Investigations on Hard Bycatch Reduction Devices for Selective Trawling

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Doctor of Philosophy

By

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This thesis is dedicated to….

My family

&

Friends

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CERTIFICATE

This is to certify that this thesis titled "***Investigations on Hard Bycatch Reduction Devices for Selective Trawling***" is an authentic record of research work carried out by Mr. T.R. Gibinkumar, M.Sc., under my guidance and supervision in the Fishing Technology Division of Central Institute of Fisheries Technology, Cochin, in partial fulfillment of the requirements for the degree of Doctor of Philosophy and that no part thereof has previously formed the basis for award of any degree, diploma, associateship, fellowship or any other similar titles of this or any other university or institution.

Cochin-29
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DECLARATION

I, T.R. Gibinkumar, hereby declare that the thesis entitled *Investigations on Hard Bycatch Reduction Devices for Selective Trawling*, is an authentic record of the research work carried out by me under the supervision and guidance of Dr. M.R. Boopendranath, Principal Scientist, Fishing Technology Division, Central Institute of Fisheries Technology, Cochin, in partial fulfillment 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 one of the oldest occupations and has been recognized as a powerful income and employment generator. It has got a prominent role in the economic and social wellbeing of millions of people worldwide. Fish is considered as a cheap protein source, especially for the poorer sections of the society, and thereby it serves as a means to ensure the food security of millions of people, contributing about 20% of animal protein supply. According to FAO (2004a) the total world capture fish production was about 93 million tonnes and the contribution from marine capture fisheries was about 90%. The annual growth rate reduced from 6% during 1950-1970 to almost zero after 1990, since most of the fish stocks have apparently reached their maximum sustainable level of exploitation.

The rapid technological developments which has occurred in the capture fisheries sector caused increased landings in the second half of the last century and most recently these technological advancements were blamed as the major cause for the current over-exploitation of the fish stocks and other resultant impacts (Pauly et al., 2000; Valdemarsen, 2001; Kennelly and Broadhurst, 2002).

1.1. Marine Trawl Fisheries of India

India is endowed with a long coastline of 8129 km, Exclusive Economic Zone (EEZ) of 2.02 million sq.km and continental shelf area of 0.5 million sq.km. Annual marine fishery potential of Indian EEZ is estimated at 3.93 million tonnes (Sudarsan et al., 1990) and India occupies seventh position in the world marine capture fish production. The marine fish landings of India during 2006-07 have been provisionally estimated at 2.71 million t, which recorded an increase of about 4.1 lakh tonnes over the previous year. The pelagic fishes constituted 55%, demersal fishes 24%, crustaceans 16% and molluscs 5% of the total landings. While considering the sector-wise contribution of marine fish landings during the year 2006, the mechanized sector accounted for 71%, motorized sector 24% and artisanal sector 5% of total production (CMFRI, 2006a).

Trawling is the most important commercial fishing method used in mechanized sector, in India. Trawling involves the dragging of a conical shaped bag net with wings and a codend, which works on the principle of filtration. Classification and description of trawling systems are given by various authors (Hjul, 1972; Nedlec, 1982; Brandt, 1984; Sainsbury, 1996; Hameed and Boopendranath, 2000). A major portion of the world's fish supply for direct human consumption is provided by trawls (Sainsbury, 1996) and in terms of investment and yield trawling is considered to be a very effective method for capturing demersal fish populations (Scofield, 1948).

The first attempt for introduction of trawling in Indian waters was by the mechanized vessel *S.T. Premier* in 1900 off Bombay coast (Chidambaram, 1952; Mukundan and Hameed, 1993) and by the Ceylon Company for Pearl Fishing Survey (Hornell, 1916). According to Gnanadoss (1977) only 13 mechanised fishing vessels were in operation in 1947. Pair trawling operations was conducted from Japanese Trawler *Taiyo Maru-17*, during 1947-1953 (Chidambaram, 1952). Kurian (1965) has reviewed the trends in shrimp fishing techniques, with special reference to trawling and the increased export demand for shrimps caused rapid development of otter trawling in Indian waters.

In Kerala, motorized and mechanized fishing were introduced in the mid-fifties. Kristjonsson (1967) mentioned about the experimental shrimp trawling conducted in 1955 from a 6.6 m L_{OA}, 10 hp open motor boat, off Malabar coast under FAO Technical Assistance, using a Gulf of Mexico type flat trawl of 9.6 m head line. Mechanized fishing was first introduced in 1956 at Sakthikulangara – Neendakara in the Quilon coast, and it had extensive effect on the socio-economic status of fishermen in this area (Sathiadhas et al., 1981; Devaraj and Smitha, 1988). Construction of small mechanized boats fit for commercial trawling was made by the erstwhile Indo-Norwegian Project (INP) in 1957 (Sandven, 1959; Gnanadoss, 1977; Gulbrandsen, 1984; Gulbrandsen et al., 1992; Pillai et al., 2004).

The number of trawlers operating in Indian waters has been recently estimated at 29,241 (CMFRI, 2006b), with maximum number operating in Gujarat (27.4%), followed by Tamil Nadu (18.1%), Maharashtra (14.4%), Kerala (13.6%), Karnataka (8.6%), Andhra Pradesh (6.2%), Orissa (4.6%), Goa (2.8%), West Bengal (2.1%), Pondicherry (1.1%) and Daman & Diu (1.1%). Of the total trawler fleet in India, 67.9% operates in the west coast and 32.1% in the east coast. Penaeid shrimps and deep-sea shrimps form the mainstay of Indian fishing industry, which also forms the major component of marine products exports from India. The bulk of the wild caught shrimps landed in India are caught by trawling. Though trawling is an efficient method of harvesting shrimps, it is also considered as one of the most destructive and non-selective method of fishing. In addition to shrimps, they also catch considerable amount of non-shrimp resources, which are either discarded at the sea or landed and utilized for purposes other than human consumption.

1.2. Bycatch in Fisheries

As per the United Nations Convention on the Law of the sea in 1982, the rights and responsibilities for the management of the resources within the EEZ are vested with the coastal states. According to the principles and international standards set out by FAO in 1995 through the Code of Conduct for Responsible Fisheries, emphasis is given to responsible fishing practices in order to ensure long-term sustainability of the fishery resources, protection of biodiversity, energy conservation and environmental safety.

Development and promotion of selective fishing gears and methods which would minimize fishing mortality of non-target and protected species and ensure biodiversity by promoting ecofriendly fishing gears are the important areas stressed in the Code of Conduct for Responsible Fisheries.

Bycatch and discards are the common problems faced by all fisheries globally and it is a major component of the negative impacts of fishing on marine ecosystems. It is an extremely complex set of scientific and ecosystem-wide issue and includes many economic, political and moral factors. Bycatch is recognized as unavoidable in any kind of fishing but the quantity varies according to the gear operated (Riedel and DeAlteris, 1995; Clucas, 1998; Pillai, 1998; Ortiz et al., 2000; Hall et al., 2000; Matsushita, 2000; Costa et al., 2001; Madsen and Hanson, 2001; Chuenpagdee et al., 2003; Morgan and Chuenpagdee, 2003; Sandra, 2003; Lewison et al., 2004; Fonseca et al., 2005a; Harrington et al., 2005; Pierre and Norden, 2006). Bycatch quantity also varies with the season, area of fishing operation, type of fishery, type of fishing vessels, etc. (Adlerstein and Trumble, 1998; Ye, et al., 2000, Herrera, 2005).

Bycatch is closely associated with fishing from the very beginning of the commercial fishing operations and it presents some unique problems to the fishery managers. The changing perspectives of bycatch itself offer the greatest challenge, as yesterday's bycatch becomes today's target catch (Boyce, 1996). The accuracy of estimation of bycatch is an important aspect as it is essential in the identification of spatial and temporal closures to fishing and to help gear technologists to develop suitable mitigative measures (Kennelly, 1999b; Ortiz et al., 2000; Lewison et al., 2004). The target catch is the catch of a species or species assemblage, which is primarily sought in a fishery and incidental catch, is the retained catch of non-targeted species. Discarded catch is that portion of the catch returned to the sea as a result of economic, legal, or personal considerations (McCaugran, 1992).

1.2.1. Bycatch in world fisheries

Bycatch is defined as the discarded catch of any living marine resource plus retained incidental catch and unobserved mortality due to a direct encounter with the fishing gear (NMFS 1998; 2003). Saila (1983) has done a detailed examination of bycatch and gave a new angle to this issue, in terms of potential losses occurring as the result of discards in world fisheries. Saila prepared a detailed report on world bycatch and discards and estimated a minimum world discard of fish and shellfish of about 6.72 million tonnes. This publication forced the international fishery managers to focus on the issues of bycatch and discards, its documentation and search for solutions to reduce bycatch levels. The need for bycatch assessment has been stressed by various authors (Alverson et al, 1994; Alverson, 1997; 1998; 1999; Matsuoka, 1999; Ortiz et al., 2000; Cook, 2001; Sandra, 2003). Andrew and Pepperell (1992) estimated a global bycatch in world shrimp fisheries as 16.7 million tonnes. Alverson et al., (1994) estimated a world bycatch level of about 29 million tonnes and of this 27 million tonnes (range: 17.9-39.5 million tonnes) were discarded.

Among different types of fisheries, shrimp fisheries produce about 16.4 million tonnes of bycatch and among different fishing gears, trawling accounts for a higher rate of bycatch along with target species (Alverson et al., 1994; McKenna, 1997; Bonfil, 2000; Koslow et al., 2001; Machias et al., 2001; Bergmann et al., 2002; Cryer et al., 2002; Fennessy, 2002; Schratzberger and Jennings, 2002; Wassenberg et al., 2002; Sanchez et al., 2004). It is significant to note that the bycatch from shrimp fisheries consists of diverse assemblage of aquatic life and large quantities of juveniles (Broadhurst et al., 1999; Vincent, 2003) and non-shrimp fisheries produce comparatively less bycatch (Gray et al., 2003). Trawling contributes around 35% in the global bycatch (Alverson et al., 1994). During 1996 average annual global discards were around 20 million tonnes and it came down to 7.3 million tonnes in 2004 (FAO, 2004a; Kelleher, 2004). Though recent bycatch estimates have indicated considerable decline in the past decade (FAO, 1999; FAO, 2004a; FAO, 2004b), bycatch still remains as a potent threat to biodiversity and long-term sustainability of fishery resources.

Fish are discarded for a number of reasons. Clucas (1997) Clucas and James (1997), Bonfil (2000), Hall et al. (2000), Cook (2001), Horsten and Kirkegaard (2003), Morizur et al. (2004) and EJF (2005) have given the following reasons for discards:

i. Fish of wrong species - Fishes which are not of the target species for the particular operator;
ii. Fish are of the wrong size - Fish size which command too low a price in the market or which are below the minimum legal landing size;
iii. Fish are of the wrong sex - Usually where gender is important from the processing and marketing point of view;
iv. Damaged fish - Caused by gear or predation in nets or mishandling;
v. Fish are incompatible with the rest of catch – Species with slime or causing abrasion that could cause damage to the target species are discarded;
vi. Fish that are poisonous or otherwise considered inedible are always discarded;
vii. Fish which spoil rapidly causing problems for the rest of the catch are discarded;

viii. Lack of space onboard - Where fishing operations are successful and target species take precedence over lower value or non-target species;

ix. High grading - Certain attributes of a fish make it more marketable and therefore more valuable than another and the less valuable is discarded;

x. Quotas limits - This may involve discarding of fish species that has exceeded the quota limits;

xi. Prohibited species - This involves the discards of particular species that are protected legally;

xii. Prohibited season - Where time bound constraints are made on catching particular species;

xiii. Prohibited gear - Fishes caught using prohibited gear may be discarded;

xiv. Prohibited fishing grounds - Fishing ground may be closed for capture of particular species but open for others - if the wrong species is caught it is discarded.

1.2.2. Bycatch in Indian fisheries

In tropical countries like India bycatch issue is more complex due to the multi-species nature of the fisheries. Central Marine Fisheries Research Institute attempted to estimate bycatch associated with shrimp trawling in 1979 and showed that 79.18% of total landings were bycatch (George et al., 1981). According to Sukumaran et al. (1982), shrimps contributed only 13% of average annual trawl catch in Karnataka state (India). Gordon (1991) estimated the bycatch levels in India as part of Bay of Bengal Programme of FAO. He estimated that the bycatch level in east-coast shrimp trawlers was about 90% of total catch and the quantity of bycatch being discarded by the trawlers was estimated to be 100,000-130,000 tonnes in 1988. Menon (1996) estimated a quantity of 43,000 tonnes of bycatch has been landed by trawlers in Kerala, Karnataka and Tamil Nadu states (India). In India, the bycatch in shrimp trawling is a serious problem accounting for 70-90% of the total catch and in that 40% consisted of juveniles, which implicate the severity of issue (Pillai, 1998; Pillai et al., 2004). Further studies conducted by CMFRI in 1999 revealed that the bycatch ratios along the southwest and southeast regions of India were 1:4.6 and 1:2.6 respectively (Menon et al., 2000).

In 2001-02 estimates of bycatch by Zacharia, in Karnataka state (India), quantity of trawler bycatch was 56,083 t (54.4% of total catch) in 2001 and 52,380 t (47.9%) in 2002. The quantity of discards was 34,958 t (33.9%) in 2001 and 38,318 t (35.1%) in 2002 (Zacharia et al., 2005). In Kerala state (India), quantity of discards was estimated at 2,62,000 t during 2000-2001 and 2,25,000 t during 2001-2002 (Kurup et al., 2003; 2004).

With the decline of the shrimp catch these bycatches began to contribute significantly to the overall income of the shrimp trawlers (Clucas, 1998). Along the west-coast of India, especially in Gujarat, most of the bycatch is landed and utilized for fishmeal and manure production (IIM, 2003; Zynudheen et al., 2004; Kumar and Deepthi, 2006). It is significant to note that among the bycatch about 40% consisted of juveniles and those in the early stages of development, which are invariably discarded leading to the depletion of the resources. (Pillai, 1998).

1.2.3. Operational definitions of bycatch

There are a number of definitions available with reference to the word 'bycatch' (Alverson et al., 1994; Bonfil, 2000; Horsten and Kirkegaard, 2003; NMFS, 2003; Petruny- Parker et al., 2003; Branch et al., 2006). McCaughran (1992) defined bycatch as that portion of the catch returned to the sea as a result of economic, legal or personal considerations plus the retained catch of non-targeted species. Hall (1996) defined it as that part of the capture that is discarded at sea dead (or injured to an extent that death is the result). Gordon (1991) defined bycatch as 'non-target species caught with and incidentally to the target species'. Alverson et al., (1994) concluded from a review that there are mainly three accepted definitions. In some areas bycatch is catch, which is retained and sold which is not target species. In some other areas bycatch means species or sizes and sexes of fish that are discarded and the final one is 'all non-target fish species retained, sold or discarded'.

According to the Magnuson-Stevens Act of 1996, the term 'bycatch' means fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards. Such term does not include fish released alive under a recreational catch and release fishery management program (Dobrzynski, 2004). Clucas, (1997) and Clucas and James, (1997) defined bycatch as that part of the catch which is not the primary target of the fishing effort which includes fish which is retained, marketed (incidental catch) and that which is discarded or released. According to NMFS (1998; 2003) bycatch was defined as the discarded catch of any living marine resource plus retained incidental catch and unobserved mortality due to a direct encounter with fishing gear. Hameed and Boopendranath (2000) defined that bycatch includes undersized fish, non-targeted fish species, birds, mammals and other organisms encountered during fishing operations. Pillai (1998) defined the term bycatch as the portion of catch other than the target species caught while fishing for a particular species.

In this study, operational definitions for bycatch, as proposed by the Newport National Industry Bycatch Workshop conducted in Newport, Oregon (USA) in February 1992 (Alverson et al., 1994) is followed. 'Target catch' is the catch of a species or species assemblage, which is primarily sought in a fishery. 'Discarded catch' is the catch, which is returned to the sea due to economic, legal, or personal considerations. 'Incidental catch' is the catch of non-targeted species, which is retained. 'Bycatch' is defined as discarded catch plus incidental catch.

1.3. Impacts of Bycatch

Bycatch and discards had created discernible impacts on biological and ecological aspects of many species. The disadvantages of bycatch and its effects have been mentioned by a number of authors (Brewer et al., 1997; Prado, 1997; Hall et al., 2000; Linnane et al., 2000; Horsten and Kirkegaard, 2003; CEFAS, 2003; EJF, 2005). The impact of discards on non-target populations may differ significantly from the effects felt by target species and may depend on life history features of the impacted species. The impacts of bycatch could be of biological and ecological, environmental, economic and socio-cultural nature.

1.3.1. Biological and ecological impacts

The biological impact of discards varies according to the vulnerability of the species affected. Some can be of major concern, but others are much less of a problem. It is generally understood that the physical disturbances caused by the bottom gears leads to community changes in benthos, reduction in biodiversity, biomass and size of organism (Goni, 1998; Ball et al., 2000; Jennings and Reynolds, 2000; Revil and Jennings, 2005). Hall (1996; 1999), Hall et al., (2000), Clucas (1997) Clucas and James (1997) and Cook (2001) have listed the following levels of impacts caused by bycatch and discards.

i. Critical discards of populations or species that are in danger of extinction;

ii. Unsustainable discards, where, although not currently at risk, continued mortality could put a species or population at risk;

iii. Sustainable discards which do not pose a threat to the resource;

iv. Biologically insignificant discards, where the numbers are negligible from the point of view of the population involved;

v. Unquantifiable discards for which a lack of data creates an unknown level of impact, and this category represents the greatest number of cases (Hall 1996);

vi. Ecosystems impacts, usually occur in tropical shrimp trawling, where a complex of species is removed and the biological consequences of these impacts are not estimated to the full extend;

vii. Charismatic discards, which involve species of particular significance to groups of people. The considerations against killing certain animals and the public concern over marine turtles, dolphins and whales come within this category and in many ways have fuelled public debate. The capture of these animals may or may not have significant biological consequences.

It is generally agreed that the discarding of fish may have detrimental biological effects and may have effects on the stocks of commercially important species (Prado, 1997; Adlerstein and Trumble, 1998; Hall et al., 2000). The mortality of large quantities of juveniles is a major concern as it definitely affect deleteriously on the recruitment and biomass of many stocks including those stocks targeted by other fisheries (Broadhurst et al., 1999). Bycatch and discards is now known as a major threat to the population of various species such as sea turtles, seals, dolphins, porpoises, seabirds, sea snakes, many batoid fishes (rays and skates), sharks etc (Sujatha, 1995; Milton, 2001; Wassenberg et al., 2001; Vincent, 2003; Casale et al., 2004; Koch et al., 2006; Tamini et al., 2006). Many studies were conducted regarding the survival of the discarded species and all authors come to a common conclusion that the survival rate of the discarded species is generally low (Farmer et al., 1998; Gallaway and Cole, 1998; Hill and Wassenberg, 2000; Heales et al., 2003; Laptikhovsky, 2004; Cedrola et al., 2005). The discard mortality is influenced mainly by some procedures on board fishing vessels. Fishing during hottest time of day, temperature of sorting containers, sorting time, haul duration, etc., will affect the mortality of discarded species (Gamito and Cabral, 2003; Heales et al., 2003; Macbeth et al., 2006) and the important reasons of mortality of discards are due to barotraumas (injury sustained from failure to equalize the pressure between an air space inside or beside the body and the surrounding environment), handling damage and increased vulnerability to predation (Horsten and Kirkegaard, 2003).

Apart from changes in single species stocks, the balance between species within multi species population may change. Ecosystems impacts, which occur, for instance, in tropical shrimp trawling, where a complex of species is removed (Clucas, 1997; Clucas and James, 1997; Stratoudakis et al., 1998; Gislason, 2001; Duplisea et al., 2001; Kaiser et al., 2001; Stobutzki et al., 2001). But there is no evidence so far found to prove any direct detectable genetic impacts on any marine organism due to trawling or any other type of fishing activities (Saillant et al., 2006).

1.3.2. Environmental impacts

Apart from impacts on fish populations, the raising of benthic organisms to the surface can cause habitat modifications. The oxygen depletion of water bodies due to the decomposition affects benthic community (Alverson et al., 1994; Kaiser et al., 1999; Jennings et al., 2001; Jennings et al., 2002). For scavengers, discarding may have positive effects on populations, by making otherwise inaccessible food available with little or no effort (Clucas, 1997; Laptikhovsky and Fetisov, 1999; Demetre et al., 2000; Fonds and Groenewold, 2000; Hill and Wassenberg, 2000; Kaiser et al., 2000; Gislason, 2001). Habitat modification resulting from discards may at times be confused with habitat modification resulting from the fishing gear itself or with unobserved fishing mortalities because habitat and individuals can be damaged but not brought to the surface. Thus the extend of discards versus gear induced mortalities may be difficult to quantify (Alverson et al., 1994; Clucas, 1997; Clucas and James, 1997; Fennessy, 2002; Burridge et al., 2003; Criales-Hernandez et al., 2006).

1.3.3. Economic impacts

Economic impacts though have got much significance is one of the least discussed and studied aspects of bycatch. Morizur et al. (2004), Clucas (1997) and Clucas and James (1997) have classified the economic impact into a number of differing categories:

i. Discard mortalities associated with a fishery that discards fish of economic importance to another fishery is often the most cited example (Adlerstein and Trumble, 1998; Garcia- Caudillo et al., 2000; Fennessy, 2002);

ii. Discard induced mortalities affect immature individuals or non-legal sexes of the target species and low value fishes;

iii. Economic losses due to extra costs associated with catching, sorting and discarding of the unwanted catch, higher fuel consumption, greater wear and tear of fishing system, as well as the associated opportunity costs (Hall et al., 2000);

iv. Costs associated with monitoring, surveillance and control, for reducing discards.

