Studies on Energy Requirement and Conservation in Selected Fish Harvesting Systems

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DOCTOR OF PHILOSOPHY

By

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2000

This thesis is dedicated to the memory of my parents

late Sri. M.K. Ravunny & late Smt. M.K. Devaky

CERTIFICATE

This is to certify that this thesis entitled, ***Studies on Energy Requirement and Conservation in Selected Fish Harvesting Systems***, is an authentic record of the research work carried out by **Shri. M.R. Boopendranath**, M.Sc., under my supervision and guidance at the School 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, M.R. Boopendranath, do hereby declare that the work presented in thesis entitled ***Studies on Energy Requirement and Conservation in Selected Fish Harvesting Systems***, is an authentic record of research work carried out by me under the supervision and guidance of **Dr. M. Shahul Hameed**, Professor (Retd.), School of Industrial Fisheries, Cochin University of Science and Technology, in partial fulfilment of the requirement for the Ph.D. degree in the Faculty of Marine Sciences and that no part thereof has previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title of any University or Institution.

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Contents

Chapter 1

Introduction

Fishing is a major source of food for the humanity and provides employment and economic benefits to large sections of the society. As a source of food it contributes about 20 % of the animal protein supply. At present the total world capture fishery production is around $95x10^6$ t (FAO, 1998). About 66 % of the fish production is directly utilised for human consumption; the remainder is used for other economic ends such as livestock and aquaculture feed, crop fertiliser, food and non-food additives, or as bases for production of industrial, medical and other chemicals through application of biotechnology (ICLARM, 1999)

Fishing is an ancient occupation. About 200 million people are either directly or indirectly involved in this industry. Fifty million people, of which 12.5 million are fishermen and their family members, directly depend on fishing for their livelihood. An additional 150 million people are involved in shore-based support activities, processing and marketing of fish and fish products (FAO, 1995b). Fishing contributes significantly to foreign exchange earnings of India and many other developing countries. The value of fish internationally traded has been estimated at US$ 40 billion per annum for the early nineties (FAO, 1997). The export of marine products during 1998-99 was to the tune of Rs. 46268.70×10^6 (US\$ 1106.91×10^6) and their share in the total export earnings of the country was 3.32 % (MPEDA, 2000).

A wide array of fishing gears and practices ranging from small-scale artisanal to large-scale industrial systems are used for fish capture. Over the years, traditional fishing gears have been upgraded and newer more efficient fishing systems have been introduced. Most important among these fish harvesting systems are trawls, purse seines, lines, gillnets and entangling nets and traps. Among the most significant developments which affected the historical evolution of fishing gear and practices are (i) developments in craft technology and mechanisation of propulsion, gear and catch handling (ii) introduction of synthetic gear materials (iii) developments in acoustic fish detection and satellite-based remote sensing techniques (iv) advances in electronic navigation and position fixing equipment (v) awareness of the need for responsible fishing to ensure sustainability of the resources, protection of the biodiversity and environmental safety and energy efficiency (Hameed & Boopendranath, 2000).

The fundamental objective of responsible fishing is to maximise economic returns to the fisherman without affecting the long-term sustainability of the fishery resources and with minimum impact on the ecosystem. Most fishery resources are considered to be exploited at levels close to or beyond their sustainable limits. Fossil fuels used for vessel propulsion and gear handling in active fishing systems are known to be non-renewable and limited. In recent years, increasing emphasis has been placed on adopting responsible fishing practices which seek to minimise waste by reducing the level of discards, optimise energy use and protect the environment from negative impacts.

Introduction of powerful and highly efficient harvesting systems, progress in fish detection and gear monitoring systems and market driven expansion of fishing fleet since the second world war, brought about increasing pressure on the world fishery resources. Manifestation of signs of over-exploitation of traditional fish stocks and negative impacts on the ecosystem have been a cause for increasing concern in recent years. According to FAO estimates, 35 % of the 200 commercially important marine fish stocks are over-exploited while 25 % are fully exploited and only 40 % has any potential for further development. Discards of non-target species is estimated to be of the order of 30 %. Excess capacity in the world fishing fleet is about 30 % (FAO, 1995b).

Exclusive Economic Zones (EEZs) of the coastal States embrace about 90 percent of the world's marine fishery resources. Adoption of the United Nations Convention on the Law of the Sea in 1982 brought the rights and responsibilities for the management of the resources in the EEZ to the coastal States (FAO, 1995a). Adoption of the Code of Conduct for Responsible Fisheries by FAO in 1995, has set out the principles and international standards of behaviour for responsible practices in order to ensure long-term sustainability of the aquatic fishery resources, protection of biodiversity, energy conservation and environmental safety (FAO, 1995a). Sustainable development has been defined at the 94th Session of FAO Council 1988, as "the management and conservation of the natural resource base, and the orientation of technological and institutional changes in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development conserves land, water, plant genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable" (FAO, 1996). Approaches in responsible fishing practices include prevention of excess fishing capacity and destructive fishing practices and adoption of scientific management in order to ensure long-term sustainability of the resources; development and promotion of selective fishing gear and methods which would minimise fishing mortality of non-target species and protected species and ensure biodiversity; development and promotion of eco-friendly fishing gears which would minimise negative impacts on environment; energy conservation in harvesting operations; and enhancement of resources by introduction of artificial reefs and fish aggregating devices, and restoration of coastal fishing grounds from negative impacts of environmental pollution and eutrophication.

1.1 Marine Fisheries of India

Marine fish production of India which was only 0.5 $\times 10^6$ t in 1950, increased to 2.7 $\times 10^6$ t in 1997 (Devaraj & Vivekanandan, 1999). Marine fishery potential of the Indian Exclusive Economic Zone (EEZ) is estimated at 3.92×10^6 t. The fishery potential is estimated to be 2.28×10^6 t in the 0-50 m depth zone, 1.367×10^6 t in the 50-200 m depth zone, 0.028×10^6 t in the 200-500 m depth zone and 0.246×10^6 t in the oceanic region (Sudarsan *et.al.*, 1990). The present catch of 2.7×10^6 t forms about 69 % of the estimated fishery potential and is largely derived from the intensively fished coastal zone.

At present, about 2,39,180 fishing crafts of various sizes and classes are under operation, consisting of 47,000 mechanised boats, 32,000 motorised crafts, 1,60,000 non-mechanised crafts and about 180 deep sea fishing vessels of more than 20 m L_{OA} (Vijayakumaran & Haridas, 1998). Capital investment on fishing implements is estimated at Rs. 41.17 billion, at 1996-97 prices (Sathiadhas, 1998). Mechanised fishing sector produces 72 % of the marine landings, followed by motorised sector (19%) and artisanal sector (9 %) (Anon, 1997). While the landings from mechanised sector increased from 1.33×10^6 t in 1991 to 1.66×10^6 t in 1996, that of non-mechanised sector decreased from 0.42×10^6 t to 0.27×10^6 t. The landings from motorised sector during this period remained more or less the same, fluctuating between 0.33×10^6 and 0.46×10^6 t (Sathiadhas, 1998).

1.2 Energy and fish production

Modern fishing is one of the most energy intensive methods of food production. Energy input for production of rice is one-tenth of the output. The ratio between input and output of energy is close to unity for milk production by grass-fed cows and artisanal coastal fishing. However, distant water fishing is extremely energy intensive consuming 15 to 20 times more energy than it produces (Endal, 1989a). Thomson (1988) has given an estimate of 15-21.5x10^6 t as annual fuel consumption by the fishing industry. Fuel consumed by the industrial sector (14-19 x10^6 t) is 8-14 times higher than that of small-scale sector (1-2.5 x10^6 t), whereas the production per tonne of fuel is lower by a factor of 4 to 5.

Mechanised fishing is dependent on fossil fuels. Fossil fuels are non-renewable and limited. Estimated oil resources in 1995 was 138 billion tonnes. At the current levels of consumption of 3.23 billion tonnes a year, it will last only for the next four decades, unless drastic conservation measures are taken (Anon, 1996b). India's self-sufficiency in petroleum products declined from 60 % in 1985-86 to 34 % in 1997-98. The balance recoverable resources of crude oil in India has declined after peaking at 805x10^6 t in 1991 (TERI, 1999).

Most of the environmental problems that confront mankind today are linked to the use of energy in one way or another. The total costs of environmental degradation and pollution in India, is not adequately known. The calculations performed on this aspect by World Bank add up to 4.5 %

of the GDP (gross domestic product) (World Bank, 1996). Fossil fuels produce increased levels of carbon dioxide in the atmosphere. Increase in levels of carbon dioxide in the atmosphere produces the phenomenon known as "green house effect". Green house effect leads to global warming, irreversible climatic, oceanographic and sea level changes, which are of serious consequence to the inhabitants of the earth. Use of fossil fuels also produces other pollutants such as suspended particulate matter and gaseous emissions such as sulphur dioxide, carbon monoxide and oxides of nitrogen, which are detrimental to the environment and human health (TERI, 1999).

The dramatic escalation in oil prices during the seventies brought the need for fuel conservation to a sharp focus. Spiralling oil prices may severely affect the economic viability of fishing as a means of food production. (Boopendranath, 1996). Energy conservation is one of the important challenges facing the fishing industry today, apart from issues of resource conservation, protection of biodiversity and environmental safety.

Section 8.6 under *Article 8 : Fishing operations* incorporated in the Code of Conduct for Responsible Fisheries (FAO, 1995a) directly deals with Energy Optimisation. Sub-section 8.6.1. prescribes that the States should promote the development of appropriate standards and guidelines which leads to the more efficient use of energy in harvesting and post harvest activities within the fisheries sector. Sub-section 8.6.2. prescribes that States should promote the development and transfer of technology in relation to energy optimisation within the fisheries sector and, in particular, encourage owners and managers of fishing vessels to fit energy optimisation devices to their vessels. Many nations are pursuing serious large scale programmes in energy conservation, prompted by the economic and environmental imperatives. In terms of the modern environmental concept of sustainable development, the main objective of energy optimisation would be, "To ensure the use of fish stocks, capital, manpower, and energy, so that together these yield the greatest sustainable benefit to the present generation while also maintaining the potential to meet the needs and aspirations of the future generations" (Buxton & Robertson, 1989).

1.3 Review of literature

Energy inputs for production of seafood by US fishing vessels and nutritional outputs were studied by Rawitscher and Mayer (1977). Nomura (1980) discussed the variation in catch relative to fuel consumption among different fishing systems such as tuna long line, salmon drift net, skipjack pole and line, off shore squid angling, purse seine, Alaska pollack trawl and large-scale set net operations. FAO (1981) discussed the relationship between energy and other inputs in fish harvesting. Allen (1981) determined input-output ratio of the calorific values of fuel and power consumption, and that of oil, meal and solubles from Australian coastal whaling operation. Grofit (1981) studied the fuel use in trawl industry and advocated various measures for making trawling more fuel efficient.

ADB-ICLARM Workshop on Appropriate Technology for Alternative Energy Sources in Fisheries, Manila (Philippines) addressed the issue of fuel conservation in fish harvesting (May *et.al.* 1982). The Workshop advocated a shift away from the emphasis on large and powerful fishing boats towards smaller boats which are more fuel efficient; the development and use of passive fishing gears; development of improved and fuel efficient fishing methods and the use of sail power, wherever feasible. Bardach (1982) enumerated the energy resources of importance in the fishing industry. Fyson (1982) and Lee & Son (1982)) advocated the use of sails in fishing vessels as a means of reducing fuel consumption. Gifford (1982) and Jiang (1982) discussed the development of low energy fishing vessels.

The need for making fishing crafts more energy efficient has been emphasised by Bay of Bengal Programme (Anon, 1984b). Murray *et.al.* (1985) reported the use of mid-water fish aggregating devices, in order to reduce the search time and hence the energy cost of fishing. Energy saving fishing methods suitable for German cutter fisheries operating in Baltic and North Sea such as gill nets, trammel nets and long lines were studied by Steinberg (1985) and Lange (1985). Watanabe & Uchida (1984) gave an estimate of the direct and indirect energy inputs in the catch of fish for fish paste products, with respect to Alaska pollack harvest in North Pacific Ocean.

Wileman (1984) provided the gear component drag information for a range of Scandinavian trawls and delineated approaches for reducing the trawl drag and fuel consumption. Pinhorn (1986) has developed vessel analysis computing system (VACS) under the Ener Sea Programme, with a view to reduce fuel expenditure of the Newfoundland inshore fishing fleet. Veenstra (1986) studied the application of energy saving concepts in Dutch fishing vessel design and operation. Mohanrajan (1987) discussed various energy alternatives available for fisheries sector. Seafish *et.al.* (1993) studied fuel saving possibilities by improving design and rigging of otter boards . Fuel saving concepts in trawl design such as rope trawl and large mesh trawl have been studied by Marlen (1989a,b), Rao & Narayanappa (1994), Rao *et.al.* (1994) and Kunjipalu *et.al.* (1989, 1998).

Several papers connected to energy optimisation in fishing, were presented and discussed in the 1988 World Symposium on Fishing and Fishing Vessel Design (Anon, 1989a). Importance of management schemes that foster energy conservation in fishing was discussed by Endal (1989a). Energy optimisation by lengthening of hull, introduction of hull features and vessel redesign were discussed by Magnusson (1989), Goudey & Venugopal (1989) and Enerhaug (1989). Methods of improving fuel efficiency were discussed by Dickson (1989), Gardner (1989) and Billington (1989a). Application of computer-assisted analysis for energy optimisation was discussed by Fridman & Lissovoy (1989) and McIlwaine *et.al.* (1989).

International Fisheries Energy Optimisation Working Group Meeting, 28-30 August 1989, University of British Columbia, Canada, considered how existing harvesting techniques, vessel designs, resource management methods, energy policies and operational practices could best optimise use of energy (Anon, 1989b; Buxton & Robertson, 1989). The importance of using fuel flow measurements has been highlighted by

Billington (1989b), based on experience in New Zealand fishing industry. The advantages of computerised vessel, engine and gear performance monitoring systems in fuel conservation have been discussed by Burchett (1989) and Tait (1989). Fridman (1989) and Sevastanov (1989) enumerated the problems of energy optimisation in fisheries, related to fishing techniques and ship building and engineering, in the erstwhile USSR. Developments in midwater trawl design aimed at drag reduction and energy saving have been described by Kwidzinski (1989) and Marlen (1989b). Significance of hull form in efficient operation of fishing vessels has been discussed by Frostad (1989). Energy consumption pattern in coastal fisheries have been studied by Ben-Yami (1989) and Hameed & Hridayanathan (1989). Energy saving in fishing vessels by introducing bulbous bow and improvements in propulsion systems have been described by Calisal & McGreer (1989), McIlwaine (1989) and Kohane & Ben-Yami (1989). Brothers & Pinhorn (1989) reported the impact of Ener Sea Program developed for transferring the energy saving and cost reduction technologies to the New Zealand fishermen, which resulted in a saving of about 2.0×10^6 US$. Endal (1989b) reviewed the policies, challenge and opportunities in energy optimisation in fisheries.

National Workshop on Low Energy Fishing, 8-9 August 1991, at Cochin, India, discussed several issues pertaining to low energy fishing gear and practices (Anon, 1993a). Ben-Yami (1993) analysed the significance of low energy fishing in the context of present day energy crisis. Low energy fishing techniques used in Indian fisheries and various related issues were discussed Kurup *et.al.* (1993c) and Gallene (1993); and low energy fishing vessels were discussed by Sheshappa (1993), George (1993), Pillai & Namboodiri (1993) and Choudhury (1993). Vivekanandan (1993) discussed the structural changes that has taken place in coastal fisheries of Kerala and the growing energy inefficiency in the fisheries sector. Hameed & Kumar (1993) discussed the problems related to energy optimisation in the fisheries sector.

Fishing Vessel Energy Efficiency Meeting organised by International Energy Agency (IEA), 25-26 March 1993, Vancouver, British Columbia, Canada, focused on specific issues such as (i) the need for an energy consumption database for each fishery sector in each of the member countries, (ii) the need for an energy conservation inventory to reduce fuel consumption and harmful emissions from fishing fleet and (iii) the use of decision support systems for energy optimisation (IEA, 1993)

Gulbrandson (1986) after evaluating fuel saving opportunities, recommended a set of fuel saving measures appropriate for small fishing boats. A study on the attitudes and knowledge on energy conservation among marine fishermen of Kerala was conducted by Sasikumar, *et.al.* (1992). A study on the economics of energy in marine fisheries of Kerala was conducted by Mathew *et.al.* (1992). Aegisson & Endal (1993) studied the economic performance of the different fishing vessel categories, operating along the coast of Kerala and Karnataka states in India, as well as their relative dependence on the inputs of energy, labour and capital. This study was conducted under an Energy Conservation Programme which was jointly supported by the Governments of India and Norway. After an analysis of the technical and operational characteristics of mechanised vessels, the authors concluded that there is a massive potential for energy saving in the Indian fisheries and identified the need for technical and operational improvements to realise this potential. Fuel consumption of medium size trawlers operating from Cochin was analysed by Nasar (1998) and redesigning of the propeller of these vessels is reported to have given a fuel saving of 20 %. Ravindran (1998) discussed the trends in fishing craft development in India. John (1996) and John *et.al.* (1998) studied some aspects of fuel optimisation in trawling operations along the Kerala coast and worked out the average yield of fish per litre of diesel consumed by trawlers. Shibu (1999) has discussed the economic aspects of fuel consumption pattern among purse seiners, trawlers and gillnetters, operating from Cochin.

Most of the available literature on energy and fisheries deals only with the operational aspects of consumption. Energy Analysis Unit of the University of Strathclyde, Glasgow, Scotland, estimated the energy requirement for various fishing methods and aquaculture production systems, based on energy analysis (Edwardson, 1976a,b). Energy analysis is the process of determination of the total non-renewable energy resources consumed in making a good or service available, otherwise known as Gross Energy Requirement (GER), which takes into account both indirect and direct energy use (IFIAS, 1975; Slesser, 1988). Studies on energy analysis have been generally confined to industrial and agricultural production systems (Berry & Fels, 1973; Leach, 1976; Pimentel, 1980; Fluck, 1985; Mittal & Dhawan, 1988; EMC, 1991; Fluck, 1991). Literature on demersal and midwater trawling , day-night variation in trawl catches and techniques of energy conservation, which form a part of the present study, are reviewed in Chapters 6, 7 and 8, respectively.

1.4 Rationale and objectives of the study

Energy is a key input into the fish harvesting process. Efficient use of energy helps in reducing operational costs and environmental impact, while increasing profits. Energy optimisation in fish production is an important aspect of responsible fishing as enunciated in the Code of Conduct for Responsible Fisheries (FAO, 1995a). Gross Energy Requirement (GER) is a measure of the intensity of non-renewable resource use per unit of the fish landed and takes into account the amount of energy used in providing all inputs into the harvesting process, including fishing vessel, fishing gear and operational sub-systems. Information on GER for different fish harvesting systems will provide an unbiased decision making support for the fishery management to optimise the yield per unit of non-renewable energy spent; decide on the mix of fish harvesting systems to be employed for optimising fuel use in the capture fish production in a region; and delineate approaches for energy conservation.

The present investigations have been carried out as there is absolutely no information on the energy cost of fish production by different fish harvesting systems being operated in Indian fisheries, based on the principles of energy analysis. Information on energy-related aspects of different trawling techniques and diurnal variation of energy requirement in trawling, is very scarce and these aspects form a part of the present study. The need for a comprehensive review of the energy saving concepts and an assessment of the diffusion of knowledge of these concepts among mechanised fishermen, have also been addressed in this treatise.

The objectives of the present study were:

- Energy analysis of the selected fish harvesting systems and determination of Gross Energy Requirement (GER), Energy Efficiency and Energy Intensity values
- Detailed description of the fish harvesting systems selected for the study in the traditional non-motorised, traditional motorised and small mechanised sectors
- Relative energy consumption in demersal and aimed mid-water trawling in the intermediate range freezer trawler operations
- Diurnal variation in trawl catches and its influence on energy efficiency of trawler operations
- Review and delineation of approaches for energy conservation in fish harvesting; and an assessment of the awareness and extent of adoption of energy saving concepts by mechanised fishermen.

Chapter 2

Materials and Methods

2.1 *Energy analysis*

Energy analysis is a methodology whereby the energy required to make available a good or create a service is computed, taking into account both direct and indirect energy use (Slesser, 1988). Chapters 3 to 5 cover energy analysis of selected fish harvesting systems and determination of Gross Energy Requirement per tonne of fish landed (GER.t $fish^{-1}$), Energy Ratio and Energy Intensity, following the methodology and conventions recommended by IFIAS (International Federation of Institutes for Advanced Study) (1975) and other authors (Edwardson, 1976a, b; Mittal & Dhawan, 1988; EMC, 1991).

2.2 *Definitions*

Gross Energy Requirement (GER) is the sum of all non-renewable energy resources consumed in making available a good or service. GER is a measure of intensity of non-renewable resource use. It reflects the amount of depletion of earth's inherited store of non-renewable energy in order to create and make available a good or service. It is a convention devised by a workshop on energy analysis methodology, held under the auspices of the International Federation for Institutes of Advanced Study (IFIAS) in Sweden in 1974 (Slesser, 1988). Renewable energies and human energy are not included in the GER. It allows conclusions to be drawn in terms of energy requirement regarding the different harvesting systems, free from any of the bias which might be associated with the arguments of economists, end-users or managers. In this study, GER in the fish harvesting up to the point of landing is estimated in selected fish harvesting systems in the traditional non-motorised, traditional motorised and small mechanised sectors.

GER is generally expressed in Giga-joules (GJ). Joule (J) is the basic unit for all forms of energy in the SI system. It is equivalent to the work done when the point of application of a force of 1 newton is moved through 1 m in the direction of action of force. 1 GJ is 10^9 joules. 1 Joule is equal to 0.239 calories, 2.778×10^{-7} kilowatt hours, 9.478×10^{-4} British thermal units or 10^7 ergs. Approximately 43 GJ is equivalent to one tonne of oil (Loftness, 1978; Mittal & Dhawan, 1988; Slesser, 1988).

Energy ratio or Energy efficiency ratio is the ratio between metabolizable (i.e. food) energy produced and the amount of non-renewable energy consumed (energy output / energy input). It is generally used in the analysis of food production systems (Slesser, 1988; EMC, 1991).

Energy intensity is the amount of energy required to create a unit of output energy (energy input / energy output). It is the reciprocal of energy ratio and is equal to GER expressed in terms of out put energy (Slesser, 1988; EMC, 1991).

2.3 Determination of Gross Energy Requirement (GER), Energy ratio and Energy intensity.

Important inputs which goes into the fish harvesting process are identified in Fig. 2.1. These include the fishing vessel construction and fitting out, fishing gear manufacture and operational energy requirement. For each type of input the amount of material used in one year was obtained and corresponding amount of energy used up in making the material available was determined using conversion ratios (Table 2.1). The capital items such as fishing vessel, machinery and equipment; and fishing gear are amortised over their anticipated useful lifetimes. GER per tonne of fish landed was then calculated by dividing the capital by anticipated life in years and adding other direct inputs such as annual fuel consumption and dividing the total by the quantity of fish landed in that year. Flow chart for energy analysis is given in Fig. 2.2. Microsoft Excel spreadsheet software was used for the purpose of computations.

2.4 Data sources for energy analysis

2.4.1 Fishing vessels

Sources of energy inputs for construction of traditional crafts used in motorised and non-motorised sectors were collected from traditional craft builders of Chellanam (Ernakulam Dist.), as per the structured Schedule prepared for the purpose (Appendix 1). Information on mechanised vessel construction were collected from boat builders in the Vypeen-Aroor belt. Quantity of material requirements for construction were estimated using the methods described by Fyson (1985) and Fyson (1991).

Small-scale mechanised Fishing vessel manufacture in Cochin is a small-scale industry. Production sequence for small-scale mechanised fishing vessel manufacture consists of (i) back bone assembly, (ii) planking,

(iii) framing, (iv) fixing of stringers, (v) deck building, (vi) engine installation, (vii) deck work and (viii) finishing. The bulk of the small-scale mechanised vessels are manufactured in wood. During nineties, however, steel was also introduced and used increasingly as construction material for trawlers and purse seiners with L_{OA} exceeding 15 m. Manufacturing process is labour-intensive. Job-production method (one-off production) is used in the manufacture of fishing vessels in the traditional yards operating at Cochin and assembly line production (series production) practices do not exist. The amount of wastage in wooden boats is taken as 30 % and for steel construction as 20 %. Small mechanised wooden hulled vessels have a planked construction. Timber used for construction are usually Jungle jack (*Artocarpus hirsuta*) and 'Venteak' (*Lagerstroemia lanceolata*).

The material inputs for both traditional and small-mechanised fishing vessel manufacture were converted to corresponding energy values using conversion factors (Table 2.1). Energy requirement for traditional crafts are given in Fig. 2.3. Energy requirement for small-scale mechanised crafts with wooden and steel hull are given in Fig. 2.4 and 2.5, respectively. Useful life-time of both traditional crafts and mechanised crafts including power plants and equipment, were assumed to be 10 years for energy amortisation purposes. Life time of outboard motors (OBMs) used for powering traditional crafts, were estimated as 2 years.

2.4.2 Fishing gear

Data on design details and rigging of fishing gears were obtained by a survey of fishing gears operated from fish harvesting systems selected for the study, as per a structured Schedule prepared for the purpose (Appendix 2). Design drawings and specifications were prepared as per conventions of FAO (1975, 1978) and recommendations of ISO (1975). Sources of energy inputs to gear manufacture were estimated from design drawings. Netting requirements were estimated as per method described by Hameed & Boopendranath (2000) using the following formula and adding 5 % by weight to compensate for the wastage during fabrication or obtained by direct inquiries from the gear fabricators:

$$W_n = \{K.[((M_{t1}+M_{t2})/2)M_n].2m.10^{-3}\}R\text{-tex}.10^{-6}$$

where W_n = the weight of the netting of each of the component sections constituting the netting panels of the gear system with a uniform mesh size, twine size and material specifications

M_{t1} and M_{t2} = number of meshes in width along the top and bottom edges

M_n = number of meshes in depth

m = stretched mesh size in mm

K = correction factor for length of twine used in a knot

= length of twine used in a knot / 2m

R-tex = linear density of netting twine ($g.km^{-1}$)

Details of the sources of energy inputs in the fabrication of sheer devices used in trawling were obtained from local manufacturers. Energy requirement for fabrication of flat rectangular otter boards of wood and steel construction is given in Fig. 2.6 and for construction of trawl gear in Fig. 2.7

Useful life-time of fishing gears estimated for amortisation purposes were 1 year for active fishing gears such as trawls, steel wire rope used as towing warps in trawlers, stake nets and lightly constructed gill nets operated from non-motorised crafts; 3 years for surrounding nets of heavy construction for mechanised purse seining, gill nets operated from mechanised vessels and for lines; 2 years for surrounding nets of light construction (ring seines); and 0.5 year for otter boards.

2.4.3 Operational inputs

Data on operational inputs were collected from different fish harvesting systems for a period of one year. Sampling centres were selected based on dominance of the harvesting system and accessibility. Major inputs for motorised and small mechanised sectors were fuel, lubricating oil and in the muti-day operations, ice for preservation of fish. Data on fuel, lubricating oil and ice were extracted from weekly statements prepared by fleet managers where they are available and quantified based on prevailing market rates for the respective input; and in other cases by direct enquiries.

2.4.4 Fish production and operational details

Data on fish production by selected fish harvesting were collected from different landing points located in Cochin, according to a pre-fixed sampling schedule, during 1997-98. Data on fishing operations were collected by discussions with the operators as per a structured Schedule (Appendix 3.1, 3.2 & 3.3) prepared for the purpose and short onboard visits. Sampling centres, sample size and sampling frequency are given in Table 2.2.

2.5 Energy equivalents

Energy equivalents for the determination of process energy requirement (PER) of various inputs to the fish harvesting system were obtained from Berry & Fels (1973), Edwardson (1976 a,b), Loftness (1978), Mittal & Dhawan (1988), EMC (1991), ECCJ (1997) and TERI (1999) or estimated from the present study (Table 2.1)

2.6 Energy equivalents for fish production

Energy equivalents for fish production by different harvesting systems were derived using mean values of data on biochemical composition of estuarine and marine finfish, crustaceans and cephalopods reported by CIFT (1993) and energy values of foods reported by Harper (1975).

2.7 Secondary data sources

General statistics on fishing crafts were collected from Registers maintained by Chief Engineer and Administrator, Cochin Fisheries Harbour and Department of State Fisheries, and survey reports of SIFFS (SIFFS, 1992; 1999) and verified by sample survey.

Table 2.1 Equivalents for direct and indirect sources of energy

	Item	Unit	Energy equivalent	Source
1	Steel	tonne	54.8 $GJ.t^{-1}$	Berry & Fels (1973)
2	Copper	tonne	25-30 $GJ.t^{-1}$	Loftness(1978)
3	Brass	tonne	25-30 $GJ.t^{-1}$	Assumed as equivalent to Copper; Loftness(1978)
4	Lead	tonne	32.4 $GJ.\ t^{-1}$	Loftness(1978)
5	Aluminium	tonne	58.0 $GJ.t^{-1}$	TERI (1999)
6	Plastic	tonne	10 $GJ.t^{-1}$	Loftness (1978)
7	PVC	tonne	162 $GJ.t^{-1}$	Edwardson (1976b)
8	Polyamide	tonne	61 $GJ.t^{-1}$	Edwardson (1976b)
9	Polyethylene	tonne	61 $GJ.t^{-1}$	Assumed as equivalent to polyamide; Edwardson (1976b)
10	Polypropylene	tonne	61 $GJ.t^{-1}$	Assumed as equivalent to polyamide; Edwardson (1976b)
11	Timber	tonne	4 $GJ.t^{-1}$	Loftness (1978)
12	Coir	tonne	10 $GJ.t^{-1}$	Assumed as equivalent to agricultural by-products; Mittal *et.al.* (1985)
13	Fish oil	tonne	49.56 $GJ.t^{-1}$	Estimated from GER for small mechanised purse seining (this study) at a yield of 12 % body oil (oil sardine)
14	Wire rope (SWR)	tonne	635 $GJ.t^{-1}$	Edwardson (1976b)
15	Metal wire	m	46.6 $MJ.m^{-1}$	Edwardson (1976b)
16	Machinery (prime movers)	tonne	64.8$GJ.t^{-1}$	Mittal & Dhawan (1988)
17	Equipment	tonne	62.7 $GJ.t^{-1}$	Mittal & Dhawan (1988) (assumed as equivalent to farm equipment)
18	Ice	tonne	0.199 $GJ.\ t^{-1}$	Edwardson (1976a)
19	Diesel	litre	56.31$MJ.l^{-1}$	Mittal & Dhawan (1988) EMC (1991)
20	Petrol	litre	48.23 $MJ.l^{-1}$	Mittal & Dhawan (1988) EMC (1991)
21	Kerosene	litre	37.2 $MJ.l^{-1}$	ECCJ (1997)
22	Lubricating oil	litre	40.13 $MJ.t^{-1}$	ECCJ (1997)
23	Electricity	kWh	11.93 $MJ.kWh^{-1}$	Mittal & Dhawan (1988)

Table 2.2 Centres, sample size and sampling frequency

Fish harvesting system	Centres	Sample size	Sampling frequency
Traditional non-motorised gill netting	Saudi-Fort Cochin (Ernakulam Dist.)	5 units (6.3 %)	Every 3 days
Stake nets	Central Kumbalam (Ernakulam Dist.)	6 units (2.9 %)	Every 3 days
Mini-trawling	Chellanum-Saudi (Ernakulam Dist.)	4 units (11.4 %)	Every 3 days
Ring seining	Chellanum-Saudi (Ernakulam Dist.)	4 units (8.3 %)	Every 3 days
Mechanised gillnetting	Cochin Fisheries Harbour	5 units (4.6 %) 89 hp, 9-11 m L_{OA} vessels	Every landing day
Trawling	Cochin Fisheries Harbour	7 units (1.2 %) 99-106 hp, 13-14 m L_{OA} trawlers	Every landing day
Purse seining	Cochin Fisheries Harbour	7 units (14.9 %)	Every 3 days

Schedule 1: Details of material inputs into construction of fishing crafts

	General information		
	Type of fishing vessel		
	Loa, m		
	Beam max, m		
	Depth, m		
	CUNO, m^3		
	Location and date		
1.0 Traditional fishing crafts			
	Item	***Material***	***Quantity***
1.1	Hull (skin and frames)		
1.2	Hull strength members (keel, stringers, etc.)		
1.3	Fender		
1.4	Copper fasteners		
1.5	Iron fasteners		
1.6	Black oxide		
1.7	Coir		
1.8	Coconut fibre		
1.9	Fish oil		
1.10	Electricity		
2.0 Small mechanised fishing crafts			
	Item	***Material***	***Quantity***
2.1	Hull shell (skin and frames)		
2.2	Hull strength members (Keel, deadwood, engine bearers, stringers, etc.)		
2.3	Deck (Deck, deck beams)		
2.4	Deck house (wheel house)		
2.5	Outfit (Joiner work, fish hold lining and insulation, masts rigging, fuel tanks, etc.)		
2.6	Fastenings (for wooden construction)		
2.7	Machinery (Main engine, shafting and propeller)		
2.8	Deck equipment (Trawl winch, purse line winch, etc.)		
2.9	Aluminium sheathing (for wooden hulls)		

Schedule 2: Survey of fishing gears

	General information	
	Name and address of the owner	:
	Loa of fishing craft, m	:
	Engine, hp; make	:
	Location and date:	
1.0	***Fishing gear using netting in construction***	
1.1	**Outline of construction of the gear with names of parts** (illustration)	
1.2	**Netting** (Tabulate separately for each of the panel section of uniform mesh size, twine size and material specifications, constituting the gear)	
1.2.1	Material:	
1.2.2	Twine size, R-tex:	
1.2.3	Mesh size, mm:	
1.2.4	Length and width of netting sections (No. of meshes):	
1.2.4	Treatment, if any:	
1.3	**Ropes (Tabulate separately for each part)**	
1.3.1	Material:	
1.3.2	Rope size (dia), mm:	
1.3.3	Length, m:	
1.4	**Floats**	
1.4.1	Material:	
1.4.2	Size, mm:	
1.4.3	Shape:	
1.4.4	Weight, g:	
1.4.5	Buoyancy, gf:	
1.4.6	Arrangement on float line, no. per unit length:	
1.4.7	Total number used:	

1.5	**Sinkers**
1.5.1	Material:
1.5.2	Size, mm:
1.5.3	Shape:
1.5.4	Weight, g:
1.5.5	Arrangement on float line, No. per unit length:
1.5.6	Total number used:
1.6	**Accessories**
1.6.1	***Otter boards (for trawls)***
1.6.1.1	Type:
1.6.1.2	Material:
1.6.1.3	Size, mm:
1.6.1.4	Weight, kg:
1.6.2	***Pursing arrangement (for surrounding gear)***
1.6.2.1	Material:
1.6.2.2	Size of rings (dia), mm:
1.6.2.3	Weight of rings:
1.6.2.4	Total number of rings:
1.6.3	***Stakes (for stake nets)***
1.6.3.1	Material:
1.6.3.2	Size (dia), mm:
1.6.3.3	Length, m:
1.6.3.4	Number:
1.7	**Method of construction**
1.7.1	Order of gear construction:
1.7.2	Hanging coefficient in different parts:
1.7.3	Other details, if any:
1.8	**Number of man-days used for construction of gear**
1.9	**Detailed sketch of items with measurements**
1.9.1	Attachment of floats to float line
1.9.2	Attachment of sinkers to line
1.9.3	Pursing arrangement (for surrounding nets)
1.9.4	General rigging used for operation

2.0	***Line fishing gear***
2.1	**Outline of construction of the gear with parts (illustration)**
2.2	**Main line (for long lines)**
2.2.1	Material:
2.2.2	Rope size (dia), mm:
2.2.3	Length:
2.3	**Branch line**
2.3.1	Material(s):
2.3.2	Specifications of constituent elements:
2.3.3	Method of connection to mainline
2.3.4	Branch line interval, m:

2.4	**Floats and Buoys**
2.4.1	Material:
2.4.2	Size, mm:
2.4.3	Shape:
2.4.4	Weight, g:
2.4.5	Buoyancy, gf:
2.4.6	Total number used :
2.4.7	Interval, m:
2.5	**Accessories**
2.5.1	Lights:
2.5.2	Anchor, weights:
2.5.3	Other items:
2.6	**Hook**
2.6.1	Material:
2.6.2	Shape:
2.6.3	Dimensions, mm:
2.7	**Detailed sketch of items 2.1 to 2.5:**
2.8	**Number of man-days used for construction:**

Appendix 3.1

Schedule 2a :Operational inputs, catch and catch composition of traditional non-motorised fish harvesting systems

NAME OF OWNER :	LOA OF CRAFT(m) :
TYPE(S) OF FISHING UNDERTAKEN:	No. AND SIZE OF FISHING GEAR:

ACCOUNT OF FISHING TRIPS, CATCH AND CATCH COMPOSITION

STARTING DATE:

DEPARTURE FROM BASE Date & Time	ARRIVAL TO BASE Date & Time	TOTAL CATCH kg	MAJOR FISH GROUPS kg	AREA & DEPTH OF FISHING

FINISHING DATE(after 12 months):

Appendix 3.2

Schedule 2b :Operational inputs, catch and catch composition of traditional motorised fish harvesting systems

NAME OF OWNER :	LOA OF CRAFT, m
TYPE(S) OF FISHING UNDERTAKEN:	
No. AND HP OUTBOARD ENGINES:	ENGINE MAKE:
No. AND SIZE OF FISHING GEARS:	

ACCOUNT OF FISHING TRIPS, FUEL, LUB. OIL, CATCH AND CATCH COMPOSITION

STARTING DATE:	KEROSENE AT HAND(litre)	PETROL AT HAND (litres) :	LUB OIL AT HAND (litres):

DEPARTURE FROM BASE Date & Time	ARRIVAL TO BASE Date & Time	KEROSENE, Litres	PETROL, Litres	LUB. OIL, Litres	TOTAL CATCH kg	MAJOR FISH GROUPS kg	AREA & DEPTH OF FISHING

FINISHING DATE(after 12 months):	KEROSENE AT HAND (litre)	PETROL AT HAND (litres) :	LUB OIL AT HAND (litres):

Appendix 3.3

Schedule 2c :Operational inputs, catch and catch composition of small mechanised fish harvesting systems

NAME OF FISHING VESSEL :	REGISTRATION No : CFH..........
TYPE(S) OF FISHING UNDERTAKEN:	LOA (m) :
HORSE POWER :	ENGINE MAKE:
No. AND SIZE OF FISHING GEARS:	

ACCOUNT OF FISHING TRIPS, DIESEL, LUB. OIL, CATCH AND CATCH COMPOSITION

STARTING DATE:	DIESEL AT HAND (litres) :	LUB OIL AT HAND (litres):

DEPARTURE FROM PORT Date & Time	ARRIVAL TO PORT Date & Time	DIESEL Litres	LUB. OIL Litres	ICE kg	TOTAL CATCH kg	MAJOR FISH GROUPS kg	AREA & DEPTH OF FISHING

FINISHING DATE(after 12 months):	DIESEL AT HAND (litres)	LUB OIL AT HAND (litres):

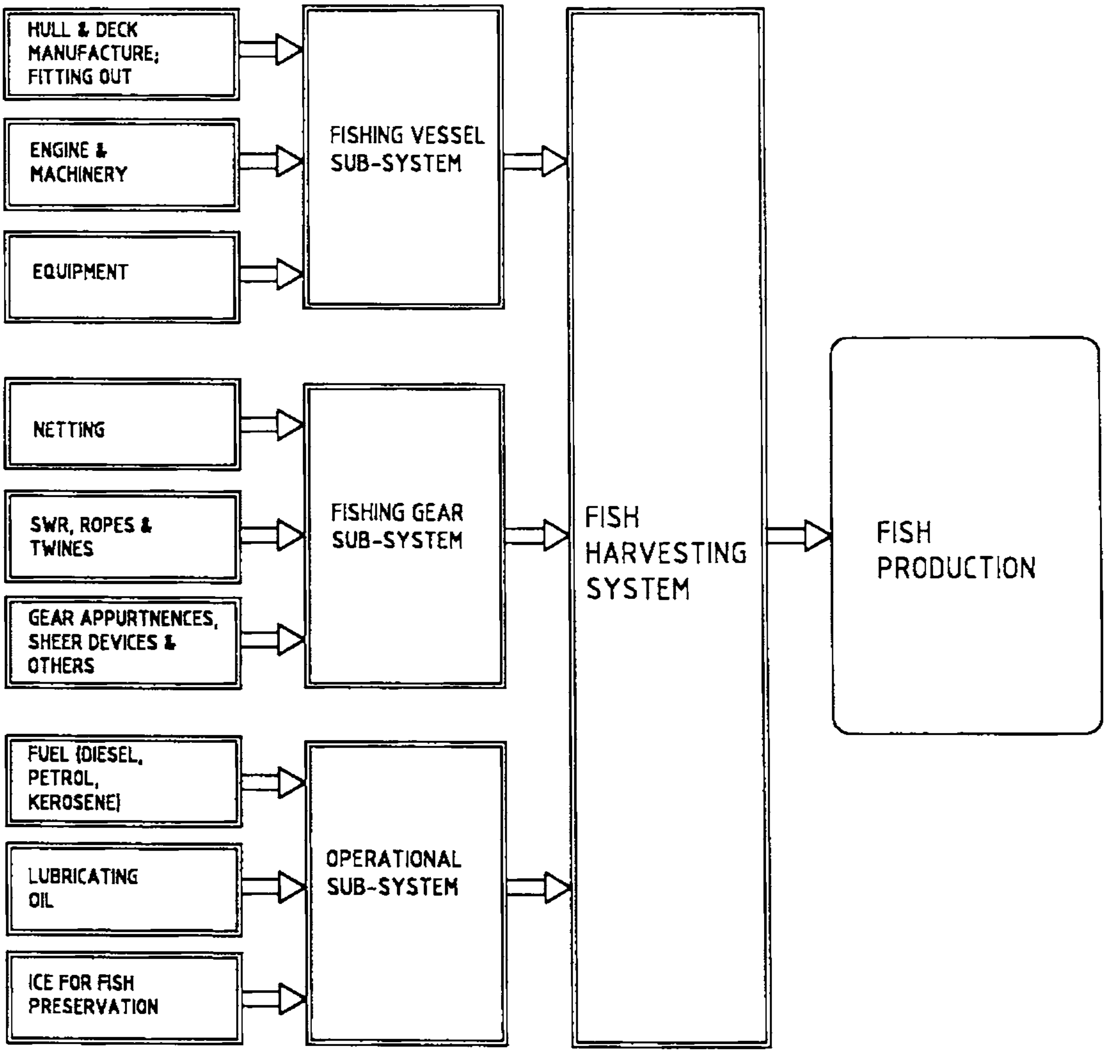


Fig. 2.1 Block diagram of fish harvesting system

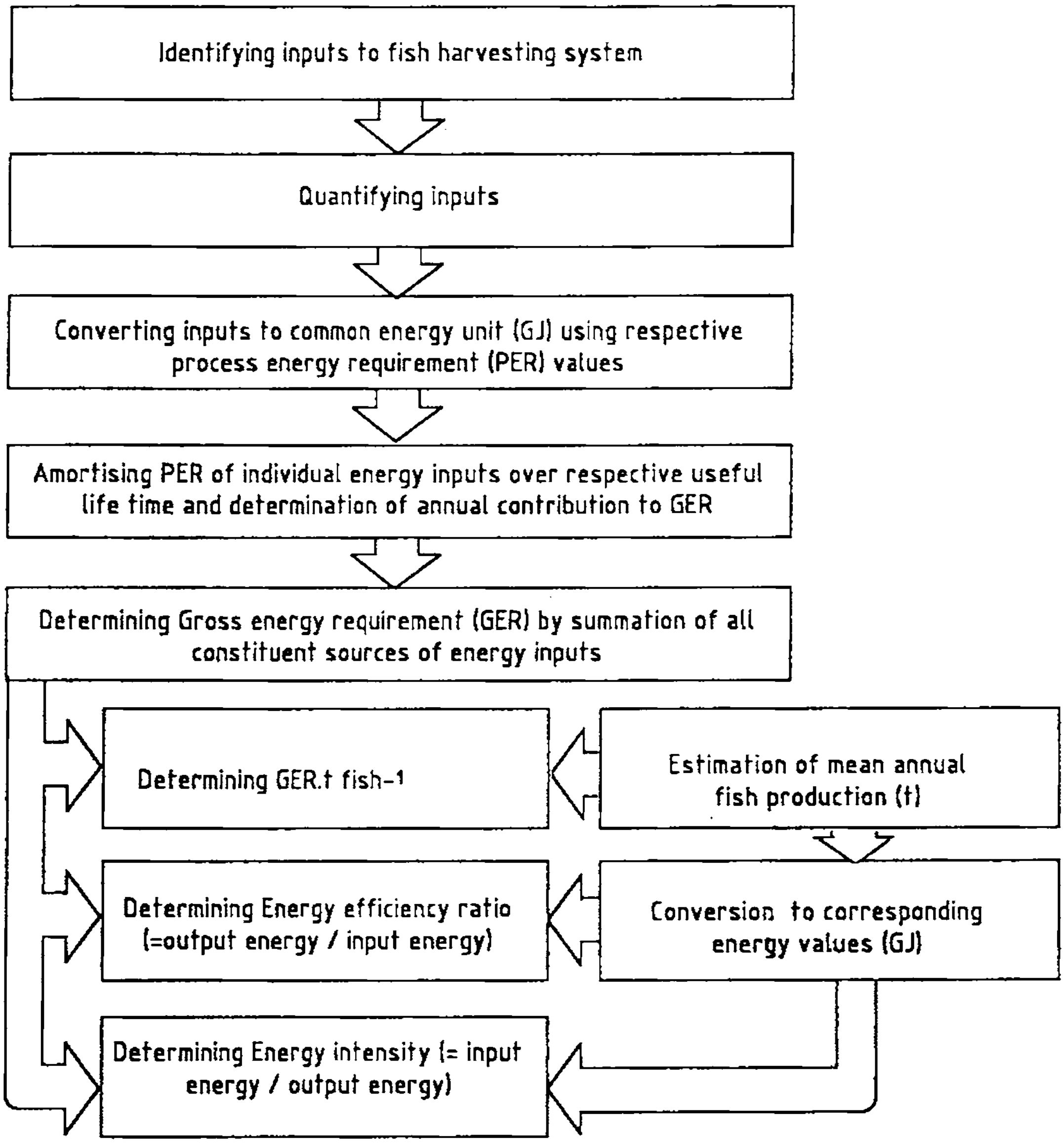


Fig. 2.2 Flow chart of energy analysis

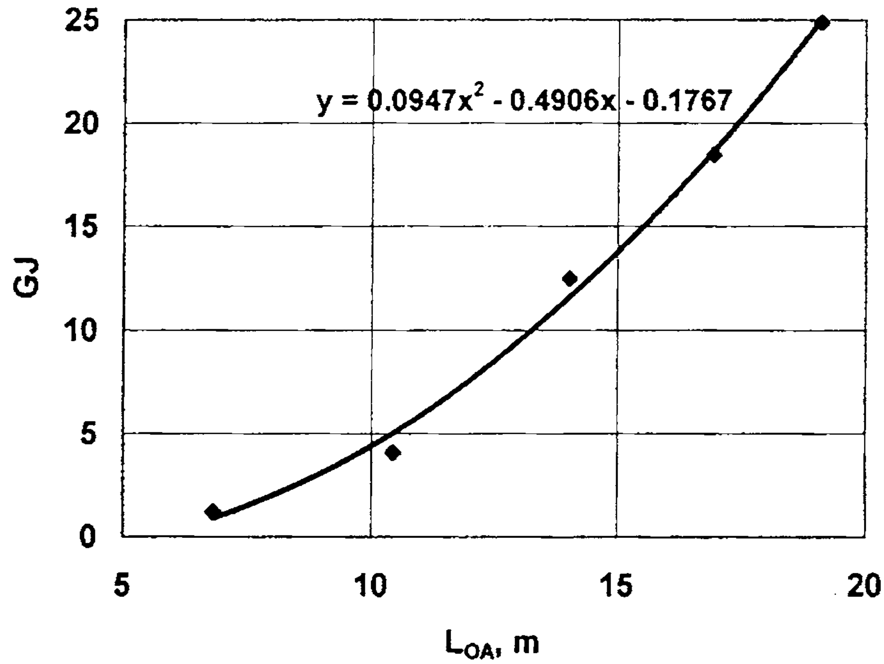


Fig. 2.3 Energy requirement for traditional fishing craft construction

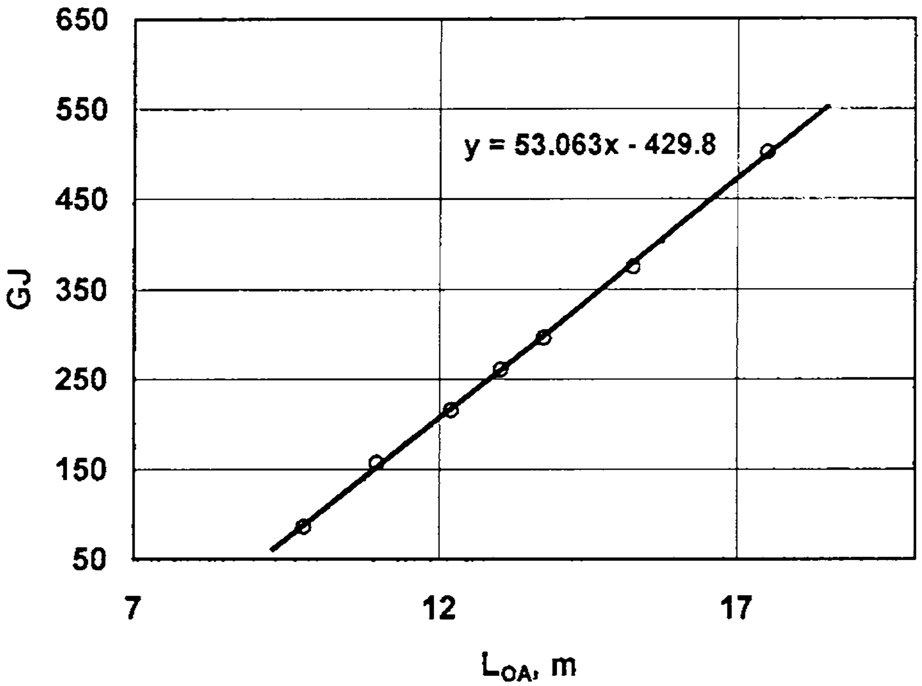


Fig. 2.4 Energy requirement for wooden mechanised vessel construction

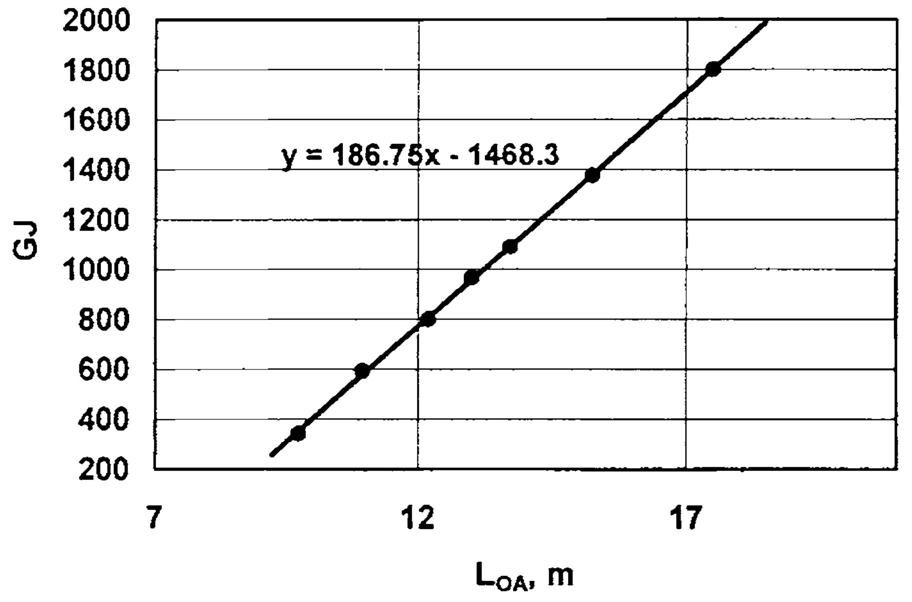


Fig. 2.5 Energy requirement for mechanised steel vessel construction

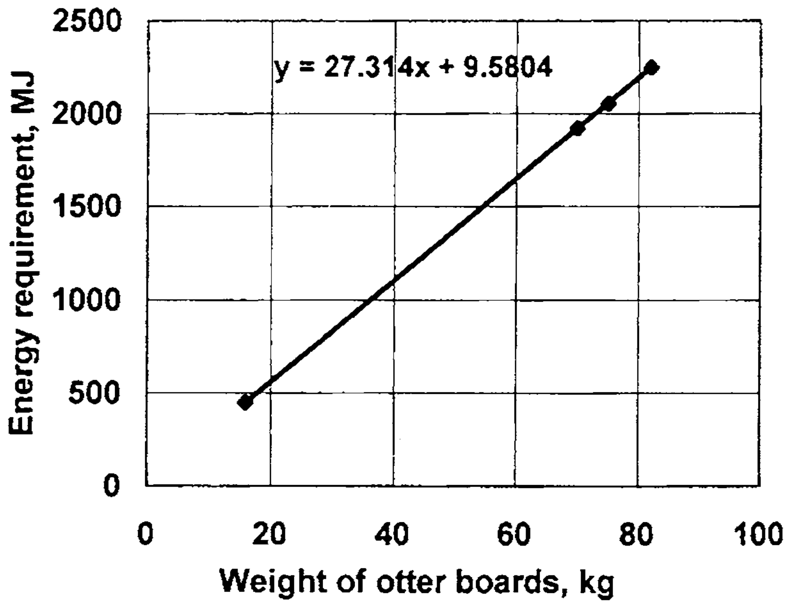


Fig. 2.6 Energy requirement for fabrication of flat rectangular, wood and steel otter boards

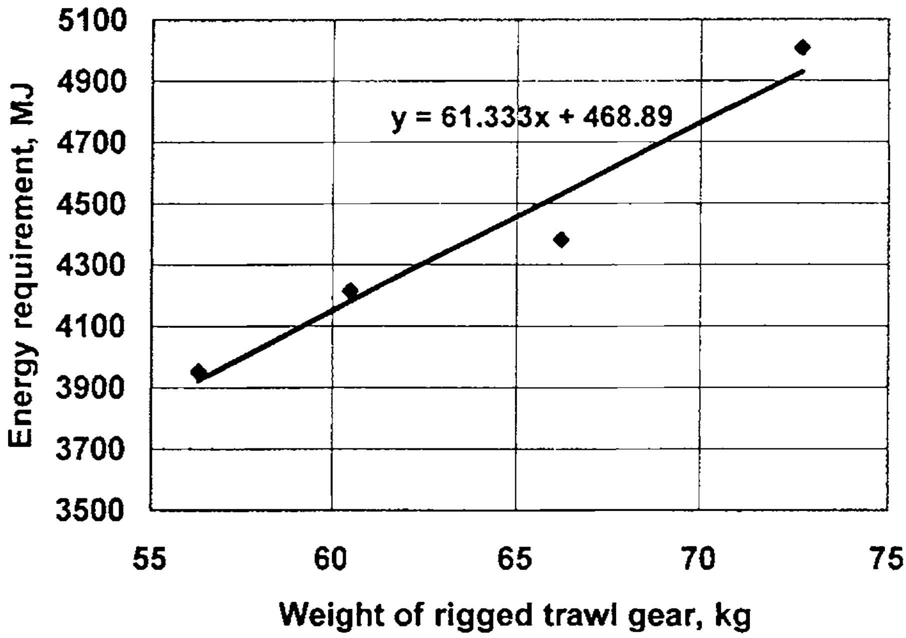


Fig. 2.7 Energy requirement for trawl gear fabrication

Chapter 3

Energy Requirement in Selected Fish Harvesting Systems in the Traditional Non-motorised Sector

Contribution of non-motorised traditional sector in the marine fish landings of India has been 0.419×10^6 t in 1991 and formed 19. 4% of the total marine landings. However, its contribution to the total marine landings steadily decreased over the years to 0.271×10^6 t in the year 1996, forming 11.4 % of the total landings (Sathiadhas, 1998). Average catch per trip of different types of fishing units also declined from 57 kg in 1991 to 51 kg in 1995. The total number of fishing units in the non-motorised sector is estimated to be 1,60,000, including plank-built boats (23.1 %), dugout canoes (10.8 %), catamarans (59.0 %) and others (7.1 %) with an estimated capital investment of Rs. 9226 million (Sathiadhas, 1998).

Traditional non-motorised fleet has declined substantially in Kerala, during the period from 1991 to 1998 (SIFFS, 1992; 1999). The growing depletion of coastal resources, competition with the mechanised fishing boats, increasing fish prices and liberal import policies gave a major boost to the motorisation of traditional crafts, beginning from 1981. Motorisation of the artisanal fisheries has brought about substantial changes in craft, gear and fishing operations. The non-motorised fleet confine their operations to the backwaters and to the shallow coastal waters. The fishing gears operated by the non-motorised sector in Kerala are predominantly gill net (78.9%) followed by trammel net (7.6 %), hook and line (6.9 %), shore seine (4.6 %) and boat seine (2.0 %) (SIFFS, 1999).

Number of non-motorised crafts in Kerala was 20545 in 1991, forming 72.8 % of the total number of traditional crafts in the state. Their number decreased to 14979 in 1998, forming 53.1 % of the total traditional crafts in Kerala State (SIFFS, 1999). In Ernakulam District, however, there was an increase in the number of non-motorised crafts from 680 in the year 1991 to 918 in the year 1998.

The brackish water resources of Kerala include extensive backwaters, estuaries and adjacent water bodies which are subjected to the tidal influx. Approximately 40,000 fishermen are actively engaged in the capture fisheries in the brackish water bodies of Kerala State (Sanjeeevghosh, 1993). Vembanad lake situated between 9°28'-10°10' N lat. and 76°13'-76°31'E long. has an area of 21,500 ha. Exploited fishery resources in the Vemabanad lake have been quantified by Kurup & Samuel

(1985a) and Kurup *et.al.* (1993a,b). The annual yield of fishes and crustaceans from the Vembanad lake has been estimated at about 7200 t, consisting penaeid prawns (48.6 %), fishes (45.7 %), crabs (4.0 %) and palaemonids (1.6 %). Seine nets, gill nets, drag nets, falling gears, stationary gears including Chinese dip nets and stake nets, and hand lines have been reported to be used for fishing operations (Kurup & Samuel, 1985b; Kurup *et.al.*, 1993a). Stake nets are an important category of stationary gear operated by the traditional fishermen, in the Vembanad backwaters, primarily targeted at the prawn resources. About 12900 stake nets were estimated to be in operation in the backwaters of Kerala, in the year 1990 (Sanjeevaghosh, 1993).

Detailed description of design, operation, fish production and energy analysis of two important harvesting systems operated in the Vembanad backwaters by the non-motorised traditional sector, viz., gill netting and stake net operations, are given in the following Sections.

3.1 Gill netting

3.1.1 Introduction

Gill nets are passive fishing gears. They are vertical walls of netting kept erect in the water column by means of floats and sinkers and set perpendicular to the direction of movement of the target fish. The simplicity of its design, construction, operation and low investment have made this gear very popular among small-scale fishermen. They are operated in surface, mid-water and bottom layers of the water column in inland, coastal and offshore waters. Gill nets and entangling nets are suitable for sparsely distributed and scattered fish populations. An appropriately hung gill net with a mesh size optimised for the target species is highly size and species-selective.

General description of the structure, classification, design considerations and operation of gill nets have been given by Baranov (1948, 1969), Nomura (1961), Nomura & Yamazaki (1975), Brandt (1984), Karlsen & Bjarnasson (1986), Sainsbury (1996), Hameed & Boopendranath (2000) and other authors. Compilations of gill net designs operated in different parts of the world have been given by FAO (1975, 1978), SEAFDEC (1986, 1989, 1995). Specific aspects of gill net design, classification, selectivity and operations have been discussed by several authors (Baranov, 1914; Andreev, 1962; Ishida, 1962; ICNAF, 1963; Baranov, 1969; Kawamura, 1972; Hamley, 1975; Pope *et.al.*, 1975; Nedlec, 1982; Fridman, 1986; Prado, 1990).

Aspects of design, selectivity, distribution and operations of gill nets have been studied in India by Mathai *et.al.* (1971), Mathai & George (1972), Sreekrishna *et.al.* (1972), George *et.al.* (1975) Khan *et.al.* (1975), Sulochanan *et.al.* (1975), Panicker *et.al.* (1978), Pati (1981) Kunjipalu *et.al.* (1984c), Khan *et.al.* (1985), Kurien & Sebastian, (1986) Pillai *et.al.* (1989), George (1991), Mohanrajan *et.al.* (1991) and others. George (1971) gave an account of the fishing gear and methods operated in the inland waters of India. Kurup & Samuel (1985b) gave an account of various gill nets operated in the Vembanad lake. Pauly (1991) studied the commercially important gill nets operated in the Vembanad lake and gave design details of the gear used for different target species. Vijayan *et.al.* (1993) studied the changes in design and operation of the coastal gill nets of Kerala. SIFFS (1992, 1999) conducted a census of artisanal marine fishing fleet of Kerala and presented the statistics on different types of gill nets operated in Kerala state.

