STUDIES ON THE TECHNOLOGICAL ASPECTS AND ECONOMIC EFFICIENCY OF TRAWL GEAR OPERATING ALONG THE COCHIN COAST

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CERTIFICATE

This is to certify that this thesis is an authentic record of research work carried out by Sri. K.C. Bellarmine, M.Sc., under my supervision and guidance in the Department of Industrial Fisheries, Cochin University of Science and Technology, in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY, and that no part thereof has been submitted for any other degree.

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DECLARATION

I, K.C. Bellarmine, do hereby declare that the work presented in this thesis is the result of my own investigations and neither the thesis nor any part thereof has been accepted nor is being submitted for any other degree. All the sources of information have been duly acknowledged.

K.C. Bellarmine

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CHAPTER I

INTRODUCTION

The trawl is a bag shaped net comprising several components viz. conical net with wings at the front end and codend at the other, ropes associated with the net and floats and sinkers for achieving vertical opening and otter doors for spreading the mouth horizontally. Many variations from the typical basic design have evolved and have been described by many authors. Bullis (1951), Scharfe (1959 a), Glanville (1961 a, b), O'grady (1951) and Fridman et al. (1973) have dealt with the design aspects, while, Garner (1956, 1957 a, b, c, d, e, f and g, 1962, 1967), Scoffield (1948), Denisov (1959), Fuss (1963 a, b), Brandt (1954), Dickson (1965), Fraser (1965), Miyazaki (1964) and Nomura et al. (1977), have dealt on the construction; Hodson, (1942), Garner (1956, 1961), Scoffield (1948), Margetts (1963 a, b) and Kristjonsson (1968) have described the method of trawl operation.

Basically trawls are considered to be further developments of towed bagnets, dredges and beam trawls, to facilitate bigger and broader nets (Brandt, 1972).

Being a towed gear, the efficiency of a trawl is directly related to the size of the mouth opening and in order to achieve a greater mouth opening, the initial attempts involved the towing of frameless bagnets from cables rigged from two outrigger poles. This method is practiced in some European and Asiatic Fisheries. But due to limitations of using longer outrigger poles the size of the mouth of the nets could not be enhanced beyond a certain limit. With the advent of powered fishing, a revolutionary method was developed to effect greater horizontal opening in trawls by the use of otter doors. There is evidence indicating the use of otter doors in other type of fishing like stow net, seine net and line fishing; but Hearder and Musgrave may be credited with for their initial experiments using otter boards in trawling and Scott of Granton was the first to design a commercial trawl with otter doors in 1884 (Scoffield, 1948; Davis, 1958; Brandt, 1972). The deployment of otter doors in trawling facilitated the use of bigger nets and the initial practice of towing from a single cable was replaced by two cable trawling with the introduction of gallows which paved the way for rapid increase in size of the net, power and size of vessels having greater endurance at sea.

Commercial Trawling in India is of recent origin - probably about three decades old. Kuriyan, (1965), stated that trawling, on a commercial level commenced at Cochin during the sixties and spread to the other parts of India. Nair et al., (1973), opined that trawling was introduced in India for the purpose of ground resource survey, which could be grouped into two - those undertaken during the pre-war period (1900 to 1930), and those undertaken during the post war period. Chidambaram, (1952), stated that beam trawling was introduced in this country for resource survey around 1900.

With the attainment of independence, greater importance was given for the development of fisheries through the various five year plans and the establishment of the Central Institute of Fisheries Technology, paved the way for systematic research on fishing gear designs, particularly trawls.

To enhance the efficiency of fishing operations there has been a constant effort by fishermen to improve their tools and techniques. Various strategies and methodologies have been developed by research workers, depending on the usefulness and availability of resources, to meet this goal.

Observing, understanding and effecting modifications with a view to improve the trawling operations was a common methodology adopted by many workers. Observation of tell-tale signs on the gear like distortion of meshes, polishing of parts, vibration, etc., have been profitably used to make changes or alterations, which, after a series of trials and errors, results in an improved gear. The trial and error method adopted, paid ample dividends in the past.

The development of science and technology facilitated gear technologists to make underwater observations for more objective based inferences. Underwater observations of fishing nets also furnish immense information on the relative position and function of the individual components as well as the behavior of fishes in the region of the trawl. Indirect observation was resorted to by filming, (Ben-Yami, 1959; Craig and Priestly, 1963; Bemish, 1967; Parrish et al. 1967), underwater television (Sand, 1957 and Livingstone 1959), echo sounding (Scharfe, 1963; Chapman and Hawkins, 1967; Okonski, 1967, Mohr, 1960; 1967) and sector scanning (Hardon-Jones, 1967; Hemmings, 1974), for detailed trawl studies.

Direct observations can be made on the gear, either in its actual operation or in a simulated environment. The former is normally possible only in a sheltered bay or in clear shallow waters, and were reported by Parrish et al. 1964, Hemmings, 1967 and 1973 and Sangster and Hemmings, 1971. The towed underwater vehicles facilitated continuous underwater observation, filming and recording as reported by Main and Sangster, 1978b, 1979, 1981 a, b, 1983 a, b, 1984 a, 1985; Korotkow and Martyschewski, 1977). Model testing of fishing gear was accepted as an excellent tool in gear designing because they are cheap, objective and accurate. (Dickson, 1959; Kawakami 1959). Chopin and McCallum (1988) analyzed the feasibility of a flume tank vis-a-vis the cost factor. Model tests conducted by many authors (Kawakami, 1955; Takayama and Koyama, 1959; Dale and Moller, 1964; Akre, 1965; Honda 1979; Wray 1979 a, b, 1980 a, b, c) provided considerable information in this regard.

Measurement of various operating parameters using suitable equipments, and the subsequent calculations was a very popular methodology adopted by several workers involved in gear research. Instrumentation, facilitating measurement of the various trawl parameters, were developed by Hamuro and Ishii, 1964; Nicholls, 1964; Sivadas, 1968a and b, 1969, 1970, 1978; Scharfe 1959; Fridman 1969; Dickson, 1959; de Boer, 1959; Takayama and Koyama 1959 and Crewe 1964, have made calculations based on the measured operating parameters and performance evaluation of the corresponding gear has been made by calculations by Crewe 1964, Carrothers et al., 1969; Fridman 1969; FAO 1974; Kowalskii and Gianotti, 1974 a and b and MacLennon and Galbraith, 1979. Except for the work of Sivadas (1968, 1969, 1970 and 1978) who developed instruments for monitoring instruments operating parameters, Sathyanarayana and Nair (1965) on warp tension and Deshpande (1960) on warp divergence, no studies have been attempted on any of the trawls operating in our country.

Initial experiments towards improving the catching efficiency of trawls were related to rigging. The use of tickler chain in bottom trawls were found to be effective by many workers. Bullis, (1956); Davis, (1958); Miyamoto, (1957); Deshpande and Sivan, (1962) and Deshpande and George, (1965). Mukundan and Hameed, (1988) reported the use of a tickler chain between the otter doors in the commercial trawls of Cochin. The effect of lengths of sweep lines were investigated by many workers. Greater sweep, besides increasing the spread between otter doors is found to minimise the scaring effect caused by the vessel. The herding effect of sweep lines was studied by Bagenal (1958); Kondratev (1965); Korotkov (1969); Hemmmings (1967, 1973) and Main and Sangster (1978 a, b; 1981 a, b, 1983 b). Crewe (1964) has attributed the herding effect to the vibrations of the sweep lines, while Hemmings (1967) relates it to visual stimulii. Main and Sangster (1981 a) in their study on the sand clouds produced by otter doors emphasises the importance of bridle lengths and bridle angles. They have opined that the bridles should be at the inner edge of the cloud thereby reducing the gap through which the fish can escape and hence the bridle needs to be placed alongwith the sand cloud.

The use of sweep lines increased shrimp catch as reported by Kuriyan (1965). Sathyanarayana and Narayanappa, (1972) have recorded catch rates of 39 kg/hour and 68 kg/hour by direct (Hoover rig) and indirect (V-D rig) rigging respectively. Narayanappa (1968 a), in his experiments to ascertain the effective length of sweep line, observed that even though the spread between otter doors increased with increasing sweep lengths, the catch rate was maximum for a sweep line length of 20m. Similar experiments with double sweep lines by Mathai et al. (1984), also established higher catch rates for 20m sweep lengths. They have also observed that using a 30m sweep line gave the fishes enough time and space to escape the path of a trawl.

For the efficient operation of the bottom trawls, they have to be dragged with firm contact with the sea bottom, and to achieve this, correct length of the towing warps is an important factor. The warp paid out is dependent on the depth of operation and is expressed as a ratio of the warp length to the sea depth and is referred to as the Scope Ratio. The normal practice is to maintain a scope ratio of 3:1 for deeper waters, while for shallow waters the ratio is about 5:1. Several workers have investigated the effect of scope ratio on trawl efficiency (Kullenberg, 1951; Ben-Yami, 1959; de Boer, 1959; Miyamoto, 1959; Pereyara, 1963; Sathyanarayana and Mukundan, 1963; Nair et al. 1966 and Sathyanarayana et al., 1978).

Fishing gear research was revolutionised with the advent of man-made fibres. Much of the work in this regard was related to comparison of the efficiency of nets made of different materials. Firth, (1950) compared nylon with cotton trawl. While Miyazaki, (1962) found nylon twines four to five times more efficient than cotton, Kuriyan, (1965) reported that cotton trawl is better than nylon trawls as cotton trawls hug the sea bed better. Kartha et al. (1974) compared the efficiencies of trawls made of cotton, polyethylene and combination (lower panel made of cotton and upper panel made of polyethylene). He has observed that the positive buoyancy of polyethylene contributed to the efficiency of the net by improving its vertical opening. A few others have also evaluated the comparative performance of trawls made of different materials. Klust (1973), has discussed the choice of materials for trawls based on requirements. Eventhough many materials with differing efficiencies are available for fishing gear construction, polyethylene continues to be the most popular gear material, mainly due to its advantages in the cost perspective.

Experiments were carried out to ascertain the correct depths of various parts of a trawl, like belly, overhang, etc. by various workers. Through a series of experiments conducted on shrimp trawls, it was shown that the belly depths of a four seam shrimp trawl could be reduced substantially without effecting catch. (Mhalathkar and Iyer, 1966; Mhalathkar and Jagdeesan, 1970, 1971). Nair et al. (1971), through a series of experiments showed that the nets with an overhang of 1.5m caught better than ones whose overhang was more than or less than 1.5m in depth. Kuriyan (1965), observed that by adding extra wings to the trawl, the catch of prawns could be enhanced. This was confirmed by Sathyanarayana et al. (1976).

Many experiments have been carried out to improve the vertical opening of trawls, giving due consideration to the fact that this aspect is a matter of importance as far as efficiency of a trawl is concerned. Brandt (1972), quoted the use of sticks between the upper and lower edges of a net at varying and graded distances. Other references in this regard include the use of mouth stretchers (Hayashi, 1933 quoted by Brandt, 1972); triangular gussets (Takayama and Koyama, 1959); use of kites - either singly or double (Dickson, 1960); transmitting the pull of the vessel to the codend through the lastridge line, thereby relieving the headline from strain, due to the pull of the vessel and permitting it to rise, insertion of triangular wedges on the wings, splitting the wings along the selvedge (Dickson, 1960, Okonski and Sadowski, 1959); use of more buoyant and hydrodynamic floats with better lift/drag ratio (Catasta, 1959, Grousella, 1959, Phillips, 1959); use of sail kite (Anon, 1979, Boopendranath et al., 1986); etc.

Experiments to evaluate the performance of trawls have led to the development of various types of trawls. Hamuro, (1959, 1964 a and b, 1967), after extensive studies on two and four seam trawls, reported the defects of two seam trawls such as higher resistance, choking of water at the trawl mouth, difference in waterflow inside and outside the trawl, dragging of the ground by considerable portion of the wings and swollen belly. As a remedy to these, Hamuro suggested four seam trawls. Varghese et al.'s (1968) experiments on a new four seam trawl was encouraging in the catch perspective. Bulged belly trawls were compared with other designs of trawls such as long winged and four paneled trawl (Pillai et al., 1978), six seam trawl (Kunjipalu et al., 1979 b), six seam and long wing trawl (Mhalathkar et al., 1985), eight seam large mesh trawl (Kunjipalu et al., 1984), six seam and high opening trawl (Pillai et al., 1979), dual purpose trawl (Kartha and Sadanandan, 1973) split belly trawl (Kartha et al., 1985).

The various types of trawls developed, due to their complicated designs were difficult to construct. Hence they remained largely confined at the experimental level. The Food and Agricultural Organisation (FAO)/Swedish International Developmental Authority (SIDA) aided Bay of Bengal Project (BOBP), recognising the fact that the decline of the shrimp catches have made the operation of small class of vessels uneconomical, after detailed studies, developed four types of trawls, viz.

a) two boat high opening bottom trawl
b) two boat mid-water trawl
c) one boat high opening bottom trawl and
d) two boat fish cum shrimp trawl

The one boat trawls are characterised by large mesh, light construction, dove tailed wings and two seam. These trawls became very popular in Tamilnadu (Pajot and Crocket, 1980; Pajot et al., 1982, 1983), Orissa (Pajot and Mohapatra, 1986) and Gujarat (Raja, 1987). Mukundan and Hameed (1988) reported that these trawls have replaced conventional trawls in Cochin area as well. Hameed et al. (1988) reported the use of a modified and small version of the one boat, high opening bottom trawl for mini trawling.

Another aspect of trawls, where considerable research work has been carried out, is on selectivity. Fishing is the purposeful control of the various components of a fishing system so as to affect fish capture. All these components will jointly be responsible for influencing the catch although the magnitude of the influence of each component may vary considerably. The extent to which these components can be manipulated will decide the success of the fishing operations and the overall influence of these components will give rise to selection. Parrish (1963) has defined selection in fishing as any process which give rise to differences in the probability of capture among the members of the exploitable fish. In the larger perspective, selection is the act of choosing, taking, distinguishing or separating a group of individuals from the larger group, aggregation or population of which they are part, on the basis of difference in one or more recognised characters. Selection process in fishing may be attributed to the following three major components :

a) Availability

b) Vulnerability and

c) Inherent gear selectively

Availability

Availability has been defined by Widrig (1954) "as the number of fish in the population that are within the scope of the fishing operations during a season, to the number of fish in the total population". This type of selectivity occurs as a result of the differences in the distribution of fishing fleet. This may be attributed to the following reasons.

Economic

Economic operations may restrict the fishing operations to certain regions, advantageous in the operational perspective. For example regions which are within daily landing distances will have a greater fishing intensity than grounds farther away. Also, economic factors may direct the fleet's activity to regions of particular sizes or qualities of fish.

Technological

Technological factors may prohibit fishing on certain grounds occupied by the species under exploitation. For example, limitations of range and fishing facilities among the small vessels will restrict the fishing effort to grounds compatible to these vessels, although the distribution of the exploitable fish stock may extend well beyond the scope of these vessels.

Legislative

Legislative measures like closed seasons, restricted grounds, contract systems, etc. result in an unequal distribution of fishing effort.

All of these factors will collectively or individually create an unequal distribution in the fishing efforts and give rise to selection.

Inherent gear selectivity of a gear is its capacity to catch fishes of certain size and species from a mixed population. This factor depends mainly on the principle of the fishing method used, but is also dependent on design parameters of the fishing gear such as mesh size, load on twines, material and thickness of twines, hanging ratios, towing speed, etc. Thus, it is evident that, unlike availability and vulnerability, inherent gear selectivity is an intrinsic property of the gear and is hence not influenced by a number of external factors. As such, inherent gear selectivity is the most easily measurable of all selection processes. This however does not imply that it is of minor importance or that there are no longer any outstanding problems in relation to it, but merely that the field is one in which quantitative evaluation of the process can usually be made.

The one most popular character that is used in gear selectivity studies is the length of fishes. Through gear selectivity is influenced by a number of factors, the reason for taking length of fishes as an index to study selectivity is due to practical reasons and also because the other factors related to it are more difficult and time consuming to measure.

The nature of length selectivity differs according to the type of gear used and most commercial gears in use today can be placed in one of the following two main categories :

i) those which select at one end of the length range.

ii) those which select at both ends of the length range.

The first of these is the simplest and the easiest type of situation to handle and is the best known one. Gears like trawls, seines, ringnets, poundnets, etc. belong to this category. In this type of selection, all the fishes of lengths less than one particular value escape. The selection in gears like gillnets, have a different pattern. Only fishes within a particular length range are retained by the net, i.e. there is selection at both ends of the length range.

Selectivity in Trawls

Selectivity of catch by trawls operate at various stages in the overall fishing procedure even before mesh selection can come into operation. The availability of fish to gear is a part of the total selection process. The relation between the spatial distribution of fish and the water swept by the gear i.e. features of vulnerability, availability and accessibility may give rise to selection. Within the gear, selection could occur by escapes occurring through the various parts and a number of factors account for this.

Mesh size

Trawl selectivity depends largely on the mesh size. Increasing the mesh size would be sufficient for effecting the escape of undersized fish. If the mesh is so small that undersized fish cannot squeeze through it, the selective effect of such mesh can be disregarded. However, investigations conducted in the Soviet Union showed the impossibility of achieving selective trawling merely by changing the size of mesh.

Since, in a trawl the mesh sizes gradually decrease from the front to the codend, the most significant and relevant selection, the latter particularly from the commercial and resource conservation perspective, occurs in the codend. For the same reason, almost the entire lot of available data on selectivity experiments are confined to codend selectivity.

An increase of mesh size in sole and plaice experiments, reduced the total catch, resulting in a higher selection factor and smaller selection range. A significant direct effect of mesh size on the selection factor could be demonstrated only in the case of sole. Jonsson (1960) in his experiments on Icelandic haddock with mesh sizes varying over a large range from 67 cm to 78 mm observed the selection factor to reduce from 3.8 at small to 2.9 at large mesh sizes. Coull (1987) also conducted selectivity experiments on Cod, Haddock and Whiting with 80, 90 and 100 mm codends. He observed a clear increase in selection factor with increasing mesh sizes. Treshev (1963) has further stated that even meshes of codend, double in size, will not secure a complete elimination of young, though it will sharply decrease the catches of marketable fish.

Catch quantity

Beck et al. (1983) observed that the amount of catch in the codend significantly influences the selection parameters. A number of other factors, such as mesh size, towing speed which is directly dependent on engine horsepower, duration of tow, etc., also influence indirectly, the codend selectivity i.e. via. codend filling. Bohl (1977) obtained a reduction in selection factor from an average of 3.9 to 3.5 when the total catch increased from the average 1.3 tons to 5.3 tons. Eltink (1983) and Howard et al. (1983) stated that in pelagic and shellfish fisheries, where the mesh size used is very small, there is little or no selection when the total catch is large. However, Charuou (1979 b) found the selection factor to increase with total catch.

Gear Material

The effect of gear material on selectivity is chiefly attributable to material stiffness. This is particularly true when there is not much tension on the netting lines and at which times the inherent stiffness of the material is more pronounced. Observations of netting sections, made in flume tanks, have shown that mesh openings are highly dependent on netting stiffness, if the netting is under low tension. Tension in codends are low until catch builds up. Many experiments have been conducted to study the influence of gear material on gear selectivity. Bohl (1987) obtained a selection factor of 8% less for polypropylene, in comparison to a polyamide codend. In another experiment which compared polyamide with polyamide-polyethylene combination codends, Bohl (1981) obtained selection factors 12% lower for the combination yarn codend. Alonso-Allende (1981) compared polyamide with polyethylene codends and obtained selection factors 12% lower for polyethylene.

Charuou (1979) on the other hand observed no difference in selectivity between polyamide and polyethylene codends. Since most of the above quoted experiments encompassed only limited hauls and codends, and since no statistical analysis of significance has been carried out, perhaps the difference in the selectivity observed are not directly influenced by the material quality, but rather other unrelated factors such as method of construction, material treatments for the individual codends, etc.

Twine Thickness

Though the influence of twine thickness on selectivity is rather important, very few experiments have been carried out to establish the importance of this parameter. Bohl (1969 a) reports an insignificant reduction in selection factor, on the basis of an experiment in which he compared an extra thick R1800 tex double nylon with normal R6484 tex double nylon codends. In another study carried out by Treschev and Shevtsov (1975) using polyamide twines of R1122 tex and R561 tex, selection factors of 3.8 and 4.3 respectively, were obtained.

Hauling Techniques

Stern trawling is observed to have lower selection factors than side trawling. Bohl (1980) has suggested that lower factors for stern trawlers are due to their being continually under tension as they are always moving ahead. Side trawlers haul the gear differently, as do trawlers with net drums mounted on the fore deck and pair trawlers, such that the strain is taken off the gear at times. Declerck et al. (1981) observed selection factors to vary with weather conditions. Selection factor increased with increased wave height, possibly due partly to increased jerking on the trawls under hauling and awaiting emptying.

Type of Gear

Selection factors are lower for the same species caught in trawls than in seines. This is because the fishes are more exhausted in trawls, particularly those near the codend regions, than in seines. Jones (1963 a) and Jacobsen (1985) suggest that fish make repeated attempts to escape. If the fish are arriving at the codends at different stages of exhaustion, dependent on the detailed gear design, then there may be considerable differences in codend selectivity even for the same basic fishing method.

Mesh Configuration (shape)

Selective properties of the trawled fishing gear depend on a complex system of interconnected technical and biological factors (Efanov, et al., 1987). The technical factors comprise physical and mechanical properties of nets, the geometric form, the angle of attack of netting, hydrodynamic properties of the trawl as a whole and of its parts, thread tension, working mesh form and size formed in the process of fishing in the different parts of the trawl, etc. The biological factors include distinction of fish behaviour in the fished zone and directly in the fishing gear, maneuverability, endurance of fishes moving in the trawl (Saburenkov, 1977, quoted by Efanov et al. 1987), size composition of the exploited fish, exterior variables, body form type, character of scales and the presence of slime. (Soldatov, 1934 and Suvorov, 1948, quoted by Efanov et al. 1987). The success of a fish in escaping through the meshes depends to a very great extent on the mesh lumen which is a consequence of mesh configuration. However, in actual trawling, the mesh configuration changes constantly. In the conventional diamond shaped meshes, the mesh opening coefficient, though normally around 0.4 to 0.6, keeps fluctuating, depending on a number of factors like load on the twines, etc. But this phenomenon is almost completely curtailed in square shaped meshes. In square shaped meshes, the nettings are mounted effectively turned through 45 degrees so that the meshes become square shaped with one set of mesh bars parallel to the trawl axis and the other at right angles. Since most of the selectivity occurs at or near the codends, square meshed codends promises to be an excellent tool in regulating the capture of under sized fishes.

The term square mesh refers to the shape the mesh assumes once the webbing has been cut. The shape is accomplished by tapering each side of the webbing by a continuous bar cut. When the webbing is stretched in a horizontal and vertical direction, the mesh assumes a square, rather than the traditional diamond shape. Gilder, in 1929, quoted by Hearn (1988), patented a codend held open by a wooden frame and using square mesh. The concept was to improve the escapement of small fish. Many series of experiments pertaining to selectivity in codends were carried out at the Marine Laboratory in Aberdeen. Subsequently, square mesh has been a topic of very interesting and important experiments of several gear technology research institutes of the world. Escapees through the square meshed codends have shown better survival rates. Joseph and Daniel (1988) have observed that square mesh escapees showed 79% survival after 12 days, while diamond mesh escapees had only 18% survival after 15 days.

The foregoing indicates that, except for a very few references, research work on trawls in our country has largely been confined to comparison of the catches made by the various types of trawls fabricated, mainly to compare their efficiencies. There has not been even a single instance of using the method of measurement and calculation for estimating trawl performance. Therefore the present study attempts to evaluate the efficiency of trawls operating from Cochin an important fishing center along the south-west coast of India.

CHAPTER II

ESCAPEMENT STUDIES

2.1Introduction

For successful gear designing, an important factor to be considered is the behaviour pattern of the species sought. Perhaps, the most efficient method for studying this aspect is by direct bservation. However, due to constraints of facilities available, this method is not applicable in many cases. An indirect method is to study the behavioural aspects vis-a-vis the selectivity, is to estimate the escape pattern of fishes through the meshes of the trawl net. Escape pattern studies will give an idea of both the fish behaviour and the selection characters of the netting considered.

Except for a work by Panicker and Sivam (1965), who studied the selective action of the codend meshes of a shrimp trawl, no work on selectivity has been attempted in India. This study therefore aims to analyse the escape pattern of fishes through the different parts of a trawl net.

2.2. Objectives

The various panels that go into the construction of a trawl have varying functions. While the panels in the anterior regions of a trawl have functions chiefly pertaining to guiding the fishes within the mouth of the trawl, those at the posterior regions have selective function. The latter functions also have a bearing on the behavioural aspects of the target species. An analysis of the escape pattern through the various panels will go a long way in designating the role of the respective panels in abetting fish capture. It would also throw some light on the behaviour pattern of the species under study.

2.3 Experimental Gear

A popular fish trawl being operated from the Cochin Fisheries Harbour was selected as the experimental gear. The design details of the experimental gear is given in Figure 3 . It is a 33m, high opening, two seam, bottom fish trawl. The design is largely based on the BOBP high opening bottom trawl. Though minor differences do exist, given the fact that these nets are locally made by different net makers, essentially all fish trawls operated in the area are similar.

2.4 Experimental Species

Nemepterus japonicus, which were available in plenty during the trawl experiments, were taken as the experimental fish.

2.5 Fishing Craft

The experiments were carried out form a commercially operated mechanised wooden fishing trawler of OAL 11m. These vessels are powered with onboard engines of 90 HP. They are stern trawlers with twin drum hydraulic winches and single gallows resembling the Norwegian Type.

2.6 Materials and Methods

Two methods commonly employed in mesh selection experiments include the covered net experiments and paired tows (hauls). Both the methods have their own advantages and disadvantages and which have been discussed extensively on various occasions. (Saetersdal, 1963; Templeman 1963). A modified version of the covered net experiments was employed in the present study in which pockets were used to capture the escaped individuals. This methodology is similar to the one described by Ellis (1963) and Clark (1963).

Pockets were attached to six strategic locations on the trawl. Since the gear under study was a bottom trawl, the attachment of pockets to the different parts were confined to the upper seam only; the escapement through the lower seam, which usually dragged over the bottom, if any, could not be successfully estimated due to limitations of the experimental procedure. Each pocket covered an area of one square metre at the site of attachment and any escapement that occurred in this region gets collected in the respective pocket.

2.2.6.1 Description of pockets

The pockets were made from knotless polyamide webbings of mesh size 15mm. Each pocket was made of two panels - an upper and a lower. Figure 2.1.1 gives the description of a pocket and its attachment. The upper seam was longer than the lower, though both were of equal widths. The two seams were tied together posteriorly so as to form a receptacle which collects the escaped individuals. The pockets were attached to the trawl panels by means of polyethylene twines.

Seven pockets were attached to the following locations on the trawl (Figure 2.1.2).

Pocket 1	Left Wing (or Right Wing)
Pocket 2	Overhang
Pocket 3	Forebelly

Pocket 4	Mid belly
Pocket 5	Lower belly
Pocket 6	Throat
Pocket 6	Codend

Pocket 1 was changed of its position - from left to right and vice versa, during alternate fishing days.