1.3.4. Socio-cultural impacts

Though social and cultural impacts that arise because of discarding fish is difficult to quantify (Clucas, 1997; Clucas and James, 1997; Alverson et al., 1994), the significance of conservation of biological equilibrium and maintaining stocks of commercially important fish stocks, in the maintenance of livelihoods of the poorest sections of the fishing community is generally recognized.

The data regarding bycatch and discards are sparse and our understanding of the demography of the affected population is often rudimentary. In addition to that the large spatial scale that marine biota cover, make timely and accurate estimates of bycatch difficult. Though we can vaguely classify the effects of bycatch in to the above-mentioned categories it is essential to note that the full impact of bycatch has not been properly comprehended and further studies have to be oriented in this direction (Matsuoka, 1999; Lewison et al., 2004).

1.4. Bycatch Reduction in Trawling

The discarding of harvested fish and its associated mortalities have been recognized as a global problem by fisheries scientists, conservationists as well as by fishermen in the management of world fisheries since the very beginning of this century (Clarence, 1997). Bycatch in world fisheries is at the forefront of concern by fishery managers, the fishing industry, conservationists, and the public (Alverson et al., 1994; Warren et al., 1997; Hall et al., 2000; Costa et al., 2001; Madsen and Hanson, 2001; Chuenpagdee et al., 2003; Lewison et al., 2004; Fonseca et al., 2005a).

Many programs and techniques have been tried world wide to reduce bycatch and discards (Bjordal, 1999; Bonfil, 2000; Van Marlen, 2000; Davis and Ryer, 2003). One such technique was the introduction of mesh regulations to reduce the catch of undersized target species which is considered as a long-accepted management technique and voluntary actions were probably taken much earlier by fishermen attempting to reduce sorting time of bycatch. Many countries have set minimum mesh sizes coupled with minimum size and time/area restrictions for nets, pots, traps, and other gear to minimize catches of juveniles (Duthie, 1997; Isaksen, 1997; Fletcher, 1998). Improved trawl selectivity through strategic use of colored twine was experimented by Averill in 1990. But so far these regulations were not able to address bycatch issue (Powell et al., 2004). Further, many states have also introduced or passed legislation limiting fish capturing methods and operational techniques for selected waters, regions and also for certain species of importance (Duthie, 1997; Isaksen, 1997; Fletcher, 1998). Reduction of bycatch is central to several of the NMFS's (National Marine Fishery Service, USA) governing statutes, including Magnuson-Stevens Fishery Conservation and Management Act, the Endangered Species Act and the Marine Mammal Protection Act (Dobrzynski, 2004).

Bycatch have historically been discarded at sea, leaving fishery managers and public unaware of the extent of bycatch mortality upto mid seventies (Diamond, 2003). Keen interest is shown in the recent years by fisheries scientists, fishery managers and conservationists in the development of solutions for bycatch problems. This sudden interest to a great extend has followed the phenomenal growth of world conservation and environmental groups and their early interest in the consequences of fishing activities affecting populations of marine mammals, birds, and turtles. There is also growing understanding, especially by industry that marine resources are exhaustible and fishing efforts are excessive and threatening marine stocks (Alverson et al., 1994; Warren et al., 1997; Leadbitter, 1999; European Communities, 2000; Costa et al., 2001; Horsten and Kirkegaard, 2003).

The major attempts going on world wide for dealing with bycatch and discards can be summarized under this following heads:

i. Ignoring bycatch: Primitive attitude towards bycatch, which cannot be practiced now, because of the high potential of bycatch to produce indirect negative impacts;

ii. Controlling fishing effort: This is relatively simpler way, can be adopted as a last option when other solutions are tried and proven ineffective;

iii. Mesh regulation: This method has been the common measure for reducing bycatch. Many of the earlier trials with mesh regulations proved to be inappropriate when implemented without considering the survival of escapees;

iv. Improvements in fishing methods and technology: Technological changes for improving gear selectivity have been experimented world wide which include the use of bycatch reduction devices (BRDs), acoustic pingers to shun cetaceans from gill nets, modified foot ropes for trawls, semi pelagic trawl nets etc (Kraus et al., 1997; Dawson, 1991; Hameed and Boopendranath, 2000; Kennelly and Broadhurst, 2002; FAO, 2004c; Madsen et al., 2006);

v. International legislation and guidelines: Promotes bycatch reduction technologies and conservation initiatives. The adoption of the Code of Conduct for Responsible Fisheries by FAO in October 1995 was an important step in this direction;

vi. Time - Area closures: Seasonal and temporal closures limiting fishing activities when and where yields became sub optimal. This is a popular management tool which require a good knowledge on stock dynamics;

vii. Establishment of quotas: Separate bycatch and discard quotas are allotted and in certain cases full use strategy is imposed forbidding discarding of any part of the catch. A thorough knowledge of recent bycatch rates and population dynamics is essential for setting of the quotas;

viii. Incentive based programmes: Incentives to reduce or use bycatch is usually given and it is the best way of introducing new bycatch reduction technology. The Nordmore grid and the development of the policy of avoidance of bycatch hotspots were some of the results of incentive programmes (Clucas and James, 1997);

ix. Controls based on information sharing among vessels: Hotspots, where bycatch abundance occurs is identified and the information is transferred so as to avoid fishing in that area (Gilman et al., 2006);

x. Education and awareness programmes: For spreading the knowledge on correct use of the new technology and also to disseminate the basic concepts in stock assessment and biology;

xi. Observation and monitoring: This is essential in generating unbiased and precise estimates of bycatch and discards (Kennelly, 1999a; Norman, 2000);

xii. Adaptive management: Measures of management are evolved and adapted with the involvement of all stakeholders (Alverson et al., 1997; Kennelly and Broadhurst, 2002).

Bycatch mitigation is also needed in the context of trawling induced mortality of huge quantities of juveniles and sub-adults (Pillai, 1998; Alverson et al., 1994). In order to ensure long-term sustainability of fishery resources, indiscriminate destruction of juveniles and sub-adults must be avoided by giving them a chance to escape from the fishing gear. This can be achieved through selective fishing practices and by deployment of appropriate bycatch reduction devices or BRDs (Bjordal, 1999; Hameed and Boopendranath, 2000; Valdemarsen and Suuronen, 2003; Fennessy, 2002). This is also one of the most effective ways to minimize the broader ecological impacts of harvest fisheries is to improve the selectivity of fishing gear (Robertson, 1984; Liu et al., 1985; Alverson et al., 1994; Briggs et al., 1999). Given the changing public perceptions of fishing and the complexity of the bycatch issue, better information is needed on bycatch and mitigation measures, both on internal and regional basis.

1.5. Rationale and Objectives of the Study

In recent years, greater efforts have occurred to document the body of scientific data concerning quantities of bycatch, levels of discards, survival of discards, impacts of losses resulting from discards on target and non-target marine populations and bycatch mitigation measures, in different parts of the world. However, there is a paucity of information on bycatch, in general, and bycatch reduction technologies, in particular, in the context of Indian fisheries. In this study, a detailed investigation on the following aspects pertaining to trawl bycatch and bycatch reduction measures is attempted:

i. Design and development of hard bycatch reduction devices incorporating rigid materials, for trawling;

ii. Comparative evaluation of hard bycatch reduction devices, for selective trawling appropriate for small scale mechanized sector;

iii. Conduct a bycatch characterisation study of trawl catch, off Central Kerala; and

iv. Characterisation of the existing trawling systems operated off Central Kerala.

__Chapter 2__

Review of Hard Bycatch Reduction Devices

2.1. Introduction

Bycatch Reduction Devices (BRDs) can be defined as any device that can be incorporated in a fishing gear in order to exclude or reduce non targeted and unwanted catch in a fishing system and thereby making it more selective. BRDs are also known as Trawl Efficiency Devices or Trash Excluder Devices. Turtle Excluder Devices (TEDs) are a specific type of BRD design to exclude large animals such as sea turtles, stingrays, sharks, sponges etc. BRDs can have other benefits such as improving the quality of the catch, reducing at sea work loads and some times increasing the prawn catch. BRDs can be broadly classified into three categories based on the type of materials used for their construction, as Hard BRDs, Soft BRDs and Combination BRDs. Hard BRDs are those, which use hard / semi flexible grids as separating devices in their construction (DeLancy et al., 1997; Fletcher, 1998).

2.2. Significance of BRDs

There are four main advantages to decreasing the amount of unwanted bycatch taken in shrimp trawls. (Brewer et al., 1998; Eayrs and Prado, 1998; Salini et al., 2000; FAO, 2004b). Firstly it reduces the impact of trawling on the marine community, including deaths to vulnerable or endangered species. Secondly, fishers could benefit economically from (i) Higher catch values due to the reduction in large bycatch species, so the damage occurring to the shrimps as a result of physical pressure is much reduced. (ii) Shorter sorting times. (iii) Lower fuel costs due to reduced net drag as a result of exclusion of bycatch, which contributes, to the bulk of weight. (iv) Longer tow times since the cod end would fill more slowly and (v) higher catches of shrimps. Thirdly, fishers would hear less criticism from community groups. Fourthly, recreational and non-shrimp commercial fisheries would benefit from a reduced impact on species of their concern. Use of BRDs in certain areas helped in the recovery of certain endangered species (Garcia-Caudillo et al., 2000). The significance of BRDs has been mentioned by various fishery institutions, fishery scientists, fishermen and fishery managers. About 25-64% of bycatch can be reduced without compromising the target catches by the incorporation of BRDs in fishing gears especially in trawl nets (Bjordal, 1999; Gallaway and Cole, 1999; Wienbeck, 1999; Salini et al., 2000; NMFS, 2003; Burrage, 2004; Hall and Mainprize, 2005). Experiments with Nordmore grid conducted by Pollack (1994) showed a bycatch reduction upto 95%.

Since 1987, the U.S. has required all shrimp boats in U.S. waters to use TEDs in their nets to protect sea turtles. United States in 1989 has imposed a ban on the import of shrimps from the countries that doesn't use Turtle Excluder Devices (TEDs) in their trawls as per the Article XX of the GATT (Wilson, 1998; Shaffer, 1999).

2.3. Principles of BRDs

BRDs have been developed taking into consideration the differential behavior patterns or size of shrimp and fish inside the net. While the fish are active and capable of swimming against the water flow inside the net and may escape at any time when the required facilities are provided. The position is different in the case of shrimp; shrimp is unable to swim against the water flow and carried away with the flow of water up to the cod end. (DeAlteris et al., 1997; Pillai, 1998; Hameed and Boopendranath, 2000; Van Marlen, 2000; Matsushita, 2000; Crespi and Prado, 2002; Pillai et al., 2004). The difference in the behavior forms the basic principle in the designing of selective devices so as to allow the fish and turtle to escape and to maintain the shrimp catch in the cod end (Glass and Wardle, 1996; Pillai, 1998; Graham et al., 2004a). The escapement of fish through the use of BRDs depends on the ability of the fish to sustain a swimming speed equal to, or exceeding the relative flow with the net (Watson et al., 1993).

A schematic representation of size separation and exclusion based on behaviour of catch is shown in Fig. 2.1.

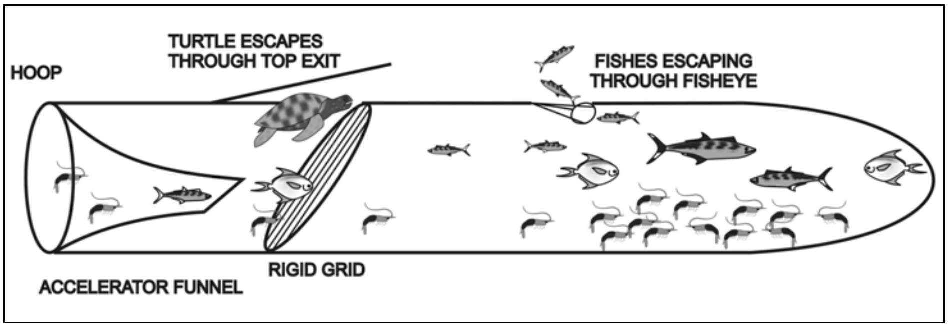


Fig. 2.1. Schematic representation showing principles of BRDs

Size selectivity in gear using netting for retention of catch, can be achieved by controlling mesh sizes and mesh shapes (square mesh panels) optimized for target species or size groups (Guijarro and Massuti, 2006). Grid type of BRDs mainly utilize the principle of size selectivity as the smaller fishes and shrimps pass through the grid and larger animals like turtles, sharks, rays, bigger fish, sponges etc get deflected out after striking the grid through an opening provided for the escapement (Hameed and Boopendranath, 2000; Crespi and Prado, 2002; Lousiana Fisheries, 2005). According to the studies conducted by Whitaker et al., 1992 larger fishes have the tendency to escape more readily through BRDs.

Separation of species such as shrimp and fish is possible to some extend by reducing the length of the trawl, adjusting the head line height, controlling the towing speed, making use of the principles of differences in swimming speed and vertical distribution. (Hameed and Boopendranath, 2000; Hannah and Jones, 2000; Hannah and Jones, 2003; Hannah et al., 2003). In addition to the above mentioned factors, other factors such as the trawl mesh size and type, BRD type, size and placement, tow duration, shrimp size, bycatch composition, wrack type, variations in bottom substrate and water depth also determine the efficiency of BRDs (EPA, 1998).

2.4. Historical Background of BRDs

BRDs were used in Gulf of Mexico fisheries ever since from 1950 onwards (Rester et al 1997; Rester, 1999) and most probably the first BRDs were designed and used by the fishermen through their constant effort and knowledge derived from their experience (Harrington and Venditti, 1996; Harrington, 1997). Since the problem of bycatch and discards has escalated over the past two decades and been acknowledged as a major management issue, greater effort have been directed towards reducing bycatch by taking advantage of the differential behavior of the range of species subject to the fishing gears deployed (Glass and Wardle, 1996). These efforts include: (i) instituting incentives and disincentive programs; (ii) making use of certain gears in certain areas illegal. (iii) completely banning the use of a particular gear technology , like high seas drift nets; (iv) permitting continued use of a gear type but regulating its discard catch efficiency, such as enforcement of mesh, hook or escapement panel size restrictions; (v) establishing fishery level discarding quotas; (vi) utilizing time / area closures (Alverson et al., 1994).

Unfortunately, afore-mentioned strategies have not yet addressed a majority of the bycatch and discard problems. Regardless of the character of the discard problem, only a few functional alternatives are available, which include:

i. Catching fewer numbers of the species or sizes and sexes of the species comprising the discard;
ii. Reducing the mortality of the discarded species;
iii. Utilization of the species or sizes of species caught and discarded.

From a historical perspective, fishery managers have attempted to minimize pre-recruitment mortality through use of mesh size regulations; that release a significant number of undersized target and non-target species. Although considerable progress in the reduction of the capture of undersized fish can be attributed to increasing mesh sizes and other gear selectivity regulations, reduction in the overall quantity of the bycatch has been offset by (i) increasing global fishery pressure; (ii) differentiated growth rates of target and non-target species; (iii) the failure of mesh regulations to deal with capture of many unwanted species; (iv) the ease of altering gear at sea and avoiding gear selectivity regulations; and (v) failure at times of the fishing industry to be willing to adapt fishing methods proven to be more selective (Alverson and Larkin, 1992; Alverson et al., 1994).

Attempts to overcome some problems associated with selectivity and rigging of the gear of active fishing nets, have over the past several decades been addressed by the introduction of square mesh, single mesh cod ends, knotless and coloured webbing, escape panels etc (Averill and Carr, 1987; Casey and Warnes, 1987; Caddy, 1989; Armstrong et al., 1990; Averill, 1990; Dawson, 1991; Alverson et al., 1994; Kunjipalu et al., 1994a; 1994b; 1997; 2001).

Historic evolution of bycatch reduction in shrimp reveals certain approaches taken such as (i) Use of separator panels made of vertical or horizontal webbing with bottom or top oriented escape chutes (excluder funnels) for finfish, (ii) Use of electrical sorting trawls; and (iii) Use of rigged selector devices (Caddy, 1989; Armstrong et al 1990; Dawson, 1991; Alverson et al., 1994).

Attempts were made even in the mid sixties to find solutions to reduce bycatch in shrimp fisheries based on behavioural differences. FAO (1973) reported the use of selective shrimp trawls in Europe. During 1960's and early 1970's NMFS selective trawls became popular in the U.S. west-coast (Alverson et al., 1994). During 1980s, development of shrimp sorting trawls became popular and experiments were conducted in several parts of the world, which lead to the development of a variety of panel separator trawls (Isaksen and Valdemarsen, 1986; Valdemarsen and Isaksen, 1986). Though showed promise, none got wide acceptance among fishermen (FAO, 1973; Watson et al., 1986; Watson et al., 1999). In early stages, panel trawl development was seen as a means of reducing sorting time, however in the 1980s, conservation of turtles and reduction in the catch of certain species of ground fish become the primary basis for alternative gear designs (Andrew and Pepperell, 1992).

Earlier experiments conducted to prevent the entry of turtles in to the trawl net by covering the trawl mouth with large mesh panel proved to be impractical due to the shrimp loss and entangling of turtles (Oravetz and Grant, 1986; Epperly 2003). A significant work carried out by National Marine Fisheries Service (US) resulted in a V-design vertical separator panel, which takes advantage of behavioral differences between shrimp and finfish (Watson and McVea, 1977). Electrical trawls, considered to resolve bycatch problems, never extended beyond prototype development. Major obstacles were the high cost of pulsar systems and conductor cables (Watson and Taylor, 1991).

Most significant event in 1980s in the development of shrimp sorting devices in trawls has been the evolution of Turtle Excluder Devices (TED) and this has led to the development of a variety of net designs incorporating finfish - shrimp separation based on behavioral differences. The first TED was developed by NMFS in early 1980’s (Watson and Taylor, 1991; FAO, 2004b).

Norwegian researchers developed solid grid separator for pandalid shrimps, called Nordmore grate during the late 1980s and early 1990s (Isaksen et al., 1992). Rigid separator trawls solved many of the objections to separator netting panels, increased separation efficiency, and minimized loss in the shrimp catches. Since the turtle excluder device was first introduced to the US shrimp fishery in the late 1980s, research and development to improve TED performance has continued and many modifications were made for obtaining optimum performance in terms of bycatch reduction and shrimp retention (Mitchell et al., 1995). McGilvray (1995) gave a summary of bycatch reduction devices in Australian waters.

Scanning the available literature, it is clear that there are a wide variety of BRDs, which are being used all over the world on commercial basis and on experimental basis. Most of the BRDs are been developed through intensive research, taking into consideration the particulars of the fishery and geographical peculiarities.

2.5. Classification of BRDs

BRDs and other selective devices are being used commercial basis and on experimental basis in the fishing industry, in order to improve trawl selectivity. There is no standard classification for BRDs found in the literature except a generalized categorization provided by some authors (Mitchell et al*.,* 1995; Talavera, 1997; Pillai, 1998; Broadhurst, 2000; Pillai et al., 2004). In this study, an attempt is made to classify hard BRDs based on the materials used for its construction and also according to the various shapes and modifications of hard BRDs.

BRDs can be broadly classified into three categories based on the type of materials used for their construction, as Hard BRDs, Soft BRDs and Combination BRDs. Hard BRDs are those, which use hard grids or solid separating devices. The materials used for making Hard BRDs include solid steel rods, aluminium rods, fibreglass rods, steel or aluminium tubing (Mitchell et al., 1995). Soft BRDs make use of soft structures or with minimum use of rigid devices such large meshed netting panels or large openings made in the netting to facilitate the escape of by catch. Soft BRDs make use of large meshed netting panels or large openings made in the netting to facilitate the escape of bycatch and in combination BRDs more than one BRD are used in a single system. Combination BRDs are generally an amalgamation of hard and soft BRDs.

2.6. Hard BRDs

Most of the BRDs have been developed through intensive research, taking into consideration the characteristics of the fishery and geographical peculiarities of the region. Hard BRDs are those, which use hard / semi-flexible grids as separating devices in their construction. Hard BRDs can be broadly classified into BRDs with grids, BRDs with slots and semi-flexible BRDs. BRDs with grids can be further classified into flat grid BRDs, bent grid BRDs, oval grid

BRDs, slotted grid BRDs, hooped and fixed angle BRDs. A classification of BRDs based on the structure, materials used and principles of operation is given in Fig. 2.2.

The materials used for making Hard BRDs include solid steel rods, aluminium rods, steel or aluminium tubing, fiberglass rods, polyamide grids and plates, rubber, etc. Over 33 different hard BRD designs developed for different resource groups and fishing areas are briefly described below:

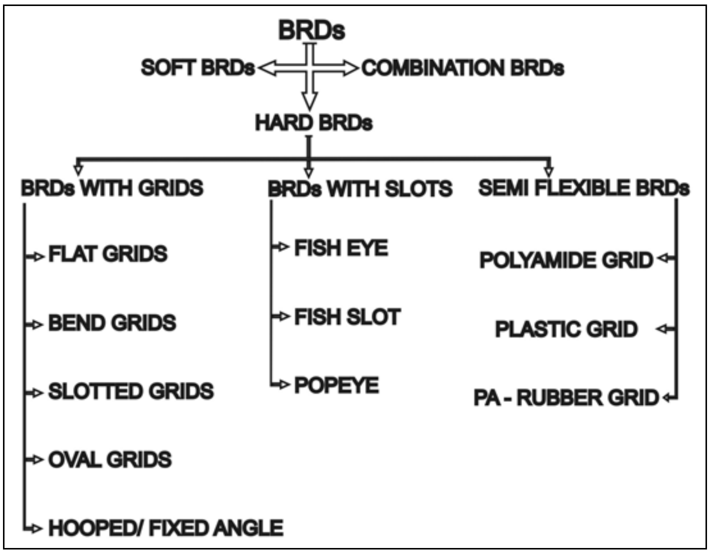


Fig. 2.2. Classification of Hard BRDs

2.6.1. Flat grid BRDs

Flat grid BRDs are mostly rectangular in shape without any bend in the grid bars (Fig. 2.3). This type of design was developed in Norway originally to exclude jellyfish (Isaksen et al., 1992). The grids are made of either aluminium or steel. The grid is usually mounted in the throat section at an angle 45-50° from the horizontal. The grid is usually associated with an accelerator funnel for guiding the catch to the grid. Escape openings are provided either on top or bottom and is either kept open or covered with a flap of netting. Examples for flat grid BRDs are Nordmore grid (Prado, 1993; Isaksen et al., 1992; Riedel and DeAlteris, 1995; Prado, 1997; Wienbeck, 1997; Brewer et al., 1998; Wienbeck, 1998; Halliday and Cooper, 1999; Wienbeck, 1999; Hannah and Jones, 2000;

Crespi and Prado, 2002; Hannah et al., 2003; Valdemarsen and Suuronen, 2003; Broadhurst et al., 2004; Fonseca et al., 2005a; Fonseca et al., 2005b), Wicks TED (Robins et al.,1999), Kelly / Girourard grid (Morris, 2001), and EXIT grid (Maartens et al., 2002).