Based on the method of operation, gill nets are grouped into drift gill nets, set gill nets and encircling gill nets (Nedlec, 1982; Hameed & Boopendranath, 2000). Drift gill nets are generally operated in the surface layers for herring, sardine, mackerel, tuna and other large pelagic species and sharks. During the operation, one end of the net is generally attached to the vessel and it drifts with the current. Drift nets are also operated in the middle layers and close to the bottom. Set gill nets or anchored gill nets are fixed to the bottom or at a distance above the bottom by means of floatation and ballast. In shallow coastal waters they are fixed by means of stakes driven to the ground. Encircling gill net is operated for catching fish shoals feeding or moving in the surface layers. It is operated in the shallow waters and the lead line usually touches the bottom. After encircling the shoal, sound and vibrations are used to drive the fish towards the net so that they are either gilled or entangled.

A simple gill net may consist of netting panel of appropriate mesh size and twine size, float line, lead line, gavel lines (side ropes), floats, sinkers, buoys and buoy lines. The netting is mounted to the float line and the lead line according to a particular hanging ratio. Hanging coefficient determines the mesh shape and the hung depth of a mounted gill net. A few meshes along the upper, lower and side edges of the main netting are generally strengthened either by using thicker twine size or by using double twine in order to protect the webbing from damage during handling and operations. A number of gill net units are attached end to end, to form a fleet of nets.

Gill net designs conform primarily to the behaviour and characteristics of the target species, their habitat and the vertical range of their most frequently observed swimming layer. Principal mechanisms of capture are gilling, entangling and trapping and the behaviour control used is deception, by making target species indifferent to the gear, the visibility of which is endeavoured to be kept below the visual threshold of the species. Major factors taken into consideration in the design process are overall dimensions, mesh size, twine size, choice of material, underwater visibility of netting, hanging coefficient and scale of operations (Nomura, 1961; Fridman, 1986; Sainsbury, 1996; Hameed & Boopendranath, 2000).

Gill netting is one of the important fishing methods used for harvesting of backwater fishery resources, at Cochin. Gill nets operated in Vembanad lake have been reported by Shetty (1965) and by Kurup & Samuel (1985b). Pauly (1991) has described 10 different types of gill nets operated at various centres of the Vembanad lake. In this Section, gill netting practised in the Vembanad lake from traditional crafts, targeted primarily at mullets is described and an analysis is conducted on the energy requirement in this fishing practice.

3.1.2 Description of the fishing gear

Design drawing and details of the gill nets studied are given in Fig. 3.1 and Table 3.1, respectively. In Ernakulam, 1617 gill nets are reported to be in operation (SIFFS, 1999). Of this, about 900 gill nets are operated from small canoes of 5.5 m L_{OA}, predominantly in the Vembanad backwaters.

Overall dimensions, depth of operation and fleet size

The overall dimensions, particularly the hung depth of the gill net unit is determined by the most frequently observed vertical range of swimming layer of the targeted fish species. Total length of the gill net operated is 180 m, each of five different mesh sizes. The hung depth varies from 2.6 to 5.6 m.

Mesh size

Selection of the optimum mesh size for the target species and target size groups, is one of the most important design considerations for gill nets. Inappropriate mesh size will lead to inefficient gilling and loss of fishing efficiency.

Mesh size is proportional to modal length of the fish caught by it (Baranov, 1948).

$$m = k.l$$

where m is the mesh bar and l is the modal length of the target species and k is the selection coefficient. The value of k varies from 0.1 for slim and long fish, 0.15 for average shaped fish and 0.2 for tall bodied fish. Optimum mesh size is also estimated from girth using the formula:

$$m = G / 2K$$

where m is the stretched mesh size, G is the maximum girth of the target species and K is the modal girth-perimeter ratio obtained from experimental operations. The value of K range from 1.08 for tall bodied fish to 1.35 for narrow bodied fish (Fridman, 1986).

The gill nets studied were primarily targeted at mullets, which formed the bulk of the landings by this gear. The predominant mesh size was 36 mm and other mesh sizes in use were 30 mm, 34 mm, 40 mm and 65 mm (Table 3.1).

Twine size

Twine size is proportional to the mesh size. Average value of twine diameter-mesh size ratio is 0.005. In rough weather conditions and in bottom gill nets a ratio of 0.01 is used while in shallow water gill nets operated in calm waters, it could be as low as 0.0025 (Prado, 1990). In the gill nets studied twine size used was 23 tex (0.16 mm dia) and twine diameter-mesh size ratio ranged from 0.0053 to 0.0025

Netting material

Netting material for gill nets should have the lowest possible visibility under water and should be as fine and soft as possible. It should have a certain degree of elasticity to hold the fish securely without cutting into the flesh and a high breaking strength. Most common netting material for gill nets studied was polyamide monofilament. Polyamide monofilament are advantageous due to their transparency and low visibility under water which is known to increase fishing efficiency.

Hanging coefficient

Hanging coefficient for gill nets is typically between 0.5 and 0.8 which facilitate gilling (Hameed & Boopendranth, 2000). Entangling gill nets are loosely hung with a hanging coefficient 0.5 or less to facilitate tangling. In the gill nets studied hanging coefficient was between 0.5 and 0.55. Polypropylene ropes of 4 mm dia (double) are used as head rope and foot rope

Floats and sinkers

Floats and sinkers are used to keep the gill net vertically erect during operations. In the gill nets studied, floats and sinkers are threaded on to float-line and lead-line, respectively. Floats are attached at the rate of 11.1 $gf.m^{-1}$ and sinkers at the rate of 11.2 $g.m^{-1}$. The lower ranges of buoyancy and ballast are used in order to decrease the tension on netting and make it more pliable. Expanded PVC floats with an extra-buoyancy of 20 gf, are attached at an interval of 1.8 m, to the head rope. Lead sinkers of 28 g each, are attached to the foot rope at an interval of about 2.5 m.

3.1.3 Description of fishing crafts

Traditional non-motorised canoes of sizes ranging from 4.6 m to 7.6 m but typically around 5.5 m, manned generally by two fishermen, are used for the gill-netting operations. The dugout canoe is made, as the name implies, by scooping out wood from a single log of mango (*Mangifera indica*) or jungle jack (*Artocarpus hirsuta*). The keel portion is left thicker than the sides which are hollowed out so as to form internal stiffening ribs. The plank canoe is made by seaming together several suitably shaped planks of jungle jack (*Artocarpus hirsuta*) with coir ropes. The finished canoe is treated with a compound consisting of sardine oil and black oxide.

3.1.4 Fishing operations

The gill nets were operated from traditional canoes of about 5.5 m size, manned by one or two fishermen, using paddling as the means of propulsion. The fishermen set out for fishing early in the morning at day-break and return by noon, for selling the catch. Gill nets are set across the current. The gear is set over the side of the craft. The buoys and sinkers are thrown overboard manually to either side of the net to prevent tangling. After completion of the setting, the end of the net is kept tethered to the boat. Soaking time is generally 1-2 hours.

Fishing operations take place from November to July. During other months fishing operations are suspended, due to the presence of large quantities of macro-vegetation, drifting downstream. Mean number of days of operation in a year, is 225 days.

3.1.5 Catch and catch composition

Mean catch per year per gillnetter was estimated to be 8.4 t. Month-wise average production per boat is given in Fig 3.2. The most productive months during the period of observations were May to July giving a mean catch per day of 5.5 to 6.2 kg, followed by March and April (3.5 - 4.5 $kg.day^{-1}$), and November to February (2.5 - 3.2 $kg.day^{-1}$). The major species groups landed were mullets (*Liza parsia*, *Mugil cephalus* and *Valamugil spiegleri*) constituting 25.1 %, followed by sciaenids (17.1 %), carangids (15.5 %), cat fishes (13.6 %), prawns (13.4 %) and miscellaneous fishes (15.2 %) (Fig. 3.3).

3.1.6 Energy analysis

Results of energy analysis is given in Table 3.2 and Fig. 3.4. The fish harvesting system under study did not incur any operational energy expenditure in terms of non-renewable resources. The sequestered energy were estimated as 0.055 and 5.091 GJ, respectively for craft and gear. Thus, nearly 99 % of the total GER was contributed by the fishing gear and the balance by the fishing craft (Fig. 3.5). GER per tonne of fish landed was estimated to be 0.61. Efficiency ratio worked out to be 8.01. Energy intensity value obtained was 0.13, which was the lowest among all the fish harvesting systems covered under this study.

3.2 Stake net operations

3.2.1 Introduction

The stake net is a form of stow net, which is operated in different parts of the world, in the artisanal sector (Brandt, 1984). Stow nets are used in rivers, estuaries and other waters with strong currents. Usually in the form of a cone or pyramid, these gears are fixed by means of anchors or stakes, placed according to the direction and strength of the current. The mouths are usually held open by a frame, which may or may not be supported by a boat (Nedlec, 1982; Brandt, 1984).

Stake nets are fixed conical bag nets operated in the shallow waters and estuaries where the tidal currents are strong. The mouth of the net is kept open against the current by means of stakes driven to the bottom. Brandt (1984) has grouped them as stow nets on stakes, under the category of gape nets which in turn fall under the class of bag nets with fixed mouth. Nedlec (1982) and Hameed & Boopendranath (2000) have grouped them as stow nets under the category of traps along with fyke nets and other trapping devices. Stake nets are passively operated stationary fishing gear. The principle of operation is filtration. The organisms which drift with the tidal current enter the net set against the current, and are filtered and retained in the codend.

Dol net, which is an important indigenous fishing gear, operated along the coast of Gujarat and Maharashtra, for catching Bombay duck (*Harpodon nehereus*), is a type of stow net. In Gujarat the gear is held stationary against the current by means of stone anchors, a system of ropes and wooden barrel buoys. It differs from the practice in Maharashtra where the gear is tied on to a pair of appropriately spaced stout wooden poles driven to the ground or fixed by using a pair of anchored wooden spikes and a system of ropes and buoys (Gokhale, 1957; Kunjipalu, *et.al.*, 1993).

Stake nets of the Coromandal and the Malabar coasts have been described by Hornell (1925; 1938). Kurien & Sebastian (1982) have described the operation of stake nets for prawn fishing, in different parts of India. Pillai & Goplakrishnan (1984) gave an account of stake nets operated in the creeks and backwaters of Kutch region, in Gujarat, targeted at prawns. Kurup & Samuel (1985b) have discussed the fishing gear and methods used in Vembanad lake, including stake nets. Hridayanathan *et.al.* (1990) conducted investigations on the design, construction, preservation and operation of stake nets in the Cochin backwaters and the variability in their catches depending on season and lunar phase. Pauly (1991) has analysed the parameters influencing the drag of the stake nets. Hridayanathan & Pauly (1993) described two types of stake nets which are operated in the backwaters of Kerala. Rao *et.al.* (1993) have conducted studies on the design improvement of stake nets operated in Kakinada, Andhra Pradesh.

Stake nets constitute one of the most important gear categories used for brackish water fishing in the Kerala state and elsewhere in India (Pillai & Gopalakrishnan, 1984; Kurien & Sebastian, 1986; Hridayanathan *et.al.*, 1990; Rao, *et.al.* 1993; Parulekar & Achuthankutty, 1993). In the Vembanad backwaters, stake nets are widely operated in areas where the tidal currents are strong, particularly in the downstream regions. Total number of stake nets in operation in the backwaters of Kerala, has been reported to be 9200 in 1984 and their number rose to 12900 during 1987-90 (Sanjeevaghosh, 1993). The stake net is known as *oonni vala* in vernacular. Based on a survey, during 1988-89, Kurup *et.al.* (1993) reported that stake nets ranked first in terms of the gear-wise landings, contributing 53.1 % of the annual landings from the Vembanad lake. In this Section, a detailed description of the design, structure and operation of the stake nets in vogue in Kumbalam (Ernakulam Dist.), is given along with the results of energy analysis of the fishing system.

3.2.2 Description of the gear system

Stake net fishing system consists of two components. The stake nets themselves which are set against the tidal current in the fishing area and the traditional two-men canoe used for collecting the catch at the end of each operation and for maintaining the gear.

The stake net is a conical bag net made of several cylindrical sections of the netting, diminishing in diameter progressively from the mouth to the codend. Variation in the structure and construction of stake nets operated in the backwaters of Kerala, has been reported by Hridayanathan, *et.al.* (1990), Pauly (1991) and Hridayanathan & Pauly (1993). Construction features and size have also changed over a period of time and the present designs operated in the area of study differ in certain aspects from the description given earlier by Hridayanathan, *et.al.* (1990), Pauly (1991), and Hridayanathan & Pauly (1993). The design of stake nets operated in the Kumbalam area of the backwater system is given Fig. 3.6. Polyamide netting is used for the construction of the gear. The mesh size decreased from mouth to codend. The mesh size varied from 200 to 60 mm in the three front sections and from 18 to 12 mm in the following sections up to codend. The mesh size of the codend was 10 mm. Twine size in the corresponding sections varied from R635tex for 200 mm meshes, R235tex for 100 mm meshes and R155tex for the rest of the netting. Polypropylene ropes of 10 mm dia are used as framing ropes. The length of the upper and the lower frame ropes were 4.5 m each and that of the side frame ropes were 9.0 m each. Loops are provided at the four corners to facilitate bunching of a few meshes in the adjacent pieces of netting and for tying to the stakes. About 12.0 kg of webbing and 1.4 kg of polypropylene rope are used in the construction of the gear. Mouth area of the gear is 40.5 m^2.

3.2.3 Description of the fishing craft

Traditional non-motorised canoes are used by fishermen for installation of the stakes and setting the gear and for routine functions of tending the gear and collection of catch. Canoes of size 5.5 to 7.6 m, manned by 2-3 fishermen, are used for operations. Propulsion is by manual paddling. Construction of the canoe is as given in Section 3.1.3.

3.2.4 Fishing operations

Prior to the operations, stakes are installed in the fishing ground where tidal currents are strong. Usually, arecanut tree trunks are used as stakes. In addition to the main stakes, auxiliary stakes of smaller diameter which is obliquely placed as props are tied to the main stake for additional strength. The stakes are installed in series at a distance of 4.5 m., to facilitate the operation of a number of nets. The installation of the stakes is done by six or seven fishermen working from two canoes, as described by Pauly (1991).

The net is set at the onset of ebb tide. Before setting the gear, codend is closed by tying the end with codend rope, which is loosely tethered to one of the stakes. A float is usually tied to the end joining the codend. The loops in the lower frame rope are attached first to the main stakes by a rope and pushed down using a forked pole. The other end of this rope is used for attaching the loop in the upper frame rope to the stake. When the net is to be hauled up, the lower loops are lifted up by pulling the ropes used for tying and as it comes up, the upper loops are untied. The net is then hauled into the canoe manually and brought to the shore. The hauling is done when the tide begins to slacken towards the end of the ebb tide.

The fishing season is continuous in the area of operations. Two fishing periods of 10 days each, known as *thakkom* in vernacular, occur in a lunar month. The first fishing period begins 2 or 3 days before the new moon and lasts 2 to 3 days thereafter. The second fishing period falls around the occurrence of full moon period. The nets are operated twice a day during these periods, first in the forenoon and then in the afternoon.

3.2.5 Catch and catch composition

Stake nets are primarily targeted at prawns, which drift with the tidal currents. Mean catch per year per stake net was estimated as 0.41 t and mean number of fishing days in a year was 210. Best catches were obtained during January-May, with catch rates ranging from 2.90 to 4.74 kg.stake $net^{-1}.day^{-1}$, followed by July, September and December (1.16 - 2.22 kg.stake $net^{-1}.day^{-1}$), while the catches were negligible or absent during the months of August, October and November (Fig. 3.7). *Metapenaeus dobsoni* formed the dominant component of the catch consisting 92.4 %, followed by *M. monoceros* (6.0 %) and *Penaeus indicus* (1.6 %).

3.2.6 Energy analysis

Energy inputs in the stake net system has been estimated at 2.13 GJ (Fig. 3.8; Table 3.3). Fishing gear and stakes constituted 95 % of the GER and the balance being contributed by the traditional plank canoe used for carrying the gear and catch (Fig. 3.9). GER was estimated to be 5.19 GJ.t fish^{-1} which was quite high for a stationary passively operated gear. The high GER value of a passively operated, non-motorised gear system like stake net, is due to the low magnitude of landings by this gear. However, the catch is constituted by high unit value components, making the operations economically viable. Energy efficiency ratio obtained was 0.65 and energy intensity value was 1.54 (Fig. 3.8). GER value of stake net operations was higher than non-motorised gill netting operations by a factor of 8.5 but was lower than purse seining and trawling operations (Fig. 5.41).

Table 3.1 Salient features of drift gill net

Target species	Mesh size, mm	Twine size, tex	Material	Hung depth, m
Mullets and small clupieds	30	23	PA mono.	3.0
Prawns(*P. Indicus*)	34	23	PA mono.	3.4
Grey mullets	36	23	PA mono.	3.6
Croakers, catfish, perches	40-65	23	PA mono.	4.0-6.5

Table 3.2 Results of energy analysis of non-motorised gillnetting

	GJ	*Annual GER, GJ*
Operational energy requirement	nil	
Fishing gear		
Netting	0.61	
Ropes	3.752	
Lead sinkers	0.324	
PVC floats	0.405	
Subtotal	5.091	**5.091**
Vessel	0.554	**0.055**
Total		**5.146**

Table 3.3 Results of energy analysis of stake net operations

	GJ	*Annual GER, GJ*
Operational energy requirement	nil	
Fishing gear		
Ropes	0.738	
Netting	0.082	
Stakes	1.200	
Subtotal	2.020	**2.02**
Vessel	1.09	**0.11**
Total		**2.13**

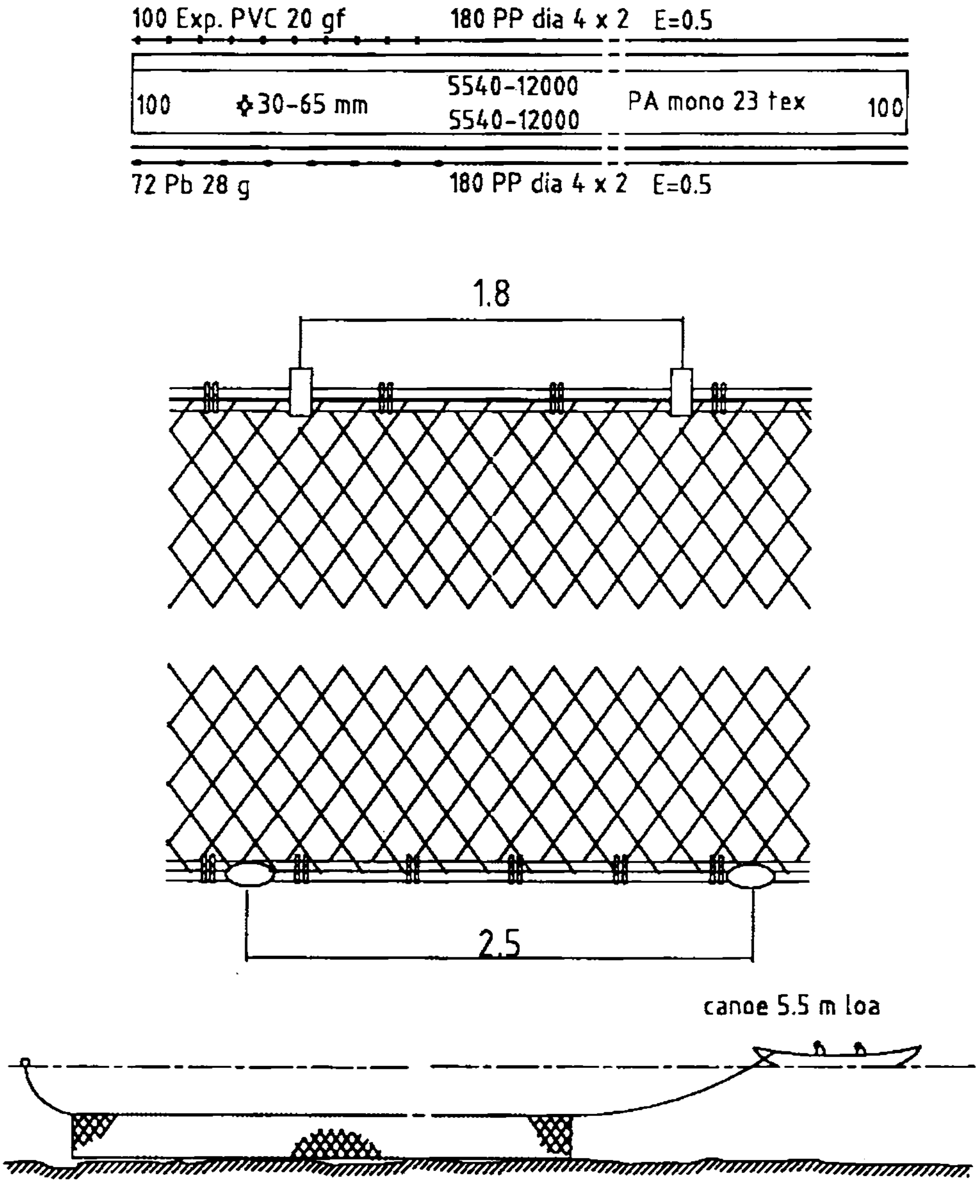


Fig. 3.1 Design of gill nets operated from traditional non-motorised crafts

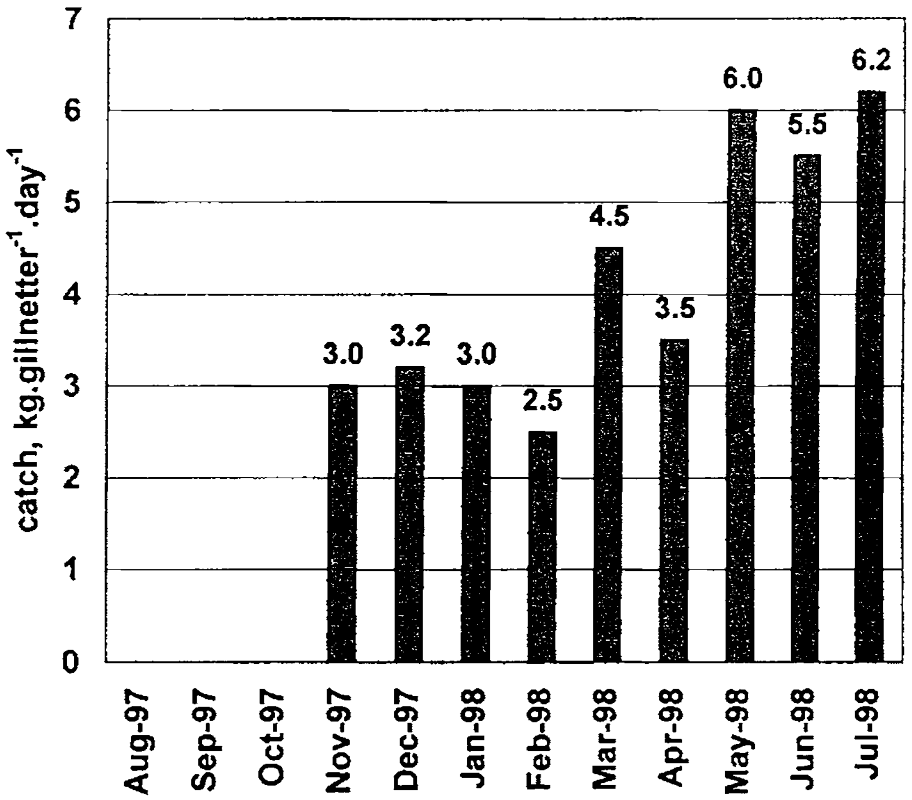


Fig. 3.2 Mean catch.day^{-1} of traditional non-motorised gillnetters

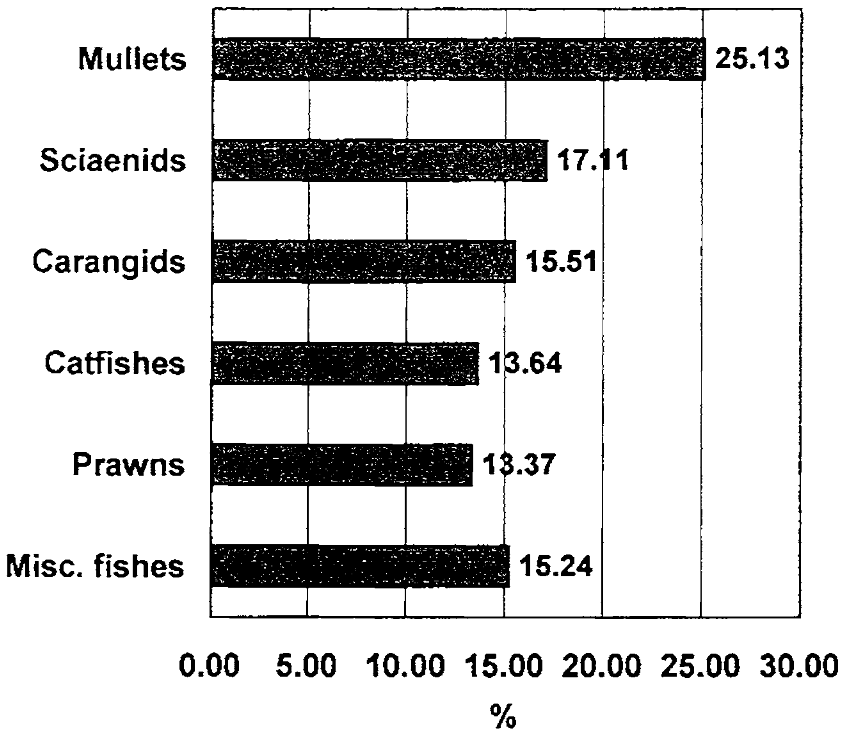
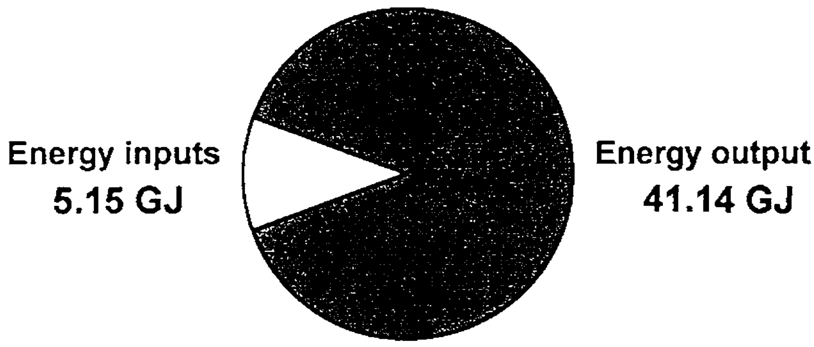


Fig. 3.3 Catch composition of traditional non-motorised gillnetters



GER.t $fish^{-1}$, GJ	=	0.61
Energy efficiency ratio	=	8.01
Energy intensity	=	0.125

Fig. 3.4 Results of energy analysis of traditional non-motorised gillnetters

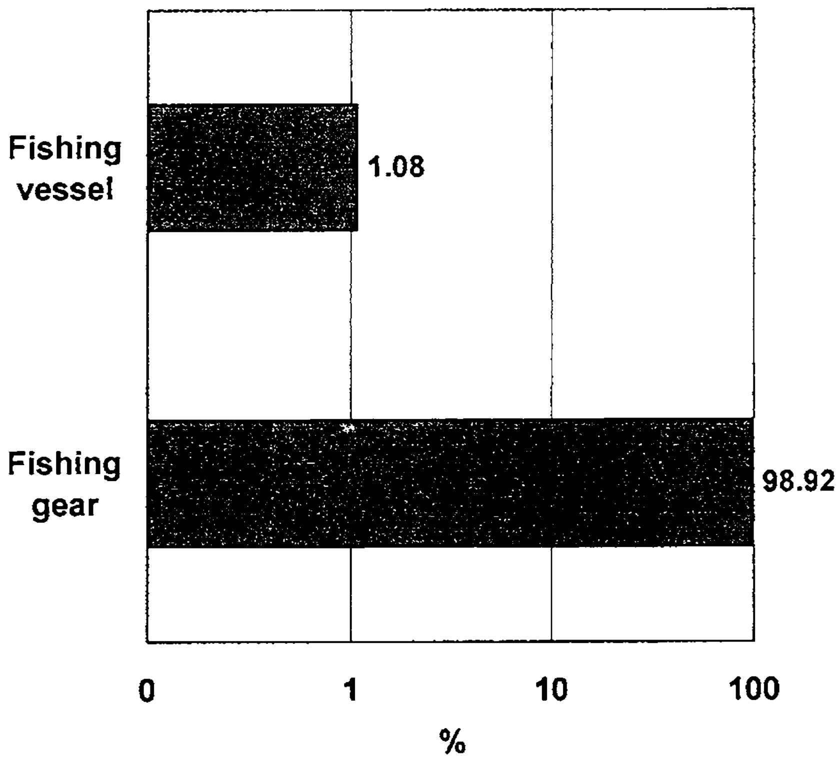


Fig. 3.5 Percentage contribution of energy inputs to GER of traditional non-motorised gillnetters

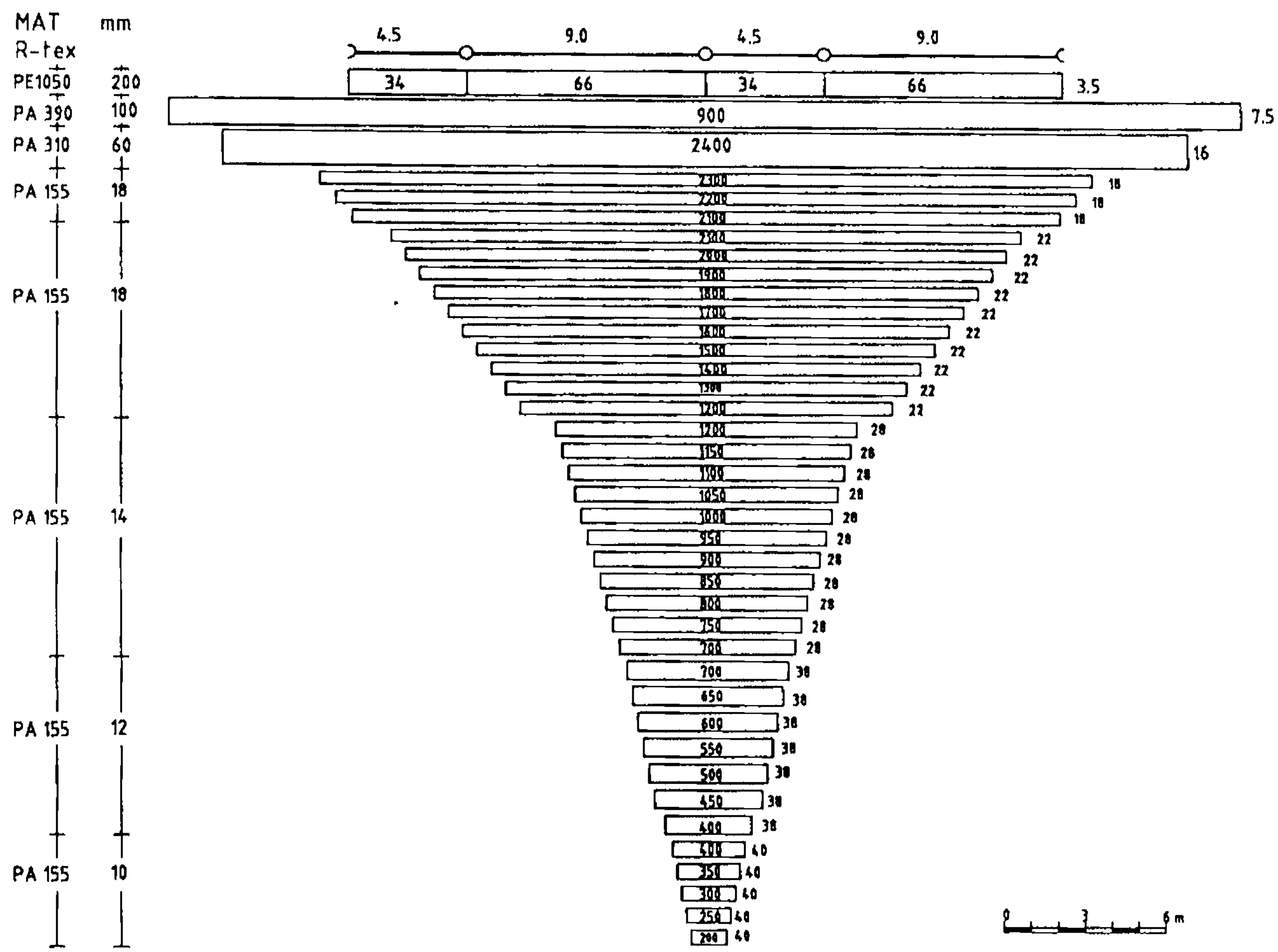


Fig. 3.6 Design of stake net

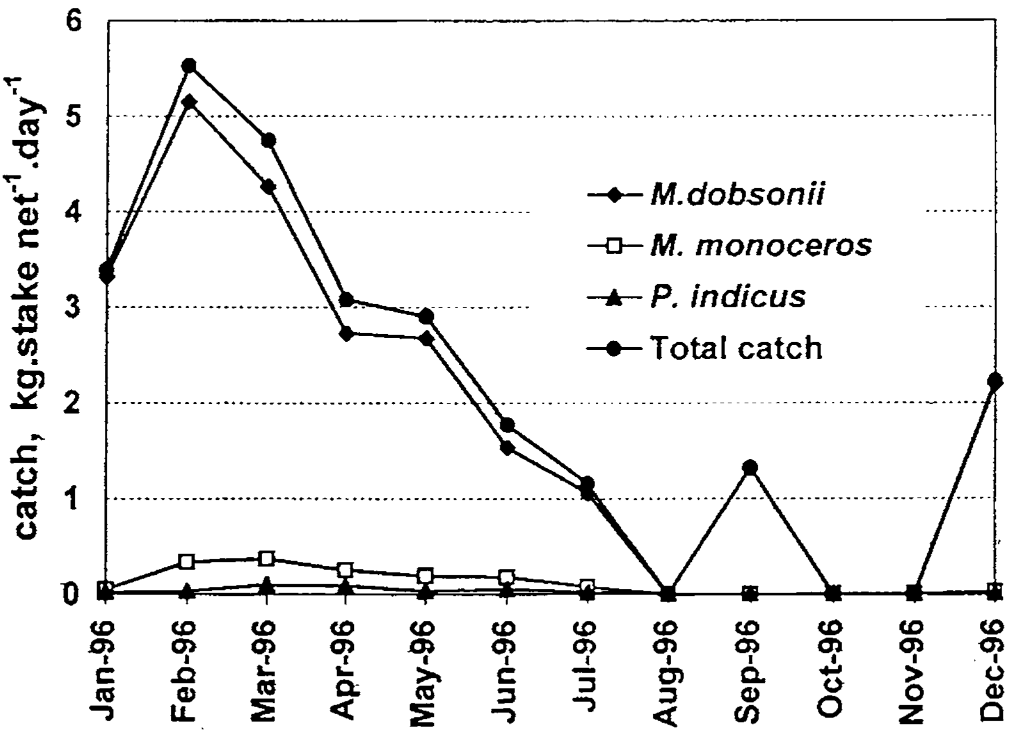
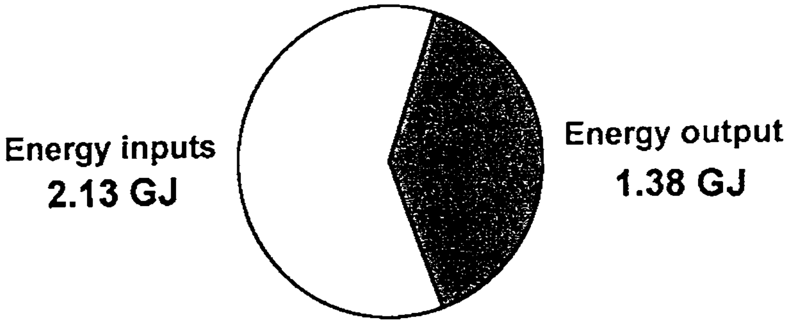


Fig. 3.7 Mean catch.day^{-1} of stake nets



GER.t $fish^{-1}$, GJ	=	5.19
Energy efficiency ratio	=	0.65
Energy intensity	=	1.54

Fig. 3.8 Results of energy analysis of stake net operations

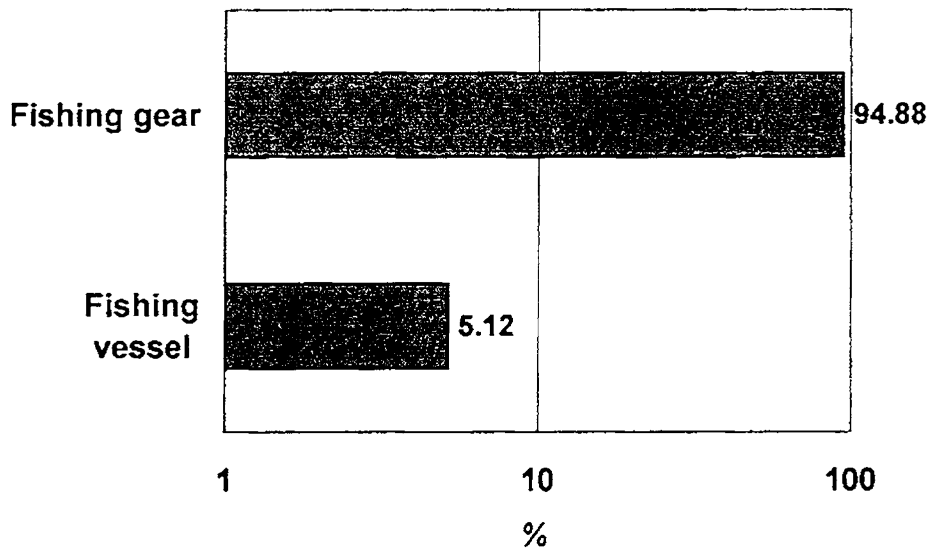


Fig. 3.9 Percentage contribution of energy inputs to GER of stake net operations

Chapter 4

Energy Requirement in Selected Fish Harvesting Systems in the Traditional Motorised Sector

Contribution of non-motorised traditional sector in the marine fish landings of India had been 0.401×10^6 t in 1991 and 0.445×10^6 t in 1996, forming 18.6 % of the total marine landings. Its contribution to the total marine landings remained more or less the same over the years (Sathiadhas 1998). Average catch per trip of motorised fishing units varied from 126 to 190 kg, during 1991-95. The number of motorised fishing crafts in India, is estimated to be 32,000 and the total capital investment on fishing implements in this sector, is about Rs. 4560 million (Sathiadhas, 1998; Vijayakumaran & Haridas, 1998).

The first attempt to motorise traditional fishing craft in Kerala, was made by Indo-Norwegian Project in 1955 (Gulbrandson & Anderson, 1992; Vivekanandan, 1993; Alagaraja *et.al.*, 1994). The project concluded that motorisation of the traditional planked canoe (*vallam*) although technically feasible, was not economically viable at that time. During 1970-

73, Indo-Belgian Fisheries Project made an attempt to motorise log crafts (*kattumaram*) at Muttam in the Kanyakumari District with 25 hp outboard motors. The project, however, failed mainly due to the high cost of the motors and problems of engine service. The efforts of Marinad Fisheries Co-operative Society in Thiruvananthapuram District, for motorisation of country crafts in 1981, also did not gather the desired momentum (Gillet, 1981). During 1981-82, Bay of Bengal Programme investigated the possibility of improving the sailing performance by introducing a new plywood craft (Gulbrandson, 1984). Further attempts to introduce modified and new types of small fishing crafts in the State of Kerala, were made during 1989-90 under an FAO funded Technical Co-operation Programme (Gulbrandson & Andersen, 1992).

Growing depletion of the coastal resources, competition with the mechanised fishing boats, increasing fish prices and liberal import policies gave a major boost to the motorisation of traditional crafts, beginning from 1981. Motorisation of the artisanal fisheries has brought about substantial changes in craft, gear and fishing operations. The number of motorised crafts increased from 9914 in 1991 to 13219 in 1998, registering a growth of 33.3 % during this period (SIFFS, 1992; 1999). As on 1998, motorised fishing fleet in Kerala consisted of 5701 plywood crafts (43.1 %), 3841 plank canoes (29.1 %), 3625 dugout canoes (27.4 %), 41 *kattumaram* crafts (0.3 %) and 11 fibreglass crafts (0.1 %). The fishing gears operated by the motorised sector in Kerala are predominantly gill net (55.6 %) followed by mini trawl (13.7 %), trammel net (9.2 %), hook and line (8.3 %), ring seine (7.2 %) and boat seine (6.0 %) (SIFFS, 1999).

The advent of motorisation of artisanal crafts from the beginning of 1980s brought about decisive changes in the traditional sector. It was considered as a major technology change in the traditional sector. Between 1981 and 1986 about 7200 country crafts were fitted with outboard motors. In 1988 it rose to 9000 and in 1990 it went up to 9914. In 1995, it reached 15336. Marine sector has undergone rapid changes with the motorisation of the traditional crafts. Consequent on the introduction of this technology, the average physical output per fisherman and productivity per unit effort have increased. It helped the crafts to reach the deeper waters and led to the increase in volume of landings. Operating cost of the crafts, however, have risen as a result of motorisation (State Planning Board, 1997). There were 11621 outboard motors in 1991, and their number rose to 16466 in 1998 (SIFFS, 1992; 1999). During 1991-95, on an average, 47.1 % (0.263×10^6 t) of the total marine landings in Kerala, was contributed by traditional motorised sector, operating ring seines, gill nets, hook and line, boat seines, mini trawls and other gears (State Planning Board, 1997).

4.1 Mini trawling

4.1.1 Introduction

The introduction of outboard motors in the recent past has transformed the face of traditional fishing activities and has brought about changes in the existing crafts and gears operated in this sector. One of the significant outcome is the facility to drag a mini version of trawl net from the small traditional craft which was modified with transom to facilitate the fitting of an outboard motor. Trawl nets are towed gear consisting of funnel shaped body of netting closed by a bag or codend and extended sides in the front to form wings (Nedlec, 1982; Hameed & Boopendranath, 2000). The mini trawl is usually operated from a single vessel, using a pair of small otter boards as horizontal spreading device. More recently, it is also operated in some areas, from two vessels using two low horsepower outboard motors (Girijavallabhan, 1994).

Tulay & Smith (1982) studied the costs and earnings of mini trawlers operated in the San Miguel Bay in the Philippines. Hameed *et.al.* (1989) described the design, operation and economic performance of mini trawls, operated from Cochin and Munambam, during 1987-88. Nair (1989) reported that about 6,400 t, consisting of predominantly penaeid prawns (73.2 %), and sciaenids (9.7 %), was landed by mini trawlers operating in

Kerala. Girijavallabhan (1994) reported a form of mini trawl operation along south Malabar coast, which is conducted using two traditional motorised boats without using otter boards (pair trawling). Vijayan *et.al.* (1990) developed an improved mini trawl design suitable for traditional motorised crafts, based on comparative fishing trials. John (1996) conducted studies on the economics of mini trawls operated from Chaliyam, Parappanangadi, Ambalapuzha, Valanjavazhi and Azhikode centres, in Kerala.

The number of mini trawl gears in Kerala, during 1991 was estimated to be 1648 (SIFFS, 1992). Their number rose to 4351 in 1998 (SIFFS, 1999), registering an average annual growth rate of 27.3 %. As on 1998, maximum number of mini trawls were in operation in Alappuzha (36.5 %), followed by Malappuram (24.5 %), Kozhikode (20.9 %), Kannur (10.7 %), Thrissur (4.3 %), Ernakulam (2.4 %), Kollam (0.5 %), and Kasaragod (0.3 %). The number of plank canoes with transom, from which mini trawls are generally operated, are estimated at 2042. Mini trawls are operated from plank canoes and plywood boats fitted with outboard engines, in the coastal waters. Plank-built canoes with transom are the dominant craft used for mini trawl operations in Alappuzha, Thrissur and Ernakulam. In Kannur, Kozhikode and Malappuram, mini trawls are generally operated from plywood crafts. The contribution of mini trawl to the marine landings in the State, has steadily increased from 3013 t in 1991 to 12584 t in 1995, registering an annual growth rate of 79.4 % (State Planning Board, 1997). Average contribution of mini trawls to the total marine landings of the State, during 1991-95, has been about 8200 t which formed 1.5 % of the total landings.

The number of mini trawls in Ernakulam were only 2, in 1991 (SIFFS, 1992). However, their number rose to 104 in 1998 (SIFFS, 1999), with major concentrations in Njarakkal (40 nets) and Chellanum Villages (26 nets), followed by Saudi (9 nets), Edavanakkad (9 nets), Puthenkadappuram (6 nets), Cherai (5 nets), Pallipuram (2 nets) and Veliyathanparambu (1 net).

4.1.2 Description of the fishing gear

Design drawing of mini trawl is given in Fig. 4.1 and details of rigging and otter boards are given in Fig. 4.2. Mini trawl has a two-panel construction. Polyethylene netting of R190tex and R370tex are used for net body and codend, respectively. Mesh size varied from 22 to 20 mm in the wings, net body and codend. Design differed in certain details from the description given by Hameed *et. al.* (1989) and Vijayan *et.al.* (1990). The head rope and foot rope of the mini trawl were generally of 11.0 and 12.4 m long, respectively. The wing-ends were connected to the otter boards by means of double bridles of 9.5 m polypropylene ropes (10 mm dia). Seven plastic floats of 100 mm dia were attached along the head rope for buoyancy and about 7 kg of iron link chain was attached to the foot rope as sinkers. Polypropylene ropes (10 mm dia) of 140 m length were used as towing warps. The otter boards used were of flat rectangular type, weighing 16 kg each and constructed of wood and steel (Fig. 4.2).

4.1.3 Description of the fishing craft

Mini trawls in the study area, are operated from plank-built canoes with transom. The size of the crafts varies from 6.1 to 7.6 m L_{OA}. The plank-built canoes with transom made their first appearance in 1980s. During the initial years, it was made by splitting a large plank-built canoe into two and providing each with a transom. However, in recent years, plank canoes with transom are being fabricated afresh, instead of splitting up an existing large plank-built canoe. The craft is constructed by seaming together appropriately shaped planks of Jungle jack (*Artocarpus hirsuta*) by means of coir ropes. Fish oil, black oxide and natural resins are used for preservative treatment and water-proofing. The transom is provided with a V-cut in order to facilitate the fixing of outboard motor. A wooden rod of about 2.5 m long and 100 mm dia was fastened to the craft, a little over 2 m, ahead of the stern. Two iron rings of 100 mm dia, one each fitted to the distal ends of the rod, served as towing blocks, during the operation of the gear.

The outboard motors used for propulsion, were of water cooled, two-stroke, twine engine type, generating a maximum output of 12 hp (8.8 kW) at 5,500 rpm. The gear ratio is 2.08 (27:13) and propeller size is 3x234 mmx203 mm (No. of blades x diameter x pitch). The engine weighs 37 kg. The engine operates on petrol from a small auxiliary tank up to 1500 rpm, and then automatically switches over to kerosene operation. Technical details of the OBMs are given in Table 8.2.

4.1.4 Fishing operations

Mini trawl fishermen set out for fishing at 05.00 - 05.30 h, in the morning. Generally, 7 fishermen are attached to a mini trawling unit and of them 2-5 fishermen go onboard for fishing. Mini trawls are operated in the coastal waters within the depth range of 5.5 to 27 m. After reaching the ground, the codend is tied and the net, bridles and otter boards are released, followed by warps at a scope ratio of 5 to 15. Normal duration of tow is from 1 to 1.5 h. The fishermen return to the base for marketing the catch, by 13.00 to 14.00 h. This fishing practice is seasonal extending from September to November and again from March to May. Mean number of fishing days per year was 120.

4.1.5 Catch and catch composition

Mini trawling is generally targeted at coastal prawn resources, particularly *Parapenaeopsis stylifera* and *Metapenaeus dobsoni*. Mean catch per year per mini trawler during the period of study was 10.26 t, 48.1 % of which was constituted by prawns, followed by flat fishes (33.1 %), crabs (12.0 %) and miscellaneous finfishes (6.8 %) (Fig.4.3). The mean catch.day^{-1} obtained was maximum during the month of September (160 kg.mini-trawler^{-1}.day^{-1}). During other productive months viz., October- November and March-May, the catch varied from 54 to 84 kg.mini-trawler^{-1}.day^{-1} (Fig. 4.4). There has been no fishing operations during the months of December, January - February and June - August, due to poor availability of prawns in the coastal waters.

4.1.6 Energy analysis

Results of energy analysis is given in Fig. 4.5 and Table 4.1. Total embodied energy inputs into mini trawler operation was estimated to be 207.04 GJ and the energy equivalent of fish produced was 38.62 GJ. The GER.t $fish^{-1}$ for mini trawling was estimated to be 20.2 GJ, which is quite high for a coastal fishing operation. Kerosene constituted 86.24 % of the GER, followed by petrol (8.39 %), and lubricating oil (3.30 %), fishing gear (1.4 %), outboard motor (0.58 %) and fishing craft (0.06 %) (Fig. 4.6). Energy ratio for mini trawling was 0.19 and energy intensity 5.36 (Fig. 4.5).

4.2 Ring seine operations

4.2.1 Introduction

Ring seines, otherwise known as mini-purse seines, are a group of lightly constructed purse seines adapted for operation in the traditional motorised sector. They are classified as surrounding nets or encircling nets and fall under the group of active fishing gears (Nedlec, 1982; Brandt, 1984; Sainsbury, 1996; Hameed & Boopendranath, 2000). Surrounding nets are roughly rectangular walls of netting rigged with floats and sinkers which after detection of the presence of fish are cast to encircle the fish school. In purse seines and ring seines which are the predominant types of surrounding nets, the bottom of the net is closed after encircling the fish school, by a purse line which prevent the fish from escaping downwards by diving. Purse seining is one of the most advanced and efficient fishing method for capture of shoaling pelagic species (Ben-Yami, 1994b).

Intensive motorisation of the traditional crafts which began in earnest, from 1982 onwards, in Kerala State, paved way for the introduction of innovative and efficient fishing techniques such as ring seining in the traditional fishery sector. Central Institute of Fisheries

Technology (CIFT), Cochin developed and introduced a mini-purse seine, for operation from traditional motorised craft, during 1982-83 (Panicker *et.al.*, 1985). This gear had an overall dimension of 250x33 m and was fabricated of polyamide knotless netting of 18 mm mesh size. This development has offered an efficient alternative gear for operation from the traditional boat seine craft *thangu vallam*. Parallel innovations have taken place in the traditional motorised sector, around this period, leading to the development of a number of variations of ring seines (Rajan, 1993; Edwin & Hridayanathan, 1996; SIFFS, 1997).

Different aspects of ring seine fishery of Kerala have been studied by Anon (1991), Rajan (1993), Nayak (1993), Achari (1993), Sathiadhas *et.al.* (1993), Alagaraja *et.al.* (1994), Balan & Adrews (1995), Edwin & Hridayanathan (1996), and others. Edwin (1997) conducted detailed investigations on the catch and effort, energy utilisation pattern, gear selectivity, economic efficiency and management aspects of ring seine fishery of south Kerala coast. SIFFS (1997) discussed the origin and distribution of ring seines, variation in design and fishing operations and impact of ring seines on artisanal fish production. The contribution of ring seines to the average total marine fish landings in the state, during 1991-95, has been estimated to be 0.19×10^6 t (34.0 %) (State Planning Board, 1997).

A detailed census of the ring seine units operating along the Kerala coast has been conducted by South Indian Federation of Fishermen Societies, Thiruvananthapuram, in 1991 and again in 1998 (SIFFS, 1992; 1999). The total number of ring seine nets in Kerala was estimated to be 2259, in 1991. Their number increased slightly to 2277, in 1998. The number of ring seine units in Kerala, in 1991, was 1738 of which 3.0 % were operated from plywood crafts, 16.2 % from dugout canoes and 80.8 % from plank canoes. The 1998 census showed a reduction of 5.9 % in the number of ring seine fishing units. A total of 1636 ring seine units were available in 1998, constituted by plank canoe based (75.1 %), plywood craft based (15.1 %) and dugout canoe based (9.8 %) units. A significant development is the increase in the number of plywood crafts and reduction in the number of dugout and plank canoe based units. Of the 1636 ring seine units, the maximum number is operated in Alappuzha District (40.3 %), followed by Malappuram (12.5 %), Kozhikode (11.7 %), Kasaragod (9.5 %), Thrissur (7.9 %), Kollam (7.8 %), Ernakulam (5.5 %) and Kannur (4.8 %).

Ring seines are operated from plank-built canoes (*thangu vallam*) or from dugout canoes. More recently they are also operated from plywood crafts. Ring seines operated from plank canoes or plywood crafts targeted at sardines and mackerel, with a mesh size of 18-22 mm are called *ring vala*. A smaller ring seine targeted at small sized species such as anchovies, with a mesh size of 8-12 mm, operated from these vessels in shallow waters, are called *chooda vala*. Ring seines operated from dugout and plywood crafts which are targeted at sardine and mackerel, having a mesh size of 18-22 mm are called *rani vala* and those with smaller mesh size (8-12 mm) targeted at anchovies are known as *mandu vala*. Dugout canoe ring seine units are generally restricted to Kasaragod, Kannur and Kozhikode Districts and the plank-built canoe ring seine units are distributed in Alappuzha, Thrissur, Malappuram and Kozhikode.

Length overall of plank canoes (*thangu vallam*) used for ring seining range from 12.2 to 21.3 m, from Kollam to Kozhikode. Various combinations of out board motors (OBMs) are used for powering the craft such as 22+22 hp, 40+22 hp, 40+22+22 hp, 40+40+22 hp, 40+40+40 hp. Crew size varies from 15 to 35, depending on size of the boat. Plank canoes of smaller size (12.2 to 17.7 m L_{OA}) fitted with 22+12 hp OBMs, with a complement of 8-10 crew members are used as carrier crafts. Plywood crafts of 12.2 - 17.4 m L_{OA} fitted with 12+22 hp, 22+22 hp or 22+40 hp OBMs are used for ring seine operations in Malappuram, Kozhikode and Kannur Districts. Smaller plywood crafts (9.1 -12.2 m L_{OA}) or large dugout canoes (9.1-10.7 m L_{OA}) fitted with 12 or 22 hp OBMs are used as carrier boats, in this area. Large dugout canoes of 9.1-10.7 m L_{OA}, fitted with 22+12 hp OBMs, and having a crew complement of 8-9, are used for ring seining in Kasaragod.

Ring seines for sardines and mackerel (*ring vala*) with a float line length of 450-1000 m and depth of 75-90 m are operated from large plank-built canoes (17.7-21.3 m L_{OA}; 22+22 hp, 40+22 hp, 40+22+22 hp, 40+40+22 hp or 40+40+40 hp) and plywood crafts (12.2-17.4 m L_{OA}; 12+22 hp, 22+22 hp or 22+40 hp). Smaller ring seines with a floatline length of 300-400 m and depth of 50-70 m are operated from plank-built crafts of 12.2-17.7 m (22+22 hp or 40+12 hp). *Chooda vala* of 150-250 m x 30-50m are used as a subsidiary gear for anchovies, from the preceding crafts. *Rani vala* of 250-300 m x 30-40 m, targeted at sardines and mackerel are operated using 3-4 dugout canoes (9.1-10.7 m L_{OA}; 22+12 hp) or a large plywood craft (12.2-17.4 m L_{OA}; 12+22 hp/22+22 hp/22+40 hp). *Mandu vala* of 150-250 m x 20-30 m targeted at anchovies and other small sized shallow water resources are operated with 2 dugout canoes. A recent development in the plank canoe and plywood craft operations, is the introduction of purse line winch powered by diesel engine and the introduction of inboard diesel engine (89-99 hp) for *thangu vallam*

4.2.2 Description of the gear

Design of a typical ring seine operated for sardine and mackerel, in the area of observation (Chellanum - Saudi, Ernakulam Dist.) and details of its rigging are given in Fig. 4.7 and 4.8, respectively. 48 units of ring seines were in operation in the study area, during the period of observations.

Dimensions of the ring seine: The dimensions of the ring seines for sardine and mackerel, from plank-built canoes, has been reported to vary from 300 to 1000 m in length and from 50 to 90 m in depth (SIFFS, 1999). The ring seines surveyed in the area of study, has a float-line length of 585 m and a hung depth of 58 m.

Bunt: This is the section of netting where catch is concentrated prior to its removal by brailing into the vessel and is the last part of the net to be hauled in. Netting used for bunt should be stronger and made of thicker twines than other parts. Polyamide netting of R100tex with mesh size of 20 mm is used in the bunt area. The bunt is placed at the centre of the wall of netting, in ring seines.

Main body: This is the largest part of the net extending from the bunt which facilitate surrounding of the fish shoal during operations. It is constructed by joining together large sections of netting of mesh size appropriate for the target species. Relatively thinner twines are used in this section in order to reduce the hydrodynamic resistance and increase the sinking speed during setting. The main body of ring seine was fabricated of polyamide netting of R75tex with 20 mm mesh size.

Selvedges: Selvedge consists of a few rows of meshes of thicker twine and larger mesh size, provided along the upper, lower and side edges of the net body in order to protect the net from damages during operations. Selvedge along upper and lower edge is of polyethylene netting of 50 meshes in depth, with twine size of R370tex and mesh size of 20 mm. An additional selvedge of 8 meshes in depth, 80 mm mesh size and R700tex polyethylene netting has been provided along the lower edge, after the lead line. Rectangular pieces of the same material are provided on either side of the seine.

Float line, lead line, side ropes: The upper selvedge is attached to the float line and the lower selvedge to the lead line. Hanging ratio is 0.72 along the float line and 0.78 along the lead line. Selvedges on the sides are attached to side ropes. Polypropylene ropes of 8-10 mm dia are used for this purpose.

Bridles and tow line: Bridles are ropes attached to the float line and the lead line on either end and are connected to a tow line of sufficient length to facilitate setting and hauling operations.

Pursing arrangement: Purse line is used to close the bottom of the purse seine after surrounding the fish shoal. The purse line passes through purse rings attached to the lead line by short lengths of ropes. The purse line must have good abrasion resistance and high breaking strength and its length is roughly 1.5 times the length of the purse seine. Purse line used in ring seines is polypropylene rope of 24 mm dia and 700 m in length. Purse rings are made of corrosion-resistant material such as brass. About 60 brass rings of 130 mm outer dia , weighing 500 g each are used in each net.

Floats and sinkers: Lead sinkers of 200 g each are attached to the lead line to attain about 0.7 $kg.m^{-1}$. Total buoyancy of the floats is maintained at 1.5 to 3.5 times the total under-water weight of the purse seine net and its appurtenances. About 3030 plastic floats of size 85x60 mm are used as buoyancy elements.

4.2.3 Description of fishing crafts

In the area of observations, ring seines are operated from plank-built canoes known as *thangu vallam* in vernacular. The length overall of these crafts ranged from 17.7 to 21.3 m, with a modal length of 19.8 m. Carrier crafts used for transportation of catch ranged from 12.2 to 17.7 m L_{OA}, with a modal length of 16.7 m L_{OA}. The *thangu vallam* is manned by a complement of 30-35 fishermen and the carrier craft by 5-8 fishermen.

Edwin (1997) has given a detailed description of the structure and fabrication of *thangu vallam*. The wood used for construction is Jungle jack (*Artocarpus hirsuta*). Other material inputs are coir ropes, coconut fibre, copper tacks, iron fasteners, fish oil, black oxide and resins. Construction of the craft is labour-intensive, using traditional boat building practices, as described for plank canoes, in Section 3.1.3. Electricity is used for drilling holes in order to seam together the appropriately shaped planks constituting the craft, using coir rope.

The ring seine craft is powered by two outboard motors (OBMs). The OBMs used are water cooled, two-stroke, twin engine power plant, generating 22 hp at 5,500 rpm. The engine starts on petrol and automatically changes over to kerosene powered operation, at around 1500 rpm. The gear ratio is 2.08 (27:13) and propeller size is 3 x 234 mm x 229 mm (No. of blades x diameter x pitch). The carrier is powered by OBM of similar design, generating 12 hp at 5,500 rpm. Technical details of popular OBMs used in the study area are given in Table 8.2. A recent development which is gaining momentum, is the introduction of purse line winches to assist pursing operation after encircling the fish school. Second-hand diesel automobile engines of 75 hp, with an estimated useful life time of 8 years are used for this purpose. Another important development is the introduction of inboard diesel engine (ALM 370, ALM 400; 89-99 hp at 2000 rpm) in the traditional plank-built craft, in place of OBMs.

4.2.4 Fishing operations

Ring seines are adapted to the tendency of pelagic fishes to concentrate into dense shoals. Success in ring seining depends on the speed at which the school is encircled, sinking speed of the net and speed of pursing operation. Sardines and mackerels are the main schooling pelagic species targeted by large meshed (18-22 mm) ring seines, operated from *thangu vallam*.

Detection of fish school: An important step in the ring seining is the search operation and detection of schools of the target species, with sufficient catch potential. Fish schools are detected traditionally by colour, texture, turbidity, air bubbles, jumping fish or flocks of birds hovering over the school. In the night, during the dark phase of moon, the schools are detected by the bio-luminescence of the plankton caused by the school movements. Fishermen generally avoid full moon nights for ring seine operations.