The experiments were carried out from vessels operating from the Cochin Fisheries Harbour. The fishing voyage usually commenced at 2 in the morning; actual trawling however commenced only at 6 a.m. Three hauls, each of about 150 minutes duration, were made each day. Data were collected from a total of 24 hauls totaling 60 trawling hours. Measurements of the standard lengths of N.japonicus were made. Separate observations were made for the catches in the various pockets.

Length measurements for the codend catches were made through a random sampling technique in which the catch was randomly divided into several lots. The lengths of all the individual fishes of a few lots were measured. With a view to quantify the escapement in terms of their weights, a few series of length-weight measurements were also carried out.

The number of fishes caught in the various pockets were multiplied by a factor to get the total number of escapees from that region of the trawl, the factor being a function of the effective working area of the netting in the region.

2.7 Results and Discussions

The results of the escapement experiment are summarised in Tables 2.1, 2.2 and 2.3. About 75% of the total escapement occurred at the throat region, the lengths of the escapees being less than 15cm. Practically no escapement was recorded at the wings, overhang and forebelly. The escapement at the lower belly and midbelly were 14% and 7% respectively, of the total escapement through the various parts. 78% of the total fish entering the net was captured in the codend. Figures 2.1.7 and 2.1.8 shows the fate of the fishes entering the net. Figure 2.1.9 shows a diagrammatic representation of the same. In terms of weight, 95% of the fishes that entered the net got caught in the codend. 74% of the total number of fishes entering the net was captured. The rate of escapement was maximum at the throat, of the order of 15% of the total fishes entering the net. The escapement at the belly was 4%. While 6% of the total number of fishes escaped through the codend meshes, in terms of weight, the escape percentage at this region was only 0.5%, explicating that the escapement at the codend was limited to very small fishes.

The escapement was confined to the lower regions of the trawl. This establishes the fact that the fore regions of a trawl aid in guiding the fishes entering the mouth towards the codend. The meshes of these regions have very little selective function and hence their mesh sizes can be increased without impeding the fish catching capacity of the trawl in any way. Moreover, since trawling efficiency is directly related to the trawl mouth opening, the use of large meshes at the fore regions of the trawl, facilitates enhancement of the trawl mouth, which would in turn pave the way to the use of bigger trawls without a consequent increase in towing power.

Since the trawl is an extremely active fishing gear, trawling speed is an important parameter influencing trawl efficiency. Increasing the mesh sizes would improve the drag characteristics of a trawl which implies that, with the same towing power, a greater trawling speed can be effected. Trawling efficiency is also dependent on the filtration rate, as the trawl is essentially a filtering device. Increasing the mesh sizes would therefore also improve the filtration rate, thereby augmenting trawl efficiency.

The meshes of the throat and codend were so small that the length of the escapees at this region were less than 9cm. In fact these meshes do not have any selective function at all, to the extent that they do not permit any appreciable and reasonable escapement. Moreover, the survivability of the escapees are also quite likely to be very low, in view of the fact that the mesh lumen of the conventional diamond meshes range from zero, depending on the various strains on the netting twines.

Catches of undersized fishes in trawls has been a matter of concern in the management of fishery stocks and studies are on for the development a trawl with excellent selective functions. An important breakthrough in this direction has been the development of square mesh codends. Besides being excellently facilitative in the escapement of undersized fishes, the escapees through the square meshed codends have good survival rates. Joseph and Daniel (1988) have observed that the mean survivability of scup (*Stenotomus chrysops*) that escaped through square and diamond meshed codends were 94% and 50% respectively. Several studies including direct observation experiments, carried out in the recent past, have established the superiority of square meshed codends over the conventional diamond meshes for most species.

This study has revealed that real size selection occured at the throat and codend regions. It thus follows that due importance, if paid to the designing of these regions, could go a long way improving the trawl characteristics, particularly in the resource conservation perspective. Since the fore regions primarily abets in guiding the fishes towards the codend and since a fish approaching a trawl, normally tries to avoid a trawl instead of trying to go through it, resulting in it being guided to and getting trapped in the codend, the mesh sizes of the wings, overhang and belly regions can be enhanced considerably effecting substantial reduction in its total drag. The savings thus accrued may be used to drag a bigger net.

More studies in this direction is solicited and stress should be emphasised towards the development of more resource specific fishing, rather than the current multispecies exploitation, which would pave the way for a more efficient fishing technique.

TABLE 2.1 CATCHES IN THE VARIOUS POCKETS

Length (cm)	Codend catch (nos)	CATCH IN VARIOUS POCKETS						
		Codend	Throat	lower belly	Mid belly	Fore belly	Overhang	Wings
<5	2325	291	187	8	1	0	0	0
6	1981	97	141	6	2	0	0	0
7	2173	18	148	12	0	0	0	0
8	2688	0	124	10	1	0	0	0
9	1573	0	44	7	0	0	0	0
10	1827	0	8	9	1	0	0	0
11	2865	0	0	4	3	0	0	0
12	2736	0	0	4	2	0	0	0
13	3792	0	0	2	1	0	0	0
14	4961	0	0	0	1	0	0	0
15	3648	0	0	0	1	0	0	0
16	3720	0	0	0	0	0	0	0
17	2951	0	0	0	0	0	0	0
18	1876	0	0	0	0	0	0	0
19	1928	0	0	0	0	0	0	0
20	872	0	0	0	0	0	0	0
21	403	0	0	0	0	0	0	0
TOTAL	42319	406	652	62	13	0	0	0

TABLE 2.2 ESCAPE PATTERN THROUGH THE VARIOUS PARTS OF A TRAWL

Length (cm)	Total fish entering net	ESCAPE AT VARIOUS PARTS							Codend catch
		Codend	Throat	Lower belly	Mid belly	Fore belly	Overhang	Wings	
<5	7703	2619	2485	211	63	0	0	0	2325
6	5012	873	1874	158	126	0	0	0	1981
7	4618	162	1967	316	0	0	0	0	2173
8	4663	0	1648	264	63	0	0	0	2688
9	2342	0	585	185	0	0	0	0	1573
10	2234	0	106	237	63	0	0	0	1827
11	3160	0	0	105	189	0	0	0	2865
12	2968	0	0	105	126	0	0	0	2736
13	3908	0	0	53	63	0	0	0	3792
14	5024	0	0	0	63	0	0	0	4961
15	3711	0	0	0	63	0	0	0	3648
16	3720	0	0	0	0	0	0	0	3720
17	2951	0	0	0	0	0	0	0	2951
18	1876	0	0	0	0	0	0	0	1876
19	1928	0	0	0	0	0	0	0	1928
20	872	0	0	0	0	0	0	0	872
21	403	0	0	0	0	0	0	0	403
TOTAL	57093	3654	8665	1635	820	0	0	0	42319

TABLE 2.3 WEIGHT OF FISH ESCAPING THROUGH THE VARIOUS PARTS OF A TRAWL

Length (cm)	Average weight of a fish (g)	WEIGHT OF FISH ESCAPING THROUGH (kg)							Codend catch (kg)
		Codend	Throat	Lower belly	Mid belly	Fore belly	Overhang	Wings	
<5	3.50	9.17	8.70	0.74	0.22	0.00	0.00	0.00	8.14
6	7.80	6.81	14.62	1.23	0.98	0.00	0.00	0.00	15.45
7	9.89	1.60	19.45	3.13	0.00	0.00	0.00	0.00	21.49
8	14.54	0.00	23.96	3.83	0.92	0.00	0.00	0.00	39.08
9	20.62	0.00	12.06	3.81	0.00	0.00	0.00	0.00	32.44
10	29.10	0.00	3.09	6.91	1.83	0.00	0.00	0.00	53.17
11	38.59	0.00	0.00	4.07	7.30	0.00	0.00	0.00	110.56
12	53.48	0.00	0.00	5.64	6.74	0.00	0.00	0.00	146.32
13	68.34	0.00	0.00	3.60	4.31	0.00	0.00	0.00	259.15
14	82.06	0.00	0.00	0.00	5.17	0.00	0.00	0.00	407.10
15	91.13	0.00	0.00	0.00	5.75	0.00	0.00	0.00	332.44
16	100.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	373.82
17	135.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	398.95
18	162.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	304.64
19	176.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	339.79
20	219.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	191.71
21	234.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	94.52
TOTAL		17.58	81.88	32.97	33.22	0.00	0.00	0.00	3128.77

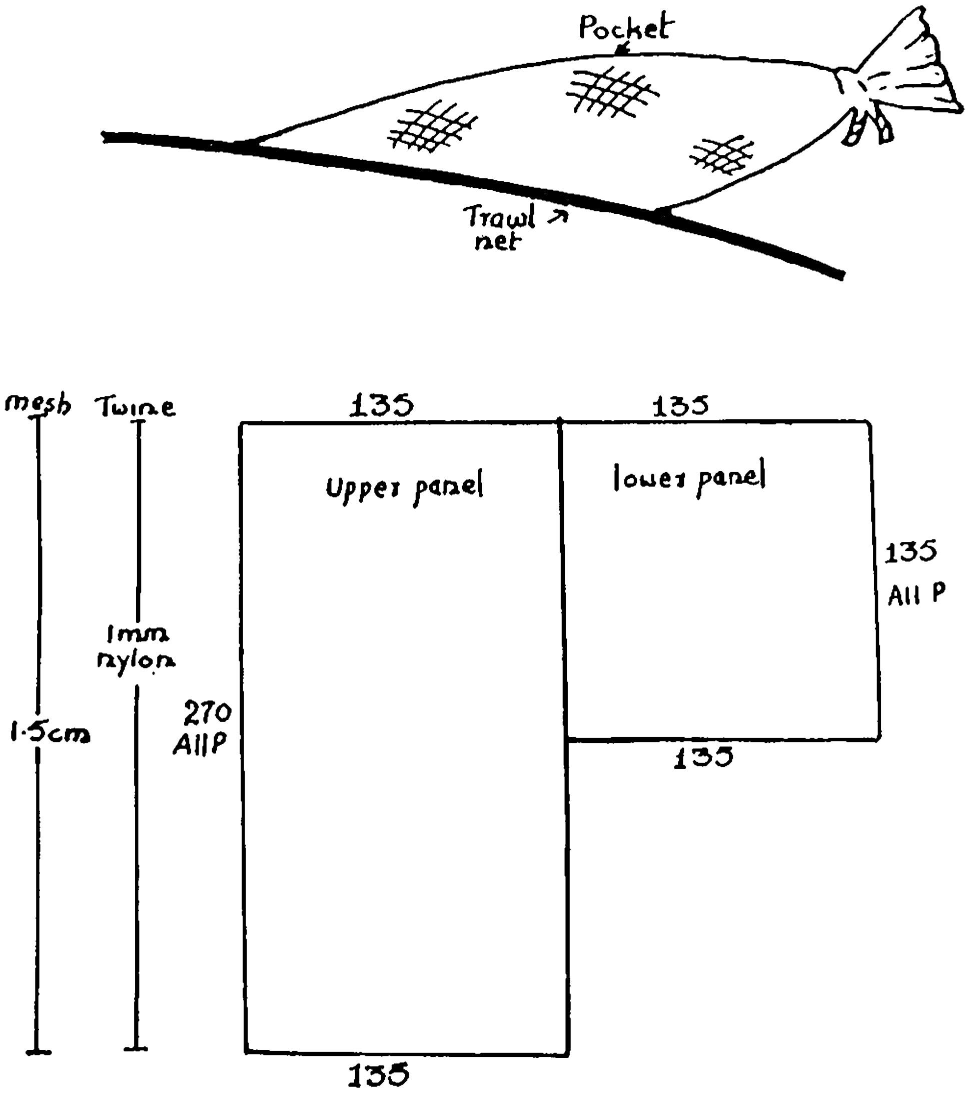


FIG. 2.1.1 Details of a pocket

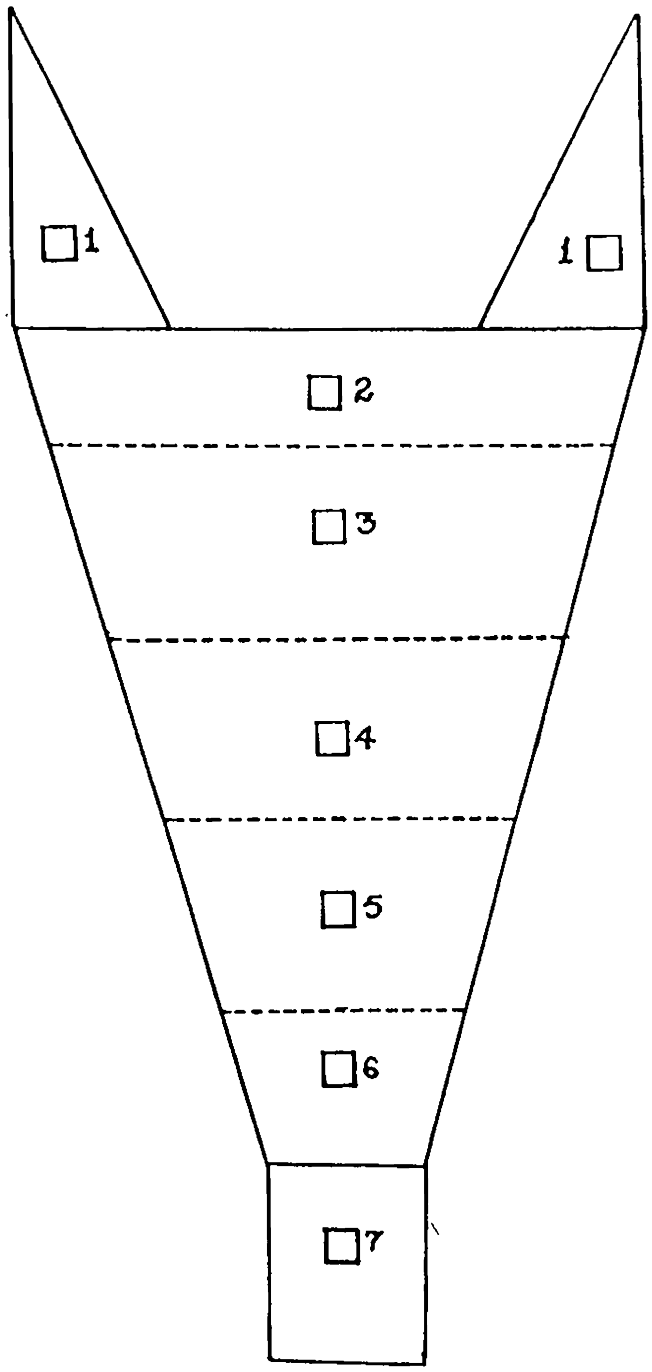


FIG. 2.1.2 Location of pockets

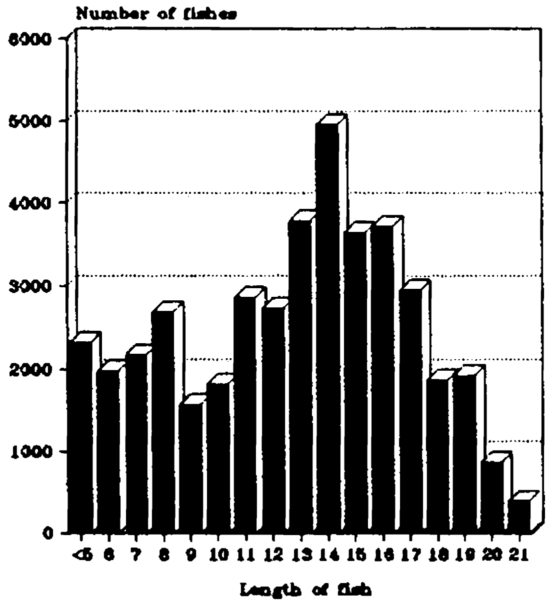


Fig. 2.1.3 Length frequency of codend catches

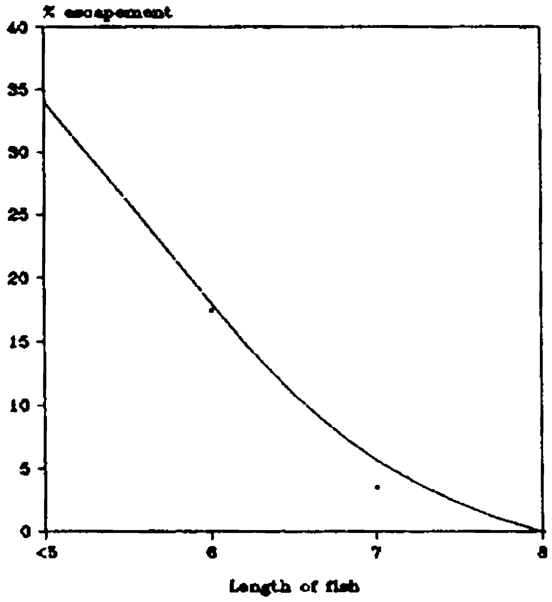


Fig. 2.1.4 Selection curve for escapement through codend

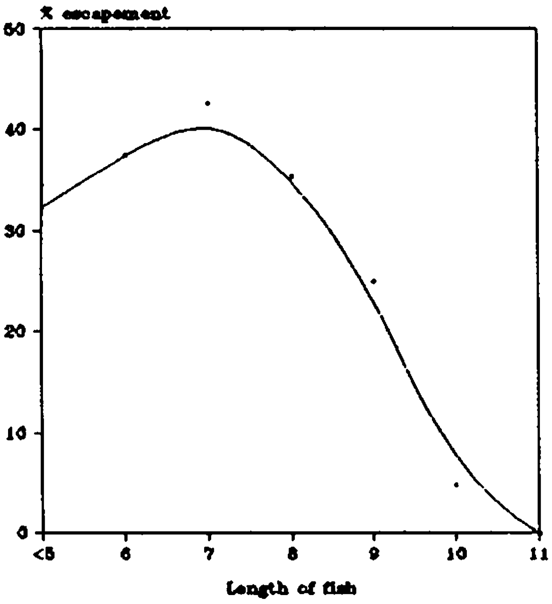


Fig. 2.1.5 Selection curve for escapement through throat

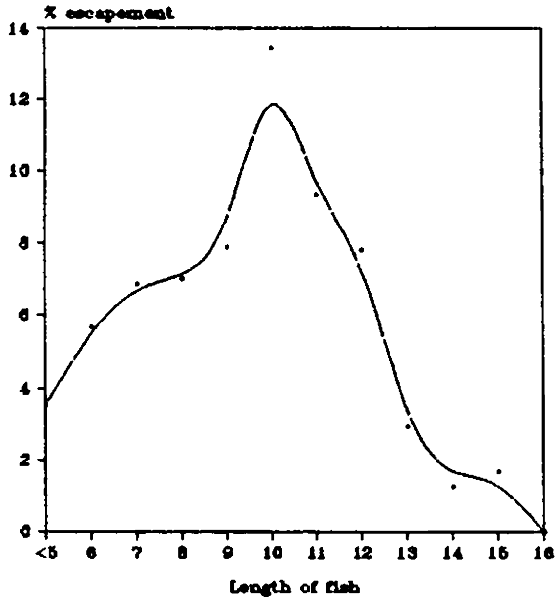


Fig. 2.1.6 Selection curve for escapement through belly

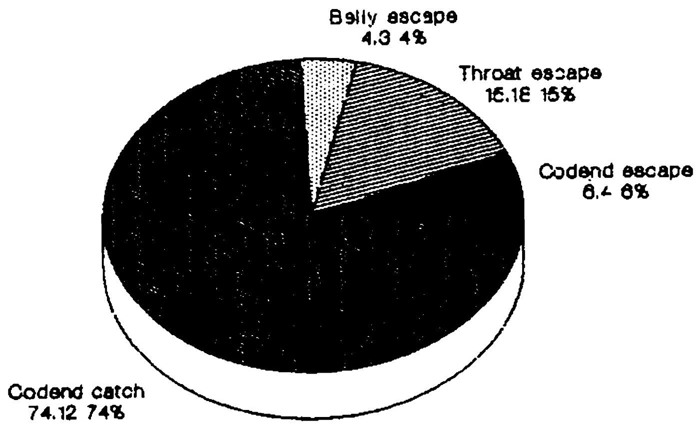


Fig. 2.1.7
Fate of fishes entering a trawl
(% numbers)

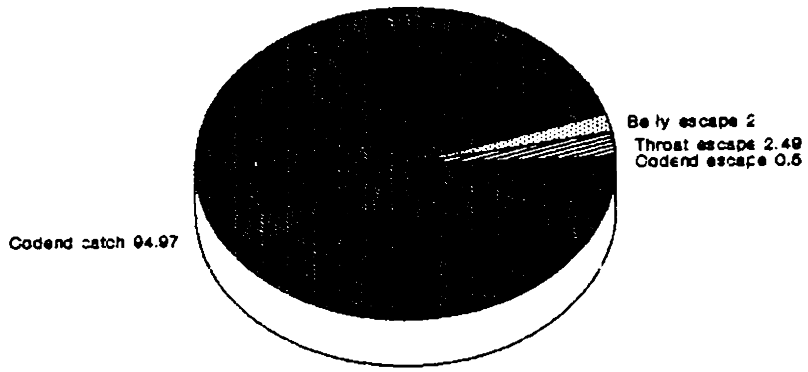


Fig. 2.1.8
Fate of fishes entering a trawl
(% weight)

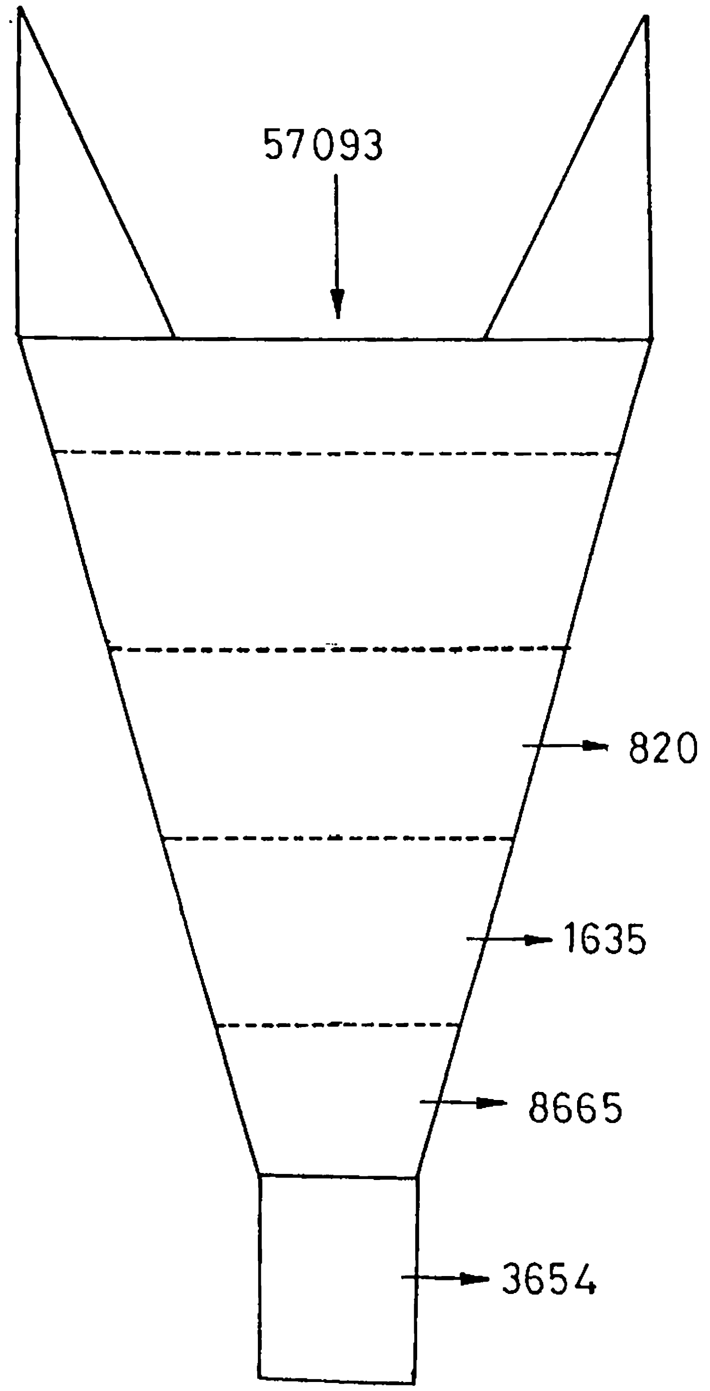


FIG. 2.1.9 Fate of fishes entering the net

CHAPTER III

DRAG CALCULATIONS

3.1 INTRODUCTION

Many attempts have been made to determine the drag of netting panels. The curved profile assumed by a netting panel when water flows past it, is a function of the forces acting on it. The determination of this shape and the drag is complicated. The drag of the panel depends on the material, type of knot, mesh size, diameter of twine, ratio of diameter to bar size, angle of setting of mesh, angle of inclination of the panel and viscosity of the medium.

To evaluate the influence of the above referred factors on drag, many investigations were carried out. Terada (1915) and Tauti et al. (1925) quoted by Kawakami (1959) and Baranov (1960) were probably the first to initiate studies on drag of netting panels. Based on their work, formulae have been put forward to calculate the drag of netting panels placed perpendicular to the water flow. Many Japanese workers (Fugita and Yokota, 1951; Miyamoto et al., 1953; Nomuro and Nozawa, 1955 quoted by Kawakami, 1959) have investigated the hydrodynamic interference between knots and twines, the effect of different kinds of knots, shape of mesh and inclination of netting.

Voinikanis-Mirskii (1952), investigated the hanging coefficients and found that the drag is inversely proportional to the hanging coefficients. Fridman (1969) while proposing a formula to determine the drag of netting placed perpendicular to the flow, stated that for calculation of the Reynolds number (R_e), the diameter of the bar alone should be taken and not the overall dimension of the net.

Stengel and Fisher (1968) gave results of investigations on drag of panels placed parallel to the flow. Tauti (1925) and Revin (1959), as quoted by Fridman (1969), determined the drag of panels inclined at different angles.

Fridman (1969), based on experiments with netting panels of different shapes, conical nets, combined nets etc. stated that the resistance of complete net is approximately equal to the sum of resistance of the simple parts that combine to form a net. This opens up new potentialities for the calculation of drag in similar nets.

Empirical formulae were used for calculating the total drag of trawl by Koyama (1972 and 1974). An equation for mid water trawl is proposed by Reid (1976). For bottom trawls MacLennon (1981) proposed an equation in which the coefficients are worked out on the basis of drag measurements. Fridman and Dvernick (1973) calculated the drag of trawls, based on drag coefficient of netting panels inclined at different angles. But this is more applicable to mid water trawls. A similar approach for the calculation of drag of bottom trawls was followed by Kowalski and Giannotti (1974 a; b). Dickson (1979) followed an approach of summation of resistance of parts, a method that is more comprehensive. Here, the calculation of drag is made without considering the drag of sweep line, otter board and towing warps. Dickson's method thus offers itself as a good method for comparing the influences of the various mesh configurations and mesh sizes on the total drag of the net. Moreover, knowledge of the forces acting on the gear and the resistance or drag of the gear would help in improving the performance of the existing ones. Except for the doctoral thesis by Mukundan (1989), no other work has been attempted in India. Hence, there is a need to study trawl drag calculations which could form a scientific basis for a more efficient gear designing.

3.1.1 Mesh size

The mesh size of trawls has a bearing on two important aspects pertaining to trawl efficiency. They are

1. size of fish caught and
2. the total drag of the net.

