electronic equipment consists of an automatic pilot, a radio-navigation system, sometimes a satellite navigation system and a radar system.

The echosounder is most often used to detect trawlable grounds. It is difficult to detect demersal shrimp by echosounding. Kristjonsson (1969) reports that it will be possible to detect concentrations of shrimp with systems using higher frequencies (200 kHz instead of 30-60 kHz). This system of detection is used in Japan for pelagic trawl fishing of Penaeus orientalis and also for temperate and cold water species of the genus Pandalus. The latter behave rather like the pelagic species and are easier to detect than most Penaidae which are demersal species and sometimes bury themselves in the soft bottom. The fact that they are found close to the bottom, in addition to their size, makes them difficult to detect with traditional detection methods. Concentrations of shrimp are most often detected with try-nets. The gregarious species such as Penaeus merguiensis in Australia are detected from the air, since movement of the shrimp across the soft bottom causes turbid areas or 'boils' to appear, which are easily detected (Hughes, 1982).

Radio systems of communication are widely used. In certain regions, this allows the search for fishing grounds to be carried out by groups of vessels or fleets, instead of by individual boats (Marcille, 1978).

Catch Handling and Stowage: The choice of storage method on shrimp trawlers is conditioned by the type of vessel and the length of trip.

Storage in ice, in bulk or in boxes, is the traditional method used in the Gulf of Mexico. This is satisfactory where the length of trip does not exceed a maximum of two weeks. In this fishery the shrimp are most often beheaded by the crew before stowage. If this is carefully done and the shrimp well washed, storage life can be extended.

Icing is also the method of choice on small artisanal vessels due to constraints on space. With the demand for improved quality from the marine capture fishery to compete with the products of aquaculture, even vessels making short (over night) trips now find it necessary to ice their catches. On small vessels this is often accomplished in insulated boxes.

The alternative for larger vessels, when working in isolated areas or for extended periods, is freezing at sea. In recent years handling, processing and freezing technology has been markedly improved and has probably reached its peak with the sophisticated Australian 20-30 m vessels which are capable of autonomous operation for up to three months.

There are two main options available after chilling and intermediate storage on deck in chilled or refrigerated sea water tanks until processing can be undertaken. These are: bulk immersion freezing in net bags, either in brine or propylene glycol, alternatively plate or blast freezing on finished products wrapped in polyethylene and packed in cardboard cartons. In both cases storage is in well insulated refrigerated holds at or below $-20^{o}C$.

In the case of immersion frozen products, they are raw material for further processing and must be thawed and refrozen in land-based factories. As shrimp is robust, and stands up well to frozen storage, this double freezing does not result in significant quality loss as long as it is done properly.

When crew size and catch rate are not limitations, final products can be produced and stored at sea. However, accurate grading of sea-frozen retail packs is often difficult due to limited quantities to select from.

Regardless of the method of stowage, it is essential than an effective washer be installed on deck, and that it is used as instructed, to remove mud and debris, either before or after sorting. Careful handing to avoid damage to the shrimp is also vital as broken shell and crushed meat reduce the value of the catch.

It should be noted that, due to space limitations and the high cost of freezing, freezer vessels generally land a much smaller proportion of the by-catch than ice boats.

3.1.2 Fishing gear

Industrial fisheries use mainly bottom otter trawls. Selective bottom trawls are discussed separately.

Bottom otter trawls

While the bottom trawl is the most commonly used gear, rigging varies widely depending on the number of trawls towed.

Rigging: One boat sterntrawling is the fishing method most used in the countries of the Bay of Bengal region (Thailand, Malaysia, India, Sri Lanka) for inshore shrimp fisheries. Simple rigging with a single trawl was formerly used in West Africa (Troadec, 1968). However, since 1969 it has been replaced by double rigging using several trawls.

The Florida-type double rigging, introduced to American fisheries in the Gulf of Mexico around 1950, has spread to all tropical fisheries and is currently the type most commonly used. Two trawls are towed at the ends of two outriggers, one at port and one at starboard, and each net is towed by a single warp terminating in a crow-foot (Figure 2). The outrigger booms are at an angle of between 20- and 30^{0} from horizontal. As far as efficiency is concerned, this type of rigging, using two small trawls, results in a catch rate 15 to 30 percent higher than with single rigging using a single trawl with a similar drag. The reason for this is that: (i) two small trawls have a wider horizontal opening than one single trawl with the same drag; (ii) two small trawls work better on the bottom than one large trawl. Moreover, it is easier to manoeuvre two small trawls. When handling, the otter boards and the nets remain suspended at the ends of the outriggers and the codends alone are taken aboard. This operation may be done by three or four men depending on the size of the trawls. Furthermore, it is often easier to repair two small trawls than a single large one, since the nets are smaller. Higher yields and therefore more income with less work for the crew has resulted in this rigging being quickly adopted, first of all in the Gulf of Mexico and then in other tropical fisheries throughout the world. Usually, a small try-net is towed from the stern of the boat at the same time as the other trawls. It is used to give a quick estimate of the quantity of shrimp available both before and during the tow.

In the early seventies, quadruple rigs were developed in the Gulf of Mexico (Ross, 1975; Hamrick, 1976; Reisinger, 1979). This system involves towing one pair of trawls at the end of each outrigger (Figure 3).

Each pair of trawls uses only two otter boards. A sledge is fixed at the inner point where the two trawls meet. With this rigging, catch yields are increased by 20 to 30 percent and fuel consumption is considerably reduced since, for the same sweep width, the drag and the power needed is less (Ross, 1975; Captiva, 1980). This type of rigging is also becoming increasingly popular for other fisheries, particularly in Australia where triple rigging has been developed to allow smaller and less powerful boats to tow three trawls without an outrigger: two small ones on each side and a large one in the middle, separated by two sledges (Hughes, 1982).

Irrespective of whether or not a double-rig is used, the most commonly used trawls are still the four types, presented by Kristjonsson some 15 years ago (1969), with the following characteristics:

(i) **The flat Gulf of Mexico trawl** (Figure 4): This is a four-panel trawl. The upper and lower panels consist of three sections - one large main section and two small triangular sections called "jibs". The central belly section is shorter than the top section by some 10 mesh lengths, allowing a slight overlap (between 0.6 and 1.0 m, depending on the size of the trawls). The sections forming the belly triangles are larger than the top section so as to form the two sides of the trawl. The height of the sides decreases from front to back. Other trawl types are obtained by altering the cut of the sides, which may also be rectangular. Depending on the cut, the triangles may also be made and assembled differently; the mesh direction may be changed to obtain a better distribution of tension (in the direction of the course of the yarn). It is essential that these sections be strengthened for they are particularly vulnerable. Flat trawls modified in this way have become "Western jib trawls". Some Japanese trawls, of the same type, are fitted with wings.

The advantage of the flat trawl was that it provided maximum horizontal opening for a small vertical opening. The "Western jib" has a larger horizontal opening .

(ii) **The semi-balloon trawl** (Figure 5) is a four-panel trawl. It consists of several strips of netting and are more elongated. It differs from the flat trawl in the way the corners or quarter pieces are made. Also, the quarter piece almost reaches the centre of the headline and footrope, which strengthens this part of the trawl by distributing the tension along the entire width of the trawl. This does not occur in the flat trawl. There is more overlap or cover in the semi-balloon trawl than in the flat trawl, but their horizontal and vertical openings are the same.

(iii) **The balloon trawl** (Figure 6) is a two-panel trawl. The two sections are attached to each other directly by means of lateral seams. To compensate for the fact that there are no side panels, the square and belly sections, in particular, are larger than in other trawls.

(iv) **The super X-3 trawl** (Figure 7) is the most recent. It is similar to the "Western jib" trawl, but the quarter piece is an elongated four-sided section which increases the wing angle and, consequently, the horizontal opening.

These trawls are the most popular trawls in the Gulf of Mexico, but other trawls have developed from these basic models. They are all utilized in single or multiple rigs.

Another generation of trawls emerged as the twin trawls developed towards a single trawl with a centre bridle similar to that fitted to the point where the two twin trawls meet. These are:

(a) **The tongue trawl** (Figure 8), is a recent design (late seventies). It is similar to the flat trawl, but has a tongue which protrudes at the mouth of the trawl. It uses the same type of rigging as that used for twin trawls, but the centre sledge is replaced by a float at the headline and a sinker at the footrope. This trawl appears to combine the pair of trawls used in quadruple rigs. It, however, has the advantage of being easier to handle than the twin-trawl design, particularly when hauling, when only one codend instead of two is taken aboard. Shrimp catches are 19 percent higher than with a similar size flat trawl with a double rig. It is also likely that fuel consumption is reduced with this arrangement; tension is more evenly distributed on the net and the panels, thanks to the central bridle with which smaller otter boards may be used (7 ft instead of 9 ft for a 72-ft trawl) (Burnett, 1979).

This trawl seems to have been easily and quickly accepted by the Gulf of Mexico fleet (Watson and Seidel, 1980) and is also in widespread use in Australia (Hughes, 1982).

(b) **The three-wing trawl** (Figure 9). This trawl has recently been developed in the USA and was described by Reisinger (1979). It is derived from the tongue trawl (by modifying a part of the net). There is no protrusion from the belly area; the net has two lateral wings and a third, forward wing on the trawl square. As regards the rigging, only the float connected to the central bridle and to the headline remain; the weight and the split central bridle have been removed. This change solves the major problem affecting the tongue trawl; the entangling of the float-weight system with the chains of the otter board brackets when the trawl was at the end of the outrigger. The semi-balloon trawl (the Cobra trawl) and the balloon trawl (Mongoose trawl) have been adapted in a similar way (Reisinger, 1979).

There is a wide range of trawls available and their performances differ considerably. Choice of trawl will depend on the vertical distribution of the species fished and the type of bottom. The table on the following page gives figures for horizontal and vertical openings; the opening ratio is the relationship between horizontal opening and the length of the headline.

The netting is made of synthetic fibres, usually nylon, because it is strong and inexpensive. As soon as it is mounted, the net is impregnated with a coating with a tar base to reduce wear caused by abrasion. The black colour of the coating has the added advantage of protecting the nets from damage by the sun's rays. This operation is repeated at regular intervals. Polyethylene is another useful material because it is light, resists abrasion and is relatively inexpensive. It is also used to make the protective chafer which is arranged around the codend.

Table 2

Opening figures for eight types of trawl, obtained by direct measurements taken by divers (from Captiva, 1980)

Measurements were taken on trawls with 18.3 m (60 ft) headlines, 2.4 m x 1.0 m (8 ft x 40 in) boards, 91.4 m (50 ftm) bridles for 137.2 m (75 ftm) warps at a depth of 9.1 m (5 ftm) and a speed of 2.5 to 3 knots

Type of trawl	Horizontal opening metres(ft)	Vertical opening metres(ft)	Opening ratio (%)
Flat trawl	12.2 (40)	1.2 (4)	66
Semi-balloon trawl	12.2 (40)	1.2 (4)	66
"Western jib" trawl	12.3 (40½)	1.1 (3½)	68
Balloon trawl	12.8 (42)	1.1 (3½)	70
Super X-3 trawl	13.4 (44)	1.1 (3½)	73
Super X-3 tongue trawl	15.5 (51)	0.6 (2)	85
Cobra trawl	14.9 (49)	0.8 (2½)	82
Mongoose trawl	14.6 (48)	1.2 (4)	80

Mesh size (stretched mesh) rarely exceeds 50 mm. It is often between 30 and 50 mm. In French Guyana it is 45 mm (Lemoine, Vendeville and Ladurelle, 1982); in West Africa it is between 40 and 50 mm (Garcia, 1978; Lhomme, 1978); in the Arabian Gulf, the codend is made of a double strip of netting of the same mesh size, which is 30-40 mm (Van Zalinge, El Musa and El Ghaffar, 1979) to 43-45 mm (El Musa, 1982); in Madagascar, regulation mesh size is 35 mm; in practice it is between 33 and 40 mm (Marcille, 1978). In India mesh size is reported to be between 30 and 35 mm (Kurian and Sebastian, 1982); in Australia it is 44 mm (Hughes, 1982).

Very often a chafer is used to protect the codend from wear. It is made of 110 mm mesh polyethylene netting. 45 cm long double polyethylene strands are attached to each knot. The local name for this type of chafer is the "Hula skirt" (Kristjonsson, 1969). This device is widely used in all fisheries conducted on hard bottom and also prevents damage by sharks.

Trawl accessories :

Otter boards are made of long planks of wood arranged with spaces between them, reinforced with metal strips. They are fitted with a wide steel base. Their shape has not changed since the first double-rigs were introduced. They vary in size between 1.8 m x 0.8 m and 4.4 m x 1.4 m, depending on the vessel's horse-power and the size of the trawls (Hughes, 1982). In French Guyana, boards used for flat trawls with a headline of 15 m measured 2.40 x 0.9 m for a unit weight of 250 kg (Venaille, 1979). The choice of board will depend on the opening required. The larger the boards the larger the horizontal opening and the smaller the vertical opening; but the type of trawl used also has an effect. Difference is greatest between traditional trawls and the "tongue" or "three-wing" trawls. For the same opening ratio, a traditional trawl will require larger boards

Sledges: The two inner wings of the twin trawls are connected by a steel sledge. For triple rigging, where only one pair of boards and no outrigger are used, the centre trawl, which is usually the largest, is connected to the two lateral trawls by means of two sledges, sometimes fitted with a vertical fin which serves to stabilize the fishing gear (Hughes, 1982).

The Tickler chain is today used in all tropical regions. This device is described by Kristjonsson (1969). The chain is shorter than the footrope. It is attached to the otter boards or to the wing tips. As it drags on the bottom in front of the trawl opening, it dislodges the shrimp buried in the sludge or sand.

A similar device with the chain connected to the footrope by short chains arranged at regular intervals is also used, and is known as the "Texas drop-down" (Kristjonsson, 1969).

Very few **floats** are used - on average three per trawl. When species that do not live close to the bottom, such as the Gulf of Mexico white shrimp (Penaeus setiferus), are being fished, the trawls are often fitted with a greater number of floats to increase the vertical opening. Watson et al. (in preparation) have shown that, for maximum flotation, for trawls with a 21.3 m (70 ft) headline, the flat trawl had a wider opening (3.4 m) than the semi-balloon trawl (2.1 m). However, the three-wing "Mongoose" trawl had the same vertical opening as the flat trawl (3.0 m), but a higher opening ratio (69 percent against 53 percent for the flat trawl). Generally speaking, the "tongue" and "three-wing" trawls seem to offer the best compromise where a larger vertical opening and smaller horizontal opening are required.

Rollers are used to work on soft muddy bottoms. These are often floats that have been perforated to make them less buoyant, or discs.

A small **try-net** is towed either on its own or together with the main trawls and serves to locate good shrimp zones and to determine the duration of the tows.

Finally, when fishing in heavy seas, **outrigger stabilizers** are suspended at the end of the outrigger and operate at a depth of between 4.5 and 6 m. These devices resemble paravanes (Hughes, 1982).

Now that quadruple rigs have been adopted by most tropical shrimp fisheries, twin trawls are becoming very popular; it looks as though the "tongue" and "three-wing" type trawls will quickly gain popularity, as they are easier to use. The present trend is towards an increase of the total net sweep width, while horse-power remains the same. Australia is a good example of this recent trend. With the acceptance of quadruple rigs and twin or triple trawls for vessels without outriggers, the total length of the headline has increased by 37 percent on average, while horse-power has remained the same (Hughes, 1982). In early 1981, 90 percent of the vessels belonging to the New South Wales king prawn fishery were using triple trawls (Glaister and McDonald, 1983). At present, regulations in some regions are attempting to limit vessel as well as trawl size (14.62 m headline) and to restrict the number of trawls per vessel to two (Bowen and Hancock, 1982). It is likely that these types of regulations will favour the development of the "tongue" and "three-wing" trawls which have a better opening ratio.

Selective bottom trawls

Shrimp catches also include large quantities of fish and other organisms (see Table 1). A large part of this by-catch is discarded in the sea. This is often done, however, under conditions which give the fish no chance of survival. These by-catches also entail more work (sorting) and when the by-catch is sizeable, the quality of the shrimp may be affected (broken) as a result of their being crushed either in the trawl or in sorting operations.

It was considered useful to develop trawl designs that would utilize the different reactions of shrimp and unwanted species to the trawl, to achieve a separation of the catch of shrimp and unwanted species.

Over the past 20 years or so, extensive research with selective trawls has been carried out on shrimp in temperate and cold zones. This research gave rise to the selective trawl, with which interesting results were obtained in separating shrimp and fish. The shrimp on which these experiments were carried out were: grey shrimp (Crangon crangon), pink shrimp (Leander serratus) in Europe (Kurc, Faure and Laurent, 1965; Brabant, 1974) and the pandalids on the northwestern Pacific coast of the USA (Hight, Ellis and Lusz, 1969). An FAO report (1973) summarizes the results of these experiments.

In an attempt to reduce the by-catch, research into selective fishing gear for penaeid shrimp was undertaken in 1975 by the NMFS (National Marine Fisheries Service) in Pascagoula, Florida for the fisheries of the southeastern USA (Watson and McVea, 1977). In the late seventies, the need to protect a certain number of marine turtle species prompted the same American scientists to find ways of preventing the turtles from being caught. A system developed for turtles was shown to be capable of reducing the catches of unwanted species.

(a) The American selective net trawl

Operating principle: The selective trawl, introduced by Watson and McVea (1977) is a four-panel semi-balloon trawl with a 12 m (40 ft) headline, fitted with a V-shaped selective panel which slopes upwards into the back of the net dividing the trawl into two compartments (Figure 10).

When the shrimp is dislodged by the tickler chain or footrope, first it jumps and then it becomes passive. It is thus carried along by the water flow and crosses the selective panel. It is trapped in the second compartment which is where the codend is located.

The fish is active, both as the trawl approaches and inside it. As it follows the selective panel, it is channelled upwards to the point of the "V" and from there it passes out of the net through a trash chute.

The NMFS also tested two other methods for discarding fish. The first was an escape device located in the codend, consisting of a sleeve held by a brass netting frame 19 cm in diameter. The purpose of this system is to allow the small fish that have crossed the selective panel to escape. The second consisted of large mesh netting (11.4 cm) in the square of the trawl at the front of the selective panel to allow the fish to escape upwards.

Trial results and acceptance by the fishermen: Six types of selective panels were tested - three square-mesh nets and three others with a diamond mesh.

The trials were conducted on a double-rigged trawler and the selective trawl was compared to a control trawl of the same type and size, fitted to the other side of the vessel.

Selectivity is measured by: (i) the percentage of shrimp lost and (ii) the percentage of by-catch retained. They should both be as small as possible. Another factor is the average size of the shrimp. They should not be much smaller than those in the control trawl, since the price paid per unit weight of large-size shrimps is higher.

The best results were obtained with 7.6 cm (3 in) square-mesh netting and 6.4 cm ($2\frac{1}{2}$ in) diamond-mesh netting. The former retained only 45 percent of the by-catch and shrimp loss was only 6 percent; the average size of the shrimp fell from 148 mm to 144 mm. The latter mesh size retained 63 percent of the by-catch and a shrimp loss of 14 percent was recorded; the average size of the shrimp caught remained almost unchanged (125 mm as against 126 mm).

The use of additional escape devices showed that the trash chute in the codend was responsible for a significant loss of shrimp. On the other hand, the largest mesh netting situated at the front of the trawl gave interesting results and considerable improvement in separating the fish without causing too great a loss of shrimp.

Later trials showed that the efficiency of the selectivity device was only valid under certain conditions. At depths of between 20 and 60 m, the by-catch retention rate was between 60 and 80 percent, but shrimp loss varied considerably. The loss was an average of 10 percent at some depths, but between 50 and 60 percent under the most unfavourable conditions. Highest shrimp losses occur especially when the trawl encounters large concentrations of fish (between 250 and 500 kg/hr) or when the fish are small; they may become entangled in the selective panel and block it. Large concentrations of fish may also prevent the shrimp from entering the selective net and carry them towards the discharge hole. The trawl may also be less effective during long tows, when the selective panel may become clogged (Seidel and Watson, 1978).

In any case, this type of trawl is not effective in coastal fishing grounds where there is a high concentration of fish and where there are small fish and catfish (Ariidae) which could easily become entangled in the selective net.

A number of drawbacks discourage the fishermen from accepting this trawl: (i) shrimp catch losses are high as compared to the traditional trawl - at best, they run to 10 percent; (ii) it cannot be used in certain conditions and cannot operate on all the fishing grounds usually used in commercial fishing, particularly coastal fishing grounds, for shrimp loss increases from 10 percent to between 50 and 60 percent; (iii) it is difficult to repair trawls with the selective panel.

(b) The marine turtle selective trawl

The decline in stocks of certain marine turtle species in the Gulf of Mexico led to the introduction of protection measures (Ogren, Watson and Wickmam, 1977), which included the closing off of areas to trawl fishing and the development of special gear to discard the marine turtles caught in shrimp fisheries. While shrimp trawlers of the Gulf sometimes catch turtles, these catches are not the sole reason for the decline in stocks but the turtles caught damage the trawl and therefore the development of an excluder device was, from this point of view, extremely valuable.

Description and operating principle of two types of trawl

Two types of gear were developed and tested by the NMFS and are based on very different principles:

The selective net trawl: The trawl opening is closed by a very wide-meshed net which prevents large-size organisms, such as turtles, from entering, but allows shrimp to enter. The selective net is made of 210/180 double nylon netting - mesh size 66 cm (26 in) placed between the headline and the footrope (Figure 11a). The netting thus forces the turtles to escape under the trawl.

The first trawls allowed between 40 and 100 percent of the turtles to escape, but caused an average shrimp loss of 27 percent (Seidel, 1979). Following further trials, the turtle escape rate reached 79 percent and shrimp loss was between 15 and 30 percent (Watson and Siedel, 1980).

The turtle excluder device: With this second type of fishing gear, designed to reduce marine turtle catches, the aim is not to prevent them from entering the trawl opening but to discard them before they enter the codend.

The device consists of a rigid frame, 1.2 x 0.9 x 0.9 m, made of 9.5 mm diameter galvanized tubing, inside of which a series of bars are arranged at an angle of 45^{o}, spaced at 15.2 cm. A door measuring 0.9 m^2 was first placed at the bottom of this open cage, but later the whole device was reversed and the door now faces the upper trawl panel (Figure 11b). The device, fitted with floats, is placed between the forepart of the trawl and the codend and the door opens towards the rear of the trawl.

Turtles and other large species are stopped by the bars and guided towards the discharge door which opens under the weight of the animals and the pressure of the water flow, and allows them to escape under the trawl in the first type, and then above it in the second. Small-size organisms, however, such as shrimps, pass through the bars and collect in the codend.

First results shows that, with this device, the escape rate for marine turtles was 89 percent and shrimp loss a mere 11 percent (Watson and Seidel, 1980).

Later, trials on commercial vessels showed that not only did this system allow marine turtles to escape, but also a part of the by-catch. In an attempt to improve this function of the device, the screen was turned over to allow escape upwards and fitted with a pair of sledges. The net funnel accelerates the water flow, improves the sorting of catches and makes it easier for fish to escape (Watson, 1983; Mc'Neill, 1983).

Results and acceptance by fishermen: The selective net trawl was not given a favourable reception by fishermen. On the one hand, it produced significant shrimp losses and, on the other, its utilization was made difficult by the fact that it was necessary to adjust the net to the trawl being used. Other adjustments were also necessary. The shrimp fished in the Gulf of Mexico are not consistent in their behaviour. The white shrimp (Penaues setiferus), in particular, is distributed vertically, while the brown (Penaeus aztecus) and the pink (Penaeus duorarum) are confined to waters closer to the bottom. The trawl rigging must therefore be adjusted (weights, floats) depending on the type of shrimp fished. The use of the selective net situated at the entrance of the trawl would require other, rather tedious, if not impossible, adjustments. It must be pointed out that white shrimp losses were higher during the trials (Seidel, 1979); this was perhaps due to a too-small vertical opening; but the losses were also high for the two other species, probably due to the fact that the trawl, affected by the currents caused by the selective net, tended to leave the bottom.

The turtle excluder device (TED): Although fishermen were rather reluctant to accept this device at first, pointing out the risks involved in handling a metal device on deck, after the first trials, which were conclusive, they readily accepted it. Trials by professionals of the more recent versions tended to show that (a) the addition of a selectivity device did not affect shrimp yields and could even improve them (Mc'Neill, 1983) - the NMFS puts the gain at 7.5 percent (Watson, 1983; NMFS, 1983); and (b) it reduced the by-catch. The rate of reduction of the by-catch, however, varies with fishing time; during the day, it may reach 53 percent; at night, it does not exceed 10 percent. Recent trials, however, with the addition of a deflector at the screen outlet (cf. Section 4.3.2), point to a significant improvement in performance for night fishing. Finally, the trials also showed that the turtle excluder was probably an energy-saving device, but the results have not yet been confirmed (Watson, 1983; Mc'Neill, 1983). As it developed, the device changed considerably. This justifies its change of name - the Turtle Excluder Device has now become the Trawling Efficiency Device.

Other fishing gear

In industrial fisheries, other gear has been or is still being used; it is used chiefly by the Penaeid fisheries in Japan. Kristjonsson (1969) gives a detailed description in his technical report on shrimp research and catches.

The pelagic trawl - has been used to fish Penaeus orientalis. At certain periods of the year, this shrimp had a pelagic behaviour and was frequently found in waters 10 m above the bottom and sometimes more (30-40 m). Vessels of between 350 and 500 total gross tonnage used midwater otter trawls with curved otter boards. The shrimp schools were detected by means of high frequency echo-sounders (100-200 kHz). This fishery has been abandoned since 1984 because these shrimp became scarce in the midwater layers of the Yellow Sea, perhaps due to a change in hydro-climatic conditions.

The pair trawl (Figure 12): These trawls do not need otter boards since they are towed by two vessels, which guarantees the wing spread. This fishing method is most often preferred to the bottom otter trawl in shallow fishing grounds (20 m) where turbulence caused by the propellers of a single boat could cause the shrimp to flee out of the path of the trawl. Pair trawling does not have this drawback for the boats pass on either side of the path of the trawl and further ahead of the trawl than in the case of a single trawler because they use longer warps. The noise of the pair trawlers may even scare the fish and shrimp into the path of the net (Nedelec et al., 1979).

The Danish seine - is used by boats of between 30 to 65 total gross tonnage, and especially for penaeid fishing. This gear is however used in small-scale penaeid fishing.

The purse seine - designed and rigged for small pelagics, these nets are occasionally used with 12-15 m boats during some periods of the year off the west coast of India and east coast of Sumatra for catching the white shrimp (P. indicus) (Pajot, 1989).

3.2 Small-scale fisheries

The wide range of fishing methods used by this sector includes fishing from motorized or non-motorized vessels, as well as from fixed points in coastal or inland waters and by fishermen on foot in the inter-tidal zone or shallow waters.

3.2.1 Boats

The boats are usually small, not exceeding 15 m in length. When they are motorized, low horse-power petrol and diesel engines - less than 150 HP - are used. Finally, the design is traditional, although technical programmes are trying to develop more suitable motorized models, e.g. plastic or aluminium hulls as in the Philippines (Smith, Puzon and Vidal-Libunao, 1980).

In North America, recreational fisheries exploit the pink shrimp (Penaeus duorarum) in Florida, and the brown and white shrimp (Penaeus aztecus and Penaeus setiferus) with small, 6 to 15 m trawlers, most often made of wood or plastic (Garcia and LeReste, 1981). The product of this fishery is used as live bait.

In Central America, the lagoon fishery on the Pacific coast of Mexico is carried out from fixed points, but pirogues and small boats are sometimes used (Edwards, 1978; Urroz Escobar, 1978).

On the northeastern coast of South America there are fixed-point lagoon fisheries (Boddeke, Dijkema and Siemelink, 1977). In the State of Para in Brazil, "carcos" are the 2 to 3 m paddle-driven pirogues. In French Guyana, net catches are collected by fishermen wading in the inter-tidal zone at low tide or from 7 to 10 m pirogues. Some 10-18 m stern trawlers have recently been introduced. In Suriname the most popular boat is the dugout, locally called "Karjaal" or "piakka", generally powered by a fuel engine. In Guyana fishing is done from flat-bottomed, 6-9 m wooden boats equipped with 6 to 9 HP engines (Dragovich and Villegas, 1983).

In West Africa dugouts are used (Lozac'Hmeur, 1981) but fishing is also done by fishermen on foot (Garcia, 1977; Garcia and LeReste, 1981).

In the Arabian Gulf, the traditional vessels are dhows which can be very large. Their average length is 16 m (8-23 m), 31 tonnes total gross tonnage (9-97 tons). Since the seventies they have been equipped with diesel engines of 94 HP on average (50-180 HP) (Van Zalinge, El Musa and El Ghaffar, 1979).

Small-scale fisheries in the Far East exploit the coastal waters up to a depth of 40 m. The boats, of which there is a wide variety, are adapted to the conditions prevailing in the sectors exploited. They are most often the traditional type, and for the most part are not motorized (in India, 99 percent) (FAO/SIDA, 1983).

In India, among the most popular types of craft is the "Kattumaram". It consists of three to five wooden logs tied together. The boats vary in size from 4.2 m to 7.6 m (Kurian and Sebastian, 1982). The most popular size is 6.7 m long and 0.9 m wide. Lately, plywood canoes are replacing the stitched plank canoes in Kerala. For shrimp trawling, 8-13 m planked mechanized boats were introduced; about 12,000 of these boats are presently employed in shrimp and fish trawling in inshore zones (Pajot, 1989).