Operation of ring seine: Once the school of appropriate size and desirable species is detected, its direction of movement, direction of current and wind are monitored, in order to decide on the best approach to close in and encircle the school. After reaching sufficiently close to the school, a fishermen designated as *chattakaran*, jumps into the water with one end of the towing rope and purse line. The craft is then propelled fast and the school is encircled quickly. When the craft reaches the starting point, the towing rope and the purse line are gathered back from the *chattakaran* and the two ends of the purse line are guided through two pulleys, in preparation for pursing operation. The crew members, numbering 30-35, split into two groups and each group pulls the two ends of the purse line through the purse gallows, quickly, thus effectively closing the bottom of ring seine preventing the escape of fish. In some Districts such as Malappuram and Kozhikode, a marker buoy is used in place of *chattakaran*. Pursing operation is a strenuous process. In recent years, purse winches have been introduced, which are powered by second-hand automobile diesel engines, to assist the pursing operations and to facilitate multiple setting operations. After the pursing operation, the catch is concentrated close to the craft in the bunt portion, by hauling up the main body of the seine from either end. The catch is then brailed into the carrier vessel for transportation to the shore, for disposal. The ring seine vessel may continue with fishing operations or return to the shore. Ring seines are operated up to a maximum depth of 40 m.

4.2.5 Catch and catch composition

Mean catch per ring seiner per year worked out to be 211.9 t of which sardines constituted 44.3 %, followed by mackerel 29.7 %, carangids 11.4 %, penaeid prawns 2.2 %, pomfrets 1.1 % and miscellaneous fish 11.3 % (Fig. 4.9). Mean catch.day^{-1} of ring seine operations were maximum during June-August (1836 - 2452 kg.day^{-1}), followed by September and May (1224-1420 kg.day^{-1}), October-December (595-990 kg.day^{-1}) and lowest during January- April (154-210 kg.day^{-1}) (4.10). Mean number of fishing days per year was 171 .

4.2.6 Energy analysis

Fuel consumption per kg of fish, in ring seine operations were inversely proportional to the volume of fish landed (Fig. 4.11). Fuel consumption per kg of fish landed was lower during the months of May-December (0.06 - 0.24 kg fuel.kg fish^{-1}) and higher during the months of January-April (0.67-0.91 24 kg fuel.kg fish^{-1})

Results of energy analysis of ring seine operations are given in Fig. 4.12 and Table 4.2. Total energy inputs into the ring seine operations were estimated to be 1300.6 GJ. Total energy output by way of fish production was determined to be 931.85 GJ. GER.t fish^{-1} was estimated to be 6.14. Among the operational inputs kerosene constituted 73.4 % of the GER, followed by petrol (12.7 %), diesel (6.7 %) and lubricating oil (2.4 %). Fishing gear contributed 3.8 %, engine 0.8 % and fishing crafts 0.3 % of the GER. Energy ratio for ring seining was 0.72 and energy intensity 1.40. Among the traditional motorised fishing systems, ring seines fared better in terms of energy requirement, compared to mini trawling. Gross non-renewable energy requirement for mini trawling was four times higher compared to ring seining (Fig. 5.41). However, GER value for ring seine operation was higher than that for mechanised purse seining, although both target the same resources. Increased energy requirement compared to mechanised purse seining could be attributed to the poor energy efficiency of two-stroke outboard motors, used for ring seine operations.

Table 4.1 Results of energy analysis of mini trawling

	GJ	*Annual GER, GJ*
Operational energy requirement		
Kerosene	178.56	
Petrol	17.36	
Lub. oil	6.83	
Sub-total	202.76	**202.76**
Fishing gear		
Mini trawl with appurtenances	1.327	**1.32**
Towing warp	0.741	**0.74**
Otter boards	0.446	**0.89**
Fishing craft	1.3	**0.13**
OBM	2.398	**1.20**
Total		**207.04**

Table 4.2 Results of energy analysis of ring seining

	GJ	*Annual GER, GJ*
Operational energy requirement		
Kerosene	954.18	
Petrol	164.95	
Diesel	86.86	
Lub. oil	30.88	
Sub-total	1236.67	**1236.67**
Fishing gear		
Ring seine with appurtenances	99.01	**49.51**
Fishing crafts		
Tanguvallam	24.67	
Carrier *vallam*	18.7	
Sub-total	43.37	**4.34**
Engines		
OBMs	8.49	**4.25**
Diesel engine	46.66	**5.83**
Total		**1300.6**

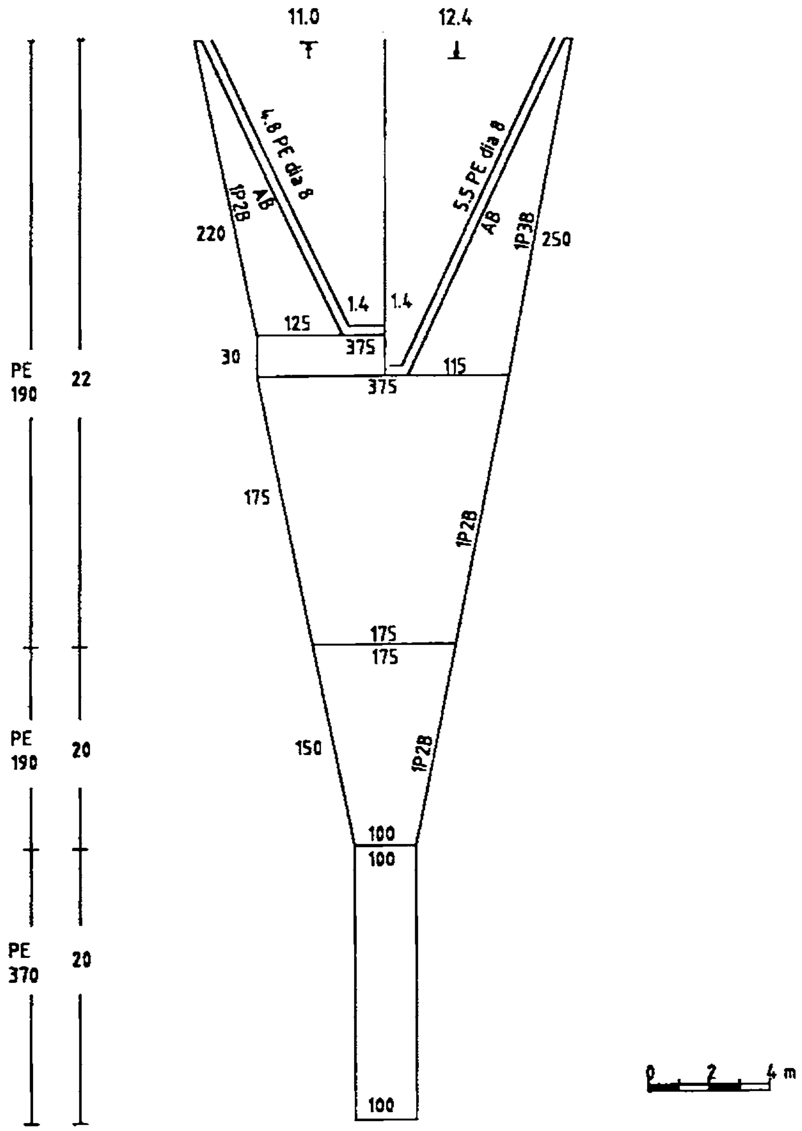


Fig. 4.1 Design of mini-trawl

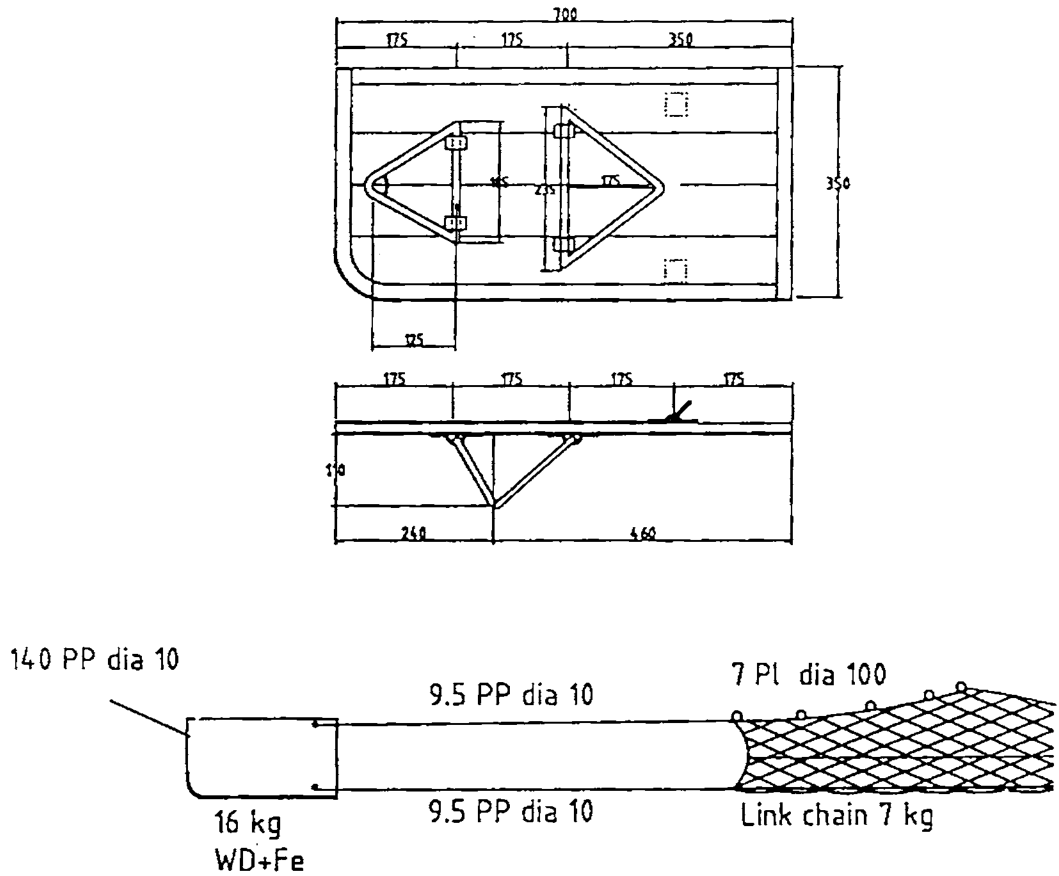


Fig. 4.2 Rigging details of mini-trawl

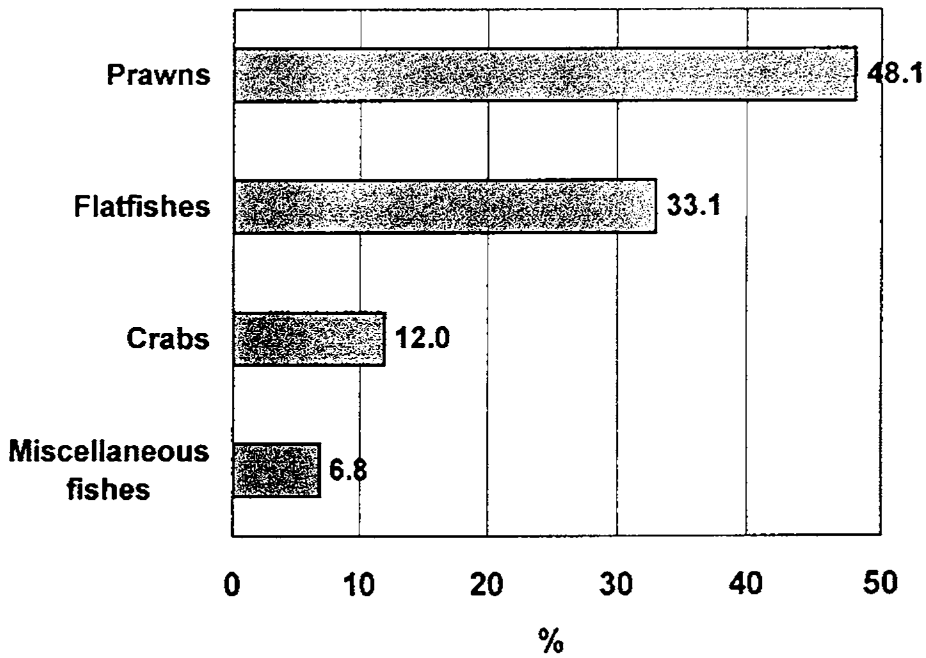


Fig. 4.3 Composition of mini-trawl catches

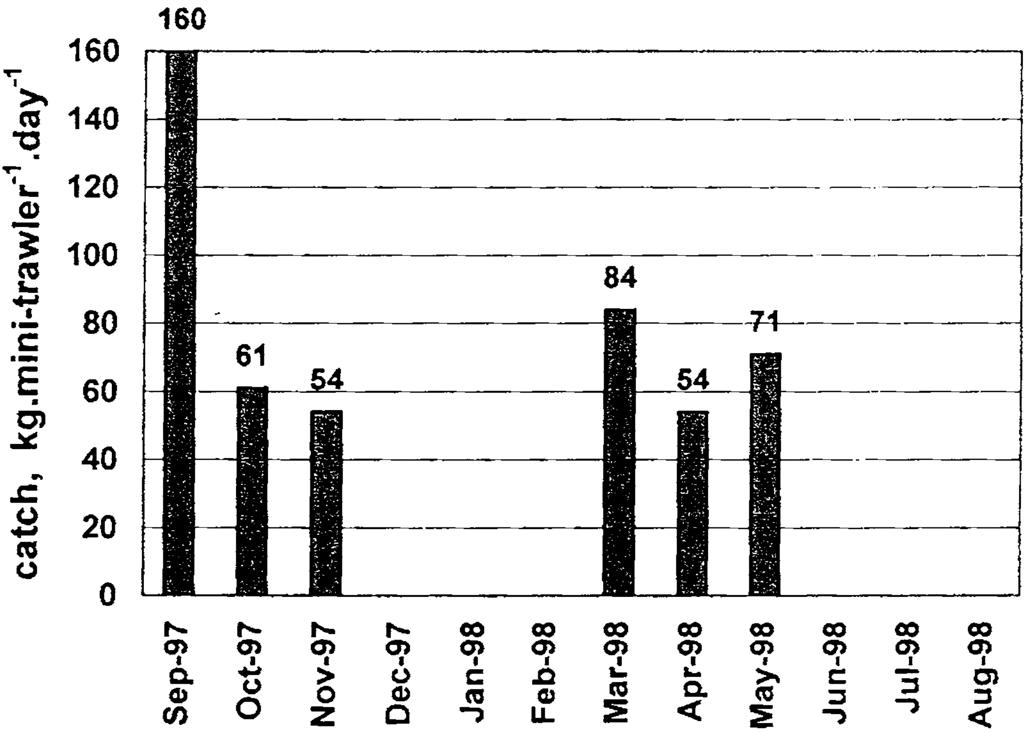
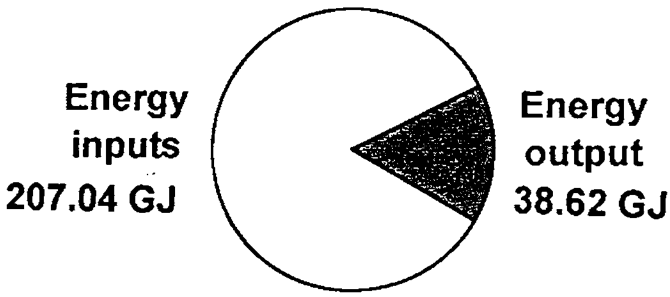


Fig. 4.4 Mean catch.day^{-1} of mini-trawlers



GER.t fish^{-1}, GJ	=	20.18
Energy efficiency ratio	=	0.19
Energy intensity	=	5.36

Fig. 4.5 Results of energy analysis of mini-trawler operations

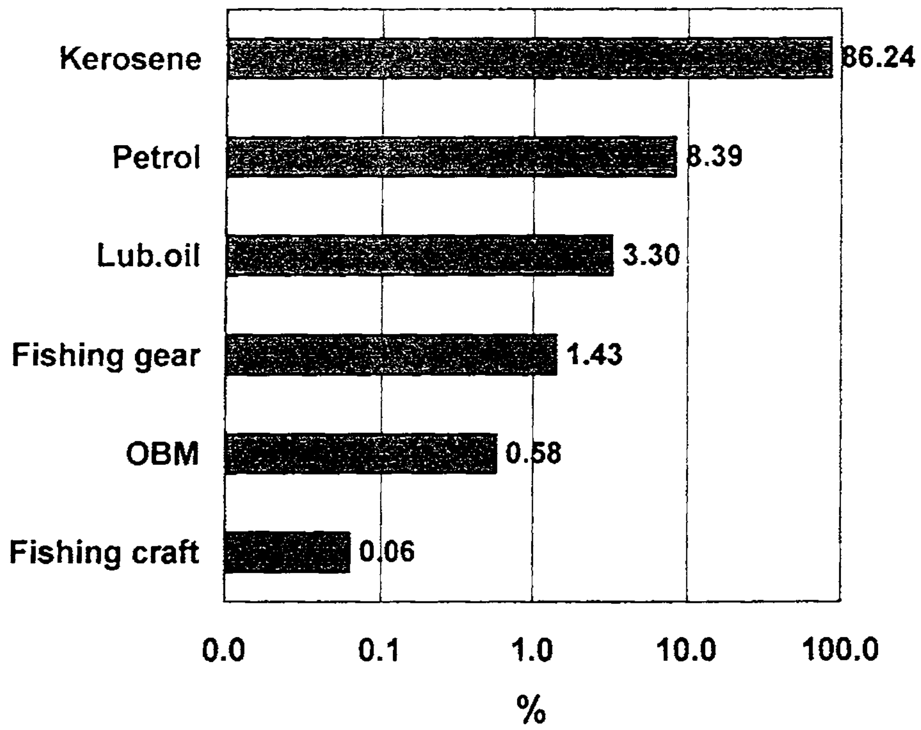


Fig. 4.6 Percentage contribution of energy inputs to GER of mini-trawlers

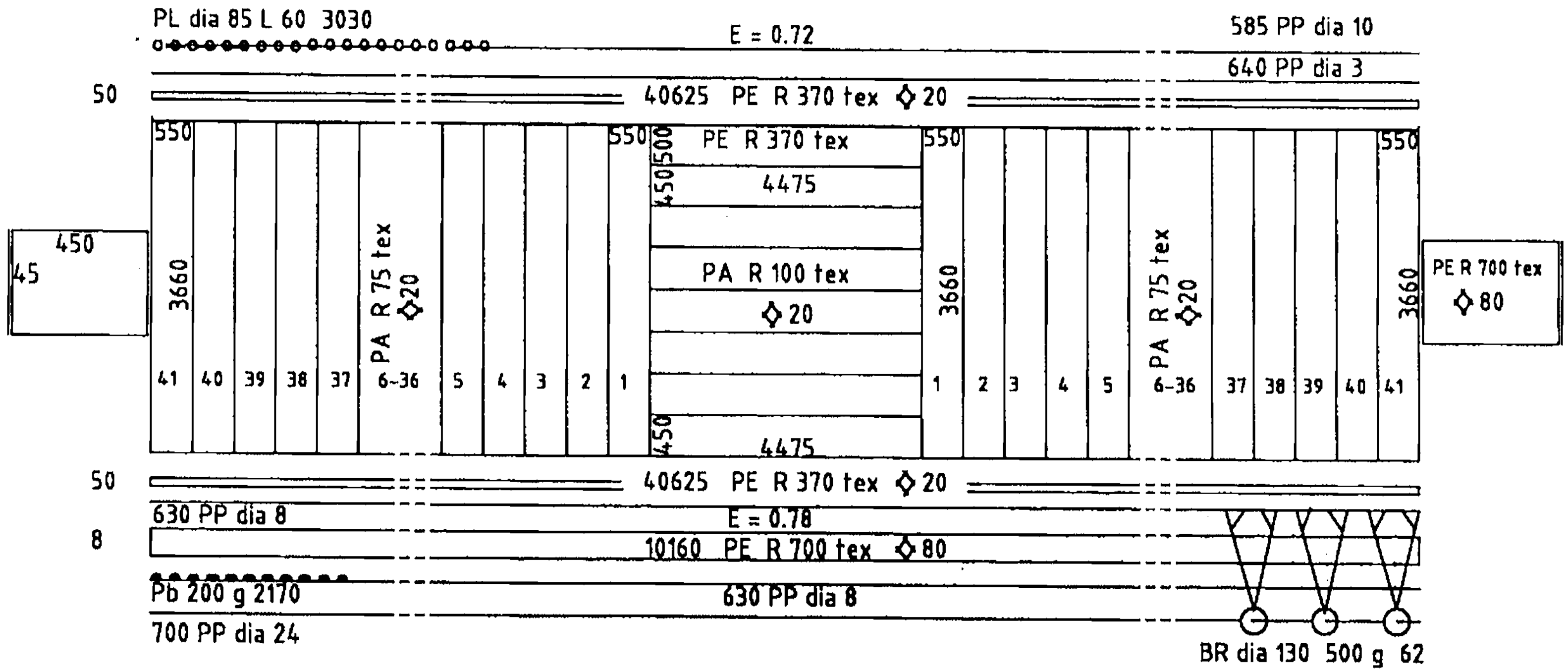


Fig. 4.7 Design of ring seine

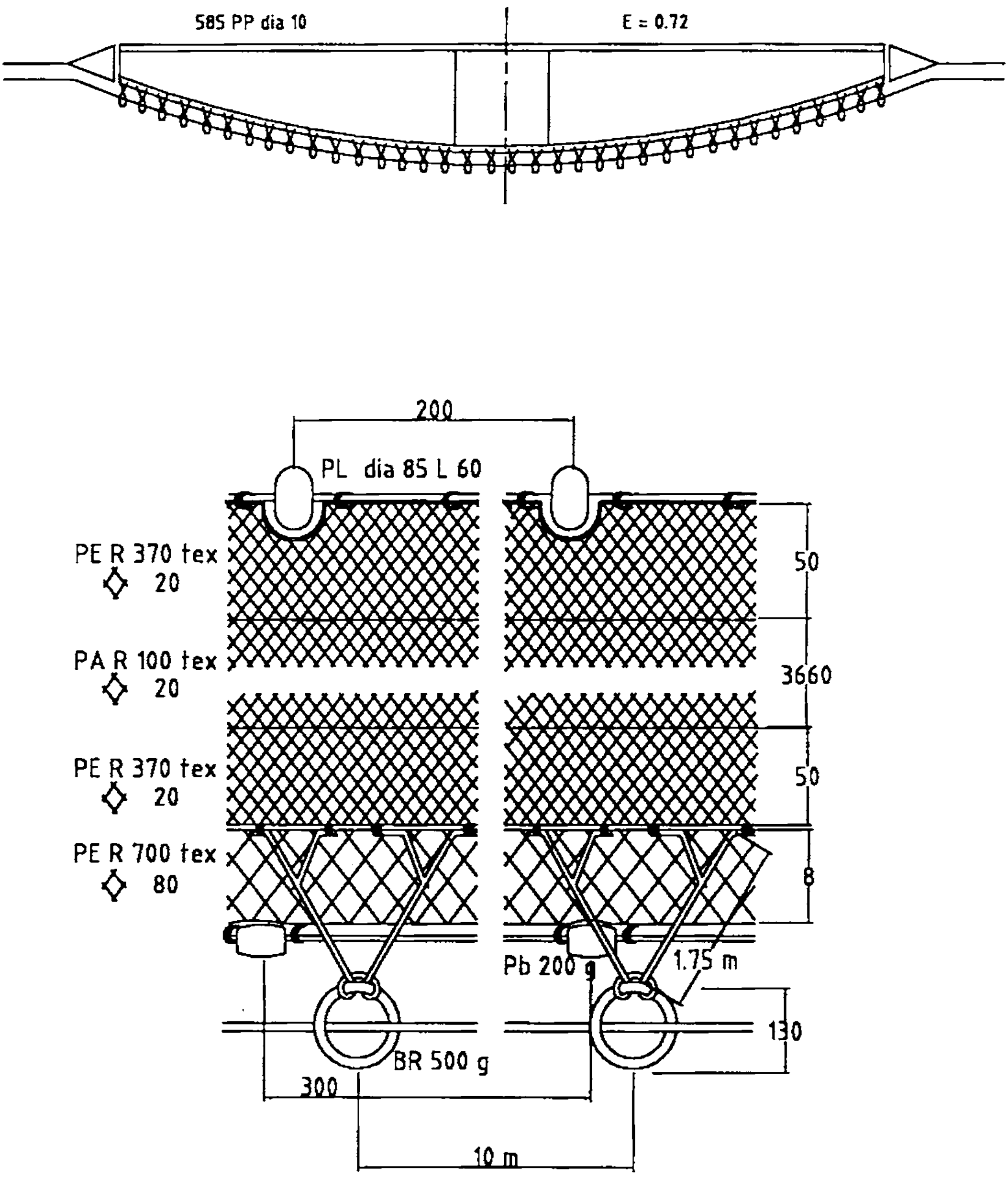


Fig. 4.8 Details of ring seine design and rigging

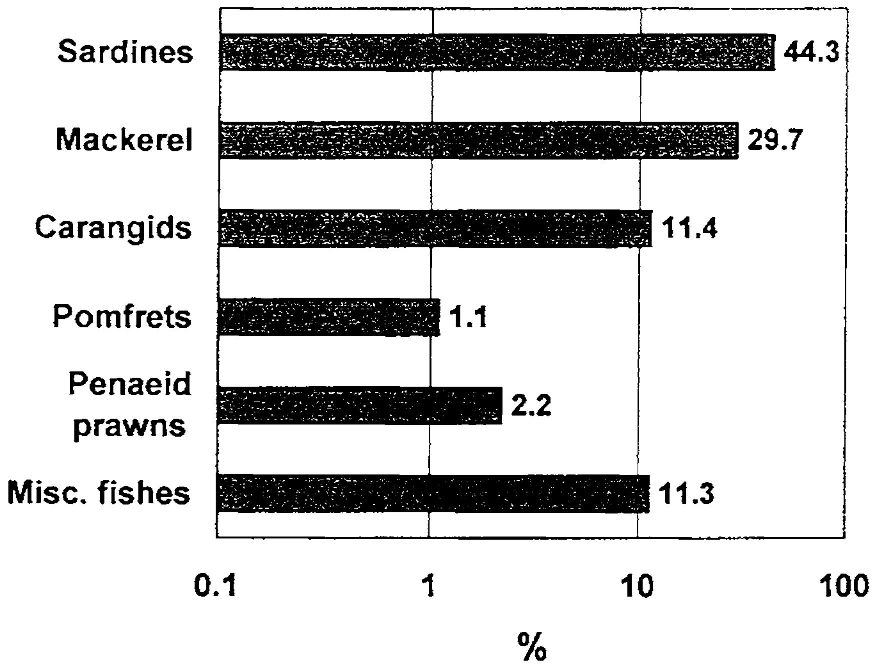


Fig. 4.9 Composition of ring seine catches

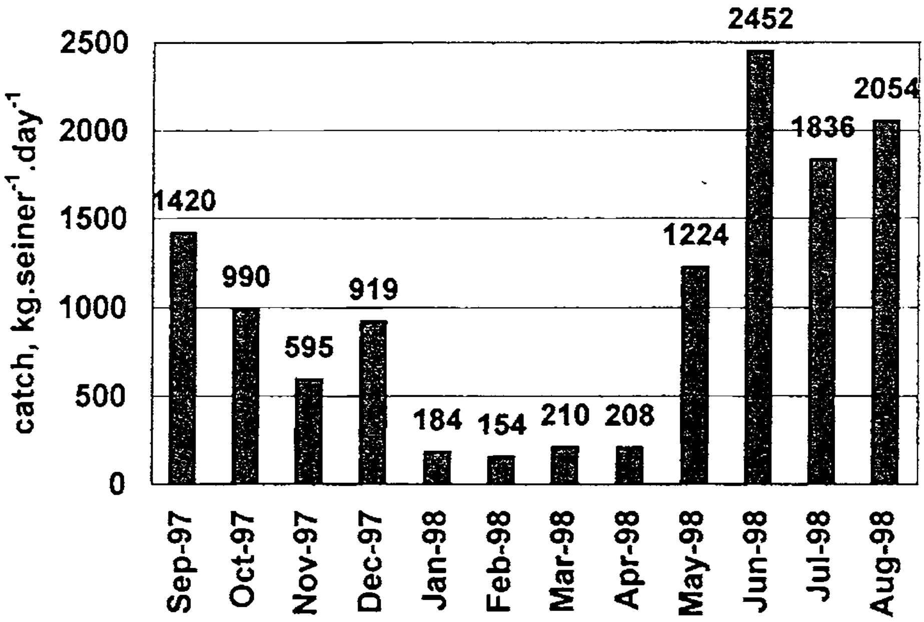


Fig. 4.10 Mean catch.day^{-1} of ring seine operations

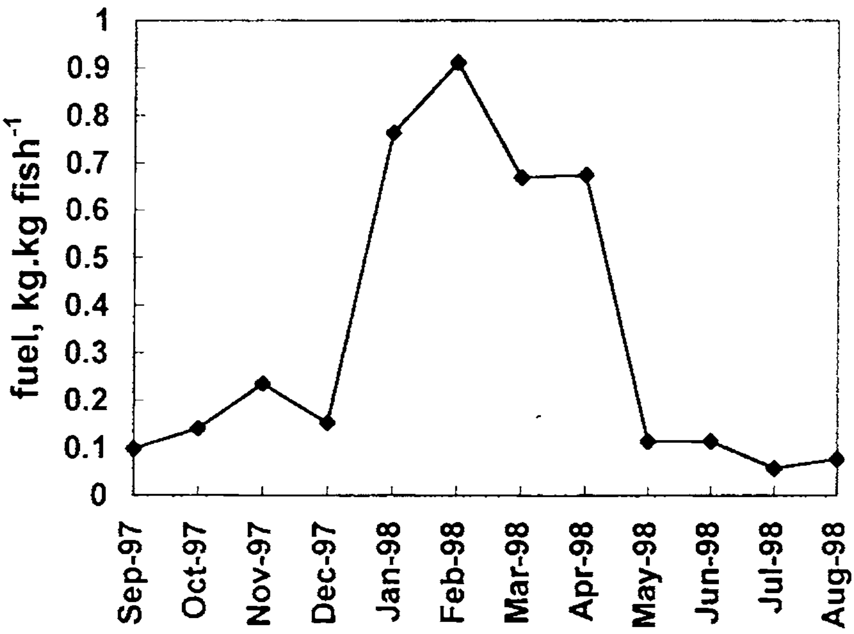
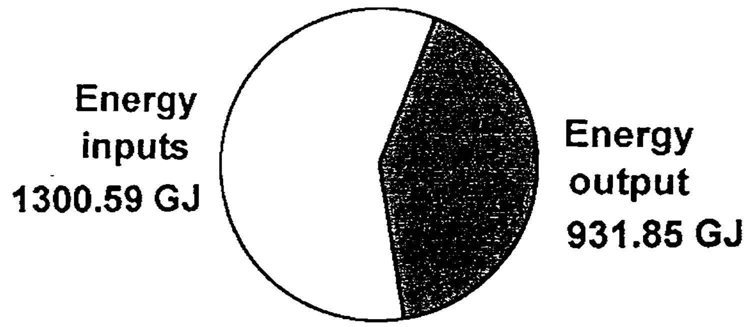


Fig. 4.11 Fuel consumption in ring seine operations per unit volume of fish landed



GER.t $fish^{-1}$, GJ	=	6.14
Energy efficiency ratio	=	0.72
Energy intensity	=	1.40

Fig. 4.12 Results of energy analysis of ring seine operations

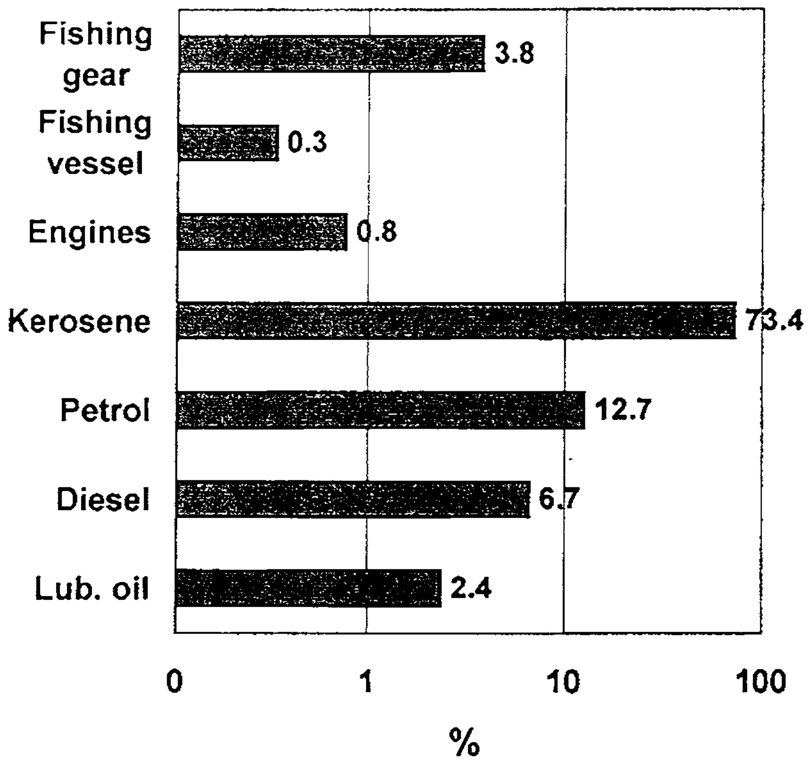


Fig. 4.13 Percentage contribution of energy inputs to GER of ring seine systems

Chapter 5

Energy Requirement in Selected Fish Harvesting Systems in the Small-Scale Mechanised Sector

Mechanisation of fishing craft consists of the installation of engine for propulsion and the use of mechanical devices for handling fishing gear. Among the most significant developments which affected the historical evolution of mechanised fishing are (i) developments in craft technology, (ii) developments in marine diesel engine technology, (iii) mechanisation of propulsion, gear and catch handling (iv) introduction of synthetic gear materials, (v) better integration of knowledge of fish behaviour in fishing gear design and capture process, (vi) developments in acoustic fish detection and satellite-based remote sensing techniques (vii) advances in electronic navigation and position fixing equipment and (viii) advances in onboard fish preservation and storage techniques (Traung, 1955; 1960; 1967; Kristjonsson, 1959; 1964; 1971; Ferno & Olsen, 1994; Sainsbury, 1996)

Fishing craft mechanisation in India progressed through four stages, beginning with motorisation of some of the existing designs of traditional crafts, followed by introduction of mechanised craft, introduction of more specialised crafts, broadening to a full-fledged fishing fleet (Gurtner, 1958). Paucity of traditional craft designs which are amenable to motorisation, led to the introduction of new designs. It was thought that the mechanisation need to be a gradual process allowing enough time for the traditional fishermen to take to more advanced craft designs. Initial attempts were to evolve appropriate designs of beach landing crafts (Gurtner, 1960) as suitable replacement for traditional catamarans and canoes. Further developmental work in this direction was pursued under FAO/SIDA Bay of Bengal Programme for Small-scale Fisheries Development (Gulbrandson, 1984; Ravikumar, 1985; Gulbrandson & Andersen, 1992; Lehtonen & Lund, 1990)

Simultaneous with the evolution of beach landing craft, introduction of small mechanised crafts which operated from harbours and sheltered bays received attention. Many designs of small and medium fishing crafts belonging to this category were introduced into the Indian Fishing industry since 1953. Indo-Norwegian Project introduced some designs in Kerala State. FAO Naval Architects and later Central Institute of Fisheries Technology introduced several standard designs of fishing crafts for different types of fishing operations (Gurtner, 1963; CIFT, 1982). Base of this mechanisation programme was the design popularly known as *Pablo*. Twelve standard designs of fishing boats ranging in size from 7.67 m to 15.25 m , suitable for operation from harbours, creeks and sheltered bays, developed by the Central Institute of Fisheries Technology, Cochin were adopted and popularised by the State Fisheries Departments and private entrepreneurs. Designs for boats for fishing in rivers and reservoirs ranging in size from 6.14 m to 9.21 m; one 11.66 m pole and line fishing vessel; one 18.42 m trawler-cum-carrier vessel and one 17.5 m steel trawler-cum-purse seiner were also developed by the Institute (Anon, 1977; CIFT, 1982).

Trawling as a major fishing method for prawns became popular with the introduction of the mechanised harbour crafts (Miyamoto & Deshpande, 1959; Kurian, 1969). Consequent to the expansion of the shrimp processing industry, interest in the trawling technique increased which resulted in an increase in the mechanised fleet and its capabilities. At the beginning of mechanisation, small mechanised crafts of 9.75 m and 10.97 m were popular and economical for undertaking one day fishing, mainly targeted at shrimp. Later, larger vessels sufficiently powered and equipped to undertake multi-day operations in deeper waters, became popular due to economic advantages. With the increased vessel capabilities, availability of more efficient gear systems, electronic navigation and acoustic fish detection equipment, areas of operations of the mechanised fishing fleet has expanded over the years, resulting in increased production.

Small mechanised sector of Indian fisheries is constituted by a fleet of 47,000. (Vijayakumaran & Haridas, 1998). Estimated capital investment in this sector is Rs. 23880×10^6 (Sathiadhas, 1998), which forms 58.0 % of the total investment in fishing implements in India. The small mechanised fishing fleet increased from about 19000 in 1980 to 47000 in 1997. The small-scale mechanised fleet consisted of 37574 trawlers (80.0 %), 6373 gillnetters (13.6 %), 1219 dol netters (2.6 %), 1118 purse seiners (2.4 %) and 716 other fishing vessels(1.4 %). The annual marine fish landings from the mechanised sector during 1991-1996, ranged from 1.34×10^6 to 1.67×10^6 t, with an average of 1.55×10^6 t. Mechanised sector landed hardly 30 % of the total catch in 1974, which rose to 40 % in 1980 and 68 % in 1997 (Silas *et.al.*, 1976; Sathiadhas, 1998). Annual average per capita production per active fishermen in the mechanised sector increased from 5260 kg in 1980 to 8130 kg in 1997. Manpower employed in mechanised fishery sector of India is estimated at 0.2×10^6.

Annual average landings in Kerala during 1991-95 was 0.56×10^6 t. of which 47.7 % (0.27×10^6 t) was contributed by small-scale mechanised fishery sector. Trawls, purse seines, gill nets and lines are operated from mechanised fishing crafts. Trawlers contributed to an average of 97.0 % of the landings produced by mechanised sector, followed by purse seiners (2.1 %), gillnetters (0.6 %) and liners (0.3 %) (State Planning Board, 1997).

Cochin Fisheries Harbour

The development of landing and berthing facilities in the country followed almost a pattern identical to that of development in the fishing industry. During the Second Five Year Plan, Government of India began to give financial assistance to the State Governments for establishment of fishing harbours and sought assistance of FAO for survey and preparation of feasibility reports for establishment of fishery harbours. During the period from 1955 to 1961, three FAO engineers identified and prepared feasibility reports for as many as 40 fishery harbours and fish landing centres including deep sea fishery harbours. During the Fourth Five Year Plan, the Government of India with the assistance of UNDP established the erstwhile Pre-investment Survey of Fishery Harbours at Bangalore and thus fulfilling the long felt need for a permanent establishment under the

Government of India for Pre-investment Survey and related work in fishery harbour construction.

Cochin Fisheries Harbour is situated at Thoppumpady, on the western side of Thoppumpady-Mattancherry road (Fig. 5.1). Construction of this major fisheries harbour was sanctioned by Government of India during the Fifth Plan, in March 1969, in pursuant of the decision to set up fisheries harbours attached to major ports of the nation. Cochin Port Trust submitted the plan to the Government of Kerala with an estimated initial outlay of Rs. 38×10^6 and the sanction was obtained in June 1971. Construction work began in March 1972 and the port was commissioned in September 1978. Facilities available in Cochin Fisheries Harbour is given in Table 5.1.

The harbour occupies an area of 26.7 acres of land with a coastline of 384 m. An area of 7 acres are utilised for common service facilities, 16.9 acres for industrial plots and 2.8 acres for the slip way facilities. The harbour is well connected to the National Highway No.47 to enable long distance transport services including commodities. The facilities within the fishing port is planned to provide streamlined movement of the fishing vessels in the quay and movement of vehicles and men on the shore side for quick materials handling including commodities.

Cochin fisheries harbour is under the direct administrative control of the Cochin Port Trust. Activities of the fisheries port is controlled through Traffic, Engineering and Administration Departments under the Chief Engineer, in charge of the fisheries harbour. Administration building is situated in the north-west corner of the harbour area.

Landing quay is of 170 m length. Retail fuel outlets are provided at the northern and southern ends of the quay. Adjoining this is an additional berthing quay of 180 m length and 76 m berthing jetty. Piled platform and auction-cum-packing hall occupies 153 m x 18 m, in which an observation cabin and cash collection office are also housed. Auction of the landed fish, icing and packing are carried out in this hall which is provided with protective asbestos roofing. Iced fish are boxed in plastic containers prior to transportation. Three types of vessels, viz., trawlers, purse seiners and gill netters are operating from this harbour. Unloading of these vessels generally take place between 06:00 and 08:00 h for gillnetters; from 13:00 h for trawlers and from 09:00 h for purse seiners.

The fisheries harbour is provided with parking area for transport vehicles, close to the auction cum packing hall; ice plant; canteen; and a number of plots for ancillary industries, facilities, stores and shops. A slip way with side slipping facility enabling simultaneous repair of a number of vessels, is provided in the southern part of the harbour area. This dry repair facility can handle fishing vessels up to 34 m length overall and 300 t displacement.

Cochin fisheries harbour has an alongside berth 350 m long and 75 m jetty for lay-by. During peak season it is observed that 400 trawlers, 25 purse seiners and 100 gillnetters would be making use of the port facilities. Traffic study revealed that 2.5% of the boats will be sick and lay by the wharf. 20 % of the boats would also lay after landing the catch, while the balance go to their jetties. This study also revealed that the arrival of trawlers was from 14:00 h to 23:00 h while that of purse seine boats was from 16:00 h to 23:00 h. Gillnetters generally land their catch during early morning hours. The traffic analysis has shown that the arrival pattern of vessels has Normal distribution. Berth length required for landing is calculated on the basis that each vessel should be able to come along side directly for landing the catch during peak hour. Lay-by length is arrived at based on the criteria that 5 vessels can lay-by abreast. Accordingly, the berth length required at Cochin is 432 m against an actual available length of 425 m. Berth Utilisation Index (BUI) which is a measure of utilisation of port facilities is defined as the ratio of berth length required under ideal conditions to the berth length actually available. At Cochin, the BUI for landing is 2.88 and BUI for lay-by is 0.40. Because, the berth length available for landing is limited to the length of only one auction hall, i.e., 150 m, landing BUI value of 2.88 physically signifies that almost three vessels has to lay side by side before the efficient unloading of the catch can start. This value is unsuitable and needs improvement. As a part of the second stage of expansion, a second auction hall and deep draught jetty for trawlers are proposed. This would change BUI to 2.27 for landing and unity for lay-by (Gopakumar, 1993; Joseph & Deviah, 1993).

Draught along the quay is about 5 m. The port is designed to handle about 900 vessels of up to 16 m L_{OA} (2 m draught) and about 59 vessels of 16-25 m L_{OA} (2-3.5 m draught). During the period of investigations, 1543 mechanised fishing vessels were registered with the Port, of which 931 (60.3 %) were in active operation. These included 72.4 % trawlers, 22.6 % gillnetter-cum-liners and 5.0 % purse seiners (Fig. 5.2).

5.1 Gillnetting-cum-lining

5.1.1. Introduction

Gillnetting is an ancient fishing method practised all over the world. Gill nets are vertical walls of netting kept in the water column by means of floats and sinkers and set perpendicular to the direction of movement of target fish. Gill nets fall under the category of passive fishing gears (Nedlec, 1982). The simplicity of its design, construction and operation and low investment requirements, have made this gear very popular among small-scale fishermen. They are operated in surface, mid-water and bottom layers of water columns in inland, coastal and offshore waters.

Based on the structure and method of capture, gill nets are grouped into simple gill nets, trammel nets and combination gill net-trammel net. Simple gill nets consists of a single wall of netting supported by floats and sinkers. Mechanism of capture is by gilling. The meshes in gill nets are large enough to the allow the fish's head but not the rest of the fish body to pass through. When the fish tries to back out of the net it gets caught behind the gill covers. Trammel nets are generally triple walled with a loosely hung small-meshed panel between two large meshed panels which are tightly hung. The inner wall intercepting a fish passing through the large mesh on the outer wall forms a pouch after passing through the large mesh on the opposite side in which the fish is securely trapped. In combination nets, generally the upper section of the netting panel is constructed as a simple gill net while the lower part is constructed as a multi-walled trammel net, thus increasing the range of capture mechanisms and efficiency. Single walled gill nets with mesh size optimised for target species and size are highly size selective and have significance in conservation of resources. Small meshed gill nets and multi-walled trammel nets are known to be comparatively less selective. Gill nets are suitable for sparsely distributed fish populations.

Based on the method of operation, gill nets are grouped into drift gill nets, set gill nets and encircling gill nets (Nedlec, 1982). Drift gill nets are generally operated in the surface layers for sardine, mackerel, tuna and other larger pelagic species and sharks. Set nets or anchored gill nets are fixed to the bottom or at a distance above the bottom by means of floatation and ballast. In shallow coastal waters they are fixed by means of stakes driven to the ground. Encircling gill nets are operated for catching fish shoals feeding or moving in the surface layers.

Large scale high seas drift gillnetting for surface and sub-surface fishing of tuna has been an important fishing method used internationally in the Pacific, Atlantic and Indian oceans. Such operations using drift nets of a hung length of 30 -50 km and depth of about 11 m, have been reported to be causing incidental mortality of marine mammals and other non-target species such as manta rays and birds for which effective solutions so far do not exist. (Anon, 1992; Hameed & Boopendranath, 2000). Because of these issues, high seas drift gillnetting is either banned or severely restricted in terms of maximum permissible length of the fleet and duration of operation, in recent years. Another ecological issue connected with gill netting which came into vogue with the introduction and widespread use of non-biodegradable synthetic netting material, is the capacity of the lost gill nets to continue to entangle fish and other marine organisms leading to unwanted fishing mortality. This process known as ghost fishing is a negative characteristic of modern gill nets which is otherwise a simple, energy efficient method of fishing particularly suitable for scattered fish populations, requiring low investment on gear and equipment.

In India, gill nets are operated in the traditional sector and in the small-scale mechanised sector. High seas gillnetting is not in vogue in Indian Exclusive Economic zone. Gill net landings account for about 15 %

of the total marine fish landings in India and the trend in production is proportional to the total landings (Luther *et.al.*, 1997). Average landings of gill nets and lines operated in the mechanised fishing fleet of Kerala, during 1991-95, has been estimated to be 2360 t which forms about 0.4 % of the total marine landings from Kerala (State Planning Board, 1997). In the mechanised gillnetters operated from Cochin, drift gillnetting is the preferred method of operation. In addition to gillnetting, long lining for shark and hand lining are also conducted from these fishing crafts, depending on season and requirements. Silas (1984) has studied the drift gillnetting operations off Cochin.

Until 1960s, gillnetting was limited to traditional sector. Mechanised drift gillnetting was introduced off Cochin in 1969. About 90 small mechanised fishing boats, operating drift gill nets were in operation in 1977 and their number gradually rose to 130 with the commissioning of Cochin Fisheries Harbour in 1977 (Silas, 1984). Currently, about 210 mechanised gillnetter-cum-liners are operating from Cochin and landing their catches at the Cochin Fisheries Harbour. It is estimated that 6373 mechanised gillnetters are in operation along the coast of India which incur a capital investment of Rs. 2549×10^6 (Sathiadhas, 1998).

5.1.2 Fishing craft

In the initial stages of introduction of mechanised gillnetting off Cochin, fishing crafts of 6.71 to 9.14 m L_{OA} fitted with 24 to 45 hp inboard diesel engines were used (Silas, 1984). These vessels were equipped to undertake daily fishing and their area of operation was confined to coastal waters generally in the 20-50 m depth zone. With the increasing fishing pressure in the coastal waters and diminishing returns, the area of operation was further extended to deeper waters and bigger vessels equipped for multi-day fishing were introduced. Now-a-days the vessels cruise to distant fishing grounds such as Pedro bank and surrounding areas and in depths beyond continental shelf. The size of the vessels currently undertaking multi-day operations off Cochin varies from 10.98 to 14.93 m L_{OA} and they are equipped with engines of 60 to 106 hp. They are equipped with adequate fish hold capacity and carry ice for fish preservation.

Gillnetter-cum-liners operated from Cochin are all wooden hulled. The mechanised gillnetter-cum-liners are owned by local persons and the fishermen from Kanyakumari, Tamilnadu. Distribution of length classes of gillnetter-cum-liners operating from Cochin is given Fig. 5.3. The predominant length class was 9.1-10.0 m (52.5 %), followed by 10.1-11.0

m (31.3 %). Distribution of installed horse power among gillnetter-cum-liners operating from Cochin is given in Fig. 5.4. Fishing crafts with 89 hp was maximum (52.3 %), followed by <60 hp crafts (36.4 %) and 99 hp crafts (11.4 %).

5.1.3 Fishing Gears

Gill nets

In the initial stages of development of mechanised gill net fishing, smaller vessels undertaking daily fishing, size of the gill nets operated varied from 800 to 1000 m with a hung depth of 4-8 m (Silas, 1984) The nets were constructed of nylon netting with a stretched mesh size of 90 to 180 mm. In recent times, large gillnetters operate gears ranging in size up to 1620 to 1890 m in hung length and 9 to 11 m in depth. Design of a typical gill net in use is given in Fig. 5.5.

Structure of the gill net

Each gill net unit consists of netting panel, float line, gavel lines (side ropes) floats, sinkers, buoys and buoy lines. Netting panel of appropriate dimensions, material, mesh size and twine size constitute the main body of the gill net. The overall dimensions, particularly the hung depth of the gill net unit is determined by the most frequent vertical range of swimming layer of the targeted species, and may vary between 8 and 23 m for different pelagic resources (Hameed & Boopendranath, 2000). Netting material for gill nets should have the lowest possible visibility under water and should be as fine and soft as possible. It should have sufficient elasticity, to hold the fish securely without cutting into the flesh, and high breaking strength. Most common material for gill nets are polyamide multifilament with soft twist (Klust, 1982). Gill nets used in mechanised fishing boats operated from Cochin is made of polyamide knotted netting. The netting is sometimes indigenously treated with tannin extracted from vegetable sources. The hung depth of the net is usually 11 m and total length of the net ranges from 1620 to 1890 m. A few meshes in the upper, lower and side edges are strengthened by using double twine in order to protect the webbing from damage during handling and operations.

Selection of optimum mesh size for the target species and size groups is one of the important design considerations for gill nets. Inappropriate mesh size will lead to inefficient gilling and loss of fishing efficiency. Mesh size is proportional to the modal length of the fish caught by it. The proportionality coefficient varies from 0.1 for slim fish, 0.15 for average shaped fish and 0.2 for tall bodied fish (Fridman, 1986). The twine size is proportional to mesh size. Average value of twine diameter-mesh size ratio is 0.005 (Hamley, 1975; Prado, 1990). Polyamide netting used in gill nets operated from mechanised gillnetter-cum-liners has a twine size of R470tex and mesh size of 70 - 80 mm and twine diameter-mesh size ratio of 0.009 - 0.01.

Netting panel is mounted to the float line according to a hanging ratio. Hanging coefficient is the ratio between hung length of the netting to the fully stretched length of the netting. Hanging coefficient determines the mesh shape and hung depth of the gill net and may vary from 0.5 to 0.8. In the gill nets studied the hanging coefficient was observed to be 0.5 to 0.6 . Float line is polypropylene rope of 8 mm size. Separate lead line is not provided in the gill net described and sinkers are not used. Floats are used to keep the gill net vertically erect during the operations. Floats are attached to the float line by means of polypropylene strops of 2 m length (6-8 mm dia). Expanded PVC floats are used in the gill nets surveyed. About 600 to 700 floats are used to attain a floatation rate of 80 to 100 $gf.m^{-1}$.

Lines

In addition to gill nets, two types of lines are operated from gill netters, depending on season, availability of target resources and market demand, in order to further improve the economics of operations. Long lines are operated for large sharks and hand lines are operated for perches, small tuna and other scombroid fishes.

The principle of capture in line fishing is based on feeding and hunting behaviour of the target species. The fishes are caught and retained individually by hooks tethered to the line. Though the quantity landed is less, catch obtained by line fishing is generally of high quality and commercial value. Environmental impact of lines are considered to be minimal, as there is no evidence of ghost fishing by lost line which is a serious ecological issue in the case of gill nets and gears like traps. Lines are highly species and size specific (Sainsbury, 1996; Bjordal & Lokkeborg, 1998; Hameed & Boopendranath 2000).

Line fishing gear is basically composed of a line and hook. Most important category of line fishing gears are long lines. Hand lines are simple line fishing gears used extensively in small-scale sector. Long lines are passive fishing gear like gill nets. They are suitable for catching scattered and sparsely distributed fish populations. Long lines are operated for both pelagic and demersal fishes and are accordingly positioned in the water column by adjusting the length of the buoy lines. Long lines for pelagic sharks operated from the gillnetter-cum-liners off Cochin are deployed in the surface layers, about 1 - 2 m below the surface..

Long line consists of a mainline to which a number of branch lines, also called snoods or gangions, are connected. A hook is attached to the end of each branch line. Other accessories used are floats, float lines, and sinkers, weights, swivels and connectors.

Drift long line for pelagic sharks

The long line for pelagic sharks used by gillnetter-cum-liners are known as *aricha mattu* in vernacular. Long line gear of smaller size operating up to 200 hooks for catching demersal sharks, used by fishermen off Kanyakumari, has been described by Mohanrajan (1982). Now-a-days fishermen are operating pelagic long lines for sharks. The mainline is made of hard twisted polypropylene rope of 4 to 5 mm dia. Total length of the main line varies from 13500 m to 16200 m. A jerry can (5 litre) float is attached to the main line by short lengths of rope (4.0 m) at intervals of every 5 branch lines and a larger float of 20 litre plastic jerry can with a flag pole is attached at an interval of every 40 branch lines. Branch line interval is usually 27 to 36 m. Branch line consists of multi-strand twisted steel wire 2.5 mm dia and length of 1.8 m connected to polypropylene twisted twine of 3 mm dia and 5.4 m length which is tied directly to the mainline. Indigenously manufactured galvanised iron hook of width 37 mm and length 87 mm are generally substituted for imported *Mustad* hooks as the cost of indigenous hooks are lower by a factor of 6. Use of swivels and connectors are not in vogue in the traditional long line gear used. Design drawing of pelagic shark long line is given in Fig.5.6.

Hand lines

Hand lines are simple fishing gears extensively used in small-scale sector. A hand line consists of a mainline, branch line, hook and sinker. Polyamide monofilament of 0.8 to 1.0 mm dia is used as mainline and polyamide 0.4-0.8 are used as branch lines. Plastic cans (5 litre capacity) are used as improvised spools for coiling the mainline. Multiple hook hand line consists of several hooks connected to the mainline though short lengths of branch lines. Design details of typical multiple hook hand lines operated from gillnetter-cum-liners for small carangids using light attraction (*mayakka* in vernacular), and for perches in rocky terrain (*paru choonda* in vernacular) are given in Figs. 5.7 and 5.8, respectively.

Hand line for small carangids has a monofilament (0.8 mm dia) handling line of 50 m. A weight of 500 g is attached to the distal end of the mainline of 0.5 mm dia and about 7m in length and is directly connected to the handling line. Monoflament branch lines of 0.7 m in length (0.4 mm dia) with hooks on the distal end are attached to mainline at intervals of 30-32 cm, from the distal end. The number of hooks varies but is generally 14. The hook which is 8 mm in width and 21 mm in length (*Mustad*, No. 15) is rigged with glittering plastic yarn to function as artificial baits.

Hand line for perches has a handling line of 90 to 270 m, depending on intended depth of operation and is 0.8-1.0 mm polyamide monofilament. One kg weight is attached to the main line of 0.8 mm dia polyamide monofilament of length 7 m. The mainline is connected to the handling line through a swivel. Branch lines of 3 to 5 m length of 0.5 mm polyamide monofilament is attached to the mainline at intervals of 0.9 m.

The hook used is of steel and has a width of 16 mm and length of 40 mm (*Mustad* No. 9 or equivalent indigenous hook).

5.1.4 Fishing operation

Detailed description of the fishing operations are given in the following sections:

Gillnetting operation

Gill net fishing season generally extends from the end of May to the end of October. The gear is set over the stern or over the side. The buoys and flag poles are tied as required and are thrown overboard manually to either side of the net to prevent tangling. Speed of the vessel while shooting is 1 to 3 knots. After completion of the setting, the end of the net is kept tethered to the boat. The nets are positioned 1 to 2 m below the surface depending on the length of float strops, used.

Drift gill nets are operated in the depth zone of 45 to 55 m, during the night in the gillnetting season (May-October). During other months occasional operations are conducted on new moon days.

Operation of lines

Lines are generally operated from November to April. Intensity of hand line operations are higher during November-February, while drift long lining for sharks intensify during February-March. More recently, however, the drift long line operations are conducted throughout the year, though with less intensity. While operating during the gillnetting season, the gill net is allowed to drift and its position is noted in the Global Positioning System (GPS). The vessel proceeds to do lining operations in an appropriate area, nearby. In recent years, an increasing number of gillnet-cum-line fishermen are in possession of GPS and admiralty charts, which permits them to locate potential fishing zones accurately.

Drift long line for sharks

Shark long lines are set in the evening and hauled up around 06:00 h in the morning. The line is shot from the stern. The first marker buoy with the flag pole, with the attached end of main line are thrown overboard at the outset of operations. The hooks are baited as the line is released. Bait type and quality is one of the critical factors affecting the fishing success in the line fishing operations. It must be fresh with an abundance of odour components and must be firm enough to be retained on the hooks for the entire period of soaking. (Bjordal and Lokkeborg, 1998). The bait most suitable for pelagic shark long lining is the cut pieces of small tuna. The vessel steams at the set course at 3-4 knots during setting operations. Marker buoy and flag poles are connected at the appropriate intervals. After setting, the vessel drift in the proximity of the line until morning hours, at which time the hauling begins. Hauling and removal of catch may continue for 1 to 3 h, depending on the intensity of catch. Area of operation is generally beyond 300 m depth which can be accessed by 6 to 10 hours cruise from the port.

Operation of hand lines

Multiple hook hand line for perches: Hand lines for high value perches (*paru choonda*)are normally operated from the middle of November to April. It is operated during day time. Fishing depth of the baited hooks are close to bottom, with the hooks actually touching the bottom. Most commonly used baits are cut pieces of small tuna and carangids. Rocky uneven areas are most suitable for the operation of the gear, as the target species are generally associated with these grounds. Perches which include large sized fishes such as *Epinephelus* spp., *Lethrinus* spp. *Lutjanus* spp. and *Pristipomoides* sp. are known to inhabit the uneven depth zone extending from 65 to 150 m, between latitudes 08°00'and 13°00' N (Anon, 1969; Oommen, 1989). Fishermen generally operate the gear in the rocky patches between 85 to 215 m, along south-west coast.

Light assisted multiple hook hand line for carangids: Multiple hook hand line are operated for catching small carangids which are attracted by light. Operations take place after moon set and around new moon when lunar illumination is poor, which generally extends to about 15 days in a month. Artificial baits of glittering yarn attached to the hooks are used. Three 24 watt incandescent bulbs kept at half a metre above the sea surface, are used for attracting the fish. Area of operation is 60 to 360 m depth zone, which could be reached by more than 5 h cruise from Cochin.

5.1.5 Distribution of fishing time

Mean number of fishing days per boat per year during the period of study was 252 days. 113 days were lost due to vessel maintenance, repairs and holidays. Roughly 50 percent of the available fishing days are used for gillnetting operations which take place from the end of May to the end of

October, and the other 50 percent for various lining operations. During the, period of study, the estimates of time spent on cruising, gillnetting, drift long lining and hand lining are given in Table 5.2.

5.1.6 Catch and catch composition

Mean annual catch per gillnetter-cum-liner worked out to be 32.83 t. Mean catch.boat^{-1}.day^{-1} was highest in the month of October (251.5 kg) followed by September (189.3 kg). Moderate catches, ranging 100 to 160 kg.boat^{-1}.day^{-1}, were obtained during November - March, May and August. April, June and July months were least productive with catches ranging from 66.4 to 95.8 kg.boat^{-1}.day^{-1} (Fig.5.9). Tunas and bill fishes along with pelagic sharks formed 57 % of the total landings (Fig. 5.10). Perches belonging to the genus *Epinephelus*, *Lutjanus*, *Lethrinus*, *Pristipomoides* formed the third largest category forming 22.8 % of the landings. Spanish mackerel (*Scomberomorus* spp.) and carangids contributed 9.5 % and 5.7 %, respectively and the balance was made up of miscellaneous fishes. Of the landings, tunas and Spanish mackerel was mostly caught by drift gill nets; sharks by drift long line and the bulk of the perches and carangids by hand line operations.

For the period of gillnetting operations, the crew members receive a share of 33.3 %, and the owner of the vessel and owner of the gill net receive 33.3 % each, of the net income after deduction of expenditure on fuel, oil, sales commission, crew wages (*bata*), ration and port charges. For hand lining operations, crew members receive 66.7 % while the owner of the vessel receives 33.3%, and for long lining operations the owner receives 60 % while the crew members receive 40 % of the net income after deduction of routine expenses such as fuel, oil, sales commission, crew wages (*bata*), ration and port charges.