Unlike gillnets, which possess knife-edge selection, trawls retain all fishes greater than a particular length. This is quite important in the resource conservation perspective. Another important influence of mesh size, is on the total drag of trawls. As far as mesh size is concerned, the entire trawl may be divided into two regions - the fore region and the aft region - both having different functions. The forward part extending from the wings through the bellies, lead the fish towards the aft part comprising the throat and codend, which retain the catch. Experiments and direct observations have shown that the fore regions merely serve to guide the fish towards the codend region where actual selection occurs. It is at this region that the fishes are really active and try to swim through the meshes and hence, the panels of this region have high selective function. It thus follows that the mesh size of these panels will have a direct influence on the size composition of the catch. The relation may be expressed as follows:

$$m_c \approx 2/3\ m_g$$

where m_c = mesh size of the panel
m_g = mesh size of a gillnet designed to capture fish of the same species and size

$m_g = l/K$ l = length of the fish
K = an empirical constant

which is species specific and may be found by experimental fishing. The value of K varies from 2.5 to 5.0 depending on the body depth of the fish.

Since the panels of the fore part of the trawls are least selective, their mesh sizes will not directly influence the size of the fish caught, but however, will contribute by a fair share to the total drag of the trawl. Altering the mesh size of these panels can to a certain extent favorably modify the total drag. Stengel and Fischer (1968) studied the drag of a panel at various d/a (ratio of diameter of twine to mesh bar). The fact that the use of large meshes can considerably reduce trawl drag led to the development of rope trawls. The latter trawls have parallel ropes in the front portion and was first published in the German Democratic Republic (van Marlen, 1988). In addition to their low resistance, rope trawls have a greater mouth opening - about 20 percent more (Rehme quoted by van Marlen, 1988) than the conventional net type trawls. Kwidzinski (1989) stated that the use of rope trawls with improved rigging could result in a six fold decrease in resistance per unit trawl mouth area. Brabant et al. (1980) established the superiority in resistance of rhombic meshed trawls. van Marlen (1989) stated that a big rhombic mesh trawl has 25 percent lesser resistance than a conventional net of similar size at the same speed. The role of mesh size on total drag of trawls thus needs no further emphasis.

3.1.2 Towing speed

Being an extremely active fishing gear, one of the factors that effect the efficiency of trawling operation is the trawling speed. The fish school sensing an approaching gear gets frightened and tries to flee. One part of the school moves away from the trawl mouth, while the other moves along the line of trawl motion. For a comparatively short interval of time the fish swim between the sweep lines or wings before getting swept into the trawl mouth. It is in the posterior regions of the trawl that the fishes actually realize that they have been trapped, and depending on their capacity of the fish to strive for freedom, starts swimming back and if the fish succeeds in swimming over the headline, then it swims to freedom. (Wardle, 1984). It thus follows that the towing speed of the net should be in conformity to the swimming speeds of fish - lower towing speeds being used to catch slow swimming fishes and higher towing speeds for fast swimming fishes. Direct observations and special experiments have shown that there is an optimal trawling speed for each species of fish and trawl design, which provide the maximum catch, all other things being equal (Fridman, 1986). For the same reason, the shape of the curve representing relative fishing efficiency and trawling speed, is parabolic. Although trawling speed has to be specific for a particular species, in the overall perspective, there are more important concerns that need attention. Since the trawl has to be towed during operation, a great deal of energy is expended and the two primary elements that influence the trawling operation efficiency are drag of the net and resistance of the boat. In order to enhance fish production, there has been a tendency, during the last few decades, towards the use of very high powered engines for trawling. Today, modern fishing is one of the most energy intensive methods of food production known to man (Endal, 1988). The need to improve energy consumption pattern in fisheries, where the role of fossil fuels is significant, has been gaining considerable momentum in recent years. One of the pertinent suggestions put forward to optimize fuel efficiency in fishing operations is based on the optimization of trawling speeds. Burchett (1989) maintained that the fuel consumption is more than doubled when the trawling speed is enhanced from 3.4 knots to 4.8 knots. Furthermore, the developed horsepower required for higher trawling speeds is also highly unbalanced. Schroeder and Roddan (1989) stated that in order to enhance the trawling speed from 9 to 10 knots, the developed horsepower has to be increased by approximately two times.

In this context, the study of trawl drag - an important contributing factor towards fuel consumption - at various trawling speeds would be significant. Hence an attempt is made to evaluate the pattern of drag at various towing speeds.

3.1.3 Twine diameter

The drag of a netting panel is directly proportional to the nominal twine surface area which is dependant on twine diameter. A matter of prime concern in fixing the diameter of twine to be used for trawl construction, is its wet knot breaking strength. Since a knot is the weakest spot on a twine, the wet knot breaking strength of the twine selected, should be sufficient so as to withstand the rigorous strain during trawling operations. Another aspect that needs attention as far as twine thickness is concerned is the capacity of the twine to withstand abrasion resistance. Thicker twines have higher knot breaking strengths and better abrasion resistance. But they also have a greater drag. The introduction of synthetic fibers for fishing gear materials revolutionized the fishing industry. Synthetic materials have greater strengths at smaller twine thickness. The use of thinner and stronger twines for trawl construction improved trawling efficiency several fold. The drag saving potential of different netting materials is directly related to the developed twine area which is a function of twine thickness. Since twine diameter is accountable for the strength of netting materials, and because different materials have different strengths, the use of high strength materials for trawl construction promises to be an excellent proposition to bring about fuel saving. High strength materials can substitute themselves at lower twine thickness without altering other vital properties of the netting material. In this context it would be interesting to study the influence of varying twine thickness on trawl drag. Also, the superiority of high strength materials with regard to its drag reducing potential could also form a thoughtful investigation.

3.2 OBJECTIVES

Trawling is the most expensive fishing method as far as operational costs are concerned. Since the energy expended per unit of time is maximum in trawling, any attempt to alleviate this, would go a long way in improving the overall trawling operation. Moreover, this has great implications in the energy conservation perspective. It is in this context that the following objectives deserve adequate significance.

3.2.1 To calculate the total net drag of two important fishing trawls being operated from the study area.

3.2.2 To evaluate an influence of a change in mesh size on total drag.

3.2.3 To compare the total drag at various trawling speeds.

3.2.4 To study the influence of twine diameter on total trawl drag.

3.2.5 To study the effect of differing panel depths on the total drag, angle of attack and nominal developed twine surface area of the different panels.

3.3 MATERIALS AND METHODS

3.3.1 The Gear

Two important trawls operating from Cochin were selected for the study, of which one was a fish trawl while the second was a shrimp trawl. The design details of the two nets are given in Figs. 3.1 & 3.2. Net 1. is a 33 m high opening, two seam, bottom fish trawl. The design of the latter is largely based on the BOBP high opening bottom trawl. Net 2. is a popular version of the various two seam shrimp trawls being operated in the study area. It has an head rope length of 27.5 m. Both the nets were made of polyethylene.

3.3.2 Operating Parameters

Since the calculations were confined to the net proper of the trawl, only two important operating parameters were needed. These included

(i) horizontal spread and
(ii) vertical opening

3.3.2.1 Horizontal spread

Since instrumentation could not be employed due to constraints of facility, a simple method involving floats, a sextant and some amount of trigonometric calculations were employed to measure the horizontal spread between wing tips from the spread of otter boards. The methodology adopted may briefly be explained as follows:

Two marker floats were attached to the otter boards, one for each door. The length of the float line was adjusted to suit the depth of operation. The floats gave an idea of the position of the otter boards underneath. Using a sextant, the angle between the two floats were measured. The distance of the two floats from the boats were also measured by paying out another float line until this float got aligned with the floats attached to the otter doors. The length of the line thus paid out will give the distance of the floats from the boat. From the angle measured by the sextant, and distance of the otterdoors from the boat, the distance between the two floats i.e. the spread between otter doors may be calculated using the following trigonometric expression

Spread between otter doors =

$$2 \, . \, \tan\frac{\theta}{2} \, . \, \text{Distance of the otter doors from the boat}$$

The spread between wing tips was then proportioned from the spread between otter doors since the length of the legs are known.

3.3.2.2 Vertical opening

The head line height measured using a portable echo sounder gave the vertical opening since both the nets were bottom trawls. The transducer of the echo sounder was fitted to the center of the headline.

3.3.3 Calculation of net drag (according to Dickson , 1979)

The drag 'D' of a trawl net in operation, is the resultant of the drag area, 'A' and the hydrodynamic stagnation pressure, 'q'. The relation can be expressed as

$$D = q \cdot A$$

where $q = \frac{1}{2} \rho \cdot v^2$

Therefore $D = \frac{1}{2} \rho \cdot v^2 \cdot A$

where ρ = mass density of water $\left(\text{kgf-sec}^2 \text{m}^{-4}\right)$

v = velocity of water $\left(\text{m sec}^{-1}\right)$

3.3.3.1 Drag area 'A'

The drag of the various netting panels that make up the net, the float and the ropes together forms the total drag of the net.

The main body of the trawl net can be considered as a cone with the latter 25% of the codend completing the apex of the cone. (Fig.3 a.) The rest of the codend is considered as a cylinder. The cone proper starts only from the belly, and the wings and overhang are considered as forward extensions.

3.3.3.2 Periphery of the cone

For bottom trawls, the mouth of the cone assumes an elliptical shape. It is practically impossible to directly measure the horizontal (major axis) and vertical (minor axis) openings of the elliptical cone mouth. But the same could be proportioned if we know the spread between wing tips and the headline height. Spiegel (1962), quoted by Dickson (1979) gives the method for calculating the perimeter, from the major and minor axes of the ellipse, in the following expression.

$$\text{Periphery} = a \,.\, 2 \,.\, \pi \left[1 - \left(\frac{1}{2} \right)^2 .K^2 - \left(\frac{1 \,.\, 3}{2 \,.\, 4} \right)^2 . \frac{K^4}{3} - \left(\frac{1 \,.\, 3 \,.\, 5}{2 \,.\, 4 \,.\, 6} \right)^2 . \frac{K^6}{5} - \left(\frac{1 \,.\, 3 \,.\, 5 \,.\, 7}{2 \,.\, 4 \,.\, 6 \,.\, 8} \right)^2 . \frac{K^8}{7} \;\ldots\ldots \right]$$

where $K = \sqrt{\dfrac{a^2 - b^2}{a^2}}$

a = semi major axis of the ellipse

b = semi minor axis of the ellipse

3.3.3.3 Setting angle of meshes, `q '

The mesh configuration and the consequent netting area is determined by the setting angle 'θ', of the meshes. This angle is found out from the primary hanging coefficient (E_1) of the cone, which is the ratio of the mounted length at the mouth of the cone i.e. the perimeter of the ellipse or horizontal length (l), to the stretched length (L) at the mouth of the cone, and is defined as l/L.

This can also be expressed as a function of the mesh angle,

$$E_1 = 1/L = \text{Sin } \theta$$

from this, the setting angle θ is found out.

3.3.3.4 Angle of attack of the netting panel

From angle θ, the vertical hanging coefficient (E_2) can be obtained by finding the cos of the angle θ. This cos θ when multiplied with the sum of the products of the number of meshes in depth and mesh size of the corresponding panels that form the cone, gives the hung depth of the cone (H_c). It will also include 25% of the codend that is considered to complete the cone, by forming its apex.

Now, to find the angle of attack, the cone can be considered to be cut open and flattened out so that the perimeter is in a straight line (Fig.3.**b**), and the flattened sheet aligned at an angle 'α' to the horizontal or the water flow. The angle 'α' is the angle of attack of the netting of the cone. It can be calculated using the relationship,

$$\sin \alpha = \frac{\bar{r}}{H_c}$$

where H_c = the hung depth of the cone.

$\bar{r}$ = mean radius of the ellipse, and may be calculated from the following expression

$$r = \frac{2 \pi a b}{\text{periphery}}$$

3.3.3.5 Drag of cone

The drag of the conical portion of the net is given by

$$D_c = \sum A_c \cdot q$$

where $q = \frac{1}{2} \rho \cdot v^2$

ρ is the mass density of water and is taken from Fridman (1986), and is 103.8 kgf $sec^2\ m^{-4}$ at $30^{\circ}C$ and salinity 30/00;

v is the velocity of water current.

A_c is the cone drag area of individual panels and is the product of the nominal developed area of the twine $\left(A_m\right)$ in a netting panel and the coefficient of drag at the inclination of the panel.

It is defined as,

$$A_c = C_{d\alpha} \cdot A_m$$

3.3.3.6 Nominal developed area, A_m

The nominal developed area of netting yarn $\left(A_m\right)$ of the various panels of the net is worked out using the following formula (Reid, 1976),

$$A_m = m \cdot n \cdot 4 \cdot a \cdot d$$

where

m is the number of meshes across. (for trapezoidal pieces 'm' becomes $\left\{\frac{m_1 + m_2}{2}\right\}$

where

n is the number of meshes in depth,

a is the bar size and

d is the twine diameter.

Here the modification of drag due to the influence of knots in the netting is not considered, since the same is accounted for, in the calculation of drag coefficients.

3.3.3.7 Calculation of drag coefficients

To calculate the drag of cone, the coefficient of drag at α° $(C_{d\alpha})$ is to be found out. Though there are different methods for calculating the drag coefficient, the approach of Crewe (1964) is the most successful and is hence followed.

As per this method, the drag coefficient at 90° (C_{d90}) and 0° (C_{d0}) are first calculated separately. Since in practice, the plot of sheet netting drag is almost linear in the range of angles 0° to 30°, C_{d90} and C_{d0} is combined to calculate $C_{d\alpha}$ in the following manner

$$K_{ct} = \left\{ 1 - \left(\frac{d_k}{d} \cdot \frac{d}{a}\right) \right\} + \left\{ C_k \cdot \frac{\pi}{8} \left(\frac{d_k}{d}\right)^2 \cdot \frac{d}{a} \right\}$$

where d_k is the knot diameter,

d is the bar diameter and

C_k is the knot drag coefficient and is taken as 0.47 as for a sphere.a sphere.

The denomination $\left(\frac{1}{1-s}\right)^2$ in equation (1) is the speed-up term and can also be expressed as $\left(\frac{v_e}{v}\right)$ where $\frac{v_e}{v} = \left(\frac{1}{1-s}\right)$ and is the factor by which the exit velocity of water through the mesh aperture is larger than the approach velocity.

s is the solidity of the mesh and is defined as the ratio of the solid or blocked area to the surface area of the mesh, and can be expressed as

$$s = \frac{\left[\frac{d}{a} \left(1 - \frac{d_k}{d} \cdot \frac{d}{a} \right) \right] + \left[\frac{\pi}{8} \left(\frac{d_k}{d} \right)^2 \frac{d}{a} \right]}{\sin \theta \ . \cos \theta}$$

A simpler approach to find solidity of a panel is to relate the developed area of the twine in a panel (A_m) to the actual working area of the panel (A_m) in the following manner,

$$\frac{A_m}{A_M} = \frac{d}{a} \cdot \frac{1}{\sin\theta \;.\; \cos\theta} = \text{Simplified solidity.}$$

where $A_M = m \;.\; 2a \;.\; \sin\theta \;.\; n \;.\; 2a \;.\; \cos\theta$

Thus C_{d90} takes the following form

$$C_{d90} = C_{dsc} \cdot C_t \left[\left\{ 1 - \left(\frac{d_k}{d} \cdot \frac{d}{a} \right) \right\} + \left\{ C_k \cdot \frac{\pi}{8} \left(\frac{d_k}{d} \right)^2 \cdot \frac{d}{a} \right\} \right]$$

$$\left[\frac{1}{1 - \dfrac{\frac{d}{a} \left\{ 1 - \left(\frac{d_k}{d} \cdot \frac{d}{a} \right) \right\} + \left\{ \frac{\pi}{8} \left(\frac{d_k}{d} \right)^2 \frac{d}{a} \right\}}{\sin\theta \;.\; \cos\theta}} \right]$$

3.3.3.7.2 Calculation of C_{d0}

The coefficient of drag of a netting panel set at an angle θ° to the water flow is found out in the following manner

$$C_{d0} = C_{dsc} \cdot C_t \left\{ \sin^2\theta + \left(C_f \cdot \cos^2\theta \right) \right\} \left\{ 1 - \left(\frac{d_k}{d} \cdot \frac{d}{a} \right) \right\}$$

$$+ \left\{ C_k \cdot \frac{\pi}{8} \left(\frac{d_k}{d} \right)^2 \frac{d}{a} \right\}$$

As in the calculation of C_{d90}, here also $C_{dsc} . C_t$ is taken as 1 and C_k to be 0.47 as for a sphere.

C_f is the skin friction coefficient and its value is taken as 0.07.

3.3.3.8 Effect of high solidity panels

In certain panels, the solidity is found to be comparatively higher than that of other panels. In such cases, when the solidity term $S \geq 0.3$, then $\frac{v_e}{v} = \frac{1}{1 - s} > \sqrt{2}$ and the drag coefficient, dependant on $\left(\frac{1}{1 - s} \right)^2$, would become >2. This condition occurs for panels with large $\frac{d}{a}$ and small setting angle θ and is indicative of the commencement of form drag.

Such a condition occur in front of and in the codend. The water entering these panels do not escape by speed-up locally through the restricted mesh openings but rather by speeding up the waterflow through the meshes of preceding panels with lower solidity.

This condition is indicated in Fig.3.c, which represents the apex of the cone. Panel N can be considered as an high solidity panel and M the preceding panel with lesser solidity, i.e. $S_n > S_m$. The approaching flow of water in panels M and N are represented by v_{em} and v_{en} respectively.

The condition is represented by Dickson (1979) in the following manner

Flux into panel N = Flux out of panel N

$$v_n \cdot A_{PN} = v_{en} \quad A_{PN} \left(1-S_n\right)$$

$$v_n = v_{en} \left(1-S_n\right)$$

where A_{PN} is the developed area of the panel N and S_n its solidity.

Then,

$$\frac{v_n}{v} = K_n = \frac{v_{en}}{v}\left(1-S_n\right)$$

and

$$\frac{v_{en}}{v} \text{ is not greater than } \sqrt{2}$$

Dickson (1979) puts $\frac{v_{en}}{v} = \sqrt{2}$ in order to get rid as much water as posible through the panel N. Then the drag coefficient for such a panel becomes,

$$C_{d90} = C_{dsc} \cdot C_t \left[\left\{ 1 - \left(\frac{d_k}{d} \cdot \frac{d}{a} \right) \right\} - \left\{ C_k \cdot \frac{\pi}{8} \left(\frac{d_k}{d} \right)^2 \right.\right.$$

Now, the panel ahead of the panel N is to be considered, and for this the flux into and out of the two panels are taken together.

Flux into panels M and N = Flux out of panels M and N

$$v_m \left(A_{PM} + A_{PN}\right) = V_{cm} \cdot A_{PM} \left(1 - S_m\right) + V_n A_{PN}$$

and

$$\frac{v_m}{v} = K_m = \left[\frac{v_{cm}}{v} \left\{ A_{PM} \left(1 - S_m \right) \right\} + K_n \cdot A_{PM} \right] \cdot \frac{1}{A_{PM} + A_{PN}}$$

where

A_{PM} and A_{PN} are the developed area of the panels M and N respectively.

After two or in some cases more panels are considered in this manner the value of $\frac{v_{cm}}{v}$ is found to fall below $\sqrt{2}$. Then all preceding panels can be considered as uninfluenced by the succeeding panels and the speed of water within them to be the same as that of the water current.

Then the drag coefficient for the intermediate panel is given by

$$C_{d90} - C_{dsc} \cdot C_t \left[\left\{ 1 - \left(\frac{d_k}{d} \cdot \frac{d}{a} \right) + C_k \cdot \frac{\pi}{8} \left(\frac{d_k}{d} \right)^2 \frac{d}{a} \right\} \right] \cdot \left(\frac{v_{cm}}{v} \right)$$

where now

$$\left(\frac{1}{1-s_m}\right)^2 < \left(\frac{v_{em}}{v}\right)^2 < 2$$

This can be considered as a simplification since in the actual situation velocities in panels cannot really change in jumps from panel to panel.

When the water speed within and outside a panel are different, it presumably affects the C_{d0} value and hence, the value used in such cases is

$$C_{dol} = 0.5\, C_{d0} \left\{ 1 + \left(\frac{v_m}{v}\right)^2 \right\}$$

Then the drag coefficient at angle α can be calculated in the following manner

$$C_{d\alpha} = 0.5 \left(C_{d90} - C_{dol} \right) \cdot \frac{\alpha}{30} + C_{dol}$$

3.3.3.9 Codend drag

In the calculation of the cone drag, 25% of the codend was considered to form a part of the cone. The remaining part of the is considered to form a tube, rather than a cone. This cylindrical portion does not contribute to the drag of the net in the same proportion as that of the cone. Hence the drag offered by this part of the codend has to be considered separately as an appendage to the rest of the net. For this calculation an expression formulated by Fridman (1973) for the drag of a netting sheet parallel to the current, is used

$$R_0 = 1.4 \,.\, l^{-0.14} \left(1 + \frac{5d}{a}\right) \left(0.9 + 0.04 \frac{E_1}{E_2} + 0.55^{-2.4 \frac{E_1}{E_2}}\right) F$$

where

R_0 is the drag of the cylindrical part in kgf.

l is the length of the cylindrical portion of the codend in me codend in m

d is the twine diameter in mm

E_1 and E_2 are the hanging coefficients

F is the developed area of the netting

v is the velocity in $m\ s^{-1}$ and

-0.14 is the term expressing the entrainment of the water developed around the last part of the cone and codend.

3.3.3.10 Appendage drag

The appendages to be considered in trawl drag calculations include the floats and ropes.

3.3.3.10.1 Drag of floats

Since floats are hollow spheres, for the calculation of their drag the following equation which gives the drag of spheres is used

$$D_f = 0.47 \cdot \frac{\pi}{8} \cdot d^2 \cdot q$$

where

d is the diameter of the float and

q is the hydrodynamic stagnation pressure.

3.3.3.10.2 Drag of ropes and sinkers

This is mainly due to the ground friction and is calculated by multiplying the ground friction coefficient whose value is taken as 0.7 with their underwater weight.

3.3.3.11 Total drag of trawl

Summation of the above explained drags such as

1. drag of cone D_C
2. drag of codend R_0 and
3. drag of float D_f
4. drag of ropes and sinkers D_r

gives the total drag of the net.

All calculations were carried out by developing a spread sheet model on Lotus 1-2-3 (Lotus Development Corporation, USA). Corollary to the trawl drag calculations, the following studies were also undertaken.

3.3.4 Influence of mesh size on total drag

In order to study the influence of different mesh sizes on total drag, the total net drag was calculated for a series of mesh sizes for each panel, keeping all the other parameters a constant. The results were represented graphically.

3.3.5 Influence of towing speed on total drag

Keeping all other parameters a constant, the total drag for a series of towing speeds were found and the results were plotted.

3.3.6 Influence of twine size on total drag

The total net drag was calculated for different twine thickness and the results obtained were represented graphically. In order to demonstrate the superiority of high strength materials with regard to trawl resistance, the total net drag as a function of different twine thickness of various netting materials, but of equal wet breaking strengths were calculated. The results were plotted to get separate curves for each material.

3.3.7 Influence of panel depth

The total net drag, the angle of attack and the twine surface area of the different panels were calculated for various panel depths and the results were represented graphically.

3.4 RESULTS AND DISCUSSIONS

3.4.1 Net drag

The results of calculation of net drag for the two nets viz. Net1 (Fish trawl) and Net2 (Shrimp trawl) are given in Tables 3.1 and 3.2 respectively. Parameters like the nominal developed twine area, solidity, cone drag area etc. of the various panels were also calculated. For the sake of comparison, the highlights of the results of calculation are given in Table 3.3.

The fish trawl had a grater cone mouth opening - about 23 percent greater than the shrimp trawl. Due to the same reason, the angle of attack of the netting panels was more for the shrimp trawl - 2.99° for the fish trawl and 2.41° for the shrimp trawl.

Whereas the differences in the total nominal developed twine area for the two nets was only 13 percent, the difference in total drag was 26 percent.

This was due to a greater angle of attack for the panels of the fish trawl nets (about 20 percent), despite of the wide variations in mesh size and twine diameter for the two nets. This establishes the fact that the developed twine area is the prime component of total trawl drag.

Although the contribution of the cylindrical portion of the codend region with regard to the nominal developed twine area for the two nets were 11.3 percent and 9.71 percent respectively, the share of these parts to the total drag was only 3.4 and 2.82 percent. This was due to the fact that the netting of this region was aligned parallel to the water flow and hence could not cause any appreciable drag. This condition holds true only in the case of an empty net; in actual trawling however, the drag of the codend is considerable due to the accumulation of catch. Among the various components of the trawl net, the cone proper contributed by as much as 89 percent in the case of net 1 and 88 percent in the case of net 2 to the total drag.

The cylindrical portion of the codend and the sinker chain contributed 6.56 percent and 2.19 percent respectively to the total drag in the case of fish trawl. Since the shrimp trawl had a heavier tickler chain, the contribution of the same was 3.77 percent, while that of the cylindrical portion of the codend was only 5.49 percent.

As far as solidity is concerned, panels F, G and H of net 1 and panels E, F and G of net 2 (i.e. aft belly, throat and codend panels) were of high solidity. As a result, the contribution of these panels to the total drag was proportionately more than the other panels especially when their share to the developed twine area is considered. Tables 3.4 and 3.5 lists the Am, solidity and drag for the various panels of net 1 and net 2 respectively.

Figures 3.3 and 3.4 gives the contribution of the various components of the two nets to the total drag.

3.4.2 Influence of mesh size on trawl drag

Increasing the mesh size of panels will

decrease the total drag of the net. Figures 3.5 and 3.6 gives the curves for plots of mesh size against total drag for the various panels of the two nets. The mesh size of the panels is inversely related to the total drag of the net, hence, any increase in the mesh size will affect the `d/a' value which consequently changes the knot correction and solidity terms. This in turn influences the coefficient of drags at 90° and 0° $\left(C_{d90}\right.$ and C_{d0} respectively) which will change the coefficient of drag at the particular angle of attack. Again, changing the mesh size will also change the nominal developed area of the twine $\left(A_m\right)$. Since the drag of a panel is the product of the coefficient of drag at the particular angle of attack $\left(C_{d\alpha}\right)$ and the nominal developed area of the twine, any change in size will influence the drag of that panel and will accordingly change the total drag of the net.

Figures 3.5 and 3.6 shows that the change in drag due to an increase in mesh size is not in proportion. Furthermore, the maximum influence due to a change in mesh size is evidenced in panels with lower mesh sizes, which means smaller the mesh size, greater is the increase in total drag. Since the curve flattens out with an increase in mesh size, increasing the mesh size beyond a particular limit will not alter the drag appreciably.

3.4.3 Towing speed

The total drag of the two nets at various trawling speeds are given in Tables 3.6 and 3.7. Figures 3.7 and 3.8 gives the plots of drag at various speeds. The increase in total drag is found to be in logarithmic proportion to an increase in trawling speed. At 0.25 knots, in the case of fish trawl, the total drag is only 25kgf while at 1.25 knots, it is 175kgf and 525kgf at 2.25 knots and so on. Therefore the need to maintain optimal trawling speeds needs no emphasis. Actually, increasing the towing speed will lead to an increase in the cone mouth area which consequently alters the angle of attack of the netting panel. Since the coefficient of drag is proportional to the angle of attack, any increase in the latter will increase the drag of netting panel. Since the vertical headline height was measured for only one trawling speed, (viz. 1.28 m s^{-2}) the influence of a greater cone mouth area on trawl drag at higher trawling speeds could not be accounted for. Hence, the total drag of nets at higher trawling speeds will be a little more than that estimated in the present study. Even though trawling efficiency is a function of trawling speed, the latter has to take into consideration many aspects concerning gear design and behaviour pattern of target species. This is possible only if the fishing operations are directed towards specific species and the current system of multispecies exploitation is curtailed. Research work should be initiated towards fish behaviour studies with particular reference to commercially important varieties so that way is paved for a more objective and scientific gear research.