Pirogues hollowed out from tree trunks (the "balams" of Bangladesh, Vanchi, Hodi and Thoni in India) are used to fish in the estuaries or brackish coastal waters. They are between 3.5 m and 14 m long (Kurian and Sebastian, 1982; FAO, 1981).

Pirogues made from wooden planks are slightly larger than those mentioned above, ranging from 6.4 to 14 m. They can take between 4 and 12 persons. These are the "nava" and "kakinda" in India and the "dinghi" and "chandi" in Bangladesh.

The "masula" or "padava" are usually built of mangrove wood. The planks are held together with rope. They are light, have no keel and operate from the beaches. They are between 2.5 and 12 m long and can take a crew of up to 8 to 12 persons (Kurian and Sebastian, 1982).

In Thailand, the plank built small canoe, propulsed with a long tail engine, is the most popular type of craft using mainly trammel nets (Pajot, 1989).

In Sri Lanka, inshore fishing for shrimp is carried out with 8.5 m boats propulsed by 30-35 hp inboard engines using trawls, and 5.5 m boats with outboard engines using trammel nets (Pajot, 1989).

Small-scale trawling with a sailing outrigger canoe "Oru" and motorized 3.5 t boats is carried out in shallow water, less than 10 m, in Sri Lanka.

Engine-powered boats are designed to exploit deeper fishing grounds than those exploited by the boats mentioned above. Some trawl in coastal waters up to a depth of 40 m (Figure 13). They are between 6.6 and 11 m long and are equipped with 10 to 80 HP engines (FAO/SIDA, 1983). Several different types are used; among them "Dan-boats" (6.6 m); "Pablo-boats" (7.4 m); and shrimp trawlers (9.6 m) (George et al., 1981), "Pomfrets" (9.75 m) and "Sorrahs" (11.41 m) (Muthu et al., 1975).

3.2.2 Fishing gear

A wide variety of fishing methods are used in small-scale fisheries. Choice of gear will depend on whether the shrimp are required for human consumption, for the local market or for export, for stocking purposes for aquaculture or as live bait for line or recreational fishing. It will also depend on local conditions.

The main small-scale fishing gears are classified below, in accordance with the system adopted and recommended by FAO (Nedelec, 1982).

Beach seines

Beach seines are used in many tropical countries for penaeid shrimp fisheries: in West Africa (Kristjonnson, 1969); Madagascar (Marcille, 1978); the northeastern coast of South America (Dragovich and Villegas, 1983); Central America (Urroz Escobar, 1978); India (Kurian and Sebastian, 1982); the Philippines (Motoh, 1980); and Bangladesh, Sri Lanka, Thailand and Sumatra, Indonesia (Pajot, 1989).

The fishery is carried out in the shallow waters of the coast and the seine is hauled on to the shore. Beach seines may be subdivided into two categories, depending on whether they are fitted with a bag or not.

(a) Seines without bags

Kurian and Sebastian (1982) describe several types currently in use in India:

- The "Rampan" or "Rampani" is a very large seine made up of between 100 and 600 rectangular strips of netting, each between 2 and 6 m long and 5 and 11 m high. The centre pieces are mounted as for most seines without bags, that is, slightly loose. Mesh size is between 12 and 20 mm; the side sections, however, have a larger mesh of between 30 and 50 mm. Floats are attached to the floatline rope while the footrope is weighted. Between 60 and 80 persons are required for crewing the boats and hauling the net to the beach. The seine is paid out from the boats and hauled onto the shore by two ropes. The shrimp and fish are trapped between the net, the surface, the bed and the shore. When the seines are very large, the catch is collected with the help of a small seine, a "yendi", which consists of between 20 and 30 sections each 4 x 5 m. It is handled by about 12 persons. Harvesting may require several days.

- Seines similar in shape, but smaller in size, are very common in India and Malaysia. The central part of the net is made up of 4 to 6 rectangles each 4 m long by 7 to 10 m high. The wings are made of between 20 and 33 sections tapering from the centre towards the wingtips. A pole 0.55 m long and most often of bamboo, is fixed to each wingtip and to these poles two ropes are attached for hauling the net (Kurian and Sebastian, 1982; Manisseri, 1982).

- Finally, small seines, which can be handled by 2 or 3 persons, consisting of rectangular sections of net. A pole fixed at each end is used to manoeuvre the net. In India, the smallest are between 3.6 and 4.6 m long, mounted on two poles 0.6 to 0.7 m long; the largest measure 18.3 m; mesh size is between 6 and 13 mm. This type of gear is widely used in Central America (Urroz Escobar, 1978) and on the northeastern coast of South America. Drag-nets are used in Guyana to fish for the sea-bob, a species of coastal penaeid, but they also catch juveniles of offshore species (Figure 14a and b) (Ben-Yami, personal communication).

Beach seines were introduced relatively recently in Madagascar. In 1978 the local fishery was using seines 100 m long by 4 m high with a mesh size of 10 to 15 mm (Marcille, 1978).

In Malaysia the dragnet is also used to catch young shrimp for stocking for aquaculture (Figure 14) (Angeles, 1978).

(b) Seines with bags (Figures 15 and 16)

In India "kamba vala" and "karamadi" consist of a funnel-shaped bag provided with two wings. The bottom of the bag is 7.6 m long and 2.7 m wide. Mesh size is smallest at the bag (7.6 mm), increasing to 17 mm at the wings. The wings, between 305 and 610 m in iength, have a mesh size of between 152 and 229 mm in the vicinity of the bag, increasing towards the wingtips where it is between 609 and 914 mm. The tow lines are 215 m long, sometimes longer. The net is paid out from a boat, then hauled from the shore.

The "perivalai" is similar to the "kamba vala" and "karamadi" but the bottom of the bag can be removed, which makes it easier to collect the catch. The headline is provided with floats at regular intervals and the hauling lines are very long - they may reach 1 km. Each tow line is hauled by about 12 persons. This type of seine may be used at an even greater distance from the shore than those mentioned above (Kurian and Sebastian, 1982).

(c) Boat seines (Figure 17)

Boat seines are used in India and Sumatra, Indonesia (Pajot, 1989).

Trawls

(a) Beam trawls (Figure 18)

This type consists of a funnel-shaped net and bag, the 2 to 4 m opening of which is held horizontally and vertically open by a wooden pole or metal frame fitted with two lateral metal sledges. This gear is very popular in South-East Asia fisheries (IPFC, 1982). In the live-bait shrimp fisheries in Florida in the USA and the Gulf of Mexico, the traditional beam trawl has developed into a more sophisticated gear where the sledges have been replaced by rollers. This is the frame and roller trawl (Figure 19) (Tabb and Kenny, 1969).

(b) Otter trawls (Figure 20)

In India, small shrimp trawlers use four-panel bottom trawls, in a single rig, 7 to 27 m wide between the wings (Kurian and Sebastian, 1982). For a 9.45 m boat, the headline measures 15.25 m (George, Suseelan and Balan, 1981). Wooden otter boards 0.61 x 1.07 m, weighing between 32 and 36 kg, are used for a trawl with a 12 to 14 m headline towed by a 30 HP boat (Kristjonsson, 1969).

In Madagascar, boats measuring between 7 and 8 m, powered by a 25 HP inboard engine tow trawls with an 8.50 m footrope (Marcille, 1978).

In the Arabian Gulf, dhows use nylon trawls with a footrope of 20 m average length (12-25 m). As is the case in industrial fisheries in the same region, the codend consists of a double netting of 31 mm (27-33 mm) mesh size to which a large mesh polyethylene chafer is fitted (Van Zalinge, El Musa and El Ghaffar, 1979; El Musa, 1982).

In South-East Asia, combined shrimp-fish trawls (Figure 21) have been introduced. Compared to the shrimp bottom trawl, these have longer wings and a 3 m instead of a 1 m vertical opening; the net is made of polyethylene and the mesh size is larger (60 mm for the wings and 40 mm for the codend) (Pajot et el., 1982; Pajot, 1989).

In Thailand, on some small trawlers, a pair of booms are added to increase the horizontal spreading of the otter boards.

In Sri Lanka, when trawling with outrigger canoes, no otter boards are used: a concrete slab tied to each side tip of the trawl is used to keep the trawl on the bottom. For horizontal spreading, the towing ropes are tied to the main hull of the outrigger canoe and to the extreme end of the outrigger. When used with motorized boats, the towing ropes are tied to two bamboo poles extending about 5 - 6 m on each side of the boat (the same rigging is used in Brazil).

(c) Pair trawls (Figure 22)

This method is used by small trawlers in India at depths of less than 20 m (Kristjonsson, 1969; Kurian and Sebastian, 1982). Two 11 m boats tow a trawl 15 m wide between the wings (George, Suseelan and Balan, 1981).

Lift nets

Lift net fishing is carried out from a fixed point or from a small craft (raft), usually in inland waters or estuaries, where currents are not strong.

In India, the "cheena vala" or Chinese net is a sort of dipnet used from a fixed point in estuaries or lagoons. The net is a square, measuring 10 m per side; a wooden lifting pole and no more than 2 to 4 persons are needed to manipulate it. Fishing is done at night and a lamp is placed above the net to attract the shrimp (Kurian and Sebastian, 1982). This method is also very popular in the Philippines (Motoh, 1980) (Figure 23).

Lift net fishing is also carried out in Thailand, Malaysia, Indonesia and Myanmar, either from small craft or from a platform on stilts erected in shallow protected inshore waters (Figure 24).

Falling gear (Figure 25)

Cast nets: These may be used only from small craft or when fishing is done on foot, in lagoons or close to the shore; this is the case in India (Suseelan, 1975; Suseelan and Kathirvel, 1982) and in all countries of the Bay of Bengal except for the Maldives, and also in Central America (Urroz Escobar, 1978) and on the northeastern coast of South America, in Brazil (Dragovich and Villegas, 1983). Cast nets are also used as additional gear to harvest catches held by barriers, i.e., in the lagoons on the Pacific coast of Mexico (Edwards, 1978).

Other falling gear: Other traditional types of gear are used in very shallow waters by fishermen fishing on foot. The "Ottal" in India is a roughly cone-shaped basket, open at both ends. The openings are 45 cm in diameter on the lower side and 15 cm on the upper. The ottal is placed on the bottom where it traps shrimp which are then collected by hand through the upper opening (Kurian and Sebastian, 1982).

Gillnets

In Japan, the Japanese shrimp, Penaeus japonicus, is fished in bays or shallow waters with nets. These are 7 m long and 2 m deep. The lower 40 cm of the net is folded over to form a bag in which shrimp are trapped before becoming enmeshed in the net (Kristjonsson, 1969). The "Kanthavala" is a drifting gillnet used in India for fishing large shrimp, such as Metapenaeus affinis, Penaeus indicus and Penaeus merguiensis; it consists of 16 to 25 sections, 3-5 m long and 2-3 m high, with a mesh size of 50-60 mm (Kurian and Sebastian, 1982). Gillnets were once used in the Arabian Gulf from dhows but they have slowly been replaced by bottom trawls (Bazigos, 1982). Shrimp drifting gillnets are also used in Casamance in Senegal (Figure 26) (Lozac'Hmeur, 1981).

However, with the introduction of trammel nets in all the countries of the Bay of Bengal (except for the Maldives), in Indonesia, Thailand and Malaysia single-wall drifting gillnets are less and less used and have been replaced by more efficient trammel nets which are today a very important fishing gear for the capture of shrimp by the small-scale fishing sector (Figure 27).

Traps

(a) Uncovered traps

In India, nets 12-13 m long and 1.5-2.5 m high of 10-20 mm mesh, are fixed on poles in the intertidal zone (Figure 28). The shape of these traps vary; they may be L-shaped, with one of the branches of the L tied to the shore; or they may consist of two parts - one straight, used to block and guide the shrimp and fish to the other part, which is curved or spiral in shape and used to trap the catch (Kurian and Sebastian, 1982). In some cases, a line of traps may be set so as to form a barrier through which nothing can pass. Such traps are also widely used in Thailand, Sumatra, Indonesia and Sri Lanka.

(b) Traps and pots

Traps and pots are not used on their own. In penaeid fisheries they are usually used in combination with lattice screens to form traps (see para. (d)). This type of arrangement was described by Kristjonsson (1969) for Benin; it is also used in India (Kurian and Sebastian, 1982).

(c) Stow nets

This type of trap, many variations of which exist, is very popular in tropical countries.

Stow nets on stakes (Figure 30): An example of this type of net is given by Garcia (1977). It is the net used by Ebrie lagoon fishermen in the Ivory Coast.

The net looks like a bag with a rectangular opening 3.5 m wide by 1.5 m high, held by two stakes. It protrudes 20 cm above the surface of the water. Average mesh size is 20 mm, decreasing gradually from the opening towards the bottom of the bag. The nets are often placed in groups, against the current, i.e. in the channels linking the lagoons to the sea (Garcia and LeReste, 1981), and can form an effective barrier.

These nets can be very large in India (Kurian and Sebastian, 1982) and Malaysia (Smith, Puzon and Vidal-Libunao, 1980). The "dol" is a good example, measuring between 12 and 200 m from the opening to the codend, and with an opening 5 to 90 m in circumference; mesh size is between 40 and 120 mm at the opening, decreasing to 10 mm in the codend.

In the state of Para in Brazil, the "Puca de Arrasto" is a similar type of net; the rectangular opening is 1.5 x 1.0 m, mesh size is between 10 and 20 mm (Dragovich and Villegas, 1983).

Stow nets operated from a boat: In Senegal, two stow nets are fixed to each side of a dugout anchored in the current (Figure 29) (Lozac'Hmeur, 1981).

Other fixed nets: There are also bag-shaped nets that are completely immersed from boats; the opening is maintained by means of floats or a wooden frame. The bag, which is attached to a buoy, is hauled from the boat at regular intervals (Kurian and Sebastian, 1982).

Mesh size in stow nets is usually small; 5 to 10 mm in the codend.

(d) Miscellaneous barriers and traps

Barriers are formed by a series of partitions made of very thin laths or wire netting, held in place with stakes.

Chinese barriers consist of a part which acts as a screen and guides the fish or shrimp towards one or several catch chambers made of screens or netting. Crosnier (1965) describes the system used in Madagascar. The trap consists of a catch chamber from which run two screens forming a V with an 80- opening. The screens which are 150 to 300 m long and 1.0 to 1.50 m high are made of strips of bamboo stakes (Figure 31). The average spacing between stakes is 7.5 mm (LeReste, 1971).

In Indonesia, Malaysia and Sri Lanka, Chinese barriers or other similar devices are used to catch young shrimp for aquaculture breeding stocks. There are various types in use. They always include a catch chamber - fixed; the catches are later collected with a scoop net, or removeable where they can either be hauled by a winch or carried ashore for the catch to be sorted. This fishery is carried out at night sometimes with the use of a light (Motoh, 1980) (Figure 32).

Traps can block off the whole width of a branch of a river or channel linking lagoons to each other or to the sea.

In the Philippines, these traps are made of two partitions made of wooden screens opening into a catch chamber (Figure 33) (Motoh, 1980; Angeles, 1978).

In the lagoons on the Pacific coast of Mexico, small-scale fisheries using barriers (tapos) were modernized as a cooperative effort. This fishery was described by Edwards (1978). The traps block off the canals linking the lagoons to each other and retain the juveniles during the ebb stream when they are migrating from the lagoon to the sea. They consist of one or several catch chambers. The more traditional types are fitted with partitions made of wooden laths and branches. The more recent are made of galvanized steel netting; the partitions are held by solid poles, most often of cement. Two grooves are made in the poles, into which two wire netting screens of 10 mm mesh size are inserted. These new "tapos" have certain advantages over the old system: (i) maintenance is easier and does not damage the catch; the wire netting screens can be taken out to remove the leaves and branches clogging them and for repainting; one of the netting screens always remains in place so that the barrier remains in operation; (ii) this system is stronger; (iii) it is also more selective because it is easier to maintain and therefore mesh selectivity is always operating; the wire netting can retain shrimp juveniles and let post-larvae pass in the other direction (sea-lagoon). These systems are, however, much more costly than the former systems but are feasibile through cooperative fishery organizations.

Miscellaneous gear

(a) Pushnet fishery

Shrimp are caught with pushnets of different sizes and shapes in the inter-tidal zone. Two types are very popular in India and Malaysia; they are also extensively used in Sri Lanka, Thailand, Indonesia and Bangladesh. The scissors pushnet, in which the net opening is held by two bamboo stakes 2.50 m long forming a cross. The net is 5.50 m long. The other type consists of a bamboo stake curved into a U shape, used as a frame for the net opening. The mesh size of these nets is 10 mm in the opening area, decreasing as we move towards the codend, where it is 7 mm (Kurian and Sebastian, 1982). Pushnets used in Senegal are called "Killis". The opening is held in position by two stakes (Garcia and LeReste, 1981); the net itself is very large - 6 m horizontal opening and 1.50 m vertical opening (Lozac'Hmeur, 1981).

In the Bay of Bengal, while the small pushnets are hand operated, the larger nets are pushed by engine-driven fishing craft of 5-15 m.

(b) Traps using branches (Figure 34)

In lagoons and estuaries, branches, tufts of aquatic grasses and coconut leaves are fixed to ropes 30 to 50 m long, fitted with floats and suspended in the water by means of stakes placed at regular intervals. The shrimp gather under the branches and can then be caught with a scoop net. This technique is used in South-East Asia, in particular in Malaysia, to harvest young shrimp for breeding purposes (Motoh, 1980; Angeles, 1978). It is similar to the "acadjas" systems encountered in Africa and, in particular, in Benin (Kapetsky, 1981).

(c) Aerial traps

This technique, described by Kurian and Sebastian (1982), is based on the shrimp's reaction to physical stimulation.

Two pirogues are attached to each other by means of two wooden beams arranged so that the boats are approximately 1 m apart and inclined at an angle towards each other (Figure 35). A chain attached to the front of each pirogue drags on the bottom. The pirogues move together. The shrimp, stimulated by the movement of the chain, jump out of the water and are trapped in the pirogues, on the floor of which coconut leaves have been arranged to prevent them escaping. This method can only be used in very shallow water or in very calm waters (lagoons - coastal swamps).

(d) Scoop nets

Hand scoop nets are operated from small paddle craft or on foot in mangrove areas off the east coast of Sumatra, Indonesia (Pajot, 1989).

4. SELECTIVITY

The catchability of any one or more species is the probability of an individual being caught by the fishing gear (Laurec and Leguen, 1981). It is contingent upon accessibility, vulnerability and efficiency.

The accessibility of the species will depend above all on its life cycle and on its relation to the fishing ground, i.e., migration, recruitment and moulting, or on behaviour and activity; during certain periods, the animal is out of the range of action of the gear. Shrimp accessibility varies throughout the year. The peak breeding period and hydrological and climatological conditions determine the size and period of peak migration towards the open sea, which corresponds to the lagoon and coastal fishery phase, that is to say, small-scale fisheries. Recruitment in the sea corresponds to the beginning of the offshore phase, i.e., industrial fisheries. This aspect is dealt with by biologists specializing in stock dynamics.

Vulnerability, inversely, is related to the ability of the organisms to escape the fishing gear once they have come into contact with it. The more effective the gear, the higher the vulnerability of the shrimp.

Efficiency is related to fishing tactics. For the same fishing effort, results may vary depending on the weather and the fishing zone (Laurec and Leguen, 1981).

The term "selectivity" will be taken to include one of the components of capturability, directly related to the fishing gear, corresponding roughly to vulnerability.

4.1 The role of selectivity and the problem of by-catches

4.1.1 Different types of selectivity

Fishing gear selectivity is the ability of the gear (i) to take one species rather than another; this is inter-specific or multi-specific selectivity; and (ii) for a single species, to retain only the individuals that have reached a certain size; this is intra-specific or size selectivity (Nedelec et al., 1979).

Inter-specific selectivity :

Fishing gear exerts its activity over a limited area. It operates at a given depth and takes only the species that are found at that depth; e.g., gillnet selectivity depends on the depth of immersion of the net; and trawl selectivity depends on the trawl's vertical opening and distance of the headrope from the seabed.

The shape and mode of operation of the fishing gear determines the species that are taken. The gear produces different reactions in different species; if the species have an active behaviour they can escape from the area of activity of the gear. With a bottom trawl, shrimp respond to the footrope and/or the tickler chain by jumping. They then become passive and are carried into the trawl by the waterflow (Watson and McVea, 1977). Fish are usually active and try to avoid the trawl by passing above it (especially pelagic fish), to the side, or under it (flat fish).

Finally, selectivity is also affected by the fishing operation itself; results will differ depending on the time at which the gear is put into operation. These variations in catchability are due to changes in activity on the part of the species which modify their accessibility or behaviour towards the gear. A large number of penaeid shrimp are active at night and are often fished at night. Activity patterns may change, however, when there are changes in hydrological conditions (Garcia, 1977, on *Penaeus duorarum*). In the Gulf of Mexico, several species with different activity patterns are fished; *Penaeus setiferus* (white shrimp) is fished in the day-time, while *Penaeus aztecus* (brown shirmp) and *Penaeus duorarum* (pink shrimp) are fished at night (Cody, Rice and Bryan, 1978).

Inter-specific selectivity depends, on the one hand, on differences in the behaviour of the species and, on the other, on gear selectivity and the mode of fishing.

Intra-specific selectivity :

Where a single species is concerned, the fishing gear selects the specimens according to size; the smallest pass or escape through the netting. As an initial approach, it may be stated that intra-specific selectivity is essentially a question of mesh size.

Selectivity may be expressed by a curve of the percentage of individuals of every size group retained by the net as against the number of individuals of that size entering the net. This curve is often sigmoid-shaped for trawls (see Figure 37) and bell-shaped for stationary gear.

4.1.2 Importance of selectivity in stock assessment

For a given species, intra-specific selectivity and recruitment determine the size - and therefore the age (l_c and t_c) - at which the species enters its exploited phase. Where penaeids, which are organisms which grow rapidly and have a short life, are concerned, the selectivity curve covers the greater part of their life cycle. It is therefore necessary to take into consideration the curve of selectivity and recruitment to determine both the size and age of the first catch, and the exploited stock by size class (Garcia and LeReste, 1981) (see Figure 37c). The choice of a suitable mesh size may help to improve the value of the harvest by reducing mortality per catch among the younger age classes, if the gain from the growth of specimens escaping offsets losses due to natural mortality.

The study of penaeid stock dynamics by global methods (e.g., production models) involves making a number of assumptions which are not always verified in the case of penaeids, and there is the added drawback of not being able to include data on juvenile catches in estuaries (Garcia and LeReste, 1981). Now that efficient methods of calculation have become common-place, analysis using structural models, better suited to the dynamics of these species, is possible. To be able to use such models, additional parameters must be known, including the selectivity curve of the gear used in the different fisheries.

Inter-specific selectivity is of importance for the by-catch problem as the by-catches of the shrimp fishery may concern young specimens of the fish species harvested in other fisheries, by other fishing methods. When they are not stored aboard, these catches are discarded under conditions which give them little chance of survival. This results in a loss for other fisheries. If the conditions under which the by-catch is released were good, the weight gain of the individuals surviving to first-catch size for fish fisheries would be profitable (see theoretical curve, Figure 36) (Caddy, 1982).

4.1.3 Limited use to which the by-catch may be put

In recent years, the problem of the by-catch of penaeid shrimp fisheries has attracted considerable attention, particularly in the developing countries where there is a high demand for animal protein. The question of the discarded by-catch is therefore important and measures to encourage its use have been taken in many regions.

Over the past ten years, studies have been undertaken in almost all regions in which penaeids are fished to estimate the size of by-catch taken by the industrial shrimp fishery (cf. Table 1). Overall results were submitted and discussed at the penaeid symposium held at Key West in 1981 (Rothschild and Gulland, 1982). There is, however, still a lack of information as regards catch composition by size and seasonal variations in catch size and composition. It is generally accepted that the fish caught are usually small (total length less than 20 cm), which limits the use to which it can be put and its marketable value.

Considerable progress has been made in processing fishery products. With new techniques for preparing minced fish, small fish can now be used in the manufacture of fish products for human consumption. In Mexico and Guyana, processing units using only by-catch as raw material have been tested on an industrial scale. The reports submitted to the meeting held at Georgetown, Guyana in 1981 showed that current processing technology made it possible to use the by-catch (FAO/IDRC, 1982).

Problems remain, however. Downstream, they are socio-economic and involve the acceptance of new products; upstream, they concern raw material storage.

The volume of the by-catch is considerably larger than the shrimp catch; the typical fish/shrimp ratio varies between 1:1 and 30:1, depending on the region. Methods for transferring catches at sea to a collector vessel have not yet been developed. Storage aboard shrimp trawlers would involve re-arranging the storage space in the hold. Shrimp and fish must be separated and the latter stored on ice, if possible (Crean, 1982). Since the shrimp catch is worth more than the by-catch, industrial trawlers are dissuaded from storing by-catches. They prefer to make the space available to shrimp only. However, while trawlers are taking increasing quantities of by-catch, landings remain small. In fact, the fish catch brought ashore consists of specimens of a certain commercial value, taken during the final days of the trips and represents only a small part of the total by-catch. A combined freezing-icing vessel would be ideal for storing part of the by-catch. However, since ice is used and the fish catch is large, the duration of the trips would have to be shortened when, in fact, as the fisheries move further offshore, the trend is towards longer trips.

On board, shrimp are washed, sorted, the heads are removed and they are sometimes packed; fish must be gutted and washed. The shrimp are dealt with first and the fish remain on the deck for one or two hours. This affects quality, but is unavoidable unless more crew are employed.

While by-catch utilization is technologically possible, the lack of incentives to retain the catch, as well as the lack of appropriate storage facilities on board and the additional labour costs that would result if the by-catch were retained, argue in favour of separating the two activities, and this raises the problem of the survival of the discarded fish.

Tropical climatic conditions (air temperature) make it impossible for the fish to remain on the decks for long periods. On the other hand, since the shrimp may be as large as the fish, the automatic seive, used in shrimp fisheries in temperate zones cannot be used. Furthermore, a large proportion of the fish cannot survive even a short period out of the water; this is notably the case for fish with a swim bladder, such as the Sciaenidae. It is preferable that the catch be sorted in the sea using either larger mesh sizes to allow the younger individuals to escape or selective shrimp gear.

In small-scale fisheries where the duration of the trips is a few hours only, the problem is different and by-catches could be systematically stored. The use of combined shrimp-fish trawls could also be developed (Pajot et al., 1982).

The question of juvenile fish catches also arises and is perhaps even more acute as nurseries are likely to be found in some of the coastal zones fished by the small-scale sector. The use of a suitable mesh size is therefore particularly necessary.

4.2 Bottom trawl selectivity

This paragraph will deal exclusively with intra-specific selectivity; i.e., the selectivity obtained with mesh size.

For a given size, there is some probability that a specimen will be retained by the netting and a further probability of it escaping through the netting. The probability estimate may be done in one of two traditional ways:

The double codend : The codend to be tested is covered with another bag, of much smaller mesh size, which will be considered capable of retaining all animals. The total number of individuals coming into contact with the gear will be taken to be the sum of the individuals contained in the two bags; percentage of specimens retained by the codend by size will then be worked out.

Try net : On double-rig trawlers, the net being tested is towed together with a control net (try net). The latter, with a small mesh size, is used to retain all individuals. Selectivity will be estimated by comparing the catches of these two trawls according to size class. This method can also be used with a single rig, by carrying out alternate hauls with the control net and the main trawl. In this case, however, the result is likely to be biassed.

Trawl selectivity for each size class is therefore the rate of retention, i.e. the percentage of individuals retained by the codend as against the number of individuals entering the trawl. The selectivity curve based on size of shrimp is symmetrically sigmoid in shape. L_o is the size at which the individuals begin to be held by the net, and L_{100} the size at which all the individuals entering the trawl are held. L_{50} is the size at which as many individuals escape as are retained. The most significant figure is the average selection size (l_s). At this size, the number of larger individuals retained by the net is equal to the number of smaller individuals escaping through the netting (considering an equal number of individuals for all size classes).

$$l_s = l_{n+1} - \Sigma h_i y_i$$

Where l_{n+1} is the upper size limit of the first class where selectivity is 100 percent and where "h_i" and "y_i" are the range and retention rates respectively of class "i" (for all classes below l_{n+1}) (Gulland, 1969).

It is generally accepted that, for a given species and gear, average selection length is proportional to mesh opening (m). This relationship determines the coefficient of selectivity (b).

$$b = l_s / m$$

It would be useful to distinguish between shrimp and fish selectivity.

4.2.1 Shrimp selectivity

Garcia and LeReste (1981) reviewed the results of selectivity studies on penaeid shrimp and collected estimates of selectivity factors. It must be pointed out, however, that these are sometimes calculated using l_{50}, and since selectivity curves are not usually symmetrical, this figure may differ considerably from l_s. Also, in some cases, cephalothoracic length (CL) and, in others, total length (TL) are used in the calculation (Table 3).