5.1.7 Energy analysis

Results of energy analysis are given in Table 5.3 and Fig. 5.11 and 5.12. During the period of study, only wooden fishing boats were in use for gillnetting-cum-lining, in the small scale mechanised sector, operating from Cochin. Wooden hulled boats of 10.1m L_{OA}, fitted with ALM 370 engines generating a horse power of 89 hp at 2000 rpm, dominated in this category of vessels. Total energy requirement for vessel construction of this length class was estimated to be 74.3 GJ. Contribution to annual GER is estimated at 7.43 GJ.

Gill nets for pelagic fishes, long line for pelagic sharks, multiple hook hand lines for perches and light assisted multiple hook hand lining for small carangids were practised by this class of vessels, during the period of study. Estimates for GER for gill nets, pelagic long line, hand line for perch and light assisted hand line for small carangids were respectively, 26.90, 28.14, 0.558 and 0.221 GJ. Total GER for gear adds up to 55.82 GJ. Assuming a useful life span of 3 years for the gear, contribution to annual GER works up to 18.61 GJ.

Energy for the fishing operations was contributed by consumption of diesel, lubricating oil and ice carried onboard for preservation of catch. Mean annual consumption of diesel, lubricating oil and ice by gillnetter-cum-liners, during the period of observations were 11.9, 0.1 and 14.2 t, respectively. Fuel constituted the bulk of the energy consumed with an annual expenditure of 799.95 GJ, followed by lubricating oil, 4.64 GJ and ice 2.83 GJ. Total operational energy requirement for gillnetting-cum-lining operations during the period of study was 807.42 GJ.

Of the operational energy requirement, fuel constituted 99.08 %, lubricating oil 0.58 % and ice used for preservation of catch during multi-day fishing 0.35 %. Usage of ice is directly proportional to the number of days in the fishing trip which ranged from 1 to 6 days during the period of observations, with a mean number of days per trip of 4.2. Among fishing gears in use, drift long line consumed 28.14 GJ (50.41%) and drift gill net 26.90 (48.19 %). Energy requirement of hand lines was, however, comparatively very low at 0.558 and 0.221 GJ, respectively for hand line for perch and light assisted hand line for small carangids. It formed 1.0 % and 0.4 % of the total energy requirement for fishing gear.

The percentage contribution of operational energy consumption, and consumption for fishing gear and fishing boat construction to the annual GER were respectively, 96.51, 2.22 and 1.27 GJ. Fuel consumption of gillnetter-cum-liner per unit volume of fish landed, during different months is given in Fig. 5.12. Fuel expended for producing unit weight of fish has been determined to be 0.364 kg fuel.kg $fish^{-1}$. Reciprocal of this value representing the fish production per unit quantity of fuel was 2.751 kg fish. kg.$fuel^{-1}$. Aegisson & Endal (1993) based on study conducted during 1990-1992 in the south-west of India has given a value of 3.50 kg fish.kg $fuel^{-1}$, for gillnetting operations. The value obtained during the present studies is 21 % lower. This could be attributed to the expansion of fishing range to farther areas, due to paucity of fish in the coastal waters as a result of fishing pressure or a general diminution in the target stocks during this period.

5.2 Trawling

5.2.1 Introduction

Trawl nets are towed gear consisting of funnel shaped body of netting closed by a bag or codend and extended sides in the front to form wings. Trawls are operated from surface to bottom for a wide variety of crustaceans, cephalopods, elasmobranchs and finfishes, in different parts of the world. Classification and general description of different type of trawling systems have been given by Hjul (1972), Nedlec (1982), Brandt (1984), Sainsbury (1996), Hameed & Boopendranath (2000). Based on the position in water column where they are operated, trawls are classified into bottom trawl and midwater or pelagic trawl. Based on the method of opening of the mouth they are grouped into beam trawl where mouth is kept open by means of a rigid wooden or steel beam, and otter trawls where otter boards are used for horizontal spread of the trawl mouth. Depending on the number of boats used there are one-boat trawl and two-boat trawl or pair trawl or bull trawl. Based on the number of trawls operated from a single vessel, there are double rig trawl system where two nets are operated from outrigger booms; triple trawl system where three nets are operated at the same time and quad rig system where two nets each are operated from two out-rigger booms.

Trawling provides a major portion of the world's supply of fish for use directly as human food (Sainsbury, 1996). It is considered to be a very effective method of fishing for demersal populations, in terms of investment and yield (Scofield, 1948). Steam powered trawlers began operating in European waters in 1880s and in USA and Japan, in early 1900s. Beam trawls which were prevalent in 1880s and still continues to be used in certain fisheries, is considered to be the forerunner of the present day otter trawl. The otter board for the trawl net in its present form appeared first in Ireland around 1885 and was adopted by commercial trawl fisheries during 1892-1905 (Brandt, 1984). In the early stages of development of otter trawl, the otter boards were attached to the wings directly. The introduction of Vigneron Dahl trawl was a significant development in 1920s. In this system, long bridles were provided between wing-ends and otter boards, for increasing the effective swept area. Granton deep sea trawl with short bridles and heavy bobbins which help to bounce over obstacles more satisfactorily were standardised and adopted in 1920s. The original method of bottom trawling was side trawling; the net being set over the side of the vessel and the warps passing through blocks hanging from two gallows, one forward and one aft. Later, side trawlers have been replaced by stern trawlers, which have the advantage of being able to use their towing power to the full, and to set their gear in a straight line (Hjul, 1972; Fyson, 1985). All stern trawlers are characterised by a wide clear working deck aft with wheel house, superstructure and living quarters placed forward. The developments in trawling gear and vessel technology have been discussed by Traung, 1955; 1960; 1967; Kristjonsson, 1959; 1964; 1971; Hjul, 1972; Garner, 1973; Garner, 1977; Ferno & Olsen, 1994; Sainsbury, 1996; Hameed & Boopendranath, 2000 and others.

Trawling was first attempted in Indian waters during exploratory surveys conducted from *S.T. Premier*, off Bombay coast, in 1902 (Chidambaram, 1952) and by Ceylon Company for Pearl Fishing Survey, during 1906-07 (Hornell, 1916). Pair trawling operations were conducted from the Japanese trawler *Taiyo Maru 17*, during 1947-1953 (Chidambaram, 1952).

Deshpande (1960) described the use of a 3.0 m beam trawl for the exploitation of demersal population. In 1955, an FAO Technical Assistance expert conducted experimental shrimp trawling with a 6.6 m L_{OA}, 10 hp open motor boat off Malabar coast, using a Gulf of Mexico type flat trawl of 9.6 m head line. He obtained consistently impressive catches of shrimp in the shallow coastal waters of 4-18 m depth (Kristjonsson, 1967). This finding gave a major fillip to commercial shrimp trawling in India. The increased demand for shrimps for the processing industry caused rapid development of the otter trawling in Indian waters. Kuriyan (1965) has reviewed the trends in prawn fishing techniques, particularly trawling. Various designs of bottom trawling gear were studied subsequently, including conventional two seam and four seam trawls, long wing trawl, bulged belly trawl and six seam trawl (Poliakov, 1962; Satyanarayana *et.al.* 1962; Kuriyan *et.al.* 1963; Verghese *et.al.* 1968; Deshpande *et.al.* 1970a). Relationship between towing power and trawl gear was studied by Miyamoto (1959).

New energy saving concepts in trawl design such as rope trawl have been discussed by Rao & Narayanappa (1994), Rao *et.al.* (1994) and large mesh demersal trawls by Kunjipalu *et.al.* (1989; 1998), Nayak & Sheshappa (1993) and Manohardoss & Pravin (1998). High opening trawls which are designed to obtain a relatively high vertical opening in order to catch species with a pronounced vertical distribution of shoals, have been studied by Kunjipalu *et.al.* (1984b; 1990; 1996). Double rig trawling in which two trawls are towed simultaneously from each of the out rigger booms of the vessel have been studied by Panicker *et.al.* (1977) and Kartha *et.al.* (1990). Double rig trawling is the most important fishing technique for catching prawns in the east coast of India. It reduces drag to the tune of 25-30 % compared to single trawl sweeping equivalent area (Anon, 1984a). Sampling gear for demersal resource surveys was studied by Boopendranath *et.al.* (1996). Investigations on sheer devices such as otter boards and head line lifting devices for trawls have been conducted by Mukundan *et.al.* (1967), Deshpande *et.al.* (1970b), Kunjipalu *et.al.* (1984a) Boopendranath *et.al.* (1986), Kunjipalu & Boopendranath (1993), Sahu & Sheshappa (1998) and Shibu & Hameed (1999).

Fuel consumption and optimisation aspects of trawling have been studied by Gulbrandson (1986), Hameed & Hridayanathan (1989), Hameed & Kumar (1993), John (1996), John *et.al.*(1998) and Nasar (1998). Discussions on the desirable parameters of trawlers appropriate for Indian waters have been given by Choudhury (1973) and Joseph (1985)

It is estimated that 37574 trawlers are operating in India, which form nearly 80 % of the small-scale mechanised fleet. The estimated capital investment for the trawler fleet in the small-scale sector is Rs. 18787×10^6 (Sathiadhas, 1998). The introduction of bottom trawling to exploit marine fishery resources beyond the traditional fishing grounds around 1950s was an important event in the capture fishery development of Kerala State.

Trawling targeted mainly at shrimps, gained wide popularity in the subsequent years and led to the development of an organised fishing industry in the State (Nair, 1991). Average annual fish production by trawling in Kerala has been estimated to be 0.259×10^6 t, during 1991-95 (State Planning Board, 1997). Total landings of trawlers operating from Cochin fisheries harbour, in 1990, has been about 28,000 t, consisting of threadfin breams (32.5 %), carangids (15.7 %), prawns (14.8 %), squids and cuttlefishes (9.3 %), mackerel (5.6 %), flat fishes (2.4 %), lizard fishes (2.3 %), sciaenids (2.1 %), catfishes (0.3 %) and miscellaneous fishes (15.1 %) (Nair, 1991).

5.2.2 Fishing Craft

A trawler is a specific boat type which is equipped to tow one or more trawl nets. They are provided with engines of sufficient power to tow the net at the appropriate trawling speed, and is fitted with trawl winches and equipment necessary to haul the net on board and lift the codend over the deck. In stern trawling, which is the most popular method of trawling in recent years, the warps are led from the trawl winch through two towing blocks attached to stern gallows. The wheel house is situated in the forward part of the vessel and the trawl winch is placed transversely, behind the wheel house. The fish hold is usually situated amidships.

In the initial phases of development of trawling, wooden crafts in the range of 8-9 m L_{OA}, equipped with 10-60 hp diesel engines, were used for trawling in Cochin and elsewhere along the coast of Kerala, mainly undertaking single-day operations. (Kristjonsson, 1967). The overall size and installed horse power of trawlers have increased subsequently, over the years. About 1120 trawlers were registered at the Cochin fisheries harbour, during the period of study. An estimated 674 trawlers land their catches at Cochin fisheries harbour. Distribution of length classes of trawlers operating from Cochin is given in Fig. 5.14. Length class of 13.1-14.0 m L_{OA}, predominated in the fleet (55.8 %), followed by 12.1-13.0 m (12.3 %), 11.1-12.0 m (9.1 %), 14.1-15.0 m (8.4 %), 10.1-11.0 m (5.8 %), 15.1-16.0 m (4.6 %) and 9.1-10.0 m (3.9 %) vessel classes. Distribution of installed engine power among the trawlers is given in Fig. 5.15. Largest number of vessels were equipped with 106 hp engines (53.2 %), followed by 99 hp (30.5 %), 122 hp (9.1 %) and 89 hp engines (7.1 %). Thus, over 80 % of the trawlers belonged to the length class of 13.1-14.0 m L_{OA} and were fitted with 99-106 hp power plants. Non-availability of quality timber at reasonable price, difficulties in the maintenance of wooden crafts, and the availability of steel of the required grade, have increased the acceptance of steel as a construction material for trawlers. During the period of study, about 20 % of the trawlers operating from Cochin had steel hulls and the rest were of wooden hull construction.

Because of the special net towing function, trawlers have different design requirements from those vessels engaged in handling of static fishing gear such as line and gill nets or from the vessels which must encircle a school of fast moving fish, as a primary function of fishing (Fyson, 1991). Towing a net through the water over the seabed requires an engine horse power chosen to provide enough thrust to overcome the resistance of the trawl system and to propel the boat at the speed, appropriate for the target species. Effective horse power (EHP) is the power required to overcome resistance of the vessel at a given speed. A trawler uses power to overcome the hull resistance and to overcome the drag of the trawl system. Total drag of the trawl system should not exceed the available towing force which is total towing force less towing force expended in overcoming hull resistance. A margin of 20 to 30% of the available towing force is generally allowed for higher towing speeds and trawl manoeuvring purposes. Available towing force is apportioned among the different components in the trawl system such as otter boards, sweeps and bridles and the net and its rigging.

The maximum dimensions of the trawl could be found from empirical relations developed for the purpose (Nomura & Yamazaki, 1975; MacLennan, 1981; Fridman, 1986). In a typical bottom trawl system, about 20 % of the drag is contributed by the otter boards, another 10 % by sweeps and bridles, and the balance by the trawl and its rigging (Wileman, 1984; Fridman, 1986; Fyson, 1985; Seafish *et.al.*, 1993).

$EHP = R.V/75$ where R is the total resistance in kg
V is speed in $m.s^{-1}$

$EHP_{TRAWL} = k.EHP_{TOTAL}$

where k is a variable factor determined from full-scale field tests; EHP_{TRAWL} is the horse power required to overcome trawl drag; EHP_{TOTAL} is the total effective horse power.

Available towing force in kgf = $75.k.EHP_{TOTAL}/V$

Fridman (1986) has given the following formula for the approximate estimation of available towing force:

Available towing force, kgf = BHP.(K-0.7V)

where BHP is the brake horse power of the engine; K is the empirical towing force coefficient, ranging from 10 to 15 depending on propeller type; and V is towing speed in knots.

5.2.3 Fishing Gears

Trawls

All trawls are basically funnel shaped, with their sides extending in the front to form wings to prevent the fish in front of approaching trawl from escaping. The modern bottom trawl is constructed generally from two panels of netting, top and bottom or from four panels, top, bottom and sides. Nets with two panels are known as two-seam and nets with four panels as four-seam trawl. In more complex designs of bottom trawl such as six-seam and eight-seam trawls, additional panels are inserted between the top and bottom panels, so that the net body assumes a more favourable shape in terms of filtration and catching efficiency. The trawl body may be divided into the different sections such as codend, extension piece, belly, baitings (top belly), square, lower wings and top wings. Bottom trawls usually have a top canopy called the square extending forward from the top belly to prevent the fish from escaping over the top of the net. Panel sections are generally tailored from machine-made webbing. Top and bottom panels are attached to the head rope and the foot rope, respectively. Most commonly used buoyancy elements are spherical PVC floats which are attached along the head rope. Floats along the head rope and weighted foot rope keeps the net mouth vertically open during operations. Trawl mouth is kept horizontally open using rigid sheer devices known as otter boards which are attached to the wings by bridles. The shape assumed by the trawl while being towed in water is determined by the balance of forces acting on it such as drag, floatation and weight. Drag is primarily contributed by twine surface area of netting, floats, weights and net shape and it changes as a function of the towing speed (Wileman, 1984; Seafish *et.al.*, 1993). Detailed designs of bottom trawls operated in different trawl fisheries of the world are given by FAO (1975, 1978) and SEAFDEC (1986; 1989; 1995). General classification and descriptions of the structure and evolution of trawl designs are given by Garner (1973; 1977), Nomura &Yamazaki (1975), Nomura (1981), Nedlec (1982), Brandt (1984), Chokesanguan (1985) and Hameed & Boopendranath (2000)

Designs of typical trawl nets used in the small-scale trawler operations, are given in Figs. 5.16 - 5.19 and details of their rigging are given in Fig. 5.20 & 5.21. Four types of trawls are used from trawlers which are targeted at specific resources. Generally, a complement of 8 nets are carried in a small mechanised trawler. Depending on the behaviour and distribution characteristics of the target resources, each trawl has certain differences in design and rigging.

Demersal shrimp trawl: Design of a typical shrimp trawl, which is known as *chemmeen vala,* used in the small-scale mechanised trawl fisheries is given in Fig. 5.16 and its rigging details are given in Fig. 5.21. The material used for fabrication is machine-made polyethylene netting of R370tex size. Mesh size varied from 40 mm in the wings, 35-30 mm in the net body, to 20 mm in the codend. The headline length is typically 33.5 m. 18 spherical PVC floats of 152 mm dia are used as buoyancy elements. About 20 kg of lead sinkers are used along the foot rope. The wing-ends are connected to the otter boards by double bridles of 18 m polypropylene ropes of 14 mm dia.

Demersal fish trawl: Demersal fish trawl is known as *meen vala* or *mixture vala,* in vernacular and is primarily targeted at finfish resources. Design details and rigging of demersal fish trawl are given in Fig. 5.17 and 5.20, respectively. The gear is fabricated of machine made polyethylene netting, with a twine size of R900tex. It is provided with larger mesh sizes in the front trawl sections. The mesh sizes range from 160 mm in the wings, 120-40 mm in the net body, to 40 mm in the codend. The head rope length is typically 41.2 m. 17 spherical PVC floats of 152 mm dia, are used as buoyancy elements and 24 kg lead sinkers are attached along the foot rope. The wing-ends are connected to the otter boards by double bridles and a wooden danleno assembly, as shown in Fig. 5.20, the collective length of which is about 34 m.

Squid-anchovy demersal trawl: Squid-anchovy demersal trawl is known as *chooda vala*, in vernacular, and is primarily targeted at squid, anchovies and ribbon fish resources. Design details and rigging of squid-anchovy demersal trawl are given in Fig. 5.18 and 5.20, respectively. The gear is fabricated of machine made polyethylene netting, with a twine size of R370tex. The mesh sizes range from 120 mm in the wing and square sections, 120-30 mm in the net body, to 25 mm in the codend. When trawling for anchovies, an inner liner of R50tex polyamide netting with 10 mm mesh size, is provided inside the codend, to prevent escapement and gilling. The head rope length is typically 43.6 m. 20 spherical PVC floats of 152 mm dia, are used as buoyancy elements and 16 kg lead sinkers are attached along the foot rope. The wing-ends are connected to the otter boards by double bridles and a wooden danleno assembly, as for demersal fish trawl (Fig. 5.20).

Demersal cuttlefish trawl: Demersal cuttlefish trawl is known as *kanava vala*, in vernacular and is primarily targeted at cuttlefish resources. Design details and rigging of demersal fish trawl are given in Fig. 5.19 and

5.20, respectively. The gear is fabricated of machine-made polyethylene netting, with a twine size of R900tex. It is provided with larger mesh sizes in the front trawl sections. The mesh sizes range from 160 mm in the wings, 120-40 mm in the net body, to 25 mm in the codend. The head rope length is typically 41.6 m. 17 PVC spherical floats of 152 mm dia, are used as buoyancy elements and 24 kg lead sinkers are attached along the foot rope. The wing-ends are connected to the otter boards by double bridles and a wooden danleno assembly, as for demersal fish trawl (Fig. 5.20).

Otter boards

Otter boards are rigid sheer devices which are used to keep the trawl mouth, bridles and warps horizontally open. They keep the bottom trawl in contact with the sea bed. Otter boards were first used in trawling in 1894, in Scottish waters (FAO, 1974). By the end of the century, otter trawling had become popular. Originally otter boards were attached directly to the wings of the net. By around 1920, Vigneron-Dahl system was introduced. In this system otter boards were attached to the wings by means of sweep lines and bridles. This increased the catch rate by increasing the effective swept area through the herding effect of sweep lines and otter boards on finfishes. Otter boards contribute about 25 % of the total drag of the trawl system and is responsible for about 16 % of the total fuel consumption in trawling operations (Wileman, 1984; Seafish *et.al.*,1993).

Otter board size is represented by length and height. The length of the otter board is the horizontal distance between the forward and aft edges of the otter board. The height is measured perpendicular to the length. Aspect ratio is the height divided by the length. Projected area is the surface area of the projection of the otter board which takes into account losses due to shape and camber. Angle of attack of otter board is the angle between the shoe of the otter board and the direction along which the otter board is being towed. Angle of attack is adjusted changing the warp attachment points. Angle of attack above 45° is considered inefficient and could lead to high drag and low spreading force. The heel angle of the otter boards refers to its natural behaviour to lean inward or outward. Pitch or tilt angle is the angle which the otter board makes to the horizontal in an upward or downward direction.

When the otter board moves through water, resultant force of all combined forces acting on it is at right angles to the face of the otter board. This otter board force is caused by the water flow around the otter board and in addition, in the case of bottom otter board, by ground sheer. Otter board spreading force or sheer force acts at right angles to the direction of towing and is used to spread the trawl mouth, warps and bridles, horizontally. Otter board drag force acts in the direction opposite to the direction of towing. Weight of otter boards acts downwards and helps to keep the gear in contact with the seabed in a bottom trawl. When the otter board is heeled outwards a part of the otter board force is directed downwards pressing the otter board to the seabed. However, if the heel is inwards, a part of the otter board force is acting upwards, reducing the pressure on the seabed.

The otter board spreading force (sheer) and drag are directly proportional to the projected area. It has also been established that the otter board spreading and drag forces, increase with the square of the speed, provided running attitude remain unchanged. Coefficients of sheer and drag are obtained by dividing the force by the projected area of otter board, the square of towing speed and density of water (FAO, 1974; Seafish *et.al.*, 1993).

Sheer coefficient, $C_L = L/(0.5.\rho/g.A.V^2)$

Drag coefficient, $C_D = D/(0.5.\rho/g.A.V^2)$

Where ρ = density of sea water (1000 $kg.m^{-3}$ for fresh water and 1024 $kg.m^{-3}$ for sea water) g = acceleration due to gravity (9.81 $m.s^{-2}$)

A = projected area of otter board in m^2

V = towing speed in $m.s^{-1}$

L = Spreading force in kg

D = Drag force in kg

The efficiency of the otter boards can be represented by the ratio between sheer force and drag force (C_L/C_D). The larger the value of C_L/C_D the more efficient the otter board will be, provided the other aspects of otter board such as stability and spreading force are within acceptable levels. Most widely used otter boards in the small-scale commercial trawl fisheries are rectangular flat wood and steel otter boards, followed by V-shaped steel otter boards and oval slotted steel boards.

Rectangular flat otter boards: The design of rectangular flat otter board of wood and steel construction which is most commonly used in the small mechanised sector is given in Fig. 5.22. Rectangular flat otter boards of wood and steel construction are one of the earliest known design and are still most widely used type for bottom trawling. Aspect ratio for this board is typically 0.55 and common angle of attack is 40°. It is not very efficient hydrodynamically as a great deal of turbulence occurs in water behind the boards which increases drag and reduces spreading force. Sheer-drag ratio, C_L/C_D for this type of board is 1.14 (FAO, 1974). Flat rectangular otter boards of 1474x737 mm (70 kg), 1524x762 mm (75 kg), and 1626x813 mm (82 kg), are used by vessels powered by 99 hp, 106 hp and 156 hp engines, respectively. Wood used for construction is Jungle jack (*Artocarpus hirsuta*), of 25 mm thickness. About 43 % of the weight of the board is contributed by wood and 57 % by steel. It takes 24-32 man-hours to construct a pair of boards, irrespective of size. About 60 % of the trawlers operating from Cochin, use flat rectangular otter boards.

Rectangular V-type otter boards: Recently, V-shaped steel otter boards have been inducted to the small-scale commercial trawl fisheries. The design of a typical board in this category, is given in Fig. 5.23. The advantages of the V-shaped boards have been discussed by FAO, 1974, Kunjipalu *et.al.* (1984a), and Sahu & Sheshappa (1998). V-shaped otter boards were first developed in 1950s. It is simple in design and is generally constructed in mild steel. The main plate is bent along a horizontal plane to form a V angle of approximately 25-30°. Main advantages are their ability to ride over hard stony ground, inherent stability and long working life. The inter-changeable towing brackets is another important design advantage. The disadvantage of V-type otter board is its inferior spreading force. Aspect ratio is generally 0.65 and C_L /C_D ratio is typically 1.23 (FAO, 1974). V-type boards of size 1370x760 mm of 65 and 70 kg weight, is used by vessels powered by 99 hp and 106 hp, respectively. Mild steel plate of 4 mm thickness is used as back plate and 38.1 mm dia steel rod is used as shoe. It usually takes 64 man-hours to construct a pair of steel V-shaped boards. About 35 % of the trawlers operating from the Cochin fisheries harbour, use V-shaped steel otter boards.

5.2.4 Bottom trawling operation

Stern trawling was first introduced in late 1940s and has become widely popular since then. Advantages of the stern trawler is the maximum utilisation of the towing power and the ability to set the gear in a straight line (Hjul, 1972; Fyson, 1985). The bridge and accommodation is usually placed forward leaving the aft deck clear for the fishing gear and fish handling. Gallows with the towing blocks are fixed on either side of aft deck of small trawlers. A clear view of the aft deck from the bridge is provided, so that the fishing master can observe and ensure increased safety during the operations.

One-boat bottom otter trawling is conducted by small-scale trawlers of Cochin. In this trawling technique, the wing-ends of the trawl net is connected through sweeps and bridles to the otter boards and the otter boards in turn are connected to the main warps. The sheer force generated by the otter boards keep the warps, sweeps and bridles and trawl mouth horizontally open. The warps are paid out and hauled by means of winches. Trawl winches are mechanically driven by power take-off from the main engine. They have two drums, one for each of the two warps. Hauling speed is about 30 $m.min^{-1}$.

The crew consist of 1 *syrang*, 1 engine driver and 4 deckhands. The operations are conducted from 05:00 to 22:00 h, daily. Usually, about 6 hauls of about 2 h duration each are taken. Generally, multi-day fishing operations are undertaken, due to its economic advantages, over single day fishing. The average trip duration varied from 2 to 4 days. Normal fishing depth is up to about 110 m. Availability of fish, depth and nature of sea bottom in the fishing ground are ascertained, based on previous experience. Of recent, however, an increasing number of trawlers have started using Global Positioning System (GPS) and navigation charts for locating fishing grounds and echo sounders for determining the depth and nature of the sea bottom.

Prior to the operations, the trawl net is rigged and kept ready in the fishing deck. During shooting operation, codend is closed properly and released first, followed by the main body of the net. When the net is in water, with the sweeps connected to the otter boards, the vessel slowly steams ahead so the net, sweeps and bridles spread out and open properly. The otter boards are then lowered to a few meters below the surface and kept there for a few minutes to ensure that they are spreading properly. The gear is then lowered to the desired fishing depth by releasing sufficient length of warp. The length of warp released in bottom trawling depends on the depth of the fishing ground and nature of the sea bottom. The ratio of depth of fishing ground and the warp released is known as scope ratio and is typically around 1:5.

After dragging the gear for a duration of about 2 h, the hauling operation begins. The main warps are heaved in evenly on to the winch drums, until the otter boards reach the gallows. Sweeps and bridles are then hauled in followed by the main body of the net and finally the codend. The sweeps and the net are shot and hauled in manually and sweeps may remain connected to the otter boards.

5.2.5 Catch and catch composition

Mean catch per year of trawlers was 52.8 t and major catch components were threadfin breams 22.9 %, perches 17.7 %, carangids 9.9 %, lizard fish 2.8 %, sciaenids 1.7 %, crustaceans 8.8 %, cephalopods 12.2 % and miscellaneous fish 24.0 % (Fig. 5.24). Mean catch.day^{-1} of mechanised trawlers during different months, are given in Fig. 5.25. Catches ranging from 303-383 kg.trawler^{-1}.day^{-1} were obtained during April- September. During other months of the year, it ranged from 145-153 kg.trawler^{-1}.day^{-1}. During these months the trawlers have diversified into line fishing, due to the paucity of trawl resources and the resultant economic reasons. Fishing operations were suspended during a period of 45 days from 15th June to the end of July, during the period of study, due to the monsoon trawl ban imposed by the State Government.

5.2.6 Energy analysis

Energy analysis was performed separately for wooden and steel hulled trawlers. Results of energy analysis are given in Fig. 5.26, 5.27, 5.28. and 5.29 and Tables 5.4 and 5.5. Total energy inputs for trawling with wooden trawlers, was estimated to be 1624.33 GJ (Fig. 5.26).

Percentage contribution of operational and capital energy inputs to GER in respect of wooden trawlers were 85.7 % for diesel, , 0.3 % for lubricating oil 0.4 % for ice, 11.8 % for fishing gear, 1.8 % for fishing vessel (Fig. 5.28). Gross non-renewable energy requirement per tonne of fish landed by this category of trawlers worked to be 31.40 GJ. Energy output in terms of fish landings worked out to be 223.77 GJ. Energy efficiency ratio and energy intensity were respectively, 0.13 and 7.69 (Fig. 5.26).

Total energy inputs of steel trawlers was estimated to be 1993.86 GJ which was 22.8% higher than that for wooden trawlers (Fig. 5.29). Percentage contribution of operational and capital energy inputs to GER of steel trawlers were 84.5 % for diesel, 0.3 % for lubricating oil, 0.3 % for ice, 9.6 % for fishing gear and 5.3 % for fishing vessel (Fig. 5.29). Energy efficiency ratio and energy intensity for steel trawlers were 0.11 and 8.91, respectively (Fig. 5.27). Gross non-renewable energy requirement per tonne of fish landed by steel trawlers was estimated to be 36.97 GJ. GER values for trawling. This value was 17.7 % higher than that for wooden trawlers. The GER values for trawling ranging from 31.4 to 36.97 $GJ.t\ fish^{-1}$ were the highest among the various harvesting systems covered under the present study (Fig. 5.41).

Fuel consumption of trawlers per unit volume of fish landed, during different months is given in Fig. 5.30. Fuel expended for producing unit weight of fish ranged from 0.47 to 0.53 kg fuel.kg $fish^{-1}$, during the months from April to September, barring the period of monsoon trawl ban. However, during the months from October to March when the trawlers diversified into line fishing operations, the fuel consumption per unit volume of fish landed came down markedly and ranged from 0.28 to 0.34 kg fuel.kg $fish^{-1}$.

5.3 Purse seining

Purse seines are the predominant type of surrounding nets, in which the bottom of the net is closed after encircling the fish school, by a pursing line which prevent fish from escaping downwards by diving (Nedlec, 1982; Brandt, 1984). Purse seining is one of the most aggressive and efficient commercial fishing methods for capture of shoaling pelagic species (Ben-Yami, 1994b; Sainsbury, 1996). Small pelagic species, which are used predominantly for industrial reduction such as anchovies, herring, scads, pollack, pilchard, mackerel, menhaden and capelin, and high value food fishes such as tunas and king mackerel, are caught by purse seines. Purse seining account for over 30 % of the total world fish landings. (Ben-Yami, 1994a)

Purse seines evolved from beach seines in 1920s with the incorporation of a pursing arrangement in order to close the net at the bottom after surrounding the shoal, facilitating its operation in deeper waters. They are used in both small-scale and industrial sectors. Purse seines are adapted to the tendency of pelagic fishes to concentrate at densities varying from 0.5 to 5 $kg.m^3$ (Fridman, 1986). The tendency of the pelagic fish to dive down-wards during surrounding is counteracted by the pursing operation.

Advances in purse seining were supported by the introduction of high tenacity synthetic twines of high specific gravity, improvements in vessel technology and gear handling equipment such as puretic power block, fish aggregation techniques and acoustic fish detection and remote sensing techniques (Traung, 1955; 1960; 1967; Kristjonsson, 1959; 1964; 1971; Ben-Yami, 1984a; Fyson, 1985; Hameed & Boopendranath, 2000). Success in purse seining depends on the speed at which the school is encircled, sinking speed of the net and speed of pursing operation. Sinking speed may vary from 40 to 260 $mm.s^{-1}$ depending on netting material, mesh size, size and surface texture of twine, weight of lead line and purse rings. High specific gravity of netting material, large mesh opening, thinner and smoother twine increases the sinking speed. Purse seine is operated from a single vessel or a pair of vessels. Fishing operation consists of active search, chase and interception of the shoal or attraction and concentration the fish by luring techniques or aggregation devices; encircling and pursing operations; concentrating the catch in the bunt by progressively hauling in the net; and brailing out the catch before concluding the operation.

Major gear handling equipment on board large purse seiners are net haulers, pursing winch and pursing gallows. Power block is the most widely used net hauling system. It is a large hydraulically driven pulley with heavy-duty rubber linings, hung from an adjustable deck boom. Power block is a significant development which has made large-scale purse seining possible by facilitating the hauling of the huge net with minimum man-power. Other equipment used for net hauling are triplex or three cylinder parallel powered net hauler and turnable net drums. Pursing gallows with two blocks guiding the purse line are fixed on the fishing side. Pursing winches are positioned with the drums facing gallows. A powerful skiff carried onboard in large seiners or towed behind in small-scale seiners render assistance during encircling and fish brailing. Net brailers are used for transferring the catch from the bunt to the fish hold. Fish pumps and fish-water separators are some times used for transferring small pelagic species, in industrial operations. Gear handling equipment in small-scale purse seining, is generally restricted to pursing gallows and pursing winches for hauling purse lines which closes the net after setting and hauling of net is generally done manually (Kristjonsson, 1971; Fyson, 1985; Ben-Yami, 1994; Hameed & Boopendranath, 2000).

Purse seining experiments were conducted in India by the erstwhile Indo-Norwegian Project as early as 1954. The Project spent about 5007 fishing hours during 1954-1985, off Kerala coast, and caught 3346 t of fish consisting of sardines (79.9 %), mackerel (11.8 %), tunas (2.5 %), carangids (0.6 %), anchovies (0.5 %), horse mackerel (0.3 %) silver bellies (0.1 %) and others (4.3 %). Operations were conducted from 10.92 m (48 hp) vessels using 292 m x 26 m sardine purse seine; 17.5 m purse seiner (233 hp) using 366 m x 46 m sardine/mackerel purse seine; and 27.3 m purse seiner (750 hp) using 502 m x 72 m tuna/mackerel purse seine (Oommen, 1989). Purse seining was attempted in Goa in 1957, when two Portuguese built purse seiners of 13.5 m L_{OA} were commissioned and encouraged by their successful operations, two more purse seiners were added in 1970 (Sadanandan *et.al.*, 1975).

Purse seining in the commercial small-scale mechanised sector was started earnestly in India with the technical assistance from Integrated Fisheries Project, Cochin (earlier Indo-Norwegian Project), in November 1974 when a purse seine unit started functioning in Ponnani, under a Fishermen Co-operative Society (Mukundan & Hakkim, 1980). Beginning with its introduction in December 1975 in Karnataka, about 20 purse seiners began operation during 1976-77. Sadanandan *et.al.* (1975) studied the design, construction and operation of purse seines operated from Goa, during 1970s. The number of purse seiners in India is estimated to be 1219, which form 2.6 % of the small-scale mechanised fleet. The estimated capital investment on purse seine fleet is Rs. 1342×10^6 (Sathiadhas, 1998).

The average landings by mechanised purse seiners in Kerala, during 1991-95, is estimated to be 5507 t (State Planning Board, 1997). Purse seine landings, in Kerala, mainly consist of oil sardine and mackerel, and lesser quantities of other sardines, carangids, seerfishes, catfishes, tunas, and prawns (Nair, 1991). Purse seining was started from Cochin by entrepreneurs only during the latter half of 1979. About 78 purse seiners are registered at Cochin Fisheries Harbour, of which 47 vessels forming 5.0 % of the entire mechanised fleet operating from the harbour, were in active operation during the period of study.

5.3.1 Purse seine crafts

Purse seiners are either wooden or steel hulled. Wooden vessels constitute 78.3 % of the purse seine fleet and the balance 21.7 % constitute steel vessels. The length overall varies from 13.7 to 19.8 m. The horse power of the diesel engine depending on the size of the vessel varies from 90 to 272. The vessels generally have low free board to facilitate the hauling of the gear. The wheel house is placed forward. The winch is fitted with parallel drums and situated opposite to the pursing gallow. The net is carried in the stern of the vessel. Observation crow's nest is provided at an elevated platform in the fore deck of the vessel, to assist in the spotting of fish schools. The skiff which is towed behind the purse seiner is unpowered and its size varies from 3 to 3.7 m. Earliest purse seiners operated from Cochin were of 13 - 13.7 m L_{OA} with 100-125 hp engines. The size of the vessel and installed engine power gradually increased to 19.2 - 19.8 m L_{OA} and 156 - 272 hp, respectively, in recent years.

Distribution of length classes of purse seiners operated from Cochin is given in Fig. 5.31. Purse seiners of length class 15.1-16.0 m L_{OA} constituted 21.2 %, followed by 14.1-15.0 m (19.7 %), 13.1-14.0 m (19.7 %) 16.1-17.0 m (13.6%), 12.1-13.0 m (13.6 %), 17.1-18.0 m (10.6 %) and 18.1-19.0 m (1.5 %) length classes. Distribution of installed horse power among purse seiners operated from Cochin is given in Fig. 5.32. Maximum number of purse seiners were powered by 156 hp engines (36.2 %), followed by 106 hp engines (34.0 %), 122 hp engines (21.3 %) and 235 hp engines (8.5 %). Thus, most abundant length class of purse seiners were 13.1-17.0 m L_{OA} and about 45 % of the vessels were having installed power of 156-235 hp.

5.3.2 Purse seine gear

The length of the purse seine gear varied from 768 to 823 m and its hung depth varied from 65 to 73 m depending on the size of the vessel. Purse seines operated from smaller vessels, at the time of introduction of the technique ranged from 340 to 410 m in length. Design, size and rigging of the purse seines vary depending on the depth of operation, target species and vessel characteristics. Design details and rigging of a typical purse seine gear operated from Cochin are given in Fig. 5.33 and 5.34.

Purse seines operated in the purse seine fisheries off Cochin consist of the following features:

Bunt : This is the section of netting where catch is concentrated prior to its removal by brailing into the vessel and is the last part of the net to be hauled in. Netting in the bunt is relatively stronger and is made of thicker twines than other parts. Polyamide netting of R310tex with a mesh size of 22 mm, is used in the bunt. The bunt is placed at one end of the purse seine net.

Main body : This is the largest part of the net, extending from the bunt, which facilitate surrounding of the fish shoal during operations. It is constructed by joining together large sections of netting of mesh size appropriate for the target species. Relatively thinner twines are used in this section in order reduce the hydrodynamic resistance and increase the sinking speed during setting. Polyamide netting of R230tex of 22 mm mesh size is used for fabrication of the main body of purse seine net.

Selvedges : Selvedge consists of a few rows of meshes of thicker twine and larger mesh size, provided along the upper, lower and side edges of the net body in order to protect the net from damages during operations. Polyethylene netting of R1050tex with a depth of 10 meshes of 30 mm mesh size is used along the upper edge. Polyethylene netting of R3500tex with a depth of 5+5 meshes of 80 mm mesh size are used along the lower edge. Square pieces of the same material of 280 meshes depth and 55 meshes in length are used at either end.

Float line, lead line, side ropes : The upper selvedge is attached to the float line and the lower selvedge to the lead line, maintaining a hanging coefficient of 0.70 Selvedges on the sides are attached to side ropes. Polypropylene ropes of 10 mm dia are used as head line, lead line and side ropes.

Bridles and tow line : Bridles are ropes attached to float line and lead line on either end and are connected to a tow line of sufficient length to facilitate setting and hauling operations. Polypropylene ropes of 10 mm dia are used for this purpose.

Pursing arrangement : Purse line is used to close the bottom of the purse seine after surrounding the fish shoal. The purse line passes through purse rings attached to lead line by short lengths of ropes. The purse line must have good abrasion resistance and high breaking strength. Polypropylene ropes of 24 mm dia and 900 m length are used as purse line. Sixty-two purse rings of 100 mm dia, made of brass weighing 800 g each, are attached along the lead line.

Floats and sinkers : Cylindrical PVC (Polyvinyl Chloride) floats with a specific gravity of 0.099 are generally used in purse seines. About 5400 lead sinkers of 200 g each are attached to the lead line to attain 1.5 $kg.m^{-1}$ and 3960 expanded PVC floats with a buoyancy of 610 gf each, are attached along the float line, to attain a buoyancy rate of 3.4 $kgf\ m^{-1}$.

5.3.3 Purse seining operations

Success in purse seining depends on the speed at which the school is encircled, sinking speed of the net and speed of pursing operation. Sinking speed of purse seines may vary from 40 to 260 $mm.s^{-1}$ depending on netting material, mesh size and surface texture of twine; weight of lead line and purse rings. High specific gravity of the netting material, large mesh opening, thinner and smoother twine increases the sinking speed (Ben-Yami, 1994).

Single vessel purse seining operations are conducted from Cochin. Only single day fishing is undertaken by the commercial small-scale purse seiners. Fishing operations consist of (i) active search, chase and interception of the shoal, (ii) encircling and pursing operations, (iii) concentrating the catch in the bunt by progressively hauling in the net, and (iv) brailing out the catch, before concluding the operation. Attraction and concentration of the fish by light-luring techniques or aggregation devices as used in purse seine fisheries in other nations such as Japan, Philippines and Thailand (SEAFDEC, 1986; Ben-Yami, 1994; SEAFDEC, 1995; Hameed & Boopendranath, 2000) are not in practice in India. Purse seines are operated from Cochin throughout the year, barring three months from

June to August, during which period their operations are banned under regulations originating from the provisions of Kerala Marine Fisheries Regulation Act 1980.

Main gear handling equipment on board purse seiners is pursing winch. A skiff towed behind the small-scale seiners render assistance during the encircling and fish brailing. Net brailers are used for transferring the catch from the bunt to the fish hold. Modern equipment such as net haulers and acoustic fish detection equipment are not used in the small-scale purse seiners. Net hauling is done manually while pursing is mechanically assisted.

The crew onboard include *Syrang*, Engine Driver, crew member responsible for the detection of fish shoals and for giving guidance on the direction of approach and timing of the encircling operation (*Ariyakaran* in vernacular), cook and about 18 deckhands. Another 8 members of the crew, attached to the purse seine unit, remain onshore and replace the deckhands on the subsequent of days operation, as needed.

Day-time purse seining operations

The purse seiner departs for day operation in the early morning hours. After reaching the fishing ground, usually located within 3 hours cruise from the harbour, search operation begins. Fish shoal is detected by colour, texture, jumping fish or flocks of birds hovering over the school. The crew member responsible for shoal detection (*ariyakaran*) perches on the crow's nest provided at an elevated platform in the fore-deck of the purse seiner and watches for the potential shoals in the vicinity. Immediately on detection of the potential shoal, he alerts the crew and the vessel moves swiftly towards the shoal. Speed and direction of the target school, speed and direction of the wind and current are taken into consideration before the final approach and the beginning of surrounding operation. On reaching the proximity of the shoal, the skiff to which one end of the net (tow line) and the purse line are secured, is launched; the net is set at full speed and the shoal is surrounded by the purse seine. On completion of the encircling, the skiff transfers tow line and the purse line to the seiner and pursing is immediately started by operating the pursing winch. The skiff is manned by two people. The hauling of the gear begins immediately afterwards which is very labour-intensive and about 16-18 fishermen participate in the hauling. Usually one or two motorised canoes join the skiff to assist the seining by preventing the escape of the shoal over the float line by bunching it together, prior to hauling by the purse seiner. After concentrating the catch further, the transfer of the catch is started by brailing. The brailing net is about 2 m in dia. and is provided with a handle of 2-2.5 m and the hung depth of the netting is about 1.25 m. A derrick which is located in the fore-deck facilitates the brailing operation and positioning of the catch in the storage area, assigned in the fore-deck. The brailer is handled by overhead falls from the derrick which is taken to the warping head of the winch. After completion of the transfer of the catch by brailing, the operation is concluded by hauling in of the rest of the net. The net and the appurtenances are usually stored in the port side. In a smooth operation, the whole process from shooting to hauling of the net takes about 3 hours.

Night-time purse seining operations

The vessel departs for night operations in the afternoon or later hours adjusting the time so as to reach the destined fishing ground in the night ahead of local moon-set time. After the moon is set all the lights, except the essential navigation lights, are put off and the vessel moves at a slow speed ahead, searching for potential shoals. The crew member responsible for shoal detection perches on the crow's nest and watches for the potential shoals in the vicinity. In the night, fish schools are detected by the bio-luminescence of the plankton caused by the school movements. After the detection of the shoal, the vessel passes over it to identify the shoal by close observation facilitated by the low free board of the vessel. Once it is decided to commence fishing operation, the vessel moves ahead at full speed towards the shoal and the operation proceeds as in day-time operations. When about two-thirds of the net is hauled in, the deck lights are put on. The communication between the fishermen onboard the skiff and the skipper during the night operation is maintained by torch light signals.

Cruising to the fishing ground, typically takes about 3 h, searching 1-1.5 h, encircling 3-4 min, pursing about 20 min, hauling of net prior to brailing 1.5 to 2 h, brailing 1 h, return cruise to port another 3 h. The owner and the crew receives, respectively, a share of 40 % and 60 % of the amount obtained after deduction of expenditure on fuel, oil, sales commission, crew wages (*bata*), ration and port charges.

5.3.4 Catch and catch composition

Mean number of fishing days were 124 days for 235 hp wooden purse seiners and 181 days for 156 hp steel and wooden seiners. No fishing was conducted during the months of June, July and August as it is closed season for purse seining in the State, on account of fishery regulations. Mean catch per year were 325.3 t, 340.5 t and 277.6 t, respectively for 156 hp wooden seiner, 156 steel seiner and 235 hp wooden seiner, respectively. The catch was constituted by sardines 54.30 %, mackerel 44.5 %, tunnies 0.23 %, pomfrets 0.08 % and miscellaneous fish 0.89 % (Fig. 5.35).

Mean catch.day^{-1} of purse seiners during different months are given in Fig. 5.36. Most productive months were September and October with catches ranging from 4445 - 5302 kg.siener^{-1}.day^{-1}, followed by November and December (1540-1860 kg.siener^{-1}.day^{-1}) and January-May (479-1301 kg.siener^{-1}.day^{-1}).

5.3.5 Energy analysis

Results of energy analysis are given in Fig. 5.37 and Tables 5.6, 5.7 and 5.8. GER values were estimated separately for 156 hp wooden seiners, 156 hp steel sieners and 235 hp wooden sieners. Total energy inputs for 156 hp wooden seiners was 1802.46 GJ, contributed by diesel (90.08%), lubricating oil (0.40 %), gear (6.39 %) and vessel and skiff (3.12 %). Gross non-renewable energy per tonne of fish landed for this category of purse seiners was estimated to be 5.54 GJ. Total energy inputs for 156 hp steel seiners was 2019.60 GJ, which was 12.05 % higher than that for wooden vessels with the same installed horsepower. Percentage contribution to total energy inputs was 85.95 % for diesel, 0.35 % for lubricating oil, 5.71 % for gear, 7.99 % for steel vessel and wooden skiff. GER was estimated to be 5.91 GJ.t $fish^{-1}$ for steel seiners. For 235 hp wooden seiners, the total energy inputs was 1776.95 GJ. Total energy inputs for 235 hp wooden vessels, was the lowest among the three classes of seiners, due to the lower number of fishing days and consequent lower annual operational energy expenditure of this class of vessels, during the period of study. The gross energy requirement for this class of seiners was estimated to be 6.40 GJ.t $fish^{-1}$, which was the highest among the three classes of seiners due to the relatively high fuel consumption of the power plant. Percentage contribution to the total energy inputs was 90.17 % for diesel, 0.18 % for lubricating oil, 6.49 % for gear and 3.17 % for vessel and skiff.

Mean GER for all classes of seiners worked out to be 5.94 $GJ.t\ fish^{-1}$, which was lowest among the different mechanised craft-gear combinations, covered under the present study. Mean energy output in terms of landings for all seiners was estimated to be 1388.33 GJ, 98.8 % of which was contributed by sardines and mackerel. Mean energy inputs for purse seiners was 1866.35 GJ contributed by diesel 88.6 %, lubricating oil 0.3 %, fishing gear 6.2 % and fishing vessel 4.9 % (Fig. 5.37; 5.38). As purse seining is conducted on a daily basis, ice for preservation of catch does not form a part of energy inputs for purse seiners, unlike mechanised gillnetter-cum-liners and trawlers. Energy efficiency ratio for purse seiners was estimated to be 0.75 and energy intensity value was 1.34 (Fig. 5.37).

Fuel consumption per unit volume of fish landed by 235 hp purse seiners during different months is given in Fig. 5.39. Minimum values ranging from 0.03 to 0.12 $kg\ fuel^{-1}.kg\ fish^{-1}$ were obtained during the months of September-December; intermediate values ranging from 0.13 to 0.17 $kg\ fuel^{-1}.kg\ fish^{-1}$ were obtained during February-April; and maximum values ranging from 0.3 to 0.38 $kg\ fuel^{-1}.kg\ fish^{-1}$ were obtained during January and May. Fuel consumption pattern per unit volume of fish landed by 156 hp purse seiners during different months are given in Fig. 5.40. Minimum values ranging from 0.03 to 0.09 $kg\ fuel^{-1}.kg\ fish^{-1}$ were obtained during September to December months and in February, maximum value of 0.49 kg $fuel^{-1}$.kg $fish^{-1}$ in January and intermediate values ranging from 0.12 to 0.21 kg $fuel^{-1}$.kg $fish^{-1}$ in March to May. The variation in the values are dependent on several factors such as the distance to the fishing ground, time spent on searching, success percentage of the sets and resource availability in the fishing ground.

Results of energy analysis of different fish harvesting systems studied ranging from non-motorised (Chapter 3) , motorised (Chapter 4) to mechanised systems (Chapter 5) are summarised in Fig. 5.41. Among the fish harvesting systems studied, traditional non-motorised gillnetting was the most energy efficient having the lowest GER and energy intensity values and highest efficiency ratio, producing more energy than the amount of non-renewable energy consumed. Mechanised trawling was the most energy intensive fish harvesting system with GER.t $fish^{-1}$ values ranging from 31.40 to 36.97 GJ, indicating an overall consumption of 0.73-0.86 t of fuel for every tonne of fish produced. Among the non-motorised systems, stake nets have a relatively high energy intensity, as the annual landings were lowest and the economic viability of the operation was due to the catch of high value prawns. In the motorised operations, ring seines have a lower GER.t $fish^{-1}$ value than mini-trawling. For a fishing system, which is restricted in its operation, to shallow coastal waters, the energy cost of mini-trawling is adjudged to be high. Economic viability of the mini-trawling could be derived from high value landings of prawns during its seasonal operation. GER value of ring seines was higher compared to 156 hp mechanised purse seiners, probably due to lower fuel efficiency of outboard motors compared to inboard diesel engines. Mechanised gillnetting-cum-lining operations are conducted at comparatively distant fishing grounds due to scarcity of resources in the inshore waters, which explains the relatively high GER.t $fish^{-1}$ values obtained for a system, operating passive fishing gears. Steel vessels generally gave higher GER.t $fish^{-1}$ values compared to wooden vessels used in purse seining and trawling, due to larger inputs in terms of energy into vessel construction.

Table 5.1 Details of facilities at Cochin fisheries harbour

	Land side facilities	
1	Total area, ha	11
2	Auction hall, sq.m	2340
3	Ice pants, $t.day^{-1}$	40
4	Slipways/drydock, No. of bays	9
5	Water storage, $x10^6$ liters	0.4
6	Electric substation, KV	11
7	Fuel	available
	Water side facilities	
1	Fish landing quay, length, m	259
2	Idle berthing quay Length, m Depth, m	 176 6
3	Outfitting quay length, m	125
4	Repair quay Length, m Depth, m	 30 3
	Ancillary facilities	
1	Parking area, m^2	864
2	Loading area, m^2	900
3	Net mending area, m^2	756
4	Processing industry, ha	2.42
5	Land leased to ancillary industries, ha	0.2

Table 5.2 Mean utilisation of time for various activities of gillnetter-cum-liners operated from Cochin

	Activity	Time, %
1.0	***Line fishing***	***34.80***
1.1	Hand lining	23.20
1.1.1	Light assisted multiple hook hand lining for small carangids (*mayakka*)	5.80
1.1.2	Multiple hook hand lining for perch (*paru choonda*)	17.40
1.2	Drift long lining for pelagic sharks (*aricha mattu*)	11.60
1.2.1	Cruising and searching	2.41
1.2.2	Shooting	0.24
1.2.3	Soaking	5.80
1.2.4	Hauling and removal of catch	0.96
1.2.4	Other activities	2.19
2.0	***Gill netting***	***34.25***
2.1	Cruising and searching	4.09
2.2	Shooting	0.72
2.3	Soaking	17.26
2.4	Hauling and removal of catch	7.26
2.5	Other activities	4.92
3.0	***Non-fishing days***	***30.96***

Table 5.3 Results of energy analysis of Gillnetter-cum-liners operated from Cochin

	GJ	*Annual GER, GJ*
Operational energy requirement		
Diesel	799.95	
Lubricating oil	4.64	
Ice	2.83	
Sub-total	807.42	**807.42**
Fishing gear		
Drift gillnets	26.90	
Drift long line for sharks	28.14	
Hand line for small carangids	0.22	
Hand line for perches	0.56	
Sub-total	55.82	**18.61**
Vessel	74.30	**7.43**
Total		**833.46**

Table 5.4 Results of energy analysis of wooden trawlers

	GJ	*Annual GER, GJ*
Operational energy requirement		
Diesel	1392.66	
Lubricating oil	4.86	
Ice	6.26	
Sub-total	1403.77	**1403.77**
Fishing gear		
Trawls with appurtenances	35.28	**35.28**
Towing warp	147.83	**147.83**
Otter boards	4.114	**8.23**
Line fishing gear	0.558	**0.56**
Fishing vessel (wooden) with power plant & equipment	286.6	**28.66**
Total		**1624.33**

Table 5.5 Results of energy analysis of steel trawlers

	GJ	*Annual GER, GJ*
Operational energy requirement		
Diesel	1684.65	
Lubricating oil	5.64	
Ice	6.40	
Sub-total	1696.69	**1696.69**
Fishing gear		
Trawls with appurtenances	35.28	**35.28**
Towing warp	147.83	**147.83**
Otter boards	4.114	**8.23**
Line fishing gear	0.558	**0.56**
Fishing vessel (steel) with power plant & equipment	1052.7	**105.27**
Total		**1993.86**

Table 5.6 Results of energy analysis of 156 hp wooden purse seiners

	GJ	Annual GER, GJ
Operational energy requirement		
Diesel	1623.70	
Lubricating oil	7.27	
Sub-total	1630.97	**1630.97**
Fishing gear		
Purse seine with appurtenances	345.75	**115.25**
Fishing vessel (wooden) with power plant, equipment & skiff	562.36	**56.24**
Total		**1802.46**

Table 5.7 Results of energy analysis of 156 hp steel purse seiners

	GJ	*Annual GER, GJ*
Operational energy requirement		
Diesel	1735.90	
Lubricating oil	7.14	
Sub-total	1743.04	**1743.04**
Fishing gear		
Purse seine with appurtenances	345.75	**115.25**
Fishing vessel (steel) with power plant, equipment & skiff	1613.08	**161.31**
Total		**2019.60**

Table 5.8 Results of energy analysis of 235 hp wooden purse seiners

	GJ	*Annual GER, GJ*
Operational energy requirement		
Diesel	1602.26	
Lubricating oil	3.21	
Sub-total	1605.46	**1605.47**
Fishing gear		
Purse seine with appurtenances	345.75	**115.25**
Fishing vessel (wooden) with power plant, equipment & skiff	562.36	**56.24**
Total		**1776.96**

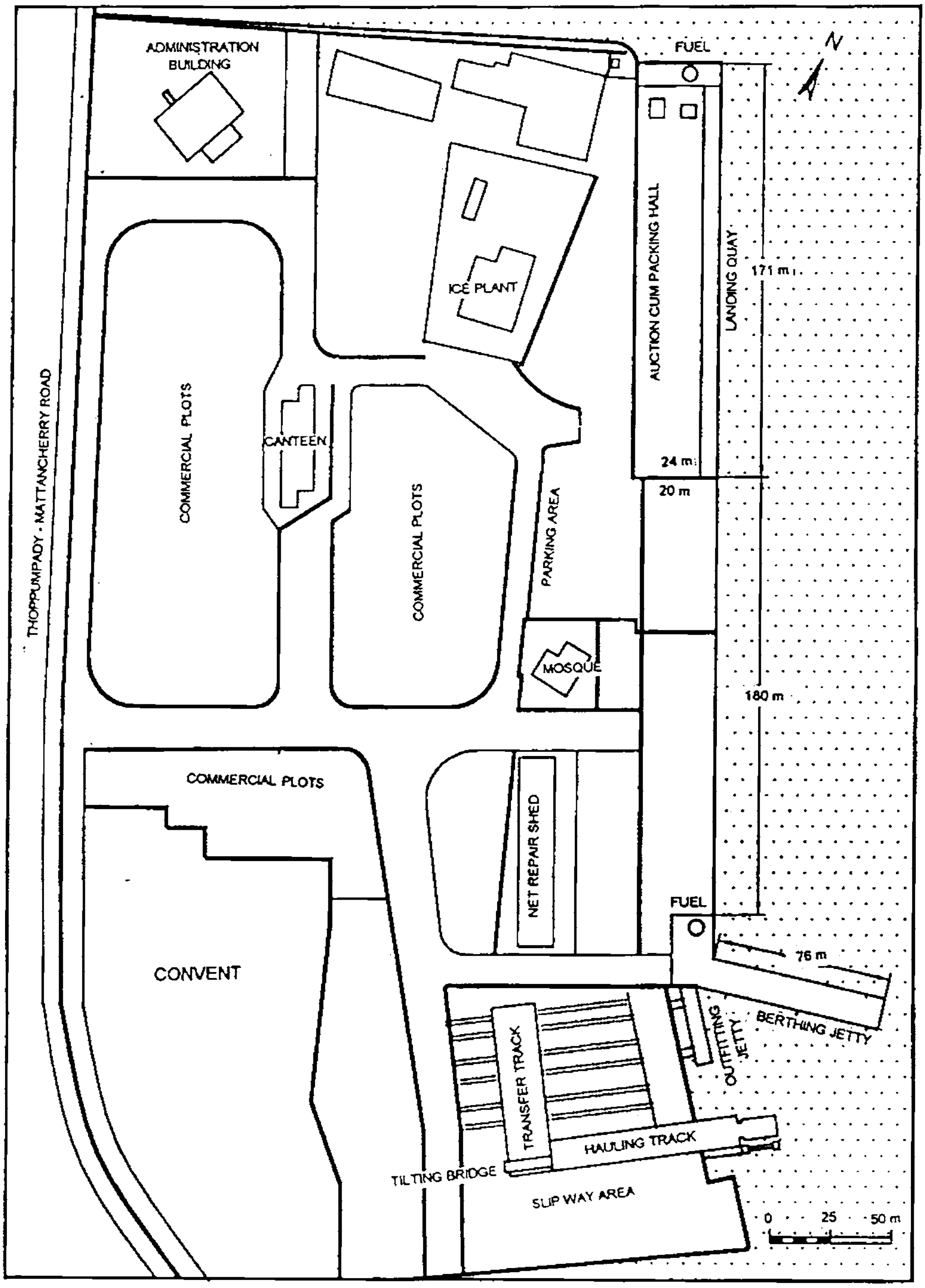


Fig. 5.1 Cochin Fisheries Harbour - layout of wharf and industrial area

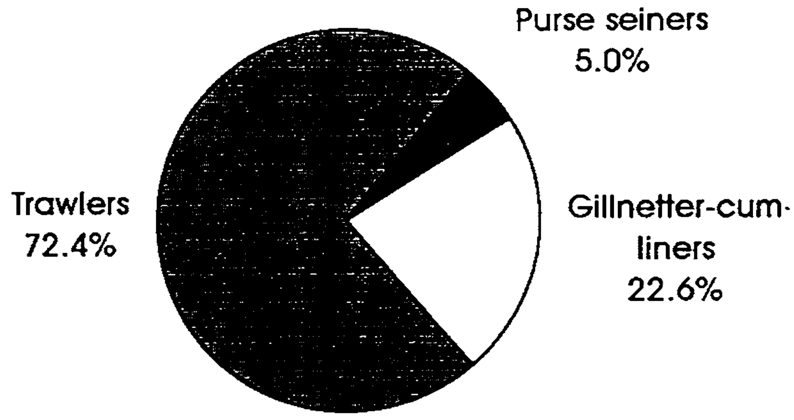


Fig. 5.2 Percentage composition of mechanised fishing vessels operating from Cochin Fisheries Harbour

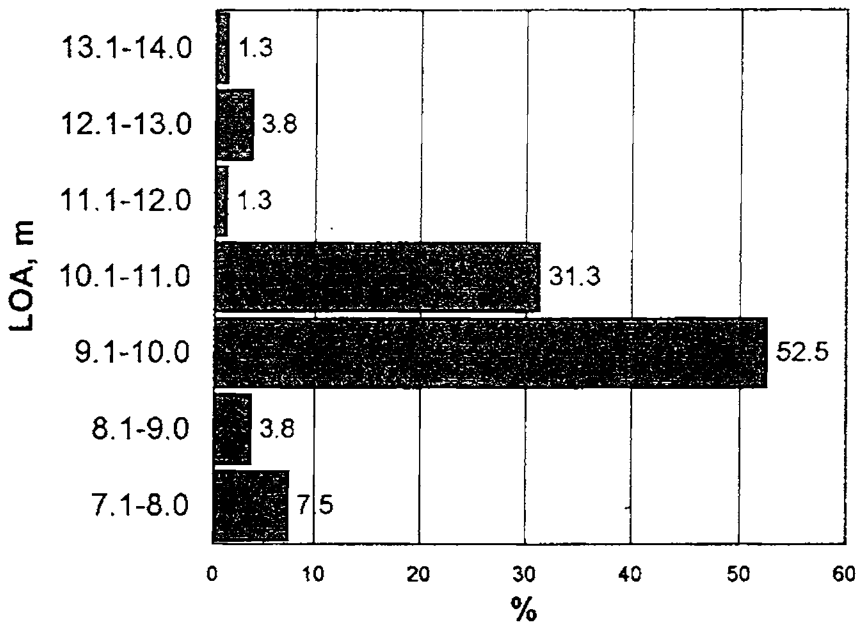


Fig. 5.3 Distribution of length classes of gillnetter-cum-liners operating from Cochin