3.4.4 Twine Thickness

Tables 3.8 and 3.9 gives the total net drag for different twine thickness.

Since the twine diameter is directly proportional to twine strength, in practice the twine thickness cannot be reduced as such to affect a drag reduction as twine thickness forms an important criterion for material selection. Figure 3.9 shows the plot of drag as a function of wet breaking strength for different twine thickness, but of equal breaking strengths, of polyethylene, polyamide and polyester. The twine diameter for these materials at equal breaking strengths were taken from Klust (1973). Nylon being stronger than polyethylene, the curve for the latter lies above the former. Similarly the curve for polyester lies below that of polyamide since the former is stronger than the latter. If instead of polyethylene, polyamide is used for the construction of fish trawl, the drag would be reduced by 20 percent which can bring about considerable amount of fuel savings. But the cost factor is a primary constraint that prohibits the use of high strength materials like nylon for trawl construction in our country. There is thus a need to develop cheaper and stronger materials for fishing gear construction which would go a long way in optimizing trawl efficiency.

3.4.5 Panel depths

The drag of a netting panel set against a water current is the product of the hydrodynamic stagnation pressure and the drag area of the panel. The latter is dependant on the twine surface area and the coefficient of drag at the particular angle at which the netting panel is inclined to the water flow. The various panels of a trawl net make up the cone of the trawl which sets the constituent panels at the corresponding angle of attack. For a given cone mouth the angle of attack is dependant on the cone length. Increasing the panel depth by adding more meshes will increase the cone length. Since the cone mouth remains almost a constant, the immediate effect of an increased cone length is a lowering in the angle of attack which can lower the net drag. But, increasing the panel depth will also increase the total twine surface area affecting a corresponding enhancement in drag. Thus the effect of an increase in the panel depth will be a lowering of the angle of attack with a simultaneous increase in twine surface area. Both these factors are antagonistic in their effects on total drag. As long as the influence of a lower angle of attack on total drag offsets the influence of an increased twine area, the total drag will fall. This is particularly evident in panels with bigger meshes. Figures 3.10 & 3.11 shows the effect of an increasing panel depth on the total drag, angle of attack and twine area. Since the panels A, B and C were having larger meshes, increasing the panel depths decreased the total drag initially. But as the panel depth was further increased, the effect of an increased twine area overcame the influence of a lowered angle of attack, thereby increasing the total drag. Thus panel depths form an important factor that may profitably be used to improve trawl design especially in the drag perspective.

TABLE 3.1.a DRAG CALCULATION RESULTS OF NET1 (Fish trawl)

Panel	No of meshes				Mesh size (m)	Dia.of twine 'd' (m)	No. of parts
	depth'm'	Uppr.edg	Lowr.edg	across'n'			
A (Upr.Wng)	89	16.5	60	38.25	0.160	0.00125	2
B (Lvr.Wng)	104	16.5	60	38.25	0.160	0.00125	2
C (Ovr.Hng)	15	180	165	172.50	0.160	0.00125	1
D (Bely)	60	220	160	190.00	0.120	0.00125	2
E (Bely)	70	240	170	205.00	0.080	0.00125	2
F (Bely)	90	233	143	188.00	0.060	0.00125	2
G (Thrt)	130	214	80	147.00	0.040	0.00125	2
H1(25% Cod)	75	140	140	140.00	0.024	0.00125	2
H2(75% Cod)	225	140	140	140.00	0.024	0.00125	2

Cdsc.Ct	----->	1.00000
Ck	----->	0.47000
Cf	----->	0.07000
HR at belly (m)	----->	4.00000
No of meshes at belly (m)	----->	60.00000
Mesh size at belly (m)	----->	0.16000
Otterdoor spread/Horiz.opening (m)	----->	16.50000
Vertical opening/Headline height (m)	----->	1.80000
Length of legs (m)	----->	5.00000
Diameter of floats (m)	----->	0.15200
Number of floats	----->	15.00000
Weight of ropes (kg)	----->	8.25000
Weight of sinkers (kg)	----->	25.00000
Mass density of water (kgf-sq.sec/m^4)	----->	103.80000
Velocity of water flow (m/s)	----->	1.28000
Primary hanging coeft. = Sin 0 = E1	----->	0.41667
Secondary hanging coeft. = Cos 0 = E2	----->	0.90906
Angle (deg)	----->	24.62432

TABLE 3.1.b DRAG CALCULATION RESULTS OF NET 1 (Fish trawl)

```
 ____________________________________________________________________________________________
I                                                                                            I
I          Semi Major axis of cone `a' (m)                 -------)      4.391617264034819 I
I          Semi Minor axis of cone `b' (m)                 -------)      0.821739130434783 I
I          Periphery of cone (m)                           -------)     18.992229233473627 I
I          Setting angle of meshes `0' (deg)               -------)     24.613578261004254 I
I          Angle of attack '   ' (deg)                     -------)      2.987113230202346 I
I                                                                                            I
I____________________________________________________________________________________________I
I           I                 I                  I                  I                     I
I   Panel   I    Am(sq.m.)    I    AM(sq.m.)     I    Simplified    I    SOLIDITY (s)     I
I           I                 I                  I     solidity     I                     I
I___________I_________________I__________________I__________________I_____________________I
I           I                 I                  I                  I                     I
I A (Upr.Wng) I 2.723400000000001 I    65.9981934730 I 0.082529531694333 I  0.140931833773106 I
I B (Lvr.Wng) I 3.182400000000001 I    77.1214845078 I 0.082529531694333 I  0.140931833773106 I
I C (Ovr.Hng) I 1.035000000000000 I    25.0819307647 I 0.041264765847166 I  0.140931833773106 I
I  D (Bely)   I 6.840000000000001 I   124.3191350946 I 0.110039375592444 I  0.187192709512628 I
I  E (Bely)   I 5.740000000000001 I    69.5508611543 I 0.165059063388666 I  0.278639857714402 I
I  F (Bely)   I 5.076000000000001 I    46.1289422325 I 0.220078751184888 I  0.368654201546483 I
I  G (Thrt)   I 3.822000000000001 I    23.1553476770 I 0.330118126777332 I  0.544384476101565 I
I H1(25% Cod) I 1.260000000000000 I     4.5801786614 I 0.550196877962219 I  0.878651372775410 I
I H2(75% Cod) I 3.780000000000001 I    13.7405359841 I 0.550196877962219 I  0.878651372775410 I
I___________I_________________I__________________I__________________I_____________________I
I           I                 I                  I                  I                     I
I   Panel   I      Cd 90      I       Cd0        I     Cd alpha     I         Ac          I
I           I                 I                  I                  I                     I
I___________I_________________I__________________I__________________I_____________________I
I           I                 I                  I                  I                     I
I A (Upr.Wng) I 1.326509853750041 I  0.143048397441343 I 0.201967237249840 I  0.550037710096215 I
I B (Lvr.Wng) I 1.326509853750041 I  0.143048397441343 I 0.201967237249840 I  0.642740694943392 I
I C (Ovr.Hng) I 1.326509853750041 I  0.143048397441343 I 0.201967237249840 I  0.209036142303535 I
I  D (Bely)   I 1.471188464571831 I  0.147362395050485 I 0.213269367829718 I  1.458762475955272 I
I  E (Bely)   I 1.840884601308439 I  0.155990390268768 I 0.239873220090234 I  1.376872283317944 I
I  F (Bely)   I 1.887796123374167 I  0.159657309724151 I 0.245693031920865 I  1.347138033330309 I
I  G (Thrt)   I 1.831694194061251 I  0.150571680448984 I 0.234266735482354 I  0.895367463013559 I
I H1(25% Cod) I 1.719490323435417 I  0.142886957227180 I 0.221378503460216 I  0.278936914359373 I
I H2(75% Cod) I 1.719490323435417 I  0.111379573386391 I 0.191439721671426 I  0.723642147917989 I
I____________________________________________________________________________________________I
I                                                                                            I
I          Total nominal twine surface area (sq.m)         -------)     33.458800000000008 I
I          Drag of cone `Dc'(kgf)                          -------)    566.225277337422376 I
I          Drag of codend `Ro'(kgf)                        -------)     41.836399392852315 I
I          Drag of floats `Df'(kgf)                        -------)     10.878110633261027 I
I          Frictional drag due to ropes `Dr'(kgf)          -------)      4.620000000000001 I
I          Frictional drag due to sinker chain `Ds'(kgf)   -------)     14.000000000000000 I
I                                                                                            I
I                                                                   --------------------I
I          TOTAL DRAG OF NET `D'(kgf)                      -------)    637.559787363535989 I
I                                                                   --------------------I
I____________________________________________________________________________________________I
```

TABLE 3.2.a DRAG CALCULATION RESULTS OF NET 2 (Shrimp trawl)

Panel	No of meshes				Mesh size (m)	Dia.of twine 'd' (m)	No. of parts
	depth'm'	Uppr.edg	Lowr.edg	across'n'			
A (Upr.Wng)	240	30	150	90.00	0.050	0.000750	3
B (Lwr.Wng)	285	30	150	90.00	0.050	0.000750	3
C (Ovr.Hng)	45	450	450	450.00	0.050	0.000750	1
D (Bely)	150	450	300	375.00	0.050	0.000750	3
E (Bely)	180	380	200	290.00	0.040	0.000750	2
F (Thrt)	140	240	100	170.00	0.035	0.000750	2
G1 (25% Cod)	100	120	120	120.00	0.020	0.001000	2
G2 (75% Cod)	300	120	120	120.00	0.020	0.001000	2

Cdsc.Ct	1.00000
Ck	0.47000
Cf	0.07000
HR at belly (m)	3.50000
No of meshes at belly (m)	150.00000
Mesh size at belly (m)	0.05000
Otterdoor spread/Horiz opening (m)	12.50000
Vertical opening/Headline height (m)	1.25000
Length of legs (m)	1.50000
Diameter of floats (m)	0.15200
Number of floats	12.00000
Weight of ropes (kg)	7.25000
Weight of sinkers (kg)	35.00000
Mass density of water (kgf-sq sec/m^4)	103.80000
Velocity of water flow (m/s)	1.20000
Primary hanging coeft. = Sin 0 = E1	0.46667
Secondary hanging coeft. = Cos 0 = E2	0.88443
Angle (deg)	27.81814

TABLE 3.2.b DRAG CALCULATION RESULTS OF NET 2 (Shrimp trawl)

Semi Major axis of cone 'a' (m)	------->	3.595589284560078
Semi Minor axis of cone 'b' (m)	------->	0.566037735849057
Periphery of cone (m)	------->	15.449132434751460
Setting angle of meshes '0' (deg)	------->	24.329079002313435
Angle of attack ' ' (deg)	------->	2.410333986991358

Panel	Am(sq.m.)	AM(sq.m.)	Simplified solidity	SOLIDITY (s)
A (Upr.Wng)	3.240000000000001	40.5422251280	0.159833358419477	0.270067969131982
B (Lwr.Wng)	3.847500000000001	48.1438923394	0.159833358419477	0.270067969131982
C (Cvr.Hng)	1.518750000000000	19.0041680287	0.079916679209738	0.270067969131982
D (Bely)	8.437500000000001	105.5787112707	0.159833358419477	0.270067969131982
E (Bely)	6.264000000000001	62.7053081979	0.199791698024346	0.335711914245999
F (Thrt)	2.499000000000001	21.8890476594	0.228333369170681	0.382141741041159
G1 (25% Cod)	0.960000000000000	3.6037533447	0.532777861398256	0.853608500900925
G2 (75% Cod)	2.880000000000001	10.8112600341	0.532777861398256	0.853608500900925

Panel	Cd 90	Cd0	Cd alpha	Ac
A (Upr.Wng)	1.801060848951541	0.153045458364993	0.219249916815253	0.710369730481418
B (Lwr.Wng)	1.801060848951541	0.153045458364993	0.219249916815253	0.843564054946684
C (Cvr.Hng)	1.801060848951541	0.153045458364993	0.219249916815253	0.332985811163165
D (Bely)	1.801060848951541	0.153045458364993	0.219249916815253	1.849921173128694
E (Bely)	1.899016516436750	0.158923477644192	0.228831699981840	1.433401768686243
F (Thrt)	1.384590304499143	0.151554736565101	0.221174645399372	0.552715438853032
G1 (25% Cod)	1.730710710498001	0.169919626037039	0.232620089328195	0.223315285755068
G2 (75% Cod)	1.730710710498001	0.110223548254389	0.175322136298372	0.504927752539310

Total nominal twine surface area (sq.m)	------->	29.646750000000005
Drag of cone 'Dc'(kgf)	------->	444.400678584636928
Drag of codend 'Ro'(kgf)	------->	27.649076977355023
Drag of floats 'Df'(kgf)	------->	7.648671539011658
Frictional drag due to ropes 'Dr'(kgf)	------->	4.060000000000000
Frictional drag due to sinker chain 'Ds'(kgf)	------->	19.600000000000005
TOTAL DRAG OF NET 'D'(kgf)	------->	503.358427101003606

TABLE 3.3 HIGHLIGHTS OF TRAWL DRAG CALCULATION RESULTS OF NETS 1 & 2

PARAMETERS	Fish trawl	Shrimp trawl
Semi Major axis of cone 'a' (m)	4.391617264034819	3.595589284560078
Semi Minor axis of cone 'b' (m)	0.821739130434783	0.566037735849057
Cone mouth area (sq.m)	28.703973822311732	18.993208167341713
Periphery of cone (m)	18.992229283473627	15.449132434751460
Setting angle of meshes '0' (deg)	24.613578261004254	24.329079002313435
Angle of attack ' ' (deg)	2.987113230202346	2.410333986991358
Total cone drag area	7.382533915738637	6.451201015553613
Total nominal twine surface area (sq.m)	33.458800000000008	29.646750000000005
Drag of cone 'Dc'(kgf)	566.225277337422490	444.400678584636928
Drag of codend 'Rc'(kgf)	41.836399392852322	27.649076977355027
Drag of floats 'Df'(kgf)	10.878110633261027	7.648671539011658
Frictional drag due to ropes 'Dr'(kgf)	4.620000000000001	4.060000000000000
Frictional drag due to sinker chain 'Ds' (kgf)	14.000000000000000	19.600000000000005
TOTAL DRAG OF NET 'D'(kgf)	637.559787363536103	503.358427101003663

HIGHLIGHTS OF DRAG CALCULATIONS

TABLE 3.4 - FISH TRAWL

Panel	SOLIDITY	Am		Drag	
		sq. m.	%	kgf	%
Upper Wing	0.1409318338	2.72340	8.14	46.77133	7.34
Lower Wing	0.1409318338	3.18240	9.51	54.65414	8.57
Over Hang	0.1409318338	1.03500	3.09	17.77496	2.79
Upper belly	0.1871927095	6.84000	20.44	124.04289	19.46
Mid belly	0.2786398577	5.74000	17.16	117.07953	18.36
Lower belly	0.3686542015	5.07600	15.17	106.04784	16.63
Throat	0.5443844761	3.82200	11.42	76.13575	11.94
25% of Codend	0.8786513728	1.26000	3.77	23.71883	3.72
75% of Codend	0.8786513728	3.78000	11.30	41.83640	6.56
Floats				10.87811	1.71
Ropes				4.62000	0.72
Sinker chain				14.00000	2.20
TOTAL		33.45880	100.00	637.55979	100.00

TABLE 3.5 - SHRIMP TRAWL

Panel	SOLIDITY	Am		Drag	
		sq. m.	%	kgf	%
Upper Wing	0.2700679691	3.240000	10.92868	53.09019	10.54719
Lower Wing	0.2700679691	3.847500	12.97781	63.04460	12.52479
Over Hang	0.2700679691	1.518750	5.122821	24.88603	4.943997
Upper belly	0.2700679691	8.437500	28.46011	138.25571	27.46665
Lower belly	0.3357119142	6.264000	21.12879	107.12671	21.28239
Throat	0.3821417410	2.499000	8.429254	41.30774	8.206426
25% of Codend	0.8536085009	0.960000	3.238128	16.68969	3.315667
75% of Codend	0.8536085009	2.880000	9.714386	27.64908	5.492920
Floats				7.64867	1.519527
Ropes				4.06000	0.806582
Sinker chain				19.60000	3.893845
TOTAL		29.64675	100	503.35843	100

TABLE 3.6
TOTAL DRAG AT VARIOUS TOWING SPEEDS

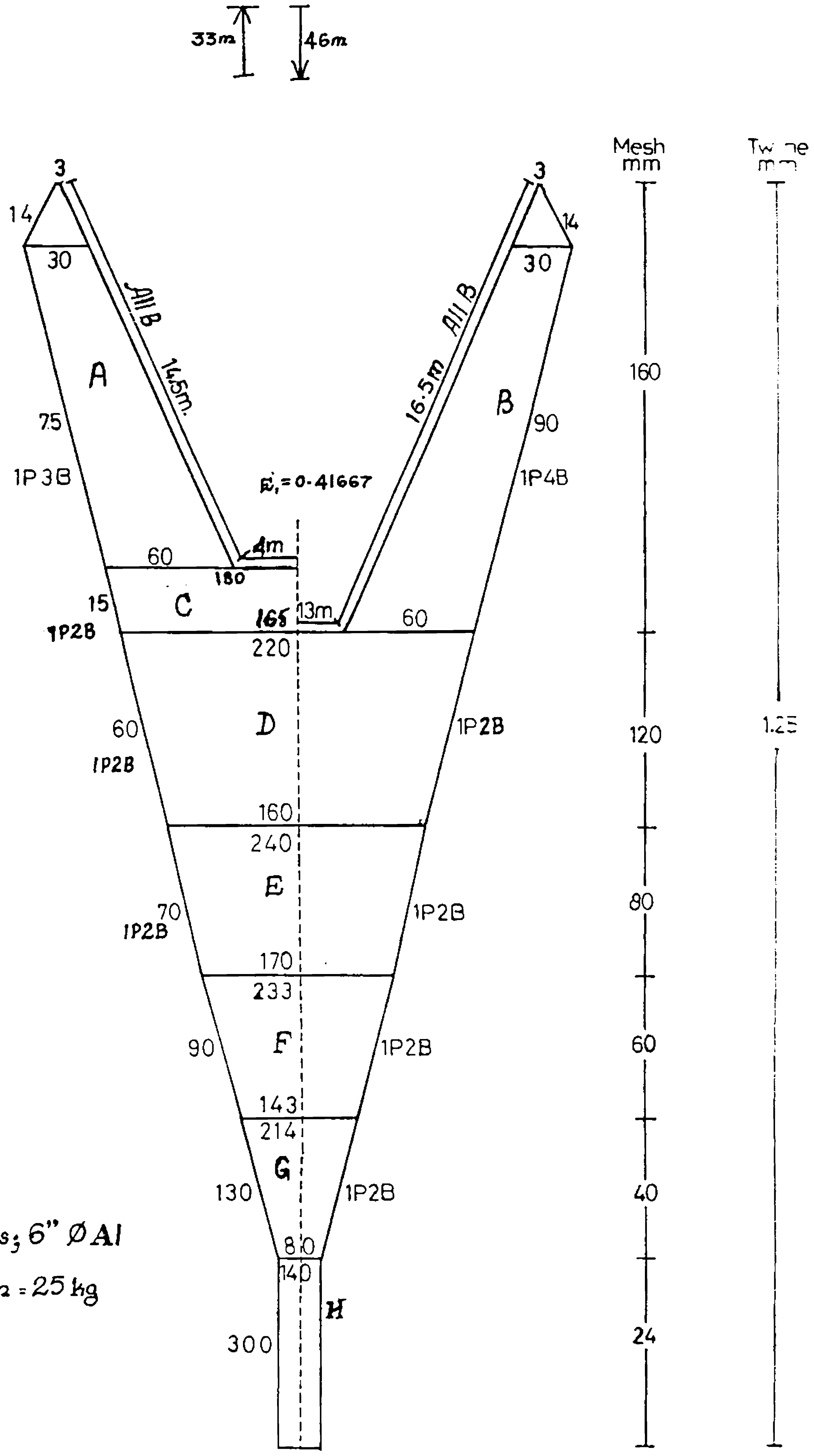
Towing speed (knots)	Total drag (kgf)	
	Fish trawl	Shrimp trawl
0.25	24.91	29.20
0.50	43.73	45.78
0.75	75.04	73.38
1.00	118.85	112.00
1.25	175.13	161.61
1.50	243.88	222.23
1.75	325.10	293.84
2.00	418.77	376.43
2.25	524.90	470.02
2.50	643.48	574.59
2.75	774.50	690.13
3.00	917.97	816.66
3.25	1073.88	954.17
3.50	1242.23	1102.65
3.75	1423.02	1262.10
4.00	1616.24	1432.52
4.25	1821.89	1613.91
4.50	2039.97	1806.23
4.75	2270.49	2009.61
5.00	2513.42	2223.90
5.25	2768.79	2449.16
5.50	3036.58	2685.33
5.75	3316.79	2932.57
6.00	3609.42	3190.72
6.25	3914.47	3459.83
6.50	4231.94	3739.89
6.75	4561.83	4030.92
7.00	4904.13	4332.90
7.25	5258.85	4645.84
7.50	5625.98	4969.74
7.75	6005.53	5304.59
8.00	6397.49	5650.40

TABLE 3.7 TOTAL DRAG FOR DIFFERENT TWINE THICKNESS FOR FISH TRAWL

Twine dia (mm)	Panel A	Panel B	Panel C	Panel D	Panel E	Panel F	Panel G	Panel H1	Panel H2
0.10	594.04	586.70	621.02	621.02	543.25	555.03	577.32	615.45	624.38
0.15	595.69	588.64	621.65	621.65	546.07	557.37	579.19	616.36	624.95
0.20	597.37	590.59	622.29	622.29	548.98	559.83	581.20	617.34	625.52
0.25	599.06	592.57	622.93	622.93	551.99	562.41	583.35	618.41	626.10
0.30	600.77	594.57	623.58	623.58	555.10	565.12	585.67	619.58	626.67
0.35	602.51	596.60	624.24	624.24	558.31	567.96	588.15	620.86	627.24
0.40	604.26	598.65	624.91	624.91	561.62	570.93	590.82	622.28	627.82
0.45	606.04	600.73	625.58	625.58	565.04	574.04	593.67	621.86	628.39
0.50	607.84	602.83	626.26	626.26	568.57	577.30	596.73	622.80	628.96
0.55	609.65	604.95	626.95	626.95	572.21	580.71	600.02	623.74	629.54
0.60	611.49	607.10	627.65	627.65	575.97	584.28	603.54	624.68	630.11
0.65	613.36	609.28	628.36	628.36	579.85	588.02	607.33	625.64	630.68
0.70	615.24	611.48	629.08	629.08	583.85	591.93	608.36	626.60	631.26
0.75	617.15	613.71	629.80	629.80	587.99	596.03	610.95	627.56	631.83
0.80	619.08	615.96	630.54	630.54	592.25	600.32	613.56	628.54	632.40
0.85	621.03	618.25	631.28	631.28	596.65	604.82	616.18	629.52	632.97
0.90	623.01	620.56	632.03	632.03	601.20	609.53	618.81	630.50	633.55
0.95	625.01	622.90	632.79	632.79	605.89	614.48	621.46	631.49	634.12
1.00	627.04	625.27	633.56	633.56	610.74	619.67	624.11	632.49	634.69
1.05	629.09	627.67	634.34	634.34	615.76	623.36	626.78	633.49	635.27
1.10	631.17	630.09	635.13	635.13	620.94	626.91	629.46	634.50	635.84
1.15	633.27	632.55	635.93	635.93	626.29	630.45	632.15	635.52	636.41
1.20	635.40	635.04	636.74	636.74	631.83	634.01	634.85	636.54	636.99
1.25	637.56	637.56	637.56	637.56	637.56	637.56	637.56	637.56	637.56
1.30	639.74	640.11	638.39	638.39	643.49	641.12	640.28	638.59	638.13
1.35	641.96	642.70	639.23	639.23	656.18	644.68	643.01	639.62	638.71
1.40	644.19	645.31	640.08	640.08	660.66	648.24	645.74	540.66	639.28
1.45	646.46	647.96	640.94	640.94	665.15	651.80	648.49	641.71	639.85
1.50	648.76	650.65	641.82	641.82	669.65	655.36	651.24	642.76	640.43
1.55	651.09	653.37	642.70	642.70	674.14	658.93	654.01	643.81	641.00
1.60	653.45	656.12	643.60	643.60	678.64	662.49	656.78	644.87	641.57
1.65	655.84	658.92	644.51	644.51	683.14	666.06	659.55	645.94	642.14
1.70	658.26	661.75	645.43	645.43	687.65	669.63	662.34	647.01	642.72
1.75	660.71	664.61	646.36	646.36	692.15	673.20	665.13	648.08	643.29
1.80	663.20	667.52	647.30	647.30	696.66	676.76	667.93	649.16	643.86
1.85	665.72	670.46	648.26	648.26	701.17	680.33	670.74	650.24	644.44
1.90	668.27	673.45	649.23	649.23	705.68	683.90	673.55	651.33	645.01
1.95	670.86	676.47	650.22	650.22	710.20	687.47	676.37	652.43	645.58
2.00	673.48	679.54	651.21	651.21	714.71	691.03	679.20	653.53	646.16
2.05	676.15	682.65	652.22	652.22	719.23	694.60	682.04	654.63	646.73
2.10	678.85	685.80	653.25	653.25	723.74	698.16	684.88	655.74	647.30
2.15	681.58	689.00	654.29	654.29	728.26	701.73	687.73	656.85	647.88
2.20	684.36	692.25	655.35	655.35	732.77	705.29	690.59	657.97	648.45
2.25	687.17	695.54	656.42	656.42	737.29	708.85	693.45	659.10	649.02
2.30	690.03	698.87	657.50	657.50	741.81	712.41	696.32	660.23	649.59
2.35	692.93	702.26	658.60	658.60	746.32	715.97	699.20	661.36	650.17
2.40	695.87	705.70	659.72	659.72	750.84	719.53	702.09	662.50	650.74
2.45	698.86	709.19	660.86	660.36	755.35	723.09	704.98	663.65	651.31