Table 3

Coefficient of selectivity of some penaeids

Authors	Species	Coefficient of selectivity (b) C.L.	T.L.
Aoyma (1973)	*Penaeus orientalis*	0.4	
Lhomme (1978)	*Penaeus notialis*	0.37-0.52	2.0-2.6 1/
Regan *et al.* (1957)	*Penaeus duorarum*	0.35-0.37	
Lluch (1975)	*Penaeus* spp.		2.0-2.4 2/
El Musa (1982)	*Parapenaeopsis stylifera*	0.30 3/	

1/ Transformation by Garcia and LeReste, using Garcia's CL/TL ratio (1970)

2/ Calculations by Garcia and LeReste, using figures from the original publication

3/ Calculations by the author using the figure contained in the original publication, the trawl tested had a double codend

These results are comparable and suggest that the coefficient of selection differs only slightly from one species to another. This, however, does not prevent the selectivity curves from varying considerably. Some authors consider that penaeid shrimp selectivity is haphazard (Gulland, 1972; Hancock, 1974). This is due to the morphology of the shrimp; their many appendages make them prone to becoming entangled in the net, and it is likely that size is not the only selectivity factor.

There are other factors which play a role in selectivity. Some are: (1) intrinsic, i.e. characteristic of the species studied; others, (2) extrinsic, i.e. due to the test or trawling condition: (i) for a given species, there may be vulnerability differences between the sexes and the sexual phases - this may be related to dimorphism concerning cephalothoracic diameter (Lhomme, 1978); (ii) by means of selectivity trials on Penaeus aztecus with mesh sizes of 32, 48, 64 and 76 mm, Berry and Hervey (1965) showed that there was a linear relationship between l_{50} and mesh size, but that this relationship varied depending on the duration of the trawling. The reason for this could be that the codend becomes clogged by the shrimp and other organisms entangled in the meshing, which is likely to have a significant effect on selectivity.

As regards shrimp, codend selectivity is not the only reason why they escape (Simpson and Perez, 1975); by using two small bags placed on the body of the trawl and by comparing two double-rigged trawls, one the control net and the other fitted with a double codend, it has been shown that shrimp do not escape only through the codend, but also through other parts of the trawl. These results have furthermore been confirmed by recent studies carried out in Cuba, where Perez, Puga and Hondares demonstrated that shrimp escaped most frequently through the sides of the trawl and that it was the smaller size classes that escaped. They also showed that the survival rate was high: 91.4 percent for Penaeus schmitti and 96.8 percent for Penaeus notialis (in Baisre, 1983).

Finally, it is a common practice among fishermen, especially in the Arabian Gulf (Van Zalinge, El Musa and El Ghaffar, 1978; El Musa, 1982), to use a double codend of the same mesh size, which has a significant effect on selectivity. El Musa (1982) gives a selectivity curve for Parapenaeopsis stylifera for a trawl fitted with a double 45 mm mesh codend. Average selection length, calculated from this curve, is 13.2 mm (CL); and, if the coefficient of selectivity figures given for other species are used, the use of a double codend has the same effect as reducing mesh size by between 7 and 37 percent. The author wishes to stress that, with a single codend, l_{50} was 19 mm, while with the double, it was 14 mm. The double codend therefore has the same effect as a 33 mm instead of 45 mm mesh, i.e. a reduction of 26.3 percent. In their selectivity studies on Penaeus duorarum in the Gulf of Campeche, Simpson and Perez (1975) confirm that the use of the double codend has a significant effect on selectivity; a double codend with 40 mm mesh netting would give a result equivalent to that obtained with a single mesh netting smaller by one-third.

Effect of increasing mesh size :

The effects of changing mesh size are twofold: there is the immediate effect which directly follows the adoption of the new mesh size, and the long-term effects which are the benefits likely to stem from the growth and natural mortality of the individuals which have escaped through the new netting.

Once the selectivity curves corresponding to the old and new mesh sizes are known, the calculation shows the immediate effect; for penaeids with a rapid growth rate and a short life span, the calculations must be carried out on the basis of data relating to the stock. These data are seasonal and not annual.

The long-term effects will be obtained during the course of the year in which the mesh size is changed (Garcia and LeReste, 1981; Lhomme, 1978).

Calculation methods are set out or mentioned in the study by Garcia and LeReste (1981); this document may be consulted for further details.

Lindner (1966) states that larger average size shrimp would be caught only if a much larger mesh were adopted and the immediate effects would be a loss which could not be economically endured by the Gulf of Mexico fisheries.

A study of selectivity curves for Senegal (Figure 37a) (Lhomme, 1978) shows that larger average size shrimp could be obtained with greater than 80 mm mesh size (40 mm per side - see Figure 39); the immediate result of adopting such a mesh size would be excessive losses - the mesh used in the fishery has an opening of 36.9 mm (stretched mesh length approximately 40 mm); increasing the mesh to 54 mm (stretched mesh length 60 mm) should, in the opinion of this author, have little effect on shrimp catches, but should allow small fish to escape (see Section 4.2.2).

Griffin and Grant (1982) carried out a computer simulation of mesh size increase using data from the Ivory Coast Penaeus duorarum fishery. Increasing mesh size to bring first catch size to 29.51 mm CL instead of 27.67 mm CL would cause a very small reduction in landings and possibly in income and profits (Figure 38). In some cases a reduction in landings can be more than compensated by a rise in price of better quality products, therefore in increased income and profits.

It must be pointed out that experts have not been unanimous as regards the effect of a change in mesh size. Lluch (1975) reported that a reduction in mesh size in 1961 from 64 mm to 38 mm was considered to be the cause of over-fishing in the Mexican Pacific Coast fishery (Penaeus californiensis, Penaeus stylirostris and Penaeus vannamei). It is the opinion of the author that reverting to a 64 mm mesh size would result in a catch increase of 49 percent in the long term.

In the Arabian Gulf, the replacement of trawls fitted with 43 mm mesh double codends by trawls with a single webbing codend should benefit shrimp fisheries, since the younger shrimp can escape rather than be discarded after catching because they are too small to be marketed (Van Zalinge, El Musa and El Ghaffer, 1979).

4.2.2 Fish selectivity

This aspect of selectivity which concerns only by-catch species has not been the subject of extensive study. Franqueville and Lhomme (1979) have, however, established selectivity curves for some 20 species and for mesh sizes of between 50 and 120 mm (cf. Figure 40). These results were based on the same test data as that used by Lhomme (1978) to establish curves for Penaeus notialis.

Curves for mesh lengths of between 50 and 60 mm are often identical and it is only from 80 mm that a significant change in selectivity can be perceived.

Differences between selectivity curves for small and large mesh sizes are sometimes very clear. This is the case for the catfish (Arius spp.) where levelling off occurs, perhaps due to the three pronounced spines which are typical of the species. This also occurs with flat fish (Seyacium micrurum and Cynoglossus spp.).

Table 4 below gives the main figures obtained for mesh lengths of 50 and 60 mm, as well as the coefficient of selectivity obtained for all the mesh size trials.

The coefficients of selectivity are comparable to those obtained for shrimp. The curves show that, with the exception of the catfish, a mesh change would make little difference to the size class distribution of the catches; the sizes most affected are those between l_s and l_{100}.

These curves must, however, be treated with care since biassed results can be obtained when selectivity is falsified due to the trawl net becoming clogged when the by-catch is particularly abundant and the shortage of samples and the absence of some size classes of individuals, particularly the largest and smallest.

Provided that shrimp catches would not be greatly affected, a mesh change from 40 to 60 mm would bring about only a slight change in fish catch composition by size class, and would benefit fish fisheries. Generally speaking, meshing regulations are preferable to a "laisser-faire" policy which could give rise to abuse.

4.2.3 Trawls used in small-scale fisheries

Very few data are available on the selectivity of trawls used in small-scale penaeid fisheries. In the Arabian Gulf, El Musa (1982) has established the selectivity curve for Paranaeopsis stylifera for a trawl fitted with a double codend, using a mesh size (stretched length) of between 32 and 35 mm (Figure 41). L_{50} was 11 mm (CL), which suggests that the selectivity obtained is comparable to that of industrial fishery trawls (cf. Section 4.2.2), if it is borne in mind that, for a given mesh size, the mesh opening in small-scale fishery trawls is larger, since the yarn used to make the nets for small-scale fisheries is much finer than that used in industrial fisheries.

Table 4

Length (l_s, l_{25}, l_{75} - in cm) and coefficient selectivity for 6 fish species from Senegal, for trawls of 50 and 60 mm mesh (Franqueville and Lhomme, 1979)

	50 mm			60 mm			Coefficient of selectivity	
	l_{25}	l_{75}	l_s	l_{25}	l_{75}	l_s	Average (b)	Regression (br)
Arius sp. (L.F.)	8.3	10.2	8.7	10.0	12.4	11.0	2.09	2.20
Pseudolithus senegalensis and P. typus	12.8	16.5	15.6	11.8	17.4	15.1	3.13	3.15
Pseudupeneus prayensis	9.4	13.2	11.3	9.5	15.7	12.7	2.42	2.52
Brachydeuterus auritus	9.5	12.4	11.2	9.2	13.1	11.1	2.26	2.11
Scyacium micrurum	9.5	12.0	10.7	9.7	13.5	11.7	2.51	3.71
Cynoglossus canariensis and C. goreensis	17.9	22.8	20.5	20.9	23.1	22.0	4.41	4.57

From a more general point of view, the trawling speed in artisanal fisheries is slower, which would normally result in better selectivity. However, the mesh sizes used are often smaller than those used in industrial fisheries (10 mm in India) (Pajot et al., 1982).

Finally, the hauling of the trawl by hand, which is common practice in certain regions, particularly in India, greatly reduces the catch of the trawl due to a greater escape of the shrimp through open meshes while hauling. Utilization of a mechanical winch could save handling time of the gear and render the operation much easier.

As has already been mentioned (Section 4.1.1), inter-specific selectivity overlaps intra-specific selectivity, which was dealt with in this paragraph. Recent developments in shrimp bottom trawls, particularly in industrial fisheries in the USA, offer new perspectives.

When the trawl is modified by the addition of a third wing and the use of a central bridle, the horizontal and vertical openings can be adjusted to give better opening ratios (cf. Table 2) (Captiva, 1980). By adjusting the length of the central bridle and/or by varying the number of floats used, the vertical opening of the trawl can be controlled. This type of rigging helped to improve white shrimp (Penaeus setiferus) catches in the Gulf of Mexico considerably (Burnett, 1979; Reisinger, 1979; Captiva, 1980). The vertical distribution of this species is more marked than that of other species fished in the same region (Penaeus duorarum and Penaeus aztecus), whose behaviour is clearly demersal.

The by-catch was also smaller with the three-wing trawl than with a traditional flat trawl, but was composed mainly of small fish (Burnett, 1979). It is possible that the larger fish tend to avoid this type of trawl.

4.3 Efficiency of selective trawls

4.3.1 Selective trawl

The trawl with the V-shaped vertical selective panel acts as a sieve for shrimp and fish and channels the fish towards a trash chute.

The by-catch consists of a majority of small individuals (total length less than 20 cm). Since the role of the selective panel is to separate the shrimp from the rest of the catch, its mesh must be small enough to separate a large part of the by-catch, but not too small in order to prevent too great a loss of shrimp. This attempt at a compromise often results in a loss of shrimp, particularly large-size specimens.

Best results have been obtained with a selective panel with a 76 mm mesh. Compared to the control net, shrimp losses were 6 percent, while the by-catch was reduced by 45 percent; the average size of the shrimp decreased by 2.7 percent and the average individual weight for some 15 species fell by an average 8.2 percent in the selective trawl (Watson and McVea, 1977).

Further studies have shown that both selectivity and the separating capacity of this type of selective trawl vary widely depending on the conditions under which it is used. In zones in which the by-catch is abundant (i.e. coastal zones): (1) the fish may clog the trash chute and thus nullify the separating capacity of the selective panel; (2) they may also become entangled in the separating panels, clog it, alter the selectivity capacity and the efficiency of the trawl and cause significant shrimp catch losses; (3) finally, when shrimp are caught along with large quantities of fish, the latter may form a barrier between the net panel and the shrimp, which can then escape along with the by-catch. In view of this, selectivity and separating capacity vary depending on the duration of the tow. When conditions are most unfavourable, shrimp losses may be 50 to 60 percent higher than those obtained with a traditional shrimp trawl, particularly in fishing grounds where fish are abundant (250 to 500 kg/hour for two 40-foot trawls) (Seidel and Watson, 1978). Such a rate of loss is intolerable in commercial fishing and thus limits the usefulness of this selective device.

4.3.2 Trawl fitted with turtle excluder device

The first device, which consisted of a large mesh selective front panel, was difficult to fit on to the many different types of shrimp trawl. The cut of the panel must fit the trawl opening perfectly, which is a handicap for fisheries oriented towards several different shrimp species, whose behaviour requires the shape of the trawl opening to be changed by adjusting the rigging. This device was used chiefly to separate marine turtles of a certain size, and the results were inferior to those obtained with the second type of rigid frame sieve, called the Turtle Excluder Device. Separation rate was 79 and 89 percent respectively. The first type also produced higher shrimp losses, 15 to 30 percent, while these were 11 percent with the second type (Watson and Seidel, 1980). For these reasons, the netting device was discarded in favour of the second type.

The rigid frame device (Turtle Excluder Device) which had been developed to separate marine turtles and to allow them to escape from the trawl, was also shown to be effective in separating by-catch from shrimp, increasing shrimp catches and was probably also fuel-saving (for this reason, it was rechristened "Trawling Efficiency Device", TED).

The most recent model, fitted with a funnel made of 44 mm mesh netting, with the trash chute facing upwards, has made it possible to reduce shrimp catch losses and in some cases has increased catches. Fish separating capacity is 53 percent higher than with a traditional trawl during day-time fishing, but this falls to 10 percent, sometimes less, during night fishing (Watson, 1983). This is probably due to visibility differences and to the nocturnal behaviour of fish, particularly with respect to the time required to respond to stimuli; since the fish is more passive at night, the grating of the screen acts as a mere sieve. This is confirmed to some extent by the results of the most recent experiments conducted by the NMFS with devices modified to improve separation capacity during night fishing. By adding a grating to the base of the sieve, good results were obtained; by-catches were reduced by between 71 and 84 percent during the day and 36 and 56 percent at night, without any loss in shrimp catch. The grating, which consists of an oval frame made of galvanized tubes into which are placed alternating rows of steel bars and 2.4 mm cable (3/32 inches), is firmly attached to the sieve with 3 straps fixed to one of the sides and to the upper cross bar and rear bar of the sieve. The grating prevents fish from entering the codend and its movements and the vibrations of the cables and cross bars are certainly detected by the fish and help to improve the efficiency of the device by causing the fish to escape upwards.

Such devices seem capable of improving inter-specific trawl selectivity considerably without affecting trawl efficiency with regard to shrimp, and without modifying the composition by age class of the shrimp catch. The author wishes to point out that the reaction of the fish to the device varies according to species; separation efficiency in particular depends on the species swimming capacity;

separation of small carangids (Chloroscombrus chrysurus) was 91 percent, while for sciaenids (Micropogon undulatus) it was 55 percent, and for synodontids (Synodus sp.) it was 34 percent.

The combined use of a water flow accelerating device which accentuates the behaviour patterns of the animals - passive for shrimp, active for fish - and devices to stimulate fish escape appears to be a satisfactory solution for reducing by-catches in penaeid shrimp fisheries, since separation is not based on size differences between shrimp and fish, which are often insignificant.

4.4 Seine selectivity

Very little research has been done on seine selectivity for shrimp fisheries. It must be pointed out, however, that seines with bags function in the same way as trawls, and selectivity depends on mesh size.

Mesh size is also a selectivity factor in beach seines without bags. Marcille (1978) observed that beach seine selectivity in Madagascar was comparable to that of coastal barriers. For a mesh size of between 10 and 15 mm, the majority of shrimp caught were smaller than 11 cm (TL) and selectivity began at 2 cm (TL). Urroz Escobar (1978) considers that the use of beach seines is harmful to the shrimp fishery in Nicaragua. This is also the opinion of Ben Yami (personal communication) as regards the Guyana fishery, even if its impact remains slight. The verdict seems to be that this gear catches small-size shrimp, of low market value; it is also probable that it also catches juvenile fish.

4.5 Comparing the selective capacity of lift nets, cast nets and gillnets

George, Gopalan Nayar and Krishna Iyer, (1974) conducted a comparative study of several types of small-scale fishing gear in the Cochin region in India. The types of gear compared included stakenets of 8 to 12 mm mesh size (see also Section 4.6), 9 to 11 mm mesh paddy filter nets, 9 to 17 mm mesh lift nets, 20 to 28 mm mesh cast nets, and 30 to 35 mm mesh gillnets. Analysis of the frequency histograms by size classes for 6 species of shrimp (Penaeus indicus, P. semisulcatus, P. monodon, Metapenaeus dobsoni, M. monoceros and M. affinis) showed that, with these types of fishing gear, selectivity by size is achieved through mesh size. For Penaeus indicus 57 percent of catches were smaller than 10 cm (TL) with stakenets; with paddy filter nets, lift nets, cast nets and gillnets, the figures were 75, 66, 64 and 62 percent respectively. Analysing the catch composition of Penaeus indicus by size classes showed very significant variations with cast nets of different mesh size. It is the opinion of the authors that mesh sizes of 33, 44 and 53 mm for stakenets, paddy filter nets and lift nets would give catches of Penaeus indicus exceeding 10 cm, but that initially, a 20 to 25 mm mesh size would suffice to improve catch composition by size classes without ensuing excessive losses in size or value. These would moreover be offset from the second or third year, depending on the change in mesh size, and the shrimp above market size would serve to increase the offshore stock.

The fact that some results differ significantly from George's (1962, in Kurian and Sebastian, 1982), suggests that selectivity results are not always definitive and that they can vary according to season, due perhaps to changes in shrimp behaviour or environmental conditions (e.g., speed of currents during high water) which make escape easier.

It must also be noted that gillnet selectivity operates for a certain size range. Small individuals pass through the mesh and larger ones cannot become enmeshed. This gives a bell-shaped selectivity curve. On the other hand, with filtering gear, the larger the individuals the higher the percentage retained, which gives a sigmoid selectivity curve.

The use of bait, lures or attracting devices can increase the efficiency of fishing gear. When fishing is done with a cast net from boats in the Manakkudy estuary, India, coconut wastes are used to attract the shrimp before the net is cast (Suseelan, 1975). Lift-net fishing is done at night and a light is almost always used to attract the shrimp (Kurian and Sebastian, 1982; Motoh, 1980). Kurian et al. (1952, in Kurian and Sebastian, 1982) compared several types of lighting and it emerged that a green, blue or red light is more efficient for shrimp than a white light, and that efficiency increases with luminous intensity up to a maximum level and then decreases. Other species are also attracted by light, especially crabs and fish.

4.6 Stow net selectivity

The few selectivity studies carried out on fishing gear used in small-scale fisheries concerned stow nets.

Garcia and Lhomme (1977a) established stow net selectivity curves for pink shrimp juveniles (Penaeus duorarum notialis) in the Ebrie lagoon in the Ivory Coast, using mesh sizes of between 20 and 32 mm (Figure 42a). The test method consisted of comparing catches obtained with nets of these different mesh sizes with those obtained with a 16 mm mesh size control net (mesh side 8 mm), bearing in mind that there was no selectivity in the control net. The selectivity curve is not the usual sigmoid shape, especially for the small mesh sizes; the drop in the curve for the larger sizes could be due to avoidance - this could occur when the current is sufficiently weak to allow some of the shrimp to leave the net against the current or to avoid the net.

In India, the study by George, Gopalan Nayar and Krishna Iyer, (1974) showed that selectivity with stow nets was based on mesh size and the authors recommended a mesh size of 33 mm (cf. Section 4.5). The study using nets of mesh sizes ranging between 12 and 24 mm, as well as an 8 mm double bag confirmed the selective role played by mesh size with respect to size for Penaeus indicus and Metapenaeus dobsoni. The selectivity curves established using the authors' data suggest, however, that selectivity is haphazard (Figure 42b).

4.7 Selectivity of traps, barriers, etc.

Although no detailed study has been carried out on the selectivity of this fishing gear, it is possible to set out some general principles.

Barriers :

The coastal barriers of Madagascar (Figure 31) catch small shrimp (Penaeus indicus). LeReste (1971) has shown that the space between the stakes forming the lathing of the partitions was 7.5 mm on average and that this figure was too low for selectivity to be satisfactory. Samples of the size range showed that 2 cm (TL) was the smallest size retained and that 94 percent of the catches were smaller than 11 cm (TL), which is the size at which the first signs of maturity appear. Crosnier (1965) states that barriers are not very effective, for they are often damaged by branches and tree trunks brought by the floodwaters of the rivers. It is also probable that leaves and branches can also considerably modify the selectivity of these devices by partly clogging the lathing. Marcille (1978) recommends a spacing of 11 mm between stakes, which could be obtained by intertwining a rope of appropriate diameter with the bars of the lathing, or even doing away with or reducing the number of barriers because of the harm they do to fish juveniles. They could be replaced by beach seines which can be just as selective depending on the mesh size used, but which have the added advantage of being more easily controlled should mesh size regulations be introduced.

Barriers of galvanized grating on the Pacific coast of Mexico (Tapos) are examples of an improved traditional fishing gear. They have numerous advantages, particularly as regards selectivity (see 3.2.2 Traps (d)).

Barrier efficiency may be improved by using light.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Interaction of the different fisheries

5.1.1 Catches of fish or organisms other than shrimp

Fish catches which are obtained along with shrimp are discarded into the sea, either because they are smaller than market size, or because it is in the interest of the fishermen to keep the storage area on board available for shrimp. This is not always the case, however, and in certain regions a large proportion of the fish catches are utilized (Rothschild and Gulland, 1982; FAO/IDRC, 1982).

The small-size fish caught are usually juveniles. Such catches, which are largely obtained by the industrial fishery, can be harmful to other fish fisheries (Anon., 1980; Garcia and LeReste, 1981). The same applies to coastal waters and lagoons when the shrimp fishery uses mobile, often small meshed, fishing gear (trawls, push nets) (Motoh, 1980), and to the Chinese barriers used in the Guyanas, where mesh size is 6 mm (Dragovich and Villegas, 1983).

Catches may also include shellfish exploited by another fishery. This occurs with scallops on the west coast of Australia, where shrimp trawlers sometimes catch undersized specimens. For these reasons, Hancock (1974) recommends a regulation mesh of 89 mm (3½ inches) for shrimp trawlers.

5.1.2 Juvenile shrimp catches

Young shrimp are, above all, caught in coastal and lagoon zones when they are migrating from the nurseries towards the open sea. One effect of small-scale fisheries may be to reduce the stock in the sea and, with respect to the animal's life cycle, they may play a more significant role than offshore fisheries (Panayotou, 1982). This is particularly clear in the case of Penaeus duorarum in the Gulf of Guinea, where offshore fishery results, especially in value, depend on the lagoon fishery (Garcia and Lhomme, 1977a; Troadec, 1982; Griffin and Grant, 1982).

5.1.3 Damage caused by other fishing gear

Exploitation of resources, even when these are different resources, by different sectors in a single fishing ground, may cause physical interactions because of the fishing methods used. A bottom trawl fishery is likely to cause serious damage to other sectors and fishing gear may be damaged or lost. The following examples may be cited: the surface gillnet fishery in the COPACE zone (FAO/UNDP, 1982a); crab fisheries using pots in Florida, USA (Anon., 1980; Donaldson, 1983), and especially in South-East Asia and in Malaysia, where conflict between industrial and small-scale fisheries has caused loss of equipment (stationary gear and boats) as well as loss of lives. In Indonesia, conflicts prompted the government to ban trawlers in October 1980. Similar conflicts have occurred in India, Thailand and in the Philippines (Panayotou, 1982).

5.2 Recommendations for future action

It has been decided to limit recommendations to technical matters (technology, regulations, transfer and extension).

5.2.1 Fishing technology research

A wide variety of fishing gear is used in shrimp fisheries, particularly in the small-scale sector, which uses gear based on a number of operating principles. It emerged during this study that there was a serious lack of knowledge, both of the fishing gear used and its method of operation. It could be useful to direct future efforts to:

- A detailed description of fishing techniques so as to obtain a better understanding of production methods, particularly those of the small-scale sector.

- Comparative studies of the efficiency of different fishing techniques; in particular, to carry out more studies like the one done by George et al. (1974) in the small-scale sector in South-East Asia, where a large number of fishing techniques are used, and in South and Central America. These studies could be carried out at different times of the year so that the seasonal variations in fishing gear efficiency may be tested. As regards industrial fisheries, comparisons between different types of trawls could be very useful.

- Mesh selectivity studies for both shrimp and fish: These may involve a comparative study using control gear with a sufficiently small mesh size so that it may be considered to produce no size selection. With a trawl, a double rigging can easily be used so that the control trawl can be towed on one side and the trawl being tested on the other. When a single rigging is used, alternate hauls with the control trawl and the test trawl will be carried out. A sufficiently large, small-meshed bag could also be placed around the codend. Selectivity studies on other parts of the trawl from which there is a high shrimp escape rate could also be carried out; an appropriate method consists of placing a number of small-meshed bags at different points of the trawl. In this connection, observations by Giudicelli (1978) in the Mediterranean (Figure 43) could be useful.

- Trials on selectivity devices: Those carried out for temperate and cold water shrimp showed that the performances of such devices could be improved gradually on the basis of the behaviour differences of fish and shrimp, and could become more selective than the traditional gear (Kurc, Faure and Laurent, 1965; Hight, Ellis and Lusz, 1969; FAO, 1973; Brabant, 1974; Hillis, 1983). The only study on penaeids was conducted by the NMFS (National Marine Fisheries Service) of Pascagoula, USA. The case of the turtle sieve, which has developed into its present form where it separates the shrimp from the fish, is exceptional in that the fishermen have adopted it very quickly. Selectivity devices based on other principles could be tested, e.g., electrified trawls, on the subject of which the work of Pease and Seinel (1967) on Penaeus duorarum and Penaeus aztecus, as well as the work of Seidel and Watson (1978) (Figure 44) may be cited. However, these trawls are high energy-consumers, which is a handicap if they are to be accepted by professionals. Furthermore, they have taken a long time to develop and they are relatively difficult to use (De Boer, personal communication). Sternin and Allsopp (1982) suggest a different approach to the problem, based on different responses to different stimuli and the swimming speed of shrimp and fish. These authors suggest providing one or several types of stimuli, such as light, sound or electric currents (Figure 45) to an area situated at one minute in front of the trawl opening (i.e., 75 m for a trawling speed of 3 knots). These studies would require direct observation methods, either by divers or by closed-circuit television to be developed; with the vertical sampling method (Figure 46), tested on pandalids (Fontaine et al., 1982), the vertical distribution of shrimps could be examined.

- Finally, it would be interesting to experiment with square meshes on shrimp trawl codends. Studies on haddock and herring fisheries have showed that this arrangement modified selectivity; the selection curve is more sloping; l_{50} and the selectivity factor is higher and the selection interval (l_{75}-l_{25}) is smaller than for the traditional diamond-shaped arrangement (Robertson, 1983); the square arrangement could be useful in dealing with the by-catch, in that it would allow a larger number of small individuals to escape. The selectivity of polygonal meshes (hexagonal) could also be the subject of a study on trawls and on seines with bags (Olsen, 1982).

5.2.2 Fishing technique regulations

Introducing fishing gear and mesh size regulations are just two of the methods available to management. To be able to do so requires a thorough knowledge of the efficiency and selectivity of the fishing gear.

Fishing gear regulations for shrimp fisheries were only introduced fairly recently, with a few minor exceptions. Only recently has trawling been banned in zones closest to the coasts, i.e. it is banned along the six-mile coastal fringe in Senegal (FAO/UNDP, 1982a); in French Guyana, shrimp trawling was banned below a depth of 30 m - the measure is now under study for possible modification; in Surinam, the limit is 12 fth or 15 fth, depending on the season (WECAFC, 1983); in the Gulf of Mexico, the regulations involve zones and seasons closed to trawling (Cody, Rice and Bryan, 1978); in India, small-scale trawlers are banned from a coastal strip 5 km wide, while for industrial trawlers (exceeding 25 tons), this zone extends to 10 km (FAO/SIDA, 1983).

Mesh regulations are now very commonly used in shrimp fisheries management. A few cases may be cited, however: in Surinam, mesh length is restricted to 57 mm for the belly and wings of the trawls and 45 mm for the codend (WECAFC, 1983); in Senegal, mesh length is limited to 66 mm for foreign vessels; in Morocco, north of Cape Noun, it is 40 mm (FAO/UNDP, 1982a); and in Madagascar, it is 35 mm (Marcille, 1978).

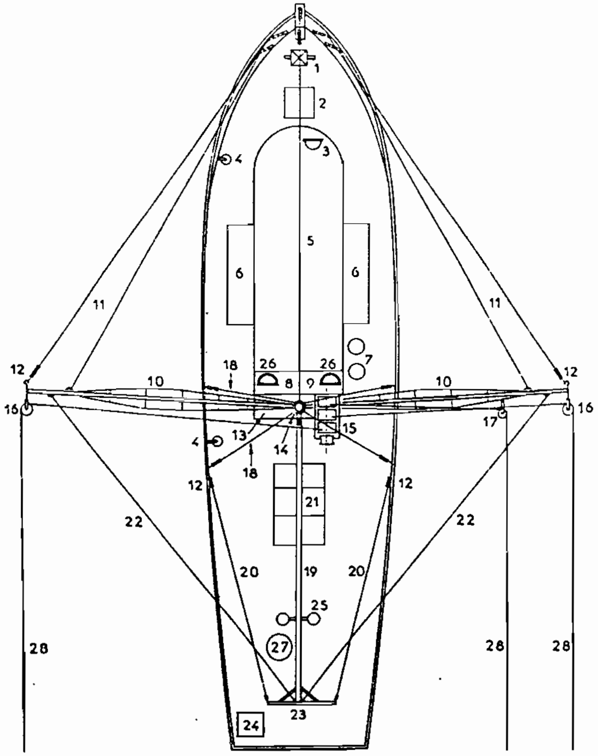
Another type of regulation, designed to control fishing effort, concerns trawl size and the number of trawls per boat; in Australia, in Shark Bay and Exmouth Gulf, two trawls with a maximum headline length of 14.63 m (48 ft) are allowed (Bowen and Hancock, 1982).