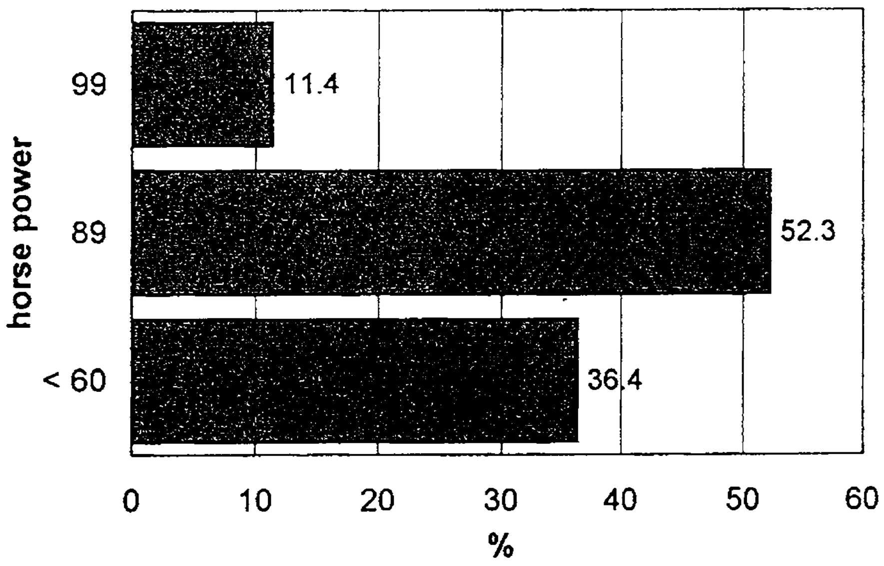


Fig. 5.4 Distribution of installed horse power of gillnetter-cum-liners operating from Cochin

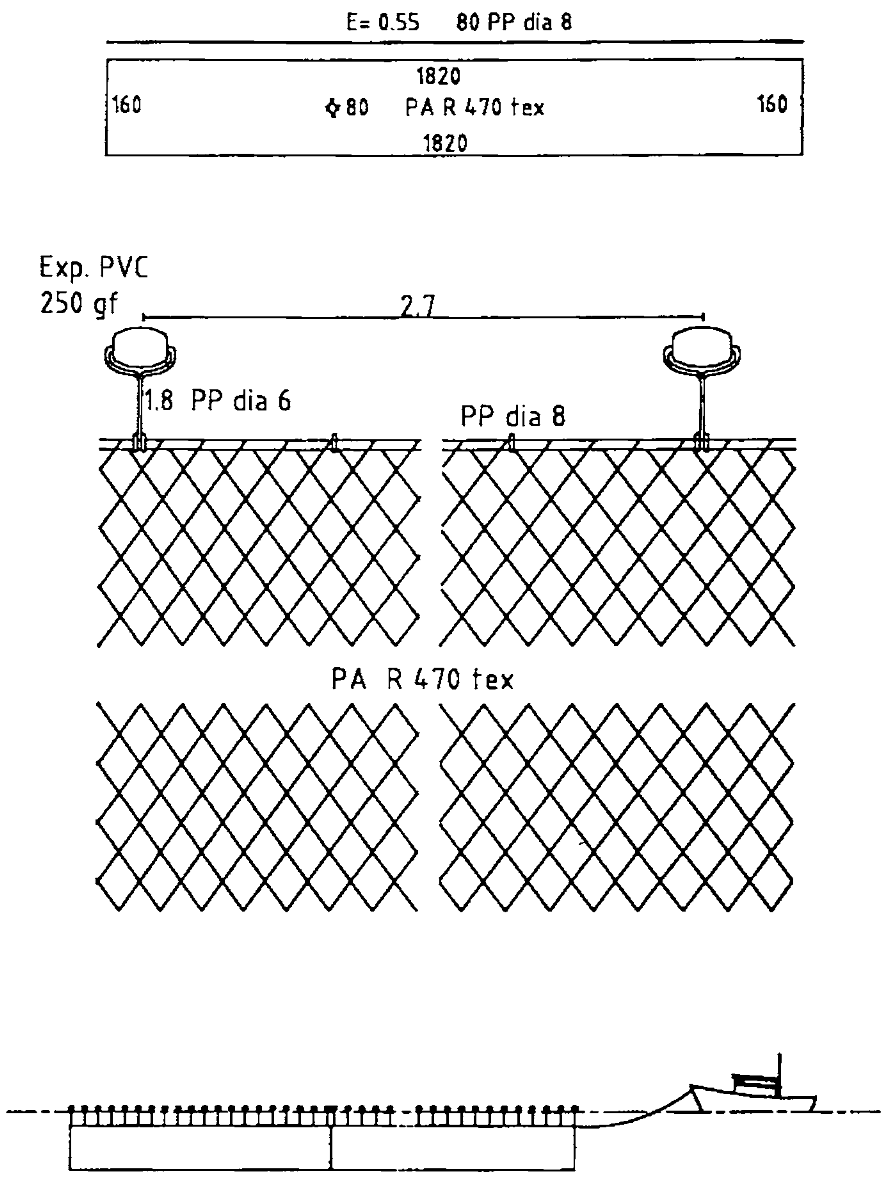


Fig. 5.5 Design of pelagic gill nets operated by gillnetter-cum-liners

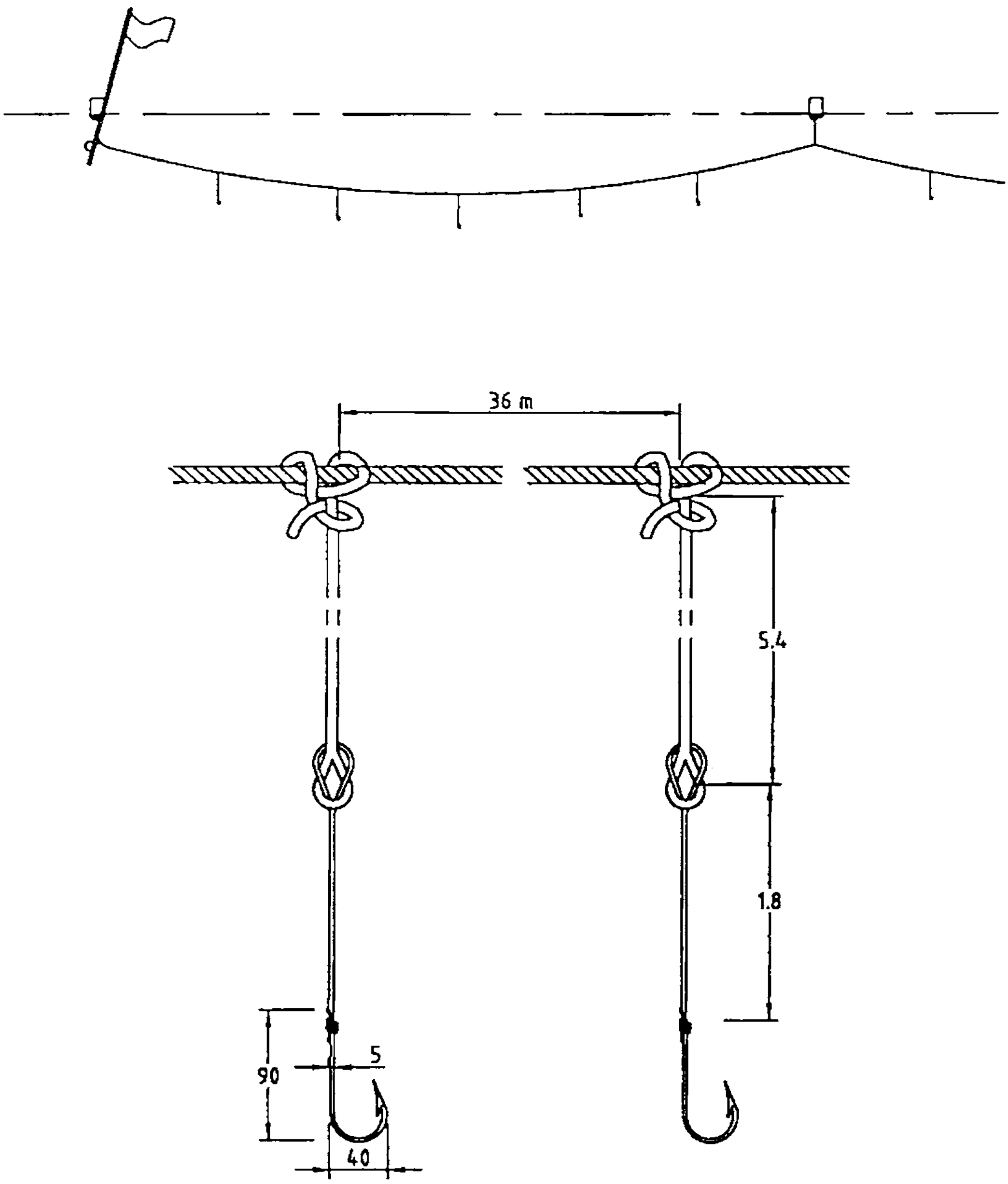


Fig. 5.6 **Drift long line for pelagic sharks (*aricha mattu*) operated by gillnetter-cum-liners**

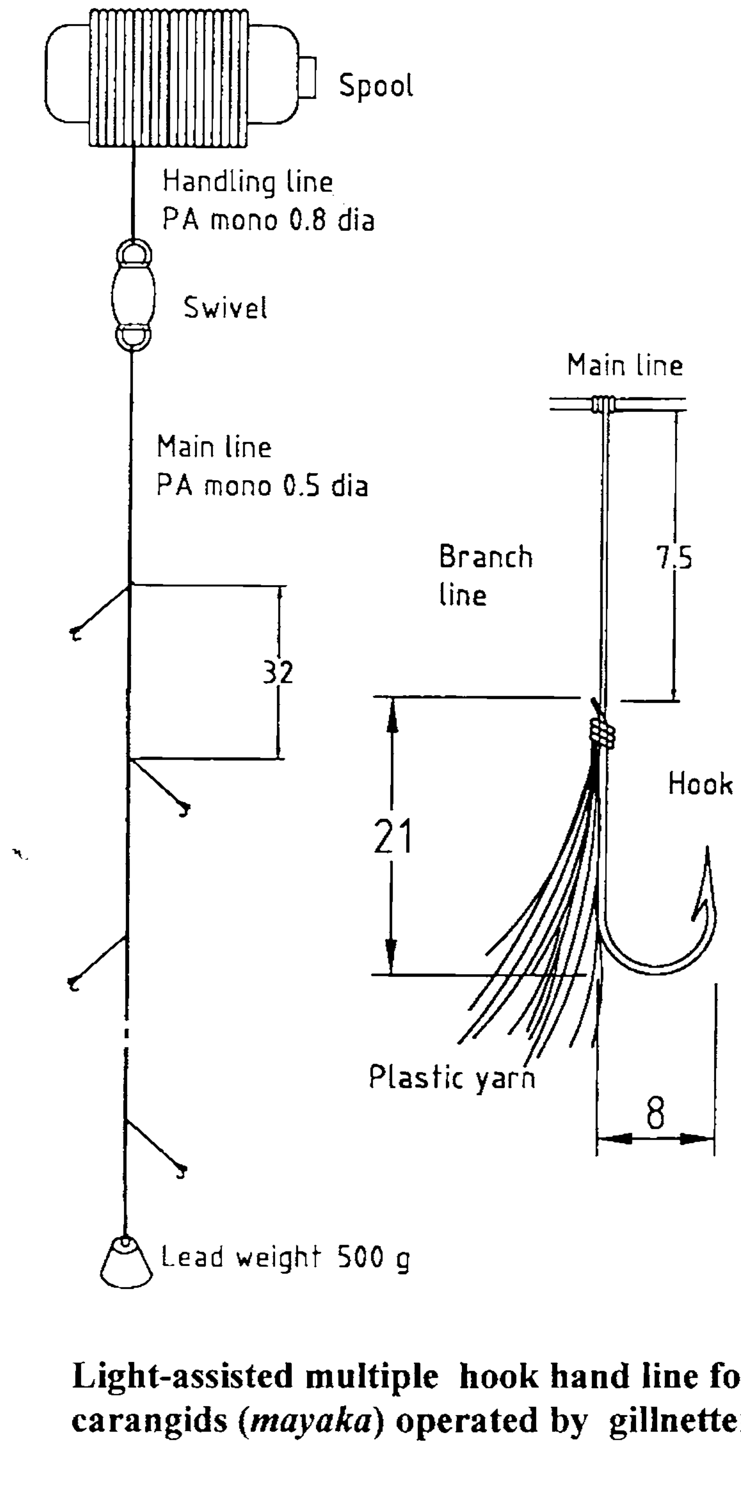


Fig. 5.7 Light-assisted multiple hook hand line for small carangids (*mayaka*) operated by gillnetter-cum-liners

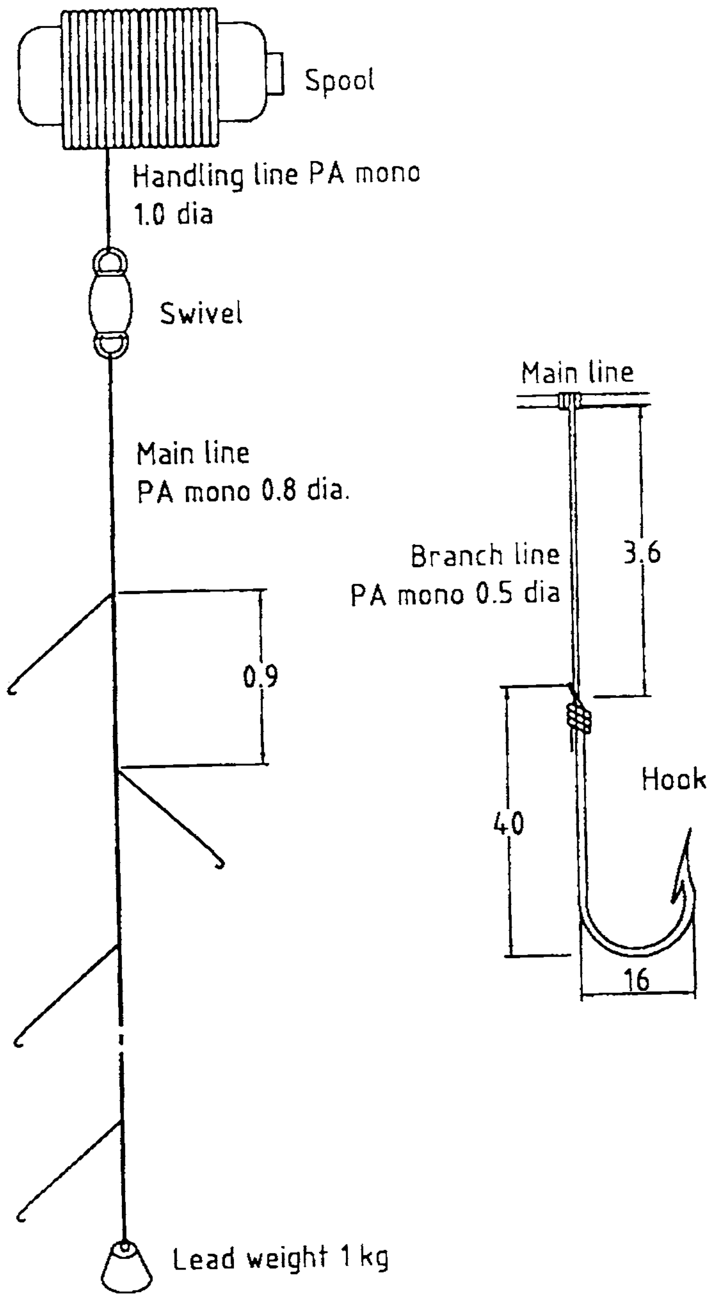


Fig. 5.8 Multiple hook hand line for perches (*paru choonda*) operated by gillnetter-cum-liners

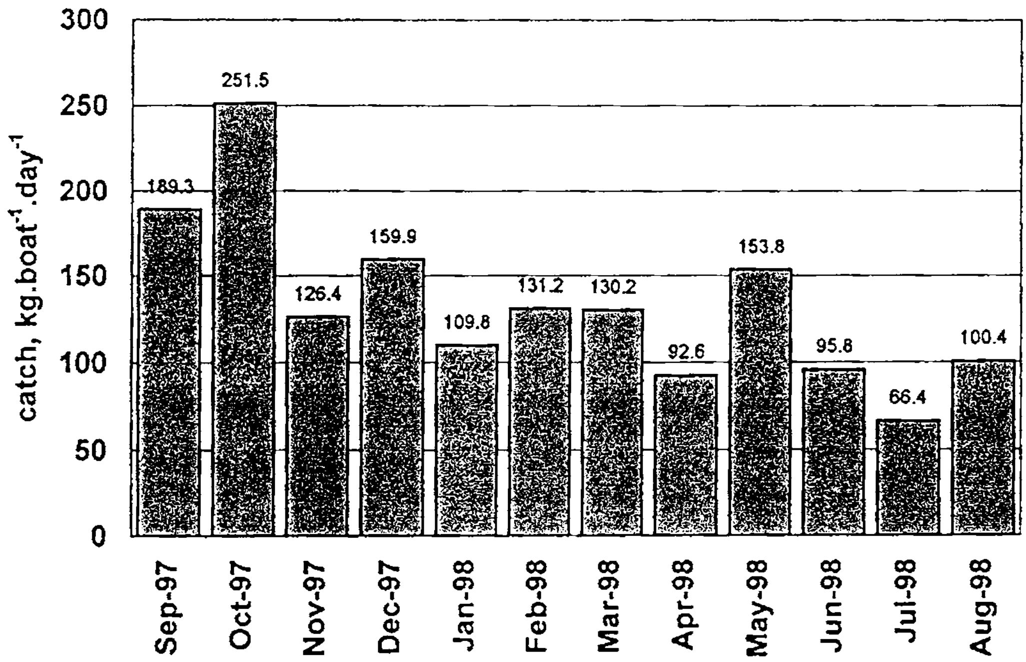


Fig. 5.9 **Mean catch.day^{-1} of gillnetter-cum-liners**

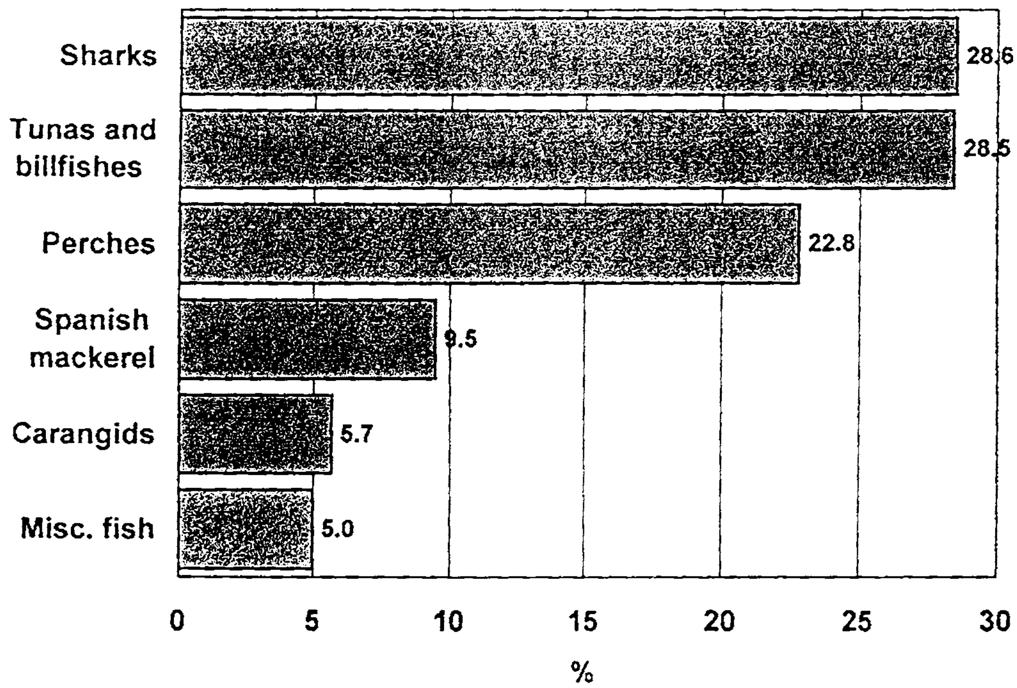
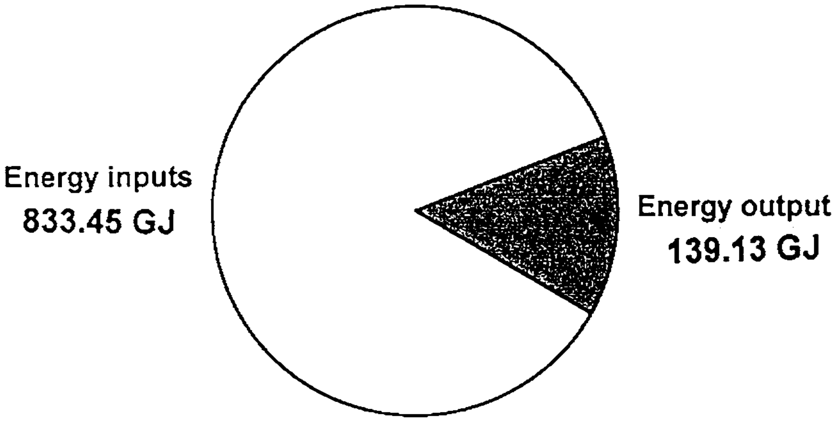


Fig. 5.10 Catch composition of gillnetter-cum-liners



GER.t fish^{-1}, GJ	=	25.39
Energy efficiency ratio	=	0.17
Energy intensity	=	5.99

Fig. 5.11 Results of energy analysis of gillnetter-cum-liners

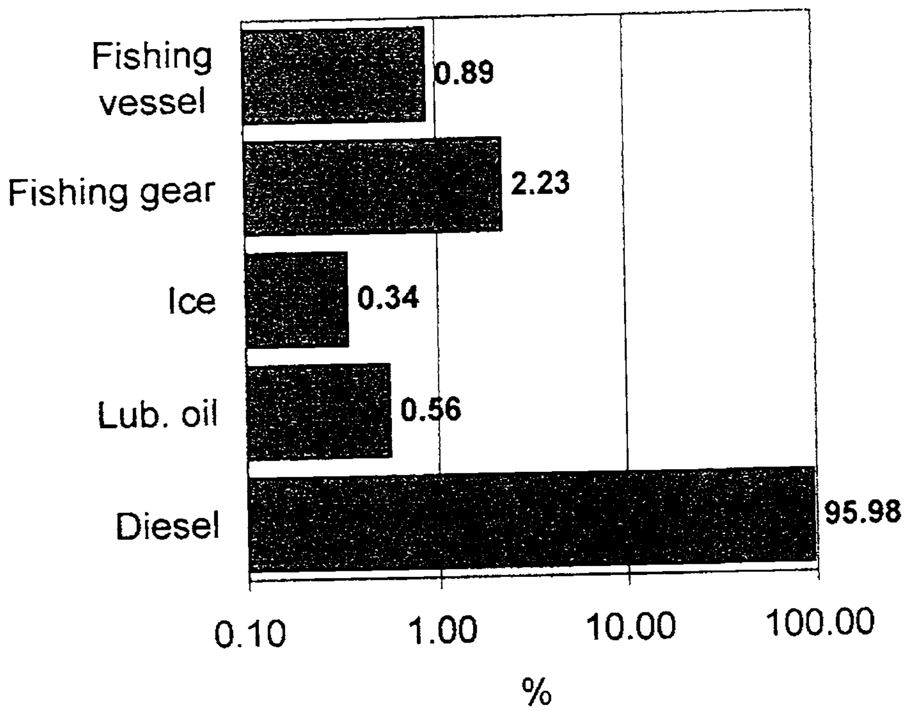


Fig. 5.12 Percentage contribution of energy inputs to GER of gillnetter-cum-liners

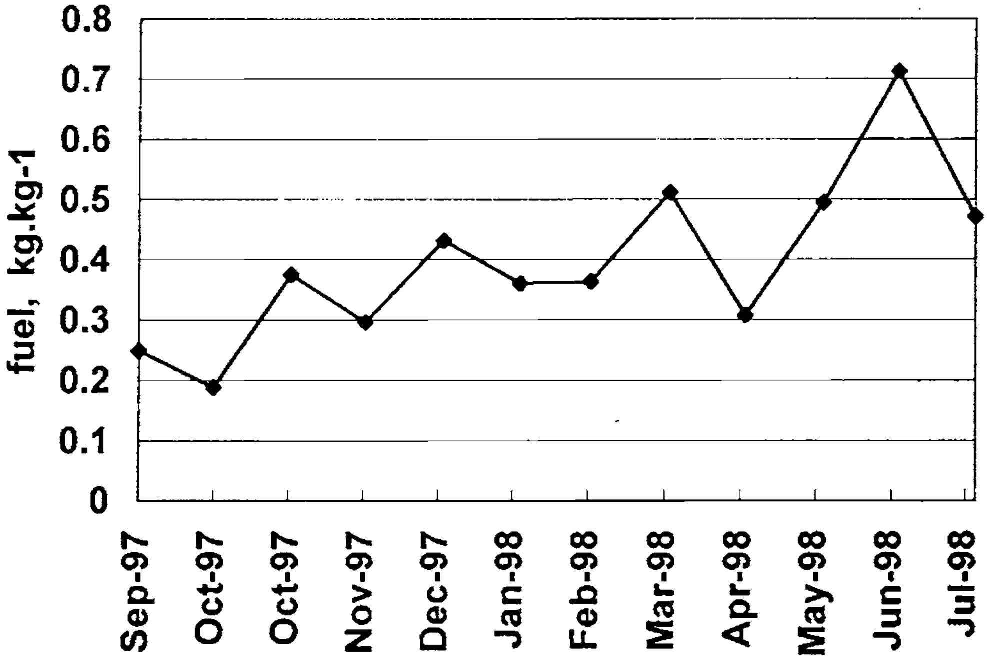


Fig. 5.13 Fuel consumption of gillnetter-cum-liners per unit volume of fish landed

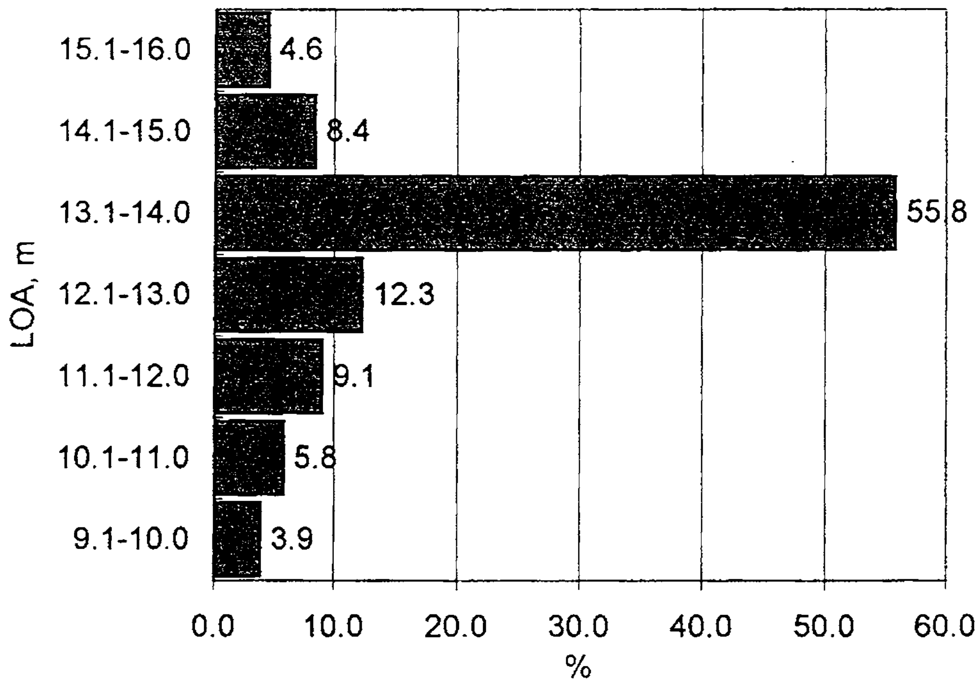


Fig. 5.14 Distribution of length classes of trawlers operating from Cochin

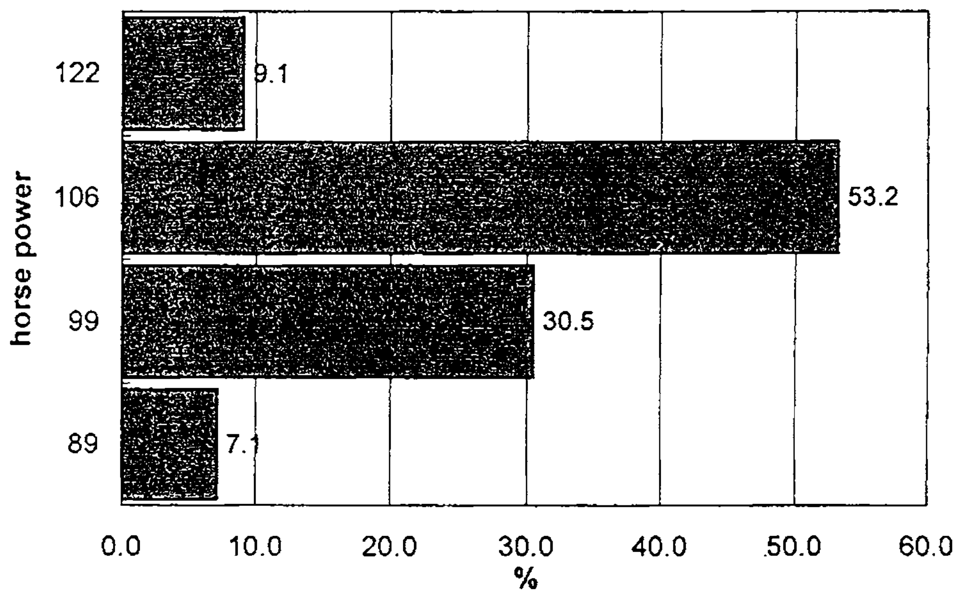


Fig. 5.15 Distribution of installed horse power of trawlers operating from Cochin

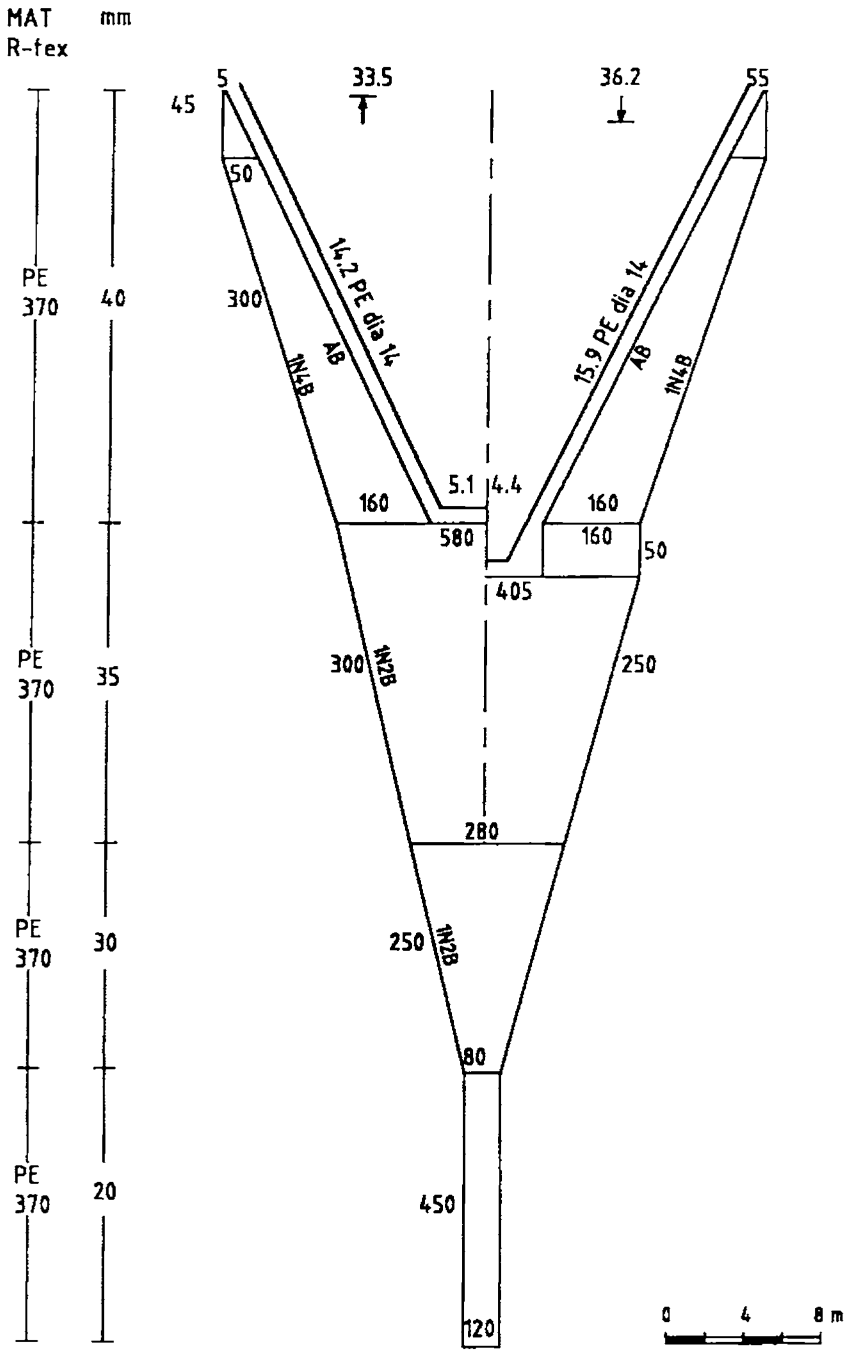


Fig. 5.16 Design of 33.5 m demersal shrimp trawl

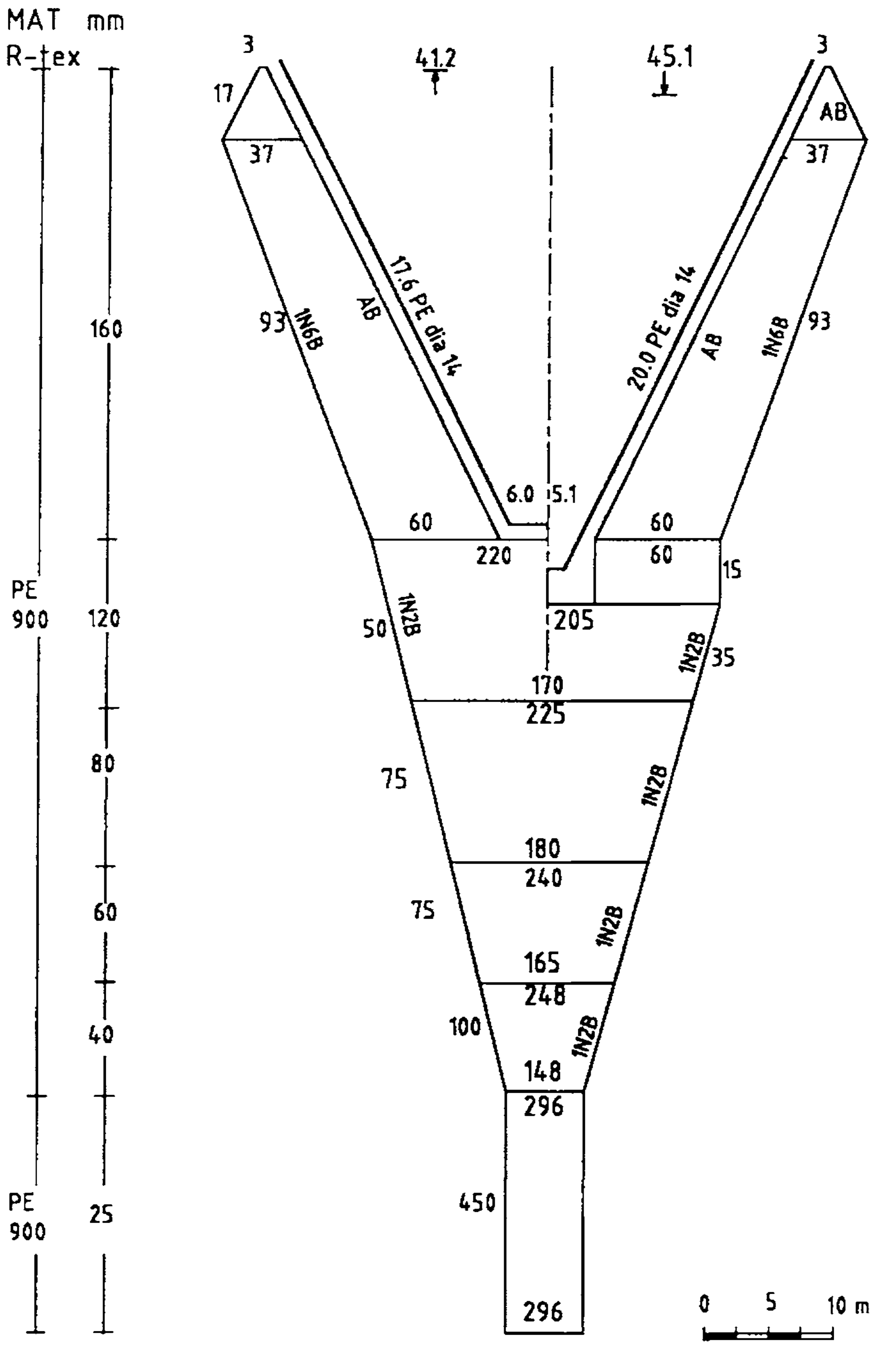


Fig. 5.17 Design of 41.2 m demersal fish trawl

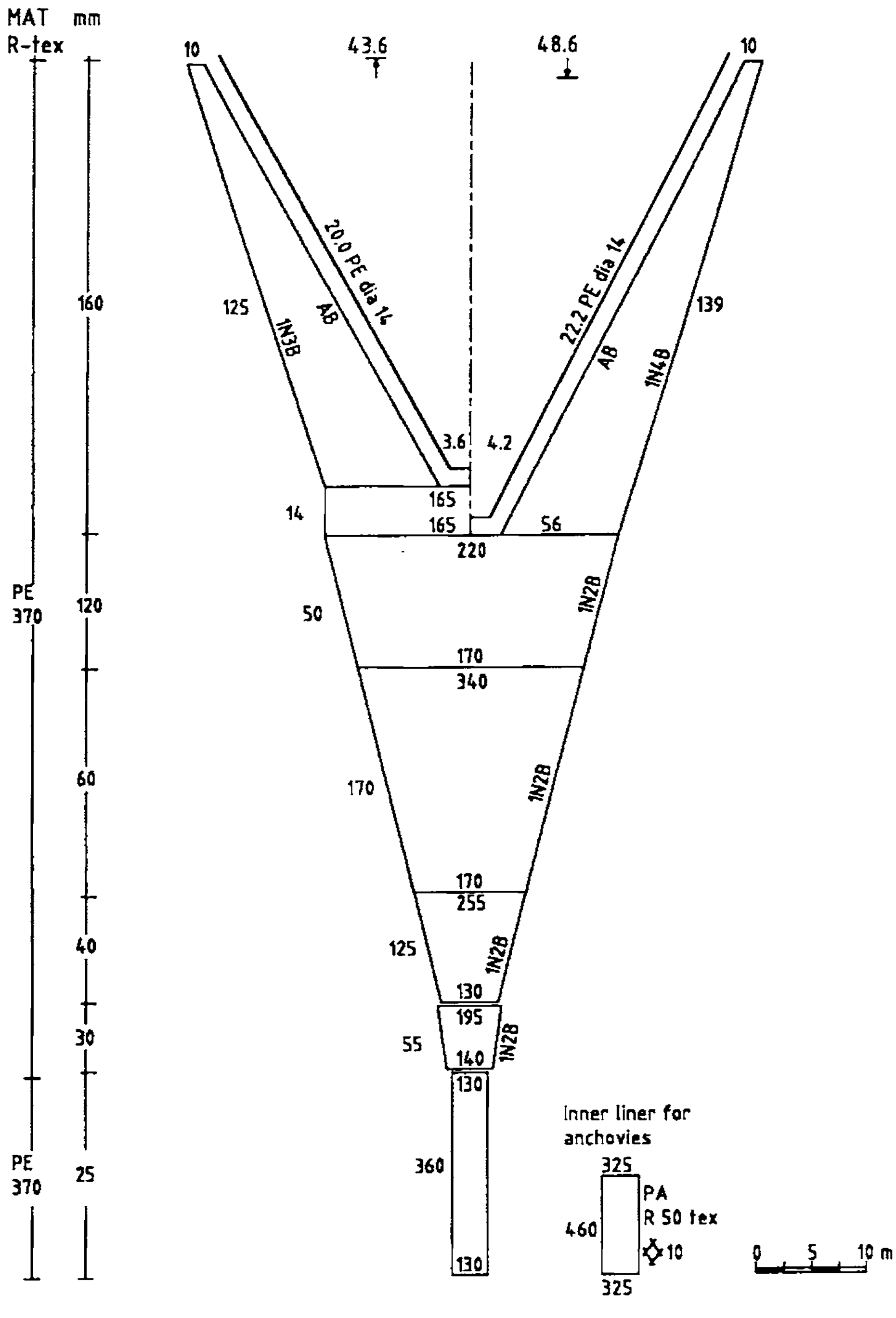


Fig. 5.18 Design of 43.6 m squid-anchovy demersal trawl

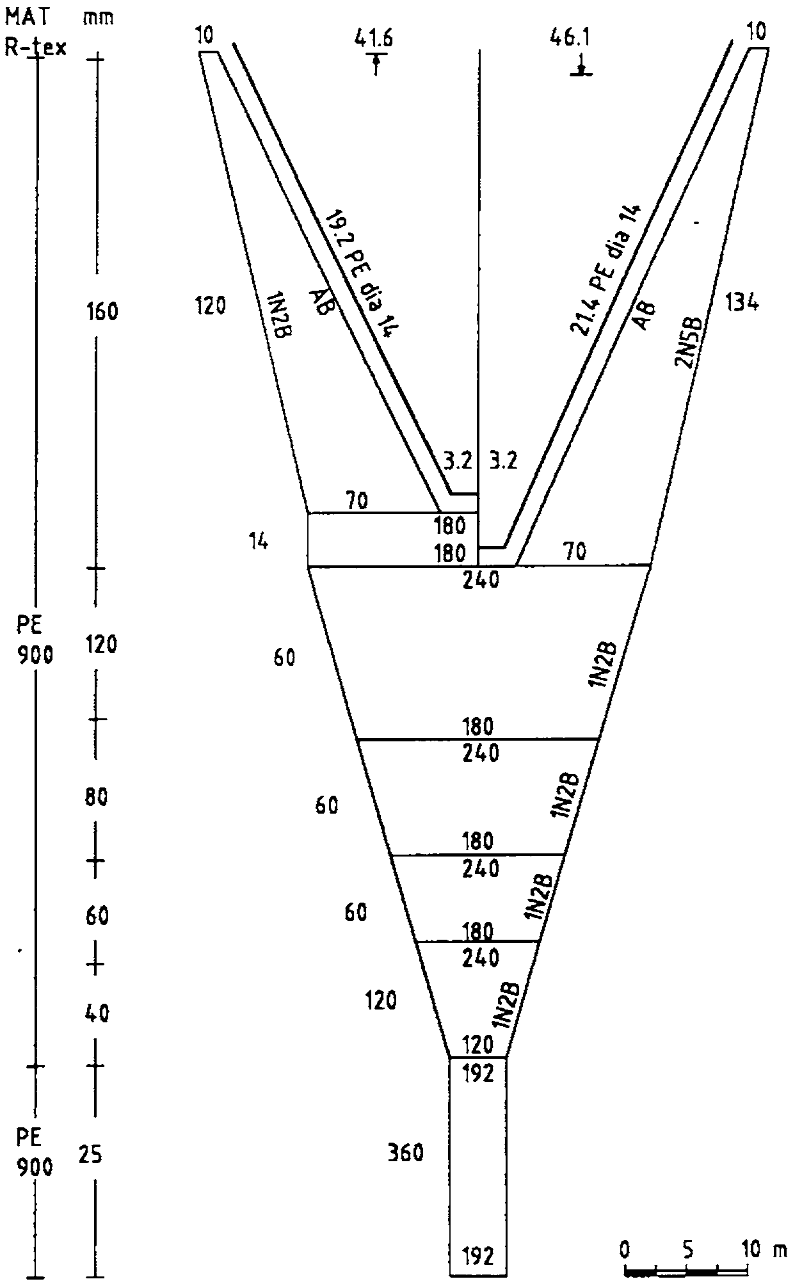


Fig. 5.19 Design of 41.6 m demersal trawl for cuttlefish

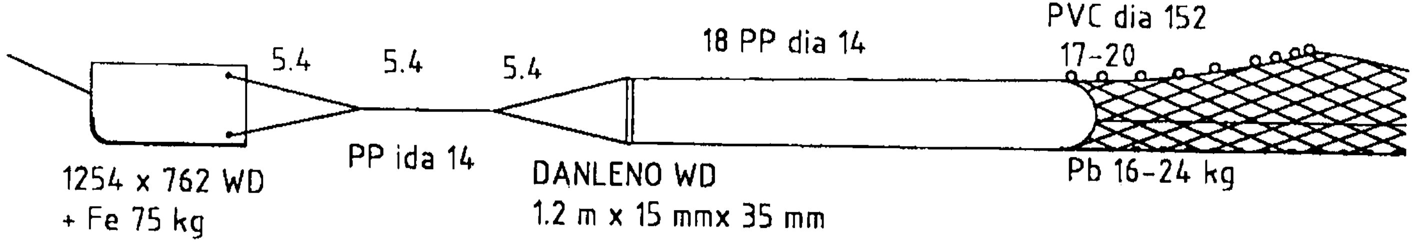


Fig. 5.20 Rigging of trawls for fish, squid & anchovies, and cuttlefish

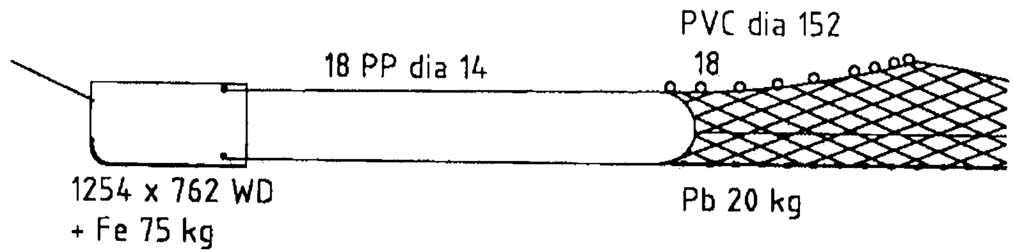


Fig. 5.21 Rigging of shrimp trawl

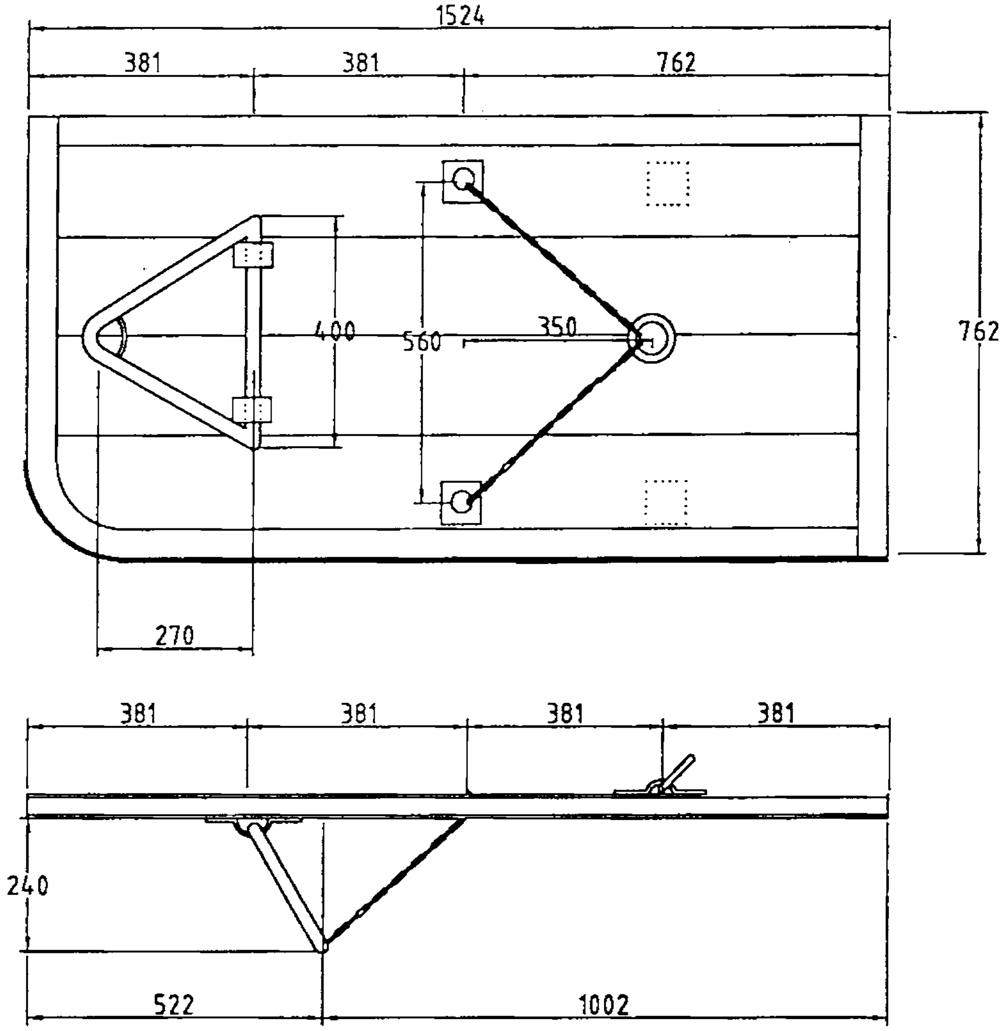


Fig. 5.22 **Design details of flat rectangular otter board of wood and steel construction (1524x762 mm; 75 kg.)**

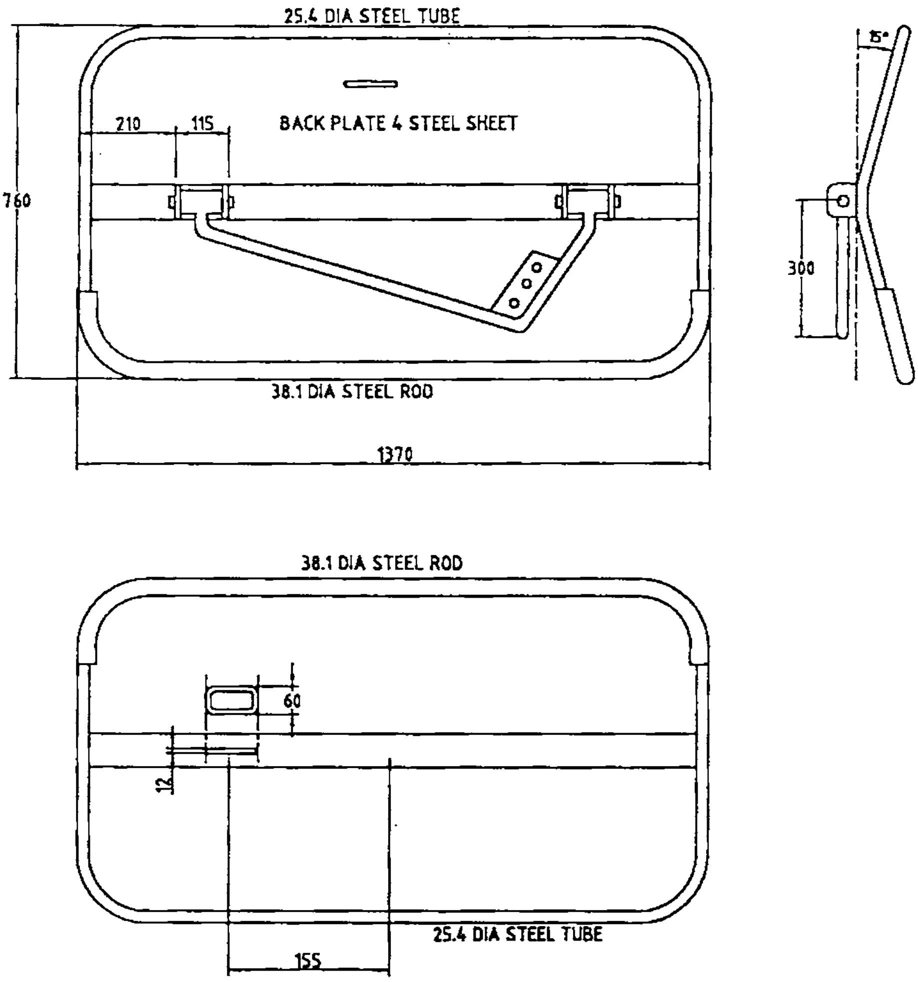


Fig. 5.23 Design details of rectangular V-form steel otter board (1370x760 mm; 65 kg.)