2.6.2. Bent grid BRDs

Bent grid BRDs are either rectangular or elliptical in shape. In this group of BRDs, the grid bars and, in some cases, grid frame are bent at one end near the exit opening (Fig. 2.4). This is to facilitate the easy ejection of the debris, seaweeds, and bycatch components and prevent clogging of the grid. Exit holes are guarded with flap of netting. The grid is mounted in the aft section of the trawl just in front of the codend at an angle between 45 and 55° from the horizontal. Material used for its construction is steel or aluminium. Super Shooter TED (Mitchell et al., 1995; Brewer et al., 1997; Brewer et al., 1998; Kirubakaran et al., 2002; Steele et al., 2002), Seymour TED (Robins et al.,1999), Juvenile and Trash Excluder Device (JTED) (Chokesanguan et al., 2000) NAFTED (Brewer et al., 1998; Eayrs, 2004) are BRDs coming under this category.

2.6.3. Oval grid BRDs

These are flat grids, which are either oval or circular in shape (Fig. 2.5). The grids are made of steel and are mounted in a netting section between throat and codend of the trawl net. Grid angle varies from 45 to 55° from horizontal. Exit openings are at either the top or the bottom of the section. Various grid designs of this type are used worldwide, which include Georgia-Jumper (Mitchell et al*.,* 1995; Federal Register, 2000; Boopendranath, 2003;), Saunders grid (Talavera, 1997), Thai Turtle Free Device (Chokesanguan, 1996; Talavera, 1997); Galvanisada (Talavera, 1997), Oregon grate (Hannah et al., 2003), CIFT-TED (Dawson and Boopendranath, 2001; Boopendranath, 2003), Seal Excluder Device (Fishing News International, 2004; Hammer and Goldsworthy, 2006) and Halibut Excluder Grate (Rose, 1999; Rose and Gauvin, 2000).

2.6.4. Slotted grid BRDs

These are flat grids mostly rectangular in shape made of either aluminium or steel (Fig. 2.6). Slotted grid BRD is inserted in the aft section of the trawl just in front of the codend. The main characteristic of this category of BRDs is that they are provided with slots for allowing the passage of targeted species other than shrimp. The slots may be either at top or at bottom, made by welding cross bars or by leaving one end of the bars without joining to the frame. Steel, aluminium and polyamide are used to construct the grids. The important grids under this category are Flounder TED (Mitchell et al*.,* 1995; Talavera, 1997; Dawson, 2000; Federal Register, 2000; Belcher et al., 2001; Dawson and Boopendranath, 2001; Boopendranath, 2003; Federal Register, 2003), Matagorda (National Research Council, 1990; Federal Register, 2000; Federal Register, 2005), Johns TED (Boopendranath, 2003), Hinged grid (Eigaard and Holst, 2004) and Anthony Weedless (Mitchell et al*.,* 1995; Talavera, 1997; Dawson and Boopendranath, 2001; Boopendranath, 2003; Federal Register, 2003).

2.6.5. Hooped and Fixed angle BRDs

Hooped and Fixed angle BRDs have circular, oval or rectangular hoops in front and rear of the deflecting grid, which is rigidly fixed in a framework at the desired angle (Fig. 2.7). Materials used for construction are steel or aluminium. The main advantage of hooped TEDS are (i) sturdier construction for fishing in rugged conditions and (ii) constant angle of the deflector bars unaffected by changes in the eleongation of netting. However, these designs are relatively cumbersome in terms of onboard handling and hence are not in popular use. The NMFS Hooped BRD, Cameron shooter BRD and Fixed angle BRD comes under this category (Oravetz and Grant, 1986; Prado, 1993; Mitchell et al., 1995; Prado, 1997; Rogers et al., 1997; Talavera, 1997, Dawson, 2000; Federal Register, 2000; Hameed and Boopendranath, 2000; Boopendranath, 2003; Federal Register, 2003).

2.6.6. BRDs with rigid escape slots

BRDs with rigid escape slots are designed to facilitate the escapement of fish from the codend (Fig. 2.8). Fisheye is the most important BRD coming under this category. It consists of an oval shaped rigid structure with 8 - 15 cm height and 30 - 40 cm width, with supporting frames made of stainless steel rods. Fishes swim backward from the codend and escape through the fisheye (Brewer et al*.,* 1995; Brewer et al*.,* 1998; Pillai, 1998; Hannah et al., 2003; Burrage, 2004). There are several design variations of fisheye such as Florida Fish Eye (FFE) used in the Southeast US Atlantic and in the Gulf of Mexico (Wallace and Robinson, 1994; Steele, et al., 2002), Florida Fish Excluder (FFE), (Anon, 1997) and Snake eye BRD used in North Carolina Bay (Fuls and McEachron*,* 1997). Fisheyes of different size and shape are used in south Atlantic and in the Gulf of Mexico (Anon, 2002).

Fish slot (Morris, 2001), Sea eagle BRD (Anon, 1997) and Popeye Fish excluder or Fishbox BRD (Anon, 2004) are other designs in this category.

2.6.7. Semi-flexible BRDs

Semi-flexible BRDs are constructed out of semi flexible or flexible materials like plastic, polyamide, FRP, rubber, etc. (Fig. 2.9). These include (i) flexible plastic grid made of polyethylene and the grid frame consisted of plastic tubes used in the North Sea brown shrimp fishery (Polet, 2002), (ii) Polyamide grid with hinges for operation from net drums used in the Danish experiments in the North Sea shrimp fishery (Madsen and Hanson, 2001) and (iii) Polyamide-rubber grid design from Denmark (Fishing News International, 2002; 2003)

2.6.8. Combination BRDs

Sometimes, two or more BRDs are combined in a single gear to enhance the efficiency (Fig. 2.10). Researchers proposed different combinations of grids, slotted BRDs such as fisheye and soft BRDs such a square mesh window, bigeye BRD, etc., to obtain optimum results. The AusTED designs experimented in Australian shrimp trawl fishery are important examples for combination BRDs (Mounsey et al., 1995; Robins-Troeger et al., 1995; Brewer et al., 1998;

McGilvray et al., 1999; Robins et al., 1999; Robins and McGilvray, 1999; Ramirez, 2001; Steele et al., 2002; Eayrs, 2004). Broadhurst et al., 2002 described a combination of square mesh panel with Nordmore grid.

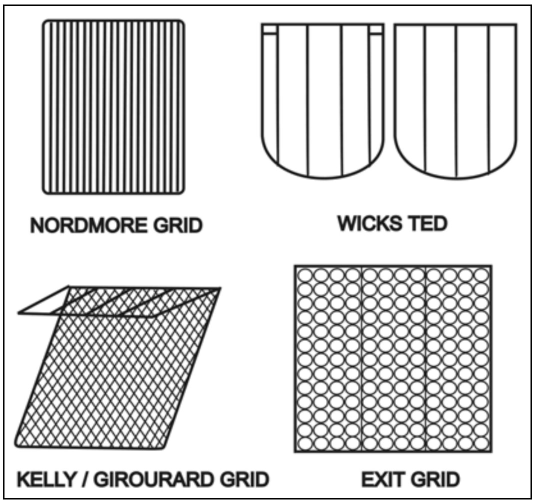


Fig. 2.3. Flat Grid BRDs

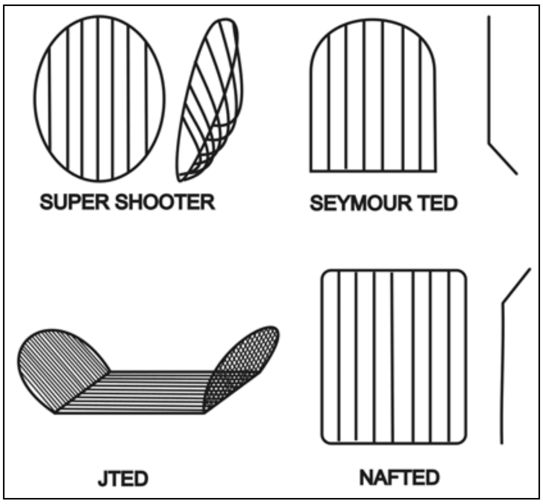


Fig. 2.4. Bent Grid BRDs

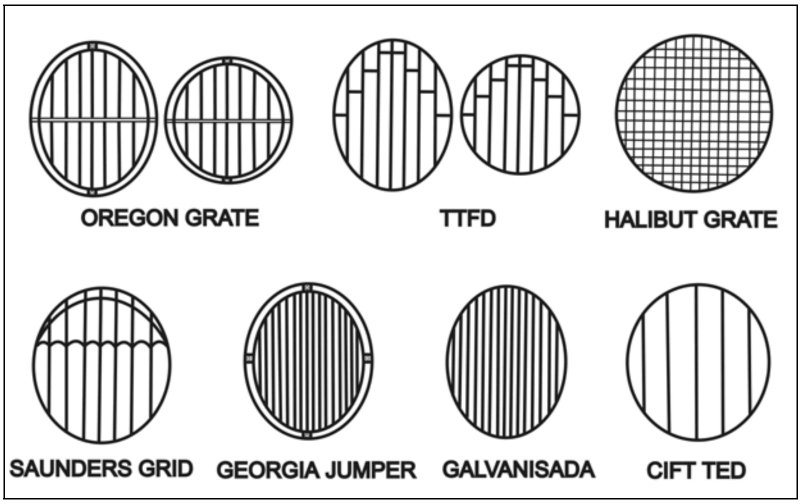


Fig. 2.5. Oval Grid BRDs

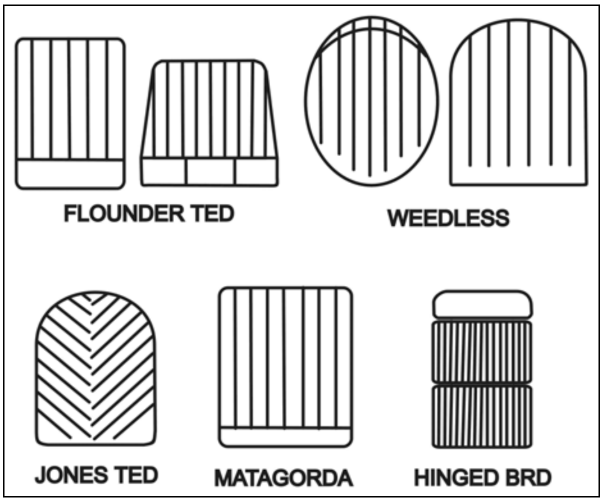


Fig. 2.6. Slotted Grid BRDs

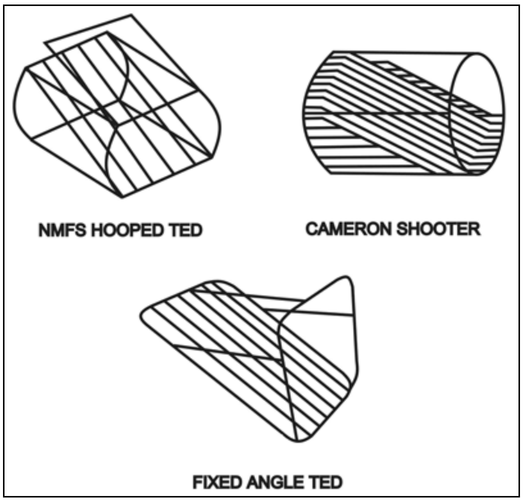


Fig. 2.7. Hooped BRDs

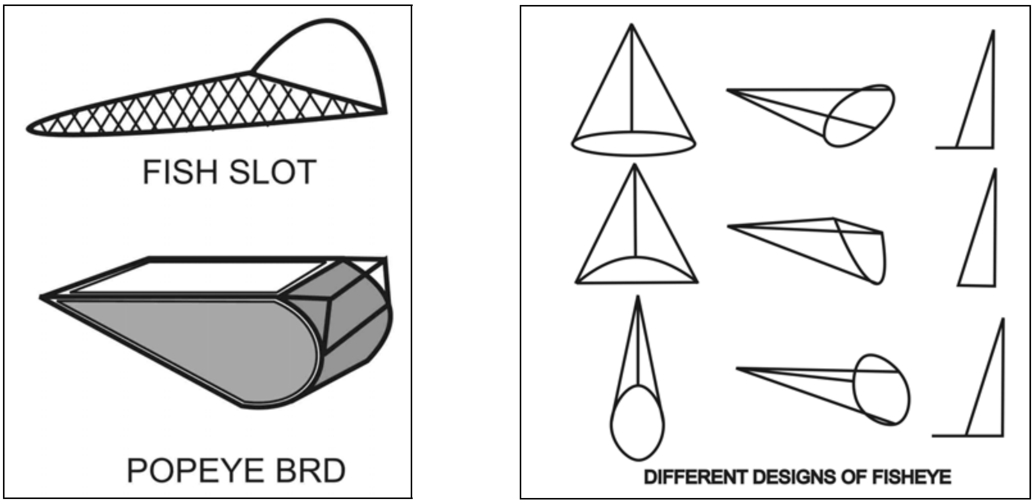


Fig. 2.8. BRDs with rigid escape slots

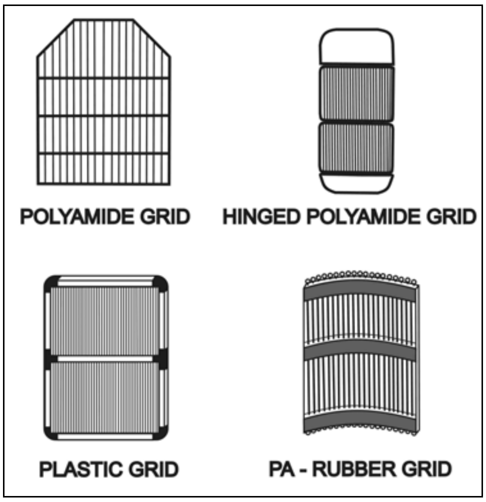


Fig. 2.9. Semi-flexible BRDs

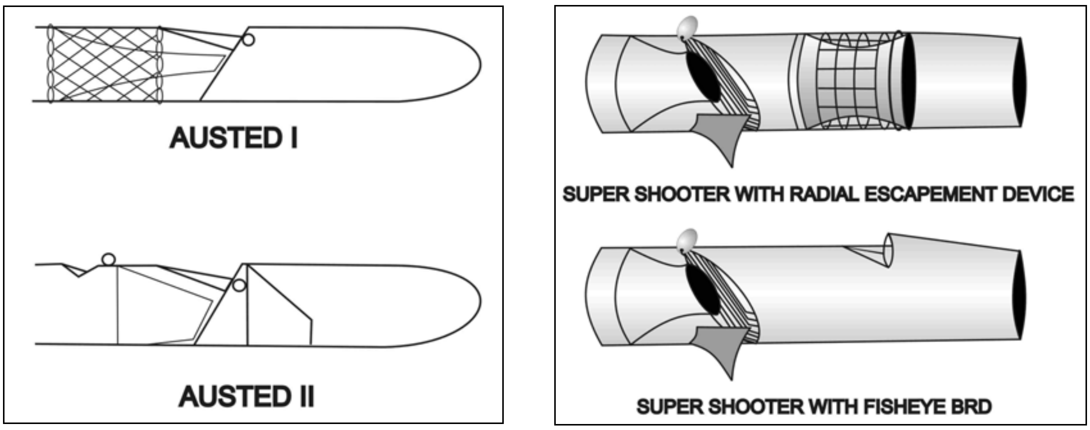


Fig. 2.10. Combination BRDs

2.7. Discussion and Conclusions

Thirty-three hard BRD designs described have been operated either experimentally or commercially in different fishing areas with promising results. Super shooter TED operations has indicated shrimp loss between 2 and 12% in Australian waters (Brewer et al., 1998). The Super shooter TED also performed well in areas where the other inclined grid BRDs tended to clog due to accumulation of sponges and seaweeds and worked well when used in combination with other BRDs such as fisheye. Super shooter TED operations off Visakhapatnam, India, has indicated higher exclusion of fish when the exit was on the lower side (43.4%) than when the exit was on the upper side (13.7%). In both cases, 100% escapement of turtles was observed (Kirubakaran et al., 2002). The NAFTED operations in Australian waters only during the commercial trials indicated shrimp loss of 3.3% in the catch of a standard trawl. It is also used in combination with square mesh window (Brewer et al., 1998). CIFT-TED operations in Arabian Sea and Bay of Bengal has indicated 100% exclusion of sea turtles with minimum catch loss of shrimp and targeted finfish species (Boopendranath et al., 2003)

Experiments with Nordmore grid, in Norwegian waters, have shown a low and fairly constant shrimp loss of 2-5% (Isaksen, et al., 1992). Fishes above 200 mm size were observed to escape. Experiments using Nordmore grid in Nova Scotia, Canada showed target catch loss of 2-5% and bycatch reduction of 48-98% (Halliday and Cooper, 1999). Nordmore grid experimented in Clarence river of New South Wales showed 77% reduction in bycatch with no reduction in prawns (Broadhurst et al., 1999). Experiments with Nordmore grid in Portuguese continental waters showed up to 78.5% exclusion of large bycatch species with negligible target catch loss (Fonseca et al., 2005a). Experiments using modified versions of Nordmore grids made of plastic, conducted in the North sea reduced >70% fish and 65% benthos with a target catch loss of 15% (Polet, 2002). Maartens et al. (2002) observed the escapements of juveniles up to 95%, during experiments with two different rigid sorting grids *viz* Sort-V grid and EX-it grid, in coastal waters off Namibia.

Performance of fisheye depends on the shape, size, position, light and water current. Fisheye experiments conducted in Florida and in coastal Australian waters showed enhanced bycatch reduction when used in combination with other BRDs (Brewer et al., 1998; Steele et al., 2002). During experiments using Fish slot in North Carolina, USA an average reduction of weak fish was about 30% and shrimp loss was about 55%. This model is prone to hang on the bumper rails of the vessels sides and can damage the tail bag or BRD (Morris, 2001). Experiments using Popeye fish excluder or fish box BRD in Queensland waters showed 29-60% reduction in bycatch (Anon, 2004) Flexible polyamide grid experimented in North Sea has been shown to be efficient in fish and lobster exclusion, and also has flexibility to be wound into the net drum (Madsen and Hanson, 2001).

Combination BRDs are used in order to increase the efficiency of the BRD in terms of bycatch reduction and retention of target catch. Experiments with flat gird and square mesh conducted at the Fladen Ground in the North Sea showed negligible shrimp loss and 42-56% reduction of under-sized fishes (Madsen and Hanson, 2001). Experiments with flat-hinged grid in combination with square mesh window conducted in North Sea showed bycatch reduction in the range 37-57% (Eigaard and Holst, 2004). Super shooter TED operations in combination with fisheye in Australian Northern shrimp trawl fishery showed more than 25% exclusion of bycatch and less than 5% loss in target catch (Brewer et al.,1998). Experiments with AusTED-I and its modified version AusTED-II conducted in Australian waters showed promising results in terms of bycatch reduction, shrimp retention and exclusion of turtles and large animals (McGilvray et al., 1999, Robins et al., 1999, Mounsey et al., 1995, Robins-Troeger et al., 1995, Brewer et al., 1998, Robins and McGilvray, 1999). Average bycatch reduction ranged between 18 and 55% for AusTED-I and between 15% and 49% for AusTED-II depending on fishery conditions.

A variety of BRDs have been developed and used either on commercial or on experimental basis, in order to mitigate regional bycatch issues and increase the selectivity of trawl nets. Some BRDs have been developed through intensive research, taking into consideration the characteristics of the fishery and the geographical peculiarities. There has been significant reduction in world bycatch levels during the past two decades. Increased use of BRDs in trawling could be an important reason contributing to the reduction in bycatches, in recent years.

Experimental fishing trials alone could never encompass the range of commercial fishing conditions and the environment in which the fishery operates (Robins et al, 1999). Cooperation between fishing industry, scientists and other stakeholders is fundamental for the success of bycatch management efforts (Krapf, 1994; Alverson et al., 1997; Kennelly and Broadhurst, 2002). Ease of construction and operation of the BRDs, cost-effectiveness of the technology and the economic benefits influence the adoption of bycatch reduction technologies. Efficiency in terms of target catch retention and retention of marketable species is most critical since fishermen are wary of anything that will further reduce their catch and income (Krapf, 1994; Garcia-Caudillo et al., 2000). BRDs most appropriate to the regional fishing conditions should be adopted and enforced legally, after careful scientific evaluation and commercial trials, in order to ensure long-term sustainability and protect the biodiversity of fishery resources.

__Chapter 3__

Materials and Methods

The objectives of the study included design and development of hard bycatch reduction devices (BRDs), comparative evaluation of hard bycatch reduction devices, for selective trawling, bycatch characterisation of the trawl landings, off Central Kerala; and investigations on status of the existing trawling systems operated off Central Kerala.