TABLE 3.8 TOTAL DRAG FOR DIFFERENT TWINE THICKNESS FOR SHRIMP TRAWL

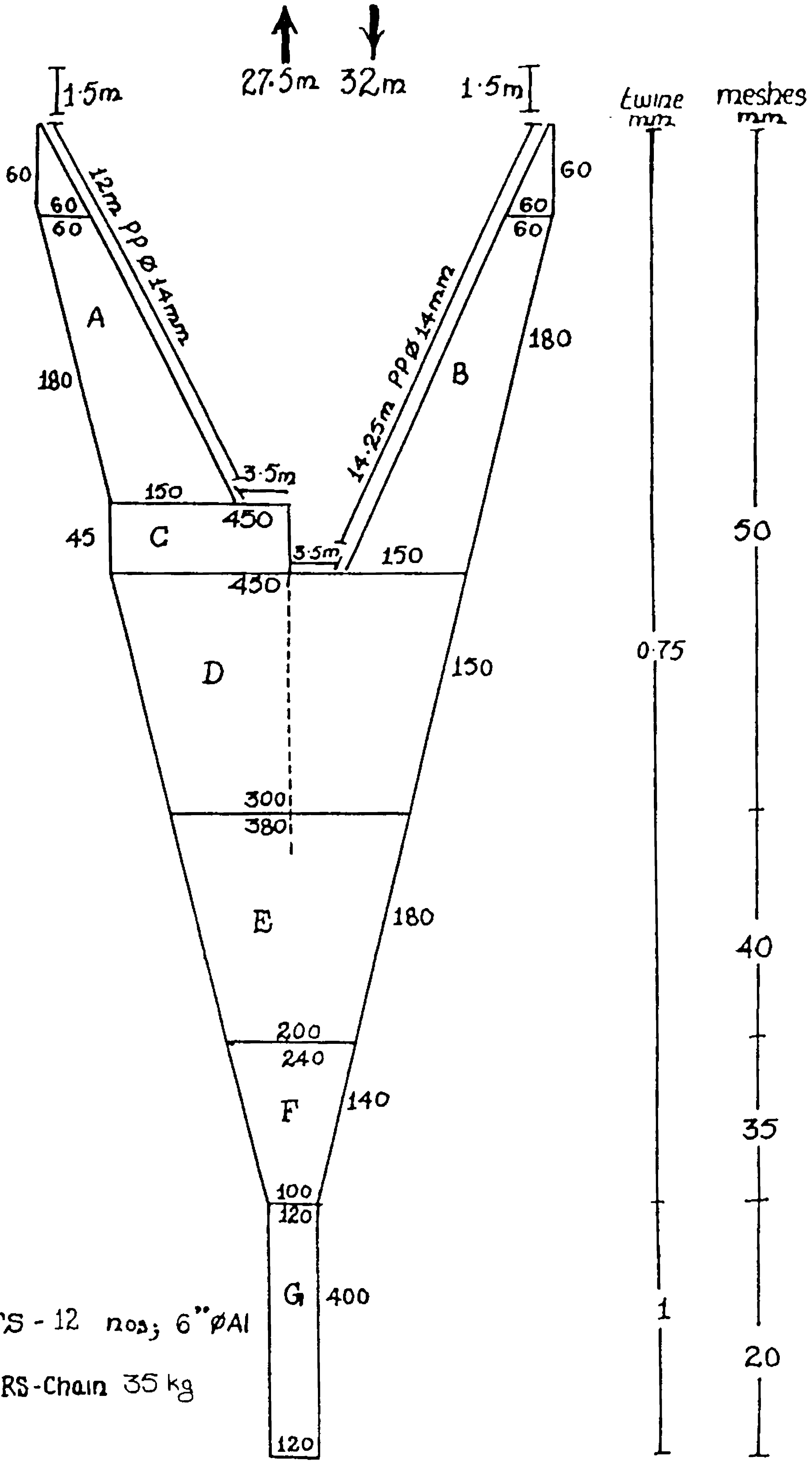
Twine dia(mm)	Panel A	Panel B	Panel C	Panel D	Panel E	Panel F	Panel G1	Panel G2
0.10	455.73	446.80	481.03	395.65	416.47	472.04	487.95	495.06
0.15	458.61	450.22	482.38	401.77	421.32	473.82	488.69	495.52
0.20	461.60	453.78	483.79	408.19	426.47	475.74	489.50	495.99
0.25	464.71	457.46	485.24	414.93	431.91	477.81	490.39	496.45
0.30	467.93	461.29	486.75	422.00	437.67	480.04	491.39	496.91
0.35	471.27	465.26	488.32	429.41	443.78	482.44	491.98	497.37
0.40	474.75	469.38	489.95	437.17	450.24	485.02	492.79	497.83
0.45	478.35	473.67	491.64	445.32	457.09	487.81	493.61	498.29
0.50	482.11	478.12	493.40	453.86	464.36	490.81	494.45	498.75
0.55	486.01	482.76	495.23	462.81	472.08	494.04	495.29	499.21
0.60	490.08	487.59	497.13	472.22	480.28	495.95	496.15	499.67
0.65	494.32	492.62	499.12	482.08	489.01	498.39	497.02	500.13
0.70	498.74	497.87	501.19	492.45	496.85	500.86	497.90	500.59
0.75	503.36	503.36	503.36	503.36	503.36	503.36	498.78	501.05
0.80	508.19	509.10	505.62	514.83	509.87	505.88	499.68	501.52
0.85	511.79	514.47	508.00	523.93	516.40	508.42	500.59	501.98
0.90	514.75	518.62	509.78	531.02	522.92	510.98	501.50	502.44
0.95	517.64	522.73	511.57	537.99	529.45	513.56	502.43	502.90
1.00	520.47	526.82	513.36	544.84	535.98	516.17	503.36	503.36
1.05	523.23	530.87	515.15	551.58	542.52	518.79	504.30	503.82
1.10	525.94	534.90	516.94	558.22	549.05	521.44	505.25	504.28
1.15	528.59	538.90	518.74	564.75	555.58	524.10	506.21	504.74
1.20	531.19	542.87	520.54	571.18	562.10	526.78	507.17	505.20
1.25	533.74	546.82	522.34	577.51	568.63	529.48	508.14	505.66
1.30	536.25	550.73	524.15	583.75	575.15	532.19	509.13	506.12
1.35	538.70	554.62	525.95	589.89	581.67	534.92	510.11	506.58
1.40	541.12	558.48	527.76	595.96	588.18	537.67	511.11	507.04
1.45	543.50	562.31	529.57	601.95	594.68	540.43	512.11	507.51
1.50	545.84	566.12	531.38	607.86	601.18	543.21	513.12	507.97
1.55	548.16	569.90	533.19	613.71	607.68	546.00	514.14	508.43
1.60	550.44	573.65	535.00	619.49	614.16	548.81	515.16	508.89
1.65	552.71	577.37	536.81	625.22	620.65	551.63	516.19	509.35
1.70	554.95	581.08	538.62	630.90	627.12	554.46	517.23	509.81
1.75	557.18	584.75	540.44	636.53	633.59	557.31	518.27	510.27
1.80	559.39	588.40	542.25	642.13	640.05	560.17	519.32	510.73
1.85	561.60	592.03	544.07	647.69	646.50	563.05	520.38	511.19
1.90	563.81	595.63	545.88	653.24	652.95	565.93	521.44	511.65
1.95	566.02	599.21	547.70	658.76	659.39	568.83	522.51	512.11
2.00	568.23	602.77	549.51	664.28	665.83	571.74	523.59	512.57
2.05	570.46	606.31	551.33	669.80	672.26	574.67	524.67	513.04
2.10	572.70	609.83	553.14	675.32	678.68	577.60	525.76	513.50
2.15	574.96	613.33	554.96	680.86	685.10	580.55	526.85	513.96
2.20	577.25	616.82	556.77	686.42	691.52	583.51	527.96	514.42
2.25	579.57	620.28	558.58	692.01	697.93	586.48	529.07	514.88
2.30	581.92	623.73	560.40	697.65	704.34	589.46	530.18	515.34
2.35	584.31	627.16	562.21	703.32	710.74	592.46	531.30	515.80
2.40	586.75	630.58	564.02	709.06	717.15	595.46	532.43	516.26
2.45	589.23	633.99	565.84	714.86	723.55	598.48	533.57	516.72



FLOATS - 15 nos; 6" ØAl

SINKERS - chain = 25 kg

FIG 3.1 FISH TRAWL



FLOATS - 12 nos; 6" ØAl

SINKERS - Chain 35 kg

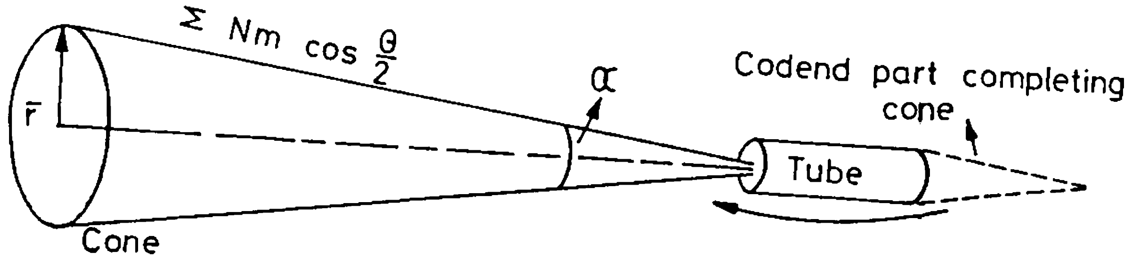


FIG. 3. a Apex of the cone

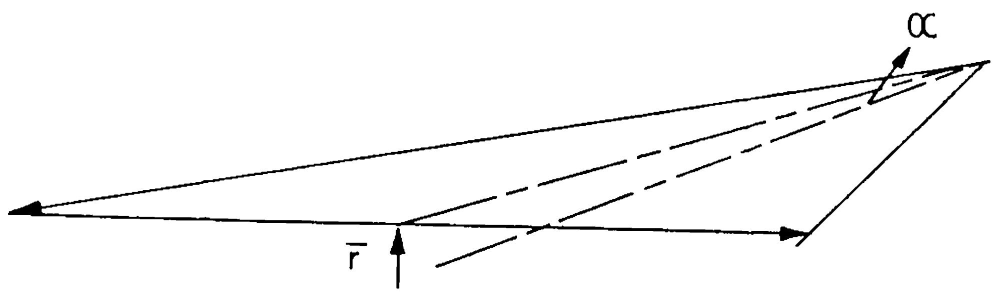
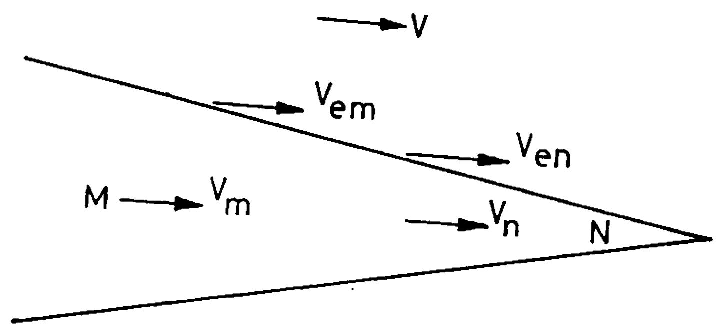