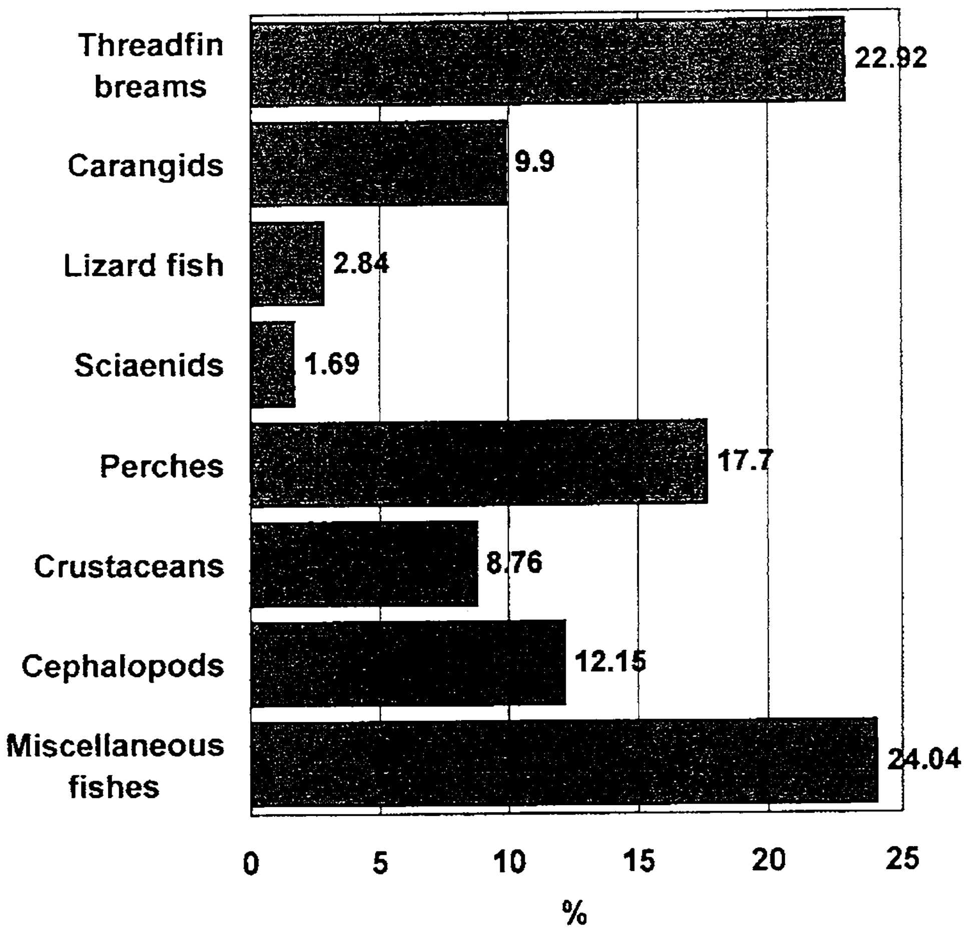


Fig. 5.24 Composition of trawler catches

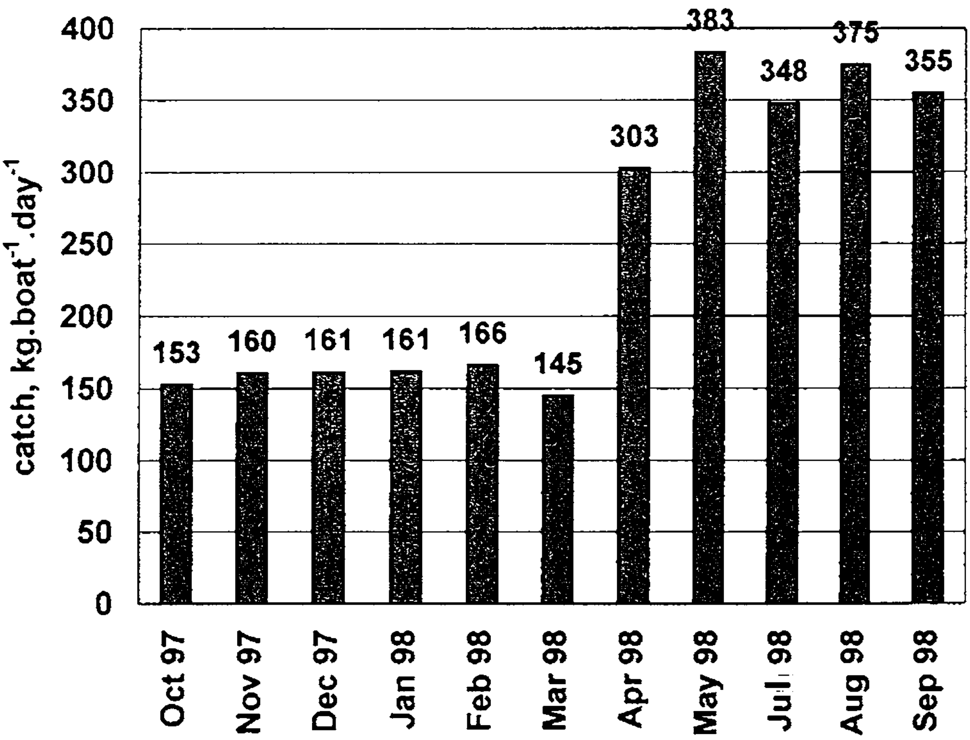
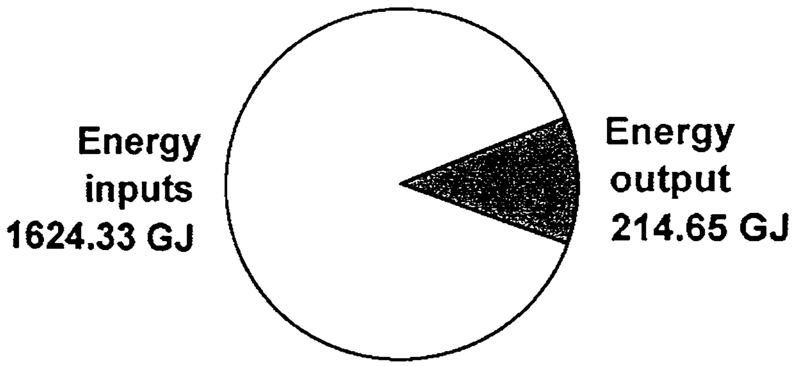
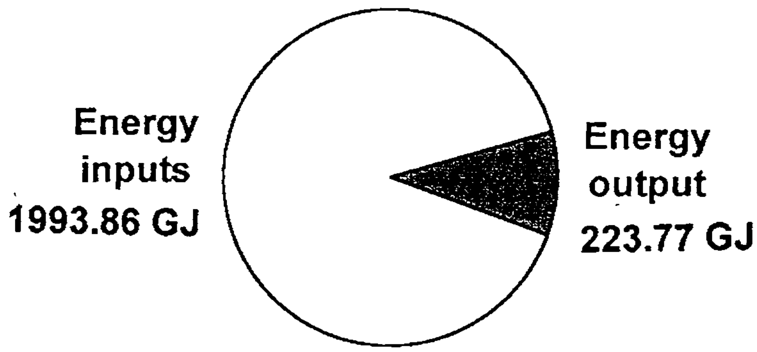


Fig. 5.25 Mean catch.day^{-1} of mechanised trawlers



GER.t $fish^{-1}$, GJ	=	31.40
Energy efficiency ratio	=	0.13
Energy intensity	=	7.69

Fig. 5.26 Results of energy analysis of wooden trawlers



GER.t fish^{-1}, GJ	=	36.97
Energy efficiency ratio	=	0.11
Energy intensity	=	8.91

Fig. 5.27 Results of energy analysis of steel trawlers

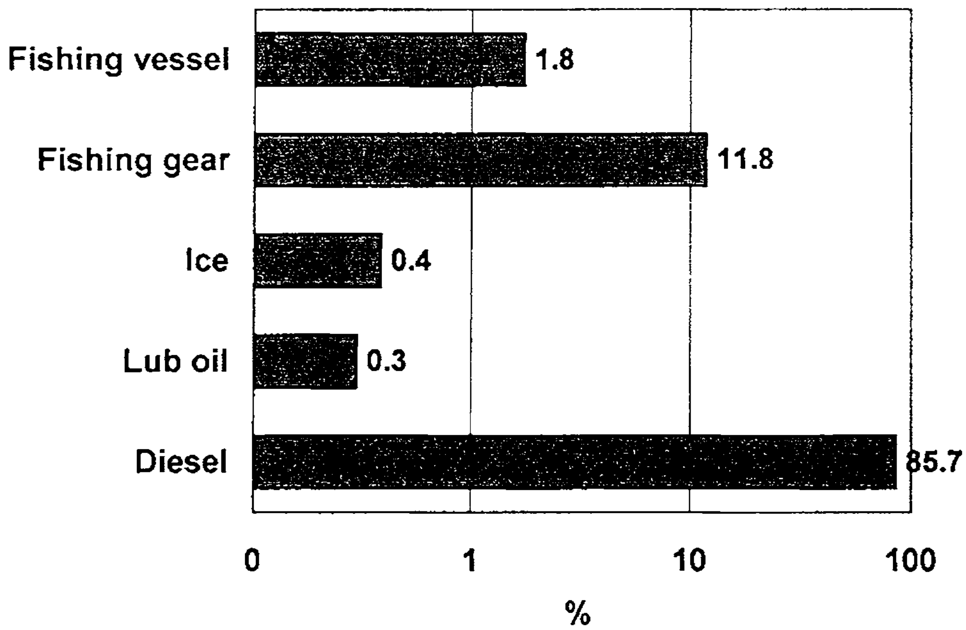


Fig. 5.28 Percentage contribution of energy inputs to GER of wooden trawlers

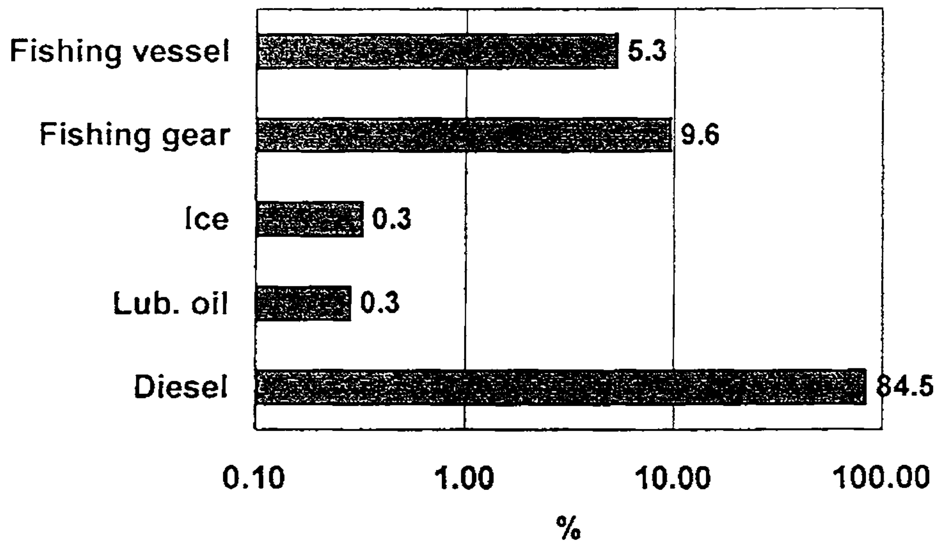


Fig. 5.29 Percentage contribution of energy inputs to GER of steel trawlers

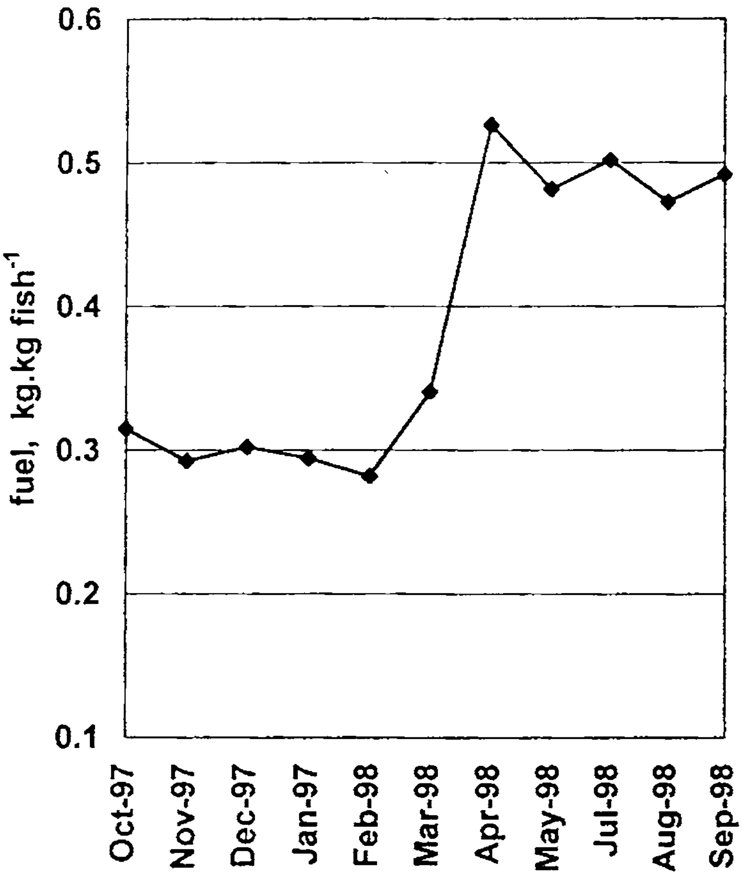


Fig. 5.30 Fuel consumption of trawlers per unit volume of fish landed

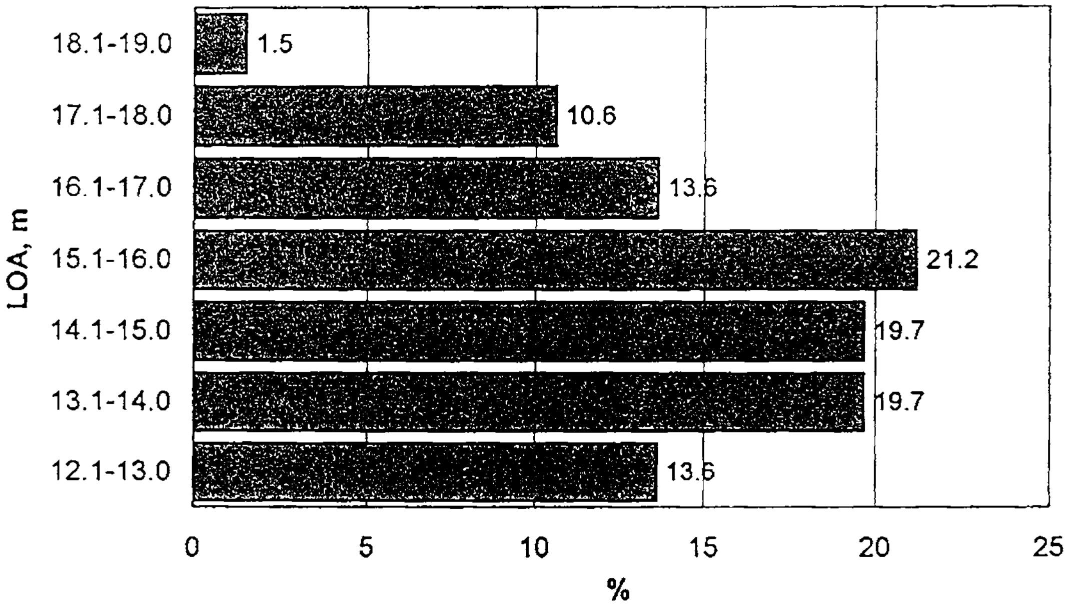


Fig. 5.31 Distribution of length classes of purse seiners operating from Cochin

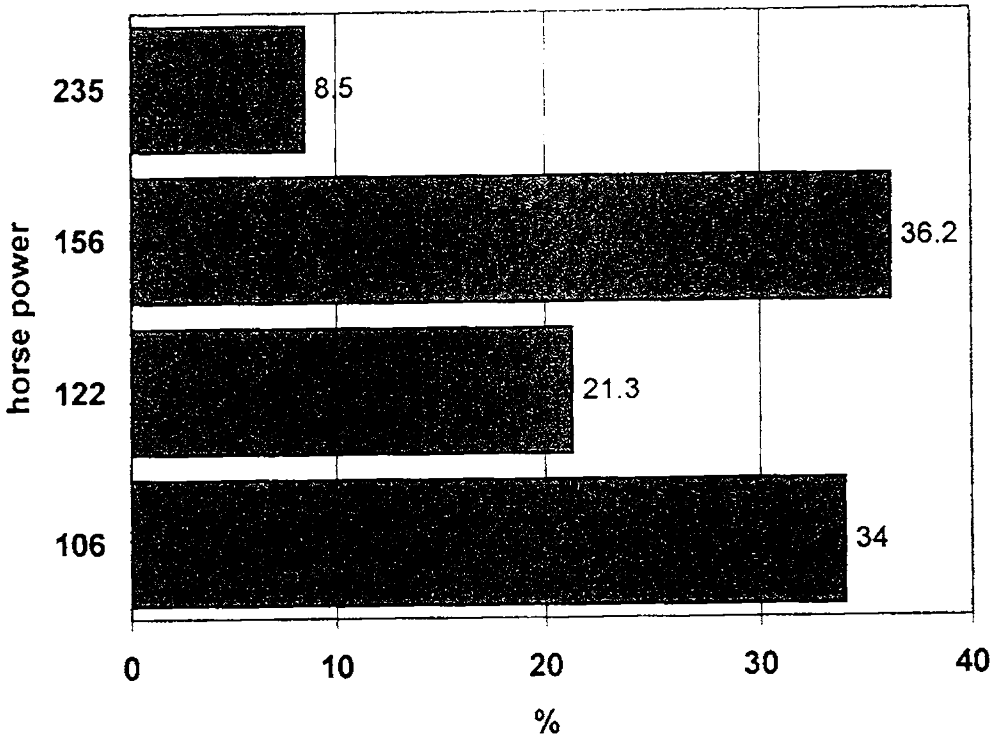


Fig. 5.32 Distribution of installed horse power of purse seiners operating from Cochin

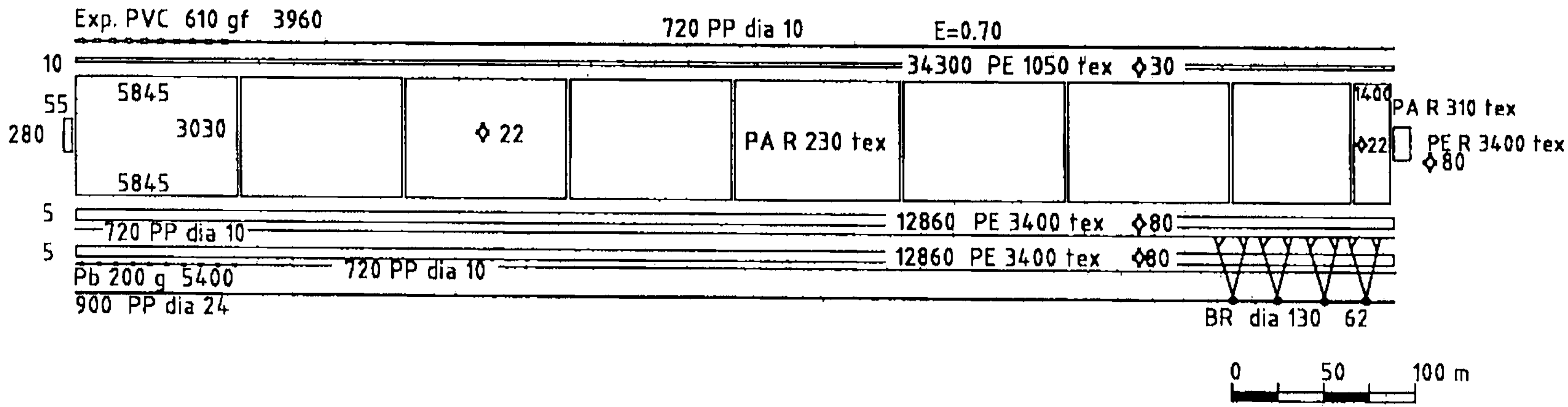


Fig. 5.33 Design of purse seine operated from small mechanised purse seiners

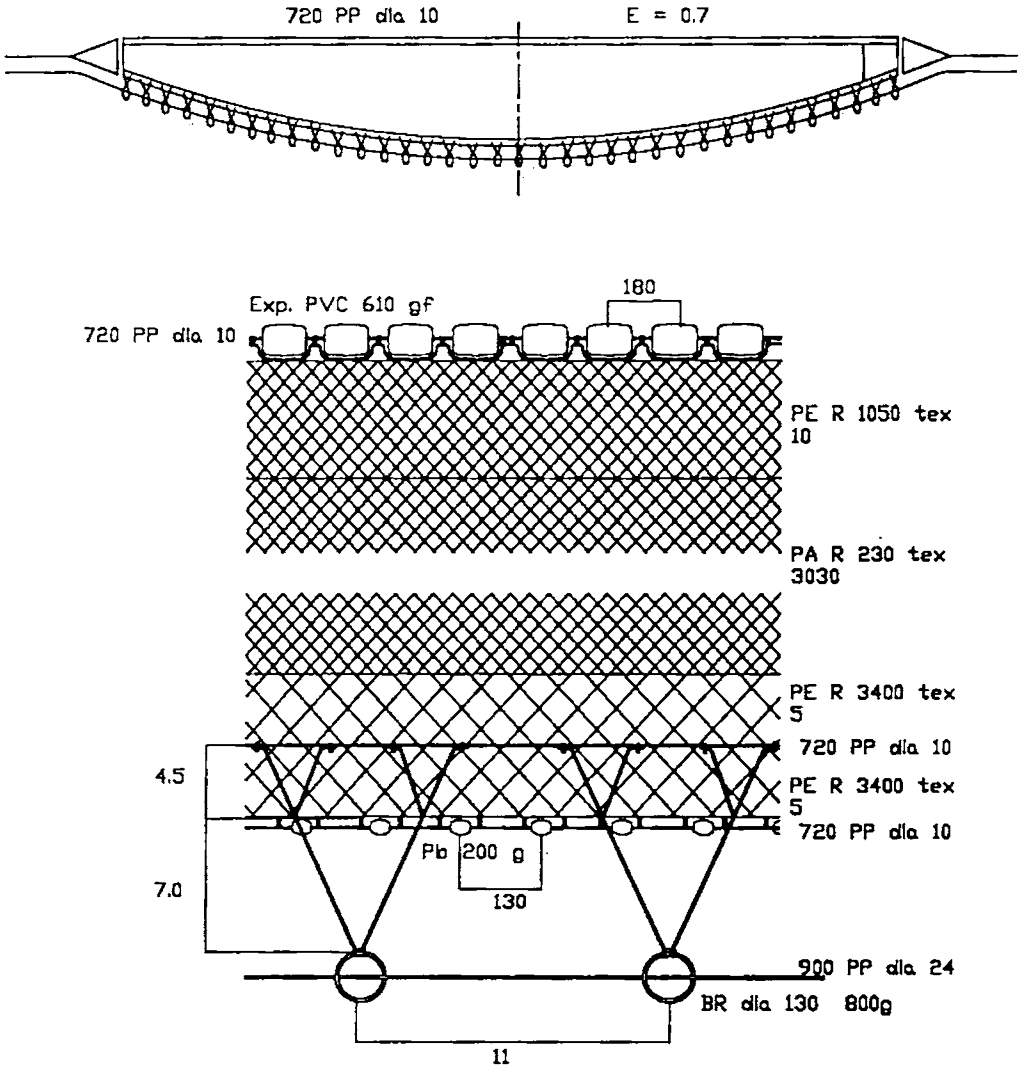


Fig. 5.34 Details of purse seine design and rigging

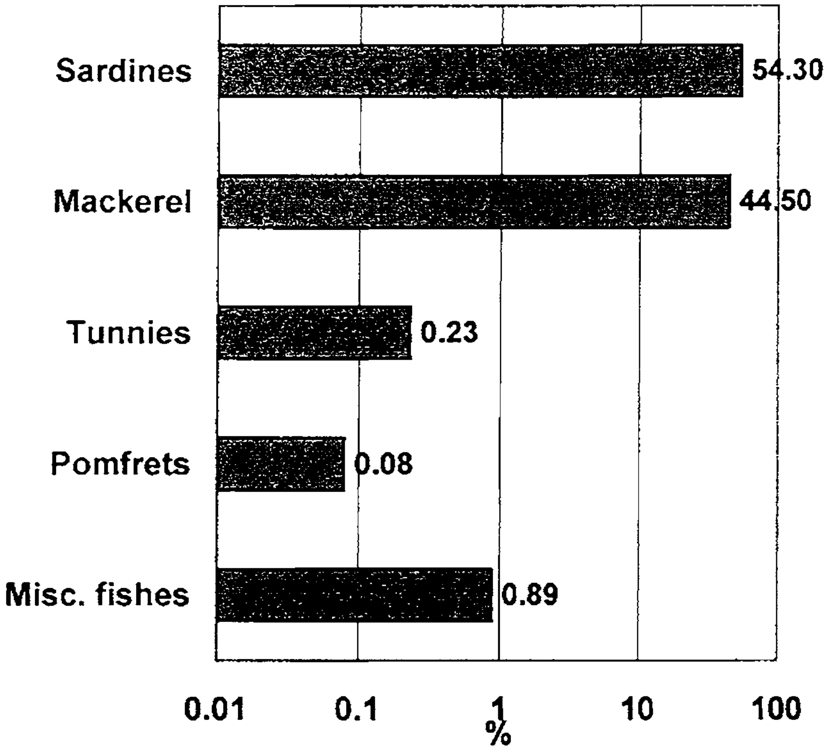


Fig. 5.35 Catch composition of mechanised purse seiners

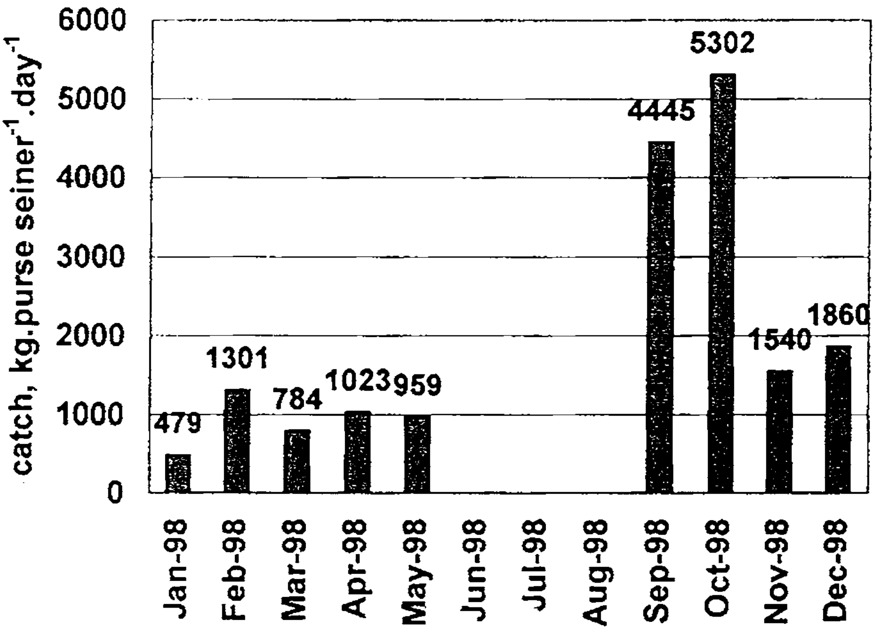
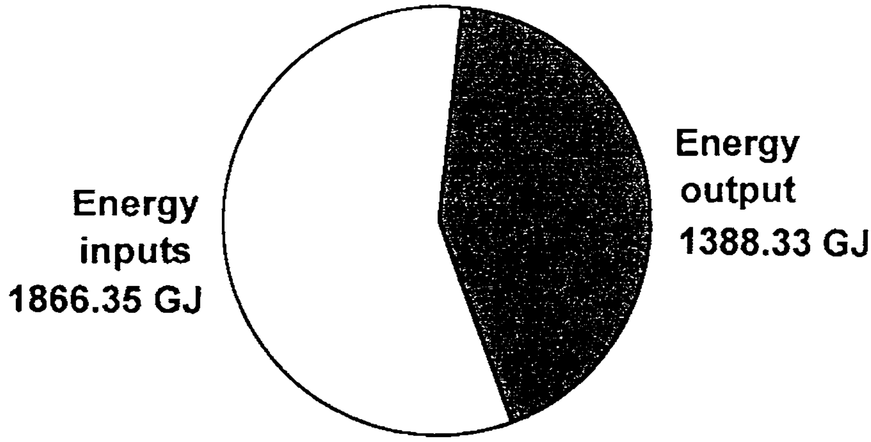


Fig. 5.36 Mean catch.day^{-1} of mechanised purse seiners



GER.t fish^{-1}, GJ	=	5.94
Energy efficiency ratio	=	0.75
Energy intensity	=	1.34

Fig. 5.37 Results of energy analysis of mechanised purse seiners

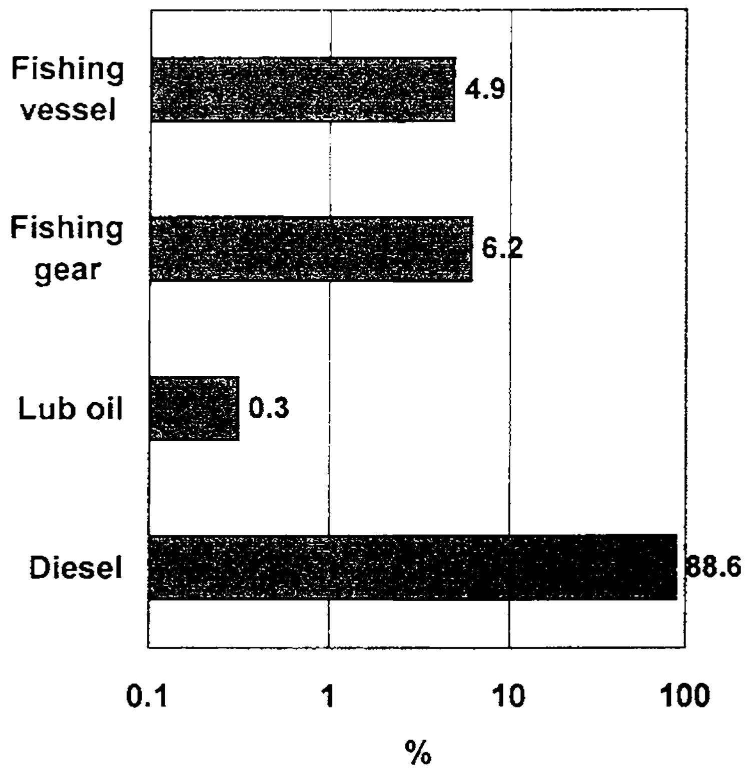


Fig. 5.38 Percentage contribution of energy inputs to GER of mechanised purse seiners

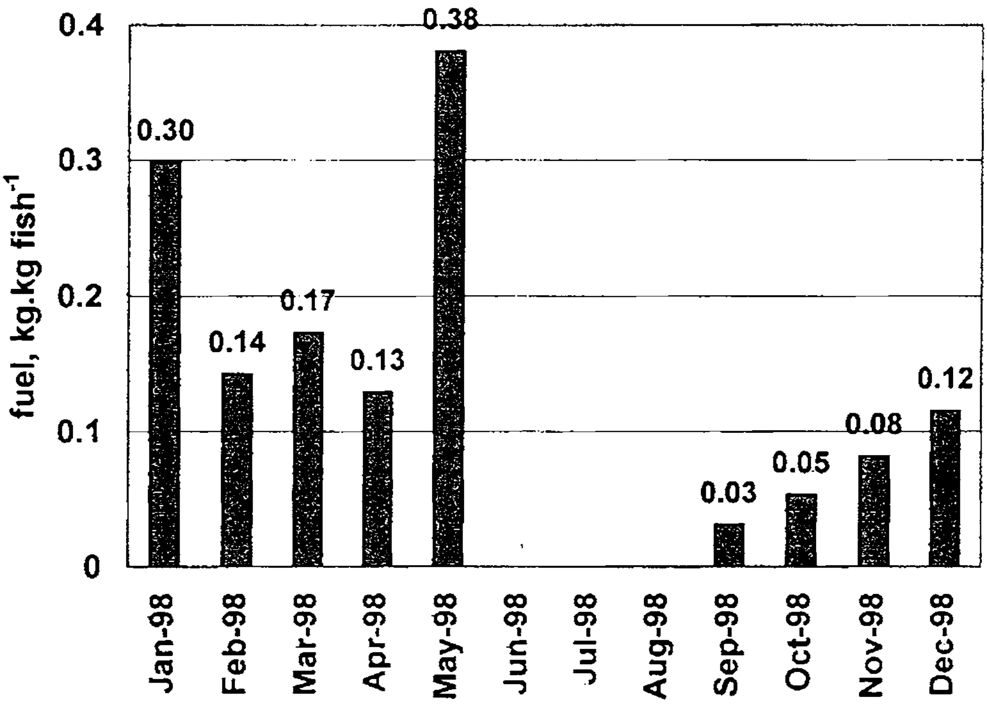


Fig. 5.39 Fuel consumption of 235 hp purse seiners per unit volume of fish landed

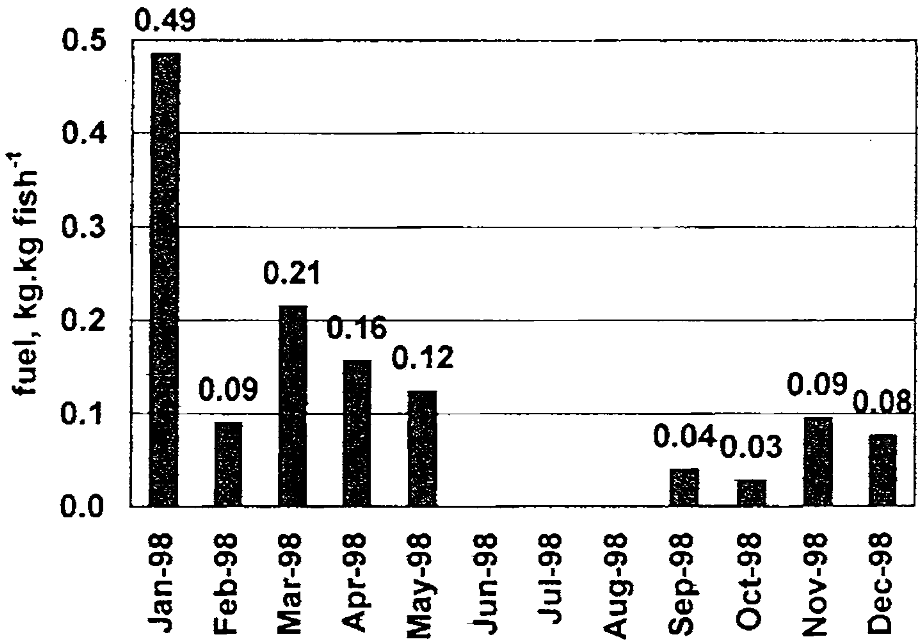


Fig. 5.40 Fuel consumption of 156 hp purse seiners per unit volume of fish landed

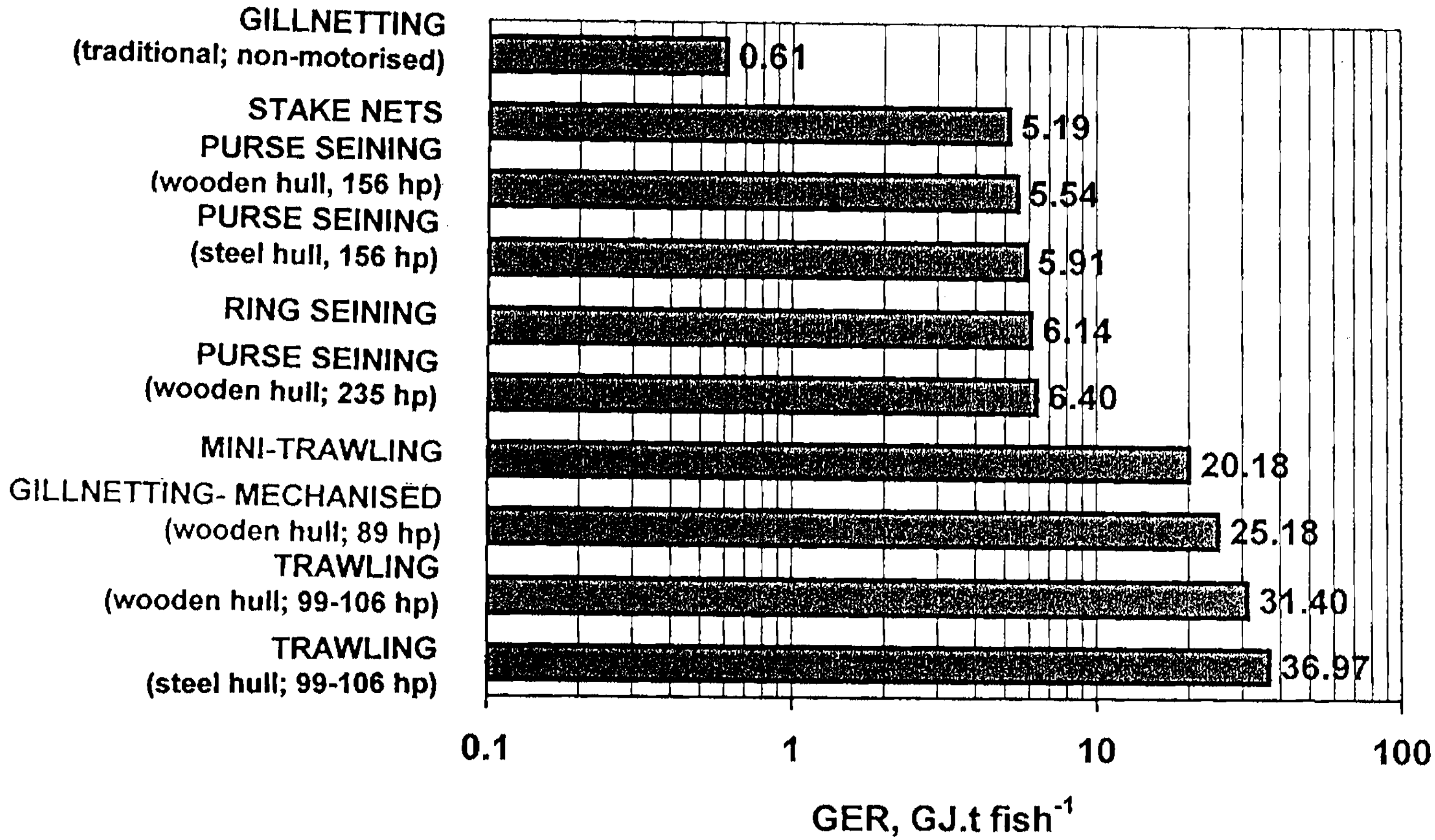


Fig. 5.41 **The range of Gross Energy Requirements for fish harvesting systems**

Chapter 6

Relative Energy Consumption in Demersal and Aimed Midwater Trawling in an Intermediate Range Freezer Trawler

6.1 Introduction

With the declaration of the Exclusive Economic Zone in 1986 over 2 million square kilometres, extending to 200 nautical miles from coastline, was brought under the exclusive national jurisdiction. This has restricted the free and open access of the distant water fishing fleet operated by developed nations such as Japan, Taiwan, Korea and erstwhile USSR. The need for developing deep sea fishing industry for harvesting the extended area of jurisdiction was reflected in the formulation of deep sea fishing policy during 1991 and its subsequent reviews (Anon, 1977; Anon, 1996a; Vijayakumaran & Haridas, 1998). Over 180 fishing vessels of 20 m L_{OA} and above and about 30 large vessels under joint venture / charter scheme, were in operation in Indian waters in 1990s. The vessels under joint venture / chartered category were large trawlers equipped for undertaking demersal and/or midwater trawling, and long liners. The main objective of the deep sea fishing policy was modernisation of deep sea fishing sector of

India, in a phased manner by acquisition of technology and expertise in order to harvest the under-utilised deep sea fishery resources in the Indian EEZ.

Single boat midwater trawling was developed in the late 1940s to capture pelagic shoaling fishes. Since then, the development and application of this fishing technique has progressed at a great speed in different parts of the world. In midwater trawling, the gear must easily be manoeuvrable in accordance with the distribution of shoals of target species between surface and sea bed. Successful midwater trawling require effective use of acoustic fish detection and net monitoring equipment, in order to guide the net accurately into the position of shoals. Both one-boat and two-boat midwater trawling are practised in commercial fisheries, in different parts of the world (Amos, 1980; Brandt, 1984; Sainsbury, 1996; Hameed & Boopendranath, 2000).

Pelagic species are generally fast swimming. They form dense shoals during day-time and respond to stimuli collectively. Pelagic fishes posses well developed sight and hearing capabilities. Midwater trawling is most successful when shoals are dense and large; when fishes are less active due to low ambient temperature or physiological states such as non-feeding, spawning or spent conditions; and when visibility is poor causing fish to react more slowly. Main design requirements for midwater trawls are high stability, large mouth opening, low turbulence and low drag. Midwater trawls require largest possible opening of the mouth, permitted by the available towing force of the vessel at the required towing speed, allowing roughly 30 % margin of reserve power for gear manoeuvre during operations. The large mouth opening is usually achieved by the incorporation of large side panels. Wings are consequently reduced in size or absent altogether in the midwater trawl, unlike the bottom trawl. The mouth opening may be oval, circular or square depending on the design and rigging. In some designs of surface operated trawls, the lower panel is extended ahead of the head rope. This is to counteract the tendency of pelagic fishes to dive downwards in response to disturbance caused by the approaching trawl (Scharfe, 1969; Kristjonsson, 1971; Amos, 1980; Anon, 1993b).

Smooth water flow through the net is an extremely important requirement in midwater trawls in order to prevent turbulence in the proximity of the trawl mouth. In order to achieve smooth water flow, midwater trawls are longer and more finely tapered with longer extension piece and codend, compared to bottom trawls. In addition, very large meshes are generally used in the wing and front trawl sections which reduce the drag and improve the water flow. Most pelagic fishes are effectively herded by the large meshes used in the front trawl sections, into the small meshed hind part and codend. Increase in mesh sizes of the front trawl sections is a major design improvement that has taken place in midwater trawl design. Mesh size of 200 mm used in earlier designs gradually increased to 3000 mm or more in large modern midwater trawls. Brabant *et.al* (1980) have reported the technological superiority, in terms of drag reduction and increase in volume filtered, of pelagic trawls wherein front sections are replaced with large meshes and ropes. Fishes are generally subject to herding effect when they approach near the netting panel (Glass *et.al.*, 1993). Effective dimension of the net mouth thus, would be less by the distance from the panel at which the herding response is effective.

One of the important features of midwater trawl is the high towing speed required for catching fast-swimming pelagic fish. Size of the net and the resultant drag has to be matched with the vessel's available towing force at the towing speed effective for the target species. Drag of midwater trawl is primarily determined by twine surface area of the netting. Drag is also influenced by the shape and taper of the net and gear appurtenances such as floats, weights and sheer devices. Drag changes significantly with changes in towing speed (Reid, 1977; Amos, 1980; Fridman, 1986). The most popular otter board used for one-boat midwater trawling is suberkrub design (Suberkrub, 1959). Suberkrub otter boards have high hydrodynamic efficiency with a sheer-drag ratio in excess of 6.0, high aspect ratio of 2:1 and is vertically cambered. Introduction of suberkrub otter boards is a significant development in one-boat midwater trawling (Brandt, 1971; FAO, 1974).

Some of the earliest developmental stages in one-boat midwater trawling were the introduction of Larsson's phantom trawl; British Colombian trawl for herring; and Cobb pelagic trawl for Pacific hake (McNeely *et.al.*, 1965; Brandt, 1971; Anon, 1993b). Wider commercial acceptance of the technique took place after the successful introduction of the German one-boat midwater trawling system in 1960s and the simultaneous developments in the acoustic fish detection and net monitoring equipment. Success of the German one-boat trawling has proved that a midwater trawl of large mouth area towed even at a slower speed could be more effective than a trawl with small mouth area towed at a greater speed (Scharfe, 1969). Midwater trawl designs operated in different parts of the world tend to be similar in general features with regional variations in the structure and rigging of the gear components.

General information on aimed midwater trawling technique have been given by Brandt (1971; 1984); Sainsbury (1996), Hameed & Boopendranath (2000). In aimed midwater trawling, the vessel is steamed towards the shoal of the target species after its location by sonar. At a reasonable distance from the target shoal, the gear is shot and its position under water is adjusted so as to take in the shoal. The fishing depth of the trawl is adjusted by varying vessel's speed and the length of the towing warps, either singly or in combination, for quicker response. The net monitor (net sonde) attached to the head rope of the trawl provides the data on the fishing depth, vertical opening of the net mouth and the catch entering the net, which are required for successful gear manoeuvre, based on data from sonar and echo sounder. Additional sensors in net monitoring system could provide data on the horizontal spread of the trawl mouth and at otter boards, *in-situ* temperature and catch increment in the codend (Allison, 1971; Horn, 1971; Mross, 1989; Larsen, 1989).

In midwater trawl, towing tension is on the head rope and the vertical opening is primarily achieved by the depressor weights attached to the lower wing-ends. Floats attached to the head rope help in keeping the head rope clear during shooting and hauling operations. Thus, in midwater trawling, the combined length of the lower sweeps and bridles between wing-end and otter board are longer than the upper sweeps and bridles. In contrast, the towing tension is on the ground rope along the sea bed in the bottom trawl and the vertical opening is achieved by lifting the head rope from the sea bed by net design features and floatation. Towing speed varies with the target species. A towing speed of 2.5 - 3.0 kn may be good enough for slow swimming target species while for fast swimming species towing speeds of 4.5 - 8.0 kn are used.

In India, studies on midwater trawling from small trawlers were conducted by Perumal (1966) Sivan *et.al.* (1970), Kartha & Sadanandan (1973), Mhalathkar *et.al.* (1975), Mhalathkar *et.al.* (1983) and others. Indo-Norwegian Project conducted two-boat midwater trawling using midwater trawls of 17.6 m head rope from 9.76 m L_{OA} vessels, within 25 m depth zone off Kerala coast, during 1973-78. Single boat midwater trawling was conducted off Kerala within 40 m depth, using 26.8 m x 26.8 m midwater trawl from 17 m L_{OA} (233 hp) and 19.81m L_{OA} (220 hp) vessel; 43.3m x 43.3 m midwater trawl from 23.8 m (480 hp) vessels and 36.1 m x 44.4 m midwater trawl from 28.0 m L_{OA} (400 hp) vessel, during 1973-75. Major landings during these operations were silver bellies, glass perches, clupieds, carangids and anchovies (Verghese, 1975; Verghese & Nair, 1975; Oommen, 1989). Kuttappan *et.al.* (1990) conducted midwater trawling trials form *FORV Sagar Sampada* using three variations 46.4 m midwater trawls, rigged with 750 kg Lindholmen pelagic otter boards. Midwater rope trawls were operated successfully during Indo-Polish Industrial Fisheries Survey, along the north-west coast of India for pelagic resources such as horse mackerel, ribbonfish, elasmobranchs, pomfret, catfishes and carangids (Dwivedi *et.al.*, 1977). Boopendranath *et.al.* (1999) conducted investigations on midwater trawling for Antarctic krill, during the First Indian Antarctic Krill Expedition (FIKEX) 1995-96.

Demersal trawls suitable for deep sea operations from large vessels such as high speed demersal trawls, bobbin trawl, hybrid trawl for squid and high opening trawl, were developed by Central Institute of Fisheries Technology, based on investigations from *FORV Sagar Sampada* (Panicker, 1990; Kunjipalu *et.al,*1996).

The relative operational energy consumption in fish production by demersal and aimed midwater trawling has not been studied so far in Indian waters. In the present study, fuel consumption and direct energy expenditure in fish production by an Intermediate Range Freezer Trawler which was in operation in Indian waters during 1990s has been undertaken.

The objectives of the present study were :

i. survey of the fishing gear, equipment and operation in an intermediate range freezer trawler operations;
ii. determination of daily production of the trawler by midwater and bottom trawling in the north-west coast of India; and
iii. estimation of operatuonal energy requirement per unit production of fish by aimed midwater trawling and bottom trawling.

6.2 Materials and methods

Data on landings obtained during two cruises of Intermediate Range Freezer Trawler which operated in Indian waters during 1993-94 were utilised for this study. The freezer trawler was designed for stern trawling using a bottom or midwater trawl and for onboard production of frozen fish packed in master cartons; production of fish meal and technical fish oil from non-food fish; for storage of fish products and transportation of products to the port or transhipment to the transport ships (reefer vessels). The trawler had a length overall of 62.2 m and gross registered tonnage of 1898 t. It had an installed engine horsepower of 2400 hp, controllable pitch propeller in the steering nozzle and stern ramp for lowering and lifting of the fishing gear. Details of the vessel, equipment and fishing operations were collected during a cruise onboard in January 1994. The main particulars of the vessel, power plant and fishing equipment are given in Table 6.1. A view of the Intermediate Range Freezer Trawler and catch obtained by aimed midwater trawling are given Fig. 6.7 and 6.8, respectively.

Operations were conducted off west coast of India, between latitudes 14° and 22° N, within the depth range of 31 and 125 m. (Fig. 6.1). Bottom trawl of 47.5 m headline length rigged with bobbin gear for rough bottom operation and oval slotted otter boards (6.5 m^2; 1750 kg each) were used for bottom trawling. Midwater trawl of 70.0 m headline length and suberkrub otter boards (8.0 m^2; 2750 kg each) were used for aimed midwater trawling. Design details of bottom trawl and midwater trawl are given in Fig. 6.2 and 6.3, respectively. Vertical opening of the trawl mouth and horizontal opening between otter boards were measured by acoustic trawl monitoring equipment with sensors for vertical opening attached to the trawl headline and otter boards. Towing speed was measured using Doppler log.

Average duration of tow for bottom trawling was 2.57 h and 2 to 4 hauls were taken per day. The mean towing speed was 4.23±0.24 knots.

Seventy-five hauls spread over 24 days were taken during the period of study. Average duration of tow for aimed midwater trawling was 1.88 h and 2 to 3 hauls were taken per day. The mean towing speed was 4.33±0.16 knots. Seventeen aimed midwater trawling operations spread over 6 days, were conducted during the period of study. Details of operation and catch for bottom and aimed midwater trawling are given in Table 6.2 and 6.3, respectively.

Estimated duration of time spend for searching, shooting, towing and hauling for both bottom and aimed midwater trawling operations are given in Fig. 6.4. The difference in daily catch rates by bottom and aimed midwater trawling operations were analysed using Student *t*-test after logarithmic transformation of data (Snedecor & Cochran, 1967).

Fuel consumption was estimated from the specific fuel consumption of the power plant for the estimated period of operation of the engines. Fuel consumption per unit volume of fish landed by both bottom trawling and aimed midwater trawling were determined from the data on the daily fuel consumption and landings. The daily fuel consumption per kg of fish landed were subjected to statistical analysis using Student *t*-test after logarithmic transformation of data, to determine if there is any significant difference between the values obtained for bottom trawling and aimed midwater trawling.

6.3 Results

Total landings during the period of operations were 272.8 t, of which 135.7 t were landed by bottom trawling during 24 days and 137.1 t by aimed midwater trawling during 6 days of operations. Mean daily catch for bottom and aimed midwater trawling were, respectively, 5655.5 kg (SE: 1461.9) and 22841.8 kg (SE: 7620.7) (Table 6.2).

Vertical opening of the bottom trawl was determined to be 6 m and horizontal opening between otter boards was 85 m. Midwater trawl attained a vertical opening of 45 m and horizontal opening between the otter boards was 160 m. Wing-end spread of midwater trawl was estimated to be 42 m.

Perches constituted 25.78 % of the total landings by demersal trawling followed by, nemipterids (13.53 %), ribbonfish (12.97 %), horse mackerel (8.55 %) sciaenids (5.75 %), cat fish (5.45 %), Indian mackerel (3.88 %), squids and cuttlefish (2.33 %), pomfrets (1.53 %), pseudosciaenids (0.96%) and miscellaneous fishes (19.27%). Over 99 % of the landings by aimed midwater trawling was constituted by horse mackerel (*Megaslpis cordyla*). Scad (*Decapterus* sp.) and miscellaneous species contributed 0.29 % and 0.51 %, respectively (Table 6.3 & Fig. 6.5).

Fuel consumption pattern for bottom trawling and midwater trawling, during the period of observations is given in Table 6.4. Total fuel consumed during the period of observations was 227.10 t of which 181.68 t was consumed during bottom trawling and 45.42 t during midwater trawling. Results of statistical analysis of the daily variation in the values of fuel consumption per kg of fish landed by bottom trawling and aimed midwater trawling are given in Table 6.5.

6.4 Discussion

The bottom and aimed midwater trawling operations, the results of which are presented in this Chapter were carried out within the depth strata of 31 and 125 m, between latitudes 14° and 22° N. The catch data showed large scale variations in the volume of total catch and catch composition.

During bottom trawling operations, the vessel spent on an average 3.46 % of the 24 h period for shooting, 33.67 % for towing the gear, 5.17 % for hauling, 4.08 % for ground shifting and 53.63 % for fishing-independent functions. During aimed midwater trawling operations, the vessel spent on an average 5.21 % for shooting, 25.79 % for towing, 5.67 % for hauling, 17.71 % for acoustic search for schools using search light sonar and 45.63 % for other functions unrelated to fishing (Fig. 6.4).

Average fuel consumption was estimated to be 7.75 $t.day^{-1}$. Overall fuel consumption per kg fish landed by bottom trawling and midwater trawling worked out to be 1.339 and 0.331 kg, respectively, showing a four-fold difference (Table 6.4). Daily values of fuel consumption per kg of fish landed ranged from a maximum of 37.83 kg to a minimum of 0.33 kg, with a mean value of 5.46 kg (SE: 1.61) and a median value of 2.70 kg, for bottom trawling. For midwater trawling, daily values of fuel consumption per kg of fish landed ranged from a maximum of 5.36 kg to a minimum of 0.15 kg, with a mean value of 1.44 kg (SE: 0.85) and a median value of 0.32. Statistical analysis of the values of daily fuel consumption per unit volume of landed catch, has shown that the variation between the two types of operations is highly significant ($p < 0.01$; df: 28) (Table 6.5). There is about four-fold increase in the consumption of fuel used for unit volume of landings by bottom trawling compared to aimed midwater trawling operations.

Investigations on one-boat midwater trawling by Integrated Fisheries Project, off the south-west coast during 1973-85, from five large trawlers of 17.0-28.0 m L_{OA} (220-480 hp), have given encouraging results (Oommen, 1989). The overall catch rate realised was 102.8 $kg.h^{-1}$. The landings consisted of anchovies 22.3 %, followed by glass perch (18.3 %), carangids (11.8 %), sardines (11.6 %), silver bellies (8.6 %), mackerel (0.5 %) and other fishes (26.9 %). Results of midwater trawling using rope trawl from *M.T. Muraena*, during Indo-Polish Industrial Survey, have shown that there is distinct possibility of catching sizeable quantity of horse mackerel, ribbon fish, pomfrets, catfish and carangids by midwater trawling from about 70-120 m along north-west coast of India (Anon, 1979). Taking advantage of the diurnal migration, squid and cuttlefish can also be caught by midwater trawling (Joseph, 1985). The present investigations have also shown that a significant improvement in landings were obtained during aimed midwater trawling. The mean daily landings rose from an average of 5.66 t, during bottom trawling to 22.84 t, during aimed midwater trawling, realising over 300 % improvement in the landings which manifested in a significant reduction in the consumption of fuel per unit volume of fish landed by midwater trawling. As there is intense concentration of effort in the bottom trawl fisheries, it could be advantageous from the resource management perspective and also from the energy conservation point of view, to encourage diversification to midwater trawling, in a controlled manner. Stern trawler does not require any large-scale modifications in structure or deck layout, for undertaking midwater trawling. However, the vessel must be large enough, highly manoeuvrable and sufficiently powered to tow a large mouthed midwater trawl at speeds exceeding 4.5 knots; should be equipped with acoustic fish detection (sonar) and trawl monitoring systems (net monitor or net sonde); and, in addition, must have provision for handling and preserving high volume landings of pelagic fish.

Table 6.1 Main particulars of the Intermediate Range Freezer Trawler, engine and equipment

VESSEL DETAILS		
Length overall	:	62.2 m
Beam	:	13.8 m
Depth to main deck	:	6.55 m
Light draught	:	4.19 m
Load draught	:	5.21
GRT	:	1898 t
NRT	:	492 t
Sea autonomy under fuel reserve	:	34 days
Crew	:	35 men
Diesel capacity	:	355.4 t
Lub oil capacity	:	13. 5 t
Fresh water capacity	:	42 t
Control of navigation and fishing	:	Centralised control from wheel house
POWER PLANT		
Main Engines		
Type	:	Diesel 8VD 26/20 AL-2
Number of engines	:	2
Power	:	1200 hp (880 kW) at 1000 rpm
Specific fuel consumption per engine	:	166 $kg.hp.h^{-1}$
Lub oil consumption per engine	:	1.8 kg.hr
Reduction gear		
Nominal output	:	2400 hp (1765 kW)
Input rotation	:	1000 rpm
Output rotation to propeller	:	203 rpm
Output rotation to shaft generator	:	1000 rpm
Auxiliary engine		
Number of engines	:	2
Power	:	846 hp (622 kW)
Specific fuel consumption	:	162 $g.hp.h^{-1}$
Lub oil consumption	:	1.5 $kg.h^{-1}$

Table 6.1 contd.

Emergency engine		
Number of engines	:	1
Power	:	102 hp (74 kW)
Specific fuel consumption	:	178 $g.hp.h^{-1}$
Lub oil consumption	:	0.2 $kg.h^{-1}$
Propulsion		
Type	:	Controllable Pitch Propeller
Number	:	1
Material	:	blades: brass; hub: steel
Number of blades	:	4
Rotation speed	:	203 rpm (3.38 $m.s^{-1}$)
ELECTRICAL EQUIPMENT		
Generators with independent drives		
Number	:	2
Power	:	568 kW
Voltage	:	390 V AC
Emergency generator		
Number	:	1
Power	:	62 kW
Voltage	:	390 V AC
Shaft generator		
Number	:	1
Power	:	640 kW
Voltage		390 V; AC
Shaft generator for driving winches		
Number	:	1
Power	:	325 kW
Voltage	:	465 V; DC
REFRIGERATION PLANT		
Purpose	:	Cooling of the fish hold; freezing of fish
Refrigerant	:	Freon 22
Freezers		
Number	:	2
Type	:	Plate freezer - rotor type ; -40°C
Capacity	:	2 x 15 $t.day^{-1}$

Table 6.1 contd.

PROCESSING CAPACITY		
Products processed onboard		Frozen fish; fish meal and technical fish oil
Freezing capacity	:	30 $t.day^{-1}$
Fish meal and technical fish oil (raw fish intake)	:	10-12 $t.day^{-1}$
CARGO HOLDS AND TANKS		
Hold for frozen fish	:	Capacity: 507 m^3; -27°C
Hold for fish meal	:	Capacity: 70 m^3
Tank for fish oil	;	Capacity: 20.3 m^3
COMMUNICATION FACILITIES AND NAVIGATION AIDS		
Radio stations	:	5 nos
Radio transmitters	:	2 nos
Radio receivers	:	3 nos
Radio distress transmitters	:	3 nos
Radar	:	2 nos; 15 kW; range : 115 km
Radio direction finder	:	1 no.
Satellite navigation system	:	1 no.
Gyrocompass	:	1 no.
Doppler log	:	1 no.
Navigation echo sounder	:	1 no.; 25.5 kHz; range: 1200 m
FISH FINDING DEVICES		
Fish finder	:	1 no.; 19.7 kHz; range: 3000 m
Search light sonar	:	1 no.; 19.7 khZ; range 1500 m
Trawl monitoring system	:	1 no.; 25.5 kHz
FISHING EQUIPMENT		
Fishing gear		
Bottom trawl with appurtenances	:	2 nos
Midwater trawl with appurtenances	:	4 nos.
Otterboards- oval slotted type	:	6.5 m^2; 1750 kg each - 1 set
Otterboards- suberkrub type	:	8.0 m^2; 2750 kg each - 2 sets

Table 6.1 contd.

Fishing machinery		
Main winch(electrical)		
Number	:	2
Tractive effort	:	90.0 kN
Speed of heaving up	:	87.5 $m.min^{-1}$
Capacity	:	4400 m; 26.5 mm dia SWR; working length: 2200 m
Multi-drum winch (electrical)		
Trawl drum		
Number	:	1
Tractive effort at first layer	:	108.0 kN
Speed of heaving up	:	54.7 $m.min^{-1}$
Capacity	:	8 m^3
Cable drum		
Number	:	2
Tractive effort	:	76.0 kN
Capacity	:	600 m of 22.0 mm dia SWR
Drum for net stowage		
Number	:	2
Tractive effort	:	57.0 kN
Speed of heaving up	:	53.3 $m.min^{-1}$
Drawing drum		
Number	:	2
Tractive effort	:	100 kN
Speed of heaving up	:	30.8 $m.min^{-1}$
Drum for running out of catch		
Number	:	2
Tractive effort	:	100 kN
Speed of heaving up	:	30.8 $m.min^{-1}$

Table 6.2 Operational and catch details of the Intermediate Range Freezer Trawler

	Bottom trawling	Aimed midwater trawling
No of days	24	6
No of hauls	75	17
Depth range, m	50-121	31-125
Mean duration of hauls, h	2.57	1.88
Total catch, kg	135732	137051
Mean catch.day^{-1}, kg	5655.5	22841.8
SE of catch .day^{-1}	1461.9	7620.7

Table 6.3 Composition of landings by bottom trawling and aimed midwater trawling

Catch compnents	Catch, kg
Bottom trawling	
Pseudoscianids	1299
Pomfrets	2079
Squids & Cuttlefish	3156
Indian Mackerel	5265
Catfish	7402
Sciaenids	7798
Horse Mackerel	11610
Ribbon Fish	17604
Nemipterids	18369
Perches	34993
Miscellaneous	26157
Sub-total	*135732*
Aimed mid-water trawling	
Scad	400
Horse Mackerel	11955
Miscellaneous	696
Sub-total	***137051***
Grand total	**272783**

Table 6.4 Fuel consumption per unit volume of fish caught by bottom trawling and aimed mid-water trawling

	Bottom trawling	**Aimed midwater trawling**
Total catch , kg	135732	137051
Fuel consumption , kg	181680	45420
Overall fuel consumption , kg fuel.kg $fish^{-1}$	1.339	0.331

Table 6.5 Results of Student *t*-test of the variation in fuel consumption per unit volume of fish landed between bottom trawling and aimed midwater trawling, using log transformed data.