On the other hand, there are few gear and mesh size regulations for small-scale fishing. Some authors recognize, however, that mesh regulations for stownets on stakes would be useful, particularly in Senegal where the shrimp set free by the new larger meshing could remain in the lagoon longer and benefit the small-scale fishery (Garcia and Lhomme, 1977a). Several authors have suggested banning barriers or subjecting them to regulations. In some areas where they block the entire width of canals, rivers or estuaries through which shrimp and fish juveniles pass as they migrate towards the sea, they should be banned (Garcia and LeReste, 1981; Marcille, 1978; Gulland, 1973).

5.2.3 Role of extension services

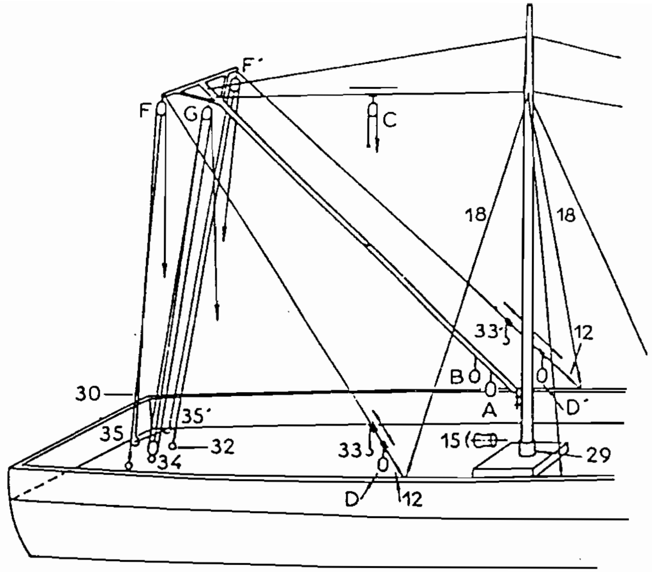
The development of extension services should improve the circulation of information among fishery professionals, fishing technology research services and the work of the various administrative departments in charge of fisheries management. The role of such a service, how it should be organized and operate, are dealt with in papers by Nédélec (1982) and Grofit (1983).

It would be worthwhile emphasizing the role such a service would play in the exchange of information with the scientific services: the extension service will be in charge of promoting new techniques; this will include training where necessary; it will also have to point out the advantages of the techniques. However, the role of the service will not be restricted to passing information from the scientific services to the profession; it will also have to channel information in the opposite direction (feedback), so that the competent authorities may be kept informed of the fishermen's problems and the results of their observations. This last point must not be neglected, for professional fishermen have contributed considerably to the development of new types of shrimp trawls: the twin trawl (Ross, 1975; Hamrick, 1976), the "tongue" trawl (Reisinger, 1979; Burnett, 1979; Captiva, 1980), the turtle excluder device (McNeill, 1983); and, in some cases, the scientific services took over from the profession to improve the performance of the new gear.



(a) Diagrammatic top view of "Sand Bar II"

1. Mooring bit
2. Forward hatch
3. Adjustable light
4. Snatch block for raising anchor
5. Forestays
6. Freshwater tanks
7. Tanks of sea water for rinsing working gloves
8. Entrance to engine room
9. Winch power take-off
10. Outriggers
11. Forestay
12. Straining screw
13. Mast shoe
14. Mast
15. Three-drum winch and warping lead
16. Towing blocks
17. Towing block for try net
18. Mast stays
19. Codend derrick
20. Forward boom stay
21. Fish hold hatch
22. Stays between codend derrick and outrigger
23 Cross-yard.
24. Hatch to steering gear
25. Deck lights
26. Accommodation lights
27. Tanks for sodium bisulphite treatment
28. Trawl warps



(b) Rigging plan of "Sand Bar II"

A & B	Snatch block above warping head suspended from codend derrick
D & D'	Blocks handing on port and starboard stays connecting end of boom to codend derrick
C	Single block hanging on one of the landing stays
G	Double tackle used to lift codend
F & F'	Single tackle blocks; these tackles are used to lift the codends above the deck
12	Straining stays used to stop blocks D and D' and mobile hooks 33 and 33'
15	Winch head
29	Mast foot
30	Stays connecting ends to deck rings
32	Eyebolts screwed into the deck
33 & 33'	Mobile hooks hanging on port and starboard stays connecting end of boom to transverse section of codend derrick
34	Double tackle hook
35 & 35'	Single tackle hooks attached to ladder

Figure 1

Industrial trawler: (a) top view; (b) side view, pulley block (Morice and Warluzel, 1968)

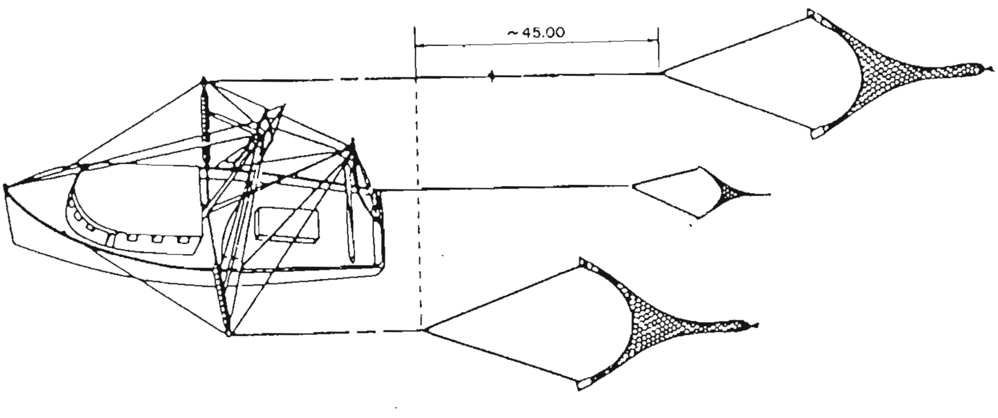


Figure 2

Double rigging: Fishing rig comprising the two main trawls and a try net (FAO, 1978)

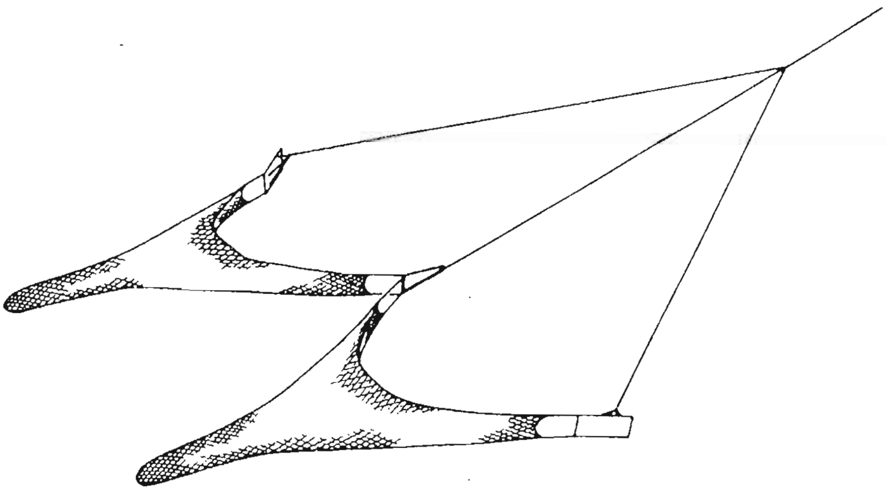


Figure 3

Twin trawl (Nedelec, 1982a)

Shrimp trawl	Chalut a crevette	Red de arrastre camaronera
bottom, otter, double rig, flat smooth bottom; Gulf of Mexico shrimp USA	de fond, à panneaux, gréement double, plat fond doux; Golfe du Mexique crevette USA	de fondo, con puertas, aparejo doble, plano fondo limpio; Golfo de México camaron EE.UU.

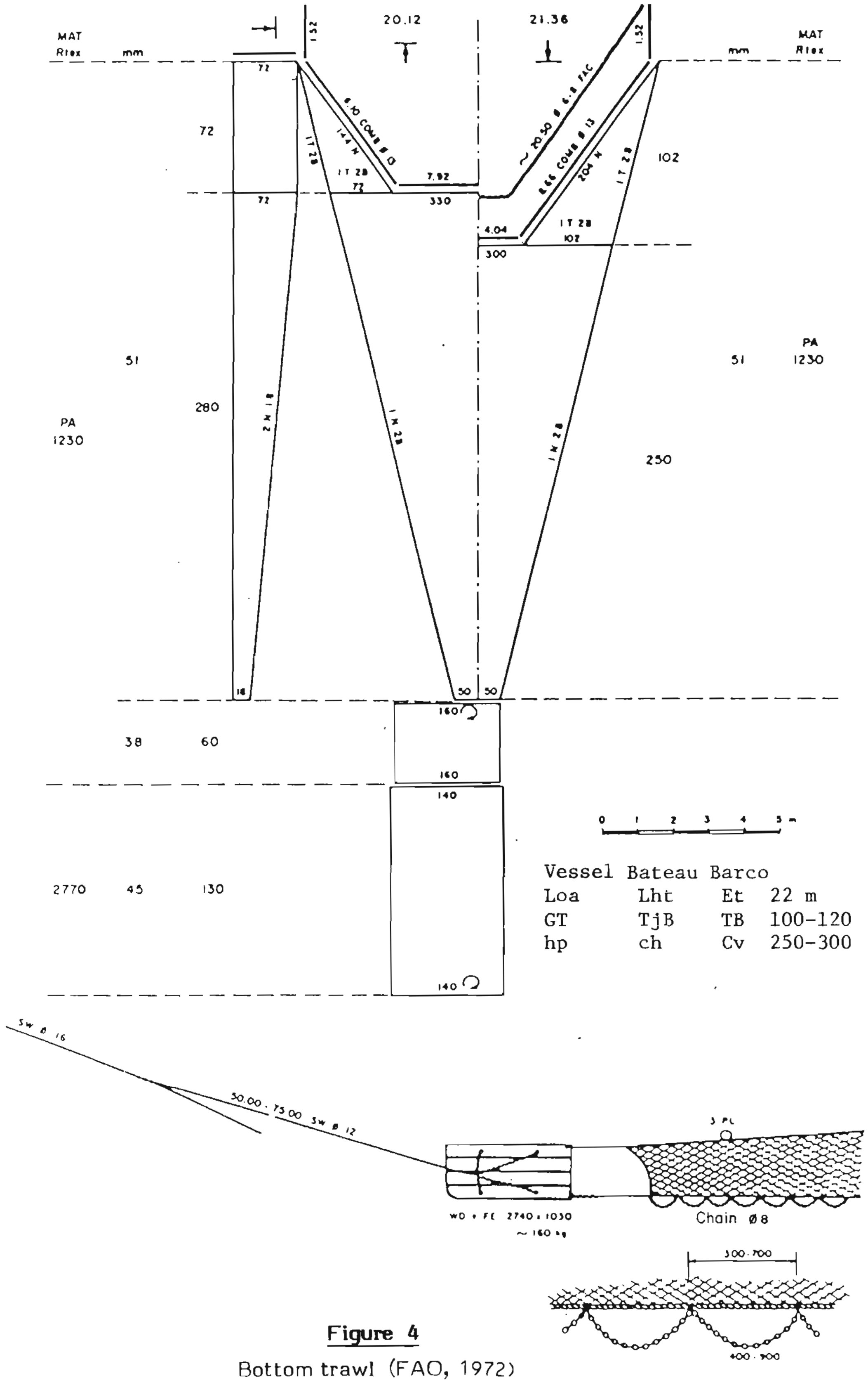
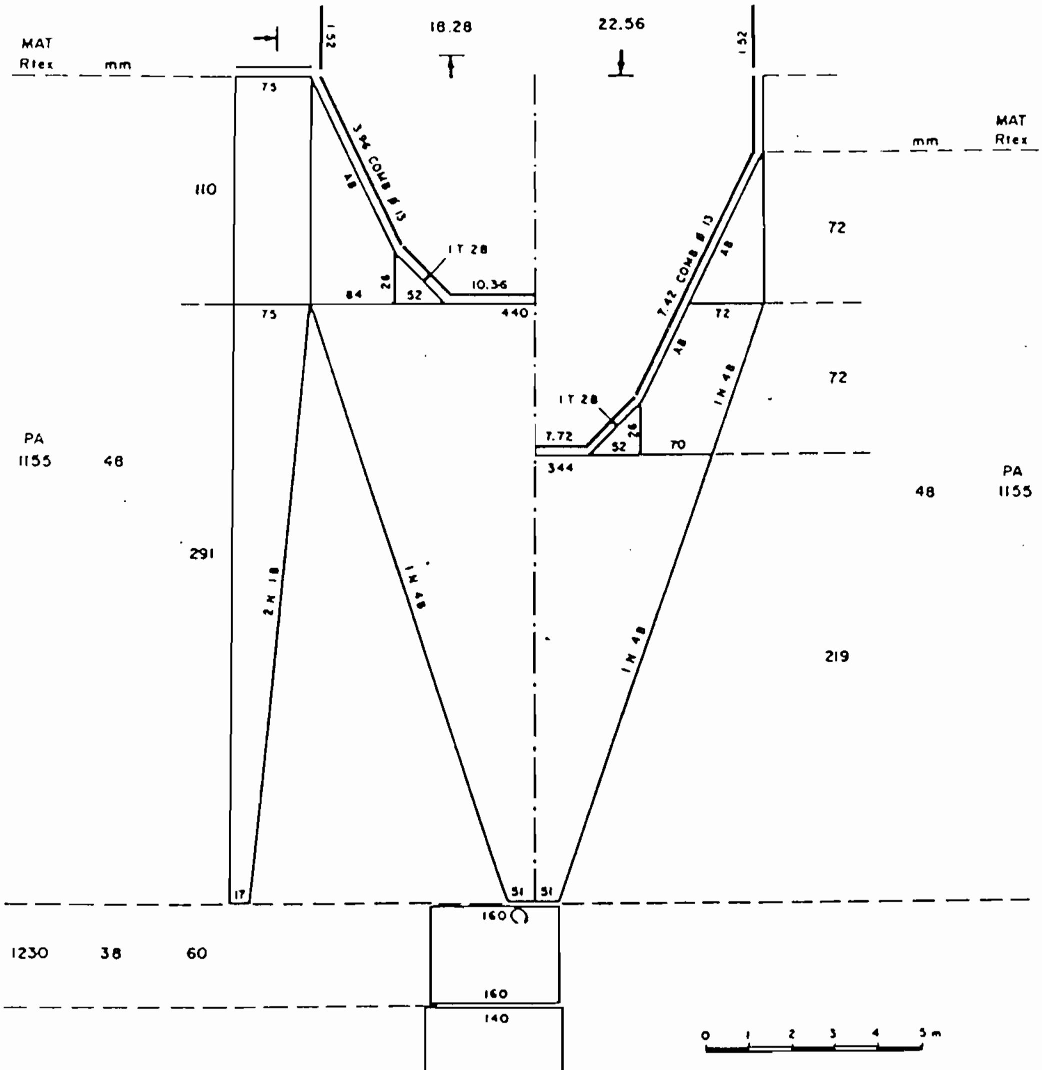


Figure 4

Bottom trawl (FAO, 1972)

Shrimp trawl	Chalut a crevette	Red de arrastre camaronera
bottom, otter, double rig, flat smooth bottom; Gulf of Mexico shrimp USA	de fond, à panneaux, gréement double, plat fond doux; Golfe du Mexique crevette USA	de fondo, con puertas, aparejo doble, plano fondo limpio; Golfo de México camaron EE.UU.



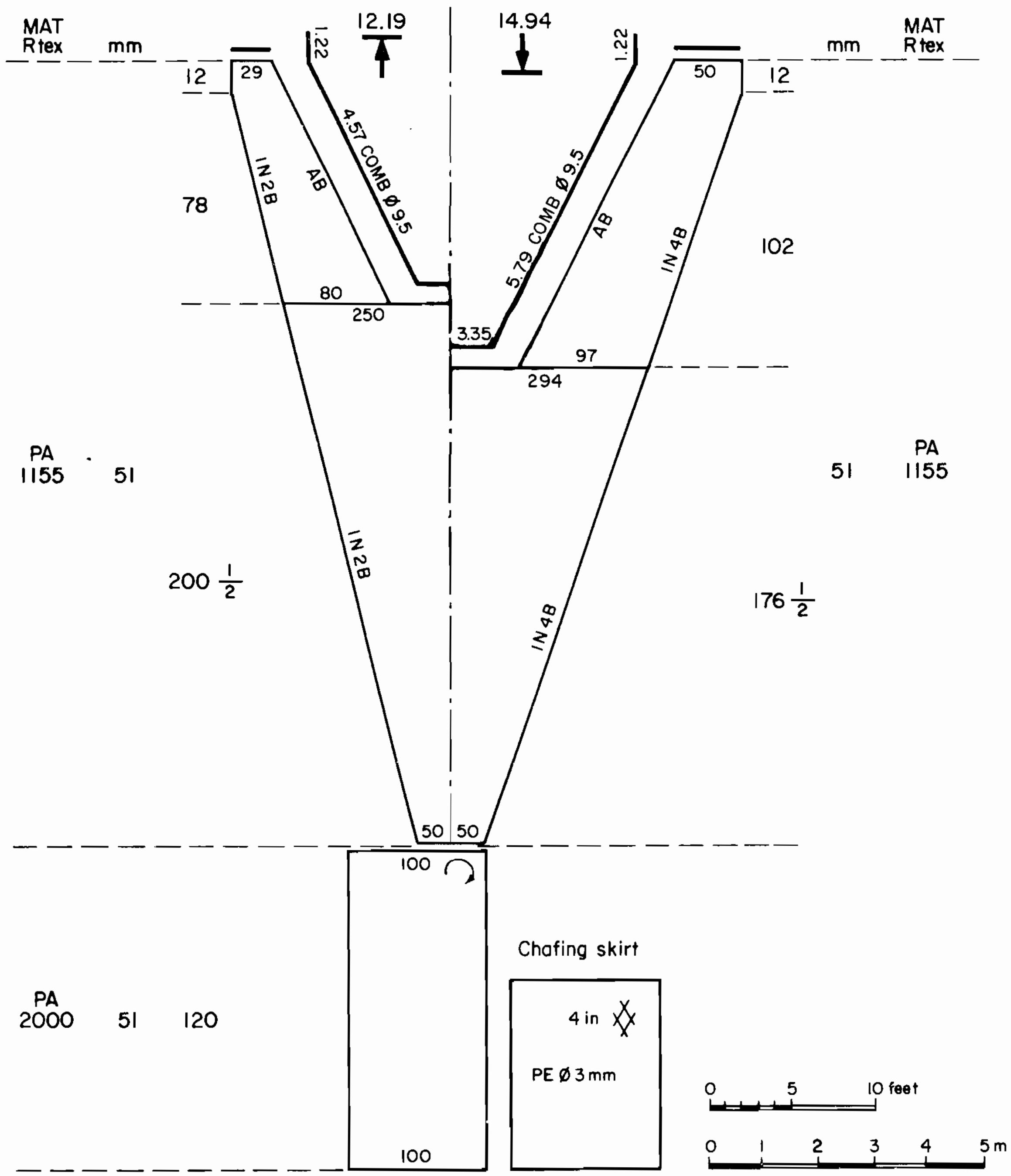
Vessel Bateau Barco

Loa	Lht	Et	22 mm
GT	TjB	TB	100-120
hp	ch	Cv	250-300

Figure 5

Semi-balloon trawl (FAO, 1972)

Shrimp trawl:
bottom, otter, double rig, balloon with two sides
smooth bottom; Gulf of Mexico shrimp trawl
(USA)



Vessel
Loa 22 m
GT 100-120
hp 250-300

Figure 6

Balloon trawl with two sides (Kristjonsson, 1969)

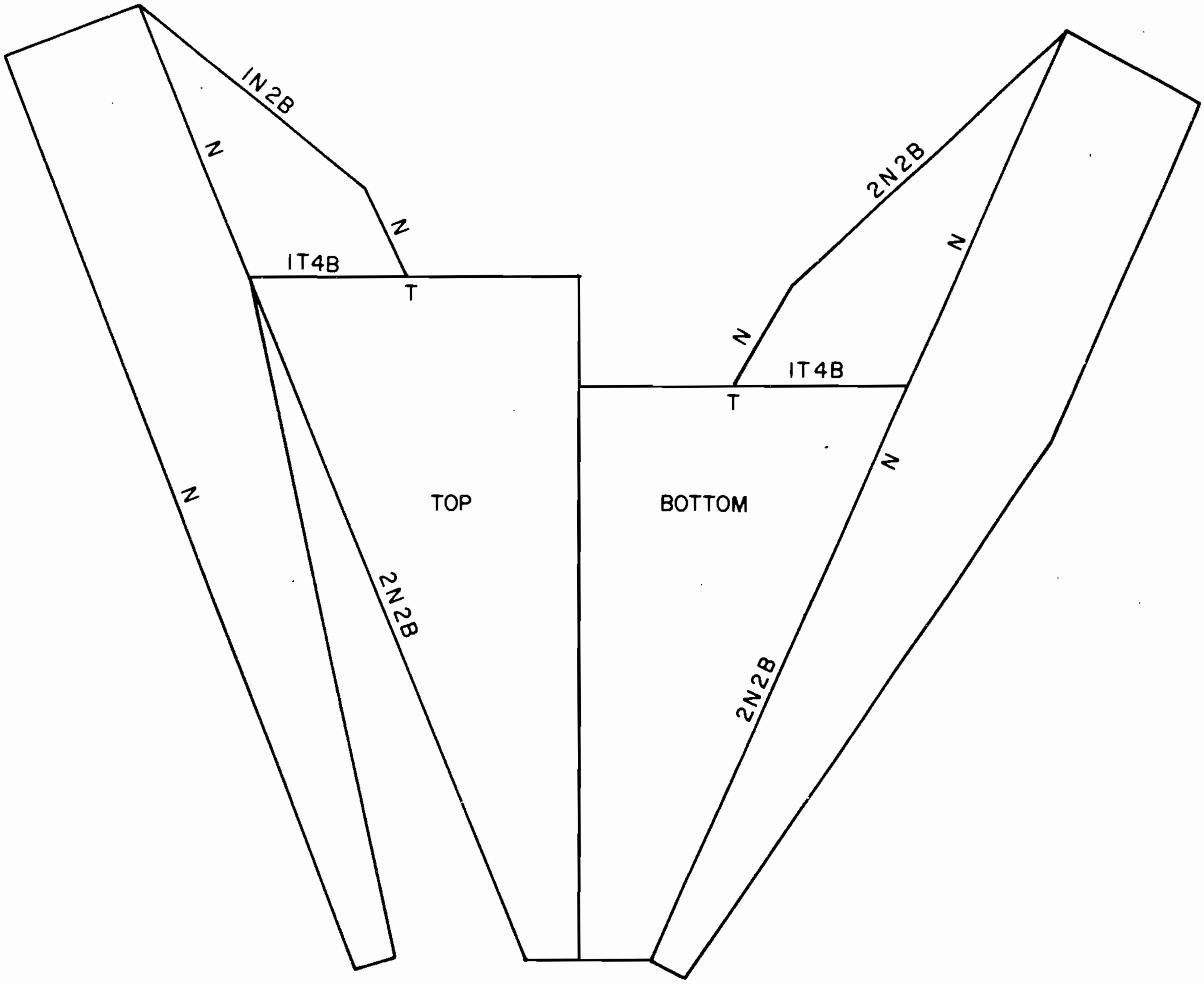


Figure 7

Super X-3 trawl

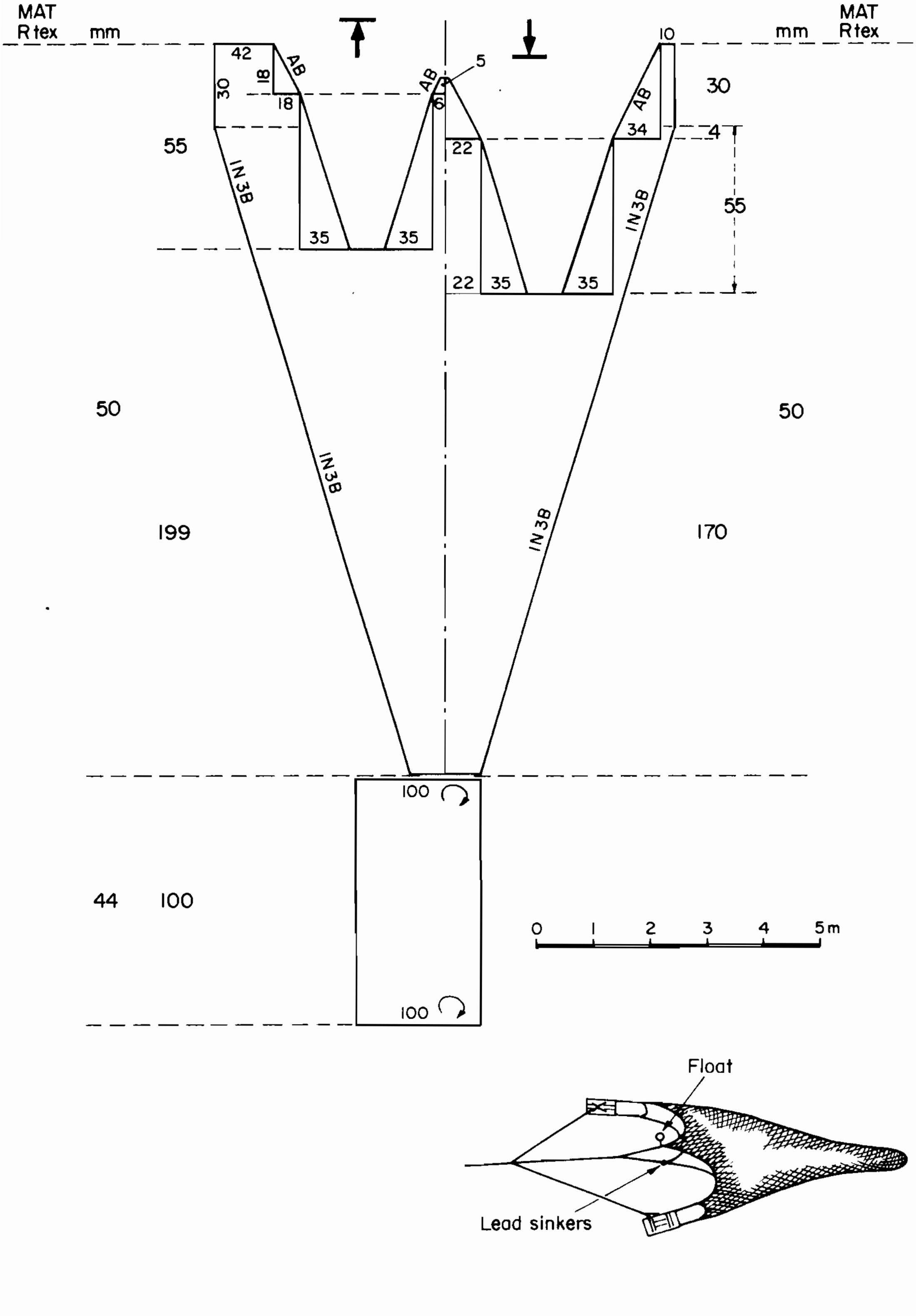


Figure 8

Tongue trawl (Hughes, 1982)