FIG. 3.b Cone flattend out



$V_e > V > V_m > V_n$
for $s_n > s_m$

FIG. 3.c Effect of high solidity panels

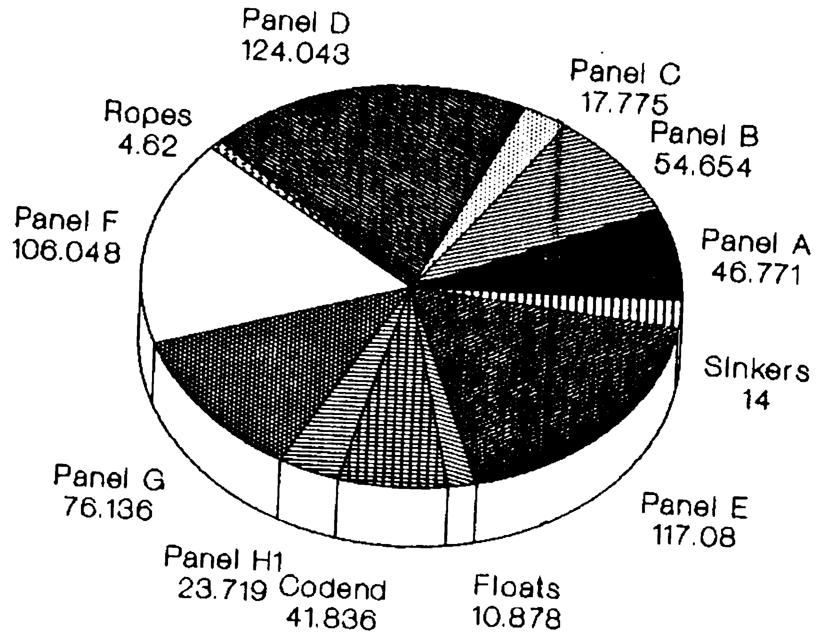


Fig 3.3
Contribution of various trawl components
to total drag - Fish trawl

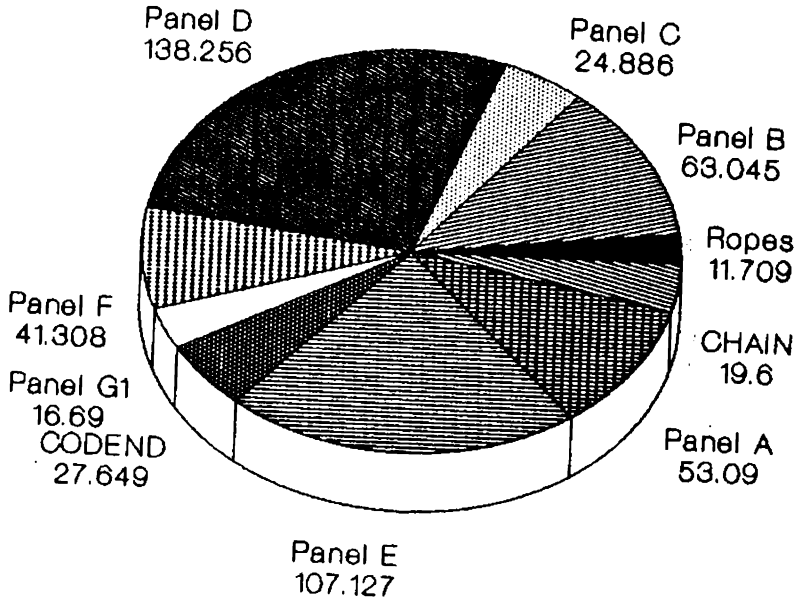


Fig 3.4
Contribution of various trawl components
to total drag - Shrimp trawl

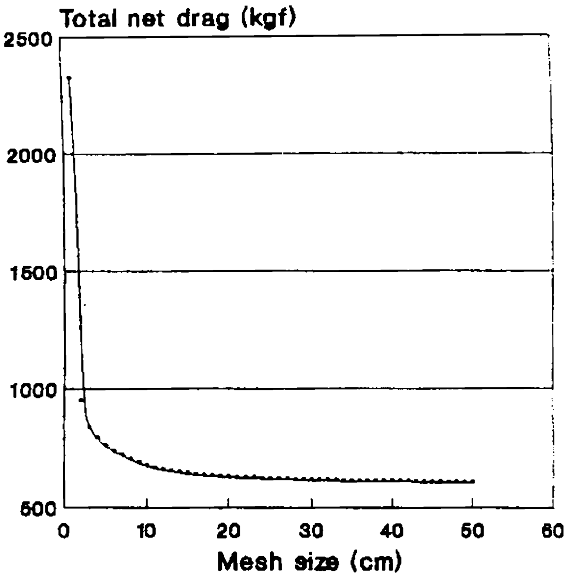


Fig. 3.5.1
Mesh size vs. total net drag
Panel A of fish trawl

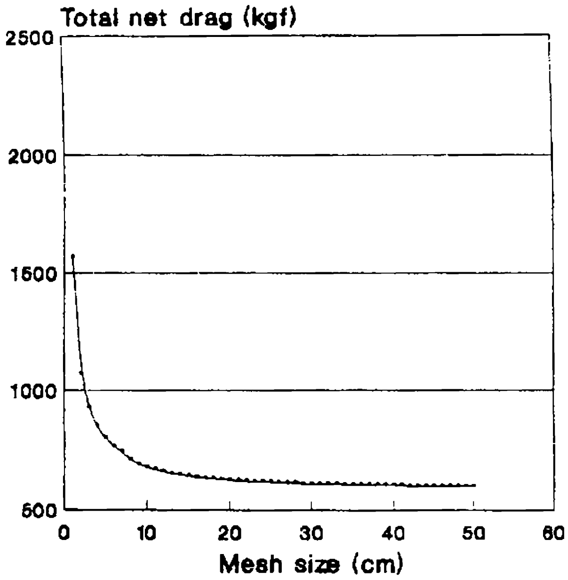


Fig. 3.5.2
Mesh size vs. total net drag
Panel B of fish trawl

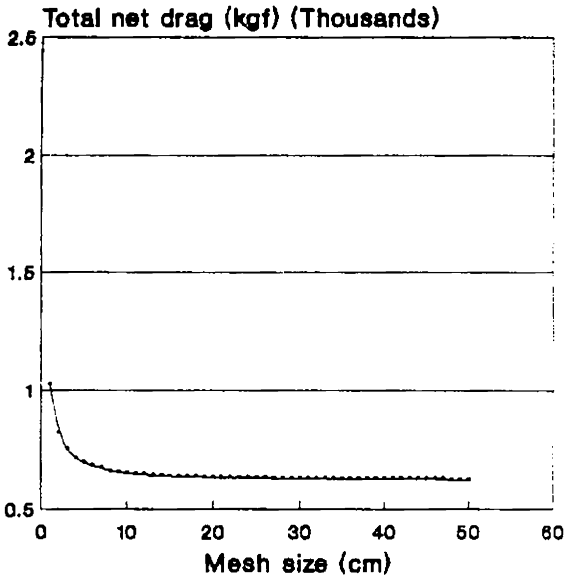


Fig. 3.5.3
Mesh size vs. total net drag
Panel C of fish trawl

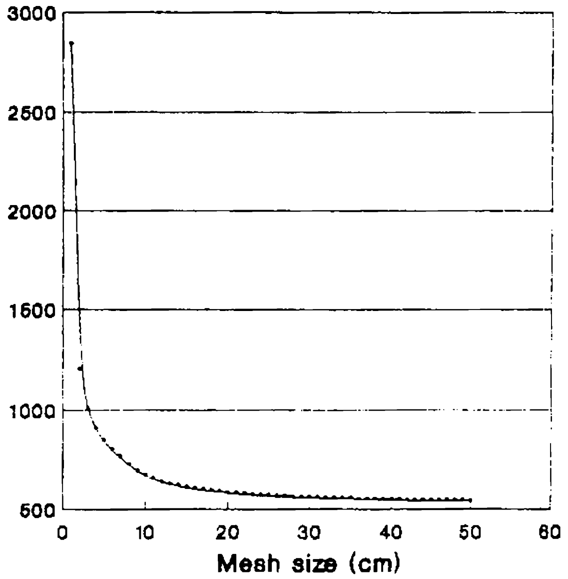


Fig. 3.5.4
Mesh size vs. total net drag
Panel D of fish trawl

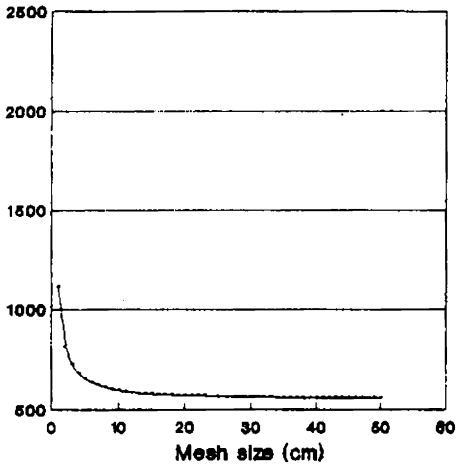


Fig. 3.5.6
Mesh size vs. total net drag
Panel F of fish trawl

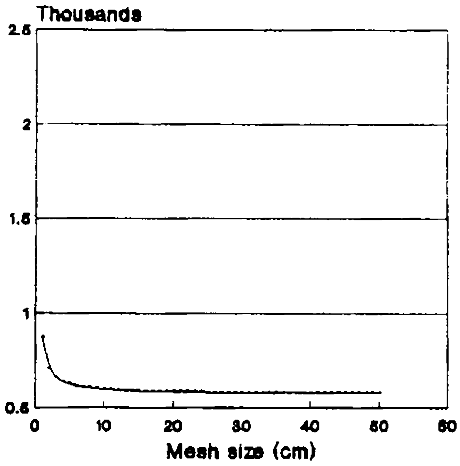


Fig. 3.5.7
Mesh size vs. total net drag
Panel G of fish trawl

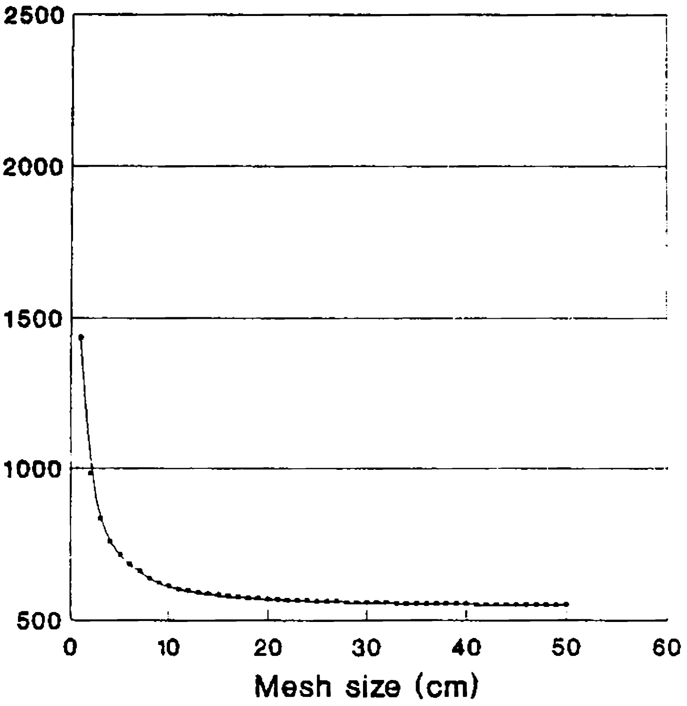


Fig. 3.5.5
Mesh size vs. total net drag
Panel E of fish trawl

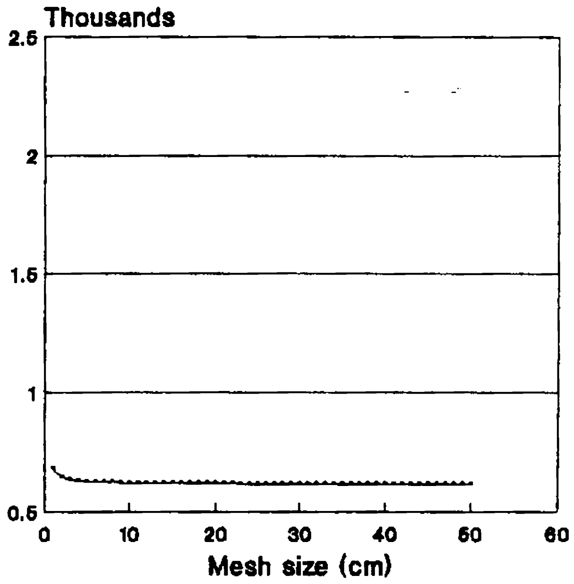


Fig. 3.5.8
Mesh size vs. total net drag
Panel H1 of fish trawl

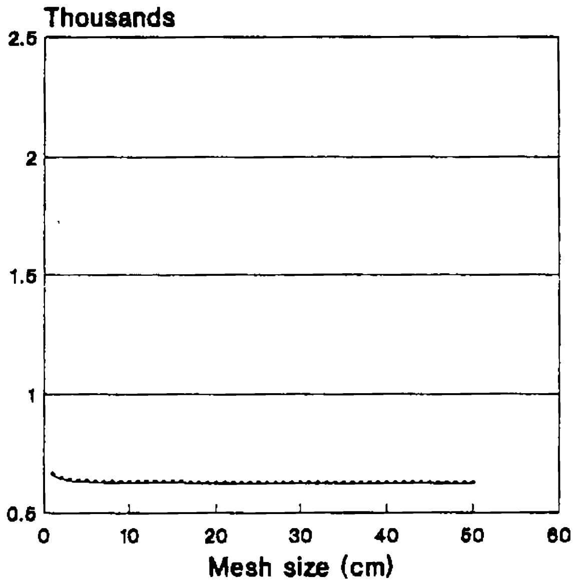


Fig. 3.5.9
Mesh size vs. total net drag
Panel H2 of fish trawl

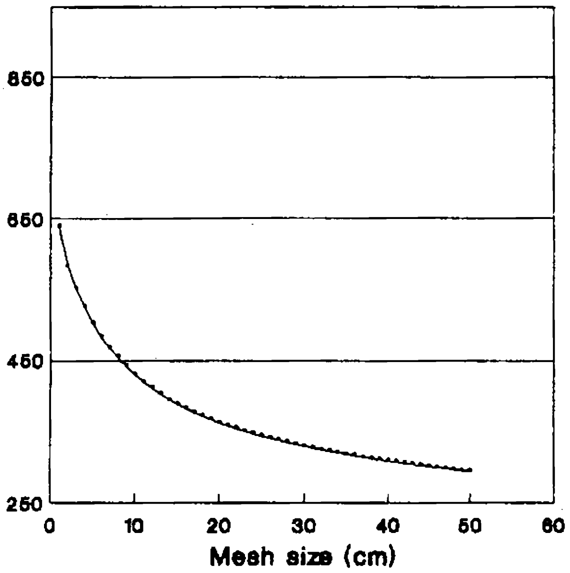


Fig. 3.6.1
Mesh size vs. total net drag
Panel A of shrimp trawl

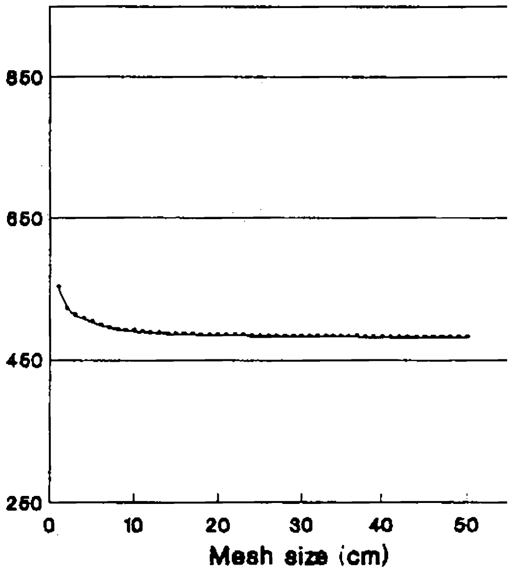


Fig. 3.6.2
Mesh size vs. total net drag
Panel B of shrimp trawl

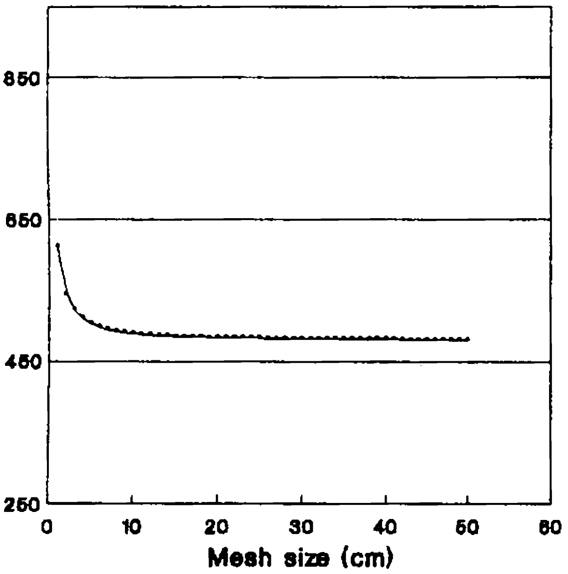


Fig. 3.6.3
Mesh size vs. total net drag
Panel C of shrimp trawl

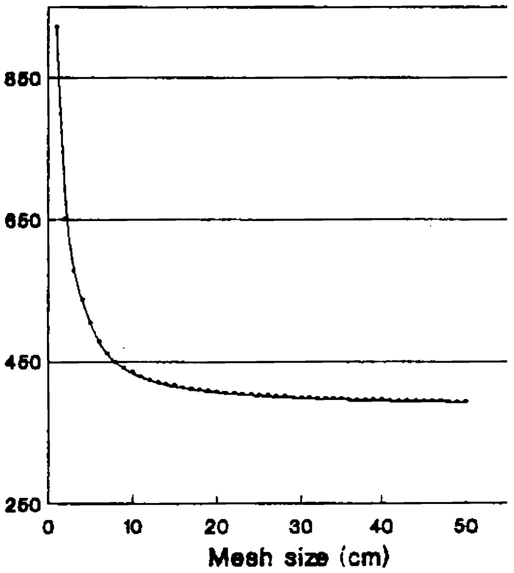


Fig. 3.6.4
Mesh size vs. total net drag
Panel D of shrimp trawl

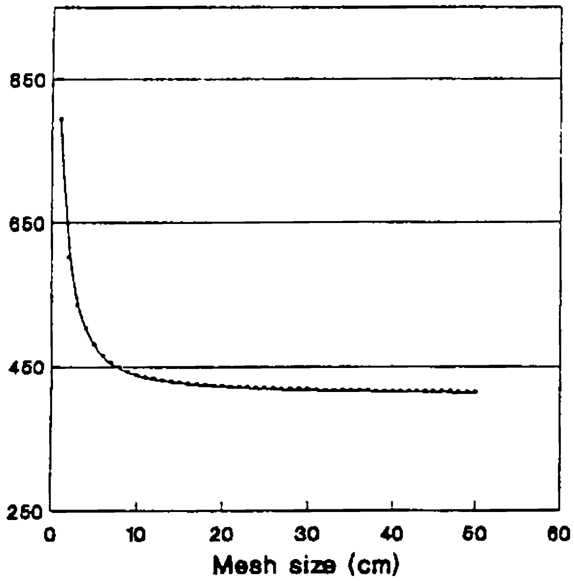


Fig. 3.6.5
Mesh size vs. total net drag
Panel E of shrimp trawl

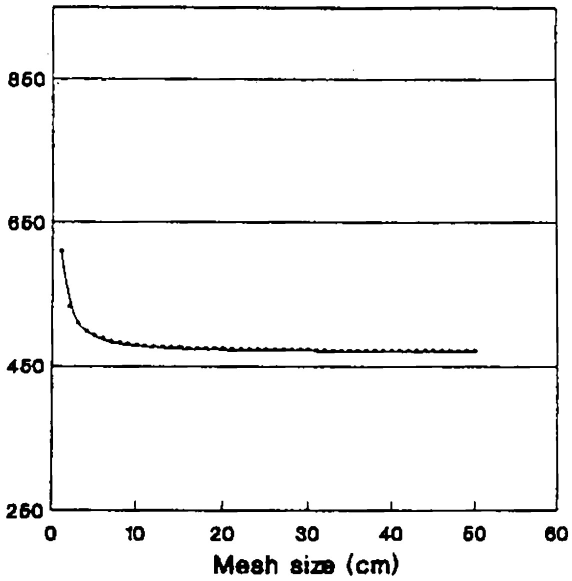


Fig. 3.6.6
Mesh size vs. total net drag
Panel F of shrimp trawl

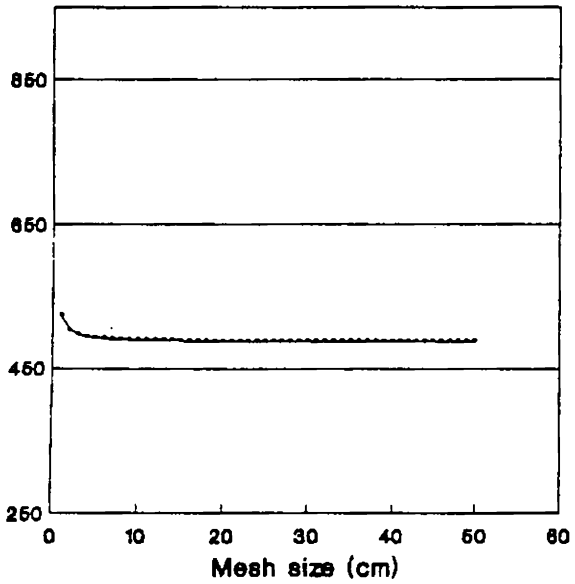


Fig. 3.6.7
Mesh size vs. total net drag
Panel G1 of shrimp trawl

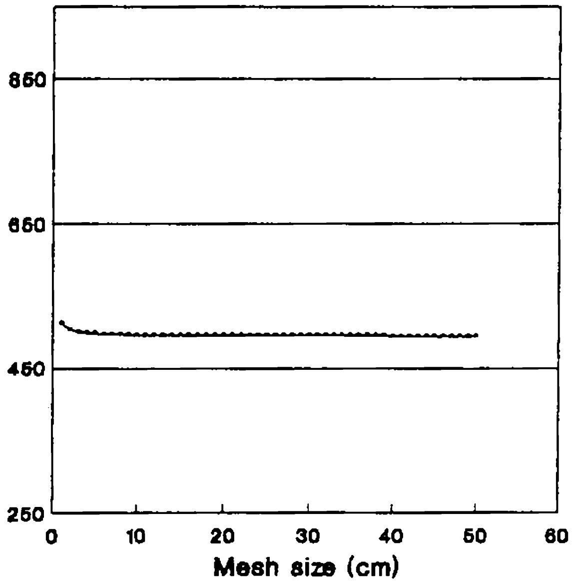


Fig. 3.6.8
Mesh size vs. total net drag
Panel G2 of shrimp trawl

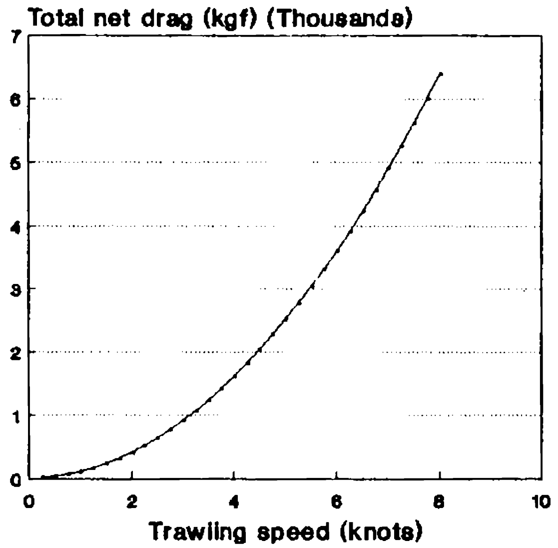


Fig. 3.7
Total drag vs. trawling speed
Fish trawl

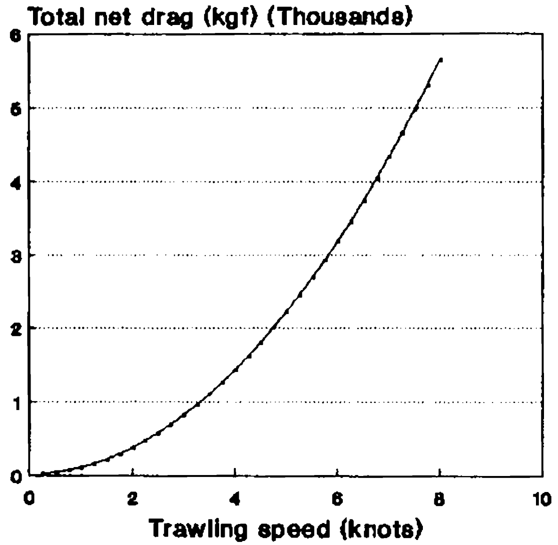


Fig. 3.8
Total drag vs. trawling speed
Shrimp trawl

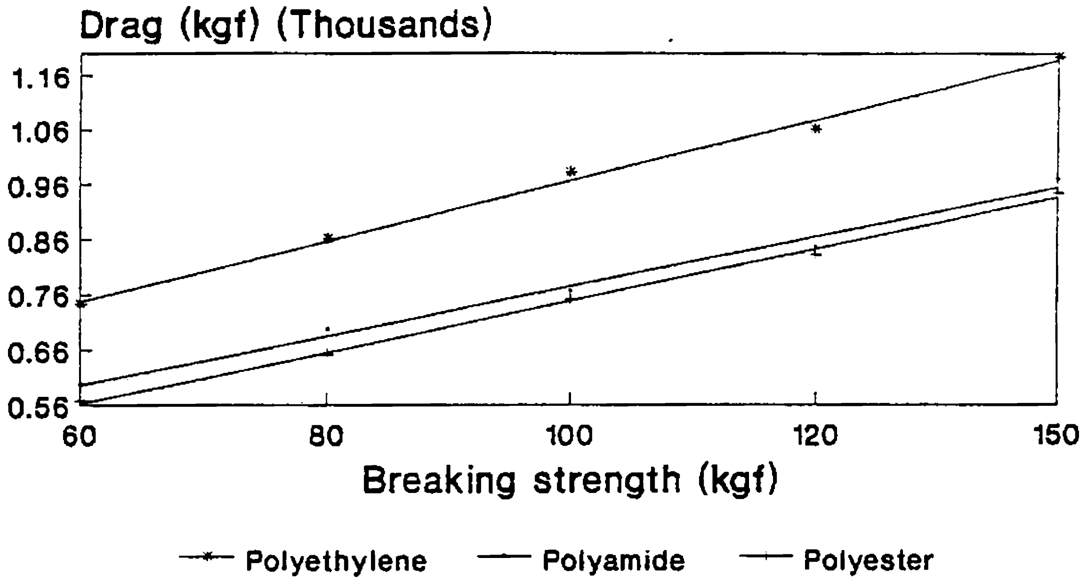


Fig. 3.9
Drag as a function of breaking strengths for PE, PA and PES twines.

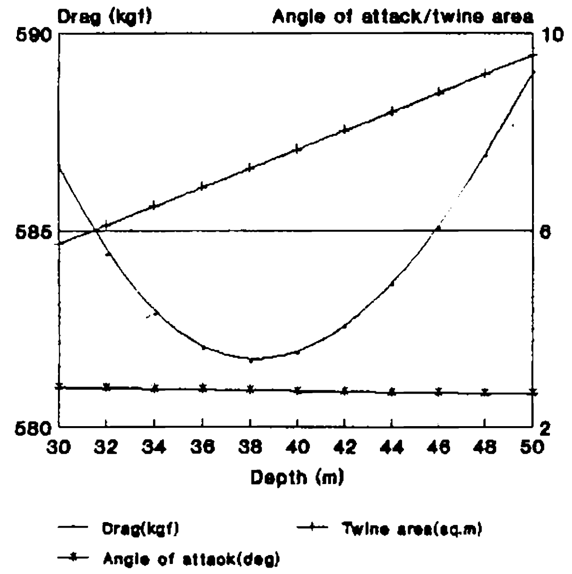


Fig. 3.10.1 Drag variation in relation to angle of attack and twine area with different panel depths. Net1. Panel A.

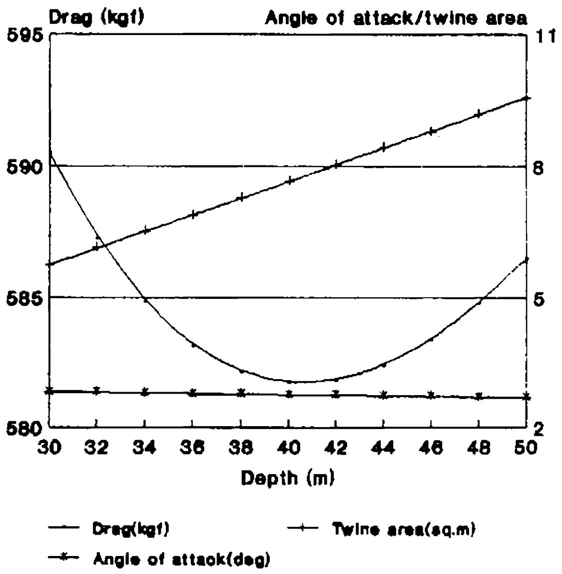


Fig. 3.10.2 Drag variation in relation to angle of attack and twine area with different panel depths. Net1. Panel B.

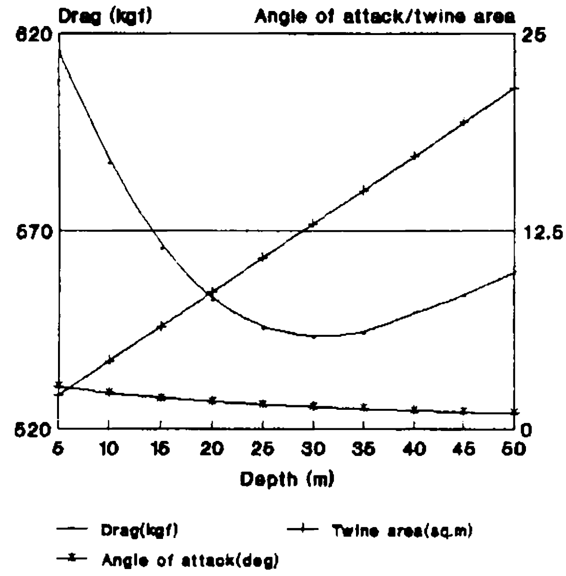


Fig. 3.10.3 Drag variation in relation to angle of attack and twine area with different panel depths. Net1. Panel C.

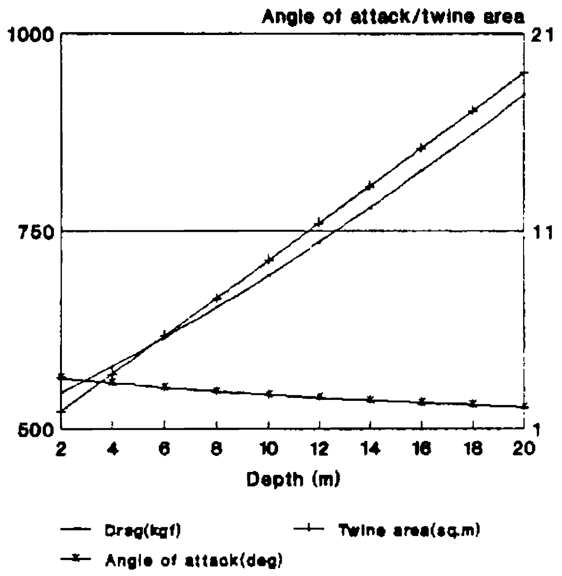


Fig. 3.10.4 Drag variation in relation to angle of attack and twine area with different panel depths. Net1. Panel D.

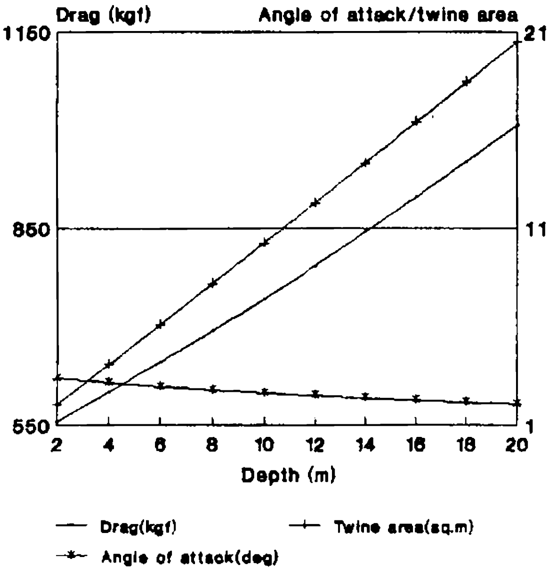


Fig. 3.10.6 Drag variation in relation to angle of attack and twine area with different panel depths. Net1. Panel E.

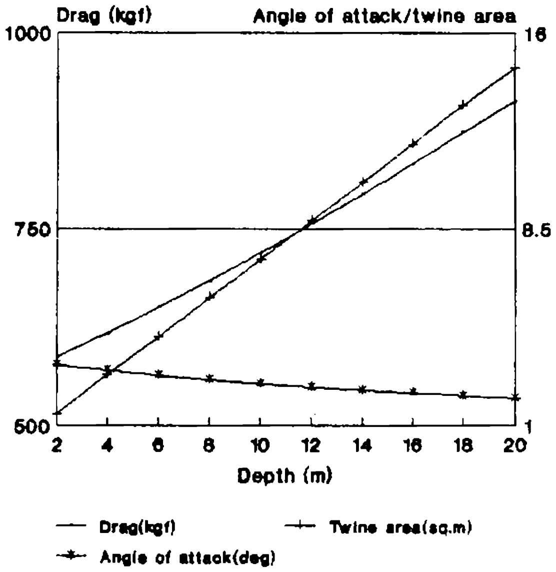


Fig. 3.10.7 Drag variation in relation to angle of attack and twine area with different panel depths. Net1. Panel G.

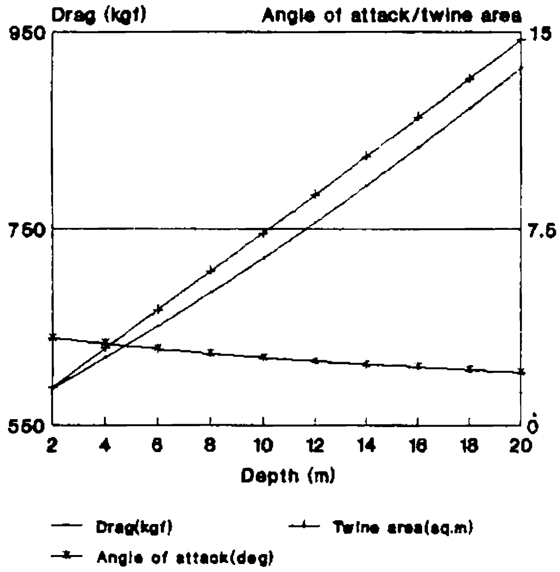


Fig. 3.10.7 Drag variation in relation to angle of attack and twine area with different panel depths. Panel G

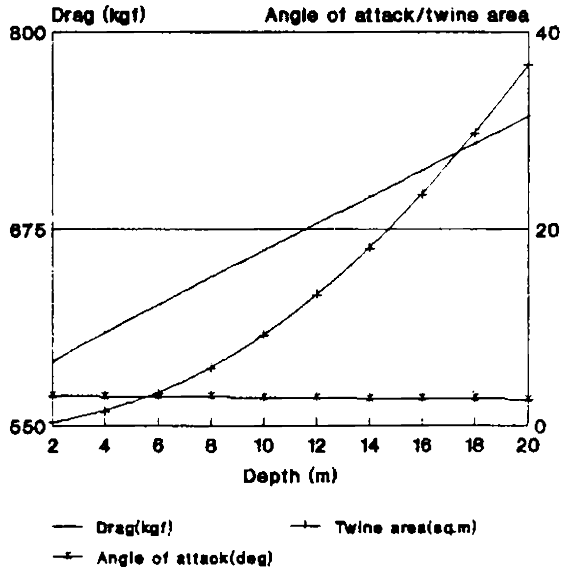


Fig. 3.10.8 Drag variation in relation to angle of attack and twine area with different panel depths. Net1. Codend.

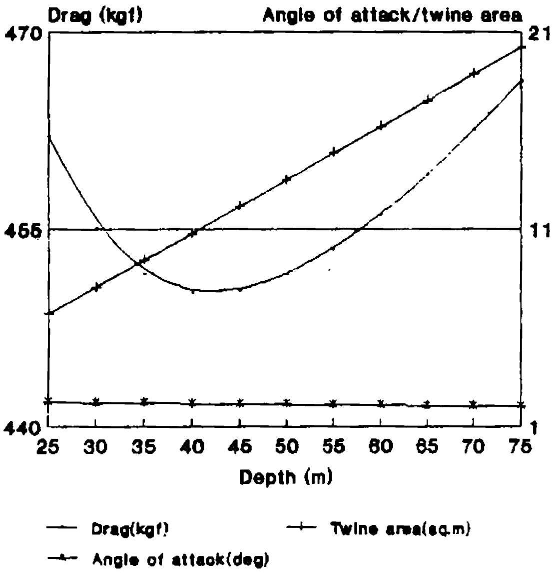


Fig. 3.11.1 Drag variation in relation to angle of attack and twine area with different panel depths. Net2. Panel A.

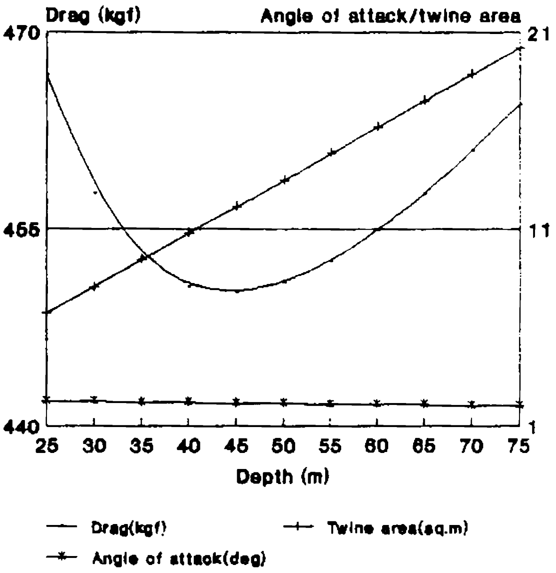


Fig. 3.11.2 Drag variation in relation to angle of attack and twine area with different panel depths. Net2. Panel B.

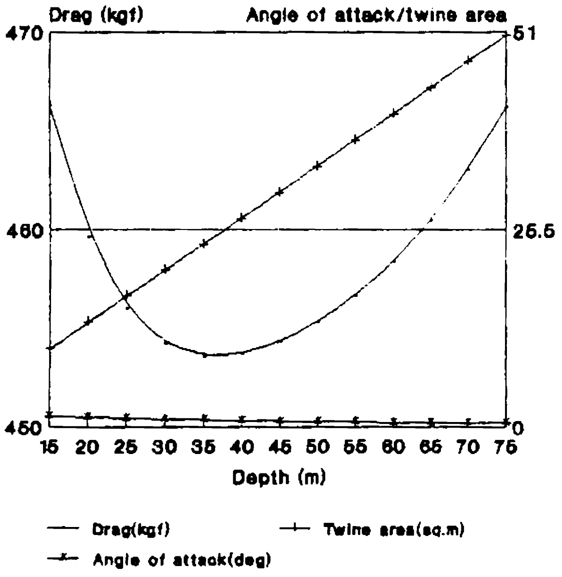


Fig. 3.11.3 Drag variation in relation to angle of attack and twine area with different panel depths. Net2. Panel C.

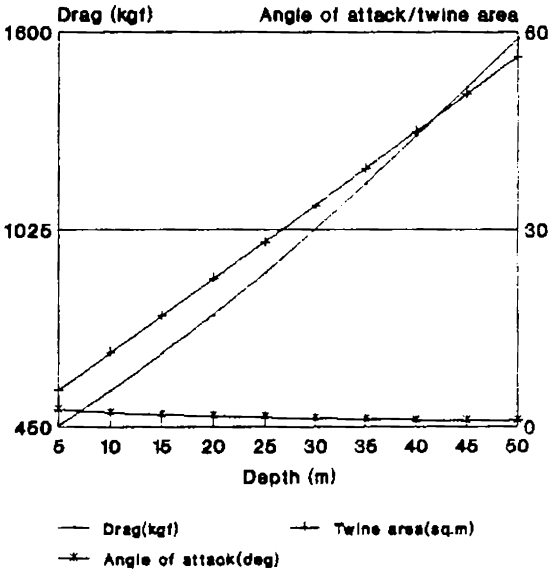


Fig. 3.11.4 Drag variation in relation to angle of attack and twine area with different panel depths. Net2. Panel D.

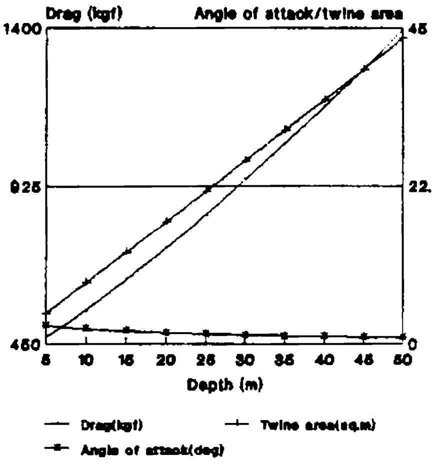


Fig. 3.11.5 Drag variation in relation to angle of attack and twine area with different panel depths. Net2. Panel E.

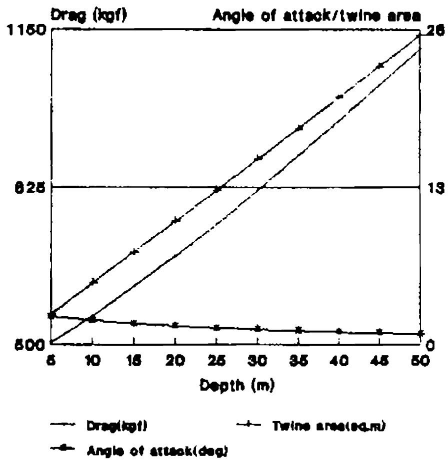


Fig. 3.11.6 Drag variation in relation to angle of attack and twine area with different panel depths. Net2. Panel F.

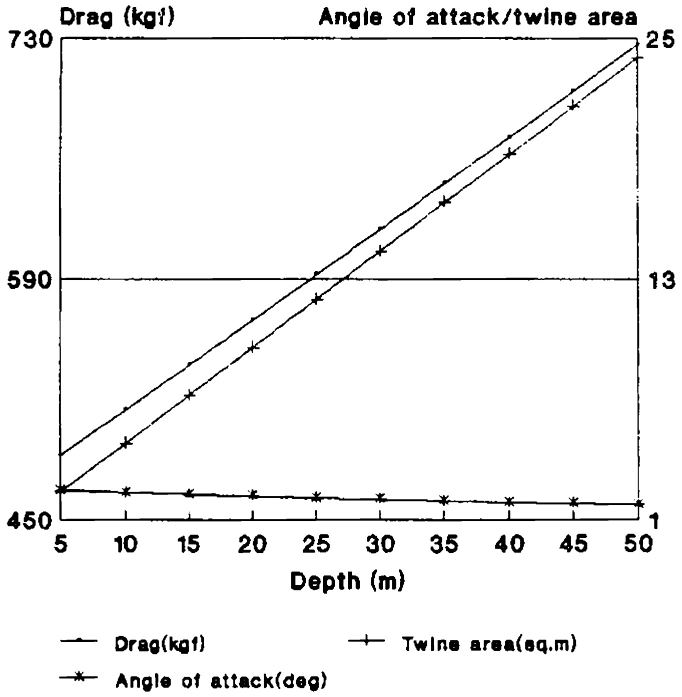


Fig. 3.11.7 Drag variation in relation to angle of attack and twine area with different panel depths. Net2. Codend.