	Bottom trawling	**Aimed midwater trawling**
Mean	0.437	-0.231
Variance	0.293	0.389
Pooled variance	0.310	
Observations	24	6
df	28	
t - stat	2.626 (Significant at 0.01 level)	

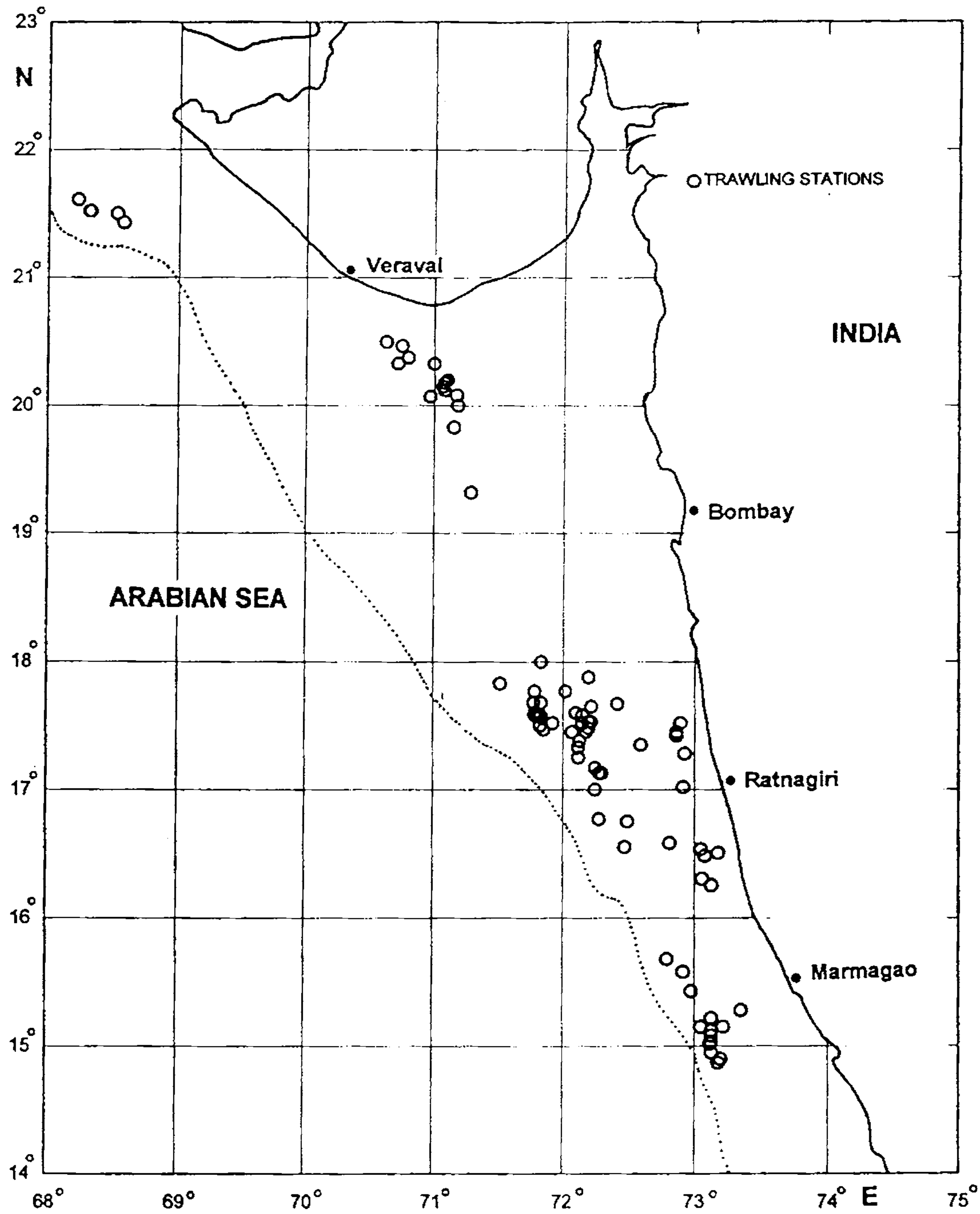


Fig. 6.1 Trawling stations of Intermediate Range Freezer Trawler

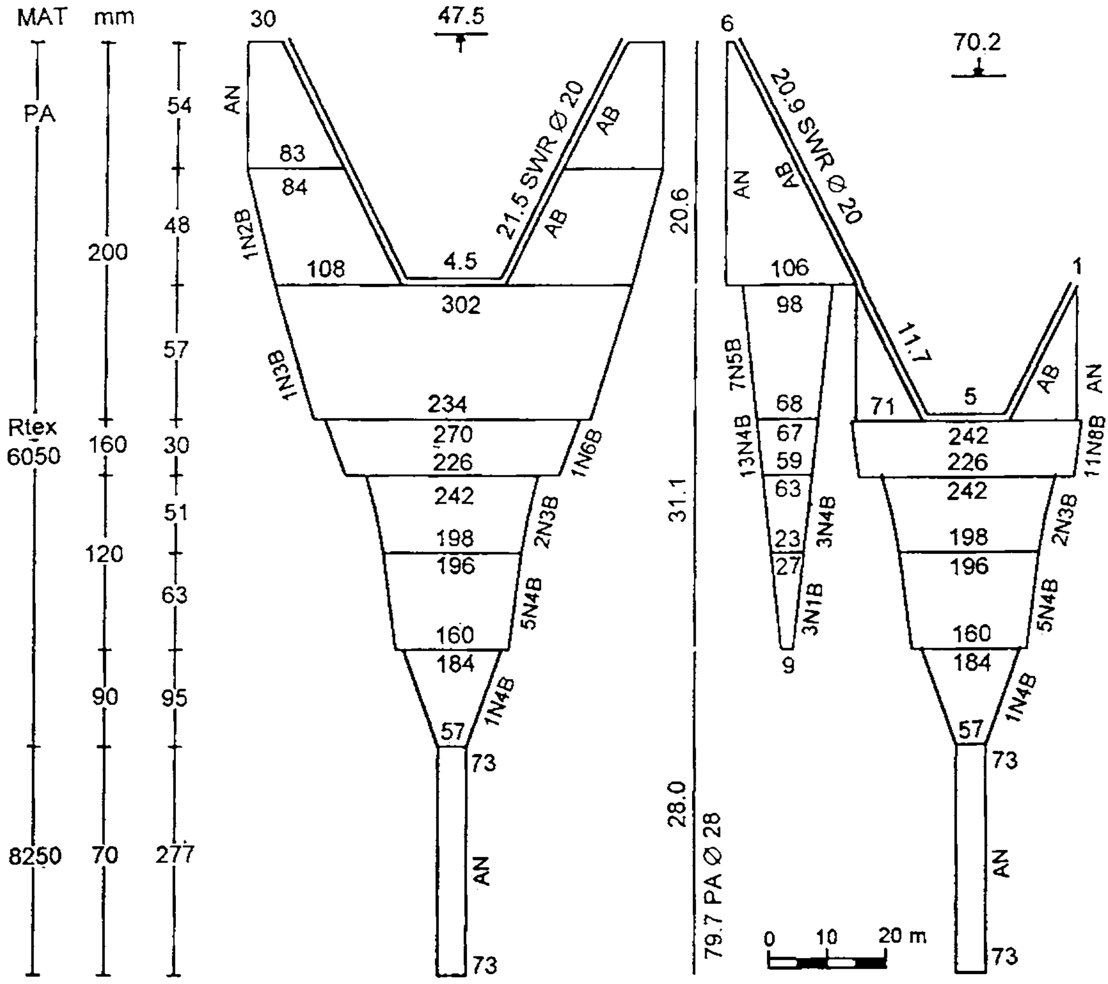


Fig. 6.2 Design of 47.5 m bottom trawl

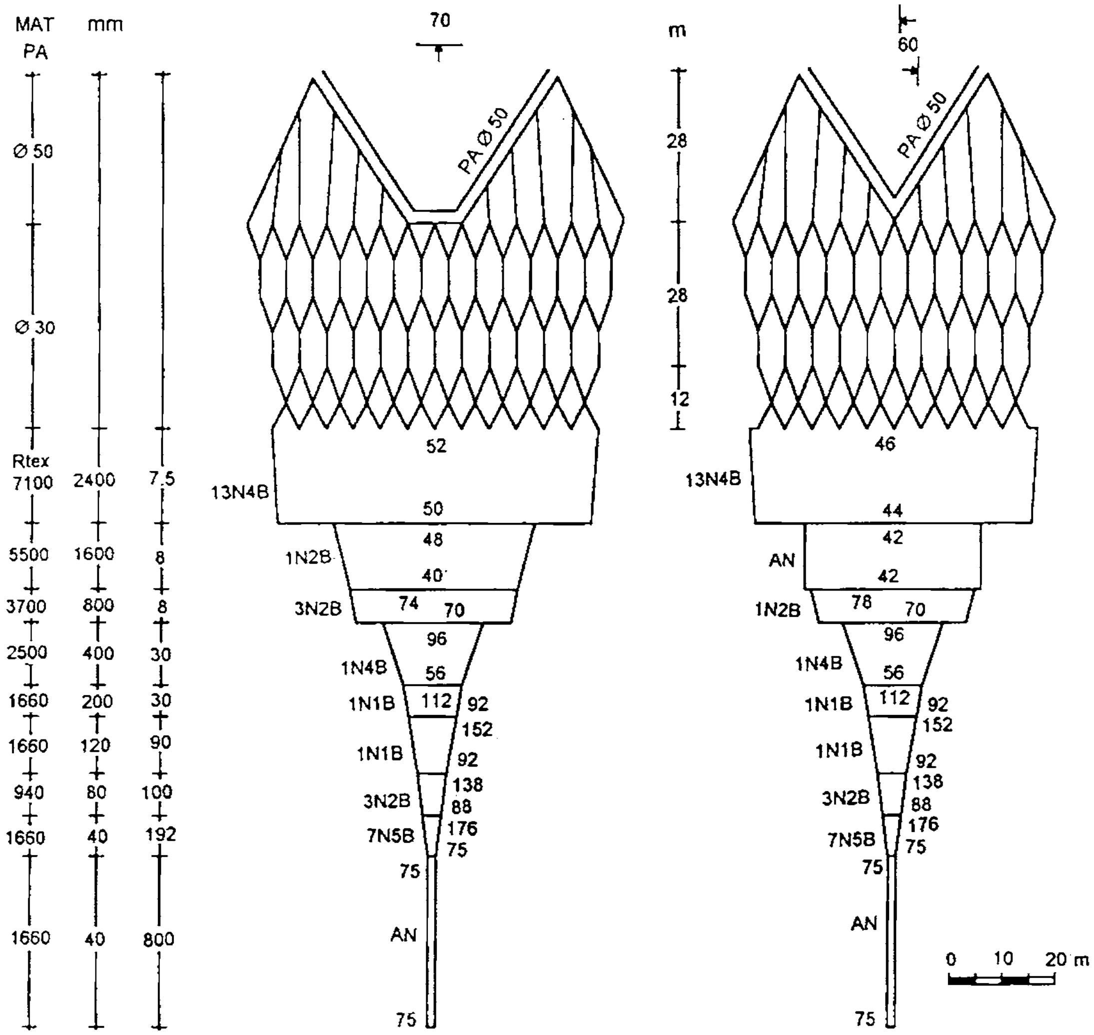


Fig. 6.3 Design of 70.0 m midwater trawl

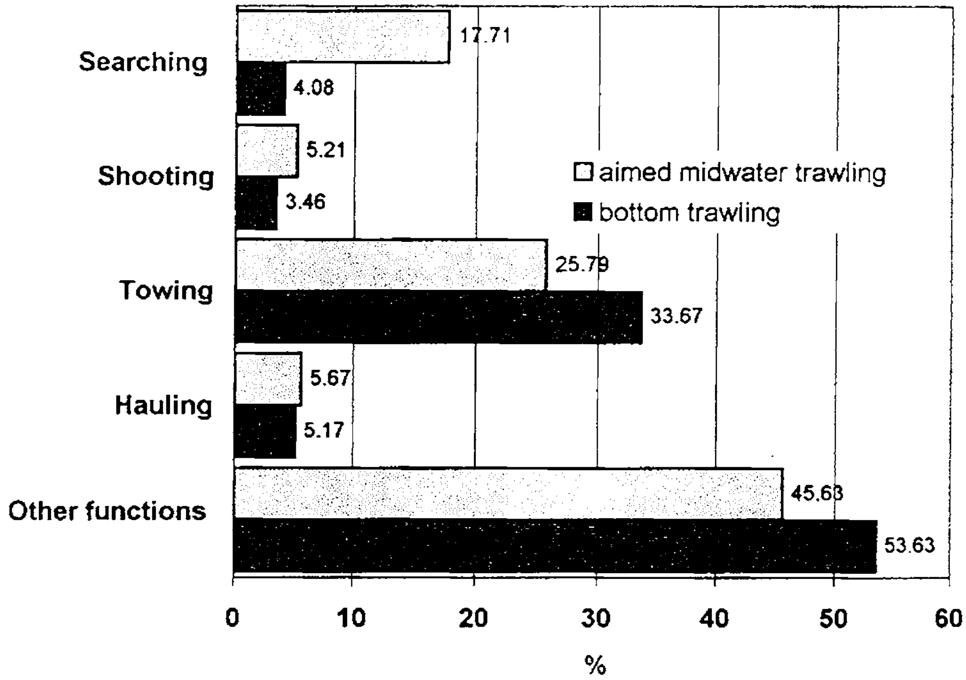


Fig. 6.4 Time utilisation per day of Intermediate Range Freezer Trawler

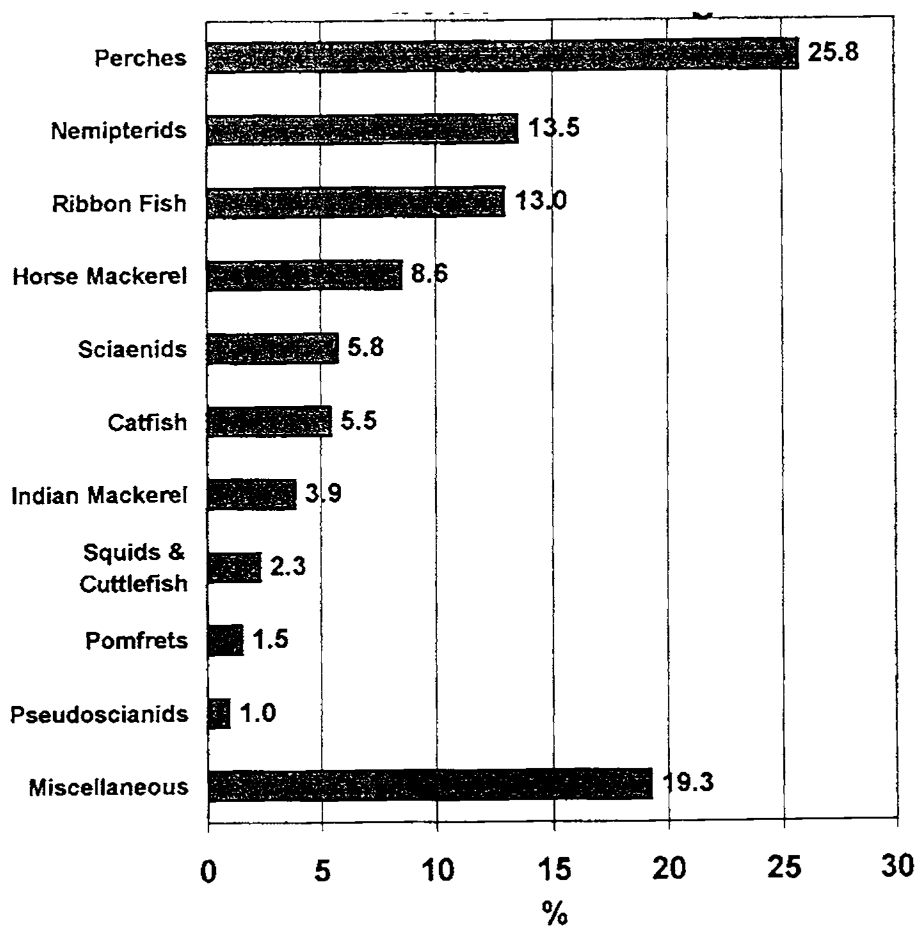


Fig. 6.5 Composition of landings by bottom trawling

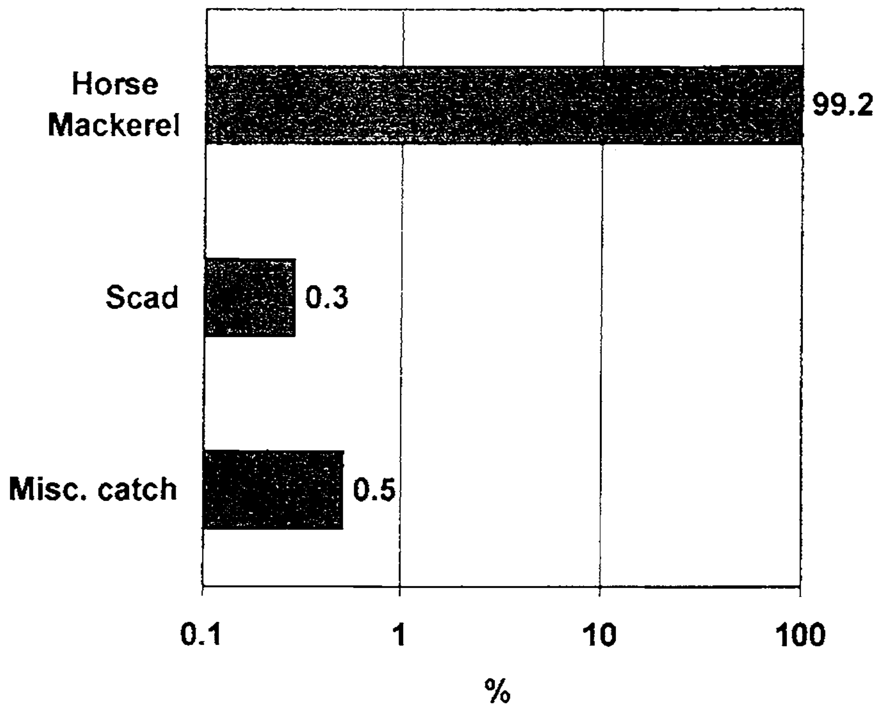


Fig. 6.6 Composition of landings by aimed midwater trawling

Fig 6.7 62.2 m L_{OA}, 1898 GRT, 2400 hp Intermediate Range Freezer Trawler

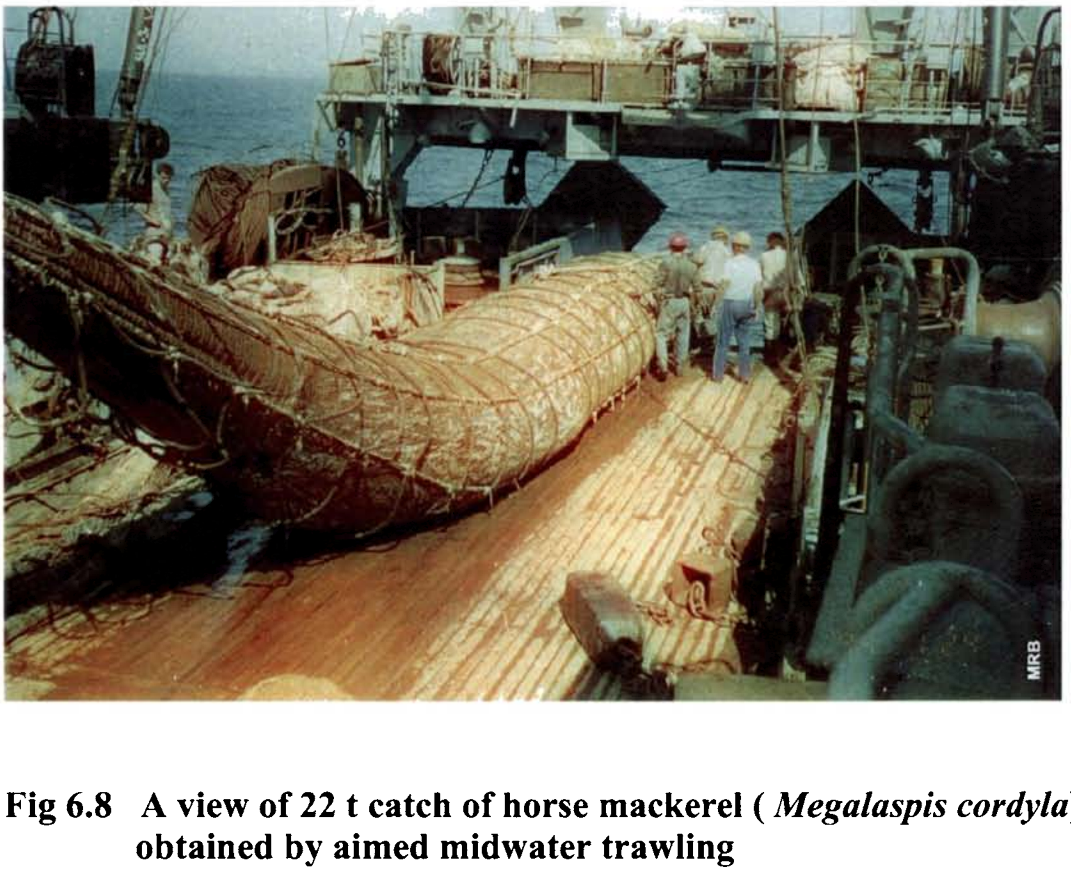


Fig 6.8 A view of 22 t catch of horse mackerel (*Megalaspis cordyla*), obtained by aimed midwater trawling

Chapter 7

Diurnal Variation in Trawl Catches and its Influence on Energy Efficiency of Trawling Operations

7.1 Introduction

Trawl catches are known to vary through out the day (Woodhead 1964; Beamish 1966; Shepherd & Forrester 1987; Ehrich & Groger 1989) The differences in length distribution and species composition between day and night catches of beaked red fish were analysed by Atkinson (1989). Analysis of trawl survey results by Hylen *et.al.* (1986) with respect to north-east Arctic cod and haddock stocks and by Godo & Wespestad (1990) on gadoids revealed a sampling problem in stock assessment surveys involving a complex set of factors including diel variation in the vertical distribution of fish. Results of a study conducted by Engas (1991) has shown diurnal variation in bottom trawl catches of cod and haddock and its influence on abundance indices. Woodhead (1964) studied the diurnal changes in trawl catches of fishes. Blaxter (1970) reviewed the studies on diurnal variations in catch by trawl and indicated some possible reasons for the same. Beamish (1966) studied the vertical migration of demersal fish in the north-west Atlantic. Shepherd & Forrester (1987) reported diurnal variation in the catchability during bottom trawl surveys off north-eastern United States. There has been no studies so far on diurnal variation in the trawl catches from the Indian ocean region.

An understanding of the diurnal variation in the catchability of the trawl resources could be beneficially utilised for their energy-efficient harvesting leading to better profits and energy conservation in trawling.

Objectives of the present study were:

i. to quantify diurnal variation in the catch rates of selected bottom trawl resources off south-west coast of India; and
ii. to evaluate the influence of diurnal variation in the catches on energy requirement during bottom trawling.

7.2 Materials and methods

Data on trawl catches obtained during 4 cruises of a Japanese factory trawler which operated in Indian waters during 1992-93, were utilised for this study. The factory vessel equipped for stern trawling has a length overall of 110 m, GRT of 5460 and an installed engine horse power of 5700 hp at 300 rpm. The main particulars of the vessel, engine and equipment are given Table 7.1. The vessel is a dedicated commercial deep sea stern trawler with onboard facilities for processing of *surimi* (washed and stabilised fish mince), fish fillets and fish meal. Views of the Japanese factory trawler and the catch obtained during day-time trawling are given in Fig. 7.7 and 7.8, respectively.

Operations were conducted off south-west coast of India, between latitudes 16° and 7° N (Fig. 7.1). The depth of operations ranged from 30 to 360 m, with 68 % of the observations falling between 50 and 140 m depth contours. Standard Japanese bottom trawl of 80.4 m head line length rigged with bobbin gear for rough bottom, were used for the operations. Design details of the fishing gear is given in Fig. 7.2 and details of rigging are given in Fig. 7.3. Bobbin gear consisted of 530 mm dia rubber and 300 mm dia steel bobbin weighing 5975 kg in air. Average tow duration during the period of operations was 2.7 h and mean towing speed measured using Doppler log was 4.0 ± 0.6 kn.

Trawl geometry was estimated from the data obtained from acoustic trawl monitoring equipment with sensors for measuring vertical opening and horizontal opening between the otter boards. The gear was so rigged as to attain a vertical opening not exceeding 10 m and assume ellipsoidal mouth configuration by providing wing-end strops and adjusting floatation, to suit the tropical demersal shoal characteristics. Horizontal opening between the wing-ends and the volume filtered per trawling hour were estimated as shown in Fig. 7.4.

The catch data was grouped by time of the day (day, night) according to the median towing hour (calculated as the hour of starting the tow plus half the tow duration). Daily hours of sunrise and sunset adjusted for specific longitude and latitude at the location of trawling station, were determined using software developed by Institute for Studies in Vedic Sciences, Akkalkot. Hauls taken between sunrise and sunset were classified as day-time hauls and those made after sunset and before sunrise as night-time hauls.

The difference in catch per unit effort (catch per hour) with respect to different species groups and total catch, between day and night-time hauls were analysed using Student *t*-test after logarithmic transformation of the data after addition of unity (Motte & Iitaka 1975). In addition to total catch, the species groups analysed were threadfin bream (*Nemipterus* spp.), bull's eye (*Priacanthus* spp.), lizard fish (*Saurida* pp.), hairtails (*Trichiurus* spp.) trevally (*Caranx* spp.), perches (*Epinephelus* spp., *Lutjanus* spp. *Lethrinus* spp.), swarming crabs (*Charybdis* spp.), cephalopods (squids and cuttlefishes) and miscellaneous fish.

Catches were normalised for 8 h trawling period for day and night, as 8 hours are typically available for towing in 12 h period of day or night allowing for time spent for shooting, hauling, ground shifting and other functions. Normalised catch data was used to estimate the percentage split between day and night operations, of the total catch and catch components.

Fuel consumption per kg of fish landed was estimated from normalised catch data and fuel expended for 12 h duration of day or night. Daily fuel consumption per kg of fish landed were subjected to Student *t*-test after logarithmic transformation of data after adding unity, to determine if there is any significant difference between day and night fuel consumption per unit volume of fish landed.

7.3 Results

Average vertical opening of the trawl mouth was 7.6 ± 0.9 m. Mean horizontal opening between otter boards was determined to be 116.7 ± 4.7 m. Horizontal opening between wing-ends was estimated to be 34 m (Fig. 7.4) which is 44 % of the head line length of the trawl. Area of the trawl mouth for the assumed ellipsoidal shape of the trawl mouth was estimated to be 209 m^2 and the volume of sea water filtered per trawling hour at 4.0 kn towing speed was estimated to be $1.5x10^6$ m^3 (Fig. 7.4).

Total landings during the four cruises conducted off south-west coast of India was 3508.6 tonnes. 466 hauls were taken with a total duration of 1254.1 hours. Of this, 2697.6 t was landed during 280 hauls taken during day-time from sunrise to sunset, expending 726.5 h. and 811.0 t was landed during 186 hauls taken in the night hours from sunset to sunrise, expending a total of 527.7 h (Table 7.2).

Catch Per Unit Effort (CPUE): Overall catch per hour during the period of operations was 3713.4 $kg.h^{-1}$ during day-time operations and 1536.8 $kg.h^{-1}$ during night time operations (Table 7.3). Mean daily catch was 31367.4 kg.day^{-1} (SE: 2743.0) for day-time operations and 9429.7 kg.day^{-1} (SE: 965.6) for night-time operations (Table 7.2).

Normalised daily catches: Estimates of catches normalised for 8 h trawling period, were 29707 kg and 12295 kg, respectively, for day and night operations and the total catch for the entire day was 42002 kg (Table 7.4). Estimates of normalised catch rates for important catch components such as threadfin bream, bull's eye, lizard fish, hairtails, trevally, perches, swarming crabs, cephalopods, scad, horse mackerel, barracuda and miscellaneous catch for both day and night operations are presented in Table 7.4.

Fuel consumption: Total fuel consumption for the period of operations were 2060 t which is equally split between day and night period of operations. Estimates of fuel consumed per unit of fish production were estimated from normalised catches during the period of operations. These were 0.403, 0.974 and 0.570 kg fuel.kg fish^{-1}, respectively for day, night and combined period of operations (Table 7.5).

Statistical analysis: Results of statistical analysis of the variation between day and night period of operations in the normalised total catch and catches of component groups such as threadfin bream, bull's eye, lizard fish, hairtails, trevally, perches, swarming crabs, cephalopods, scad and miscellaneous catch, and fuel consumption for unit volume of fish landed, are given Table 7.6.

7.4 Discussion:

The trawl operations, the results of which are presented in this Chapter, were carried out continuously during 24 h period within a depth strata 30 - 360 m, with the 95 % of the operations falling within 180 m depth contour, between latitudes 16° and 7° N, off south-west coast of India. The catch data showed large diurnal differences in the volume of total catch and catch components and in the catch composition.

During the period of operations, the vessel spent on an average 16.2 % of the time for sailing and ground shifting, 6.5 % for shooting operations, 57.9 % for towing the gear, 7.9 % for hauling and the balance for performing miscellaneous functions (Fig. 7.5).

Catch per unit effort (CPUE) in terms of total catch was 3713.4 and 1536.9 $kg.h^{-1}$, respectively for day and night operations (Table 7.3;

Fig. 7.6). The percentage improvement in CPUE realised during day-time was over 140 % compared to the night operations. The difference in daily catch rates between day and night was found to be statistically highly significant ($p<0.01$; df: 86) (Table 7.6). Percentage split of the normalised landings between day and night were 70.7 and 29.3 %, respectively (Table 7.4; Fig. 7.6).

Threadfin bream (*Nemipterus* spp.) of the family Nemipteridae represented the most abundant catch component during both day and night operations, contributing 58.31 and 57.65 %, respectively. It formed 58.16 % of the combined landings of day and night, during the period of operations. Threadfin bream is the most abundant demersal fish resource and its potential yield off west coast of India, beyond 50 m depth in the continental shelf and slope, has been estimated to be 96200 t which forms about 20 % of the total potential of demersal resources from this zone (Sudarsan *et.al.*, 1990). CPUE for threadfin bream catches were 2165.4 and 886.0 $kg.h^{-1}$, respectively for day and night hauls (Table 7.3) . Percentage split of the normalised landings of threadfin bream between day and night were 71.0 and 29.0 %, respectively, representing an improvement of 144 % over night catches (Table 7.4; Fig. 7.6). The difference in the landings of threadfin bream between day and night was statistically highly significant ($p<0.01$; df: 80)(Table 7.6).

Bull's eye (*Priacanthus* spp.) which ranked second in terms of abundance in the total landings (3.49%) contributed 3.96 % of the day-time landings and 1.93 % of the night catches. Estimated potential yield of bull's eye from the west coast of India beyond 50 m depth is 43700 tonnes which forms about 9 % of the total potential demersal yield from this area (Sudarsan *et.al.,* 1990). CPUE was 146.97 and 29.64 $kg.h^{-1}$, respectively for day and night hauls, showing a near five-fold increase during day-time compared to night landings. The day-night split of the normalised landings were respectively 83.23 and 16.77 % (Table 7.4; Fig. 7.6). The difference in daily catch rates between day and night was found to be highly significant ($p<0.01$; df: 24) (Table 7.6).

Lizard fish (*Saurida* spp.) contributed 3.26 to the day-time catches and 2.85 % to the night catches and 3.17 % to the total landings. Potential yield of the lizard fish off west coast of India beyond 50 m was estimated to be 18800 tonnes and forms about 4 % of the potential demersal resource from this zone (Sudarsan *et.al.,* 1990). The CPUE of lizard fish were 121.11 and 43.80 $kg.h^{-1}$ showing an improvement of over 170 % over the night landings. Split between day and night in the total normalised landings was 73.46 and 26.54 %, respectively (Table 7.4; Fig. 7.6). However, the difference between daily day and night landings of lizard fish was not found to be statistically significant (($p>0.05$; df: 16) (Table 7.6).

Hairtails (*Trichiurus* spp.) or ribbon fishes contributed 2.91 % to the day-time catch while it contributed only 0.06% of the night catches and ranked fourth in the overall landings (2.25%) (Table 7.3). The potential yield of hairtails from the west coast of India beyond 50 m depth was estimated to be 22100 tonnes which forms about 4.5 % of the potential demersal yield from this area (Sudarsan *et.al.*, 1990). The CPUE realised were 107.95 and 0.93 $kg.h^{-1}$, respectively for day and night operations, showing a pronounced difference in the catchability according to the time of the day. The percentage split between day and night in the normalised landings were 99.08 and 0.92, respectively (Table 7.4; Fig. 7.6). The difference in catch rates was statistically highly significant (($p<0.01$; df: 16) (Table 7.6).

Trevally (*Caranx* spp.) formed 2.72 % of the day-time catch and 0.10 % of the night landings (Table 7.3). Estimated potential yield of trevally from the west coast of India, beyond 50 m depth is 11600 tonnes which forms 2.4 % of the potential demersal yield from this zone(Sudarsan *et.al.,* 1990). The CPUE were 101.02 and 1.53 $kg.h^{-1}$, respectively for day and night period of operations. Percentage split of the normalised landings between day and night were 98.54 and 1.46 %, showing a highly pronounced difference between the two periods of operations (Table 7.4; Fig. 7.6). The difference in the daily landings between day and night was found to be statistically significant. ($p<0.05$; df: 6)(Table 7.6).

Perches consisting mainly of groupers (*Epinephelus* spp.), snappers (*Lutjanus* spp.) and sea breams (*Lethrinus* spp.) contributed 1.68, 1.94 and 1.74 %, respectively of the day, night and total landings (Table 7.3). Perches are estimated to have a potential yield of 11100 t and forms 2.3 % of the potential demersal fishery resources off west coast of India beyond 50 m depth (Sudarsan *et.al.,* 1990). The CPUE realised was 62.40 and 29.75 $kg.h^{-1}$, respectively for the day and night operations (Table 7.3). Day-time hauls contributed 67.71 % of the normalised catches of these species while night hauls contributed 32.29 % (Table 7.4; Fig. 7.6). Percentage improvement in the landings during day-time was 110 % compared to night hauls. However, the difference in the daily catch rates between day ad night was not found to be statistically significant ($p>0.05$; df: 26) (Table 7.6).

Swarming crabs (*Charybdis* spp.) contributed 0.64, 5.37 and 1.73 % respectively to the day, night and total landings (Table 7.3). The CPUE were 23.75 an 82.52 kg.h^{-1}, respectively for the day and night hauls (Table 7.3). Percentage split of the normalised landings of the species between day and night were 22.33 and 77.67 % (Table 7.4; Fig. 7.6), respectively, showing a pronounced improvement of 248 % in the night , compared to day-time operations. The difference in catch rates between night and day was found to be statistically highly significant ($p<0.01$; df: 10) (Table 7.6). Swarming crabs which form extensive swarms are considered to be an undesirable by-catch in trawl landings.

Cephalopods consisting of squids (*Loligo* spp., *Sepioteuthis* spp.) and cuttle fishes (*Sepia* spp.) contributed 0.82, 1.10 and 0.89 % of the day, night and total landings, respectively (Table 7.3). Squids and cuttle fishes are estimated to have a potential yield of 19500 t, off the west coast of India, beyond 50 m depth contour and forms about 4 % of the potential demersal resources of this zone (Sudarsan *et.al.,* 1990). The CPUE realised was 30.42 and 16.93 kg.h^{-1}, respectively for day and night hauls with a corresponding percentage split of 64.21 and 35.79 in the normalised landings (Table 7.4; Fig. 7.6). Day-time operations showed an improvement of 79 % over the night-time hauls. However, the difference in catch rates was not found to be statistically significant ($p>0.05$; df: 32) (Table 7.6).

Scad (*Decapterus* spp.) contributed 1.07, 0.36 and 0.91 % of the day, night and total landings (Table 7.3). Potential yield of scad off west coast of Indià beyond 50 m depth is estimated to be 11500 t which forms about 2.3 % of the potential demersal yield form this zone (Sudarsan *et.al.*, 1990). The CPUE realised were 39.72 and 5.49 kg.h^{-1}, respectively for day and night operations, indicating a seven-fold increase in the catch rates during day-time hauls. The percentage split in the normalised landings between day and night were 87.85 and 12.15 %, respectively (Table 7.4; Fig. 7.6). The difference in catch rates was found to be statistically highly significant ($p<0.01$; df: 14) (Table 7.6).

Horse mackerel (*Megalaspis* spp.) and barracuda (*Sphyraena* spp.) contributed 0.10 and 0.04 % of the day-time landings while they were unrepresented in the night hauls. Their CPUE for day-time hauls were 3.71 and 1.47 kg.h^{-1}, respectively (Table 7.3).

Miscellaneous catch consisting of the rest of the species groups, represented 24.49, 28.64 and 25.45 % in the day, night and total landings

(Table 7.3). The CPUE for the miscellaneous catch were 909.42 and 440.18 $kg.h^{-1}$, respectively for day and night operations. Percentage split between day and night of the normalised landings of this group were 67.39 and 32.61, respectively, showing a two-fold increase in the volume of day-time landings (Table 7.4; Fig. 7.6). The difference in the catch rates of the miscellaneous catch between and day and night, was found to be statistically significant($p<0.05$; df: 84) (Table 7.6).

The energy consumed per unit of fish production increased from 0.403 kg fuel.kg $fish^{-1}$ realised during day-time operations to 0.974 kg fuel.kg $fish^{-1}$ during the night-time operations. The percentage increase in fuel consumption per unit volume of fish caught was 142 % during night-time compared to day-time trawling. The difference in fuel consumption per unit volume of fish caught calculated in terms of normalised landings, was found to be statistically highly significant ($p<0.01$; df: 86) (Table 7.6). Results indicated a strong case for significant improvement in trawler landings and reduction in fuel requirement in capture process, with consequent increase in profitability, by maximising the fishing operations during day-time.

The degree of success of trawling operations is influenced generally by three factors viz., (i) spatial distribution of fish in relation to fishing gear; (ii) behaviour of fish in the vicinity of fishing gear and (iii) intrinsic selection properties of the fishing gear system itself (Parrish *et.al.*, 1964; Doubleday & Rivard, 1981; Hylen *et.al.*, 1986; Engas, 1994)

Diurnal differences in the catch and catch composition are reported by Woodhead (1964), Beamish (1966), Shepherd & Forrester (1987), Ehrich & Groger (1989), Walsh (1988, 1989) and others. Diurnal changes in catch rates is generally assumed to reflect changes in the availability of the resource to the trawl system, in terms of its spatial distribution and shoaling behaviour which may vary according to the time of the day. Fish behaviour in the vicinity of trawl system might also change according to the time of the day and visibility (Glass & Wardle, 1989). Studies by Engas & Godo (1986) and Engas (1991) in the Barents Sea have reported higher catch rate for cod and haddock during day-time. They also observed diurnal differences in the species and size composition, obtaining a higher haddock-cod ratio and an increase in small haddock during day-time hauls.

In the vicinity of the trawl system, fish are exposed to a number of stimuli both visual and auditory in nature, generated by the vessel; otter boards; sand-mud clouds produced by the otter boards, sweeps and ground rig; the net and its peripheral components. Even though many fish can detect sound and react to it, it is vision that cause fish to react in a firm and precise manner to an object (Wardle & He, 1996) Vision of fish is affected by light levels, colour of the objects and the background. Glass & Wardle (1989) demonstrated that mackerel ceased schooling at light levels below 10^{-6} lux. In high light level conditions in the day time, fish showed ordered patterns of behaviour in the vicinity of the trawl mouth and in the night, at light level lower than the threshold, these ordered patterns of behaviour were seen to have disappeared.

Vision could thus be considered to be the most important sense involved during day time trawling, up to depths where light penetration is above threshold level for eliciting response behaviour from the fish. The otter boards is the first conspicuous part of the trawl system sensed by the fish visually as the gear approaches (Korotkov, 1984; Wardle, 1986). The appearance of the trawl board depends on the type of the seabed, light level and the background. Fish avoid the approaching trawl board by swimming around it. The visible range is known to determine the reaction distance to otter boards (Wardle, 1986). Fish between the otter boards are guided by the sweeps and sand-mud clouds generated by the otter boards, sweeps and ground gear components, towards the centre of the approaching trawl (Main & Sangster, 1981a, b). The sweep angle which is the angle between sweeps and towing direction, is known to influence the herding and sweep angles above 20° are shown to significantly reduce the catching ability for cod and haddock (Strange, 1984). Korotkov (1984) reported that highly visible sand-mud clouds in alignment with the sweeps provide a strong herding effect. Fish herded into the vicinity of trawl mouth by otter boards, sweeps and sand-mud clouds are known to behave differentially as it approaches the trawl mouth. Fish turn to swim in the same direction of the tow at the mouth of the trawl just before the ground gear, until they are exhausted and fall back into the trawl bag (Hemmings, 1969; Wardle, 1986; Glass & Wardle, 1989; Engas, 1994). Different species show different behaviour response in the net mouth area of trawl (Main & Sangster, 1981a,b)

The capture efficiency of trawls may thus vary considerably according to the time of the day, since the reaction distance, fish orientation and escape behaviour change with the light level available at the depth of operation, at various stages of capture process. In addition, differences in species and size selectivity may take place due to variation in the response behaviour between different species and size classes. Generally herding effect is reduced at low light levels causing a reduction in the effective swept area in front of trawl mouth.

In the present study, total catch and catch components such as threadfin bream, bull's eye, hairtails, trevally, scad, lizard fish, perches, cephalopods and miscellaneous catch showed a pronounced improvement during day-time operations. On the other hand the crustacean component, viz., swarming crab, showed a significant improvement in the night operations. In the light of discussions in the preceding paragraphs, the difference in catch rates between day and night, could be attributed to diurnal variation in the spatial distribution and schooling behaviour of the catch categories, their differential behaviour in the vicinity of the trawl gear system under varying light levels of the day and night and the consequent effect on the catching efficiency, and species and size selectivity at different stages in the capture process.

In addition to its importance in the operational planning of trawling operations to realise objectives of maximising catch per unit effort and minimising fuel consumption per unit volume of fish caught, the results obtained in this study have added significance in the use of bottom trawl surveys in stock abundance estimates and biological investigations. When trawl catches are used to monitor abundance indices or for conversion of acoustic abundance to absolute abundance estimates, the basic assumption is that each trawl sample provides a representative estimate of the density of species and length classes of the particular depth stratum. It is clear from the diurnal variation observed in the catch volume and composition of catch during this study, that this assumption is not met. Though not specifically studied here, diurnal changes in the length classes is also to be expected as indicated by studies elsewhere (Engas & Godo, 1986; Engas, 1991; Hylen *et.al.*, 1986; Godo & Wespestad, 1990). Hence it is necessary to take into account the diurnal differences in estimating abundance indices and data derived from day and night need to be given equal weight, while interpreting trawl survey results, to arrive at realistic stock abundance estimates.

Table 7.1 Main particulars of factory trawler, engine and equipment

VESSEL DETAILS		
Length Overall	:	110.71 m
Beam	:	17.8 m
Depth(moulded)	:	11.00 m
Full load summer draft	:	6.767 m
GRT	:	5460.06
NRT	:	2824.36
Full load displacement	:	8554 t
Dead weight	:	4456 t
ENGINE		
Make	:	ME 9VET-45/75C Mitsubhishi
Horse power	:	5700 hp at 300 rpm
Fuel consumption	:	998 $kg.h^{-1}$
GEAR HANDLING EQUIPMENT		
Split trawl winch		
Auxiliary winches		
Gantries		
ACOUSTIC FISH DETECTION AND TRAWL MONITORING EQUIPMENT		
Fish finder	:	28kHz; 50kHz; Furuno Electric Co. Japan
Net recorder (sensors for vertical opening at trawl mouth)	:	60 kHz Furuno Electric Co., Japan
Otter graph (sensors for horizontal opening between otter boards and depth)	:	Kaiyo Denki, Japan
POSITION FIXING EQUIPMENT		
GPS Navigator	:	JLR 4200; Japan Radio Co., Japan

Table 7.2 Operational and catch details

Month/ Year	Depth range, m	No of days	No of hauls	Total duration of tow, h	Mean duration of hauls, h	Total catch, kg	Mean catch.day^{-1}, kg	SE of catch.day^{-1}
DAY-TIME HAULS								
Dec. 92	74-175	17	61	136.28	2.23	980000	57647.1	6784.3
June 93	31-176	16	47	123.58	2.63	367700	22981.3	5017.3
July 93	30-350	23	72	202.17	2.81	523960	22780.9	3946.9
Aug. 93	36-360	30	100	264.42	2.64	825940	27531.3	3750.0
1992-93	30-360	86	280	726.45	2.60	2697600	31367.4	2743.0
NIGHT-TIME HAULS								
Dec. 92	74-175	17	32	104.66	3.27	234000	13764.7	2857.1
June 93	31-176	16	32	86.42	2.70	74800	4675.0	1379.6
July 93	30-350	23	53	142.75	2.69	153490	6673.4	1161.4
Aug. 93	36-360	30	69	193.83	2.81	348660	11622.0	1611.1
1992-93	30-360	86	186	527.66	2.84	810950	9429.7	965.6

Table 7.3 Variation in catch volume, catch rate and percentage composition of day-time, night-time and day & night hauls

	DAY-TIME HAULS			NIGHT-TIME HAULS			DAY AND NIGHT HAULS		
Species groups	**Total catch, kg**	**CPUE, kg.h^{-1}**	**%**	**Total catch, kg**	**CPUE, kg.h^{-1}**	**%**	**Total catch, kg**	**CPUE, kg.h^{-1}**	**%**
Threadfin bream	1573077	2165.43	58.31	467527	886.03	57.65	2040604	1627.12	58.16
Bulls eye	106766	146.97	3.96	15638	29.64	1.93	122404	97.60	3.49
Lizard fish	87981	121.11	3.26	23113	43.80	2.85	111094	88.58	3.17
Hairtails	78420	107.95	2.91	496	0.93	0.06	78916	62.93	2.25
Trevally	73393	101.02	2.72	805	1.53	0.10	74198	59.16	2.11
Perches	45331	62.40	1.68	15699	29.75	1.94	61030	48.66	1.74
Swarming crabs	17252	23.75	0.64	43573	82.52	5.57	60825	48.50	1.73
Scad	28854	39.72	1.07	2894	5.49	0.36	31748	25.32	0.91
Cephalopods	22116	30.42	0.82	8935	16.93	1.10	31051	24.76	0.89
Horse mackerel	2694	3.71	0.10	0	0.00	0.00	2694	2.15	0.08
Barracuda	1065	1.47	0.04	0	0.00	0.00	1065	0.85	0.03
Miscellaneous catch	660651	909.42	24.49	232270	440.18	28.64	892921	711.99	25.45
Total catch	**2697600**	**3713.40**	**100.00**	**810950**	**1536.88**	**100.00**	**3508550**	**2797.62**	**100.00**

Table 7.4 Comparison of catches normalised for 8 h trawling period and percentage split of total catch and component groups between day-time and night-time catches

	Catch normalised for 8 h trawling, kg		Percentage split of catches	
Catch categories	**DAY**	**NIGHT**	**DAY**	**NIGHT**
Threadfin bream	17323	7088	70.96	29.04
Bulls eye	1176	237	83.23	16.77
Lizard fish	969	350	73.46	26.54
Hairtails	864	8	99.08	0.92
Trevally	808	12	98.54	1.46
Perches	499	238	67.71	32.29
Swarming crabs	190	661	22.33	77.67
Scad	318	44	87.85	12.15
Cephalopods	244	136	64.21	35.79
Horse mackerel	30	0	100.00	0.00
Barracuda	12	0	100.00	0.00
Miscellaneous catch	7275	3521	67.39	32.61
Total catch	**29707**	**12295**	**70.73**	**29.27**

Table 7.5 Fuel consumption per unit volume of fish caught during day, night, and day & night hauls

	DAY	NIGHT	DAY & NIGHT
Total catch normalised for 8 h effort per day for 86 days, kg	2554802	1057370	3612172
Total fuel consumption for 86 days, kg	1029934	1029934	2059872
Fuel consumption, kg fuel.kg fish $^{-1}$	**0.403**	**0.974**	**0.570**

Table 7.6 Results of statistical analysis of day and night catch rates, and fuelconsumption per kg of fish

	df	*t*-vlalue	Signicance level
Species groups			
Threadfin bream	80	3.188	Significant at 0.01 level
Bulls eye	24	3.420	Significant at 0.01 level
Lizard fish	16	0.884	Not significant at 0.05 level
Hair tails	16	6.775	Significant at 0.01 level
Trevally	6	1.917	Significant at 0.05 level
Perches	26	1.564	Not significant at 0.05 level
Swarming crabs	10	2.788	Significant at 0.01 level
Scad	14	4.323	Significant at 0.01 level
Cephalopods	32	1.183	Not significant at 0.05 level
Miscellaneous catch	84	1.674	Significant at 0.05 level
Total catch	85	8.444	Significant at 0.01 level
Fuel consumption per kg of fish caught			
kg fuel.kg $fish^{-1}$	86	5.415	Significant at 0.01 level

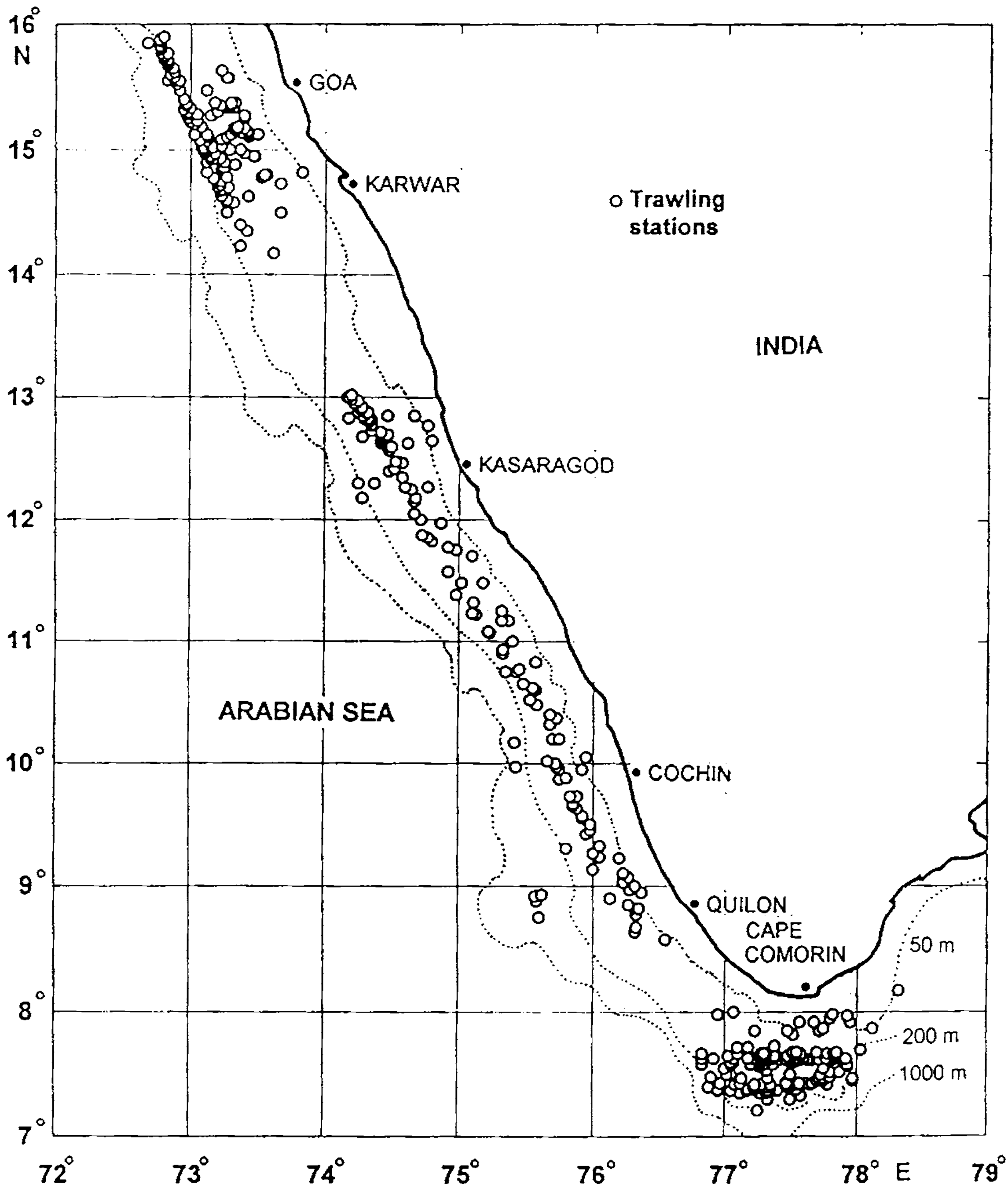


Fig. 7.1 Trawling stations of factory trawler

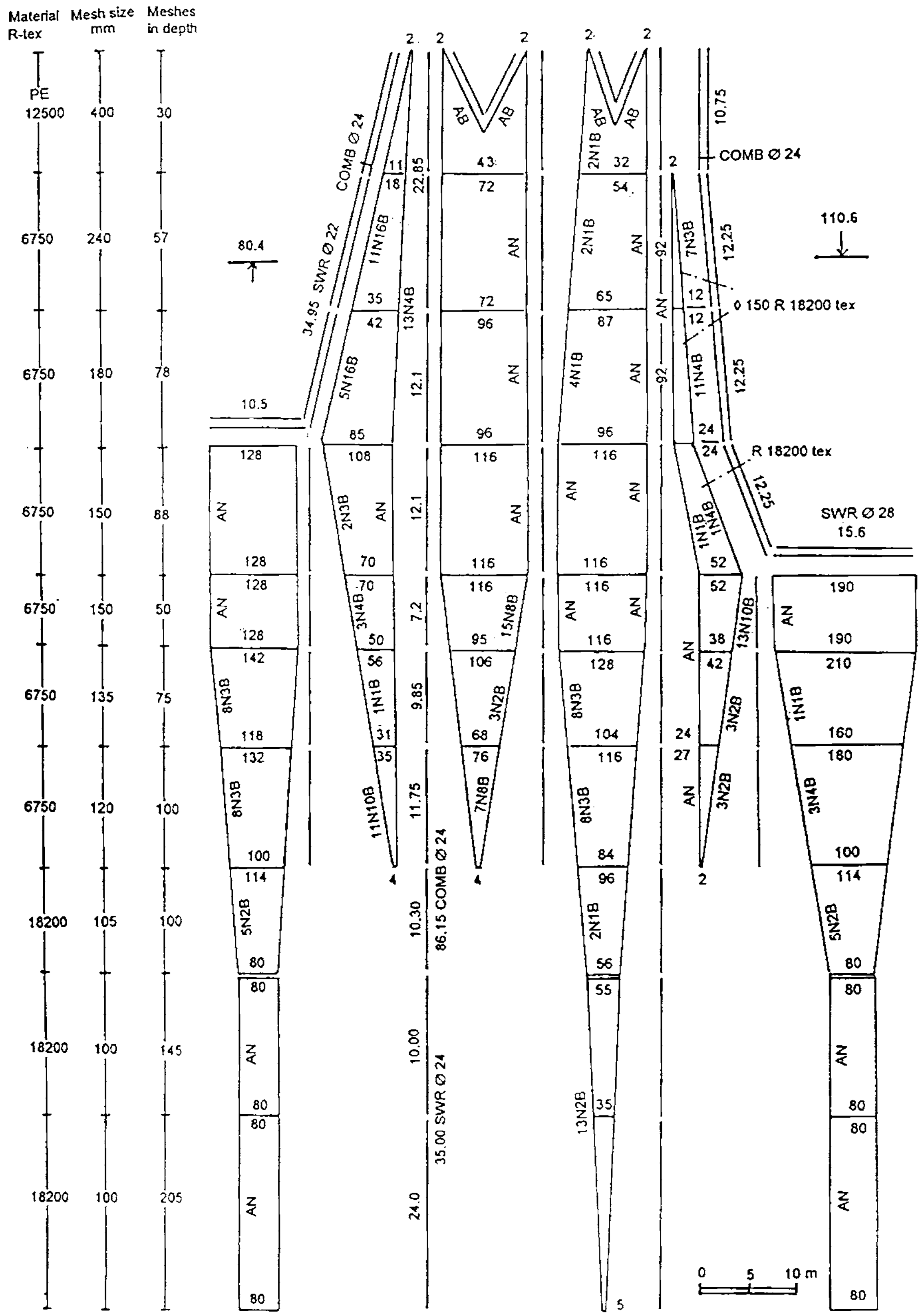
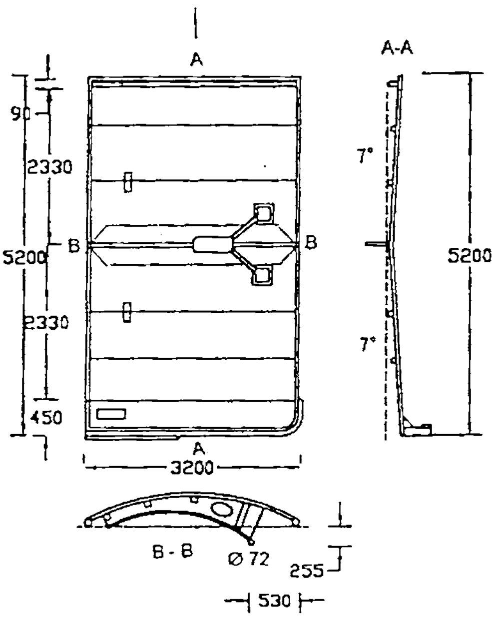


Fig. 7.2 Design of 80.4 m Japanese bottom trawl



VERTICALLY CAMBERED V-FORM OTTER BOARD

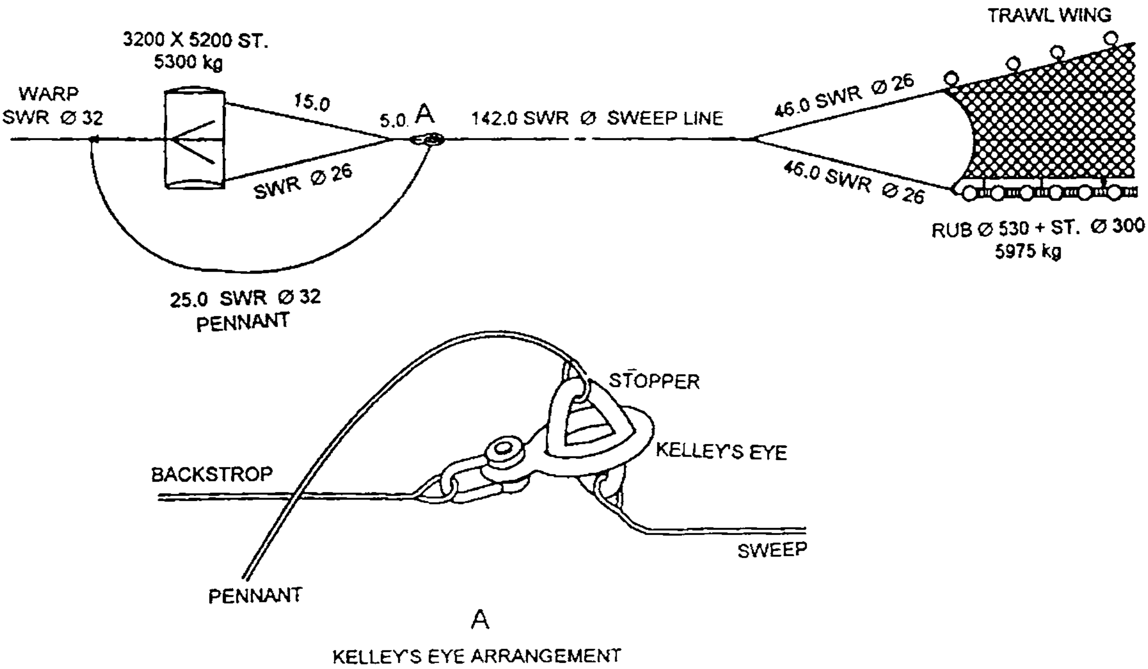
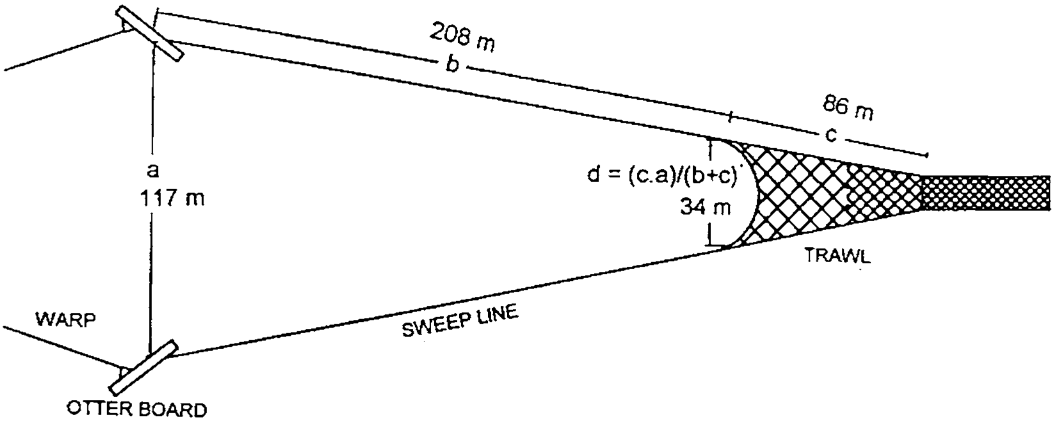


Fig. 7.3 Rigging details of 80.4 m Japanese bottom trawl



HORIZONTAL OPENING BETWEEN OTTER BOARDS : **117 m**
WING-END SPREAD (CALCULATED): **34 m**
VERTICAL OPENING OF TRAWL MOUTH : **7.6 m**
TRAWL MOUTH AREA : Π x (7.6 / 2) x (34/2) : **203 m^2**
VOLUME FILTERED AT 4 kn TRAWLING SPEED :
203 x 1853 x 4 : **1504636 m^3.h^{-1}**

Fig. 7.4 Estimation of trawl parameters

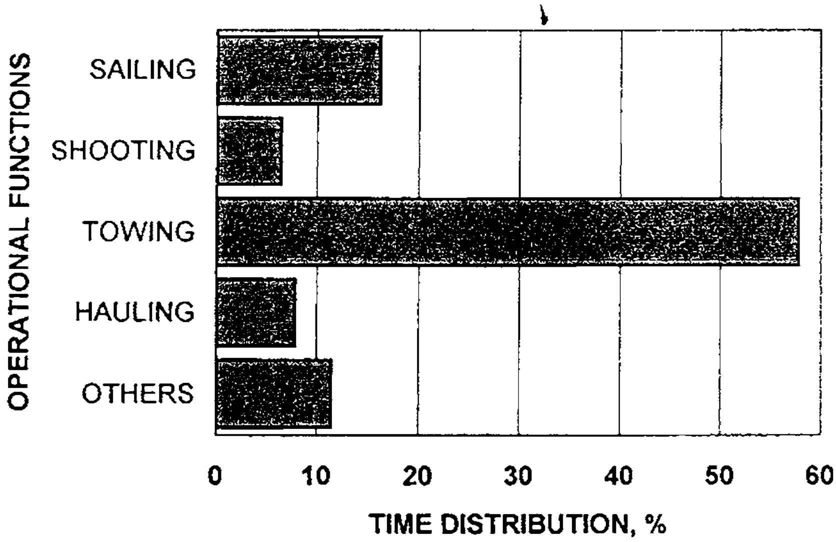


Fig. 7.5 Average time distribution during fishing trip

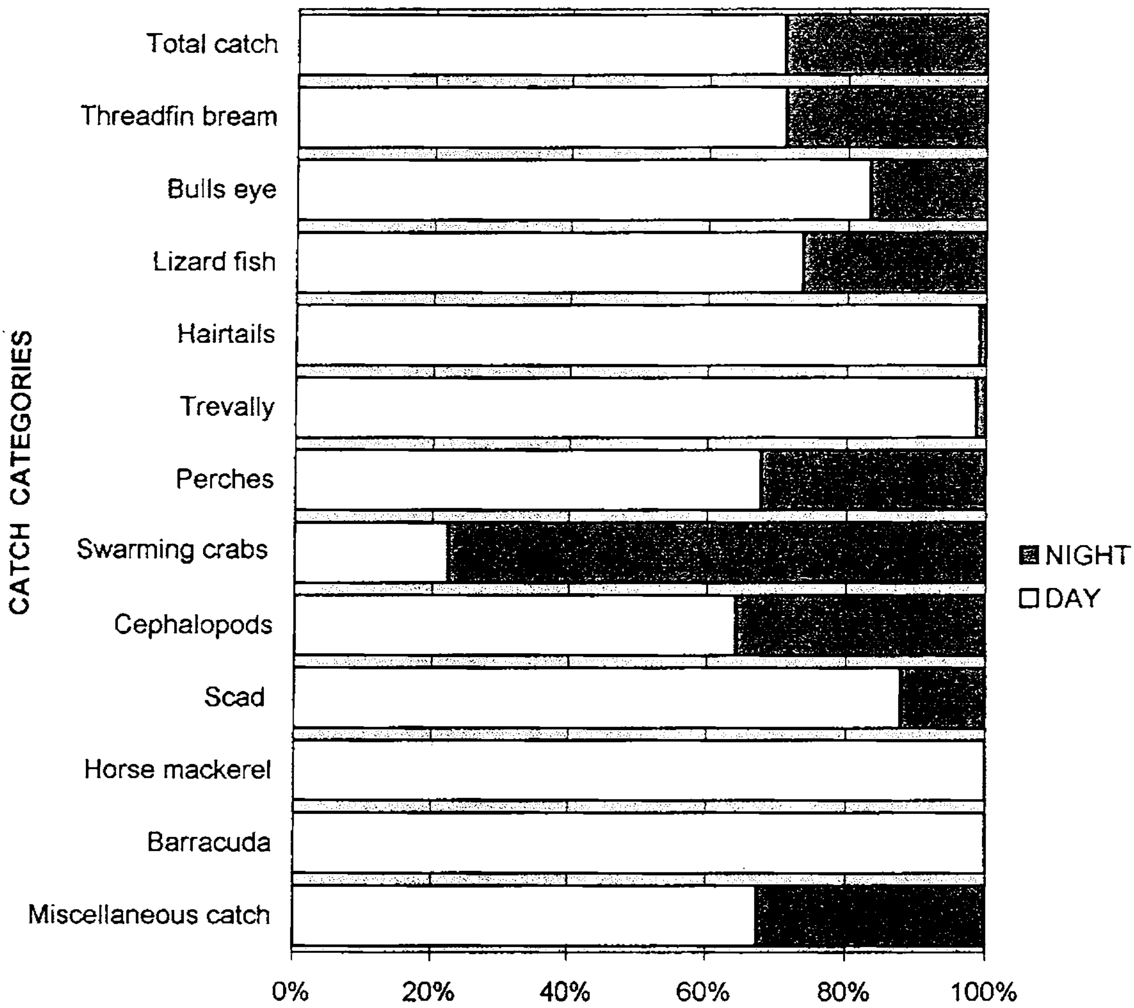


Fig. 7.6 Percentage split between normalised day and night catches

Fig 7.7 110 m L_{OA}, 5460 GRT, 5700 hp Japanese factory trawler

Fig 7.8 A view of 40 t catch of Japanese threadfin bream, obtained by day-time trawling

Chapter 8

Approaches to Energy Conservation in Fish Harvesting

8.1 Introduction

Modern fishing is one of the most energy intensive methods of food production. Energy input for production of rice is one-tenth of the output. The ratio between input and output of energy is close to unity for milk production by grass-fed cows and artisanal coastal fishing. However, distant water fishing is extremely energy-intensive, consuming 15 to 20 times more energy than it produces (Endal, 1989a; 1989b).