3.1. BRDs used for the Study

A wide variety of BRDs and their design variations have been developed and used either on commercial or on experimental basis, in order to mitigate regional bycatch issues and increase the selectivity of trawl nets (Chapter 2). Most BRDs has been developed through intensive research and constant modifications were made in their design based on the operational experience. It is important to take the characteristics of the fishery and their geographical peculiarities into consideration before designing BRDs.

The selection of BRDs for the present investigations was based mainly on (i) their applicability to the bycatch issues prevailing in the Indian waters especially along the southwest-coast of India, (ii) their record of success in reducing bycatch while maintaining the shrimp catch in fishing areas elsewhere and (iii) their potential for acceptance by the industry. The BRD designs selected for the experiments were fisheye BRDs, rectangular grids and oval grids.

3.1.1. Fisheye BRDs

The fisheye BRD facilitates the escapement of actively swimming fishes from the codend. It was fitted at different positions on the upper side of the codend. Three different designs of fisheyes were fabricated for the experiments. Fisheye consists of a stainless steel structure having an oval or semicircular opening with supporting frames made of 6 mm dia stainless steel rods. Design details of fisheye BRDs are given in Chapter 6.

3.1.2. Rectangular grid BRD

The rectangular grid design has rectangular frame of 1000 mm in height and 800 mm in width and has a grid bar spacing of 22 mm. It was fabricated out of stainless steel rods of 8 mm dia for the frame and 4 mm dia for grid bars. The grid was fixed at an angle of 45° from the horizontal, inside the trawl extension. Two floats of adequate extra buoyancy were provided on the top of the grid on either side, to compensate the weight of the grid and to keep the grid always in the upright position. An exit opening of triangular shape having dimensions 600 mm at base and 450 mm at sides was provided at the top of the trawl extension in front of the grid. This triangular opening was made by cutting all bars from the corners of the grid. The opening was reinforced by a 4 mm rope frame at its edges. An accelerator or guiding funnel was provided in front of the grid at a distance of 0.5 m from the bottom of the grid. The funnel was inclined towards the bottom so that the water flow would be directed towards the bottom of the grid. Design details of Rectangular grid BRD are given in Chapter 8.

3.1.3. Oval grid BRDs

Oval grid BRD has an oval frame of 1000 mm in height and 800 mm in width and 22 mm bar-spacing. It was fabricated out of stainless steel rods of 8 mm dia for the frame and 4 mm dia for grid bars. The grid was kept at an angle 45° from the horizontal, inside the trawl extension. Two floats of adequate extra buoyancy were provided on the top of the grid on either side, to compensate the weight of the grid and to keep the grid always in the upright position. A triangular exit opening of 600 mm at base and 450 mm at sides was provided at the top of the trawl extension in front of the grid. This triangular opening was made by cutting all bars from the upper sides of the grid. The opening was reinforced by a 4 mm rope frame at its edges. An accelerator or guiding funnel was provided in front of the grid at a distance of 0.5 m from the bottom of the grid. The funnel was inclined towards the bottom so that the water flow would be directed towards the bottom of the grid. Design details of Oval grid BRDs are given in Chapters 8 and 9.

3.2. Fishing Operations

3.2.1. Fishing area

The experimental fishing operations were conducted during daytime, in the traditional shrimp fishing grounds at a depth ranging between 9-32 m off Cochin (Fig. 3.1).

3.2.2. Research vessels

Field trials were conducted from two research vessels of Central Institute of Fisheries Technology *viz*., MFB Matsyakumari (17.5 m LOA, 57.17 GRT; 277 bhp @ 1000 rpm Kirloskar Mann engine) (Fig. 3.2) and MFV Sagar Shakti (wooden trawler 15.24 m LOA, 30 GRT, 223 bhp @ 1800 rpm Ruston MWM engine) (Fig. 3.3).

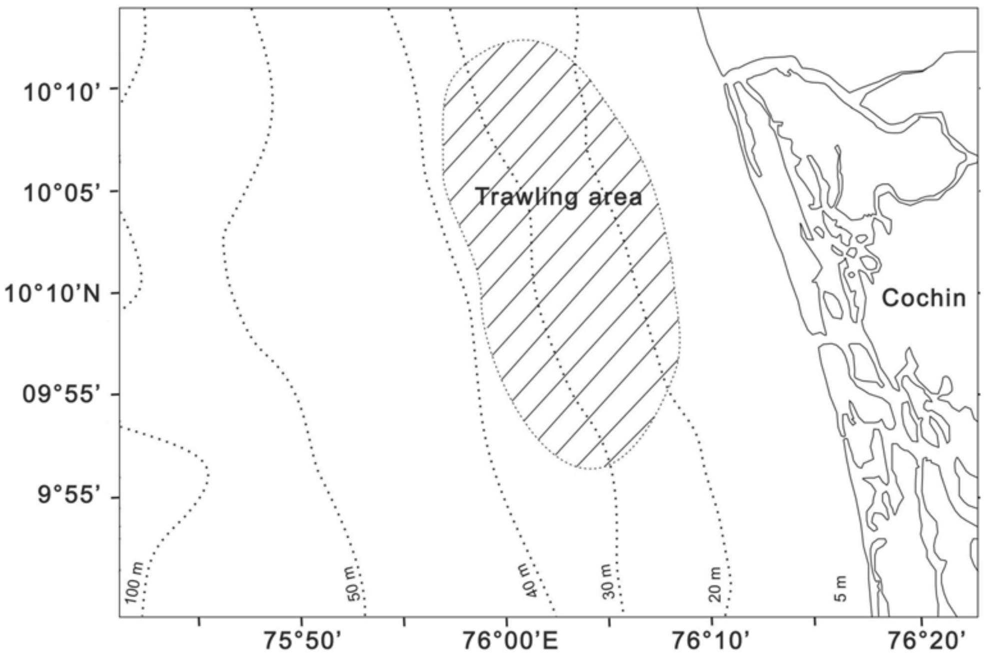


Fig. 3.1. Fishing area

3.2.3. Fishing gear

Shrimp trawl of 29.0 headline with 20 mm diamond mesh codend, which are widely used in southwest coast of India, were used for experimental fishing (Fig. 3.4). The shrimp trawl was rigged with V-type steel otter boards of size 1420x790 mm size (80 kg each) (Fig. 3.5) and 20 m double bridles (Fig. 3.6).

Fig. 3.2. MFB Matsyakumari

Fig. 3.3. MFV Sagar Shakthi

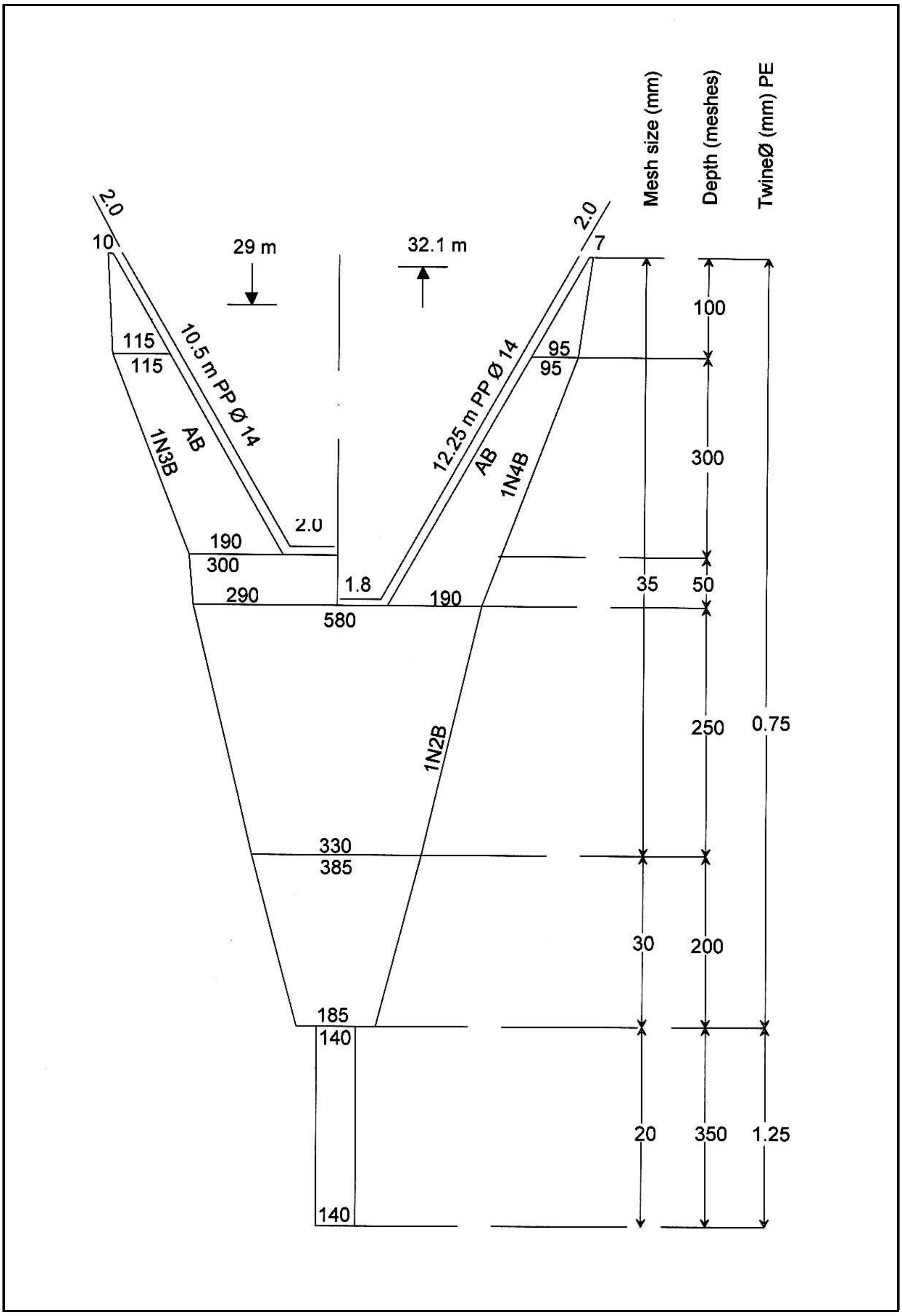


Fig. 3.4. Design of 29.0 m shrimp trawl

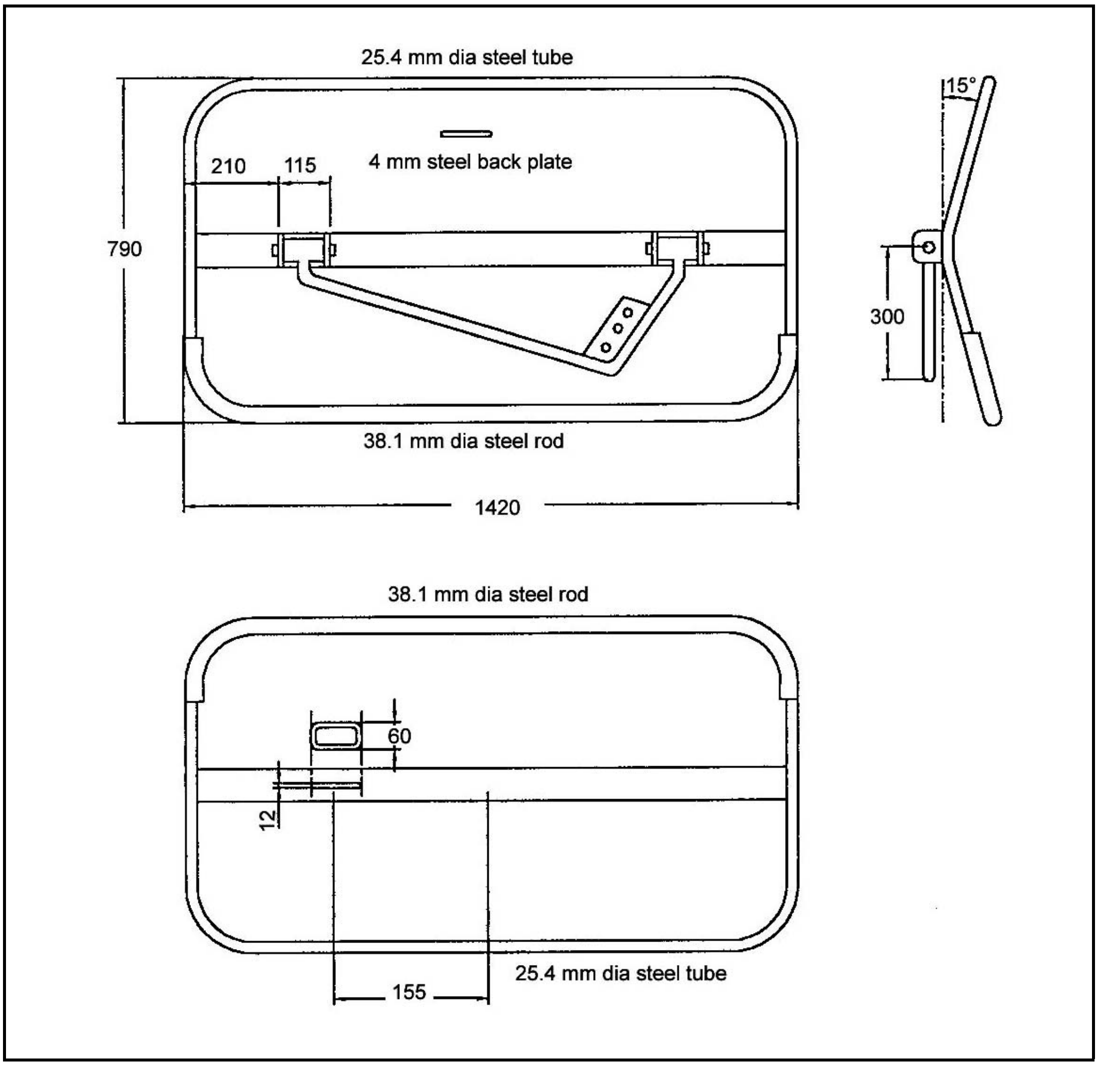


Fig. 3.5. Design details of V-type otter boards (1420x790 mm; 80 kg each)

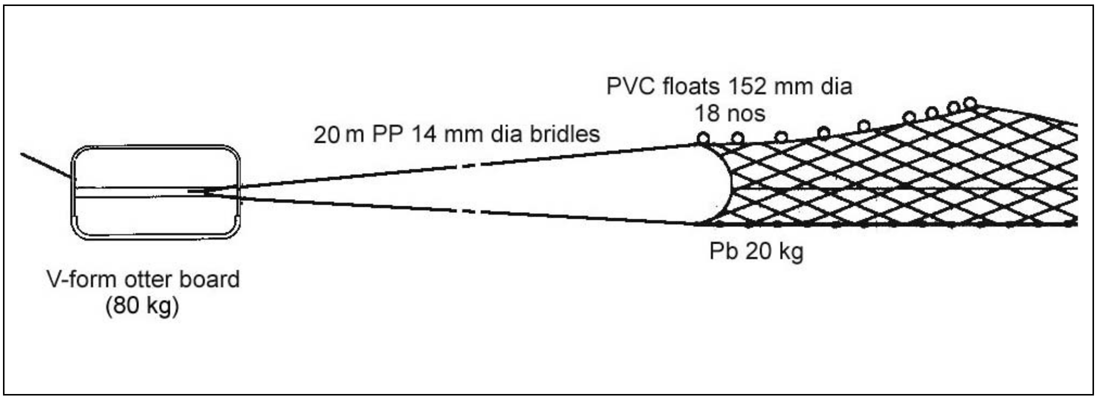


Fig. 3.6. Rigging of a typical shrimp trawl

3.2.4. Field trials, data collection and analysis

Statistically designed comparative fishing experiments were used for evaluation of comparative performance of BRDs. About 10 to 20 hauls each of 1 to 1.5 h duration were conducted for each set of experiments. Covered codend method (adapted from Sparre et al., 1989; Wileman et al., 1996) and small meshed covers over BRD exit opening (CIFT, 2003) were used to retain the excluded catch, during BRD installed trawling operations. Both retained and excluded catches were sorted and identified up to species level, in order to determine selectivity and bycatch exclusion characteristics of BRDs. In the case of large volumes of catch, sub-samples were taken for analysis. In the case of fishes and shrimps total length was taken and for cephalopods the mantle length was measured. Selection ogives and selectivity parameters such as mean selection length (L_{50}), L_{25}, L_{75} and selection range were determined based on the methods described by Sparre et al. (1989) and Wileman et al. (1996).

An assessment of the impact of trawling on the resources is possible through the analysis of the diversity indices of the catch excluded through BRDs. In the present scenario environmental impacts made by the trawling systems are also to be taken into consideration while assessing their efficiency and suitability for adoption in a resource system. Such information is also useful in the development of eco-friendly trawl systems which minimize impact on non-target resources. PRIMER software package (Version 5.2.9; Plymouth Marine Laboratory, Plymouth, UK) was used for SIMPER analysis, plotting k-dominance curves, and estimating diversity indices such as total number of species (S), Margalef richness (d), Pielou's evenness (J'), Brillouin index (H), Shannon index (H'), Simpson's dominance index (λ'), Hill number (N1), taxonomic diversity (Δ), taxonomic distinctness (Δ*) average phylogenetic diversity index (Phi+) and total phylogenetic diversity index (sPhi+). Simpson's evenness measure ($E_{1/D}$) was calculated using MS Excel by dividing reciprocal of Simpson's dominance index with total number of species (S) in the excluded catch (Clarke and Warwick, 1994; Clarke and Gorley, 2001; Clarke and Warwick, 2004).

3.3 Survey of Trawl Systems

Information on trawlers, trawl nets and accessories, bycatch issues and concerns were collected using pre-tested structured schedules prepared for the purpose (Annexure 3.1, 3.2 and 3.3), from centres of major trawling activity in Kerala such as Cochin and Munambam. Data on design details and rigging of existing commercial trawls and their accessories were obtained by a survey of trawl systems, using a trawl design template. Design drawings and specifications were prepared as per conventions of FAO (1975, 1978) and recommendations of ISO (1975).

3.4 Characterisation of Shrimp Bycatch

Methodology followed for characterisation of shrimp bycatch is given in Chapter 5.

Annexure 3.1. Questionnaire for collecting details of fishing gear

<table>
<tr><th colspan="9">GEAR DETAILS</th></tr>
<tr><td rowspan="2">1</td><td colspan="2" rowspan="2">Type of vessel</td><td colspan="2">OAL</td><td colspan="4"></td></tr>
<tr><td colspan="2">BHP</td><td colspan="4"></td></tr>
<tr><td>2</td><td colspan="4">Type of net</td><td colspan="4"></td></tr>
<tr><td>3</td><td colspan="4">Head rope length</td><td colspan="4"></td></tr>
<tr><td>4</td><td colspan="4">Foot rope length</td><td colspan="4"></td></tr>
<tr><td>5</td><td colspan="4">No. of floats</td><td colspan="4"></td></tr>
<tr><td>6</td><td colspan="4">Weight of sinkers</td><td colspan="4"></td></tr>
<tr><td>7</td><td colspan="4">Qty. of Netting</td><td colspan="4"></td></tr>
<tr><td rowspan="2">8</td><td rowspan="2">Cost</td><td>Netting</td><td colspan="2"></td><td>Float</td><td></td><td>Labour</td><td></td></tr>
<tr><td>Rope</td><td colspan="2"></td><td>Sinkers</td><td></td><td>Total</td><td></td></tr>
<tr><td>9</td><td colspan="8">Panel sections</td></tr>
<tr><td></td><td>Mesh size</td><td colspan="2">Twine size, mm dia.</td><td>Meshes in the leading edge</td><td>Meshes in the tailing edge</td><td colspan="3">Depth of meshes</td></tr>
<tr><td>1</td><td></td><td colspan="2"></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>2</td><td></td><td colspan="2"></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>3</td><td></td><td colspan="2"></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>4</td><td></td><td colspan="2"></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>5</td><td></td><td colspan="2"></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>6</td><td></td><td colspan="2"></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>7</td><td></td><td colspan="2"></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>8</td><td></td><td colspan="2"></td><td></td><td></td><td colspan="3"></td></tr>
</table>

Annexure 3.2. Questionnaire for collecting trawler details

<table>
<tr><th colspan="4">DETAILS OF TRAWLER</th></tr>
<tr><td>1</td><td colspan="2">Name of the vessel</td><td></td></tr>
<tr><td>2</td><td colspan="2">Type of vessel</td><td></td></tr>
<tr><td>3</td><td colspan="2">OAL</td><td></td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Engine</td><td>BHP</td><td></td></tr>
<tr><td>Make</td><td></td></tr>
<tr><td>Model No</td><td></td></tr>
<tr><td>5</td><td colspan="2">Type of gear</td><td></td></tr>
<tr><td>6</td><td colspan="2">No. of gears on board</td><td></td></tr>
<tr><td>7</td><td colspan="2">Crew size</td><td></td></tr>
<tr><td>8</td><td colspan="2">Area</td><td></td></tr>
<tr><td rowspan="3">9</td><td rowspan="3">Operation</td><td>Depth</td><td></td></tr>
<tr><td>Area</td><td></td></tr>
<tr><td>Time</td><td></td></tr>
<tr><td rowspan="2">9a</td><td rowspan="2">Duration</td><td>No.of hauls</td><td></td></tr>
<tr><td>Duration of hauls</td><td></td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">GPS</td><td>Model</td><td></td></tr>
<tr><td>Make</td><td></td></tr>
<tr><td rowspan="2">11</td><td rowspan="2">Echo sounder</td><td>Model</td><td></td></tr>
<tr><td>Make</td><td></td></tr>
<tr><td rowspan="2">12</td><td rowspan="2">Wireless</td><td>Model</td><td></td></tr>
<tr><td>Make</td><td></td></tr>
<tr><td>13</td><td colspan="2">Mobile</td><td></td></tr>
<tr><td>14</td><td colspan="2">No. of Fishing Days (Avg)</td><td></td></tr>
<tr><td>15</td><td colspan="2">Oil consumption/day (Avg)</td><td></td></tr>
<tr><td>16</td><td colspan="2">Type of otter board</td><td></td></tr>
<tr><td rowspan="3">17</td><td rowspan="3">Winch</td><td>Type</td><td></td></tr>
<tr><td>Make</td><td></td></tr>
<tr><td>Rope length</td><td></td></tr>
<tr><td>18</td><td colspan="2">Fish hold capacity</td><td></td></tr>
<tr><td>19</td><td colspan="2">Qty. of Ice</td><td></td></tr>
<tr><td>20</td><td colspan="2">Qty. of water</td><td></td></tr>
<tr><td>21</td><td colspan="2">Avg. monthly expenditure</td><td></td></tr>
<tr><td>22</td><td colspan="2">Avg. monthly income</td><td></td></tr>
<tr><td>23</td><td colspan="2">Catch details</td><td></td></tr>
<tr><td rowspan="2">24</td><td rowspan="2">Bycatch details</td><td>Retained</td><td></td></tr>
<tr><td>Discarded</td><td></td></tr>
</table>