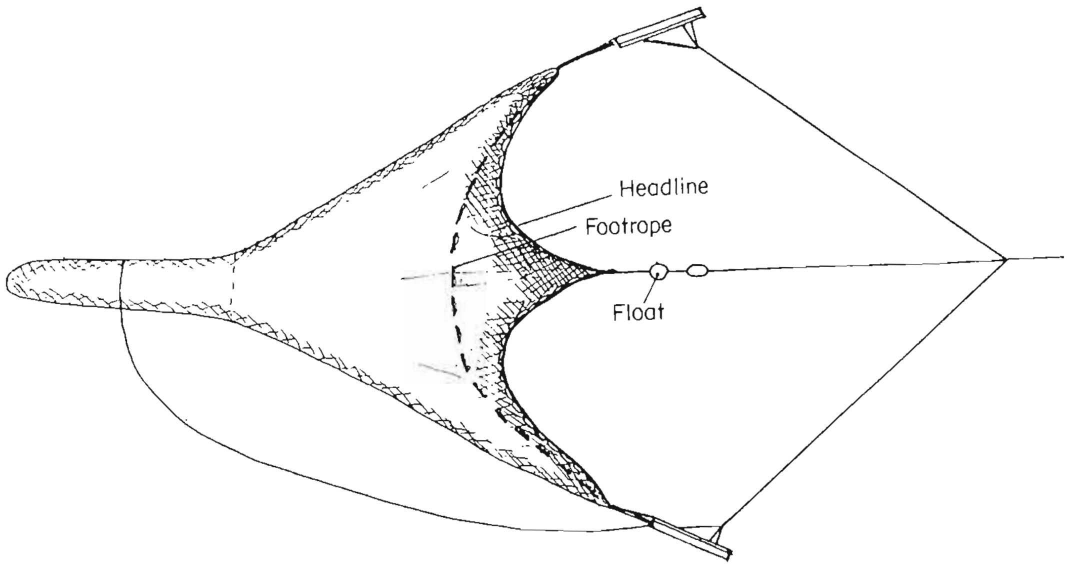
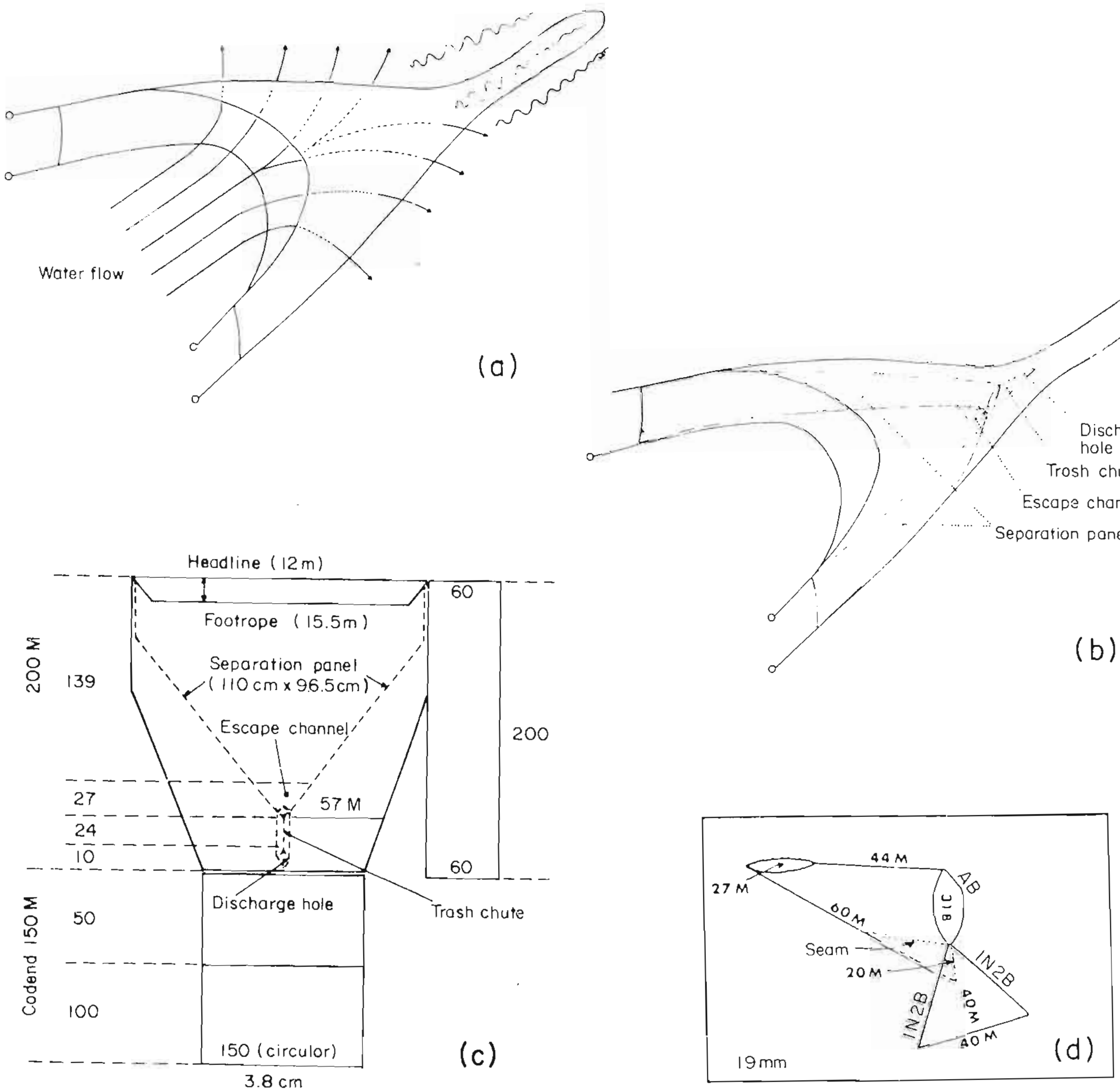


Figure 9

Three-wing trawl: bottom view (Reisinger, 1979)



(c) Main trawl: 4-panel semi-balloon
12-m headline and 15.5-m footrope

Figure 10 Selective trawl with V-shaped separation panel:

(a) Water currents in a semi-balloon trawl
(b) Overall view of trawl fitted with selective panel
(c) Plan of trawl with selective panel
(d) Detail of trash chute

(Watson and McVea, 1977)

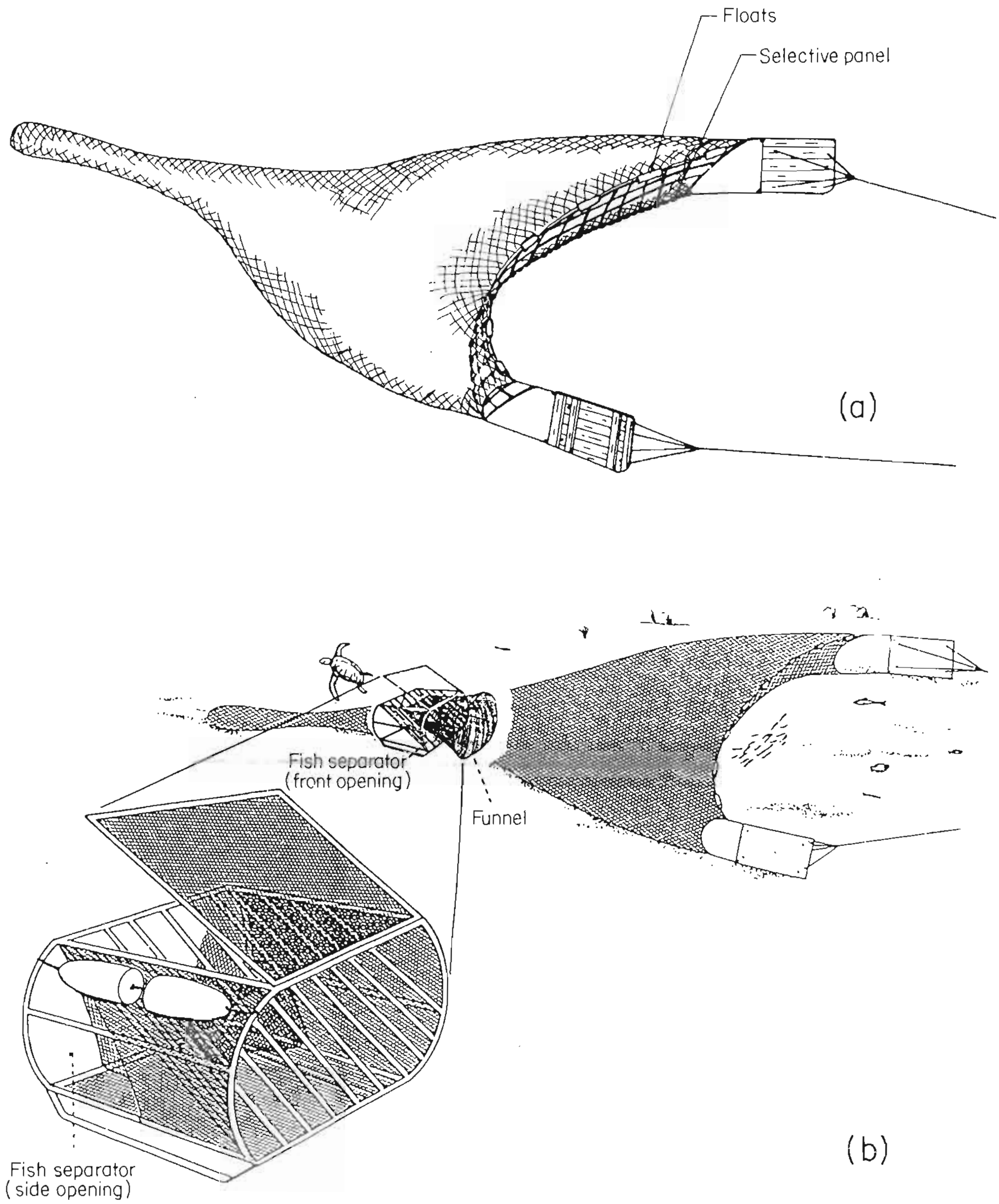


Figure 11 Selective trawls fitted with turtle excluder devices

(a) with large-mesh front selective panel (Watson and Seidel, 1980)

(b) with a rigid sieve (T.E.D., Turtle Excluder Device) (Watson, 1983)

Trawl
Bottom, pair
smooth bottom; E.China Sea
croakers, sharp-toothed eel
prawn
Japan

Vessel x 2

Loa 35 m
GT 130
hp 550

Reference:
Y. Shimozaki and Y. Osawa,
Tokai Regional Fisheries Laboratory
5 Kachidoki, Chuo-ku
Tokyo, Japan

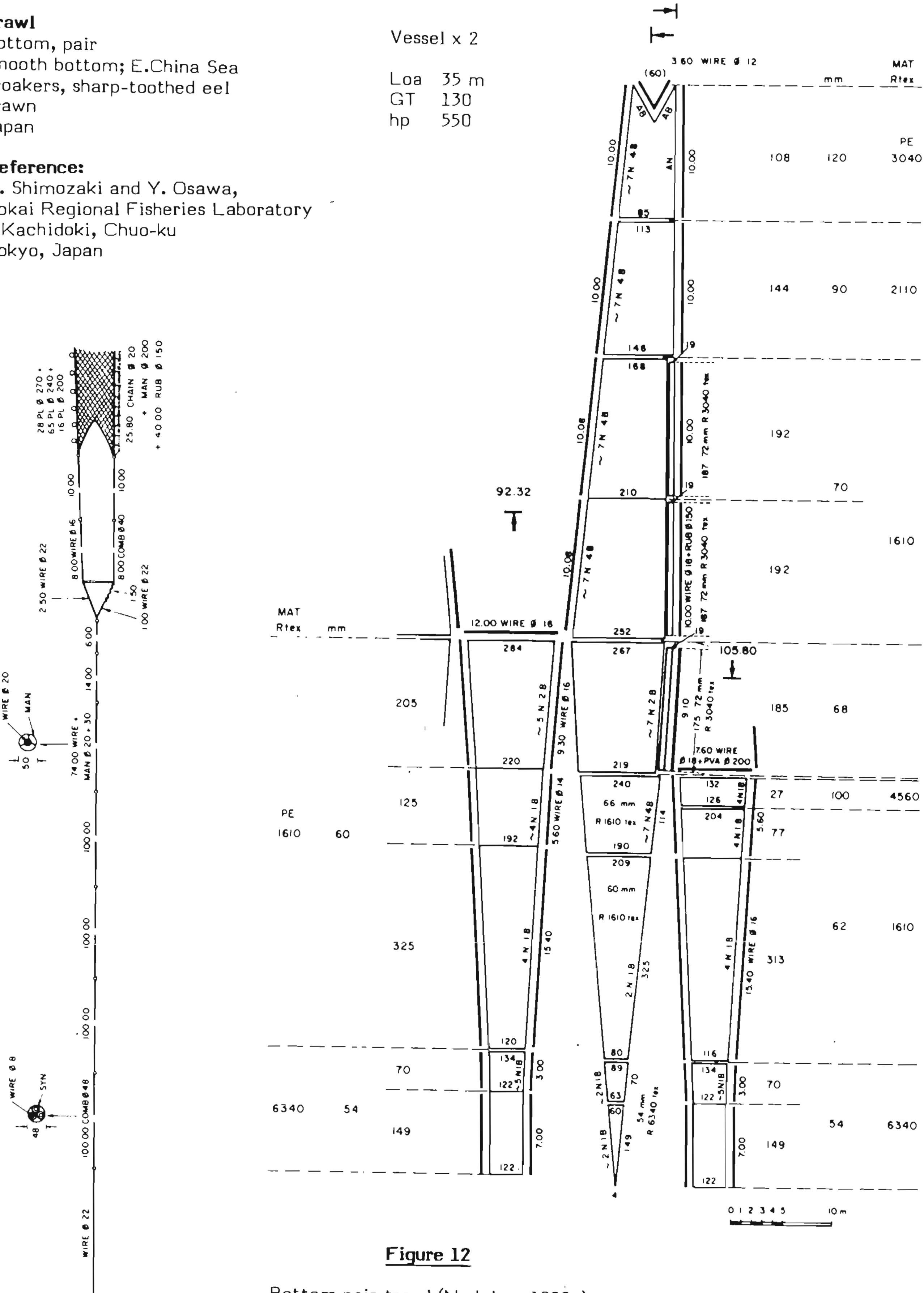


Figure 12

Bottom pair trawl (Nedelec, 1982)

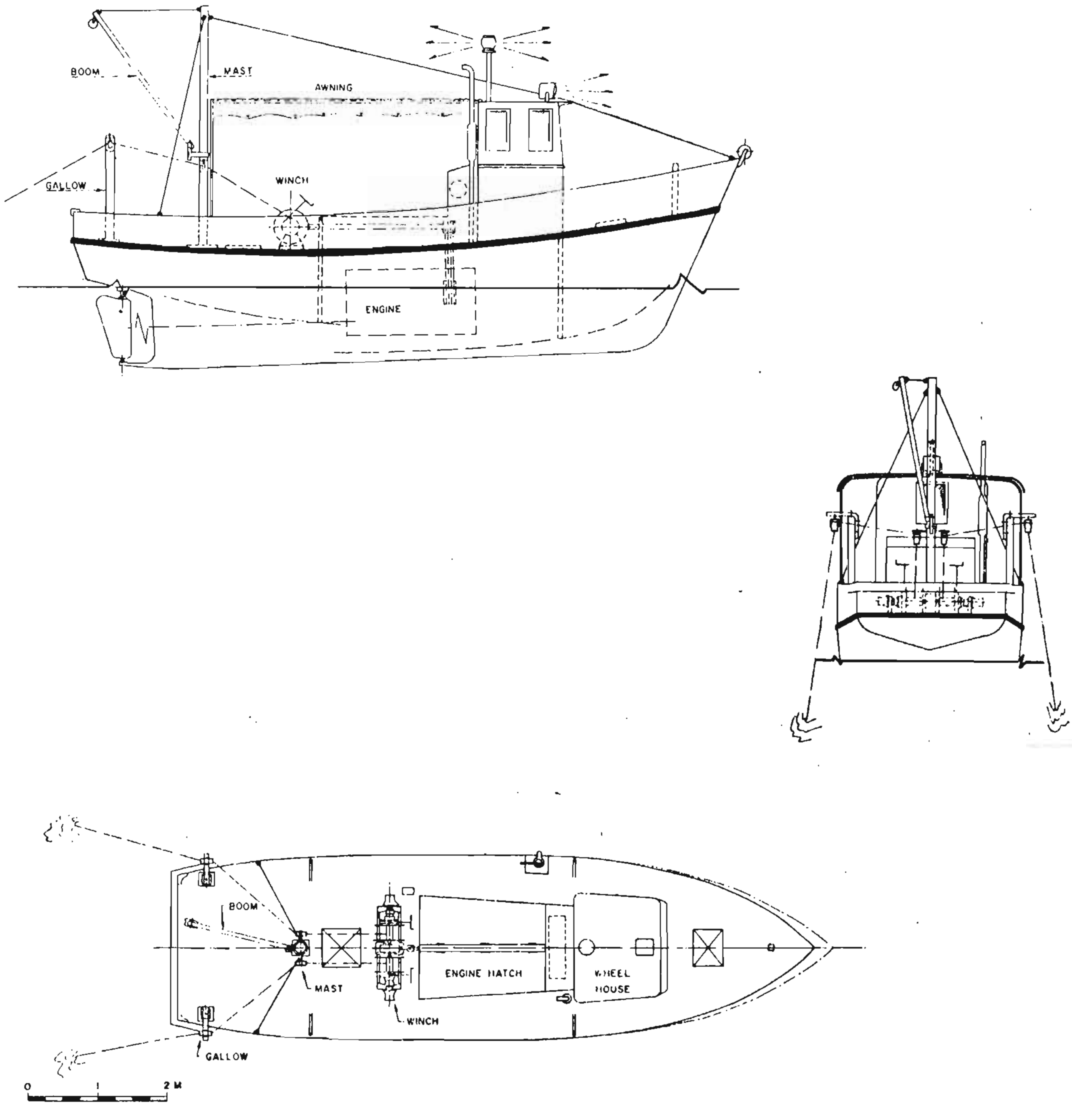


Figure 13

Motorized trawler for artisanal fisheries
(Pajot et al., 1982)

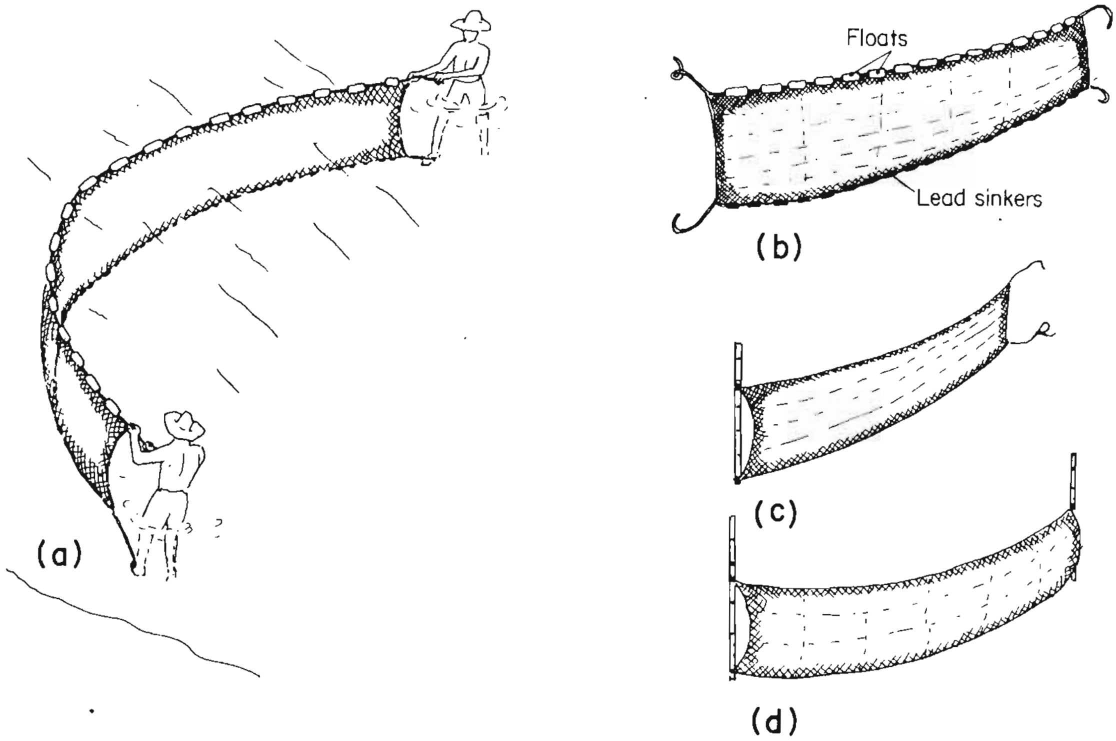


Figure 14 Beach seines without bags:

(a) and (b) "Drag-net"
(c) and (d) Other types without floats and weights (Malaysia)

(Angeles, 1978)

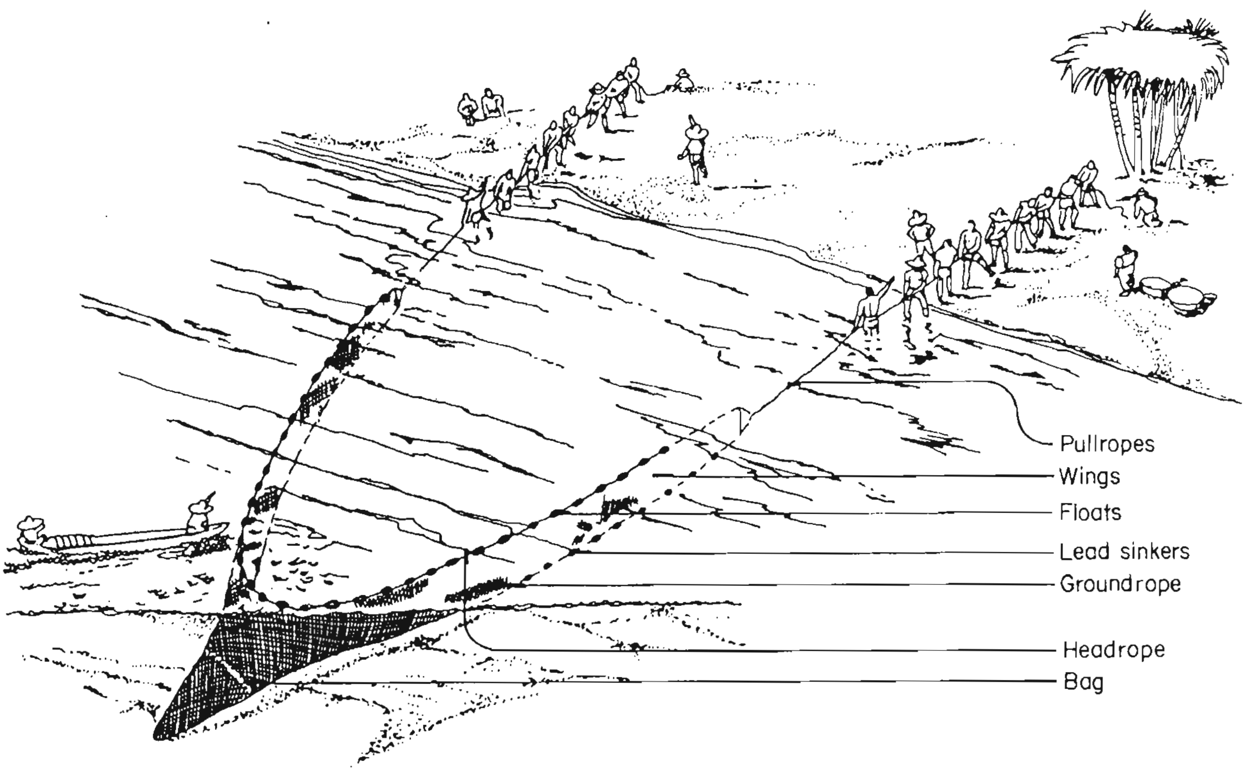
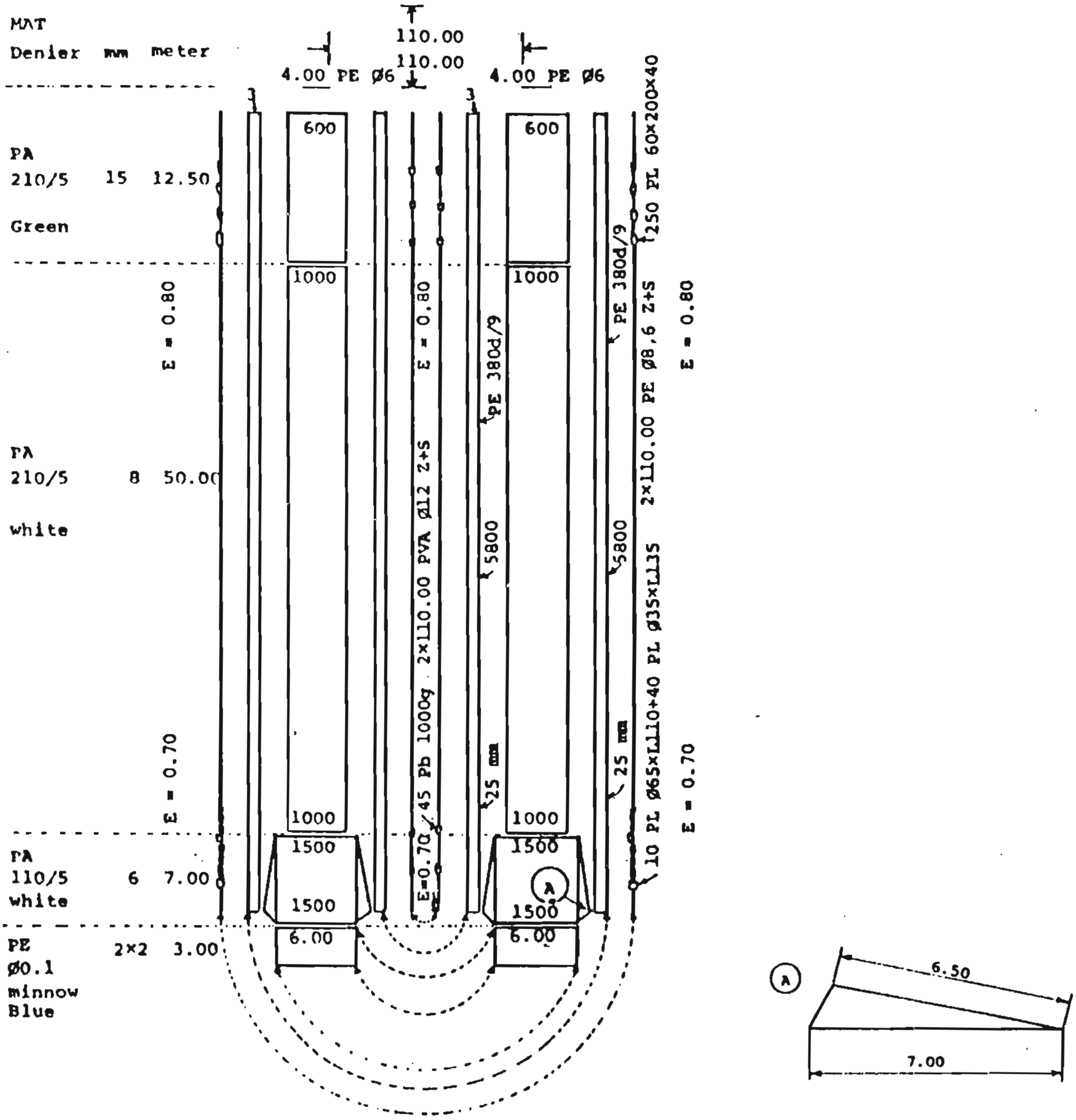


Figure 15 Beach seine with bag: "Pukot" in the Philippines (Smith et al., 1980)



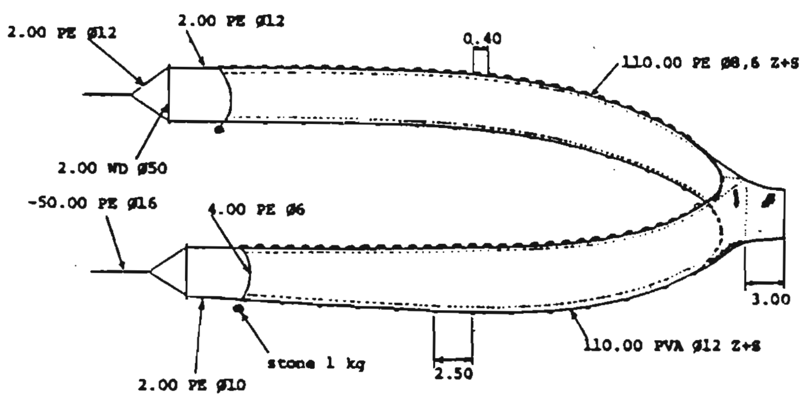
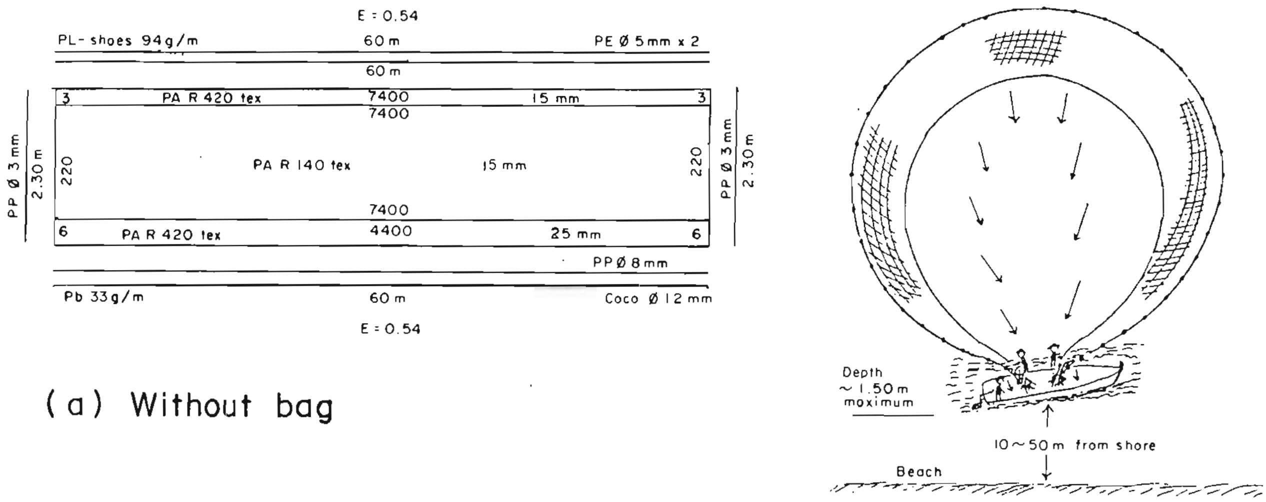