Motorised and mechanised fishing is dependent on fossil fuels, which are non-renewable and limited. Fossil fuels produce increased levels of carbon dioxide in atmosphere contributing to 'green house effect' and other pollutants which are detrimental to the environment and human health. Green house effect leads to irreversible climatic and oceanographic changes (Endal, 1989b; Hill *et.al.*, 1995; TERI, 1999). High energy intensity in fish harvesting could jeopardise the role of fisheries in food security of the people in developing countries. The spiralling oil prices may severely affect the economic viability of fishing as a means of fish production. Many nations around the world have undertaken large-scale programmes in energy conservation in consideration of these implications (Anon, 1982; Anon, 1989a; Anon, 1989b; Buxton & Robertson, 1989; IEA, 1993; Anon, 1993a;). Background studies related to energy conservation in fisheries of the States of Kerala and Karnataka have been conducted under the Energy Conservation Programme, initiated by the Government of India in collaboration with the Government of Norway, in the late 1980s (Aegisson & Endal, 1993).

A comparison of fuel consumption in the fishing industry has shown that the large-scale industrial fishing sector consumed about 14 -19 million t and small-scale fishing sector consumed about 1-2.5 million t of fuel oil. The production of fish per tonne of fuel was 2-5 t in the industrial sector and 10-20 t in the small-scale sector (Thomson, 1988; Allsopp, 1989). Total energy inputs for marine fisheries of Japan, in 1980 was estimated at 2.5×10^{14} kJ, which was contributed by trawls (28 %), angling (19 %), longlines (18 %), purse seines (10 %), gill nets (10 %) and 15 % by other fishing methods. The overall average for the entire marine fisheries of Japan was estimated as 2.5×10^{4} kJ.kg fish^{-1} (Watanabe & Okubo (1989).

Verghese & Ramachandran (1992), based on the census data, estimated that 5,45,280 kl of diesel was consumed by 23,000 mechanised fishing vessels operated in India, at that time. Current strength of the fishing fleet in the small mechanised sector in India is estimated to be 47000, consisting of 37574 trawlers, 6373 gillnetters, 1219 dol netters, 1118 purse seiners and 716 other fishing vessels (Sathiadhas, 1998), which uses diesel as fuel. An updated figure of fuel consumption by the small mechanised fleet, based on assumptions followed by Verghese & Ramachandran (1992) will be approximately 950×10^6 $l.year^{-1}$, costing about Rs.14935×10^6, at the current retail prices (Rs. 15720.49 kl^{-1}, including 16 % excise duty and 20 % sales tax; excluding transportation cost; September, 2000). Motorised fleet in India is estimated at 32000, consisting of 3141 ring seine crafts, 9423 plank canoes, 10639 dugout canoes and 2514 plywood crafts, which primarily use kerosene and petrol, as fuel. In Kerala, the fleet strength of motorised crafts is estimated to be 13219, consisting of 3625 dugout canoes, 3841 plank canoes, 5701 plywood crafts 41 *kattumaram* crafts and 11 fibre glass crafts (SIFFS, 1999). The number of OBMs in operation in the motorised sector of Kerala is estimated to be 16466 with a collective horsepower of about 252590 and mean horsepower of 15.4 per OBM. Assuming a period of operation of 5 hours per day for 200 days in a year, total fuel consumption by traditional motorised sector in Kerala works out to be 139×10^6 $l.year^{-1}$, at specific fuel consumption of 0.55 $l.hp^{-1}.h^{-1}$. Projecting this figure to all India level, assuming an average of 15.3 hp per OBM and one OBM per craft, the total fuel consumption by the motorised fishing fleet of India, would be approximately $269 \times 10^6.year^{-1}$. Assuming a consumption ratio of 9:1 for kerosene and petrol, the cost of kerosene and petrol consumed in a year, in the traditional motorised sector, would be approximately Rs. 4081×10^6, at the prevailing retail prices (Kerosene: Rs. 13699.37 kl^{-1}, including 8 % excise duty and 8 % sales tax; excluding transportation cost; Petrol: 28356.58 kl^{-1}, including 32 % excise duty and 23 % sales tax; excluding transportation cost: September, 2000) Total fuel consumption by the mechanised and motorised fishing fleet in India, is thus roughly 1219×10^6 $l.year^{-1}$, forming 1.26 % of the aggregate annual consumption of petroleum products in India, with a cost of Rs. 19016×10^6, at the prevailing retail prices.

The total production of petroleum products in India during 1997-98 was about 61 million t and aggregate consumption during this period was 85 million t (TERI, 1999). India's self sufficiency in petroleum products have declined from 60 % in 1985-86 to about 34 % in 1997-98. The country's import bill of crude oil and petroleum products was estimated to be 9.8-10.0 billion US$ in 1999-2000 (TERI, 1999). Energy security concerns assume a great significance on account of increasing demand-supply mismatch, and growing dependence of imports of energy.

The need for conserving fossil cannot be over-stressed, considering its non-renewable nature, limited availability and effect of its use on environment. Until alternative sources of energy become viable, the existing stocks have to be used with extreme care with accent on conservation and environmental safety. It is in the long-term interests of the fishing industry to take note of the urgency of the situation and translate the means available for conservation into immediate action plans and for the fishing nations to develop and adhere to a comprehensive fuel conservation strategy. In this Chapter, the existing knowledge on the energy conservation in the context of fish harvesting, is reviewed and approaches for improving energy efficiency are delineated. The results of a survey conducted on the awareness and extent of adoption of some of the immediately practical approaches for fuel conservation, by the mechanised fishing industry operating from Cochin, are also presented in this Chapter.

8.2 Methods of Energy Conservation in Fishing

Various approaches to energy conservation in fishing could be grouped under (i) fishing gear and methods, (ii) vessel technology, (iii) engines, (iv) reduction gear, propeller and nozzle, (v) sail-assisted propulsion, (vi) adoption of advanced technology and (vi) conservation and enhancement of resources. They are discussed in detail in the following sections.

8.2.1 Fishing gear and methods

Choice of fishing gear is one of the main options available for energy conservation in fishing (Bardach, 1982; Jiang, 1982; Gulbrandson, 1986; Dickson, 1989; Panote, 1991; Boopendranath, 1996; Hameed & Boopendranath, 2000). Large variations in energy use exist among different fishing gears. Edwardson (1976a) has estimated that 0.076 kg fuel was consumed by coastal fishing using net and long line in north Norway, 0.140 by long line in the continental shelf and 0.290 kg by factory vessels, per kg of fish. Energy inputs in seafood harvesting in the US have been estimated as 580 kcal for sardines, 4560 kcal for salmon, 4280 kcal for cod, 16,100 kcal for tuna and 74,800 kcal for shrimp per kg of fish (Mayor &

Rawitscher, 1978). Endal (1980) has given fuel consumption for different fishing methods as 1.0 kg for middle water bottom trawling, 0.6 kg for near water bottom trawling, 0.3 kg for middle water long lining, 0.2 for near water longlining and 0.1 kg for coastal fishing, per kg of fish landed. Nomura (1980) evaluated the fuel efficiency of different fishing systems, in comparison to the setnet fisheries of Japan. He found that 0.270-0.430 kg of fish was produced by high seas tuna longline; 0.530 - 0.822 kg by salmon drift net; 0.820 kg by far seas squid angling; 0.860-1.800 kg by skipjack pole and line; 0.960 kg by demersal fish trawl (East China Sea); 3.60 kg by pelagic fish purse seine; 4.80 kg by Alaska Pollack trawl (North-Pacific) and 12.50 kg by large-scale setnet, per litre of fuel. Gulbrandson (1986) reported that trawling consumed 0.8 kg of fuel while longlining and gillnetting consumed between 0.15 and 0.25 kg of fuel and purse seining required 0.07 kg of fuel, to catch one kilogram of fish, in Scandinavian fisheries. During 1979-86, Endal (1989) had determined the fuel consumption ranges in Norwegian fisheries, as 0.51-0.75 kg for offshore trawling, 0.045-0.07 kg for offshore purse seining, 0.32-0.46 kg for offshore longlining and 0.18-0.34 kg for coastal fishing, per kg of fish landed. Aegisson & Endal (1993), based on their studies in the states of Kerala and Karnataka in India, found that trawling produced 1.95 kg fish.kg $fuel^{-1}$, purse seining 12.72 kg fish.kg $fuel^{-1}$ and gillnetting 3.50 kg fish.kg fuel^{-1}. The introduction of man-made netting materials has increased the catching power and fuel efficiency of fishing gears. Some of the energy conserving fishing practices such as large scale purse seining became possible only with the introduction of synthetic netting material (Kristjonsson, 1959; Fitzpatrik, 1991).

Trawling is one of the most energy intensive fishing activity (Endal, 1980; Nomura, 1980; Aegisson & Endal, 1993; Boopendranath, this study). It consumed nearly 5 times more fuel compared to passive fishing methods such as longlining and gillnetting and over 11 times more fuel compared to purse seining for every kilogram of fish produced in the Scandinavian fisheries (Gulbrandson, 1986). Studies in the south-west coast of India have shown that trawling consumes 6.5 times more fuel compared to purse seining and 1.8 times more fuel than gillnetting, to produce one kg of fish (Aegisson & Endal, 1993). Studies on gross energy requirement have given the highest GER values for trawling compared to other mechanised systems of fishing such as gill netting and purse seining (Boopendranath, this study). Hence, most potential for fuel conservation exists in trawling. In trawling, typically a substantial portion of the time is spent on towing the gear. For large trawlers, fuel consumption during trawling can constitute up to 90 % of the total consumption (Anon, 1984a). During the tow, resistance of the vessel is insignificant compared to the resistance of the gear. The gear resistance, therefore, has a large effect upon overall fuel economy. Percentage of fuel cost in the operational expenditure of trawlers may vary between 45 % and 75 %, depending on installed engine power and duration of voyage (Iyer *et.al.* 1985; Verghese, 1994; Shibu, 1999).

The drag of trawl gear components vary considerably according to the design and rigging and depending on the operating conditions. Wileman (1984) has given a typical set of values for Nordic trawl designs wherein warp contribute 5 %, sweeps 4 %, otter boards 20 %, floats 3 %, foot rope 10 % and netting 58 % of the total drag. After extensive model tests and field studies on the Nordic trawl designs several means of reducing drag in trawl system have been recommended by research workers. Judicious use of knotless netting in some trawl sections, use of thinner twine and large meshes in the upper trawl sections, have been individually found to reduce netting resistance by 12 % and total resistance of trawl by 7 %; use of cambered otter boards and optimising the angle of attack of otter boards have been individually found to reduce otter board resistance by 20 % and total trawl resistance by 4 %; use of slotted otter boards have been found to reduce the otter board resistance by 10 % and total trawl drag by 2 % (Wileman, 1984). Use of double rig trawling and pair trawling has been found to reduce the total trawl resistance by 25-30 % and 30-35 %, respectively, compared to conventional trawling (Anon, 1984a). Tait (1989) found that about 12 % reduction in trawl drag is possible when it is fabricated of knotless netting, compared to knotted netting. The use of double-rig system for shrimp trawling, pair trawling, use of large meshes and ropes in the front trawl sections, use of thinner twine and otter board angle adjustment are commonly practised in fishing industry.

Judicious selection and rational deployment of an energy efficient mix of harvesting systems appropriate for the resources, at optimum capacity levels, based on GER values and updated stock abundance estimates, are necessary to maximise yield per unit expenditure of non-renewable energy, from a particular resource system. Diversification of the existing excess capacity in the fishing fleet by adopting low energy fishing techniques could lead to considerable energy savings. Encountering a period of scarcity of traditional trawl resources during the period of present study, trawler fishermen of Cochin have diversified the operations by adopting hand lining, realising savings up to 40 % in fuel use per kg of fish landed (Section 5.2, this study). Steinberg (1985) and Lange (1985) found that energy saving methods such as gill nets, trammel nets and long lines are suitable for German cutter fisheries operating in Baltic and North Sea.

8.2.2 Vessel technology

Significant improvement in operational savings have been achieved by optimising vessel and machinery design. The power required to propel a vessel is mainly a function of (i) speed, (ii) length of water line and (iii) displacement, i.e., weight of the boat including crew, fishing gear, fish and ice (Fyson,1985; Gulbrandson, 1986)

Economic vessel speed

Vessel speed is the single most important factor affecting fuel consumption of the vessel, since the fuel consumption drastically increases as the vessel approaches maximum speeds (Gulbrandson, 1986; Endal, 1989a,b; Aegisson & Endal, 1993). It has been shown that true savings in fuel consumption per nautical mile up to 37 % is possible in small fishing vessels (Gulbrandson, 1986) by reducing the speed by one knot. The Oilfish project which conducted investigations during 1981-84, to find out new ways of reducing fuel consumption in fishing vessels under Nordic Joint Scientific and Academic Organisation for Technical Research and Development (Nordforsk) concluded that a 9.3 % reduction in speed (from 10.7 to 9.7 kn) could result in 40 % reduction in fuel consumption and 18.6 % reduction in speed (from 10.7 to 8.7 kn) could result in 63 %

reduction in fuel consumption of a 24 m L_{OA} commercial trawler (Anon, 1984a). Under the Ener Sea Project, it was determined that a reduction of 1 kn from maximum speed would result in an average fuel savings of 43 %, in the Newfoundland fishing fleet. (Pinhorn & Brothers, 1989). During the studies conducted in Kerala, under a joint Indo-Norwegian programme on energy conservation, it was found that a 10 % reduction in the free running speed of mechanised vessels, reduced the fuel consumption by 35 % and a 20 % reduction in the free running speed reduced the fuel consumption by 61 % (Aegisson & Endal, 1993). Assuming the projection of savings given by Aegisson & Endal (1993) for trawlers of Kerala, to be valid for all India trawler fleet of 37574 (Sathiadhas, 1998) and adjusting for the increase of diesel prices (Rs. 15720.49 kl^{-1}: September 2000), savings could be, roughly, to the tune of Rs. 3113×10^6 (198×10^6 l of diesel) for a 10 % reduction in the free running speed and Rs. 5817×10^6 (370×10^6 l of diesel), for a 20 % reduction.

Unlike diesel engines, outboard motors (OBMs) running on kerosene/petrol used in traditional crafts, behave differently in fuel consumption pattern with respect to speed. The specific fuel consumption of outboard engines are reported to increase at lower engine rpm and in addition the engine switches over to petrol from kerosene at speeds lower than a specific rpm (1500 rpm for Yamaha OBMs). Hence, reducing speed by throttling down may not lead to fuel saving in OBMs. However, the hull resistance of the canoes is known to come down by 25-30 % and 40-50 %, respectively, when hull speed is reduced by 10 % and 20 % (Aegisson & Endal, 1993). If the hull speed of the traditional canoe is reduced by using an OBM of lower hp running at full rpm, fuel saving in traditional motorised fleet is possible. Updating the estimates in savings envisaged by Aegisson & Endal (1993) for the motorised traditional fishing vessels, it is estimated that roughly 30×10^6 l and 50×10^6 l of fuel, respectively, could be saved if speed of the traditional canoes were reduced by 10 % and 20 %, by using low powered OBMs. Economic vessel speed is, thus, the most important practical concept in fuel conservation practices.

Hull design & maintenance

Reduction in power requirements can be achieved by (i) increasing length of water line (L_{WL}) and (ii) reducing displacement wherever possible at the design stage, and by taking measures for control of hull fouling.

Length of waterline (L_{wl}): For normal economic speed the ratio between the vessel speed (kn) and the vessel length (ft), $v/\sqrt{L_{WL}}$ is close to unity. By increasing length of waterline while keeping the other dimensions same, it is possible to reduce the hull resistance and increase the speed. Although the weight of the vessel is increased in the process, the overall effect on hull resistance is often beneficial. However increase in construction cost has to be balanced against fuel saving advantages. Gulbrandson (1986) estimated a 23 % saving in fuel by increasing the length of water line from 8.0 m to 10.0 m, in spite of a resultant increase in displacement from 3.4 to 4.0 t. About 22 % reduction in powering was obtained by modifications with bulbous bow and beaver tail on existing vessels (Schroeder & Roddan, 1989; McIlwaine, 1989). The Oilfish project investigations (Nordforsk) during 1981-84, concluded that a 20 % lengthening of the vessel, without changing displacement could result in a reduction of hull resistance in calm water by 35 % (Anon, 1984a).

Hull form: Investigations in Norway, have indicated that multi-hull vessel such as catamaran fishing vessel have high speed to power ratio, energy saving potential and more spacious working deck, bridge and accommodation area than an equivalent mono-hull fishing vessel (Amble, 1989; IEA, 1993). The US Navy has conducted research work on SWATH (Small Waterplane Area Twin Hull) vessels for high speed applications, with potential for application in fishing vessel development (Altar & Scott, 1989; IEA, 1993). However, the advantages of these innovative designs have to be balanced against the increase in construction and machinery cost.

Displacement: Reduction in displacement also contribute to lower fuel consumption. Hull built of aluminium, FRP and plywood will be lighter than that of steel, ferrocement and conventional wood construction. Fuel saving advantages in such cases has to be balanced against a possible reduction in sea kindliness of the vessel. Gulbrandson (1986) has estimated that in a vessel of 8.0 m L_{WL}, displacement 3.5 t and service speed of 6.5 kn, a reduction in displacement by 14.3 % (from 3.5 to 3.0 t) could result in fuel saving by 14 %. However, fuel saving measures by way of hull design changes are difficult for implementation on existing boat and can be more easily accomplished in a new design.

Anti-fouling measures: In tropics, surface friction due to fouling is estimated to increase at the rate of 0.6 to 1.5 %. Fuel consumption due to fouling could increase by 7 % at the end of first month 44 % at the end of six months and 88 % at the end of 12 months (Gulbrandson, 1986). Hence, periodic hull cleaning and application of antifouling paints can lead to considerable savings in fuel (Sato *et.al.*, 1987; Gulbrandson, 1986; Aegisson & Endal, 1993; Hamaguchi *et.al.*, 1996).

8.2.3 Engines

Choice of engines: Specific fuel consumption of the diesel engines has decreased from 175 $g.hp^{-1}.h^{-1}$ in 1945 to 135 $g.hp^{-1}.h^{-1}$ in 1995, with the introduction of major technical improvements such as turbo charging (introduced in 1965) and new material development, advanced production and quality control systems and computer aided design techniques.

Two types of engines are used in small fishing boats (i) outboard petrol/ kerosene engines and (ii) inboard diesel engines. The main disadvantage of two stroke outboard engine is the high fuel consumption, the specific fuel consumption being 0.5-0.6 $l.hp^{-1}.h^{-1}$ compared to 0.25 $l.hp^{-1}.h^{-1}$ in diesel inboards. Modern marine diesel engines will run most economically at a service speed not exceeding 80 % of the maximum engine rpm. The propeller design and size should be so selected as to allow the engine to operate in the range of lowest specific fuel consumption. Engine power, operating range and specific fuel consumption of a typical diesel engine used in Indian fishing fleet (ALM 680; Ashok Leyland Ltd., Chennai) is given in Fig. 8.1. Details of diesel engines, widely used in fishing fleet, are given in Table 8.1 and details of OBMs used in traditional motorised fisheries in the study area, are given Table 8.2.

Right-sizing of engines: Overpowering the vessel is wasteful in terms of energy. Smaller engines have multiple benefits of lower investment cost, lesser maintenance and huge reduction in the fuel consumption. Ravindran (1990) discussed the growing tendency among the motorised fishermen to overpower their crafts. Mechanised purse seiners with 156 hp power plants performed better in terms of energy consumption per unit volume of fish landed than seiners with 235 hp power plants. (Boopendranath, this study). Sheshappa *et.al.* (1988) discussed a mathematical approach for determination of engine power for fishing vessels. Sheshappa (1993) stressed the need for selection of right type of propulsion plant, based on the requirements of fishing activity.

Preventive maintenance of engines: The loss of efficiency of a badly maintained engine can be as high as 30 % (Gulbrandson, 1986). Preventive maintenance of valves and injectors, turbo charging system, fuel and air filters, mechanical drives and belts could result in a fuel saving of 10 % (Anon, 1984a). Preventive maintenance including regular cleaning or replacement of injectors, oil changes as recommended by the engine manufacturers are very important practical steps in conserving fuel and controlling pollution (Anon, 1983).

8.2.4 Reduction gear, propeller and nozzle

Propeller size and rpm: The efficiency by which the propeller converts the engine power to thrust depends mainly on propeller revolutions, provided an optimum propeller diameter and pitch are used. Considerable fuel saving is possible if larger propeller with lower rpm (larger gear reduction ratio) matched to absorb the engine power at the lowest specific fuel consumption rpm, is used. The Oilfish project (Nordforsk) investigations have indicated that an increase in propeller size in excess of 20 % could often result in 20-30 % reduction in the fuel consumption (Anon, 1984a).

Propeller type and nozzle: Incorporation of propeller nozzle and improved design of propeller would also cut down the fuel consumption rate. Propeller nozzle is a cylindrical ring of aerofoil section, fitted around the vessel's propeller. The action of such propeller is to produce a lift force and hence a propulsive effect on the vessel. The effect of the propeller nozzle is reduced by an additional resistance created by the movement of nozzle in water. The nozzle therefore gives greater increase in pulling power when the vessel is running at lower speeds, as in trawling. The advantages of propeller nozzle are counterbalanced by the high prices and liability to damage by floating objects in water. Fyson (1985) found that a 20 % increase in bollard pull, is possible at 4 kn speed, with the installation of propeller nozzle, in a 30.6 m L_{OA} trawler with 600 hp engine. The Oilfish project (Nordforsk) studies have shown that 20-30 % better thrust is possible at speeds less than 6 kn with the use of propeller nozzles, while its effectiveness is reduced at higher speeds. It is reported that for trawlers which operate fishing gear at speeds lower than 6 kn, overall fuel savings could be to the tune of 10-14 % (Fyson, 1985). Kohane & Ben-Yami (1989) have discussed the energy saving in small trawlers by propulsion improvement, and reported a reduction in fuel consumption by 10.6 %, by installation of nozzle in a 160 hp Mediterranean trawler. Czekaj (1988) stated that when properly designed and installed onto small trawlers, the nozzle improves propulsion efficiency and allows for the use of larger gear, thus resulting in fuel savings and increased catching power. Nasar (1998) has studied the performance of redesigned open propellers based on Wageningen-B Series charts in the commercial trawlers operating from Cochin and reported an average fuel saving of 20 %. Central Institute of Fisheries Technology has recently contructed a 15.5 m L_{OA} steel trawler, incorporating energy saving principles in vessel design, including a longer L_{WL} and deep V low angle of entrance, propeller nozzle and right sizing of engine horsepower (122 hp) (CIFT, 1999).

Controllable pitch propeller: Use of controllable pitch propeller (CPP) in fishing vessel has been reported to reduce fuel consumption and at the same time increase towing power, under adequate CPP management, compared to fixed propellers (Kirihata *et.al.*, 1991; Sakai *et.al.*,1993; Nishiya *et.al.*, 1986)

8.2.5 Sail-assisted propulsion

In many countries like India, Sri Lanka and Indonesia there is a long tradition of using sail in small fishing vessels and *kattumaram*. If the sail is used as the main propulsion wherever it suits the fishing method adopted, it is possible to reduce the size of the engine to what is required for manoeuvring in harbours and fishing grounds. In low energy fishing methods such as coastal gill netting and long lining, it is definitely a practical alternative energy source. When $v/\sqrt{L_{WL}}$ is equal to unity, the horse power requirement is roughly 1 hp per displacement tonne, in calm waters. When the speed-length ratio exceeds unity, horse power requirements increases drastically, as the wave breaking resistance become more important. At $v/\sqrt{L_{WL}}$ ratio of 1.3, the horse power requirement is 4-5 hp per displacement tonne. Therefore a combination of enough engine hp, to achieve a $v/\sqrt{L_{WL}}$ ratio of 1, and sail power can result in significant increase in speed while utilising power from diesel fuel at the most economic level (Fyson, 1982). Utilisation of sail is possible in trolling, longlining, trap fishing, gill netting. In purse seining, bottom trawling and midwater trawling, use of sail could be advantageous during the free running between port and fishing ground. Traditional sail systems used in fishing vessels are sprit sail, lanteen sail, Chinese lug sail and Bermuda sail. The importance of sail was highlighted during the International Conference on Sail-assisted Commercial Fishing Vessels, 15-18 May 1983, which was held at Florida (Florida Sea Grant College, 1983). Other proposals for wind driven propulsion are fixed aerofoils, magnus rotor devices, etc., which are still in the experimental stage.

8.2.6 Adoption of advanced technology

Recent advances in technology have provided fishermen with equipment to reach the potential fishing ground accurately (Global Positioning Systems); detect the presence of fish and monitor the success of capture process acoustically (echo sounder, sonar, gear monitoring systems), thus saving the search time and fishing time and hence saving energy. Progress in the satellite-based remote sensing techniques which use sea surface temperature and ocean colour to identify areas of potential fish abundance also greatly reduces the search time as near-real time information is available to the fishermen (Montgomery, 1984; Kumari, 1993).

Installation of fuel flow monitors or vessel analysis computing systems on board fishing vessels have been proven to lead to improved operational efficiency and energy optimisation (Billington, 1989a,b; Anon, 1996c). Such devices provide decision support leading to management of engine and propeller in the most economic manner in terms of vessel energy consumption by facilitating (i) choice of optimum speed under different weather conditions and in accordance with the fishing activity, and (ii) choice of optimum engine speed and propeller blade gradient (pitch). Code of Conduct for Responsible Fisheries (FAO, 1995a) recommends the promotion of the use of such devices on board fishing vessels.

Energy is also conserved by optimising fleet management. Use of Geographical Information System (GIS) in fleet management and fishing operations; multi-day fishing in place of daily fishing; mother ship and catcher boat operations wherever practical are some of the fuel saving practices in fleet operation.

8.2.7 Conservation and enhancement of resources

Most of the important fish stocks of the world have been subject to relentless fishing pressure leading to various stages of growth and economic overfishing (FAO, 1995). This has resulted in diminishing returns from the traditional stocks, reduction in annual landings and catch unit effort, and has considerably increased the fuel cost per unit weight of fish caught. The effort in searching and catching is obviously a function of abundance of the target species. Two most effective measures with long term implications in reducing fuel cost are therefore (i) conservation of resources in order to ensure their long-term sustainability and (ii) enhancement of depleted coastal stocks. Conservation measures may include responsible fishery practices such as area closures, seasonal closures, quota systems, mesh regulation, banning of destructive fishing practices, protection of nursery grounds, promotion of selective fishing techniques, promotion of eco-friendly and low energy fishing techniques, and primarily by control of total fishing effort through a system of licenses, so that yields remain at sustainable levels. Fishery enhancement schemes may include the hatchery production of fingerlings and their release to the natural environment, sea ranching, creation of artificial reefs and restoration of less productive coastal fishing grounds (Aegisson & Endal, 1993; FAO, 1996; 1997).

8.3 Survey on awareness and adoption of fuel saving techniques

The objective of the survey was to assess the awareness and the extent of adoption of practices enabling energy saving, among the operators of mechanised fishing vessels of Cochin. Eight energy saving practices discussed in the preceding Sections, were identified based primarily on the ease of their adoption and practicality, viz. (i) adoption of alternative low-energy fishing practice; (ii) economic vessel speed, (iii) economic engine rpm, (iv) propeller nozzle (v) sail-assisted propulsion (vi) preventive maintenance of engine (vii) anti-fouling measures (vii) multi-day fishing and (viii) adoption of advanced technology. Structured questionnaire was used for the survey. Information was collected from 60 respondents, working in the mechanised fishing vessels, operating from Cochin fisheries harbour. Results of the survey on the awareness and adoption of fuel saving techniques in the study area is summarised below:

Adoption of alternative low energy practices: Survey showed that 90 % of the trawler operators, faced with the scarcity of trawl resources during the months from October 97 to March 98, diversified into low energy fishing strategies. Mean catch rates of trawlers during these months ranged from 145 to 161 $kg.trawler^{-1}.day^{-1}$ and the alternative method of fishing taken up was hand lining. This resulted in realising savings up to 40 % in fuel use per kg of fish landed, compared to other months when trawling alone was practised. The adoption of diversified low-energy fishing practices by 90 % of the trawlers, indicate the deep penetration of awareness of the energy-saving fishing techniques, particularly when faced with scarcity of traditional target resources.

Economic vessel speed: This most important and practical of all energy saving practices was not adopted by any of the mechanised vessels. While 5 % of the operator-respondents, indicated understanding of the significance of economic vessel speed, no one was actually implementing it. The reason given was economic compulsion of reaching the fishing ground first and returning to the port ahead of others to realise better prices. All the respondents went to the fishing ground and returned to the base, at maximum speed. This is identified as an area where intensive extension efforts are required to create awareness among mechanised vessel operators. A vessel-based demonstration programme with fuel computers is required to convince the fishermen on the need for following economic vessel speed.

Economic engine RPM: Economic range of engine rpm is closely related to economic vessel speed. None of the respondents had any understanding about the range of engine rpm with the lowest specific fuel consumption, which is roughly 80 % of the maximum rpm of the engines used in the study area. All vessels used 95 -100 % of the maximum continuous rpm of the diesel engines(1900-2000 rpm), during the free running to the fishing ground and while returning to the base.

Propeller nozzle: None of the vessels in the sample used propeller nozzle. However, enquiries in the field have indicated that a few trawlers operating from Cochin had earlier installed propeller nozzles, which were subsequently dismantled. The reason for non-acceptance was reportedly frequent entanglement of floating debris between propeller and nozzle. After an investigation into the failure of propeller nozzles in Kerala and Karnataka trawlers, Nasar (1998) opined that the existing hull would not benefit from nozzle propellers due to (i) operational characteristics of the vessels with respect to time engaged in free running vs. Trawling and associated speed-rpm ratios, (ii) inability to maintain minimum loading on blades during trawling with respect to thrust requirements of trawling and (iii) aft hull shapes influencing the flow over propellers. However, this is an area where further detailed investigations are necessary, considering its success in the small-scale commercial trawl fisheries, elsewhere (Czekaj, 1988; Kohane & Ben-Yami, 1989).

Sail-assisted propulsion: None of the vessels used sail as an energy saving measure. This is an area where technological innovations have to take place and where extension work is required for popularising the concept.

***Preventive maintenance of the engine*:** This energy saving approach was adopted by most of the vessel operators. 88 % of the vessels were regular in injector calibration and tuning, lubricating oil and filter changes. However, engine overhauling was not done at intervals specified by the manufacturers and extension effort is required in this area.

***Anti-fouling measures*:** Hull cleaning and painting intervals were irregular varying from 6 to 12 months or more for wooden vessels and is done when the vessel is hauled up for other repairs. Steel vessels are hauled up at intervals of about 6 months. Awareness of the significance of hull cleaning on fuel expenditure was poor among the respondents. This is an area where intensive extension efforts are required to create awareness about the extent of energy and economic loss due to hull fouling and the frequency of hull cleaning required for vessels operating in the area.

Multi-day fishing: This energy saving practice has been adopted by 63 % of the gillnetters and 93 % of the trawlers studied. Small-scale purse seiners undertake only daily fishing, in the area of study.

Adoption of advanced technology: About 10% of the trawlers owned Global Positioning Systems (GPS) and 27 % of the trawlers used echo-sounder for location of potential fishing grounds. Only 5 % of the gillnetters in the 9.1-11.0 m L_{OA} length class used GPS for accessing rocky grounds for line fishing. Purse seiners did not use any electronic navigation aids or acoustic fish detection devices. The subsidy scheme, recently introduced by Marine Products Export Development Authority, Cochin, is giving a major fillip for adoption of GPS and echo sounder by the mechanised fishermen of Kerala.

Sasikumar *et.al.* (1992) conducted a study on the attitudes and knowledge on energy conservation in marine fisheries, under the Indo-Norwegian Programme on Energy Conservation. Their study concluded that the concept of energy conservation has not evoked any serious concern among the fishing community. However, the present study has indicated a greater diffusion of understanding of fuel saving concepts, though its practical implementation was often hampered by economic compulsions and practical difficulties. It was also pointed out in the study that no serious effort has so far been taken for the dissemination of the innovations pertaining to energy conservation. The present survey indicated the continuing validity of this observation and stresses the need for extension programmes for promoting energy saving practices such as economic vessel speed, economic engine RPM, preventive maintenance of engines, anti-fouling measures and use of echo sounder and GPS, which are highly practical, easily adoptable practices, having immense potential for fuel saving.

8.4 Conclusions

Based on the review of literature on fuel conservation measures and results of survey on the awareness and extent of adoption among mechanised vessel operators in Cochin, the following conclusions are drawn and areas identified for future investigations:

1. The concept of Economic Vessel Speed is one of the most important practical approaches in the conservation of fuel in mechanised fishing sector with potential for enormous savings in fuel. Hence it is pertinent to have well organised extension schemes to create awareness among mechanised fishing boat operators on its fuel saving and economic potential. Fuel consumption dramatically increases as maximum hull speed is approached and a mere 10% reduction in speed could lead to 35 % savings in fuel.
2. Similar is the case with economic range of rpm of the diesel engines. In the most widely used diesel engine types in the small-scale mechanised fishing sector of India, Specific Fuel Consumption is the lowest at about 80 % of the maximum engine rpm.
3. It is necessary to develop an affordable fuel monitoring device with user-friendly software and display unit for use in small-scale fishing vessels which will provide decision making support on economic vessel speed and optimum engine rpm, for maximising energy efficiency in fishing operations. In conjunction with GPS such a device could be designed to have features such as graphical output of fuel consumption vs. engine rpm and speed; instantaneous fuel consumption per hour and per nautical mile and averages according to end-user requirements.

4. Preventive maintenance of the power plant is often neglected by commercial fishing industry. Awareness campaigns would be useful in this area.
5. Anti-fouling measures is another area largely neglected by commercial fishing industry and awareness needs to be generated on its fuel saving significance.
6. Design and operational improvements in energy-intensive systems such as trawls have been reported to bring about reduction in drag ranging from 7 to 35 %. R&D efforts and extension activities need to be directed towards design and popularisation of low drag gears.
7. There is need for developing and standardising fuel-efficient hull designs for the next generation of fishing vessels for small-scale commercial fishing industry in India, taking into consideration the current advances in this direction elsewhere.
8. Two-stroke outboard engines have low fuel efficiency. Wherever possible use of more fuel-efficient diesel engines and four-stroke engines need to be promoted.
9. Overpowering the fishing vessel is highly wasteful in terms of energy. Optimum size of engines for powering different vessel classes and operations need to be determined and promoted.

10. Specific fuel consumption of diesel engines have come down from 175 $g.hp^{-1}.h^{-1}$ in 1945 to 135 $g.hp^{-1}.h^{-1}$ in 1995 with the introduction of major technological improvements. However, most widely used diesel engines in the mechanised fishing sector continue to have a relatively high specific fuel consumption ranging between 173 and 202 $g.hp^{-1}.h^{-1}$. This is identified as an area which needs intensive research inputs for improving overall energy efficiency in fishing.
11. Existing combinations of reduction gear and propeller size need to be evaluated with a view to optimise performance and maximise fuel economy.
12. Propeller nozzle generally gives 20-30 % better thrust at speeds less than 6 kn, which is the case while the gear is being towed in trawling cycle. However, the introduction of propeller nozzle was not well-accepted by the fishing industry, during the period of study. The reasons given are the progressive reduction in thrust as the speed increases more than 6 knots and the possibility of propeller fouling due to flotsam and debris in the coastal waters. Further investigations are required to improve the performance of nozzles in small-scale trawlers
13. A combination of enough engine power to achieve a speed (v, kn)-length(L_{WL}, ft.) ratio ($v/\sqrt{L_{WL}}$) of 1, plus sail power can result in a significant increase in speed while utilising power at the most economic

level. Sail-assisted propulsion could be feasible in trolling, long lining, trap fishing and gillnetting.

14. Enhanced use of technological innovations such as Global Positioning System, acoustic fish detection and gear monitoring equipment (echo-sounder, sonar and net monitor), implementation of decision support systems based on satellite based remote sensing techniques and fishery-based Geographical Information Systems could facilitate easy location of potential fishing zones and save energy in fleet operations.

15. Fish aggregation devices have shown potential for saving fuel, in purse seining, hand lining and gillnetting in different parts of the world and need further studies and evaluation in Indian fisheries.

16. Energy can be saved by optimising fleet management. Multi-day fishing and mother ship-catcher boat operations have fuel saving potential. These approaches need to be promoted.

17. One of the most important long-term solutions for the issue of energy conservation in fishing, is restoration and enhancement of coastal fishery resources by promotion of responsible fishing practices, removal of excess capacity from the fishing fleet and implementation of resource conservation and enhancement strategies.

Table 8.1 Details of popular marine diesel engines used in mechanised fishing vessels operated from Cochin

Model	ALM 370	ALM 400	ALM 402 (turbo charged)	ALM 412	ALM 680
Type	Direct injection, four stroke, 6-cylinder, overhead valve, water cooled marine diesel engine; Ashok Leyland Ltd, Chennai.				
SPECIFICATIONS					
Bore, mm	103.38	107.18	107.18	107.18	127.00
Stroke, mm	120.65	120.65	120.65	120.65	146.00
Cubic capacity, l	6.075	6.54	6.54	6.54	11.1
Compression ratio	16:1	16:1	16:1	16:1	15.8:1
PTO rating Max. hp	25	25	25	25	45
Weight of engine with gear box, kg	1160	1160	1160	1180	1500
Gear box reduction ratio	3:1 & 4:1	3:1 & 4:1	3:1 & 4:1	3:1 & 4:1	4.5:1 (hydraulic)
POWER RATING					
1500 rpm					
BHP (max)	76	84	90	100	172
BHP (cont.)	69	76	82	90	129
Specific fuel consumption, $g.hp^{-1}.h^{-1}$	173	172	167		182
1800 rpm					
BHP (max)	89	99	110	122	164
BHP (cont.)	81	90	100	110	148
Specific fuel consumption, $g.hp^{-1}.h^{-1}$	172	180	168		192
2000 rpm					
BHP (max)	98	109	118	135	172
BHP (cont.)	89	99	106	122	156
Specific fuel consumption, $g.hp^{-1}.h^{-1}$	173	174	169		202

Table 8.2 Details of popular Outboard Motors used in traditional motorised sector of Cochin.

Model	Yamaha E15AK	Yamaha 25CMK
Type	Two-stroke, twin engine, water cooling	
SPECIFICATIONS		
Maximum ouput	12 shp 5500 rpm	22 shp at 5500 rpm
Displacement	246 cc	430 cc
Bore	56 mm	11.1
Stroke	50 mm	15.8:1
Gear ratio	2.08:1	45
Propeller size, No. of blades x diameter x pitch	3 x 234 x 203 mm	3 x 234 x 229 mm
Fuel	Petrol-oil mixture + kerosene-oil mixture	Petrol-oil mixture + kerosene-oil mixture
Fuel-oil ratio	30:1	30:1
Switch over to kerosene	>1500 rpm	>1500 rpm
Fuel tank capacity	24 l	24 l
Weight	37 kg	57 kg

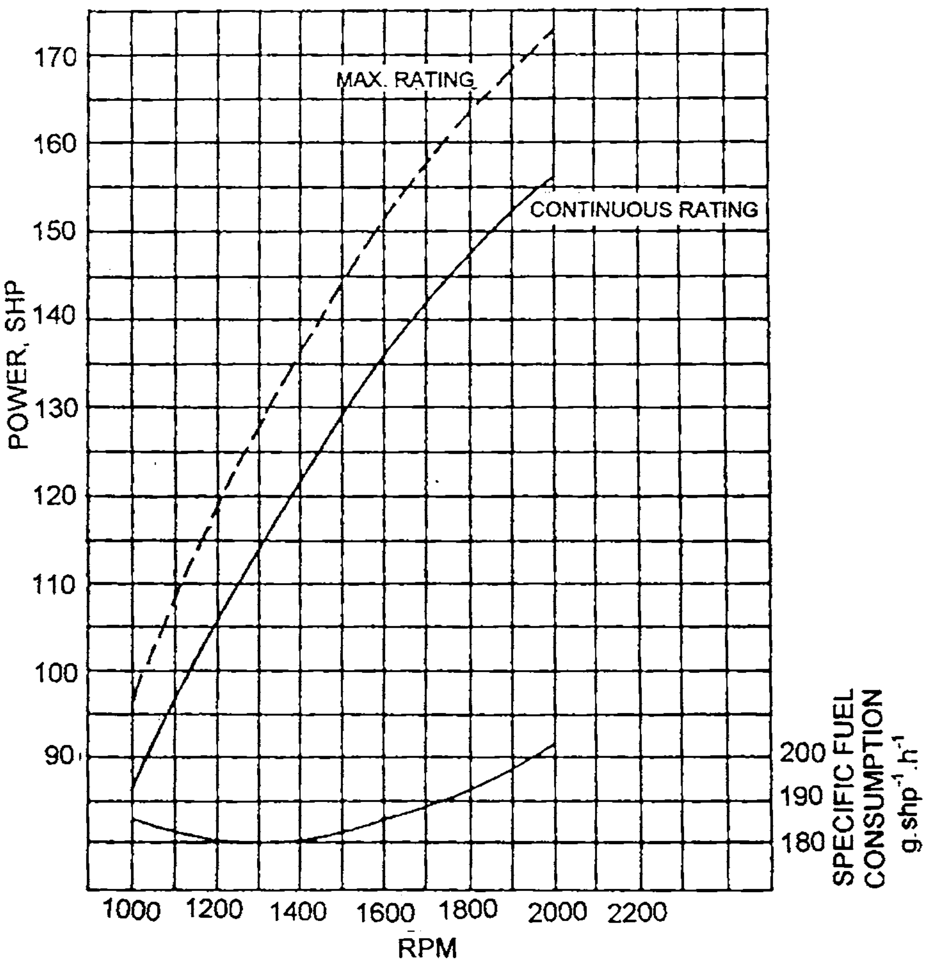


Fig. 8.1 **Engine power, operating range and specific fuel consumption of ALM 680 marine diesel engine**

Summary and Recommendations

Modern fishing is one of the most energy intensive methods of food production. Fossil fuels used for motorised and mechanised fishing are non-renewable and limited. Most of the environmental problems that confront mankind today are connected to the use of energy in one way or another. Code of Conduct for Responsible Fisheries (FAO, 1995) highlights the need for efficient use of energy in the fisheries sector. Information on energy requirement in different fish harvesting systems, based on the principles of energy analysis, is entirely lacking in respect of Indian fisheries. Such an analysis will provide an unbiased decision making support for maximising the yield per unit of non-renewable energy use, from different fishery resource systems, by rational deployment of harvesting systems. In the present study, results of investigations conducted during 1997-2000 on energy requirement in selected fish harvesting systems and approaches to energy conservation in fishing, are presented along with a detailed description of the fish harvesting systems and their operation. The content of the thesis is organised into 8 Chapters.

Chapter 1

The first Chapter gives the background of the topic of study, its relevance and significance; reviews the existing literature in the subject area and sets out objectives of the study. Objectives of the study include (i) detailed description of the fish harvesting systems selected for the study in the traditional non-motorised, traditional motorised and small-scale mechanised sectors; (ii) energy analysis of the selected fish harvesting systems and determination of Gross Energy Requirement (GER) which is a measure of the non-renewable resource use, Energy Efficiency and Energy Intensity values; (iii) relative energy consumption in demersal and aimed midwater trawling in the intermediate range freezer trawler operations; (iv) diurnal variation in trawl catches and its influence on energy efficiency of trawler operations; and (v) a detailed review and delineation of approaches to energy conservation in fish harvesting; and a study on the diffusion of such knowledge among mechanised fishermen.

Chapter 2

The second Chapter presents materials and methods used for the study on energy analysis. Procedures for determination of Gross Energy Requirement which is the sum of all non-renewable energy resources used up in producing a unit volume of fish (GER.t $fish^{-1}$), energy efficiency ratio and energy intensity as per the methodology and conventions recommended by IFIAS (International federation of Institutes for Advanced Study) (1975) are described in detail in this Chapter. Data on sources of energy inputs for traditional and mechanised fishing crafts were collected from boat builders in and around Cochin. Data on sources of energy inputs for fabrication of fishing gears and sheer devices were obtained by conducting a survey as per a structured Schedule. Data on operational inputs, fish production and operational details of fish harvesting systems were collected from different centres in Cochin, as per structured Schedules. Energy equivalents for fish production by different harvesting systems were derived using mean values of estuarine and marine finfish, crustaceans and cephalopods reported by CIFT (1993) and energy values for foods reported by Harper (1975). General statistics on fishing crafts were also collected from secondary sources.

Chapter 3

Chapter 3 covers energy analysis of selected fish harvesting systems in the traditional non-motorised sector, viz., gillnetting and stake net operations. The Chapter gives a detailed description of the design and operation of gill nets (Section 3.1) and stake nets (Section 3.2) operated in the Vembanad backwaters. Gillnetting is targeted at mullets and other estuarine resources and are operated from traditional two-men canoes of 5.5 m L_{OA}, using paddling as means of propulsion. Fishing operations take place from November to July while during the other months it is suspended due to the presence of large quantities of macro-vegetation, drifting downstream. Mean number of days of operation is 225 days. Mean catch per year per gillnetter was estimated to be 8.4 t of which mullets contributed 25.1 %, followed by sciaenids 17.1 %, carangids 15.5 %, cat fishes 13.6 %, prawns 13.3 % and miscellaneous fishes 15.2 %. GER.t fish^{-1} was found to be 0.61 GJ making this one of the most energy efficient system, among the fish harvesting systems studied. Nearly 98.92 % of the GER is contributed by fishing gear and the balance by the fishing canoe. Energy efficiency ratio was 8.01 and energy intensity value was the lowest being 0.125.

Stake nets are stationary traps with a conical bag of netting, the mouth of which is set against the tidal currents. It is primarily targeted at prawns, which drift with the tidal currents. Mean catch per year per stake net was estimated as 0.41 t and mean number of fishing days in a year was 210. *Metapenaeus dobsoni* formed the dominant component of the catch consisting of 92.4 %, followed by *M. monoceros* 6.0 % and *Penaeus indicus* 1.6 %. Best catches were obtained during January-May. GER.t fish^{-1} of 5.19 GJ was quite high for a stationary passively operated gear system. Fishing gear and stakes constituted 94.88 % of the GER and the balance was contributed by the traditional plank canoe used for carrying the gear and catch.

Chapter 4

Chapter 4 deals with the energy requirement in selected fish harvesting systems in the traditional motorised sector. Ring seining and mini trawling were introduced into the traditional sector with the advent of motorisation in 1980s. In mini trawling (Section 4.1), a small sized trawl net is towed from traditional plank canoe with transom (6.1 to 7.6 m L_{OA}) powered by an outboard motor generating 12 hp at 5500 rpm, in the shallow coastal waters of 5 to 27 m depth. Crew size varied from 2 to 5. This fishing practice is seasonal extending from March to May and again from September to November, and is specifically targeted at coastal prawn resources. Mean number of fishing days per year was 120. Mean catch per year per mini-trawler during the period of study was 10.26 t, which was constituted by prawns 48.1 %, followed by flat fishes 33.1 %, crabs 12.0 % and miscellaneous finfishes 6.8 %. The GER.t $fish^{-1}$ for mini trawling was estimated to be 20.2 GJ, which is quite high for a coastal fishing operation. Kerosene, petrol and lubricating oil together constituted 97.93 % of the GER, followed by fishing gear 1.43 %, outboard motor

0.58 % and fishing craft 0.06%. Energy efficiency ratio and energy intensity for mini trawling were 0.19 and 5.36, respectively.

Ring seining (Section 4.2) is an extensively practised fishing technique in the traditional motorised sector. Ring seines are surrounding gears with pursing arrangement targeted at pelagic shoaling resources. Two types of ring seines one with 18-22 mm mesh size targeted at mackerel and sardines and the other with 10-12 mm mesh size targeted at smaller pelagics such as anchovies in addition to sardines and mackerel, are used in ring seine fisheries. The hung length of the float line can be up to 585 m for large ring seines. In many ring seiners, purse line winches powered by second-hand automobile diesel engines of 75 hp, have been introduced recently in order to facilitate quick pursing operation which used to be laborious when done manually. This has also facilitated multiple setting operations in a single day and the carrier vessel is deployed to transport the catch. Crew size onboard the ring seiner ranges from 30 to 35 and almost an equal number of fishermen attached to the vessel remain ashore (*karanila*) and shares the profit. Large plank built canoes (*thangu vallam*) of 17.68 to 21.33 m L_{OA} powered by two outboard motors generating 22 hp at 5500 rpm are used for ring seining. Plank built canoes of 9.14-13.72 m L_{OA} powered by one or two 12 hp outboard motors are used as carrier vessels, for transporting the catch from the ring seiner to the landing point. Operation of the gear is by a single ring seiner. A recent innovation is the introduction of inboard diesel engines (99 hp) for powering large traditional ring seiners of up to 24 m L_{OA}. Mean catch per unit per year worked out to be 211.9 t of which sardines constituted 44.3 %, followed by mackerel 29.7 %, carangids 11.4 %, penaeid prawns 2.2 %, pomfrets 1.1 % and miscellaneous fish 11.3 %. Mean number of fishing days per year was 171. The GER.t $fish^{-1}$ for ring seining was estimated to be 6.14 GJ. Among the operational inputs, kerosene constituted 73.4% of the GER, followed by petrol 12.7%, diesel 6.7 % and lubricating oil 2.4 %. Fishing gear contributed 3.8 %, engines 0.8 % and fishing crafts 0.3% of the GER. Energy efficiency ratio for ring seining was 0.72 and energy intensity value was 1.40.

Chapter 5

Chapter 5 presents a detailed description and the results of energy analysis of mechanised fish harvesting systems landing at Cochin Fisheries Harbour such as gillnetter-cum-liners (Section 5.1), trawlers (Section 5.2) and purse seiners (section 5.3). An estimated 210 gillnetter-cum-liners are operating from this harbour. Majority (84 %)of the gillnetter-cum-liners belong to the length class of 9.1-11.0 m L_{OA} and over 62 % are fitted with 89-99 hp power plants. All the vessels have wooden hulls. The gillnetter-cum-liners undertook gillnetting from May to October and line fishing from November to April. Drift gillnetting operations were conducted in 45-55 m depth zone, handline operations in the rocky areas within 65 to 150 m depth zone and drift long lining targeted at pelagic sharks at depths beyond 300 m depth, off south west coast of India. Total annual catch per gillnetter-cum-liner was 32.8 t. Pelagic sharks constituted 28.6 % of the landings, followed by tunas and billfishes 28.5%, perches 22.8 %, Spanish mackerel 9.5 %, carangids 5.7 % and miscellaneous fish 5.0 %. Average fuel consumption was 0.36 kg fuel.kg $fish^{-1}$. The GER.t $fish^{-1}$ for gillnetting-cum-lining was estimated to be 25.4 GJ. Among the operational inputs, diesel constituted 95.98 % of the GER, followed by lubricating oil 0.56 % and ice for the preservation of fish 0.34 %. Fishing gear contributed 2.23 %, and fishing crafts 0.89 % of the GER. Energy efficiency ratio for gillnetting-cum-lining was 0.17 and energy intensity value obtained was 5.99.

An estimated 674 trawlers land their catches at Cochin Fisheries Harbour. Over 80 % of these trawlers belong to the length class of 13.1-14.0 m L_{OA} and are fitted with 99-106 hp power plants. About 20 % of the vessels in operation have steel hulls and the rest are of wooden hull construction. Design and construction of various trawl nets, targeted at finfish, cephalopod and crustacean resources and sheer devices used for operation are described in detail. Mean catch per year of trawlers was 52.8 t and major catch components were threadfin breams 22.9%, perches 17.7 %, carangids 9.9 %, lizard fish 2.8 %, sciaenids 1.7 %, crustaceans 8.8 %, cephalopods 12.2 % and miscellaneous fish 24.0 %. The GER values for trawling were the highest among the various harvesting systems studied and ranged from 31.40 GJ.t $fish^{-1}$ for wooden trawlers to 36.97 GJ.t $fish^{-1}$ for steel trawlers. Percentage contribution of operational and capital energy inputs to GER in respect of wooden trawlers were 85.7 % for diesel, 0.3 % for lubricating oil, 0.4 % for ice, 11.8 % for fishing gear and 1.8 % for fishing vessel. Percentage contribution to GER of steel trawlers were 84.5 % for diesel, 0.3 % for lubricating oil, 0.3 % for ice, 9.6 % for fishing gear, and 5.3 % for fishing vessel. Energy ratios were 0.13 and 0.11 and energy intensity values 7.69 and 8.91, respectively for wooden and steel trawlers.

Purse seining is an advanced fishing technique targeted at pelagic shoaling fishes which was introduced in the small mechanised sector of the region in 1970s. Purse seiners numbering 47, formed about 5 % of the mechanised fleet operating from Cochin Fisheries Harbour. 22 % of the vessels were of steel and the others were of wooden construction. Most abundant length class of purse seiners were 13.1 - 17.0 m L_{OA} and about

45 % of the vessels were having installed power of 156-235 hp. Purse seines used for operation generally has a float line length of 720 m, mesh size of 22 mm and is fabricated of polyamide netting. Small scale purse seiners operating here have pursing winches powered using power take-off from main engine, but do not have any devices for hauling the gear and hence it is done manually. Mean number of fishing days ranged from 124 days for wooden seiners fitted with 235 hp engines and 181 days for steel and wooden seiners with 156 hp engines. No fishing was conducted during June-August as it is a closed season for purse seining in the State. Mean catch per year were 325.3 t, 340.5 t and 277.6 t, respectively for 156 hp wooden seiner, 156 hp steel seiner and 235 hp wooden seiner, respectively. The catch was constituted by sardines 54.30 %, mackerel 44.5 %, tunnies 0.23 %, pomfrets 0.08 % and miscellaneous fish 0.89 %. The GER.t $fish^{-1}$ were 5.54, 5.93 and 6.4, for 156 hp wooden seiner, 156 hp steel seiner and 235 hp wooden seiner, respectively. Mean values of energy efficiency ratio and energy intensity for purse seiners were 0.75 and 1.34, respectively.

Among the fish harvesting systems studied, traditional non-motorised gillnetting was the most energy efficient having the lowest GER and energy intensity values and highest efficiency ratio, producing more energy than the amount of non-renewable energy consumed. Mechanised trawling was the most energy intensive operation with GER.t $fish^{-1}$ values ranging from 31.40 to 36.97 GJ, indicating an overall consumption of 0.73-0.86 t of fuel for every tonne of fish produced. Among the non-motorised systems, stake nets have a relatively high energy intensity, as the annual landings were lowest and the economic viability of the operation was due to the high value catch of prawns. In the motorised operations, ring seines have a lower GER.t $fish^{-1}$ value than mini trawling. For a fishing system which is restricted in its operation to shallow coastal waters, the energy cost of mini trawling is adjudged to be high. Economic viability of the mini trawling could be derived from high value landings of prawns during its seasonal operation. GER.t $fish^{-1}$ value of ring seines was higher compared to 156 hp mechanised purse seiners, probably due to lower fuel efficiency of outboard motors compared to inboard diesel engines. Mechanised gillnetting-cum-lining operations are conducted at comparatively distant fishing grounds due to scarcity of resources in the inshore waters, which explains the relatively high GER.t $fish^{-1}$ values obtained for a system operating passive fishing gears. Steel vessels generally gave higher GER.t $fish^{-1}$ values compared to wooden vessels used in purse seining and trawling, due to larger inputs in terms of energy into vessel construction.

Chapter 6

Chapter 6 deals with the relative energy consumption in demersal and mid-water trawling based on data derived from two cruises of an Intermediate range freezer trawler which operated in Indian waters during 1993-94. The trawler has a length overall of 62.2 m, GRT of 1898 and installed engine power of 2400 hp. Operations were conducted between 14° and 22° N lat., off west coast of India, within a depth range of 31 and 125 m, using 47.5 m four-seam bottom trawl rigged with bobbin gear and 70.0 m mid-water trawl. Fuel consumption was estimated from the specific fuel consumption of the power plant and the estimated hours of operation of the engines. Mean daily fuel consumption per unit volume of fish landed was estimated to be 5.46 kg fuel.kg $fish^{-1}$ and 1.44 kg fuel.kg $fish^{-1}$, respectively for bottom trawling and aimed mid-water trawling. The difference in daily fuel expenditure per unit volume of fish between bottom and aimed midwater trawling was found to be highly significant statistically.

Chapter 7

The penultimate Chapter presents the results of diurnal variation in trawl catches and its influence on energy efficiency of trawler operations. Data on landings during four cruises of a Japanese factory trawler which operated in the Indian waters during 1992-93 were used for analysis. The factory vessel equipped for stern trawling had a length overall of 110 m, GRT of 5460 and installed engine power of 5700 hp. Operations were conducted off west coast of India between 31 and 278 m depth contours, using a 80.4 m high opening bottom trawl with an adjusted vertical opening of 7.6±0.9 m. The catch data was grouped according to the median towing hour, by the time of the day. Daily hours of sunset and sunrise adjusted for specific longitude and latitude were determined using a software sourced from Institute for Studies on Vedic Sciences, Akkalkot. CPUE obtained was 3713.4 $kg.h^{-1}$ for day-time operations and 1536.6 $kg.h^{-1}$ for night-time operations. Mean daily catches were 31367 $kg.day^{-1}$ (SE: 2743) for day-time operations and 9430 $kg.day^{-1}$ (SE: 966) for night-time operations. Fuel consumption were 0.399 and 0.982 kg fuel.kg $fish^{-1}$, respectively for day-time and night-time operations. Total catch and catch components such as threadfin bream, bulls eye, hairtails, trevelly, lizard fish showed significant improvement during day-time operations while swarming crabs showed a significant improvement in the night-time operations. The difference in catch rates between day and night could be attributed to diurnal variation in the spatial distribution and schooling behaviour of the catch categories; their differential behaviour in the vicinity of trawl systems under varying light levels of day and night and consequent effect on catching efficiency; and size selectivity at different stages in the capture process. The results obtained, in addition to its importance in the operational planning of trawling in order to realise objectives of maximising catch per unit effort and minimising fuel consumption per unit volume of fish caught, has added significance in the use of bottom trawl surveys for stock abundance estimates.

Chapter 8

The final Chapter of the thesis reviews the existing knowledge on the energy conservation in the context of fisheries and delineates approaches for improving energy efficiency in fishing. The Chapter also presents the results of a survey on the awareness and extent of adoption of some of the immediately practical approaches for fuel conservation in fisheries such as choice of alternative energy efficient fishing techniques, economic vessel speed and engine rpm, propeller nozzle, sail-assisted propulsion, preventive maintenance of the engine, regular hull cleaning, multi-day fishing and use of navigational and fish detection aids among the fishing vessels.

Recommendations:

1. Evaluation of energy requirement, of the existing fishing systems and new systems proposed for introduction in future, is an important consideration for energy conservation in the fishery sector. It is

recommended to establish an Energy Analysis Unit with the objective of pursuing investigations on energy analysis in the fisheries sector; developing comprehensive fuel conservation strategies; and recommending codes of practices for energy optimisation in harvest and post-harvest operations.

2. It is recommended to establish (i) a national energy consumption data base for each fishing sector and an energy conservation inventory, to reduce energy consumption and harmful emissions from the fishing fleet; and (ii) an effective extension network with mobile training units, for diffusion of energy saving concepts to commercial fishermen.
3. Selection and rational deployment of an energy efficient mix of harvesting systems at optimum capacity levels, based on GER values and updated stock abundance estimates, are urgently required in order to maximise yield per unit of non-renewable energy use, from different fishery resource systems of the country.
4. Non-motorised gillnetting is highly energy efficient and needs to be promoted according to the carrying capacity of the resource systems, in which they are deployed.
5. Stake net operations have high Gross Energy Requirement (GER) values and their number, in consideration of its known negative impact on

juveniles of shrimp and fish species in the backwater resource system, need to be subjected to control

6. Mini-trawling which is targeted at coastal shrimp resources is an energy intensive method and its uncontrolled proliferation need to be discouraged.
7. Motorised ring seining has higher energy requirements, compared to mechanised purse seining, although both target the same resources. Number of ring seine units need to be subjected to control.
8. For coastal pelagic shoaling resources, mechanised purse seining with 156 hp vessels was most efficient in terms of GER values, and this category of seiners need to be promoted, subject to the maximum sustainable yield of the target resource.
9. Mechanised gillnetting-cum-lining depending on deep sea pelagic and demersal resources, has GER values which is higher than coastal purse seining but lower than mechanised trawling. However, as there are no competing harvesting systems targeted at these resources, gillnetting-cum-lining could be encouraged.
10. Mechanised trawling has the highest energy requirement and in addition is known to have negative ecological impacts on the resource systems. However, trawling is known to be the most effective fishing method for shrimps. Hence, a compromise approach would be to control their

number at a rational level according to the maximum sustainable yield of shrimp stocks, and encourage diversification of excess capacity into low energy fishing methods.

11. Aimed midwater trawling has been found to be highly successful for resources such as horse mackerel and scad, with significant differences in daily production and fuel consumption per unit volume of landings, compared to bottom trawling. There is scope for diversification of high powered stern trawlers into aimed trawling for midwater resources, in order to reduce the fishing intensity on demersal stocks while maintaining production at low energy intensity levels.
12. There is significant day and night variation in the catchability of trawl resources, such as threadfin bream, bulls eye, hairtails, scad, lizard fish, perches, cephalopods with consequent differences in fuel consumption per unit volume of fish landed. Day-time trawling for such resources need to be promoted, in preference to night-time trawling, in order to maximise energy efficiency in demersal trawling.

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