Annexure 3.3. Questionnaire for collecting rigging and operational details of trawl nets from trawlers

GEAR DETAILS FROM TRAWLERS											
Sl. No	Length of warp	Bridle length	Type of otter board	Weight of sinkers	No. of float	Type of float	Type of material	Coden d mesh size	Foot rope length	Head rope length	Type of trawl gear

Chapter 4

Trawl Systems of Central Kerala

4.1. Introduction

Kerala is endowed with a long coastline of 580 km and is located between north latitudes 8°18' and 12°48' and east longitudes 74°52' and 72°22', represent only 1.18% of the India's land area. Fisheries sector is very much established in Kerala and according to 2005-06 census active fishermen population is about 0.18 million scattered in 222 fishing villages. There are about 6 major harbours and 14 major fish landing centres. Annual marine fishery potential of Indian EEZ is estimated at 3.93 million tonnes (Sudarsan et al., 1990), and with respect to the coastal length Kerala occupies seventh position among the maritime states of the country. The marine fish landings of India during 2006-07 have been provisionally estimated at 2.71 million t, which recorded an increase of about 4.1 lakh tonnes over the previous year. The estimated marine fish landing of Kerala during 2006 was 5.92 lakh t. It showed an increase of 10% over that of 2005. Landings were also higher than the annual average (1988-2005) catch of 5.74 lakh t. Among finfishes, pelagic resources accounted for 71% and demersals 14%. Crustacean resources accounted for 10% while cephalopods formed 5%. Pelagic resources were mainly constituted by oil sardine (2.3 lakh t), mackerel (45000 t), ribbonfishes (41000 t), carangids (33300 t), tunas (27843 t) and seerfishes (12700 t). Demersal resources were dominated by threadfin breams and soles. Among crustaceans, penaeid shrimps were dominant (39000 t). Cephalopods, mainly squids and cuttlefishes, contributed 31200 t. Mechanized (in-board engines) and motorized sector (out-board engines) contributed 56% and 42%, respectively while traditional sector accounted for 2% of the total landing. In the mechanized/-motorized sector, among various gears, ring seines contributed 49%, trawls 33%, drift gill nets and hooks & line 18%. (CMFRI, 2006a). In 2005-06 contribution towards marine export from Kerala was about 19%. Trawls contributed 1.92 lakh t (33%) with landings dominated by penaeid shrimps, cephalopods, threadfin breams, ribbonfishes, lizardfishes, anchovies and elasmobranchs.

Trawling is the most important commercial fishing method used in mechanized sector, in Kerala. In Kerala motorized and mechanized fishing was introduced in the mid fifties. Kristjonsson (1967) mentioned about the experimental shrimp trawling conducted in 1955 from a 6.6 m LOA, 10 hp open motor boat, off Malabar Coast under FAO Technical Assistance, using a Gulf of Mexico type flat trawl of 9.6 m head line. Mechanized fishing was first introduced in 1956 at Sakthikulangara – Neendakara in the Quilon coast, which is by far the most important landing centre of the state and it had extensive effect on the socio- economic aspects of this area (Devaraj and Smitha 1988; Sathiadhas et al., 1981). Construction of small-mechanized boats fit for commercial trawling was made by the erstwhile Indo – Norwegian Project in 1957 (Sandven, 1959; Gnanadoss, 1977; Gulbrandsen, 1984; Gulbrandsen et al., 1992; Pillai et al., 2000).

The first attempt for introduction of trawling in Indian waters was by the mechanized vessel 'Premier' in 1900 off Bombay coast (Mukundan et al.,1993). The number of trawlers operating in Indian waters has been recently estimated at 29,241(CMFRI, 2006b). Currently there are about 600 trawlers operating during normal seasons making Cochin and Munambam as their base and during peak seasons more than 900 trawlers are operated in Cochin - Munambam areas. Such a large number of fishing units operate in Cochin mainly due to its geographic proximity to the major harbours such as Thoppumpady, Munambam and landing centers such as Malippuram, Murikkumpadam, Puthuvypin etc and large scale seafood processing activity in Cochin.

As a result of constant efforts to increase the efficiency of fishing boats and nets the trawl system has progressed immensely since its introduction around early fifties, both in the case of craft and gear (Thankappan, 2000, Verghese, 1998; Mukundan and Hameed 1993; George, 1980). In the case of craft Indo-Norwegian Project and CIFT has introduced and popularized wide range of trawlers from 7.62 m to 17.52 m and in the dawn of mechanization upgradation of small vessels were the most accepted procedure (Verghese, 1998). A gradual shift in the selection of boat materials and new designs giving preference to steel rather than wood was also observed.

The shrimp trawls also undergone changes in course of time with reduction of total length of the net with shorter belly and ballooning effect especially for shrimps coupled with tickler chains. Attempts were made to increase the vertical opening of the net by increasing the mesh size in the fore part of the net or by the application of uni-mesh with thinner materials (George, 1998). CIFT has introduced various designs of bottom trawling gear such as two - seam and four - seam trawls, long wing trawl, bulged belly and six - seam trawl and energy saving concepts in trawl design such as rope trawl and large mesh trawl (CIFT, 2003). In this study an attempt was made to trace the present status of the trawlers and various trawl net designs existing in Central Kerala.

4.2. Objectives of the Study

Trawling though a destructive and energy intensive fishing method, it is the most efficient method of harvesting shrimps. Trawling contributes the majority of the world's bycatch and has been the centre of criticism from the very beginning of trawling. In Kerala the majority of the landings from the mechanized sector are from ring seines and trawlers. Though trawling is the most widely adopted fishing method there is a paucity of information regarding the current status of trawling systems. In the present study, an attempt is made to document trawl systems existing in the Central Kerala including details on vessels, trawl nets and various accessories used in trawl nets and vessels.

4.3. Materials and Methods

Specific centres in Central Kerala such as Azheekode, Munambam, Malippuram, Murikkumpadam, Thoppumpady and Edakochi were selected for the study. The details of trawlers were collected from these centres and the details of trawl nets were collected from the net makers of Thoppumpady and Munambam. A map showing the study area is given in Fig. 4.1. Pre-tested questionnaires were used to collect details of trawlers and trawl nets (Annexure 3.1, 3.2 and 3.3) from boat owners, skippers / serangs, engine drivers, deckhands, boat yard engineers, net makers, suppliers of trawl accessories and navigation equipments.

A design template was used, for collecting the details of existing trawl net designs in the area. Design drawings and specifications of the trawl nets were prepared as per the conventions of FAO (1975; 1978) and recommendations of ISO (1975).

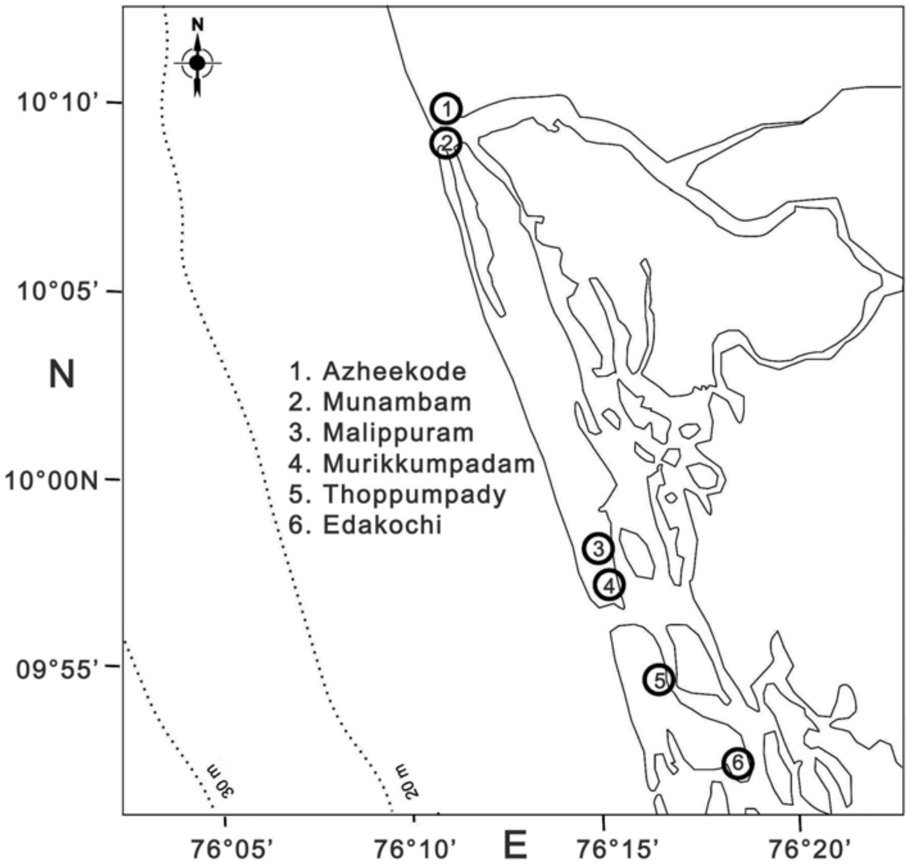


Fig. 4.1. Map showing the study area

4.4. Results

Details regarding the trawlers collected include type of vessels, material used for making, L_{OA} of the vessel, engine make, model and hp, crew size, area and depth of operation, number and duration of hauls, fish hold capacity, quantity of ice and water, diesel consumption details, type of otter boards, various electronic equipments used onboard etc. Details of trawl nets collected include type of trawling nets, their design, material used, details of accessories such as floats, sinkers etc, the seasons of operation and numbers of nets stored onboard were collected.

4.4.1. Details of trawlers

4.4.1.1. Vessel categories

In central Kerala there are only two types of boats based on type of material used for construction, *viz*., wood and steel construction. Majority of newly built trawlers of central Kerala are constructed out of steel. Though wooden trawlers also exist in the same area, all of them are more than 5-10 years old. The L_{OA} of trawlers ranges from 9.8 m L_{OA} trawlers without winch to 21.6 m L_{OA} large vessels deployed for multiday deep-sea fishing. Trawlers of central Kerala can be classified into three major classes based on length overall, cost of construction and present value of the boat.

i. Small trawlers

These are the old wooden trawlers existing in the area and having L_{OA} ranging from ranging from 8.5 m to 10.6 m (28 - 35 ft) (Fig. 4.2 and 4.3). These vessels are operated without winch also. New trawlers in this category are rarely built in these days and when built they are preferably made of steel. Old vessels have got a resale value between 0.1 to 0.15 million rupees and newer vessel cost about 0.4 million rupees. Such trawlers are still used in peak seasons for shrimp trawling.

ii. Medium sized trawlers

Medium sized trawlers ranges between 10.6 m and 15.2 m (35 - 50 ft) in L_{OA} and form the majority of trawlers in the surveyed area (Fig. 4.4 and 4.5). Cost of new vessels are in the range of Rs. 1 - 2 million and older vessels have a resale value of Rs. 0.2 - 0.7 million. Trawlers are of both wood and steel construction. Majority of the vessels and all the newly constructed vessels are made of steel.

iii. Large trawlers

Large trawlers having an L_{OA} above 15.2 m (>70 foot) (Fig. 4.6) form major percentage of the recent constructions. Investment for the large trawlers is in the range of Rs 2.0-3.0 million. Maximum L_{OA} in this area was found to be 21.6 m (71 foot). Almost entire fleet in this category use steel as building material and are well equipped for multiday and deep sea fishing.

Fig. 4.2. Small trawler without winch

Fig. 4.3. Small trawler with winch

Fig. 4.4. Medium sized wooden trawler

Fig. 4.5. Medium sized steel trawler

Fig. 4.6. Large steel trawler

4.4.1.2. Engine details

In India, engines specially designed for marine applications are not available. Currently land engines after making some modifications like fitting water pump, cooling system, belts and power take-off are installed for marine applications. The most preferred engine used in trawlers of almost all length classes in central Kerala is Ashok Leyland marine diesel engine. The reliable performance and the easy availability of spares and repair facilities has made this most preferred brand for installation in fishing vessels. Ruston engines are used in the older small trawlers without winch and small trawlers with winch having L_{OA} between 8.5 and 9.8 m (28 - 32 ft). A very small percentage of trawlers are using Cummins marine diesel engines on experimental basis. Details of engines prevalent in the area are given in Table 4.1.

Table 4.1 Details of engine models, their power and vessel type

Engine model	hp @ 2000 rpm	Length class of vessel
Ruston		8.5 - 9.8 m
Ashok Leyland - 370	90	8.5 - 12.2 m
Ashok Leyland - 400	100	12.2 - 14.6 m
Ashok Leyland - 402	107.5	12.2 - 15.2 m
Ashok Leyland - 411	110	13.7 - 18.3 m
Ashok Leyland - 412	112	13.7 - 18.3 m
Ashok Leyland - 412 TC*	124	13.7 - 18.3 m
Ashok Leyland - 680	158	15.2 - 19.8 m
Ashok Leyland - 680 TC*	177	15.2 - 21.6m

* Turbo charged

4.4.1.3. Crew size

Normal crew size in smaller vessels is 5 and for larger vessels is 6 to 8. The crew complement include one Skipper / Serang, one Engine Driver and 3-6 Deckhands. In central Kerala the payment to the crew is based on share of catch plus a *bata* of Rs 500 per fishing day for the entire crew. The *bata* amount may vary depending on boat owner's decision. After reducing the operational cost, the income is divided between boat owner and crew members. Of the total profit, 65% goes to the boat owner and 35% to the crew members. Crew share is divided into equal shares and from those two shares goes to the skipper and all the others will get a single share each.

4.4.1.4. Area and depth of operation

Area of operation mainly depends upon the season and size of the vessel. Smaller vessels (8.5-10.6 m L_{OA}) restrict their operation in and around Cochin - Munambam areas and operate up to a depth of 20-30 m. Medium vessels (10.6-15.2 m L_{OA}) operate up to 250 m depth. Larger vessels (>15.2 m L_{OA}) go even up to 450 m for deep sea fishing operaions. Medium vessels go south up to

Kanyakumari and north up to Mangalore. Large vessels while undertaking deep-sea fishing operations go up to Thoothukudy and Ervaady in the east-coast and north up to Ratnagiri. Most of the vessels mainly larger vessels operate during August-January from Cochin and during February-April from Kannur or Thalassery and in May-June again in Cochin.

4.4.1.5. Duration of fishing

Duration of fishing ranges from 9 hours to 10 days depending on the size of the fishing boat, facilities available onboard and also species targeted. Small vessels up to 10.6 m L_{OA} preferred daily fishing from 3 a.m. to 12 p.m. during the peak season only. Three or four hauls having a haul duration 1.5 to 2.5 h were taken, mainly targeting shrimps and anchovies. Medium vessels up to 15.2 m L_{OA} preferred fishing trips of 2-5 days targeting shrimps, squids and fish. They made 4-5 hauls per day with a haul duration of 1.5-3 h. Large vessels of more than 15.2 m L_{OA} preferred fishing trips of duration ranging from 5 to 10 days. The number of hauls ranged from 4 to 5 hauls during day time and up to 4 hauls if there is night fishing with the haul duration ranging between 1.5 and 3 h. All the vessels preferred day fishing and night fishing was undertaken very rarely according to the availability of shrimps and cephalopods. During the period of observations small-scale line fishing was undertaken by trawl fishermen during night and whenever time is available. Main target catches were barracuda, seer fish, reef cods, snappers and large carangids. Jigging was also conducted in reef areas to catch cuttlefish and squids.

4.4.1.6. Details of diesel consumption

Diesel cost forms the major share in the operational expenditure of the trawlers. The diesel consumption per hour varies from 8 to 18 liter/hr, depending up on the size, installed engine horse power and displacement of the vessel, location of the fishing ground and duration of the fishing trip. Most of the vessels are incorporating turbo charging system in the engine for additional savings in diesel and generally new vessels are fitted with turbo-charged engines.

4.4.1.7. Type of otter board

Small trawlers below 10.6 m L_{OA} (35 ft) used flat rectangular otter boards made of wood reinforced by steel frame (Fig. 4.7). Fishermen reportedly experienced good results when wooden boards are used for shrimp trawling in shallow areas. In Cochin area almost 95 % of trawlers above 10.6 m L_{OA} (35 ft) make use of V-type otter board as sheer device (Fig. 4.8 and 4.9). The weight of otter board ranges from 50 to 88 kg each. Table 4.2 gives the details of dimensions of otter boards commonly used in trawlers of central Kerala.

Table. 4.2 Otter board dimensions

Engine	Length (cm)	Breadth (cm)	Weight (kg)
a. V-type otter boards			
370	132.08	76.2	50 – 60
400	132.08	76.2	60 -70
402	132.08	76.2	75
412	137.16	81.28	75 -78
680	137.16	81.28 – 83.82	80 -88
b. Wooden otter boards			
370	137.16	68.58	60
400	147.32	71.12	65
402 412 680	152.40	76.2	75 -80

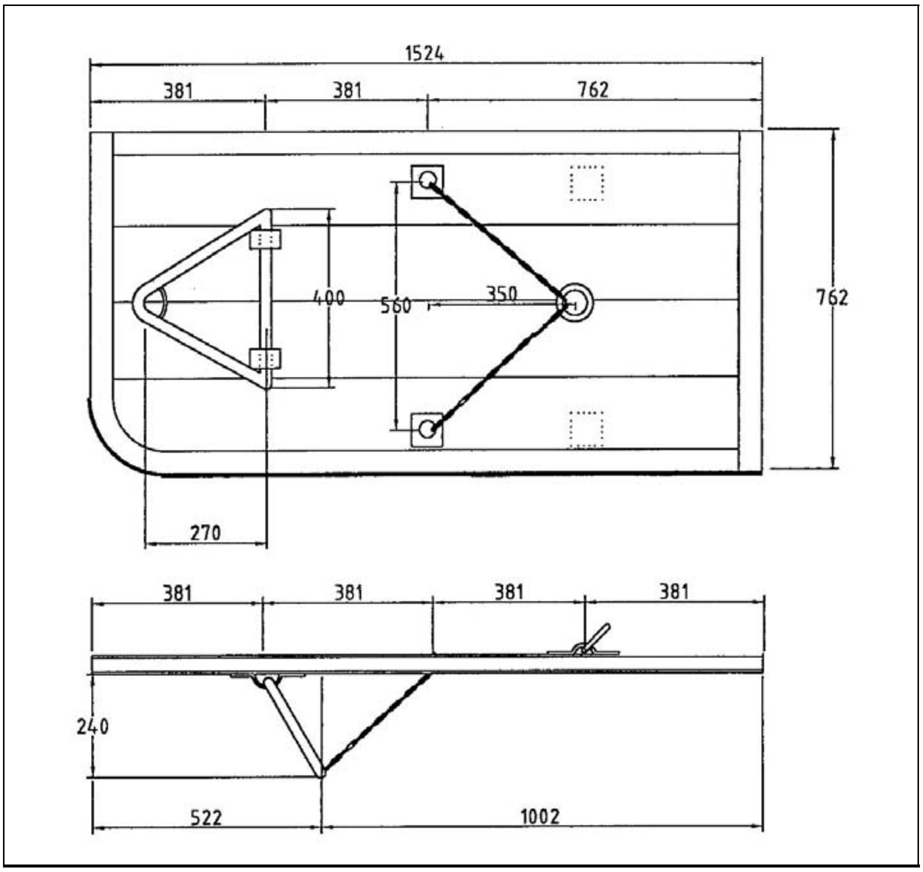


Fig. 4.7. Design details of flat rectangular otter board of wood and steel construction (1524x762 mm; 75 kg)

Fig. 4.8. V-type otter board of all steel construction (80 kg)

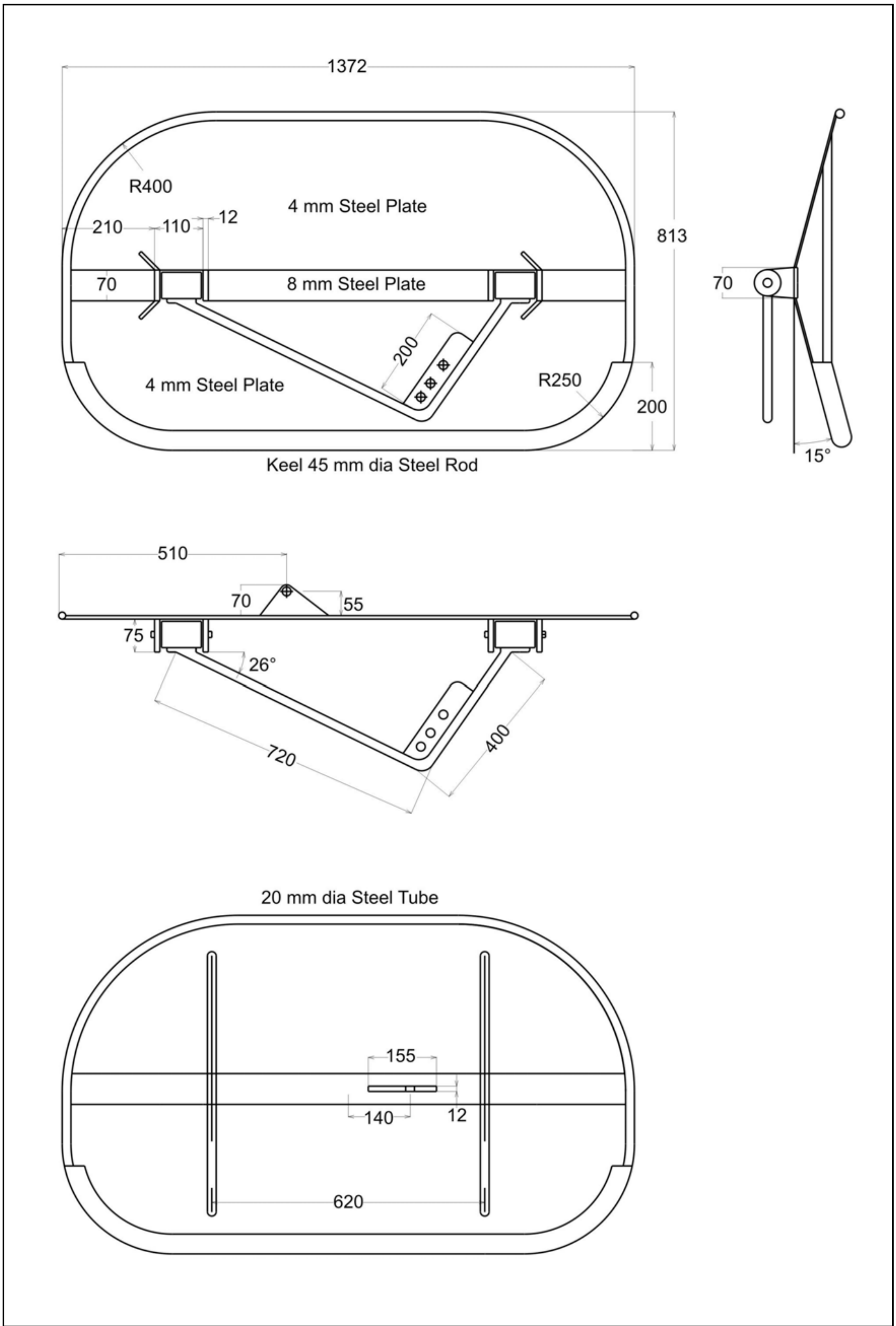


Fig. 4.9. Design details of V-type otter boards (1372 x 813 mm; 80 kg each)

4.4.1.8. Winch

Almost all the trawlers surveyed had yard fabricated winches. All of them were mechanical. Stainless steel wire ropes (SWR) of different diameters were used for trawling operation. Small and medium sized trawlers used 8 mm or 9 mm dia SWR which cost Rs 26-30 per metre and larger vessels used 10 mm mm dia SWR which cost Rs 30-32 per metre. Length of wire ropes in the winch ranged from 700 metre/drum in small trawlers to 1500 -2000 metre/drum in large vessels.