Figure 16 Beach seine with bag for planktonic shrimp (Munprasit, SEAFDEC, 1986)



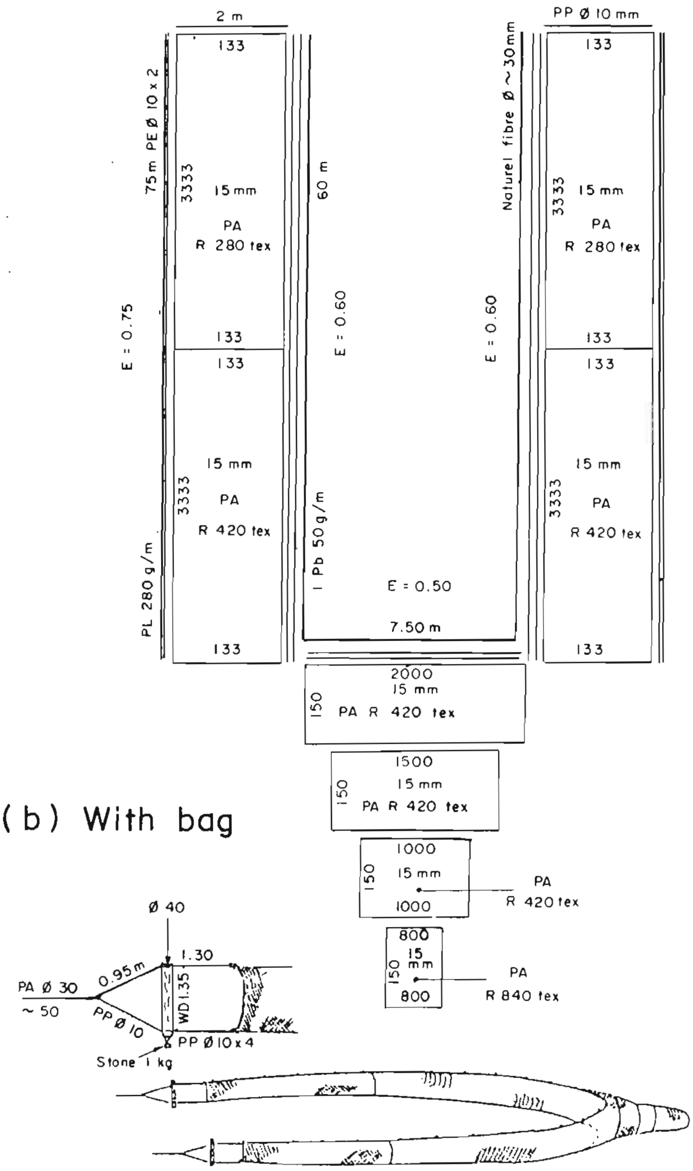


Figure 17 Boat seines used in Sumatra, Indonesia

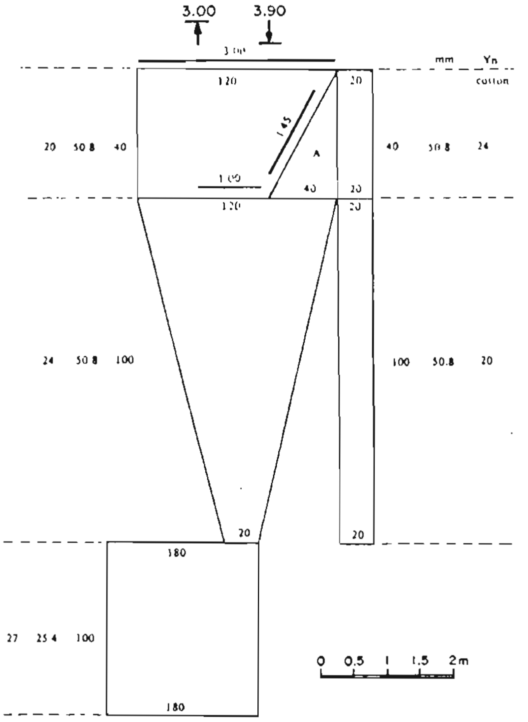


Figure 18 Beam trawl - India (Nomura, 1981)

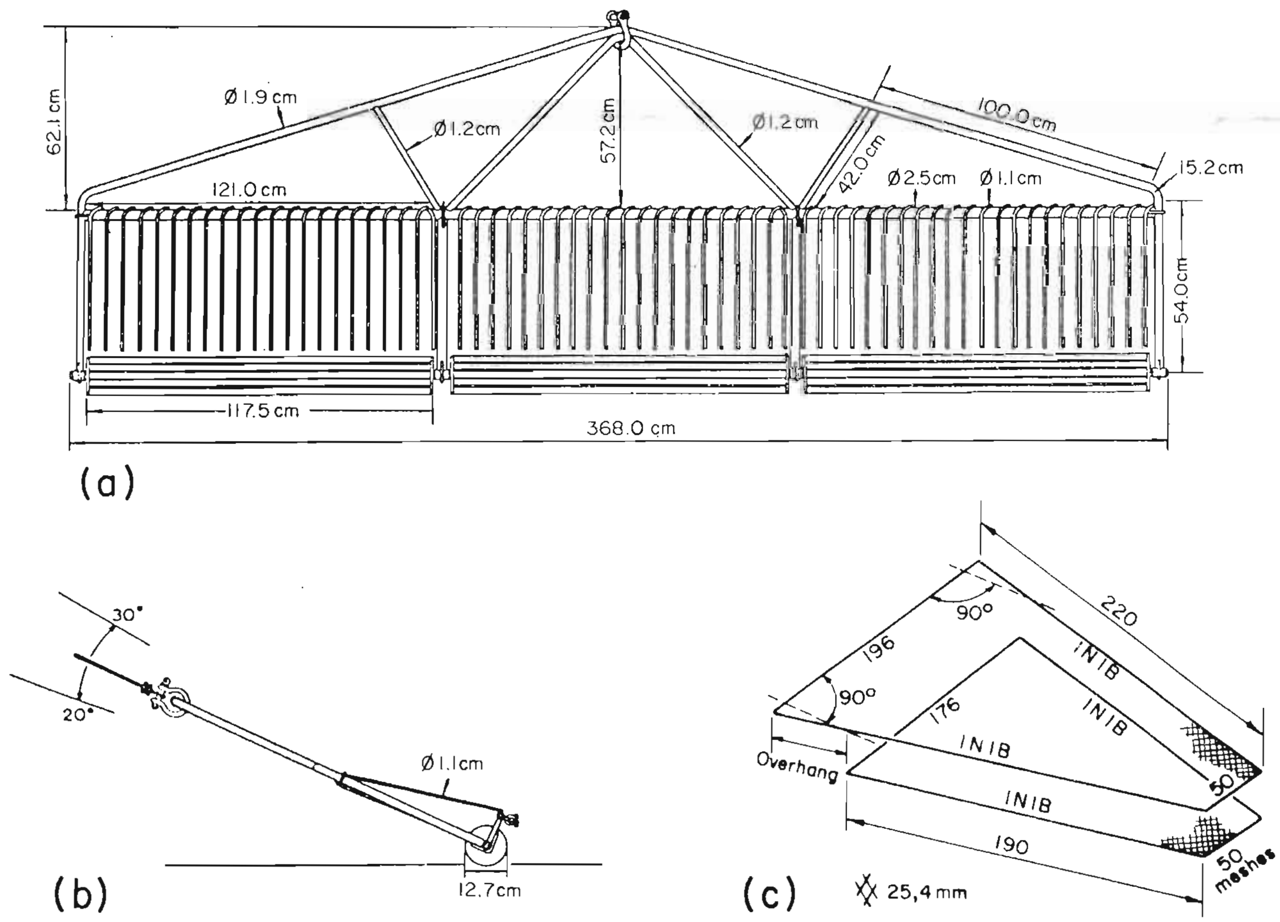
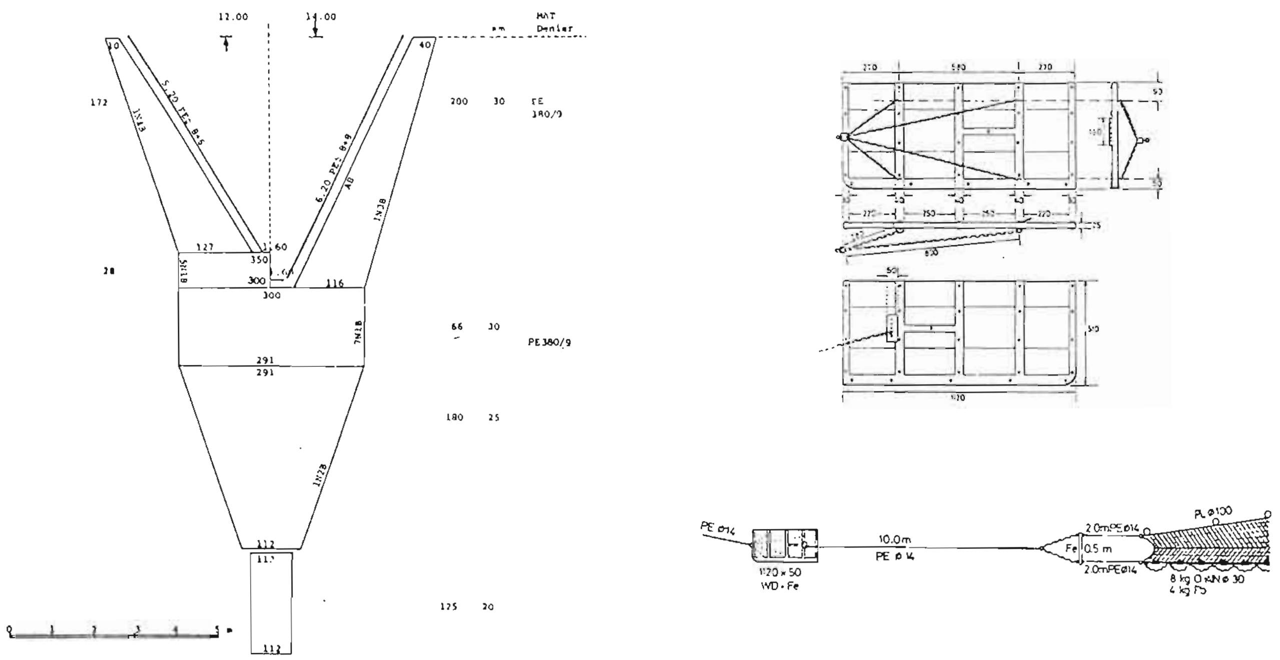
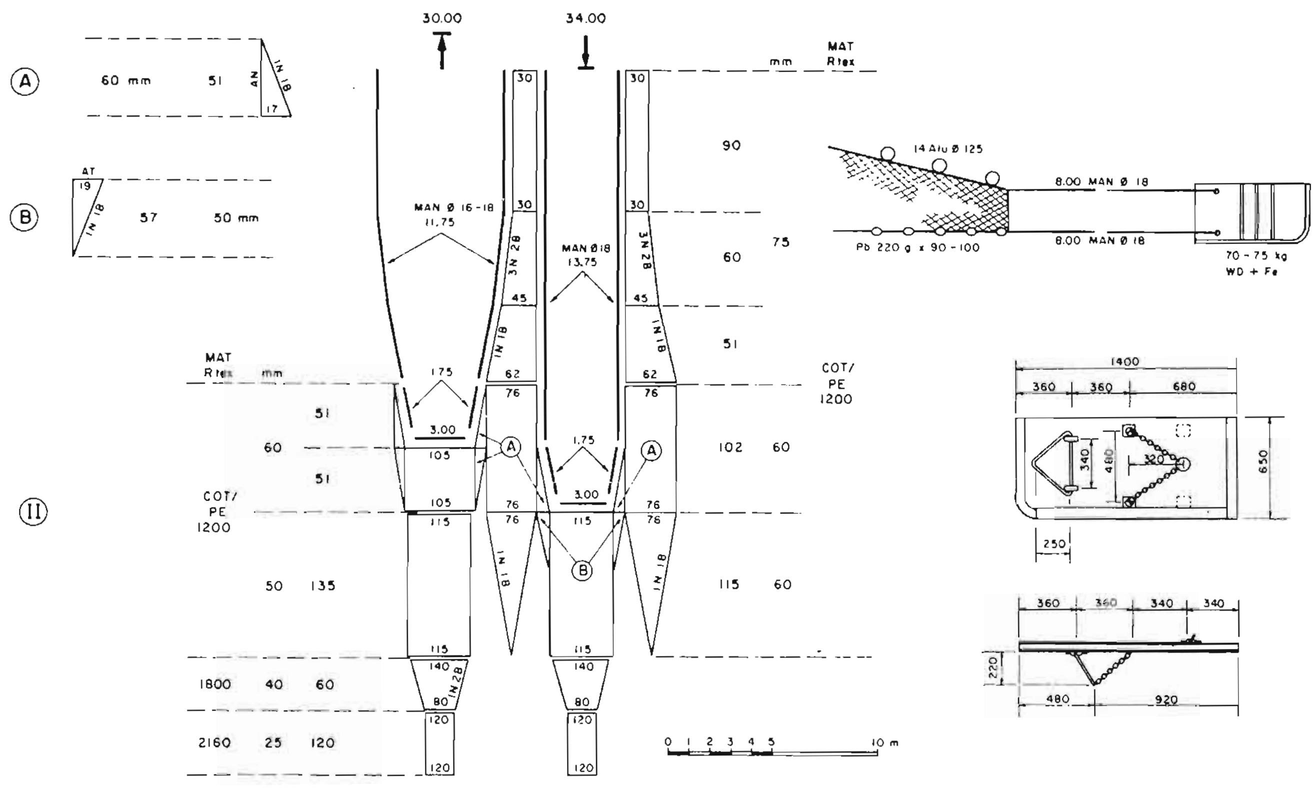


Figure 19 Beam trawl with roller - Florida, USA (Tabb and Kenny, 1969)



(a) Thailand (SEAFDEC, 1986)



(b) India (Nedelec, 1975)

Figure 20 Otter trawls for artisanal fisheries

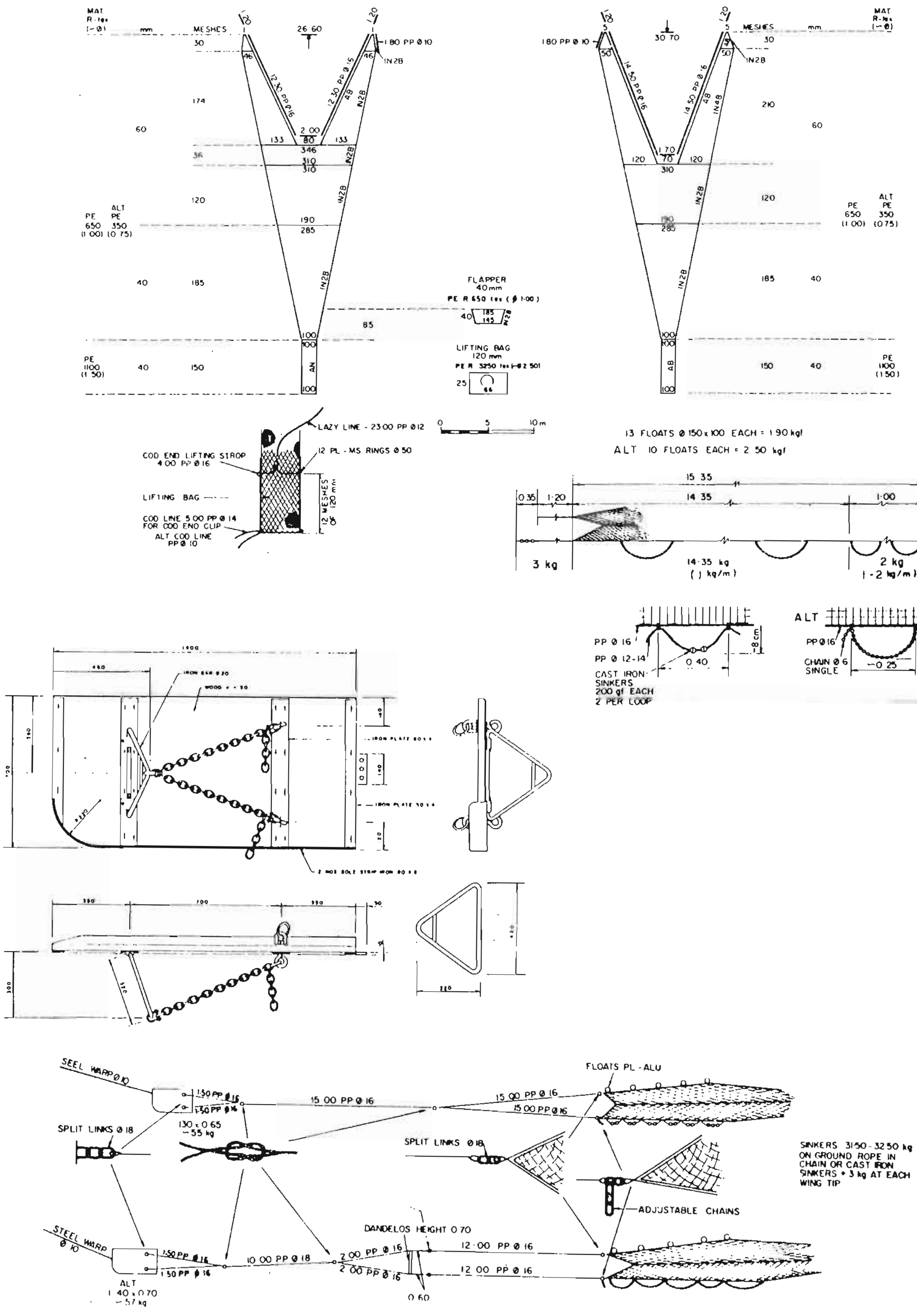


Figure 21 Combination shrimp-fish high opening trawl, for artisanal fisheries - India (Pajot et al., 1989)

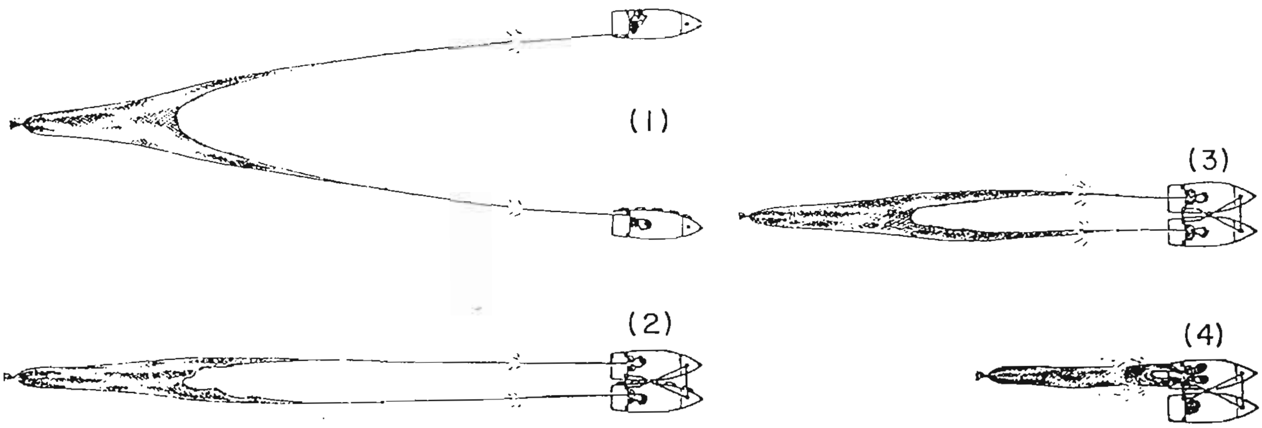


Figure 22 Pair trawl for artisanal fisheries: hauling manoeuvres (Noel and Ben-Yami, 1980)

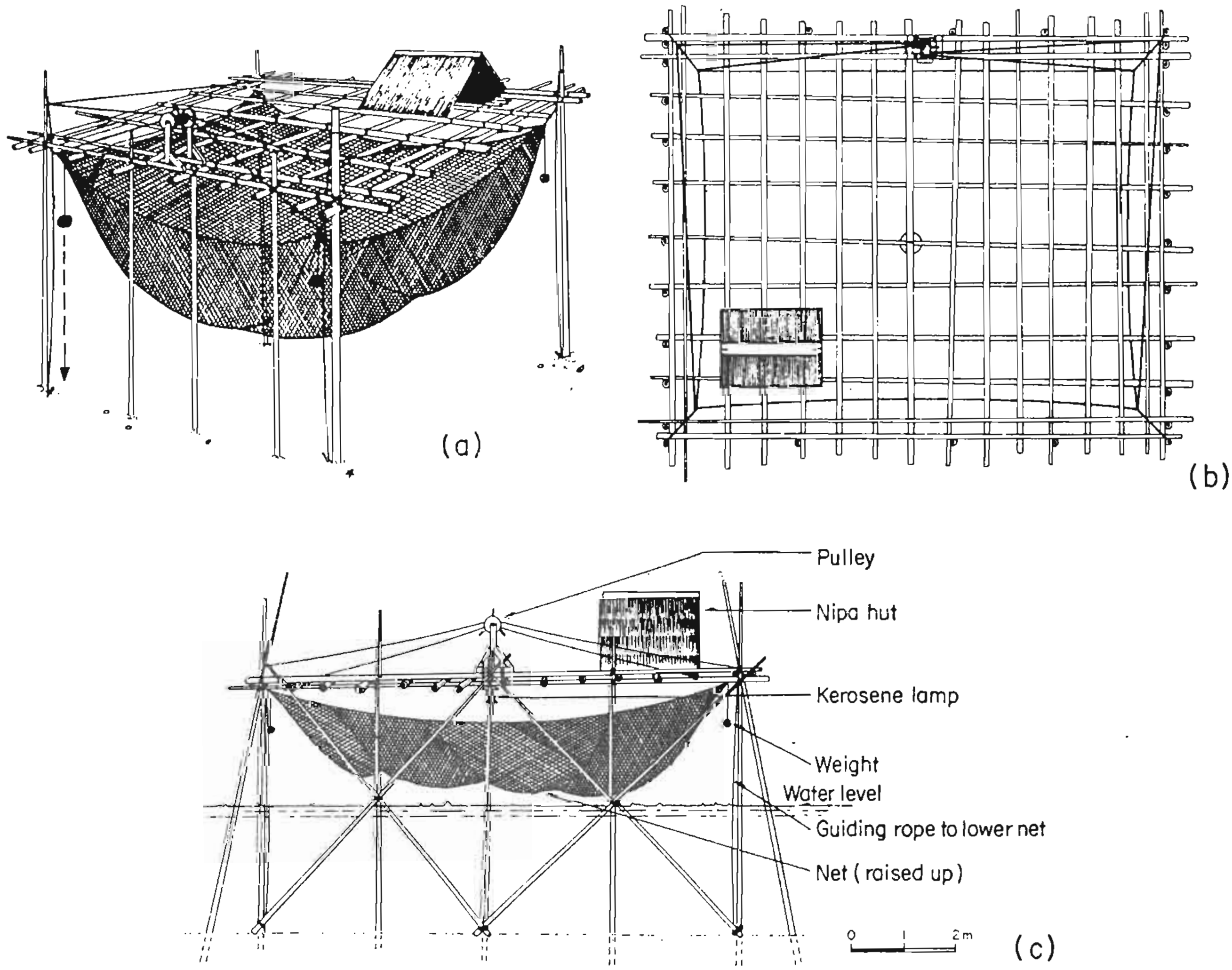
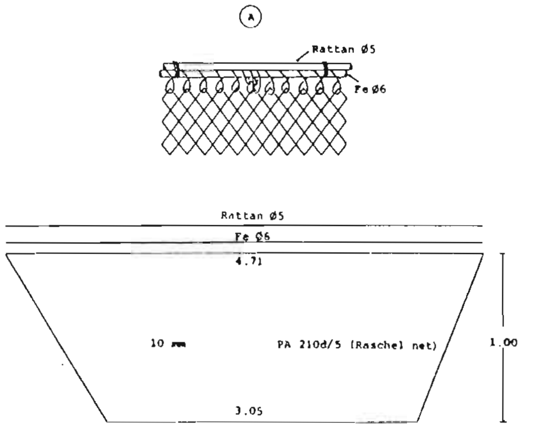
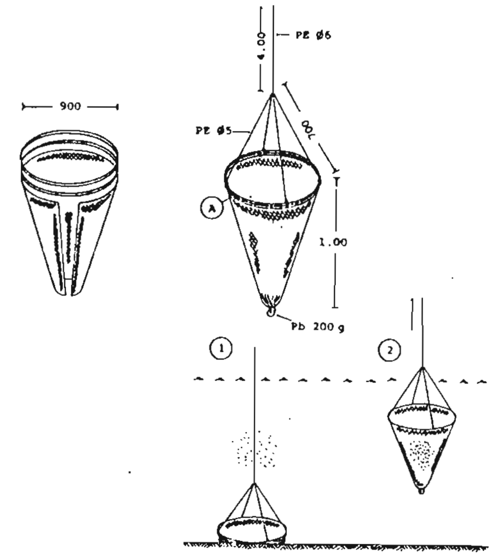
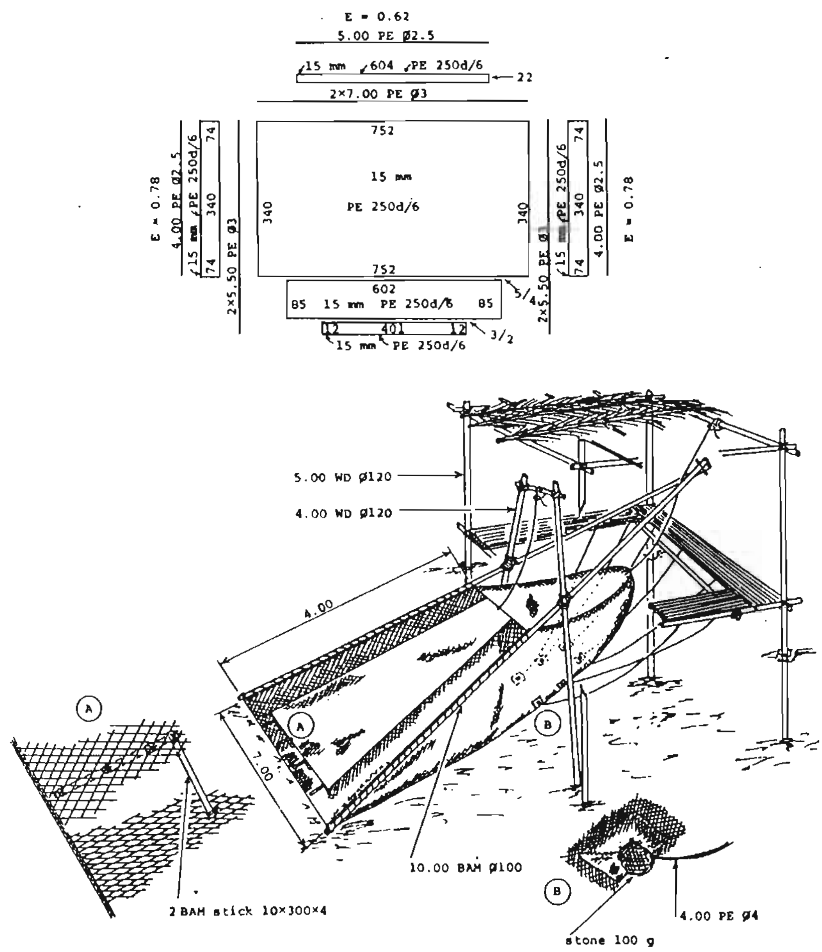


Figure 23 Liftnet of the Philippines (Motoh, 1980)



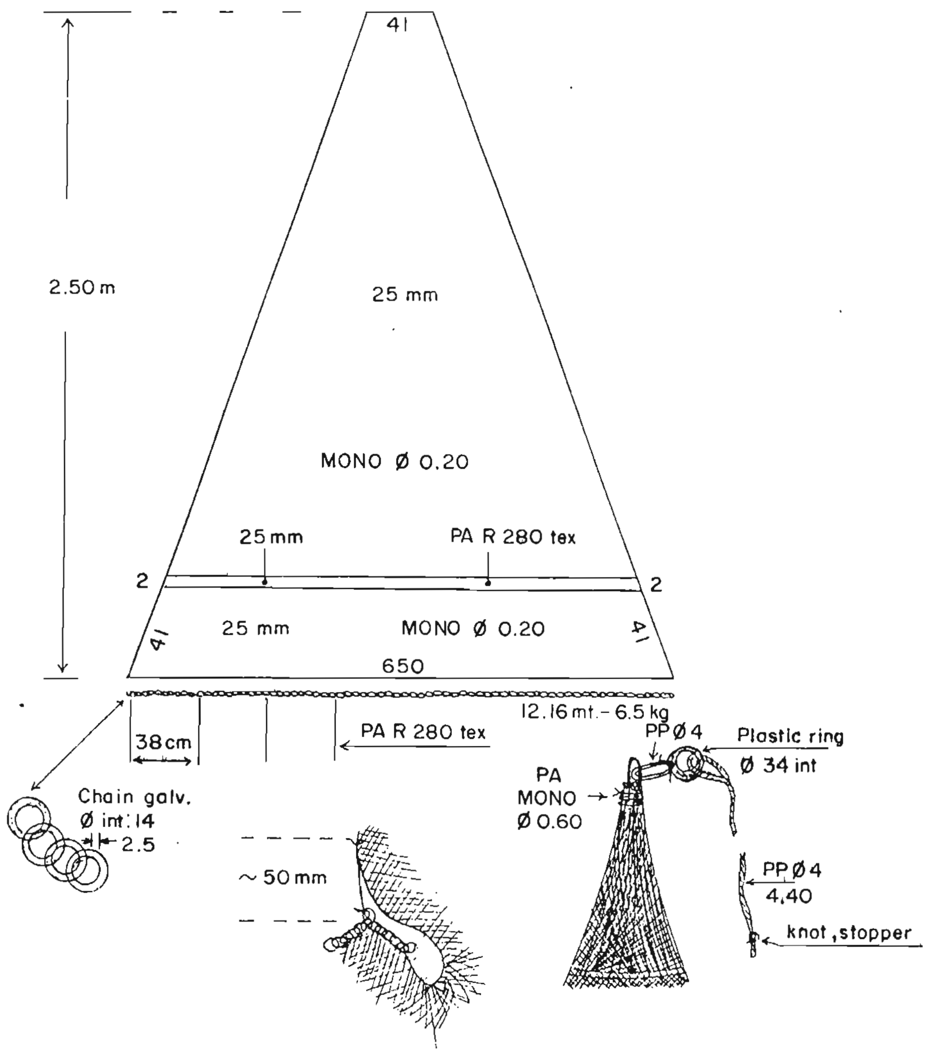


(a) Portable liftnet



(b) Stationary liftnet

<u>Figure 24</u> Liftnet used for shrimp in Thailand (SEAFDEC, 1989)