CHAPTER IV

OPERATIONAL ANALYSIS OF TRAWLERS

4.1 INTRODUCTION

The rapid industrialisation that revolutionised the pace of development, manifested its presence in the fishing industry also, resulting in an enhanced fish production by several fold during the past few years. Today fishing is a very energy expensive industry of the world and trawling continues to have the highest fuel consumption per unit operational hour. Though energy optimisation drives were initiated with substantial success in most other energy intensive industries of the world, very little has been achieved in the fishing industry in India. According to Endal (1988), there has been a tendency for developing countries to adopt energy intensive fishing methods in their fisheries, making the products from the sea too expensive for their own people and also aggravating their balance of trade problems due to increased fuel importation. A somewhat similar situation is observed in India whose marine fish landings are effected primarily by two categories of fishing units - the traditional and mechanised sectors. The latter is comprised of medium sized fishing vessels of upto 11m OAL and bottom trawlers of between 9 and 11m OAL being quite a popular class of vessels in this category.

With shrimps continuing to dominate the seafood exports from India and marine shrimp production being primarily effected by bottom trawling, there has been a rapid proliferation of bottom trawlers in the operation along the shallow waters, within depths of 75m, of the Indian coastline. This has led to over-capitalisation and overexploitation of the coastal marine resources of the country resulting in dwindled net returns and diminished catch per unit effort, further aggravated by the ever increasing fuel costs. There has been a tendency in the past few years to nullify the increasing costs and diminishing catch per unit effort by enhancing the vessel power with the ultimate goal of increasing total catch which has resulted in the operation of these vessels becoming very unstable. Despite being heavily fuel expensive, the operations of these vessels continue to be economically viable, but the extent to which the operations are successful is rather skeptical.

4.2 OBJECTIVES

To analyse the economics of operation of the mechanised fishing trawlers and to suggest appropriate measures to improve their efficiency.

4.3 Materials and methods

The study was carried out from the Cochin Fisheries Harbour during the period October 1987 to September 1989.

Through a simple random sampling (SRS) (FAO, 1980), 18 mechanized wooden fishing trawlers operating from Cochin were selected. Care was taken to see that all the units selected were approximately of the same age so as to facilitate easy estimation of their capital investments. Access to real and authentic data pertaining to economic details were given due consideration during the selection of fishing units.

A record keeping exercise was maintained to collect the following operating details:

1. Fuel expenses
2. Bata charges (Victual charges)
3. Toll charges
4. Commission
5. Repair costs

6. Miscellaneous expenses
7. Catch value realized
8. Owner's share
9. Crew share
10. Trips

Weekly statements of the above details were recorded on all Saturdays. Details of the catch and fishing operations were collected by distributing pre-tested schedules to the boat crew. These were collected back two times a week - on Wednesdays and Saturdays. Regular visits were made to the landing centers to cross check the details of catch furnished by the boat crew. Occasional fishing trips were also made on a few boats during the course of the study.

The following details were collected for each day's operation (i.e. each fishing trip)

1. Vessel
   (a) LOA
   (b) HP
   (c) Year built
2. Gear
3. Fishing area
4. Shooting time and
5. Hauling time

The collected data were used to work out the economics of operation including the various profitability ratios. Data on fishing effort was used to ascertain the catch per unit effort (CPUE), fuel expense per unit catch, revenue per unit catch, cost per unit effort etc.

In order to demonstrate the profitability, viability and plausibility of undertaking two-day fishing trips, an attempt was also made to analyse the operations from the two-day voyage perspective

4.4 RESULTS AND DISCUSSIONS

4.4 1 Fishing Operations

4.4.1.1 All the trawlers covered in the study undertook one day fishing trips which started quite early in the morning everyday. Depending on the distance of the fishing ground which varies according to season, the boats set sail for fishing between 0100hrs and 0400hrs and return to the harbour with the catches by 1700hrs the same day. A trawler normally made three hauls per fishing trip each of about two hours duration. Two predominant types of fishing gear were employed, viz fish trawl and shrimp trawl. Figs 3.1 and 3.2 gives the design details of the more popular versions of these two types of nets. The fish trawl was also used to harvest the abundant cephalopod resources especially during the post monsoon period.

The catch hauled aboard was sorted species-wise. Since no selective fishing was employed, sorting was a cumbersome process especially during shrimp fishing. The fishermen usually takes, along with them, two blocks of ice. Shrimps, cephalopods and other priced catches were iced immediately. As the fish catches were usually very voluminous, icing was a problem, and hence, the fish catches were brought to the landing centres in the raw condition.

The entire fishing operation thus comes to a close by 6 or 7p.m. taking the duration of a day's fishing operation around 18 hrs.

The fishing operations were carried out on all days except Sundays and other important holidays. But there were a few operators who undertook fishing even on Sundays, provided the season was good.

The catch was disposed off immediately after landing, by auctioning. Refueling was done the same evening and any minor maintenance required for the engine, water-gland, etc. were immediately attended to, so that the trawler was all set for the next day's fishing.

4.4.1.2 Disposal of catch

The catches brought to the landing centres were disposed off immediately by auctioning. Bid and counter bidding was the method employed for auctioning. Each boat had an auctioning agent who gets six percent of the total catch value realized, as commission. Normally, an agent has a few boats under him. The auctioning agent is responsible for collecting the proceeds once the sale has been finalized. The auctioning agent has the additional role of financing. He normally provides the working capital - namely the common expenses - necessary for a day's operation. Usually the accounts were settled by the weekend, although partial payments may be made by the agent during mid-week depending on the owner's/crew's demand.

Prawns and cephalopods were auctioned as small lots - each lot weighing between 25 kg and 35kg. In the case of fish, the entire catch was disposed off as a single lot. However, if the catch composition was quite varied, it was divided into convenient groups before auctioning.

4.4.2 Investment costs (Fixed investments)

The major components coming under this head are the following :

1. Fishing craft including accessories
2. Fishing gear and
3. Otter boards

All boats covered in the study were more than five years old. For the purpose of calculating the fixed investments, the current market value of these boats were taken. In the case of fishing gear and accessories including otter boards, the cost of new equipment were considered. The average fixed investment for a single fishing unit was Rs.2,66,500. Fig. 4.1 shows the split-up of the total fixed investments.

4.4.3 Fixed Costs

The various fixed costs were the following :

4.4.3.1 Interest on capital

This was taken at the rate of 12 percent per annum which is the current bank interest rate. This will also account, on a modest rate, the opportunity cost of money invested.

4.4.3.2 Depreciation

Depreciation costs provided the owner with money to procure a new unit after the existing one has become superannuated. The rate of depreciation was worked out using the following relation

$$\left[\frac{(\text{Cost price} - \text{Expected salvage value}) \times 100}{(\text{Service life in years} \times \text{Cost price})}\right]$$

Based on the above, depreciation for the craft was estimated at the rate of eight percent - its useful service life being about 12 years and six months. Since the nets and otter boards had an average life of three and five years, their rate of depreciation worked out to 30 and 20 percent per annum, respectively.

This method of calculating depreciation also allowed writing off the depreciation on a regular annual basis - straight line - which facilitates easy accounting.

4.4.4 Operating costs

The operating costs incurred in trawling included the following :

i) Fuel expenses

ii) Bata charges
iii) Toll charges
iv) Commission
v) Repair costs and
vi) Miscellaneous expenditure

4.4.4.1 Common expenses

Fuel expenses, Bata, Toll, Commission and Miscellaneous expenditure together constitute the common expenses. The common expenses were a conjoint liability of both the owner and the crew. Fig 4.2 gives the split-up of the common expenses

4.4.4.1.1 Fuel Expenses

This included the cost of diesel and lubricating oil and was the most important item as far as operational costs were concerned. The total fuel expenses utilized as much as 46.6 percent of the total catch value realized. (Fig.4.3.). Each boat on an average expended about 200 liters of fuel each day. Fig.4.4 shows the fuel consumption pattern for the various months of the study period. While the monthly fuel expenses remained fairly constant throughout the study period, the average fuel expense per trip showed two conspicuous peaks during May. It was during these months that the fishing season was at its worst, and hence, the trawlers had to spend more time to locate their fishing grounds, which normally lie quite far during this period of the year. The average fuel expense per haul worked out to 60 liters. Of the total fuel expenditure, only 58.77 percent is spent for actual trawling, while 41.23 percent is spent for cruising to and from the fishing grounds (Fig.4.5).

4.4.4.1.2 Bata

This provides for victuals to the crew members. This allowance for meals is not fixed. Only the actual expenditure is provided for, and hence the expenditure on this account depends on the crew strength. As an approximate amount it usually worked out to ten rupees per day per head. Bata charges were also at times paid to one or two members of the crew, even on days when there is no fishing, but who are retained to attend to any repair or allied work pertaining to the fishing craft. Fig.4.6 gives the monthly bata expenditure, during the study period. The bata expenses contributed to 6.86 percent of the common expenses (Fig.4.2). 4.09 percent of the total catch value realized is being spent as bata expenses (Fig.4.3).

4.4.4.1.3 Toll charges

This is the landing charges levied by the fisheries harbour authorities. For each landing a boat has to pay a sum of Rs.9/-. The latter was the rate for 9.75m and 11m trawlers. The toll expenditure worked out to 1 percent of the total common expenses (Fig.4.2); at the same time it consumed 0.59 percent of the total catch value realized (Fig.4.3). Since the trawlers undertook one day trips and because the boats land their catches after each day's operation, the curve for toll expenses is exactly similar to that of the trips made (Fig.4.7)

4.4.4.1.4 Commission

Fig.4.8 gives the curve for commission charges paid to the auctioneer. An auctioning charge at the rate of six percent of the total auction amount (catch value realized) is paid to the auctioning agent. The auctioning charges amounted to 10 percent of the common expenses (Fig.4.2). Since the auctioneer has the additional role of a short term financier, the 6 percent commission paid to him is reasonable.

4.4.4.1.5 Miscellaneous expenditure

Miscellaneous expenses contributed to 2.29 percent of the total catch value realized (Fig.4.3). This included sundry items like cost of ice, baskets, twine for mending nets, etc. and contributed 2.65 percent of the total costs (Fig.4.9)

The common expenses included those costs associated with the immediate operation. Apart from the above discussed heads, minor expenses such as costs associated with the repair of gear and accessories were also incurred under the common expenses. Major accounts like total loss of the net or of one or both the otter doors will be a liability on the owner alone. Even though, the costs associated with mending of nets are a common liability, it is the responsibility of the owner to get the same replaced. The common expenses utilized 59.6 percent of the total catch value realized (Fig.4.3). Its share of the total costs amounted to as much as 68.81 percent (Fig.4.9). Fig.4.11 shows the total common expenditure for the various months during the study period.

4.4.4.2 Repair costs

All costs associated with repair and maintenance of capital investments come under this head. The liability to meet these expenses rests solely with the owner. Probably because the boats were around five years old the repair costs amounted to as much as 16 percent of the total operating costs. The total monthly repair costs came to Rs.3626 while the average per trip worked out to Rs.172. Fig.4.11 gives the curves for monthly repair costs. 11.44 percent of the total catch value realized went as repair costs (Fig.4.3). Being a liability that was exclusively on the owner, the repair costs consumed as much as 40.45 percent of the owner's gross profit. The replacement costs also included the cost of replacing gear and accessories in the event of a total loss of the same. However, minor repair and maintenance of the gear were accounted for, in the common expenses.

The sum of the following thus constituted the total operating costs.

1. Fuel
2. Bata
3. Toll
4. Commission

5. Repair and
6. Miscellaneous

The total working overheads consumed 71.04 percent of the total catch value realized. The average monthly operating costs during the study period worked out to Rs.22,515 while the average per trip came to Rs.1,089. To calculate the gross profit for sharing, only a part of the total expenses (i.e. total expenses less repair costs) is deducted from the total catch. Thus even though the total operating costs amounted to 71.04 percent of the total catch, the profit for sharing approximated to 40 percent of the catch value obtained (Fig.4.3.)

4.4.5 Fixed costs

i) Interest on capital - was calculated at the rate of 12% per annum. This would also account for opportunity cost of money invested.

ii) Depreciation : was estimated at the rate of 8% for fishing craft, 30% for nets and 20% for otter boards, their useful service life being 12.5, 3 and 5 years respectively.

4.4.6 Economic Analysis

4.4.6.1 Fixed Investments

4.4.6.1.1 Cost of fishing craft	2,50,000
4.4.6.1.2 Cost of two trawl nets	15,000
4.4.6.1.3 Cost of one pair of otter boards	1,500
Total Fixed Investments	2,66,500

4.4.6.2 Fixed Costs

4.4.6.2.1 Interest on capital @ 12% per annum	31,980
4.4.6.2.2 Depreciation on fishing craft @ 8% per annum	20,000
4.4.6.2.3 Depreciation on fishing nets @ 30% per annum	4,500
4.4.6.2.4 Depreciation on otter boards @ 20% per annum	300
Total Fixed Costs	56,780

4.4.6.3 Variable costs

4.4.6.3.1 Common expenses

Fuel	1,70,055
Bata	14,890
Toll	2,142
Commission	21,765
Miscellaneous expenses	8,365
Total common expenses	2,17,216

4.4.6.4 Repair costs	41,704
Total variable costs	2,58,920

4.4.6.5 Profit for sharing

4.4.6.5.1	Owner share	1,03,091
4.4.6.5.2	Crew share	44,182
4.4.6.5.3	Owner's gross profit	61,387

4.4.6.6	Total Costs	3,15,700
4.4.6.7	Total Catch (Returns)	3,64,483
4.4.6.8	Net Profit	48,783

4.4.7 Catch Details

4.4.7.1	Prawns	Qty(tons kg)	7.87
		Val(Rs lacs)	2.07
4.4.7.2	Cephalopods	Qty(tons kg)	3.77
		Val(Rs lacs)	0.73
4.4.7.3	Fishes	Qty(tons kg)	17.93
		Val(Rs lacs)	0.85
4.4.7.4	Total	Qty(tons kg)	14.81
		Val(Rs lacs)	3.65

4.4.8 Operational analysis

4.4.8.1	Fixed cost per kg of catch (Rs)	3.84
4.4.8.2	Operating cost per kg of catch (Rs)	17.49
4.4.8.3	Total cost per kg of catch (Rs)	21.32
4.4.8.4	Fuel cost per kg of catch (Rs)	11.49
4.4.8.5	Average value realized per kg of catch (Rs)	24.62
4.4.8.6	Profit per kg of catch (Rs)	3.29
4.4.8.7	Total Fishing hours(per year)	3341
4.4.8.8	Actual Trawling hours(per year)	1964
4.4.8.9	Fuel consumption per trip (liters)	179

4.4.8.10	**Total fuel consumption (liters/year)**	**42620**
4.4.8.11	**Total fuel consumption for actual trawling (liters per year)**	**25048**
4.4.8.12	**Total fuel consumption for cruising to and from the ground (liters /year)**	**17572**

Out of the average catch value of Rs.24.62 realized per kilogram, Rs.3.84 goes towards fixed costs while Rs.17.49 is spent as operating costs and only Rs.3.29 is accrued as profit (Fig.4.13)

The total operating costs worked out to as much as 71% of the catch value realized. Since the repair costs are a liability to the owner alone, the net profit to the latter worked to only 1.26% of the total sales value realized. Of the total operating expenses, the fuel costs worked out to 66%. However, only 59% of the fuel expended is utilized for actual trawling, the balance being for cruising to and from the fishing ground. Fig.4.5 gives the pattern of fuel consumption for the entire trawling operation. In spite of the fact that 41% of the total fuel consumption is for cruising, these trawlers undertake one day fishing trips. Since these vessels have an OAL of 9.75m, they can endure out at sea for at least two days, without any additional facilities being added, particularly when they undertake voyages for shrimp fishing, wherein the catch bulk is comparatively low. The following analysis will demonstrate the advantage of undertaking two day fishing trips, over one day fishing trips.(Fig.4.13)

	One day trip	Two day trip
Total fishing trips	**238**	**119**
Total hauls	**714**	**714**
Fuel consumption for actual trawling per trip (liters)	**106**	**212**
Fuel consumed for cruising to and from the ground (liters)	**73**	**73**
Total fuel consumption per trip (liters)	**179**	**285**
No of hauls per trip	**3**	**6**
Average fuel expenditure per haul (liters)	**59.67**	**47.50**

The average fuel saving per haul thus works out to approximately 12.17 liters. This would mean an overall saving of 8,689 liters per year per boat. Taking into account that about 2500 fishing units are operating from the study area, the total savings in fuel will be enormous - of the order of 22 million liters per year. Moreover, almost the entire saving in terms of value will be accruable as profit to the respective operator. The various profitability ratios (Fig.4.14) for the two schedules of operation are as follows :

	One day trip	Two day trip
1. Return on turnover (%)	13.38	23.17
2. Return on total costs (%)	15.45	30.16
3. Return on investment (%)	18.31	31.69
4. Return on operational costs (%)	18.84	37.83
5. Pay back period (years)	3.62	2.44
6. Break even point (Rs lacs)	1.96	1.47

ECONOMIC ANALYSIS OF WOODEN FISHING TRAWLERS OPERATING FROM COCHIN FISHERIES HARBOUR

(Average for 18 boats)

MONTH	FUEL (Rs)	BATA (Rs)	TOLL (Rs)	COMN (Rs)	MISC (Rs)	REPAIRS (Rs)	TOTAL EXPENSES (Rs)	CATCH (Rs)	CREW SHARE (Rs)	OWNER SHARE (Rs)	TRIPS (nos)
OCT 87	12464.21	1428.21	189	1886.57	498.21	2054.03	18520.24	31442.86	4492.90	10483.42	21
NOV 87	14843.30	1403.57	207	2821.50	388.93	8141.37	27805.67	47025.00	8209.56	19155.64	23
DEC 87	13819.80	1062.86	171	1522.54	385.62	1973.59	18935.41	25375.71	2524.65	5890.85	19
JAN 88	12905.74	1009.71	171	1515.10	539.40	823.57	16964.53	25251.71	2734.31	6380.05	19
FEB 88	18171.24	1211.79	198	1588.79	1501.11	2991.15	25662.08	29932.14	2179.04	5084.43	22
MAR 88	17406.80	1605.36	225	1753.05	1394.17	4248.66	26633.04	29217.50	2048.68	4780.26	25
APR 88	13731.81	1294.29	180	1566.77	1069.03	3064.18	20906.08	26112.86	2482.06	5791.47	20
MAY 88	18028.33	1035.18	171	2155.61	801.46	4895.90	27087.47	35926.79	4121.05	9615.77	19
JUN 88	16486.36	1284.80	198	2427.48	802.56	2049.96	23249.16	40458.00	5777.64	13481.16	22
JUL 88	16742.62	1429.45	207	2729.64	376.05	2871.32	24356.08	45494.00	7202.77	16806.47	23
AUG 88	15477.30	1282.68	162	1663.20	427.50	2810.70	21823.38	27720.00	2612.20	6095.12	18
SEP 88	17155.68	1276.08	216	1987.20	1103.04	5768.40	27506.40	33120.00	3414.60	7967.40	24
OCT 88	12318.60	1425.00	180	2004.00	576.80	3134.60	19639.00	33400.00	5068.68	11826.92	20
NOV 88	15425.28	1474.08	216	3081.60	1314.96	4723.68	26235.60	51360.00	8954.42	20893.66	24
DEC 88	12577.32	978.48	162	1377.00	880.92	2544.48	18520.20	22950.00	2092.28	4882.00	18
JAN 89	14202.80	1402.80	180	1704.00	596.00	4769.80	22855.40	28400.00	3094.32	7220.08	20
FEB 89	18131.74	1367.30	198	1518.00	760.76	7665.90	29641.70	25300.00	997.26	2326.94	22
MAR 89	12974.22	1601.04	189	1575.00	701.82	1214.85	18255.93	26250.00	2762.68	6446.24	21
APR 89	13572.84	1028.85	171	1567.50	546.06	1518.10	18404.35	26125.00	2771.63	6467.13	19
MAY 89	16556.04	922.68	162	1587.60	459.72	2624.40	22312.44	26460.00	2031.59	4740.37	18
JUN 89	15477.62	1751.45	207	2608.20	425.50	5490.10	25959.87	43470.00	6900.07	16100.16	23
JUL 89	7969.61	750.31	99	973.50	386.87	2029.50	12208.79	16225.00	1813.71	4232.00	11
AUG 89	No operations due to State Government ban										
SEP 89	13669.75	1753.50	225	1917.00	792.50	6000.00	24357.75	31950.00	4077.68	9514.58	25
TOTAL	340109.03	29779.46	4284	43530.85	16728.99	83408.24	517840.58	728966.57	88363.76	206182.11	476