4.4.1.9. Fish hold capacity

Smaller boats operating 9 hours did not have any fish hold and in some cases 1 or 2 boxes each having a capacity of 500 kg were used. In larger boats fish hold capacity ranged from 2 t 10 tonnes. The fish holds used to be insulated using thermocol. More recently puff insulation which cost around 0.1 – 0.15 million has been preferred by most of the boat owners due to its better performance and durability. Separate compartments were available in the fish hold for storing various species of fishes, shrimps and cephalopods. Crushed ice was also stored separately in this fish hold.

4.4.1.10. Quantity of ice and water

For single day operation, vessels did not carry ice and for multi-day fishing the vessels carried ice in large quantities. On an average for one-day vessels of 15.2 m L_{OA} carried 20-30 blocks of ice weighing 25 kg each. Large vessels carried 150 blocks of ice for a fishing trip of 5 days. Ice was crushed using crushing machine at the harbour or in the ice plant and stored in the fish hold of the vessel.

Small vessels carried 500-1000 liters of water and large vessels carried 1000-4000 liters depends on number of fishing days.

4.4.1.11. Electronic equipments used in trawlers

Almost all large vessels and 75-80 % of small trawlers in the central Kerala area were equipped with modern electronic equipments such as echo sounder, GPS (Global Positioning System), radiotelephone and mobile phone. Echosounder is used for monitoring the depth of operation, nature of fishing ground and to detect the presence of fish. GPS is used for navigation and safety and accurate location fishing grounds. It also aids the rescue team to locate the boat in distress after communicating with them through wireless. Radiotelephone and mobile phone facilitated communication with shore and other vessels operating in the area.

4.4.2. Details of trawl nets

Most of the trawlers operating off Cochin were engaged in multi-day multi-species fishing. In earlier days the trawlers were mainly meant for shrimp trawling. In recent times fishing extending up to 10 days were undertaken targeting fish, squids and cuttlefish in addition to shrimps. Different designs of trawl nets were deployed for this purpose.. The number of trawl nets carried onboard ranged between 5 and 15. The large vessels carried 12 to 15 trawl nets and small ones carried up to 8 nets.

During survey, net-making centers such as Thoppumpady and Munambam areas were visited where a lot of people were engaged in the fabrication and repairs of trawl nets. Trawl nets were made entirely of polyethylene (PE), which is the most accepted material for making trawl nets (Mukundan et al., 1993). Mesh size of netting used in the front panels of trawl nets meant for fish has increased up to 1000 mm and 1500 mm. Shrimp trawls used netting of mesh size 35 - 50 mm in the front panels. Throat was made of 30 -40 mm mesh netting. The codends were fabricated either by hand braiding or by using machine-made netting with mesh size ranging from 16 to 30 mm. The cost of hand-braided codend was Rs. 200 and that of machine-made codend was Rs. 210.

Thirteen different designs of trawl nets, twelve two seam designs and one four seam design were observed during the survey, among them seven were shrimp trawl nets (commonly called as *Chemmeen vala*, *Poovalan vala*, *Pullan vala*, etc.), Four were fish nets, which include three type of fish trawl (*Meen vala*) nets and one four seam design commonly called as *Chooda vala* for capturing anchovies and two cephalopod nets (commonly called as *Kanava vala*). The design details of different trawl nets are given below.

4.4.2.1. Shrimp Trawls

Shrimp trawl - 1 : *Chemmeen vala* (Munambam design)

This is a typical 2-seam shrimp trawl (Fig. 4.10). Unlike trawlers from Cochin and Kollam, trawlers from Munambam use a common net to capture a variety of shrimps. This trawl net is commonly called as *Chemmeen vala* and is used for harvesting *Metapenaeus dobsoni*, *Metapenaeus affinis, Penaeus (Fenneropenaeus) indicus, Parapenaeopsis stylifera*, etc. It is 36 m long and made entirely of 0.5 mm twisted polyethylene twine except codend, which is made of 1.25 mm twine. Its wing and square are fabricated out of 40 mm mesh webbing. Wing piece in the upper panel is 300 meshes deep and that in the lower panel are 350 meshes deep. Belly panel is 250 meshes deep and made of 35 mm mesh. The extension piece is fabricated out of 22 mm mesh webbing and is 250 meshes deep. Codend is 300 meshes deep and made entirely of 20 mm mesh webbing. The head-rope and foot-rope of this trawl net is 24.4 m and 27.4 m respectively and the rope material is polypropylene with 14 mm dia. An average of 28 kg lead weight and tickler chain are attached to the foot-rope. About 10-15 nos of 15 cm or 20 cm HDPE floats are used.

Shrimp trawl - 2 : *Poovalan vala* (Cochin design)

Poovalan vala is a 35.6 m 2-seam shrimp trawl used to harvest *Metapenaeus dobsoni* (Fig. 4.11). Its wing panels and square are fabricated out of 40 mm mesh webbing and the upper and lower wing panels are 325 meshes and 375 meshes deep respectively. Square is 50 meshes deep and belly is 300 meshes deep. Belly is fabricated out of 32 mm mesh webbing. Extension piece is 180 meshes deep and made out of 28 mm mesh webbing. Codend mesh size is 20 mm and is 300 meshes deep. All the webbings used in this net except codend are made of either 0.5 or 0.75 mm dia twisted polyethylene twine. 1.25 mm twine is used for codend. The head-rope and foot-rope of this trawl net is 30 m and 33 m respectively and the rope material is polypropylene with 14 mm dia. An average of 30 kg lead weight and tickler chains are attached to the foot-rope. Lead weight in the form of small beads weighing 25-30 g each is attached to the foot-rope using 3 mm PP rope. About 10 - 15 nos of 15 cm or 20 cm HDPE floats are used.

Shrimp trawl - 3 : *Poovalan vala* (small) (Cochin design)

It is a 34 m long 2-seam shrimp trawl net design for catching *Metapenaeus dobsoni* (Fig. 4.12). Its wing panels and square are fabricated out of 40 mm mesh webbing and are 325 meshes deep in the upper panel and 375 meshes deep in the lower panel. Upper belly is fabricated from 30 mm mesh webbing and lower belly is fabricated from 22 mm mesh webbing and are 300 and 409 meshes deep respectively. Throat is made from 22 mm mesh and is 180 meshes deep. Twine size of the panels except codend is 0.5 mm dia twisted polyethylene. Codend is 400 meshes deep and made entirely of 15 mm mesh webbing for capturing small shrimps. In some seasons same design is used for capturing sole fishes. 1.25 mm dia twine is used in the codend. The head-rope and foot-rope of this trawl net is 30 m and 33 m respectively and the rope material is polypropylene with 14 mm dia. An average of 30 kg lead weight and tickler chains are attached to the foot-rope. About 10 – 15 nos of 15 cm HDPE floats are used.

Shrimp trawl - 4 : *Pullan vala* (Munambam design)

It is a 35.5 m 2-seam shrimp trawl net designed for deep-sea shrimp trawling (Fig. 4.13). Its wing panels and square are fabricated out of 40 mm mesh webbing. Wing with 300 meshes deep upper panel and 350 meshes deep lower panel. Belly is 300 meshes deep respectively and made of 35 mm mesh webbing. Throat section is 200 meshes in depth and made of 25 mm mesh webbing. Codend is made of 20 mm mesh webbing and is 300 meshes deep. 1.0 mm, 0.75 mm and 1.25 mm twisted polyethylene twines are used in the wings and square, belly and throat and codend respectively. The head-rope and foot-rope of this trawl net is 24.4 m and 27.4 m respectively and the rope material is polypropylene with 14 mm dia. An average of 35 kg lead weight and tickler chains are attached to the foot-rope. No float is used in this net.

Shrimp trawl - 5 : *Pullan vala* (Cochin design)

It is 38.7 m long and made entirely of 0.75 mm twisted polyethylene twine except codend which is made of 1.25 mm twine (Fig. 4.14). Its wings, square and belly are fabricated out of 50 mm mesh webbing. Its upper wing panel is 260 meshes deep and that in the lower panel are 300 meshes deep. Square and belly are 40 meshes and 150 meshes deep respectively. The extension piece throat is fabricated out of 30 mm mesh webbing and is 180 meshes deep Codend is 300 meshes deep and made entirely of 20 mm mesh webbing. The head-rope and foot-rope of this trawl net is 30 m and 33 m respectively and the rope material is polypropylene with 14 mm dia. An average of 30 kg lead weight and tickler chains are attached to the foot-rope. Floats are not used for deep sea shrimp trawling.

Shrimp trawl - 6 : *Pullan Vala* (medium) (Cochin design)

This is a medium sized deep-sea shrimp trawl used in trawlers of Cochin area (Fig. 4.15). It is 36.6 m long and made entirely of 0.75 mm twisted polyethylene twine except codend which is made of 1.25 mm twine. Its upper wing is 260 meshes deep and lower wing is 300 meshes deep and is fabricated out of 50 mm webbing. Square and belly are fabricated out of 40 mm webbing and are 150 and 120 meshes deep respectively. Extension and throat pieces are made of 35 and 30 mm mesh webbing and are 120 and 180 mesh deep respectively. Codend is 300 meshes deep and made of 20 mm mesh webbing. The head-rope and foot-rope are made of 14 mm polypropylene and are 30 m and 33 m long respectively. An average of 30 kg lead weight and tickler chains are attached to the foot-rope. No floats are used for deep sea shrimp trawls.

Shrimp trawl - 7 : *Pullan Vala* (small) (Cochin design)

This is a small sized deep-sea shrimp trawl used in trawlers of Cochin area (Fig. 4.16). It is 32.5 m long and made entirely of 0.75 mm twisted polyethylene twine except codend which is made of 1.25 mm twine. Its upper wing is 260 meshes deep and lower wing is 300 meshes deep and is fabricated out of 40 mm webbing. Square is fabricated out of 40 mm webbing and is 40 meshes deep. Belly and throat pieces are made of 35 and 28 mm mesh webbing and are

270 and 180 mesh deep respectively. Codend is 300 meshes deep and made of 20 mm mesh webbing. The head-rope and foot-rope are made of 14 mm polypropylene and are 30 m and 33 m long respectively. An average of 30 kg lead weight and tickler chains are attached to the foot-rope. No floats are used for this design of deep sea shrimp trawl.

4.4.2.2. Fish trawls

Fish trawl - 1 : *Chooda vala* (Munambam design)

Chooda Vala is a 44.8 m fish trawl specially designed for exploiting the anchovies (Fig. 4.17). It is a 4-seam design used in trawlers of Munambam areas. The wing panel of this net is fabricated out of 200 mm mesh webbing with upper panel 75 meshes deep and lower panel and side panel are 85 meshes deep. The body of the trawl net is divided into four panels. First panel is 10 meshes deep and is made out of 200 mm mesh webbing. Panel two and three are 50 meshes and 300 meshes deep respectively and made out of 120 mm and 40 mm mesh webbings. Fourth panel is 250 meshes deep and is fabricated out of 20 mm mesh webbing. Codend mesh size is 16 mm and is 300 meshes deep. The webbings used in this net are made of 1.5 mm dia (from wings and square panel) and 1.25 mm dia for second panel. Third and fourth panels are made of 0.5 mm twine and codend is made of 1.25 mm twine. Material used is twisted polyethylene. The head-rope and foot-rope of this trawl net is 30.5 m and 35.5 m respectively and the rope material is polypropylene with 14 mm dia. About 28 kg lead is used in the foot-rope. Up to 21 nos of 20 cm floats are used.

Fish trawl - 2 : *Meen vala* (Cochin design)

This design is the common 2-seam fish trawl used in Cochin areas, having a length of 64.8 m and is used for exploiting various pelagic and mid water fish species (Fig. 4.18). It uses 800 mm mesh webbing in the wing and square panels. Upper and lower wing panels are 25 and 29 meshes deep respectively. Body of the trawl is divided in to eight panels including square panel and are fabricated from 800 mm, 600 mm, 500 mm, 300 mm, 200 mm, 120 mm, 80 mm and 40 mm mesh webbings. Their depths are 2 meshes, 10 meshes, 12 meshes, 15 meshes, 25 meshes, 50 meshes, 75 meshes and 150 meshes respectively. Codend is 300 meshes deep and made entirely of 250 mm mesh webbing. Twine specification up to panel two is 2.00 mm and panel three has twine with 1.5 mm dia. Rest of the webbings use 1.25 mm dia twine. The head-rope and foot-rope of this trawl net is 54 m and 60 m respectively and the rope material is polypropylene with 14 mm dia. About 5 - 7 nos of 35 cm or 30 cm floats and 32 kg lead weight are used.

Fish trawl - 3 : *Meen vala* (Cochin design)

It is 92.4 m long large sized fish trawl used in larger trawlers of Cochin area for harvesting a wide variety if fishes (Fig. 4.19). It uses 1000 mm mesh in the wings and square. Body is divided into six panels fabricated out of 600 mm, 400 mm, 300 mm, 120 mm, 80 mm and 40 mm mesh webbings. Their depths are 33 meshes, 20 meshes, 25 meshes, 30 meshes, 50 meshes and 100 meshes respectively. Codend is 200 meshes deep and made entirely of 30 mm mesh webbing. Twine specification of wings and square is 2.00 mm and panel one has twine with 1.5 mm dia. Rest of the webbings use 1.25 mm dia twine. The head-rope and foot-rope of this trawl net is 45 m and 48 m respectively and the rope material is polypropylene with 14 mm dia. About 8 - 10 nos of 35 cm or 30 cm floats and 50 kg lead weight are used.

Fish trawl - 4 : *Meen vala* (Cochin design)

It is largest fish trawl used in larger trawlers of Cochin area having 92.4 m length and is used for harvesting a wide variety if fishes (Fig. 4.20). It uses 1500 mm mesh in the wings and square. Body is divided into seven panels fabricated out of 800 mm, 600 mm, 400 mm, 300 mm, 120 mm, 80 mm and 40 mm mesh webbings. Their depths are 10 meshes, 15 meshes, 20 meshes, 25 meshes, 30 meshes, 50 meshes and 100 meshes respectively. Codend is 200 meshes deep and made entirely of 30 mm mesh webbing. Twine specification of wings, square and first panel is 2.00 mm and panel two has twine with 1.5 mm dia. Rest of the webbings use 1.25 mm dia twine. The head-rope and foot-rope is made of 14 mm dia polypropylene rope and are 45 m and 48 m respectively. About 8 - 10 nos of 35 cm or 30 cm floats and 50 kg lead weight are used.

4.4.2.3. Cephalopod trawls

Cephalopod trawl - 1 : *Kanava vala* (Munambam design)

Kanava Vala is the typical cephalopod net operated in the Munambam area (Fig. 4.21). It is a 63.5 m long 2-seam trawl design and is more efficient in the targeted trawling of cuttle fish, squid and octopus. 400 mm mesh webbing is used in the wings and square. Body with six panels fabricated from 300 mm, 200 mm, 120 mm, 80 mm, 60 mm, 40 mm mesh webbings. Codend is 300 meshes deep and made entirely of 20 mm mesh webbing. 2.0 mm twisted polyethylene twine is used for wings, square and first panel. 1.5 mm twine is used for second panel and rest of the trawl net is made of 1.25 mm twine. 14 mm dia polypropylene rope is used for head-rope and foot-rope measuring 35 m and 39 m respectively. About 30 kg lead is used in the foot-rope. Only 3 - 5 nos of 30 or 35 cm floats are used for cephalopod trawling.

Cephalopod trawl - 2 : *Kanava vala* (Cochin design)

This typical cephalopod net operated in the large trawlers of Cochin area (Fig. 4.22). It is a 62.6 m long 2-seam trawl design widely used for capturing cuttle fish, squid and octopus. 400 mm mesh webbing is used in the wings, square and first panel. Body is divided in to five panels fabricated from 400 mm, 200 mm, 120 mm, 80 mm and 40 mm mesh webbings. Codend is 300 meshes deep and made entirely of 20 mm mesh webbing. 2.0 mm twisted polyethylene twine is used for wings, square and first panel. 1.5 mm twine is used for second panel and rest of the trawl net is made of 1.25 mm twine. 14 mm dia polypropylene rope is used for head-rope and foot-rope measuring 35 m and 39 m respectively. About 30 kg lead is used in the foot-rope. Up to 5 nos of 30 or 35 cm floats are used.