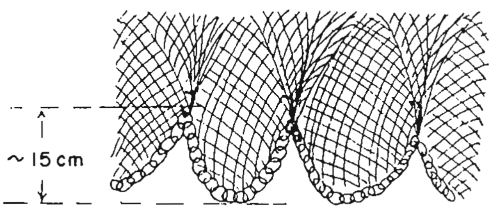


Figure 25 Castnet for shrimp, in shallow water, Sumatra, Indonesia

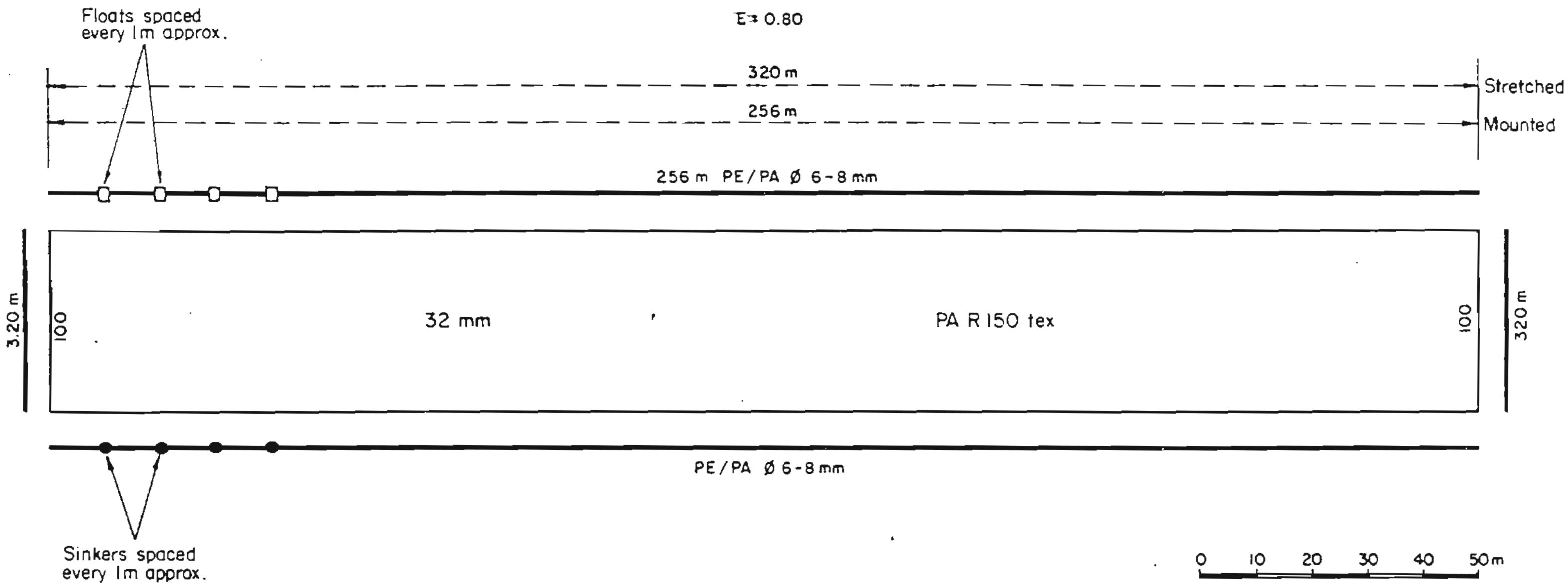


Figure 26 Bottom driftnet for shrimp, "Félé-Félé" of the lagoons in Casamance - Senegal (Lozac'Hmeur, 1981)

(a)

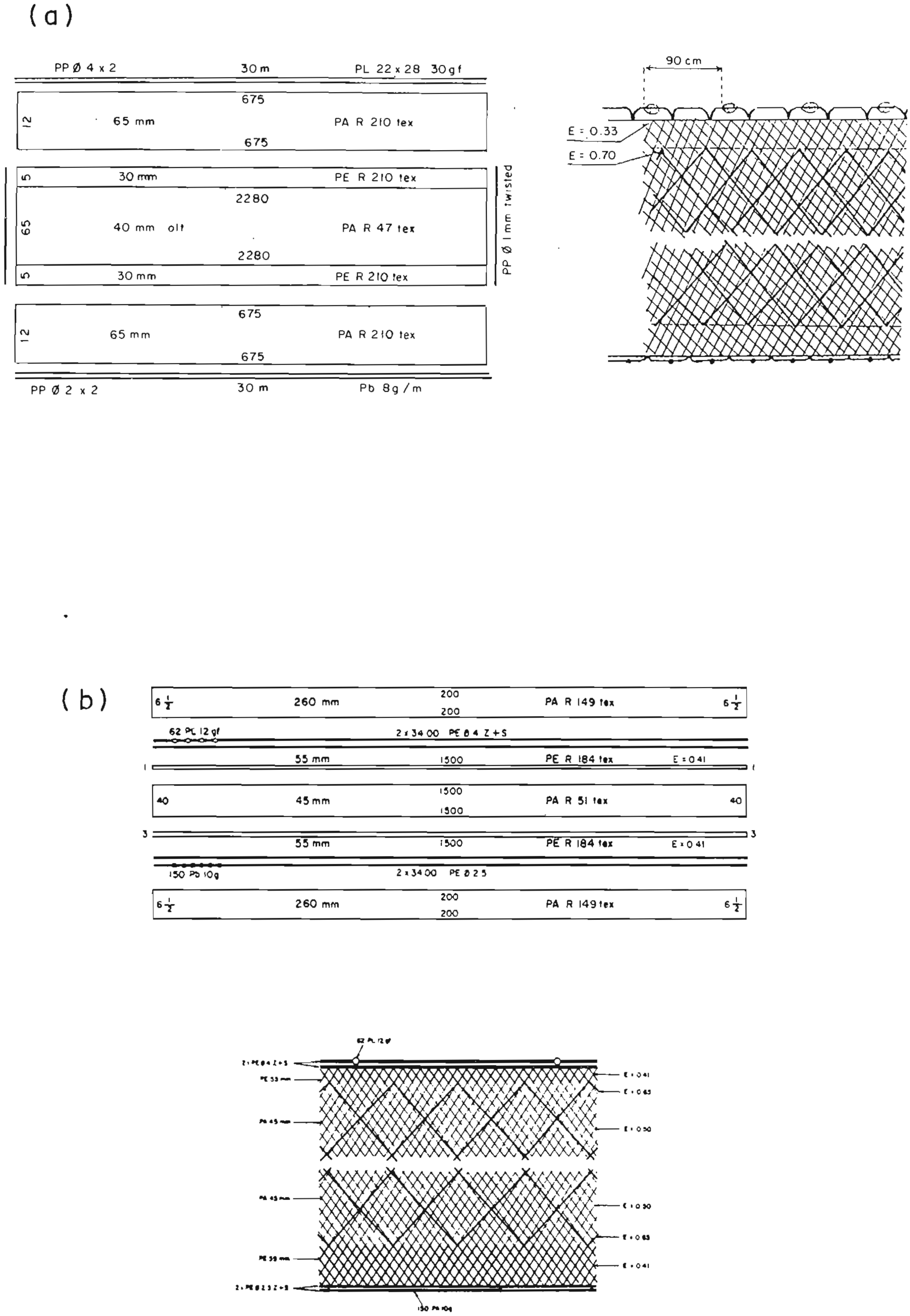


Figure 27 Trammel nets for shrimp (a) in Indonesia (Pajot, 1989)
(b) in Malaysia (Soodham/FAO, 1987)

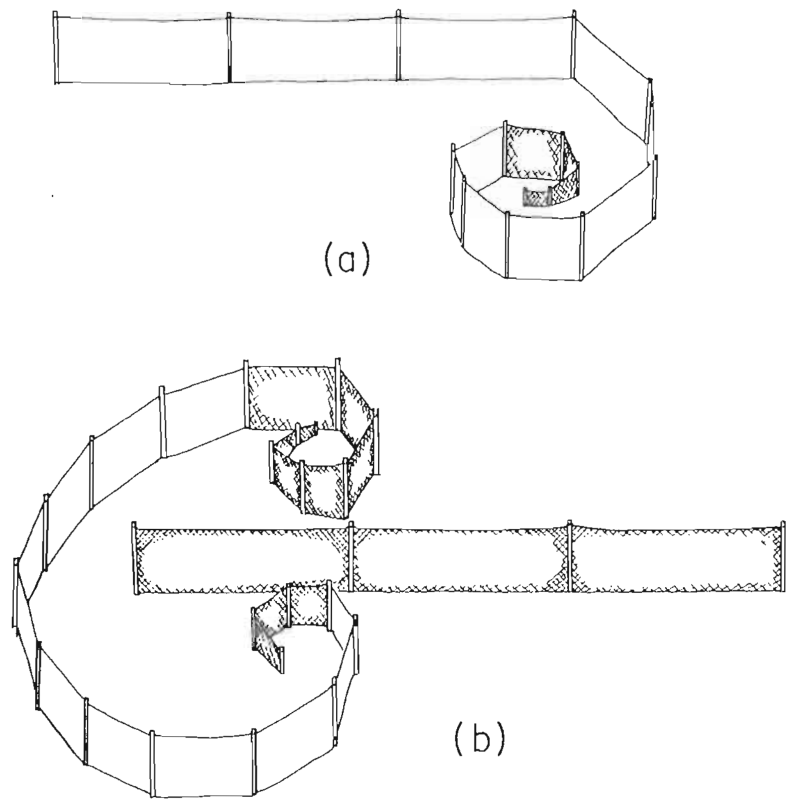
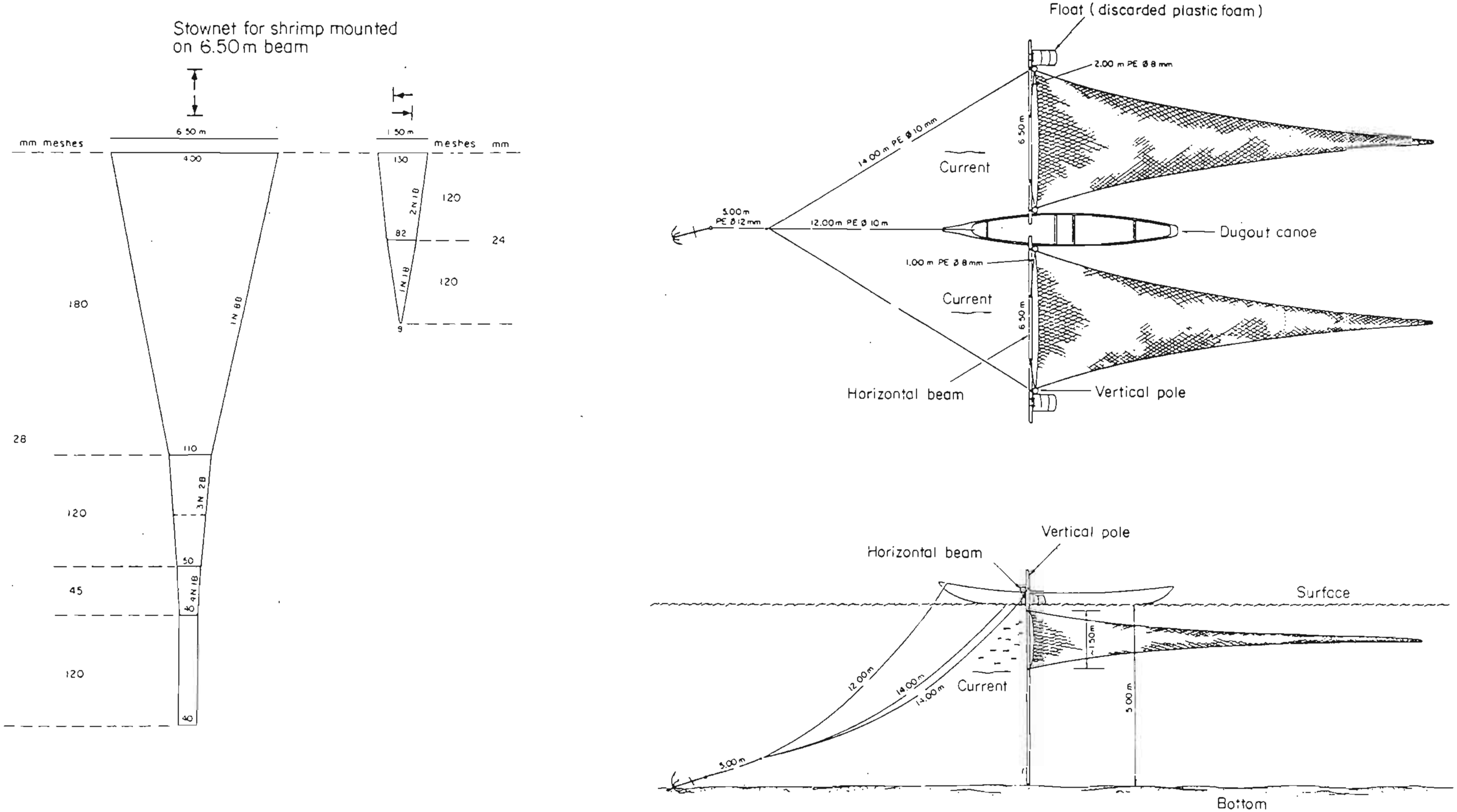


Figure 28 Shrimp trap/weir - India (Kurian and Sebastian, 1982)



<u>Figure 29</u> Stow net (Stake net) for dugout canoes in Casamance, Senegal (Lozac'Hmeur, 1981)

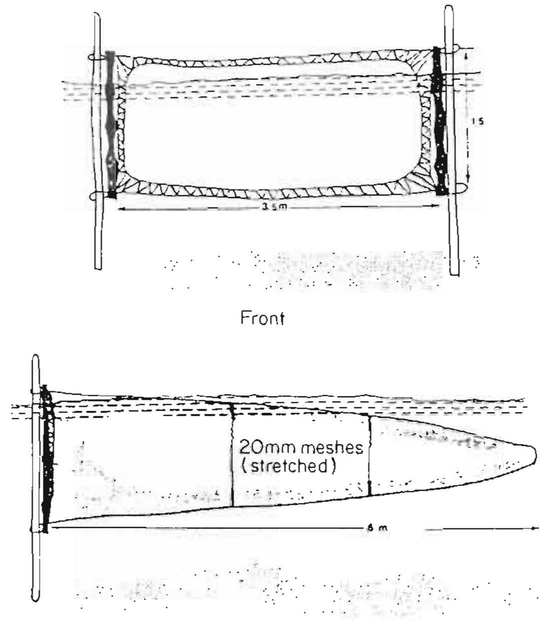


Figure 30 Stow net (Stake net) for Ivory Coast lagoons (Garcia, 1977)

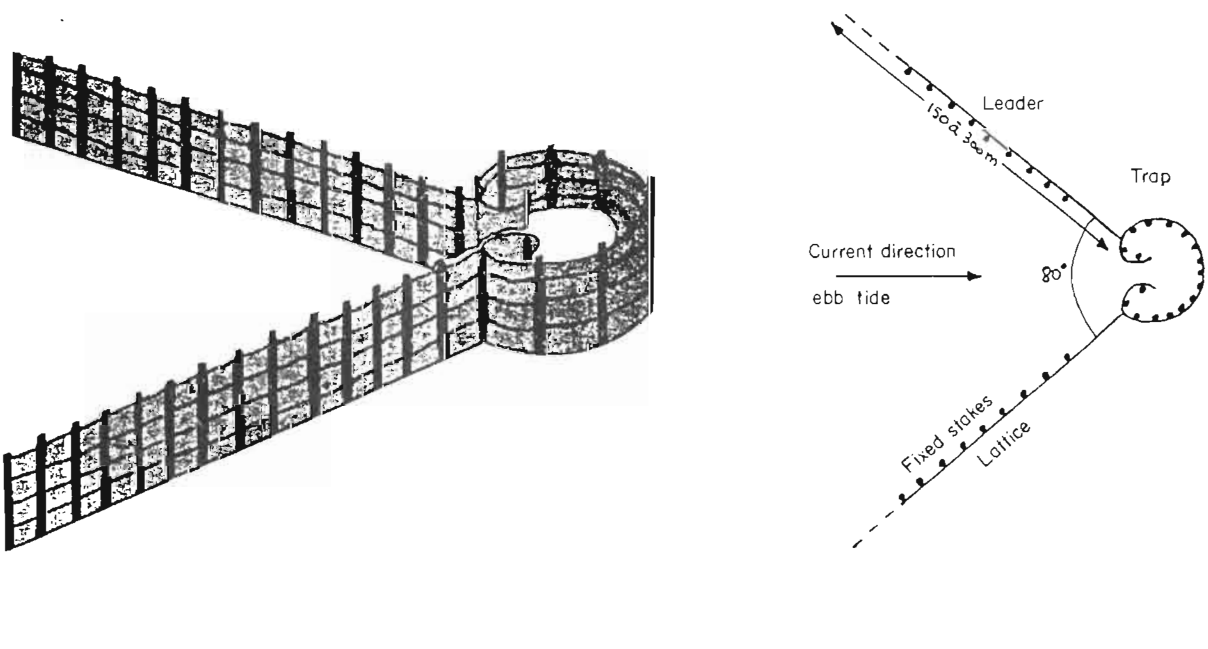


Figure 31 Coastal barrier/weir net of Madagascar (Crosnier, 1965)

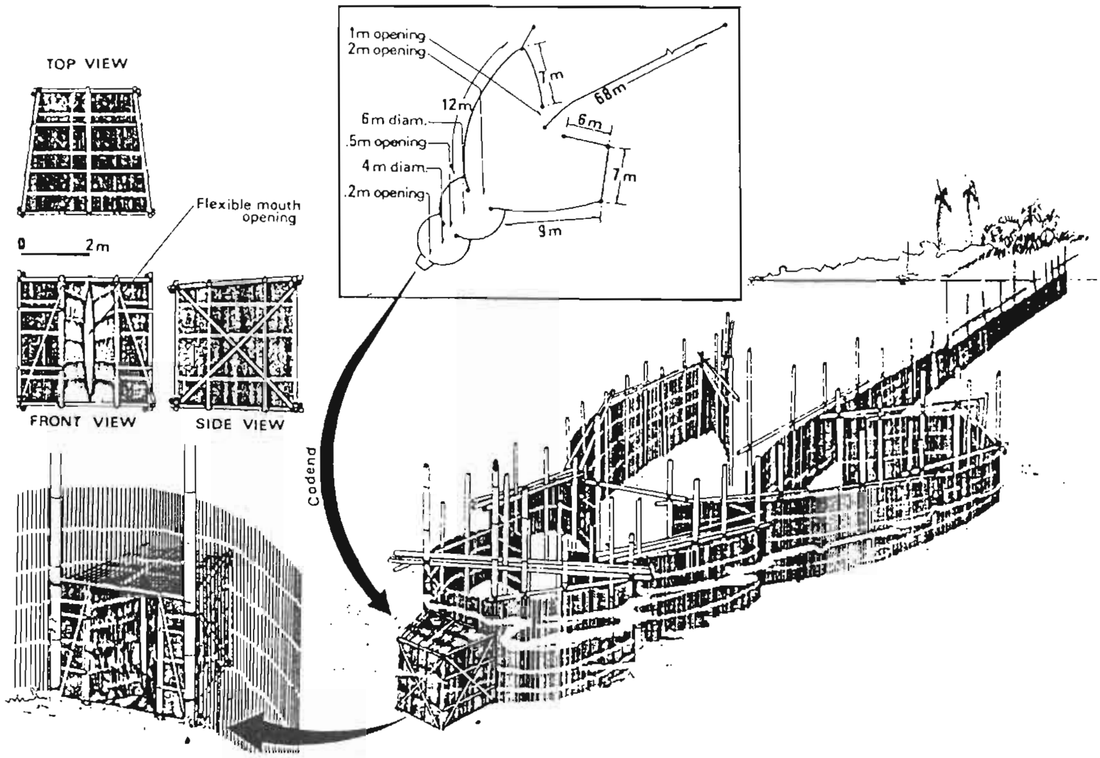


Figure 32 Fish corrals of the Philippines (Motoh, 1980)

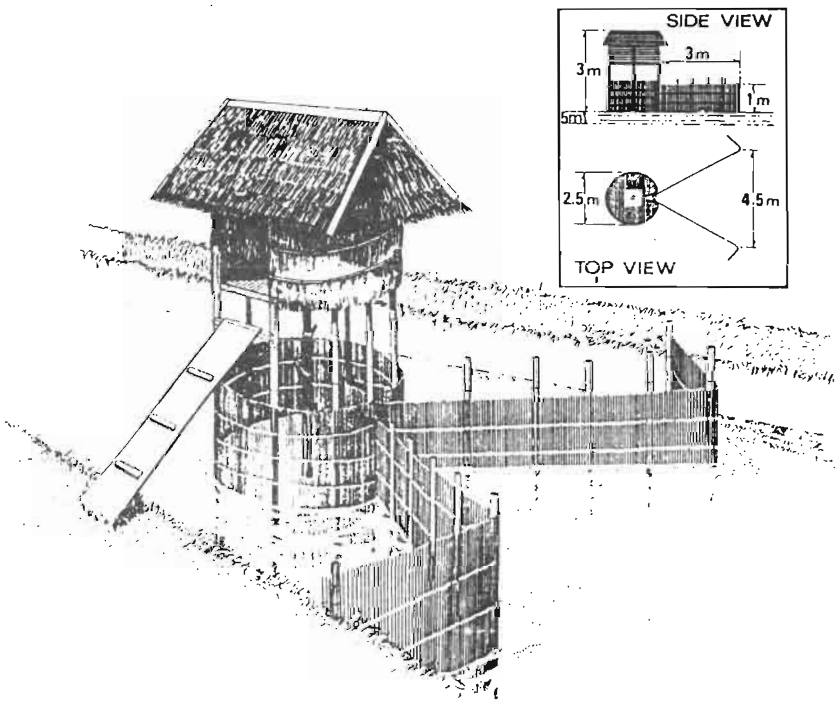


Figure 33 Canal weirs of the Philippines (Motoh, 1980)

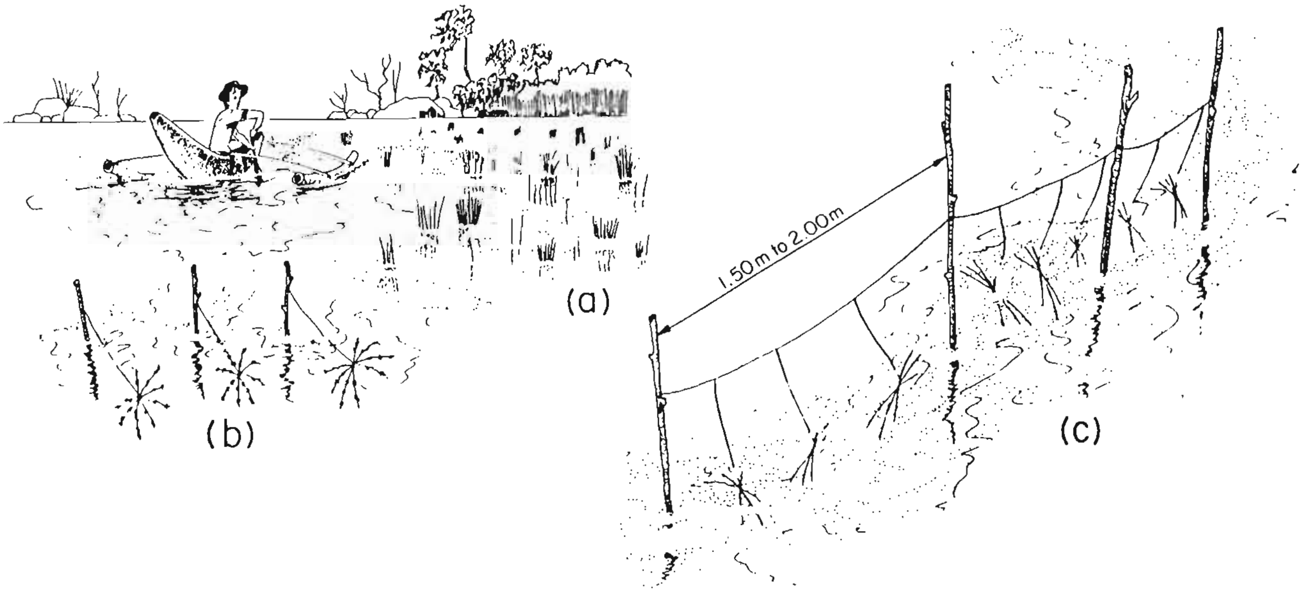


Figure 34 Branch trap in the Philippines: the lures (Paspalum vaginatum) are either: (a) planted on the bottom, (b) suspended from wooden stakes, or (c) suspended to ropes passing from one stake to another (Motoh, 1980)

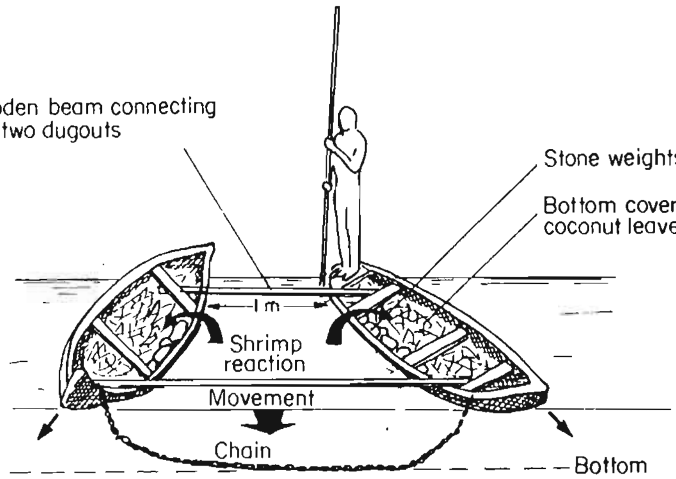


Figure 35 Aerial trap in inland waters - India, coastal swamps and lagoons (see text) (Kurian and Sebastian, 1982)

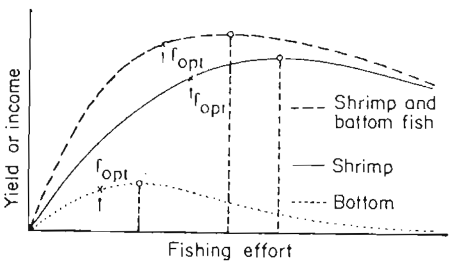


Figure 36 Theoretic curve of yields for a combined shrimp-fish fishery (Caddy, 1982)