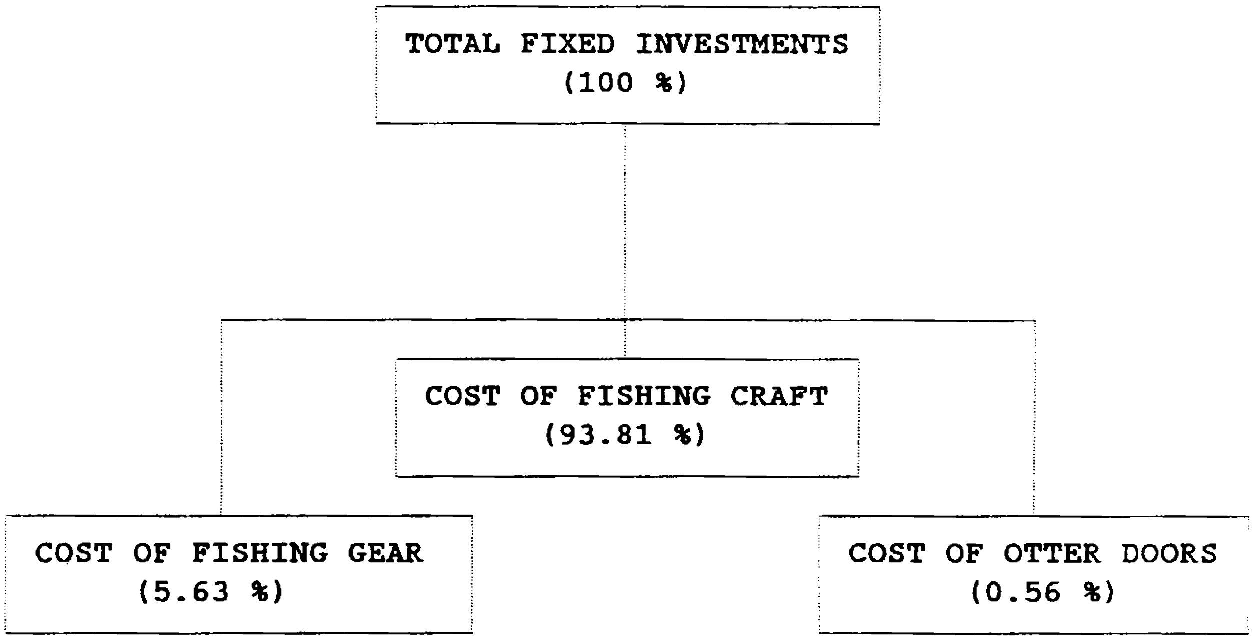


Fig. 4.1 SPLIT-UP OF FIXED INVESTMENTS

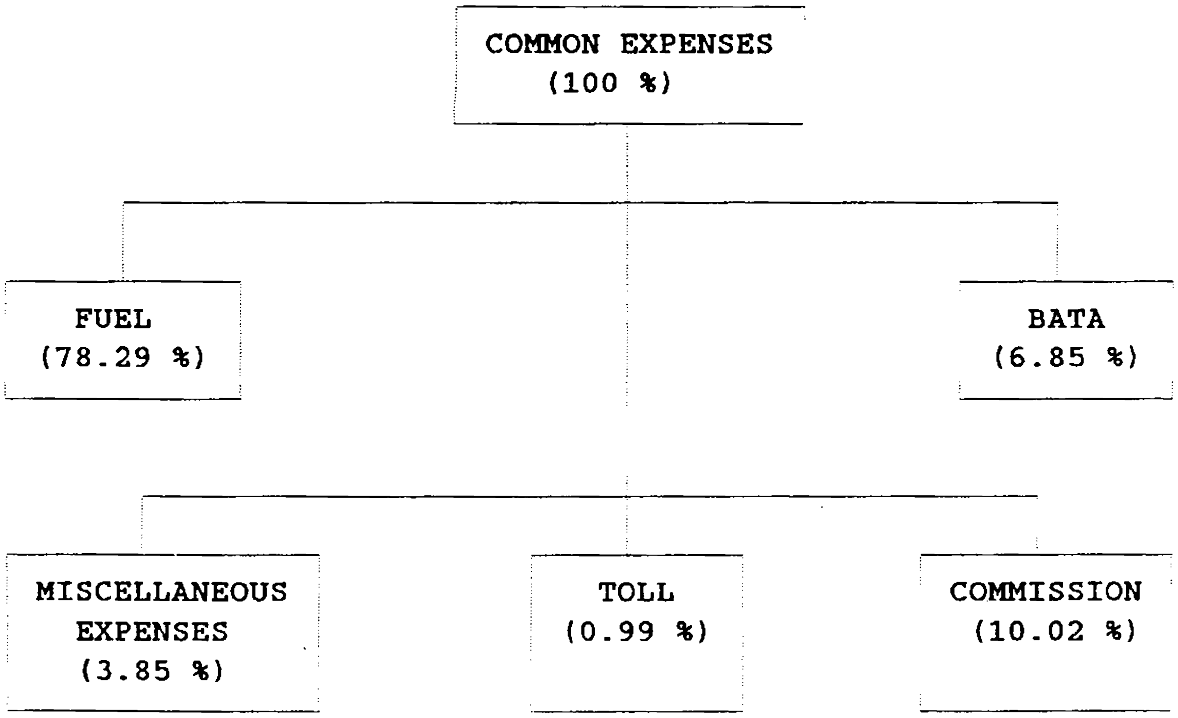


Fig. 4.2 SPLIT-UP OF COMMON EXPENSES

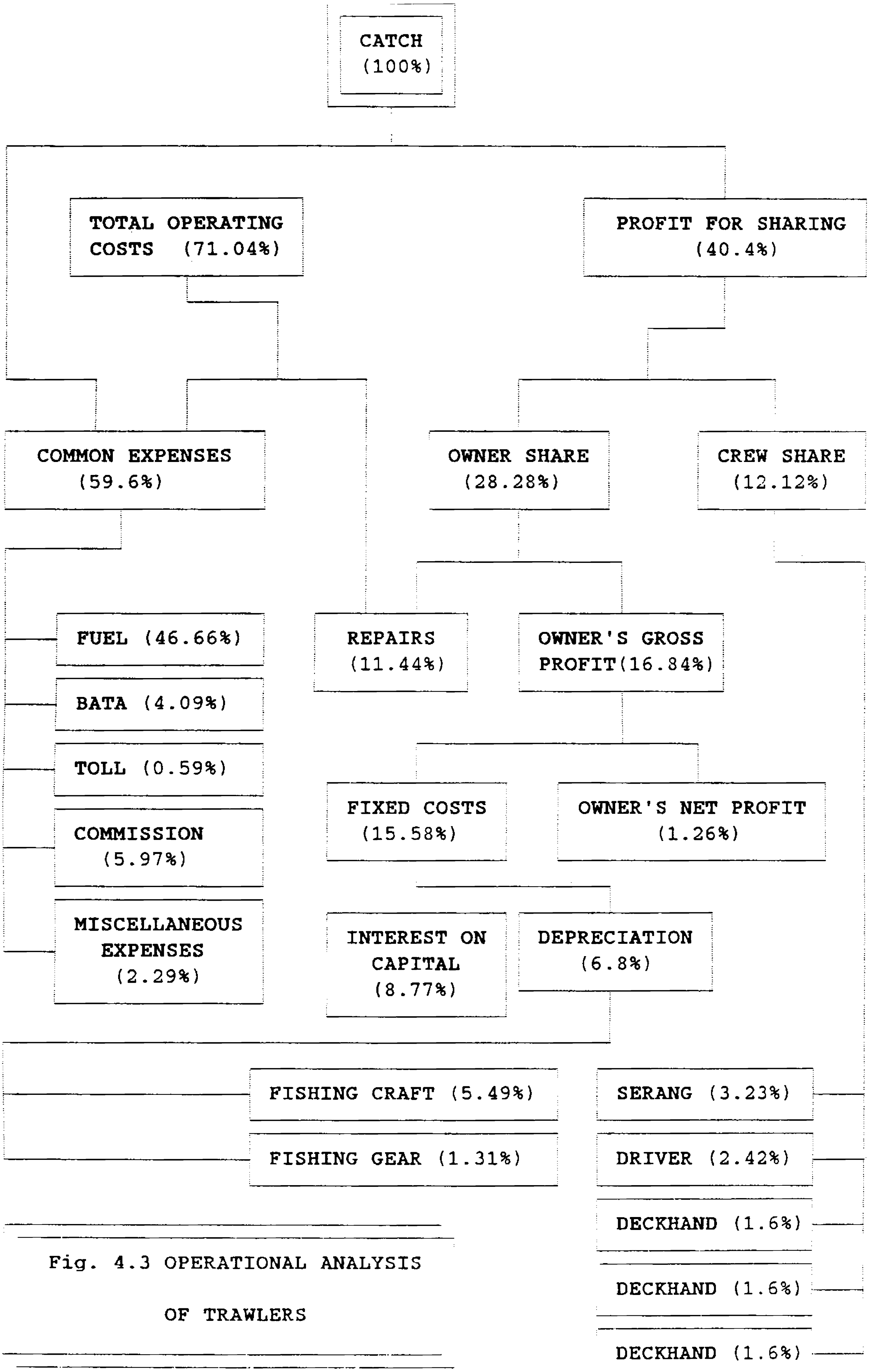


Fig. 4.3 OPERATIONAL ANALYSIS OF TRAWLERS

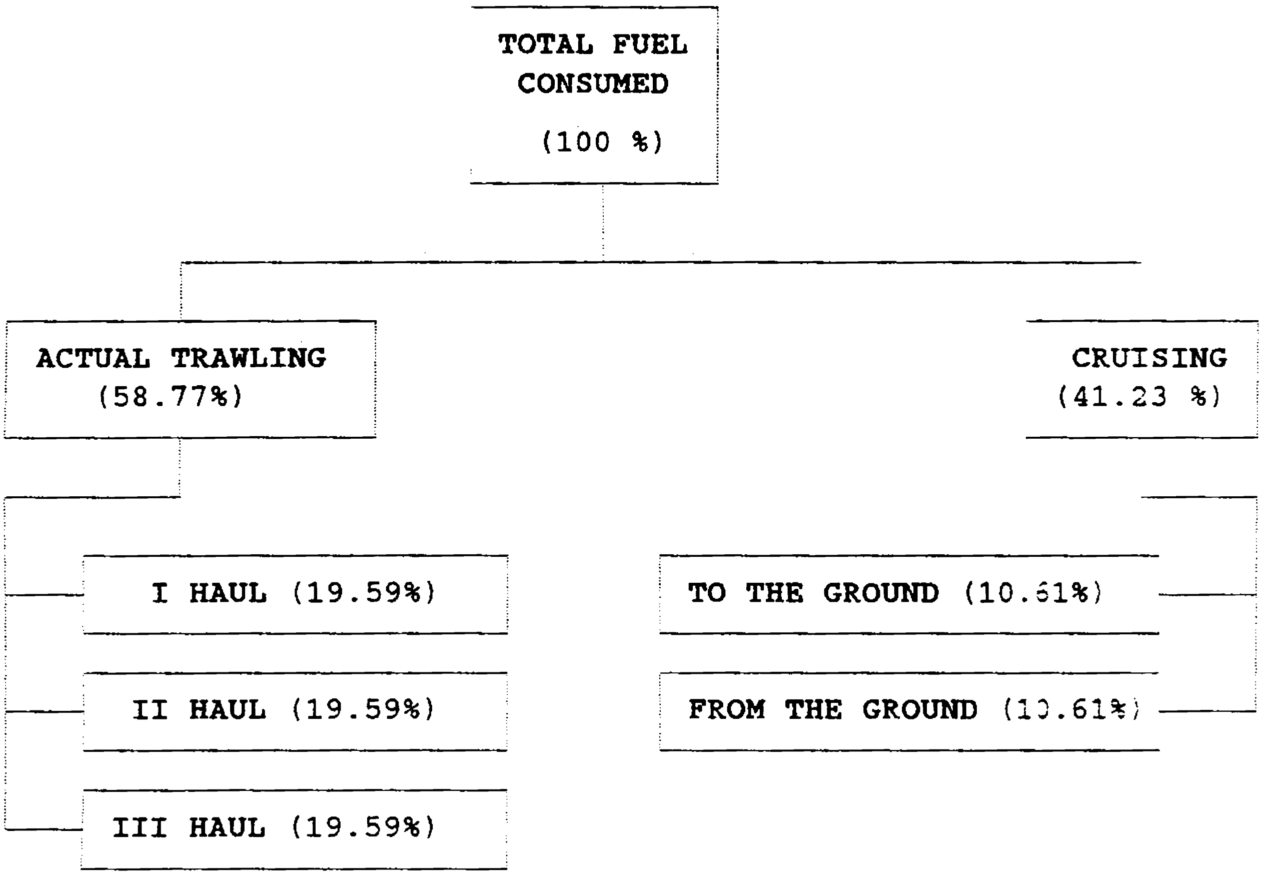


Fig 4.5 FUEL CONSUMPTION PATTERN OF THE TRAWLING OPERATION

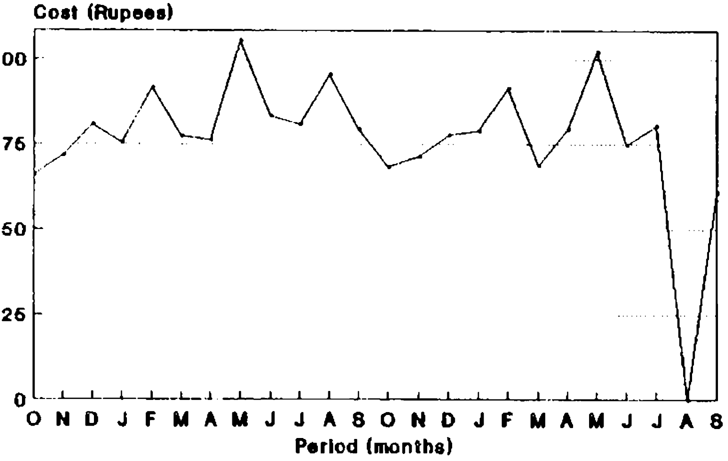


Fig. 4.4 Fuel costs
(average per fishing trip)

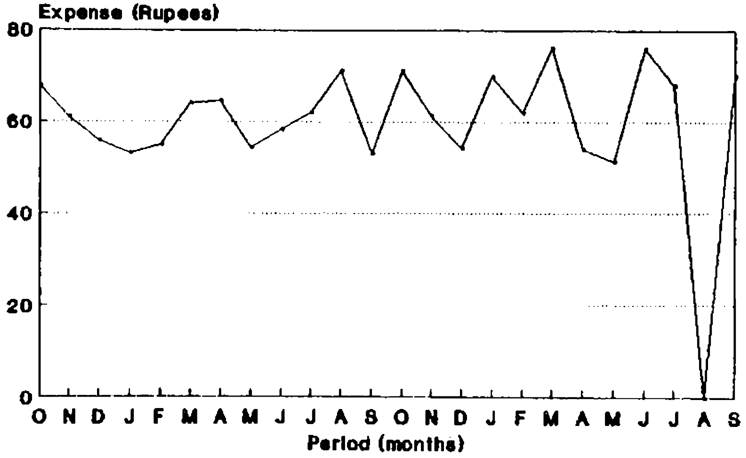


Fig. 4.6 Bata expenses
(average per fishing trip)

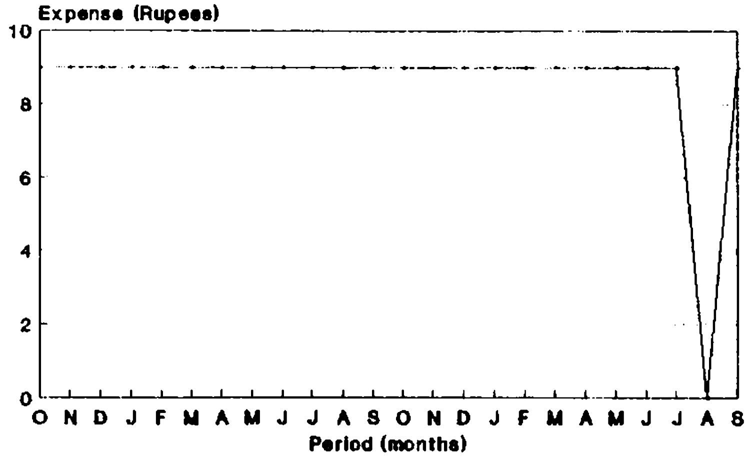


Fig. 4.7 Toll expenses
(average per fishing trip)

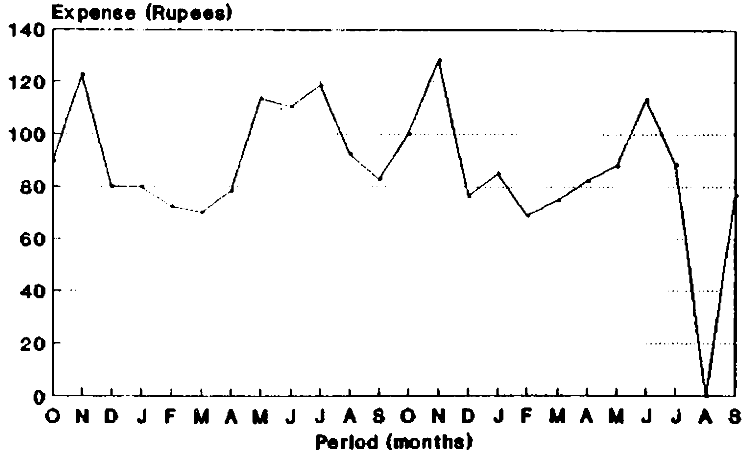


Fig. 4.8 Commission charges
(average per fishing trip)

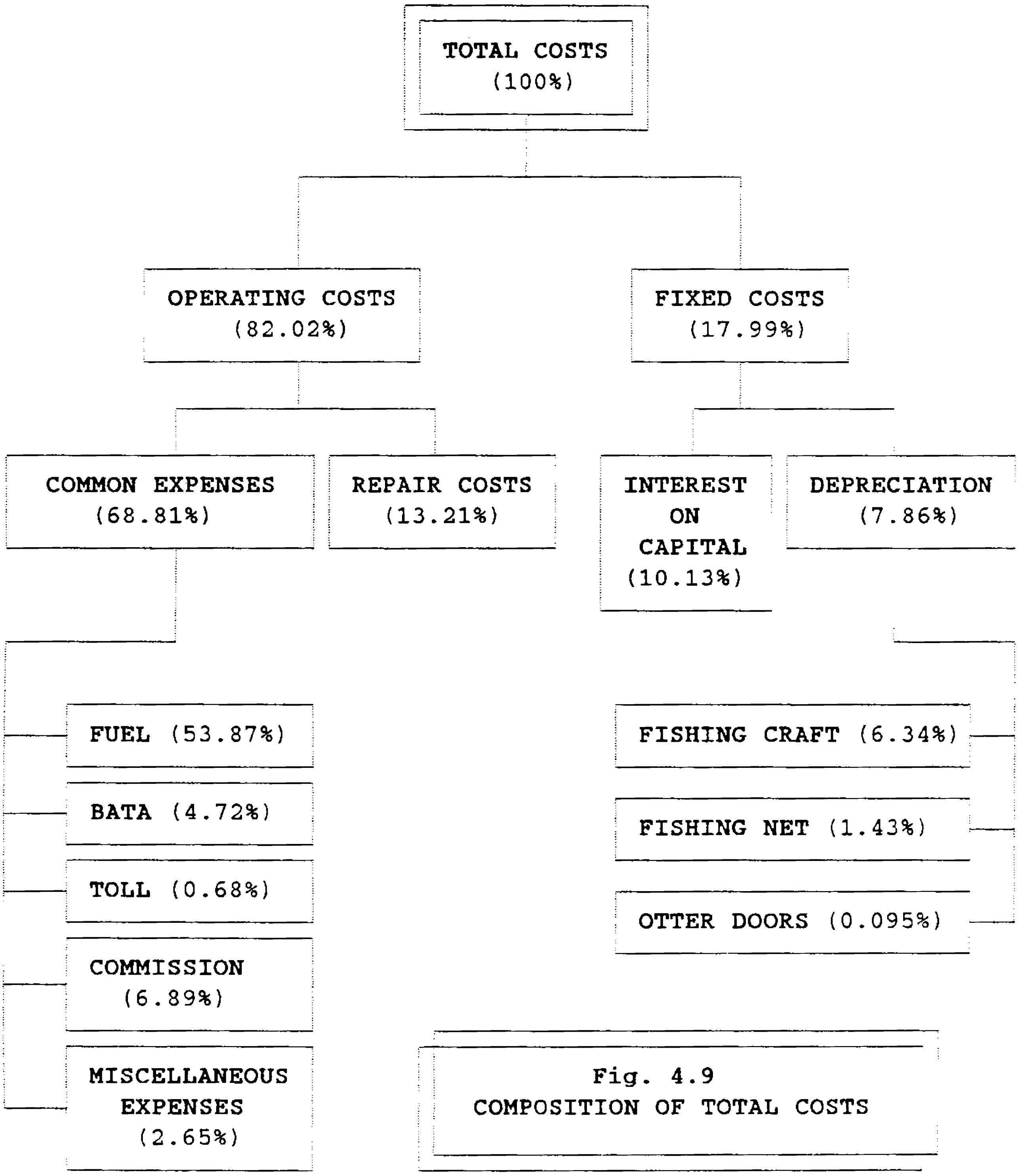


Fig. 4.9
COMPOSITION OF TOTAL COSTS

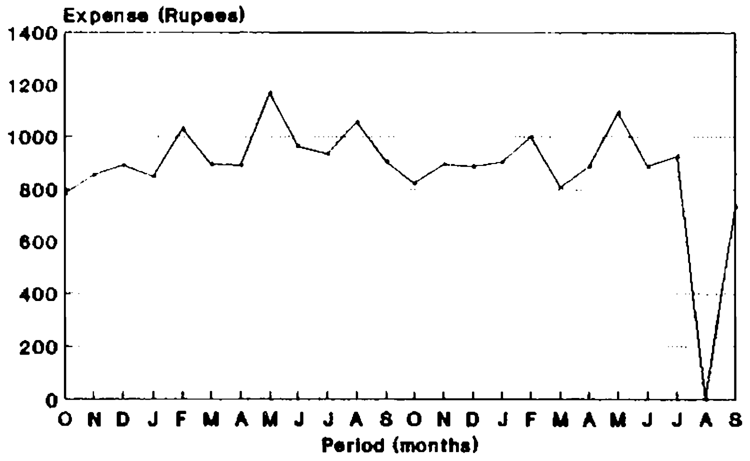


Fig. 4.10 Common expenses
(average per fishing trip)

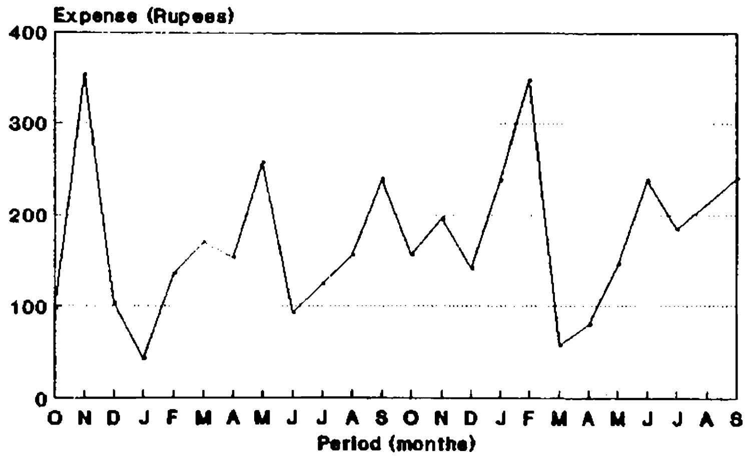


Fig. 4.11 Repair charges
(average per fishing trip)

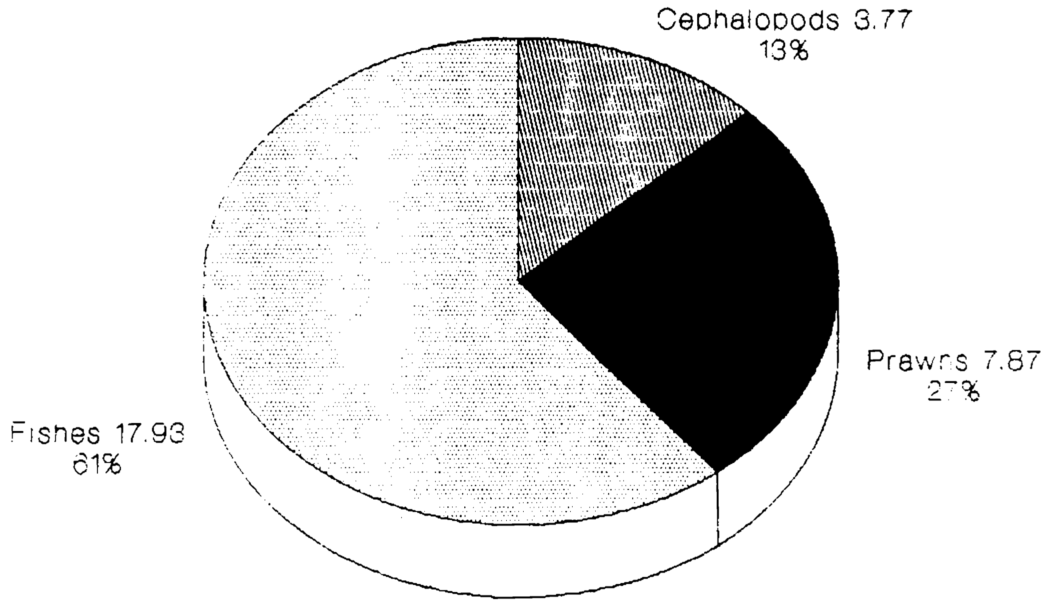


Fig. 4.12
Catch composition

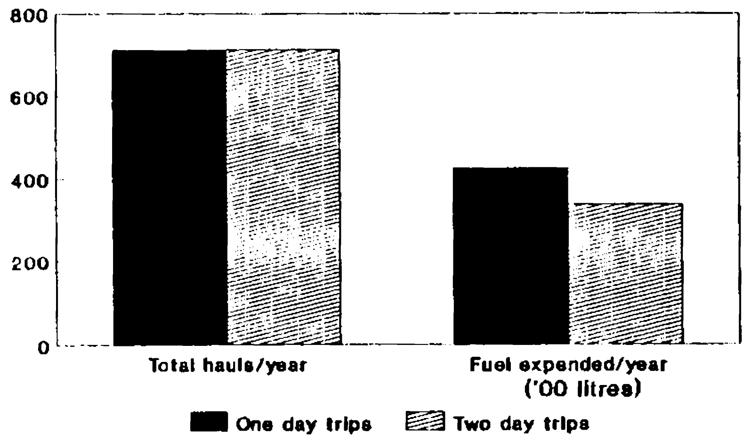


Fig.4.13 Comparison of fuel expended for one day and two day trips

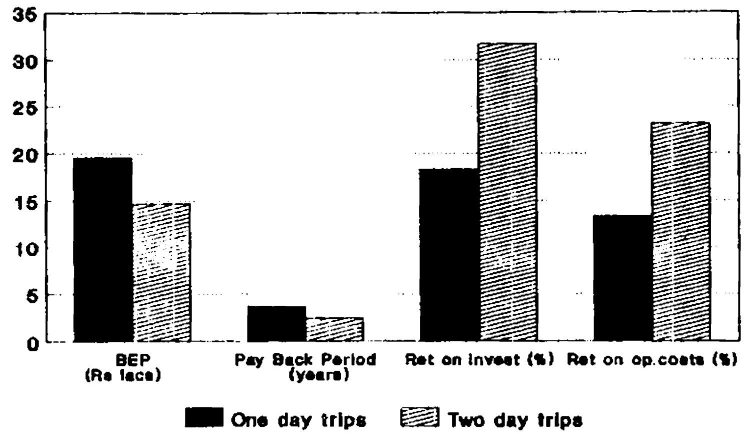


Fig. 4.14 Comparison of profitability ratios for one day and two day trips

CHAPTER V

SUMMARY AND RECOMMENDATIONS

Trawling, despite being heavily energy expensive, still continues to be the most energy expensive fishing method particularly so in view of the export oriented nature of the Indian seafood industry. This study therefore aims at analysing the efficiency of trawls operation from Cochin, an important fishing center along the southwest coast of India. The analysis is made along two perspectives - economic and technological. Eventhough technological efficiency complement economic efficiency, in the fishing parlance, parameters like the size composition of the catch, selectivity factors, etc., will have a direct bearing on the technological qualities of the trawl, and which parameters will have a significant impact on the effective exploitation of a fishery stock. Whereas the technological analysis aims at improving the efficiency with regard to the effective utilisation of fuel and fishery stocks, economic analysis ascertains the present status of the trawling operations from the commercial angle.

Chapter I

The first chapter reviews the research work done on trawls. Trawls are considered to be further extension of towed bagnets, developed to facilitate sweeping of larger areas more efficiently. The initial attempts at improving trawl efficiency were based on observations of 'tell tale' signs on trawl parts, which were followed by, with the development of science and technology, direct/indirect observation of trawling operations. Measurement of various operating parameters of a trawl, and the subsequent calculations has been a popular method adopted by several workers and many contrivances that facilitate this methodology has been developed.

Comparative fishing to evaluate superiority of various trawl designs, different with regard to parameters like rigging, number of seams, length of sweep lines/bridles, depth of panels, material for construction, etc., have been embraced by many workers. Work has also been directed at improving the vertical opening of trawls by various means. Mention is also made on the development of the various trawl designs and their adoption locally.

The capacity of a fishing gear to retain fishes of a particular length and to effect the escapement of the others, is an important factor determining the overall efficiency of the gear. The concept of selection in fishing gear, attributable to the various components viz. availability, vulnerability and inherent gear selectivity are dealt with in this chapter. A review of the work done on selectivity analysis is also made, wherein the influence of various parameters like mesh size, catch quantity, gear material, twine thickness, hauling techniques, type of gear, mesh configuration, etc., on the selective properties of a trawl, as analysed by various workers are discussed.

Chapter II

The various components of a trawl individually and collectively aid and abet fish capture. The specific role of each component part in effecting fish capture is of significant importance in the trawl designing perspective. A study of the escape pattern of fishes through the various parts of a trawl revealed that seventy five percent of the total escapement occurred at the throat region. The length of the escapees were so small that the meshes of these regions had little selective function. About seventy eight percent of the total fishes entering the net got captured in the codend. Since the escapees were very small, in terms of weight, ninety five percent of the fishes entering the net got captured in the codend. Maximum escapement occurred at the throat region, which was of the order of fifteen percent of the total number of fishes entering the net. The escapement at the belly was only four percent. Practically no escapement occurred at the fore regions of the trawl. Being a filtering device, the efficiency of a trawl is dependent on the effective filtration rate. This study has revealed the specific role of the various panels that go into the construction of a trawl. Since the fore regions of a trawl have little selective function, the mesh sizes of these panels can be increased without effecting the fish catching capacity of a trawl. Increasing the mesh sizes would also decrease the total drag of the trawl and the savings thus accrued may be profitably used to tow a bigger net without a consequent enhancement of the towing power.

Chapter III

Trawl drag calculations have been an interesting topic of research for the past few decades. The resistance offered by a trawl and the various factors that influence the total drag are investigated in this chapter. The studies investigated here include the calculation of the total drag of two important trawl designs operating along the Cochin coast and the evaluation of a change in the total drag due to a variation in the mesh size, twine size, trawling speed and panel depths. Mesh size and twine size were known to have inverse relation to total drag. This study revealed that the influence of a change in mesh sizes is more pronounced when the mesh sizes are small. Also, increasing the mesh sizes beyond a certain limit was found to have little effect on trawl drag. The study on the influence of twine diameter established the superiority of high strength materials, in the total drag perspective. It was found that, if, instead of polyethylene, polyamide is used for the construction of a fish trawl, the the total drag would be reduced by 20 percent, other things like wet breaking strengths, towing speed, etc. remaining same. Similarly polyester was a better gear material than polyamide. Increasing the panel depths was found to decrease the total drag initially, due to a lowering of the angle of attack of the netting panels. But, as the panel depths were increased further, the influence of an increasing twine surface area offset the influence of the lowered angle of attack, thereby increasing the total drag.

Chapter IV

This chapter deals with the economic analysis of the operation of mechanised fishing trawlers operating from the Cochin coast. As much as 47 percent of the total catch value realised were spent for fuel. The owner's gross profit worked out to 16 percent of the total catch value realised. About Rs.11.4 worth of fuel was spent for effecting a kilogram of catch. A comparison of the profitability ratios for one day and two day voyages revealed the superiority of two day voyages. An average fuel saving of 12 liters per haul is achieved if the fishing vessels undertook two day voyages aggregating to a saving of approximately 8,689 liters per boat per year.

RECOMMENDATIONS

1. The escapement studies have shown that the fore regions of a trawl mainly aid in guiding the fishes towards the codend. The mesh sizes of these panels should be increased from the current limits of around 160 mm to about 300 mm, which would ensure better filteration rates as well as savings in gear material.
2. Real size selection occurred at the throat and codend regions. The mesh sizes of these panels will determine the size of the catches. Due importance

should be given while determining the mesh sizes of these panels. Since the square mesh escapees are reported to have better survivability rates, these panels should preferably be made of square meshes. Work on square mesh selectivity with special reference to species available along the Indian waters is solicited.

3. Square meshes have better selective properties than the conventional diamond meshes. But whether the square meshes have an effect on the drag properties would form a thoughtful investigation.

4. Studies on drag calculations have revealed the importance of maintaining optimal levels of trawling speeds. This aspect should be well understood by the fishermen, as excess speeds would mean excess wastage of fuel.

6. The influence of twine thickness on the drag qualities have established the superiority of high strength materials. There is therefore need for the development of cheaper and stronger materials for fishing gear construction.

7. In a multi-species fishery like ours, there is need to develop more resource specific fishing.

Selective fishing methods with the help of contrivances like selective shrimp trawl would not only negate the cumbersome process of sorting the catches once they are brought aboard, but would improve the overall fishing efficiency. More research along these lines is needed.

8. The operational analysis of trawlers have revealed the very marginal viability of their operations. As this study has shown, undertaking two day voyages, particularly during the shrimping seasons would enhance the overational operational efficiency.

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