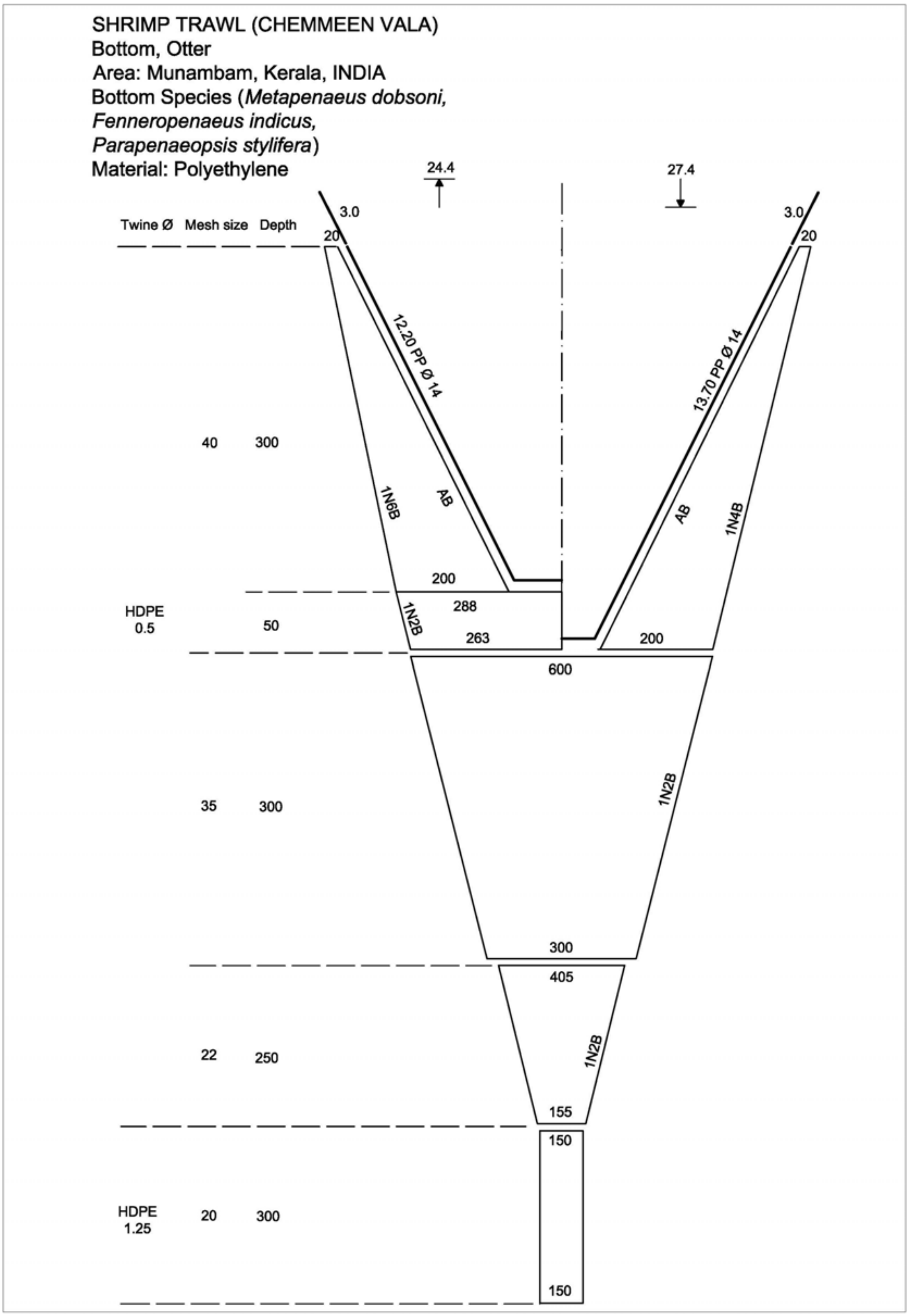


Fig. 4.10. Design of 24.4 m shrimp trawl (Munambam center)

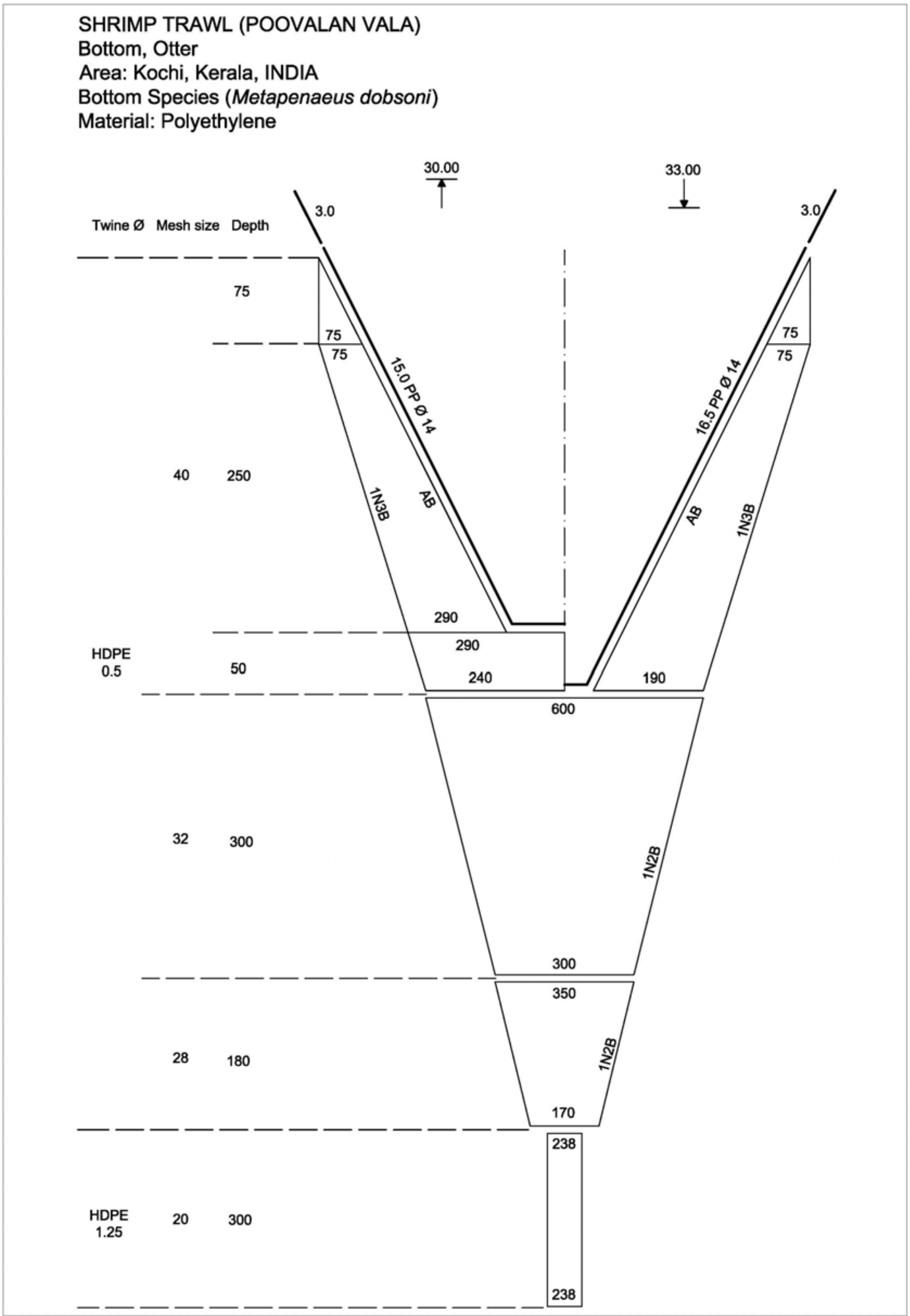


Fig. 4.11. Design of 30.0 m shrimp trawl (Cochin center)

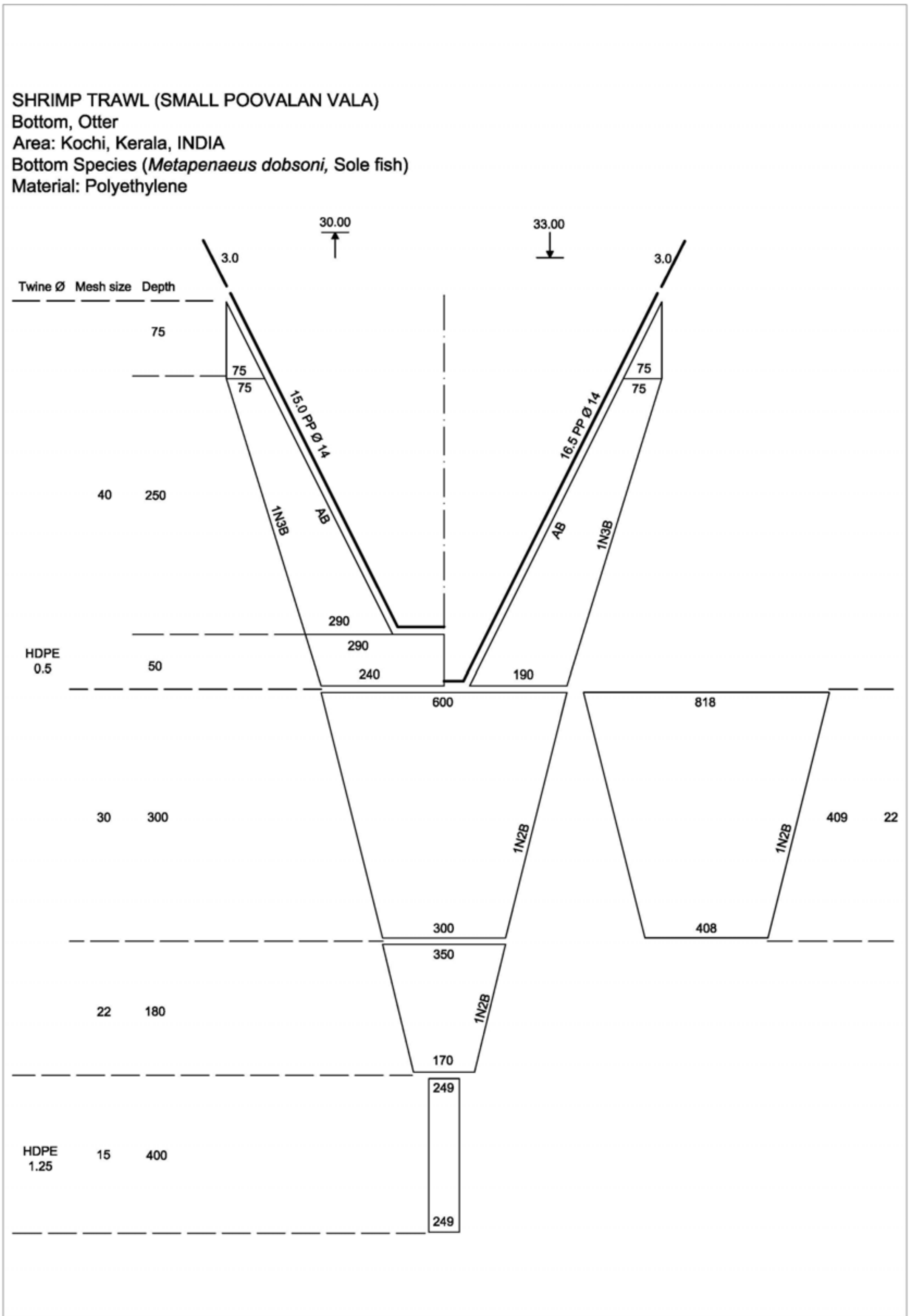


Fig. 4.12. Design of 30.0 m shrimp trawl (Cochin center)

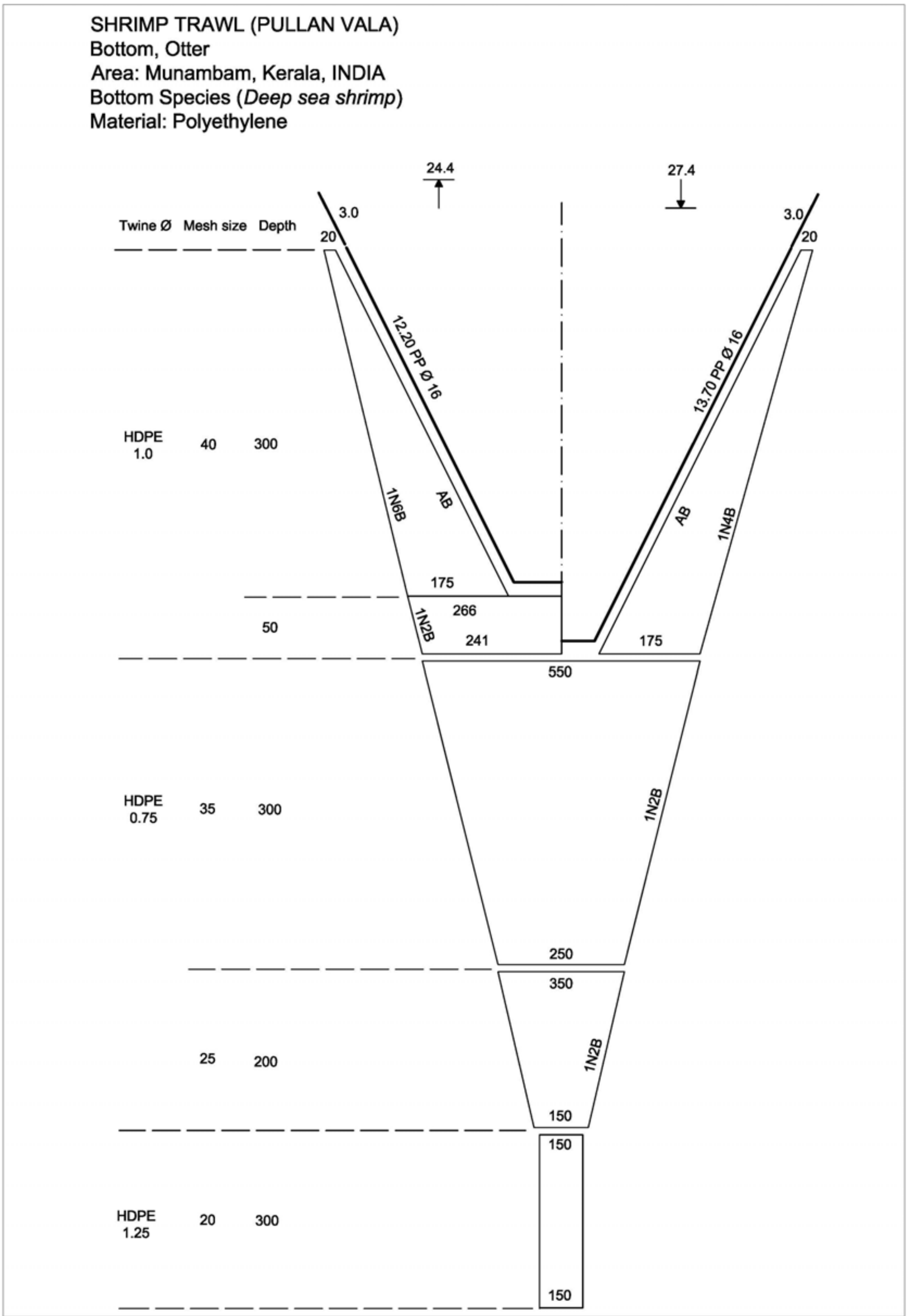


Fig. 4.13. Design of 24.4 m shrimp trawl (Munambam center)

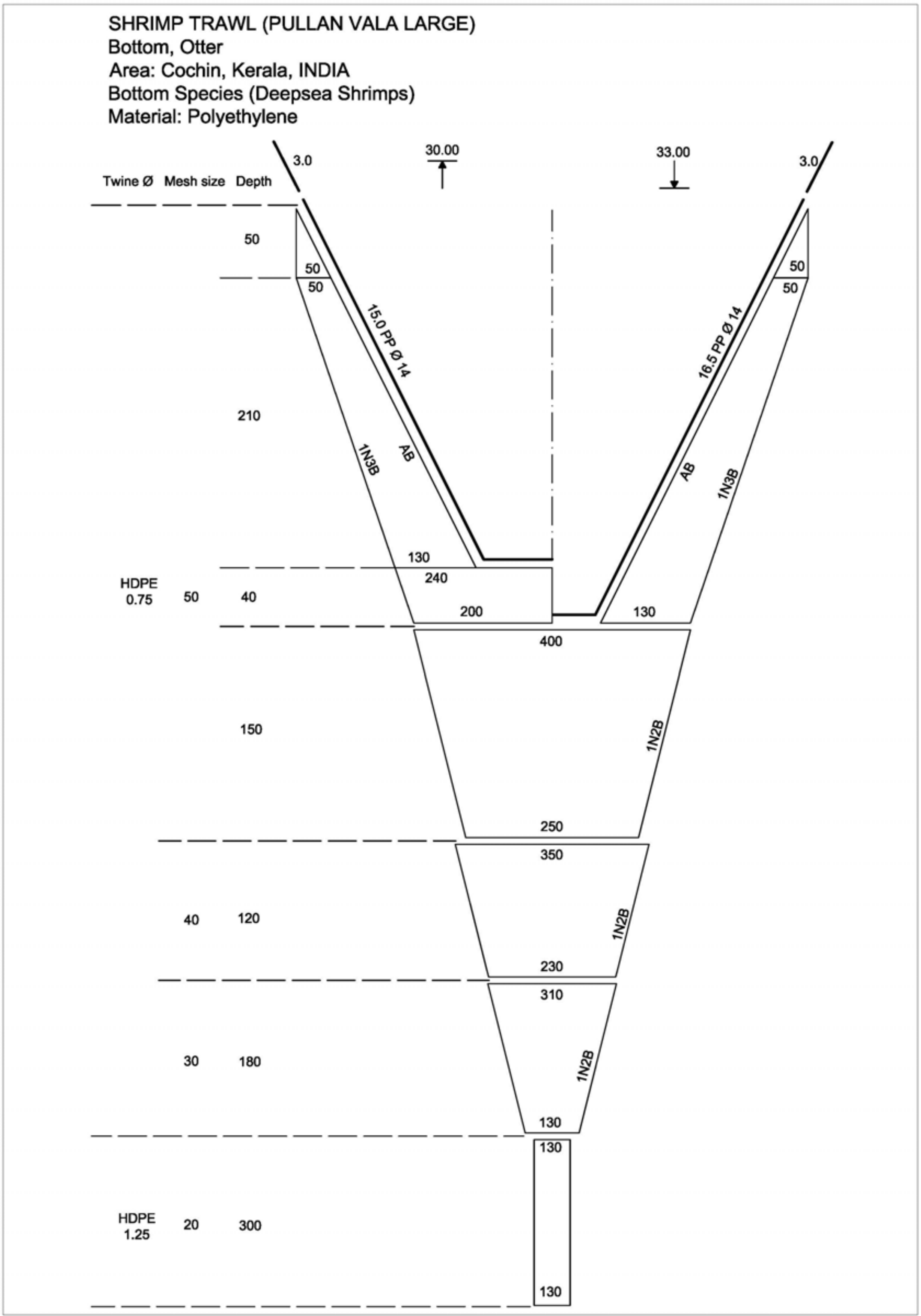


Fig. 4.14. Design of 30.0 m deep-sea shrimp trawl (Cochin center)

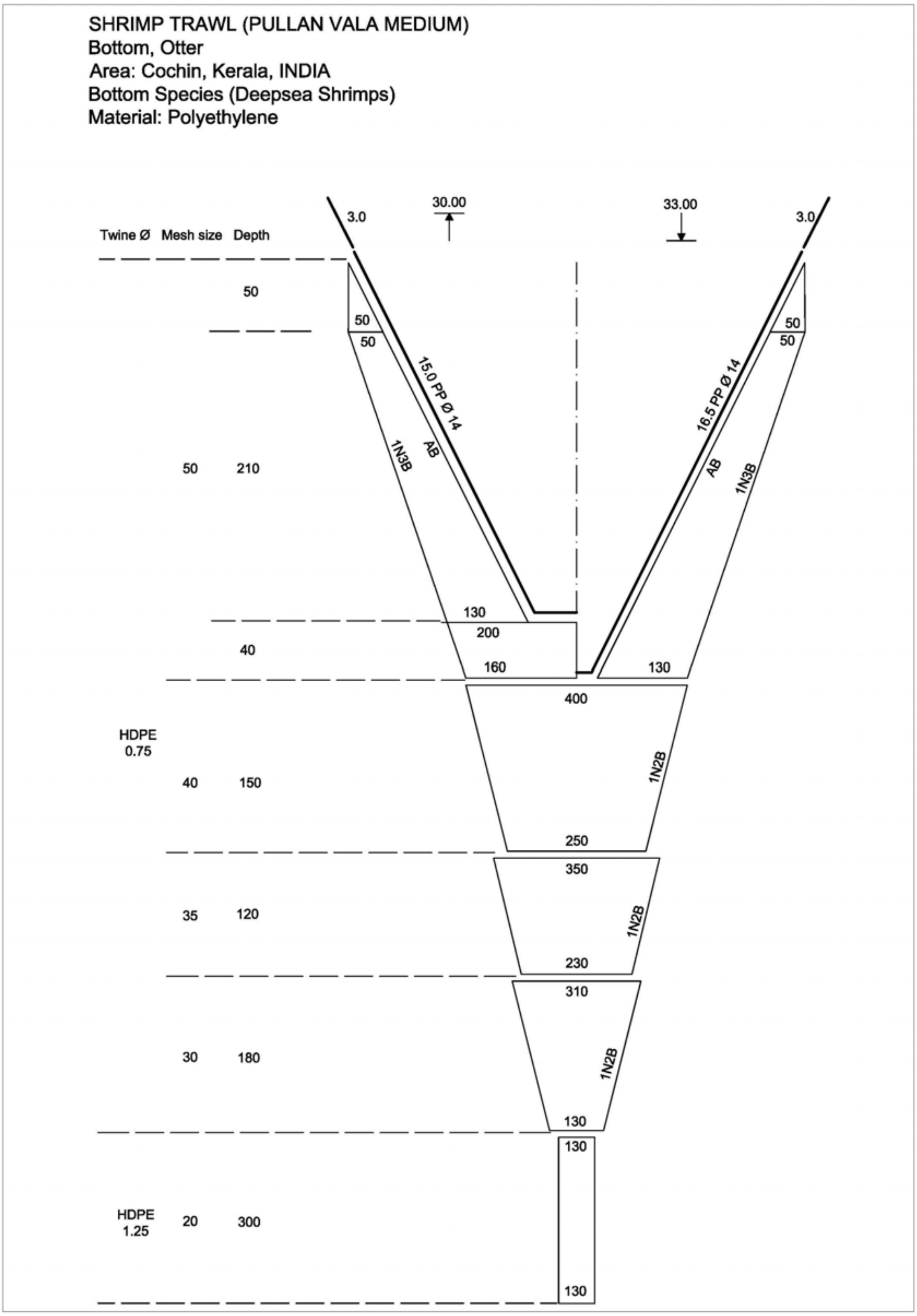


Fig. 4.15. Design of 30.0 m deep-sea shrimp trawl (Cochin center)