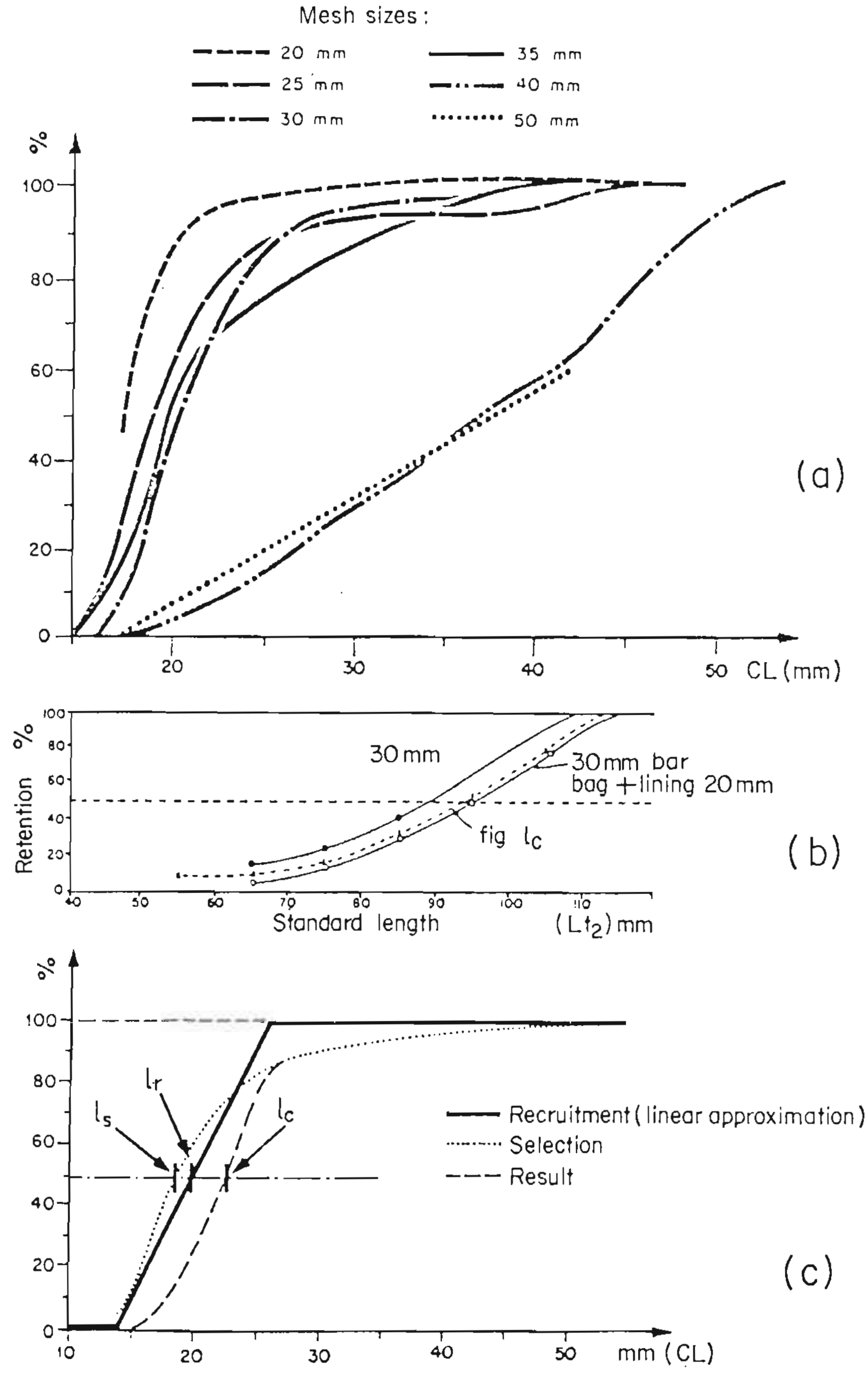
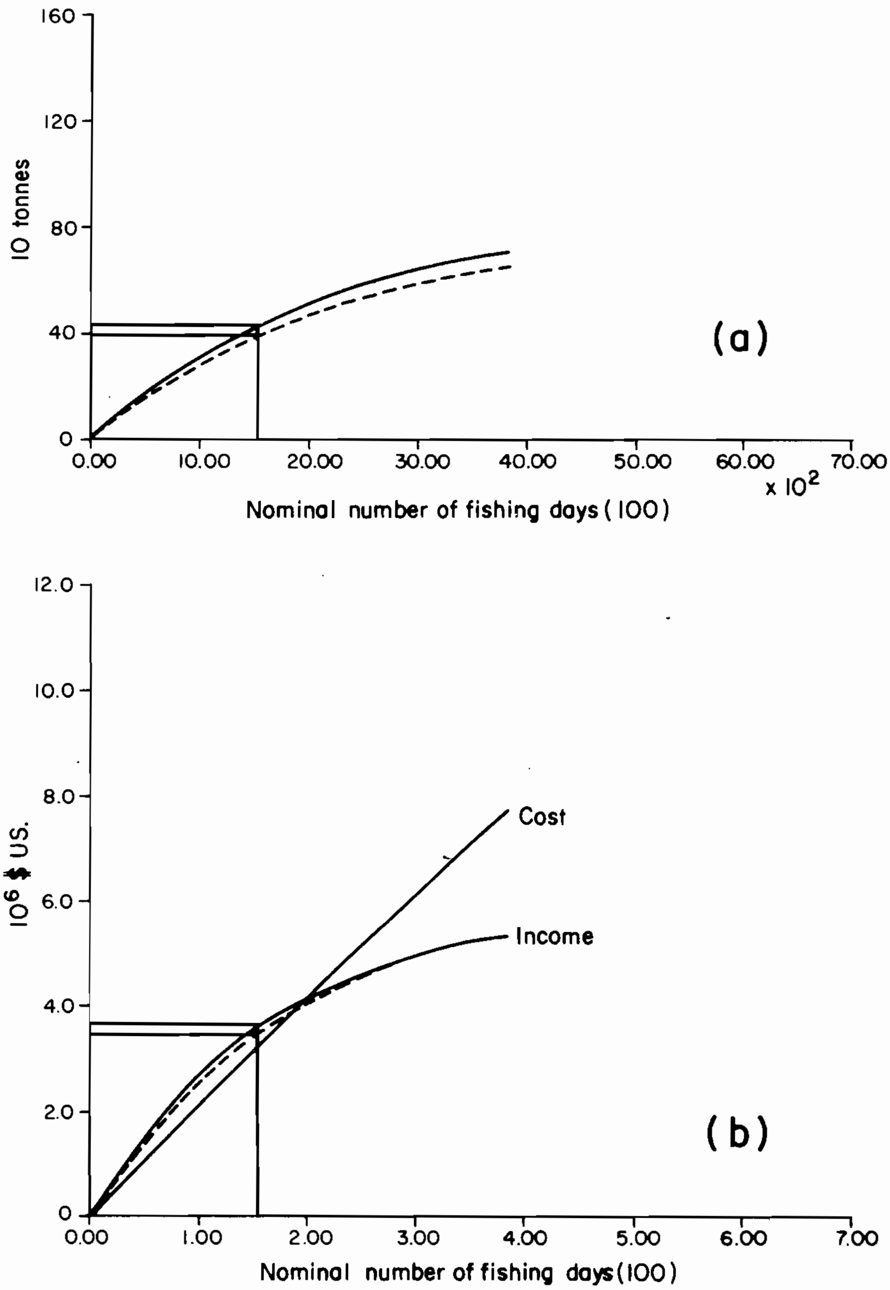


Figure 37 Selection curves for industrial bottom trawls:
(a) Between 20 and 50 mm bar mesh for Penaeus notialis in Senegal (Lhomme, 1978)
(b) For a 30 mm bar mesh for P. duorarum in Campeche Gulf (Simpson and Pérez, 1975)
(c) Selectivity, recruitment and result curves for P. notialis in Senegal (Lhomme, 1978)



<u>Figure 38</u> Effect on mesh change in industrial fisheries - comparisons:

(a) Annual landings

(b) Income and costs in the Ivory Coast, by simulation in accordance with a model considering meshing regulations which would increase the first catch size from 27.67 mm CL (——) to 29.51 CL (---)

(Griffin and Grant, 1982)

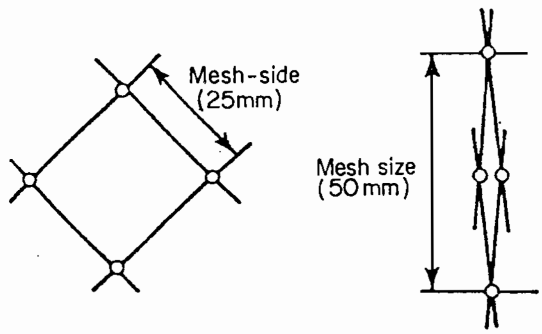


Figure 39 Different mesh measurements (Franqueville and Lhomme, 1979)

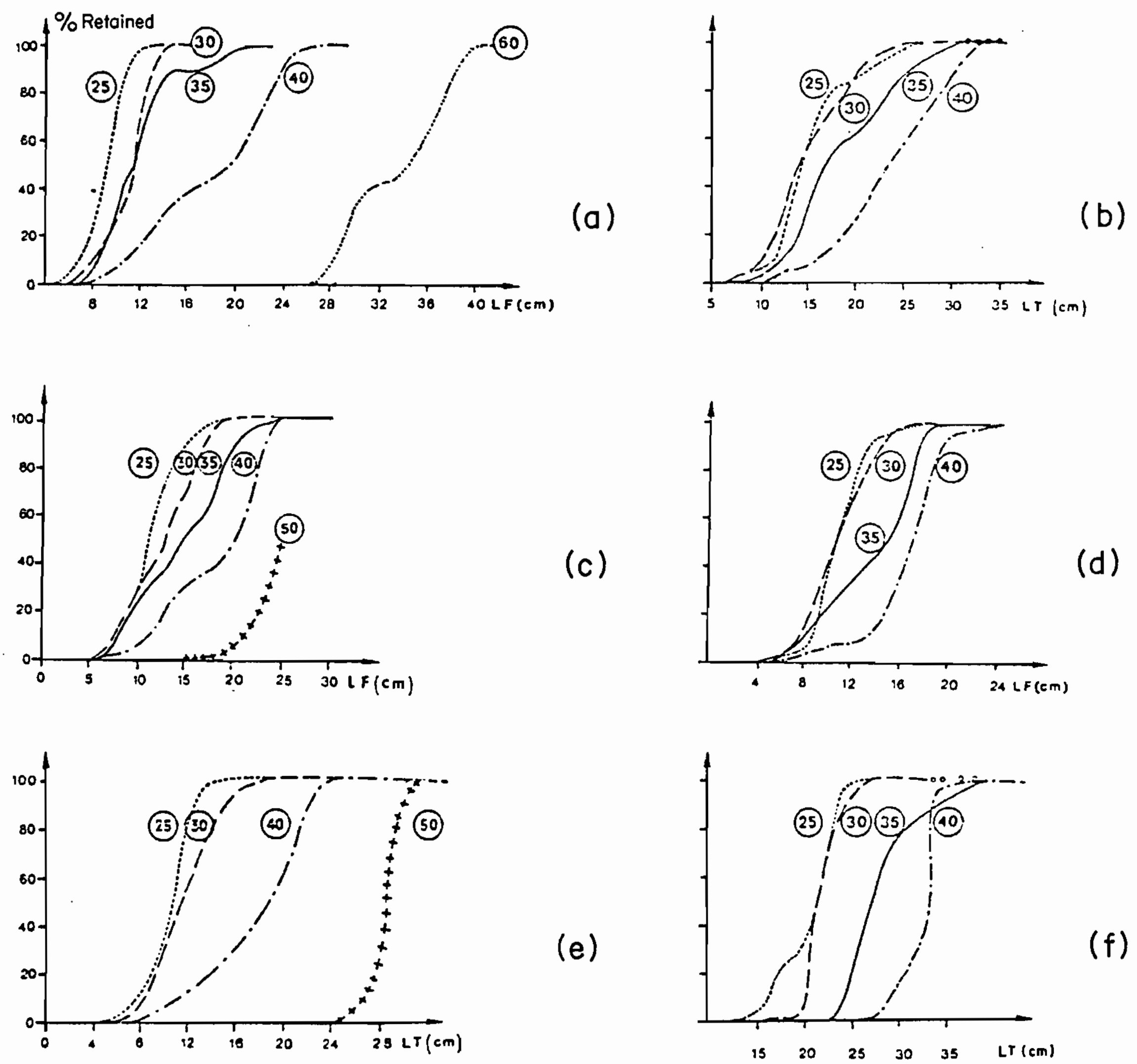


Figure 40 Selection curves for fish in Senegal (Fraqueville and Lhomme, 1979)

(a) Arius sp., (b) Pseudotolithus senegalensis and P. typus,
(c) Pseudupeneus prayensis, (d) Brachydeuterus auritus,
(e) Syacium micrurum, and (f) Cynoglomus canariensis and C. goreensis

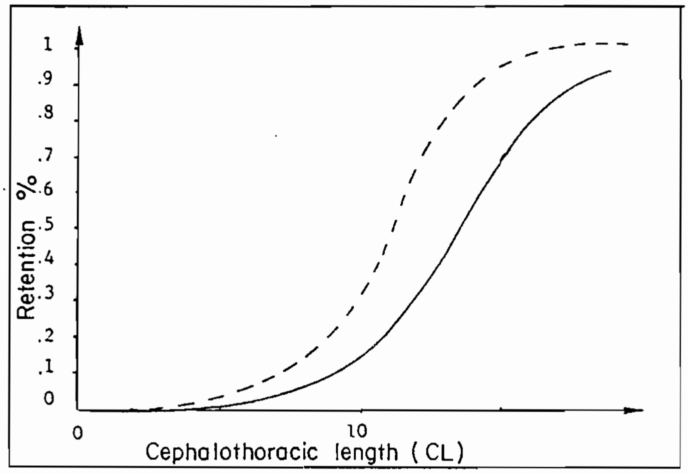
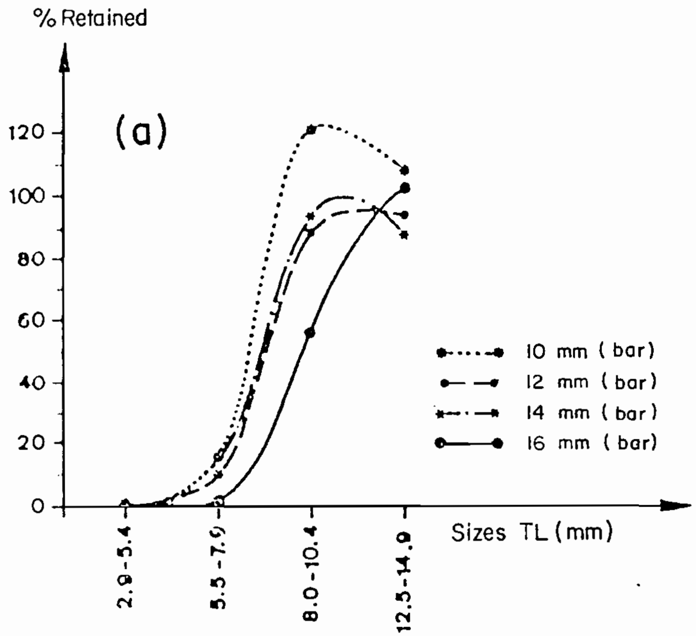
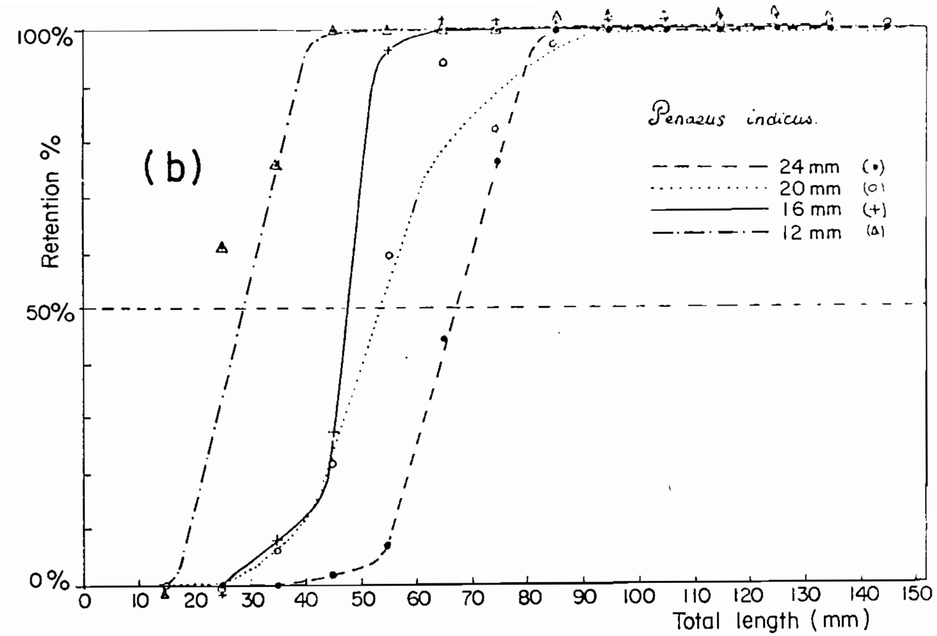


Figure 41 Selection curve of small-scale (---) and industrial (---) trawl fishing in the Persian Gulf (El Musa, 1982)





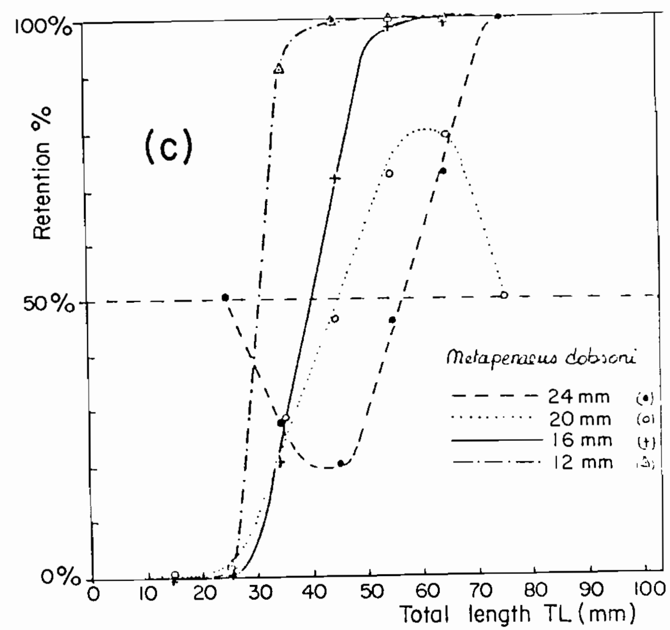


Figure 42 Selection curves for stow nets:

(a) In Ebrié lagoon (Cote d'Ivoire) for 10 to 16 mm mesh bar, for Penaeus duorarum notialis (Garcia and Lhomme, 1977a), and in India for 12 to 24 mm mesh

(b) For P. indicus

(c) For Metapenaeus dobsoni

(According to data by George et al., 1974)

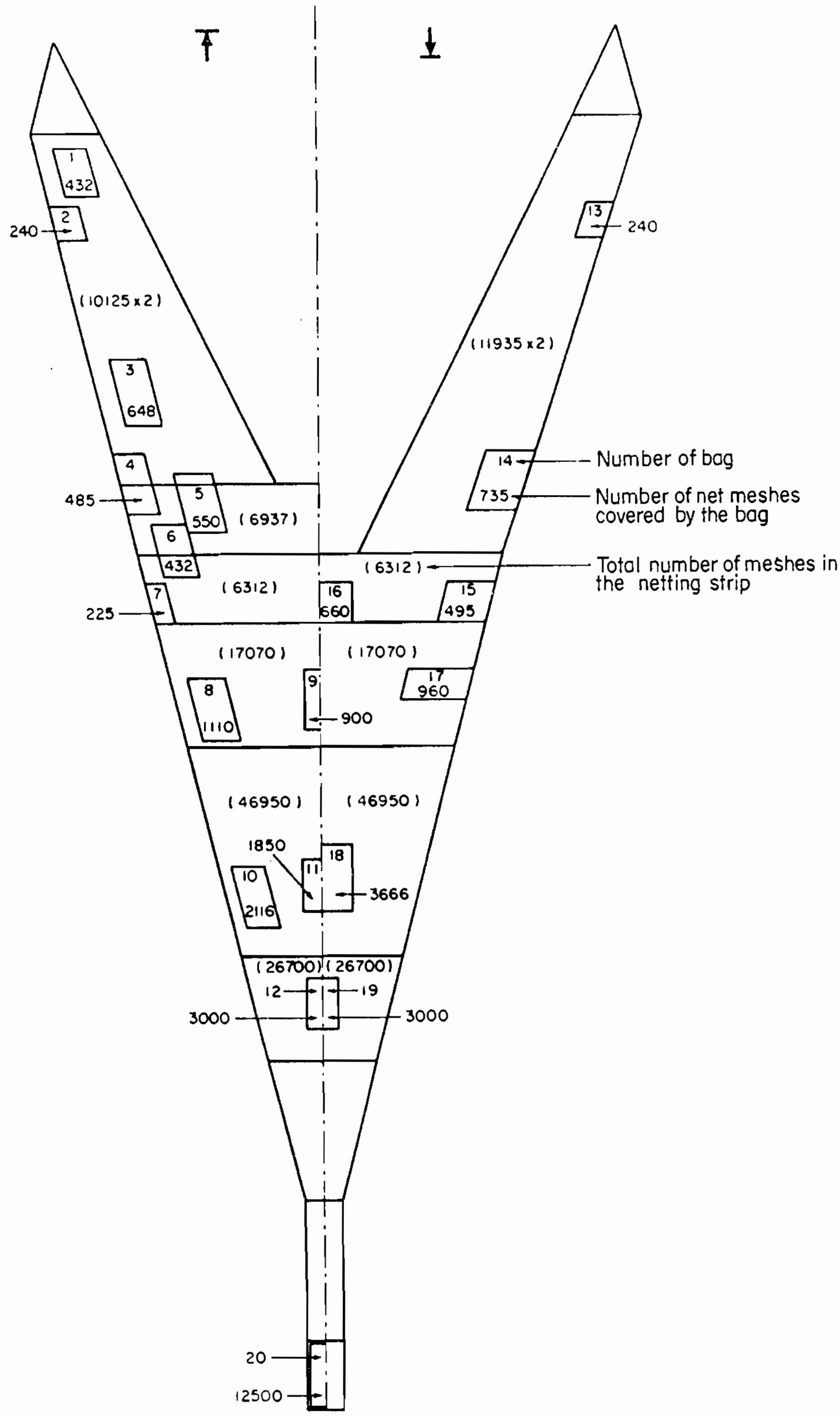


Figure 43 Position of bags on an experimental bottom trawl; the mesh size of the bags is between 20 and 25 mm (Giudicelli, 1978)

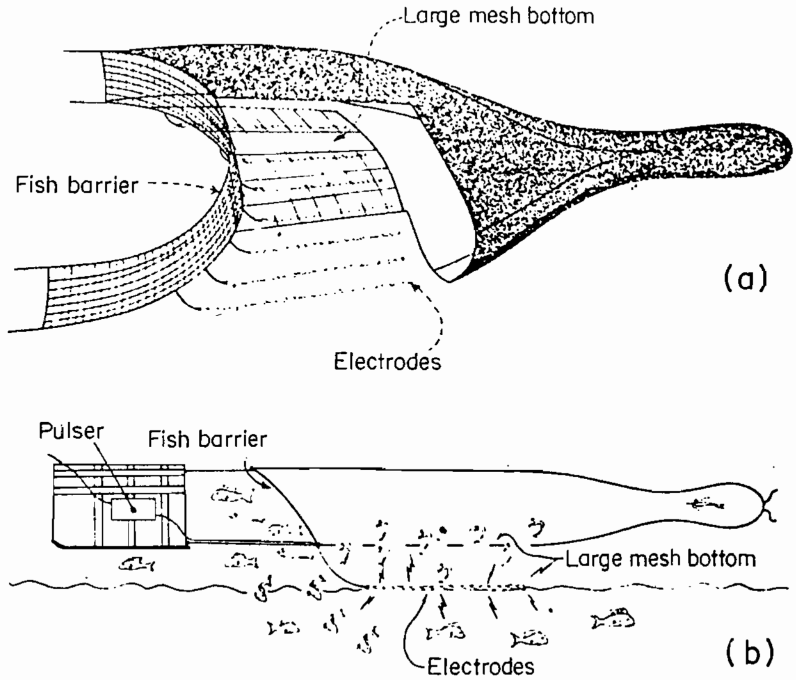


Figure 44 Example of electrified shrimp selective trawl: (a) overall view; (b) side view (Seidel and Watson, 1978)

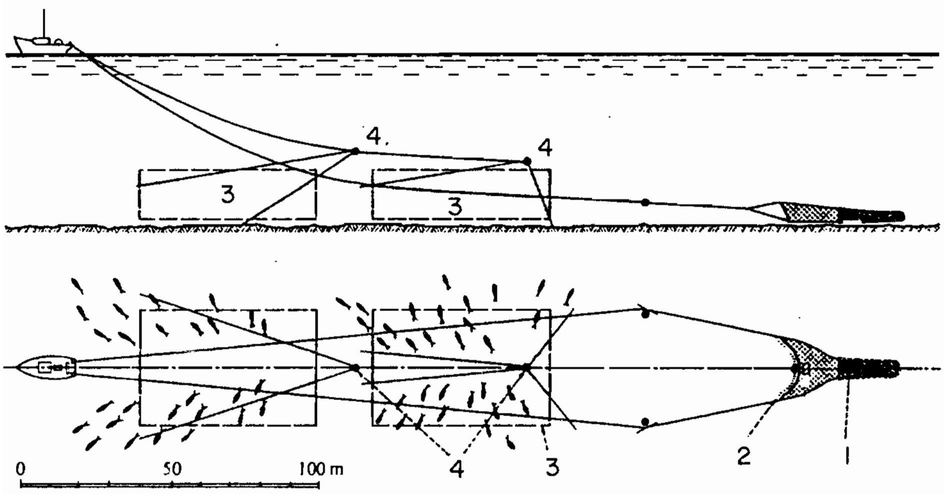
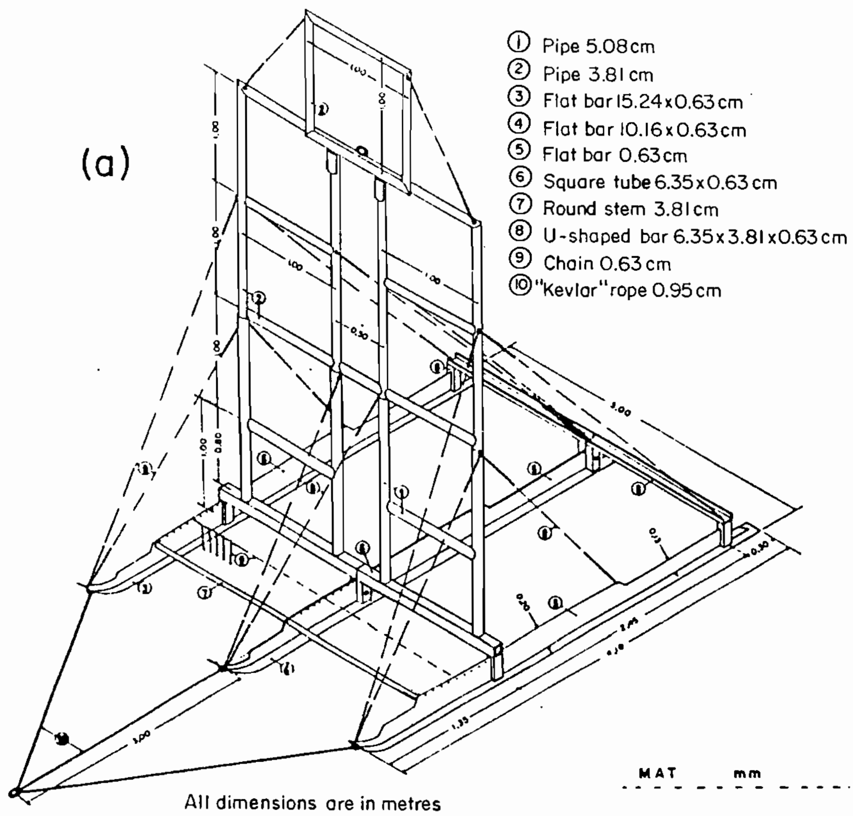
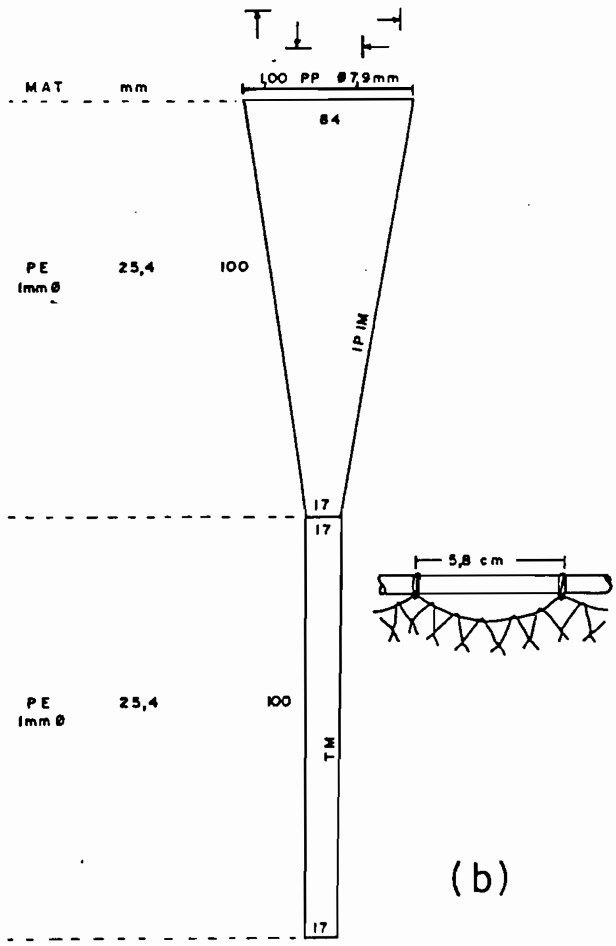


Figure 45 Selective device using several sources of stimuli (Sternin and Allsopp, 1982)

1) escape panel on the codend
2) battery for the electrodes
3) area affected by different stimuli
4) possible positions for the generator of stimuli





<u>Figure 46</u> Vertical shrimp sampling device:
(a) overall view; (b) drawing of one of the small trawls
(Fontaine <u>et al.</u>, 1982)

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