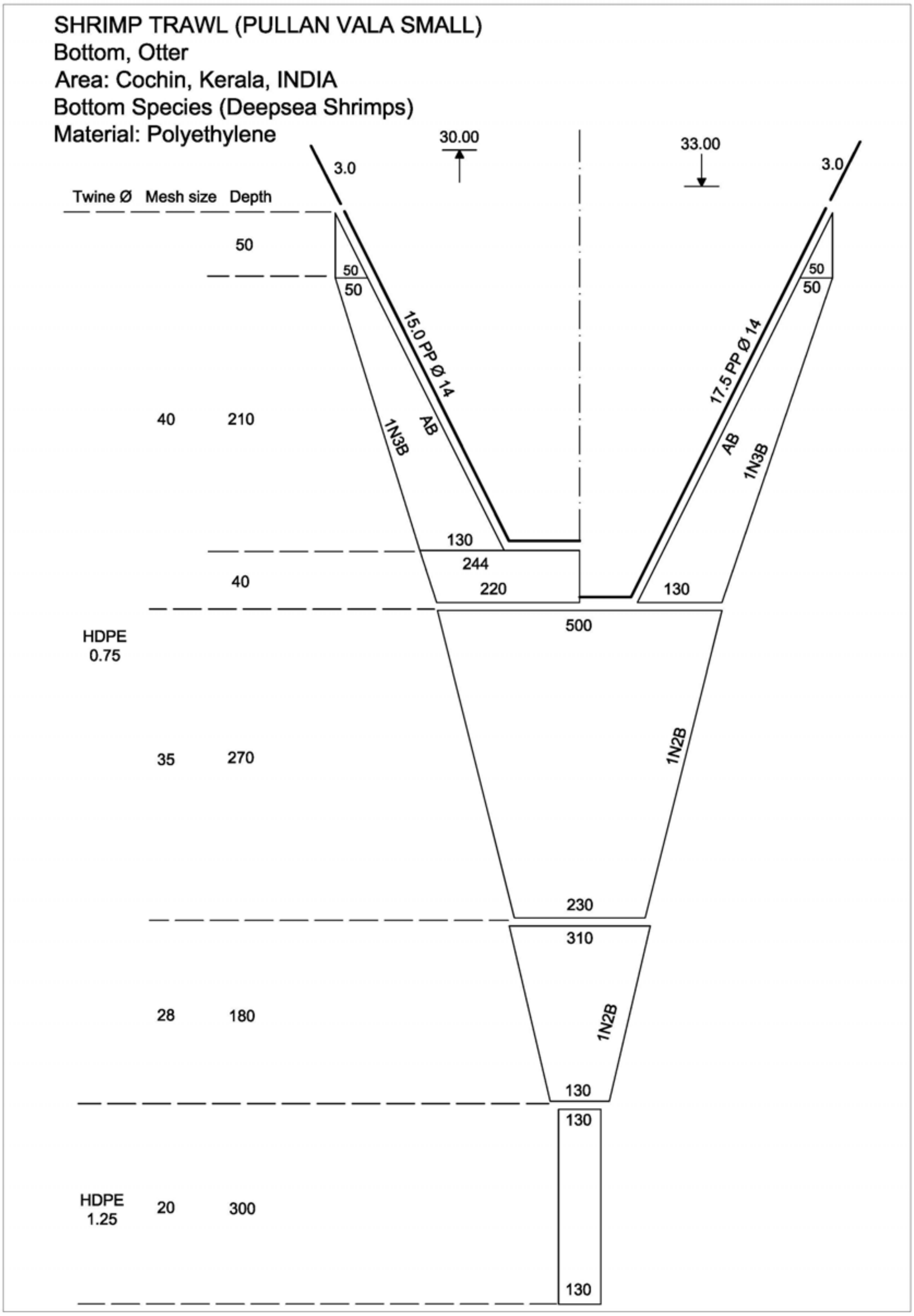


Fig. 4.16. Design of 30.0 m deep-sea shrimp trawl (Cochin center)

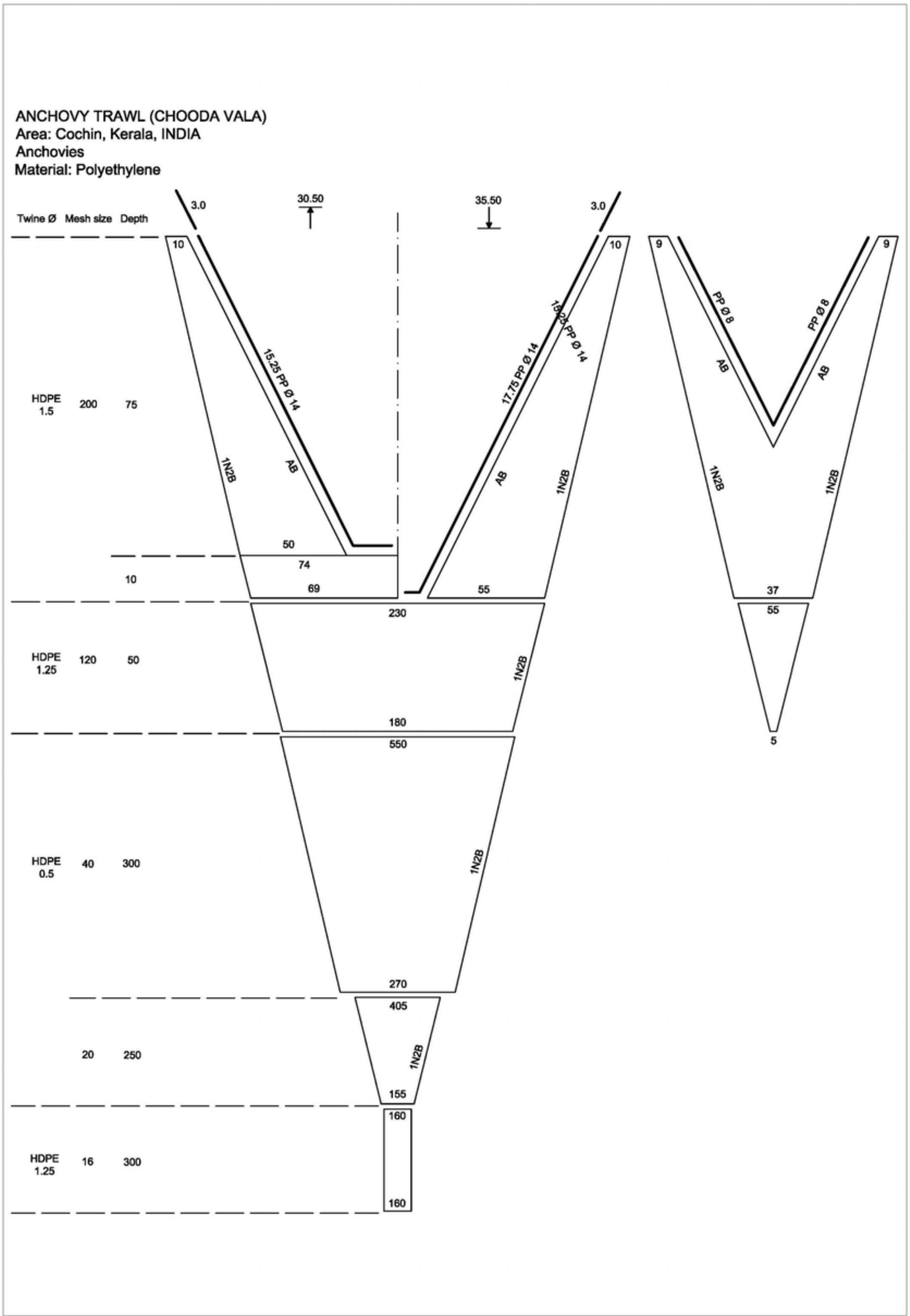


Fig. 4.17. Design of 30.5 m fish trawl (Munambam center)

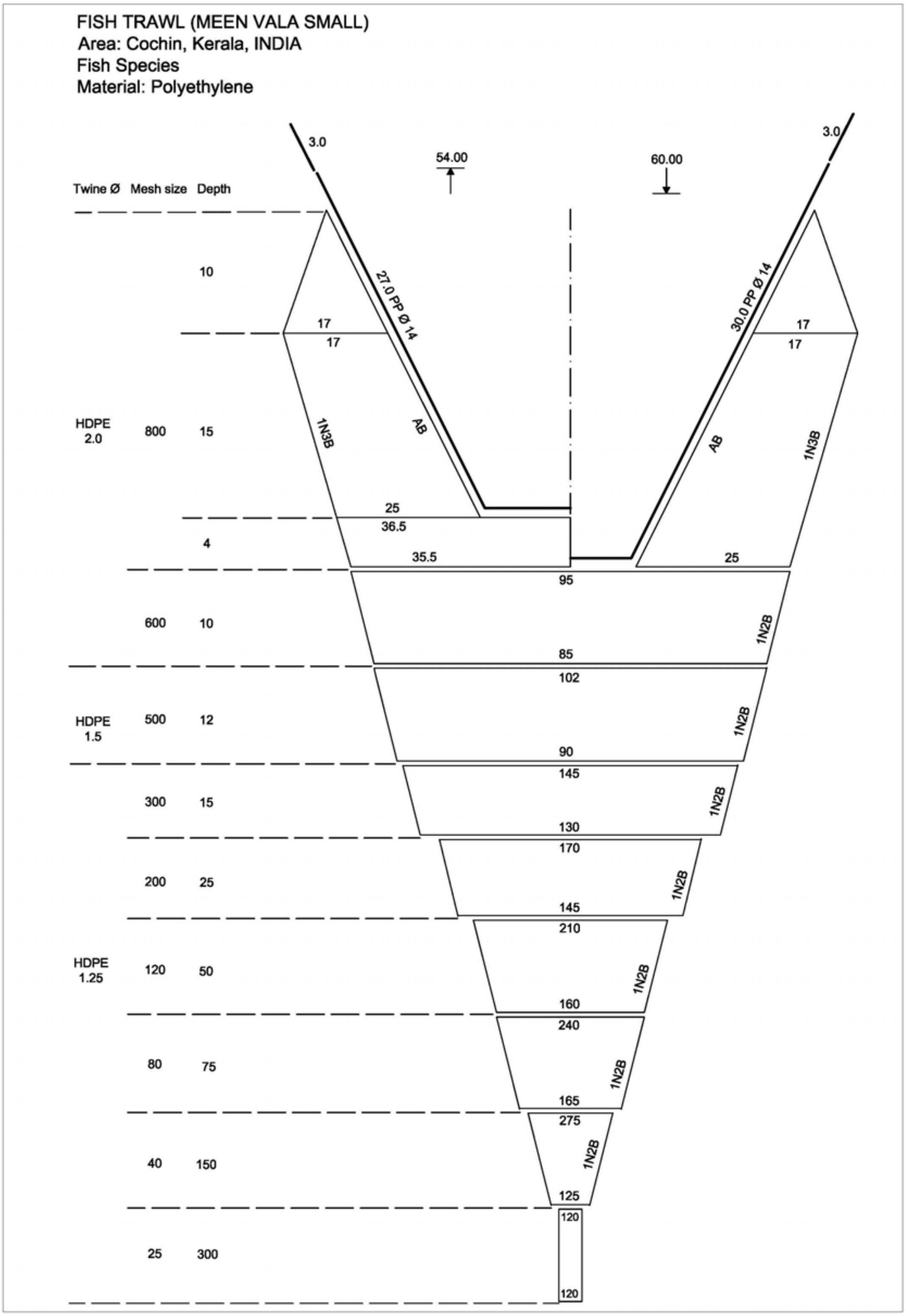


Fig. 4.18. Design of 54.0 m fish trawl (Cochin center)

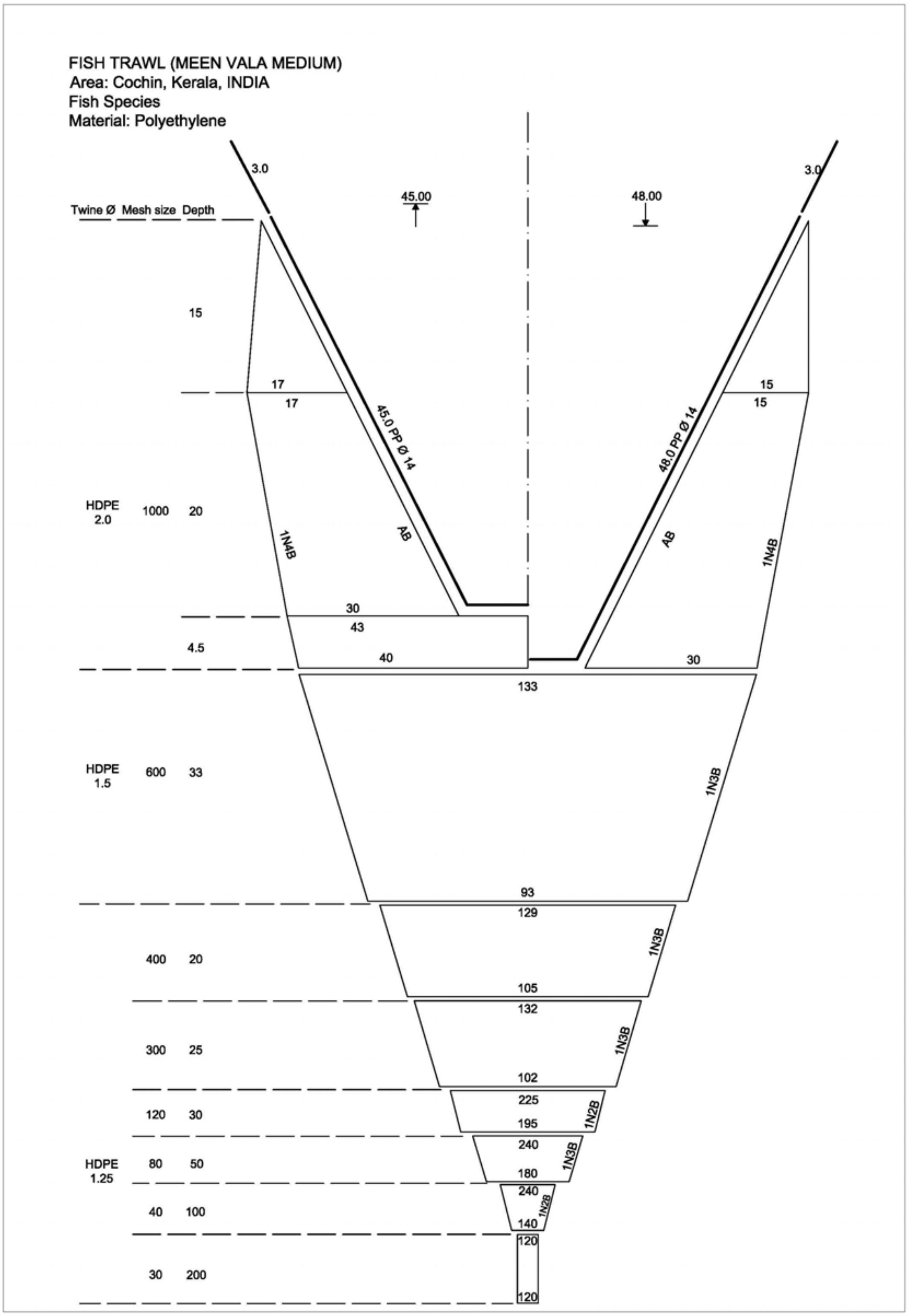


Fig. 4.19. Design of 45.0 m fish trawl (Cochin center)

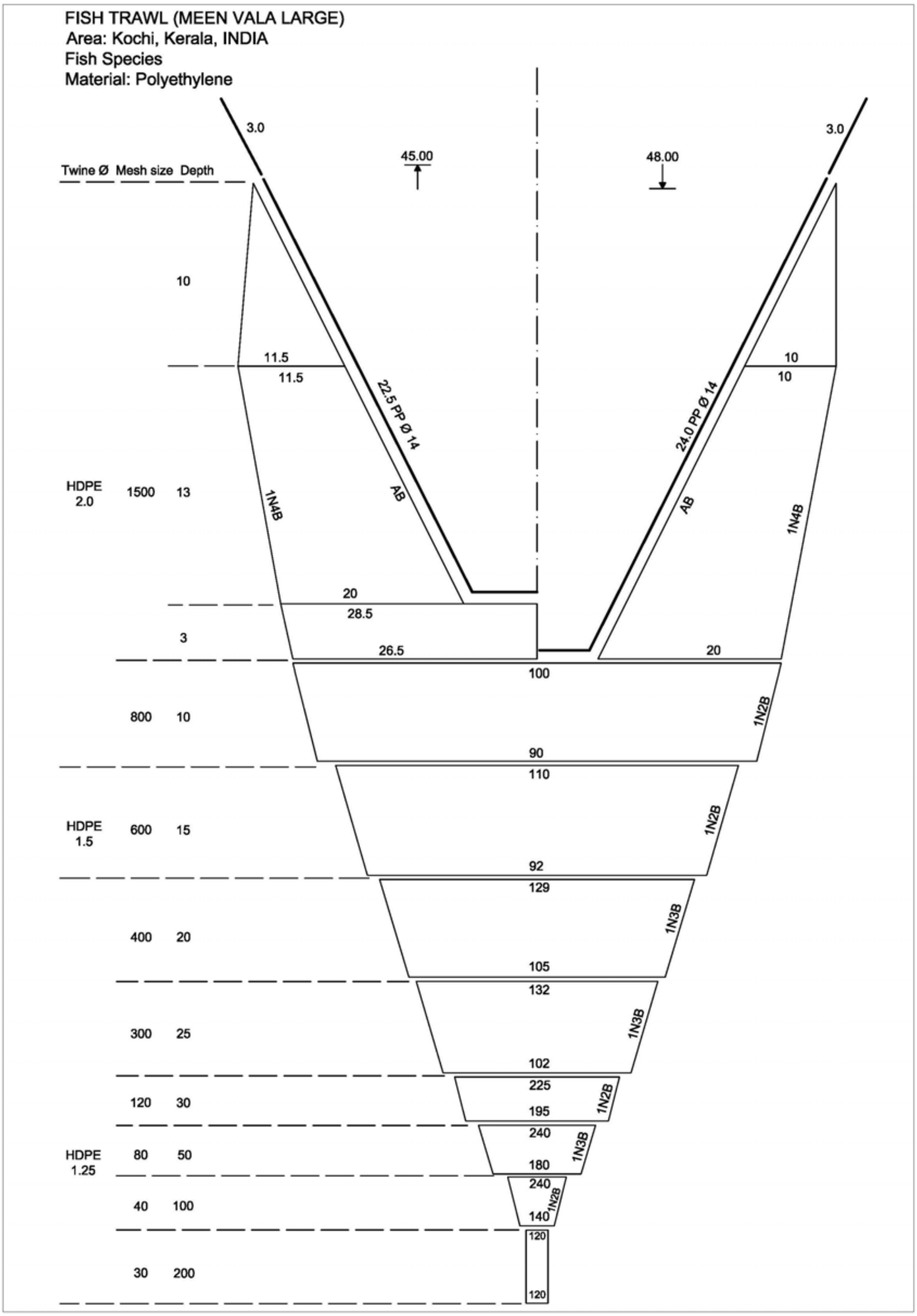


Fig. 4.20. Design of 45.0 m fish trawl (Cochin center)

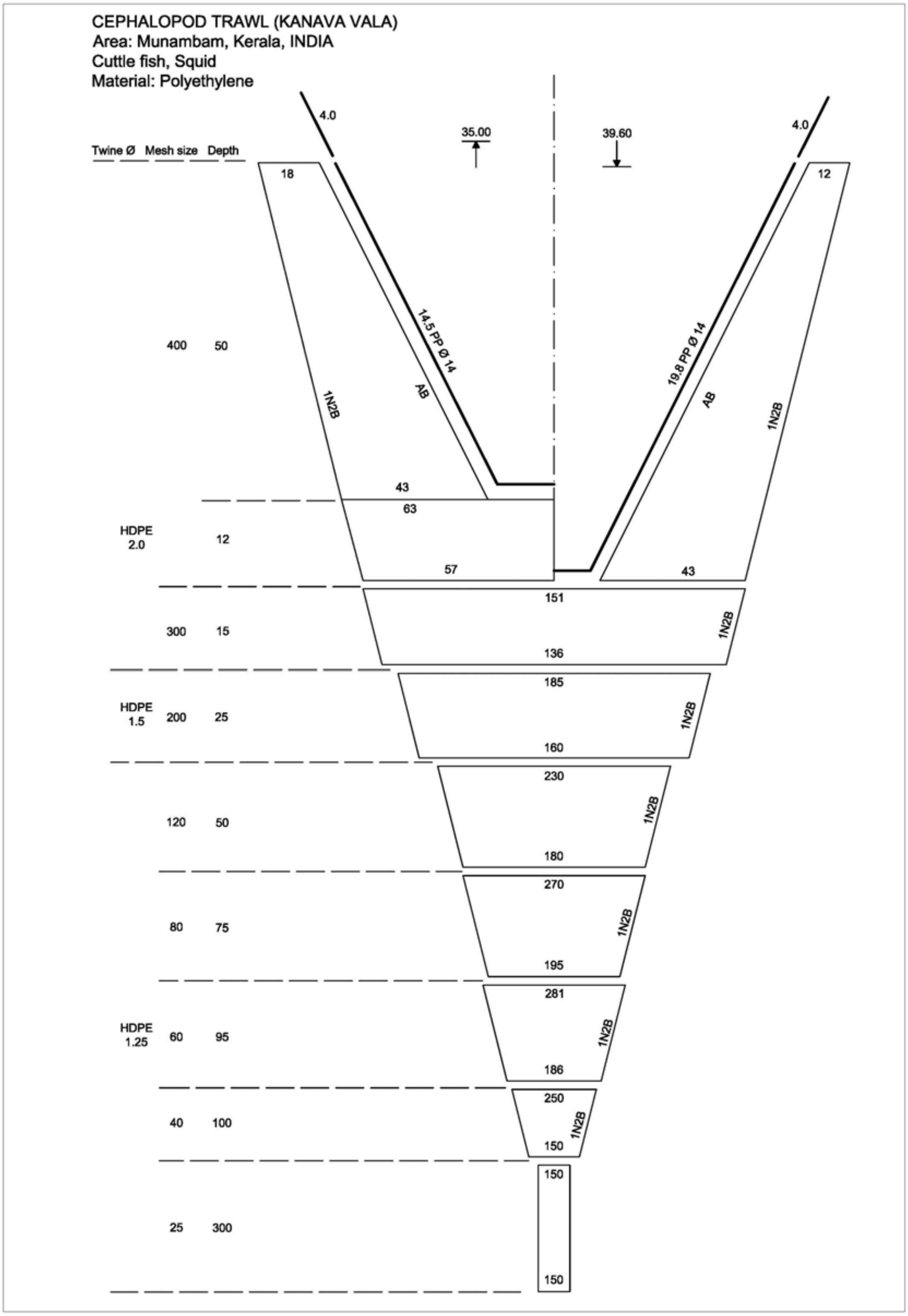


Fig. 4.21. Design of 35.0 m cephalopod trawl (Munambam center)

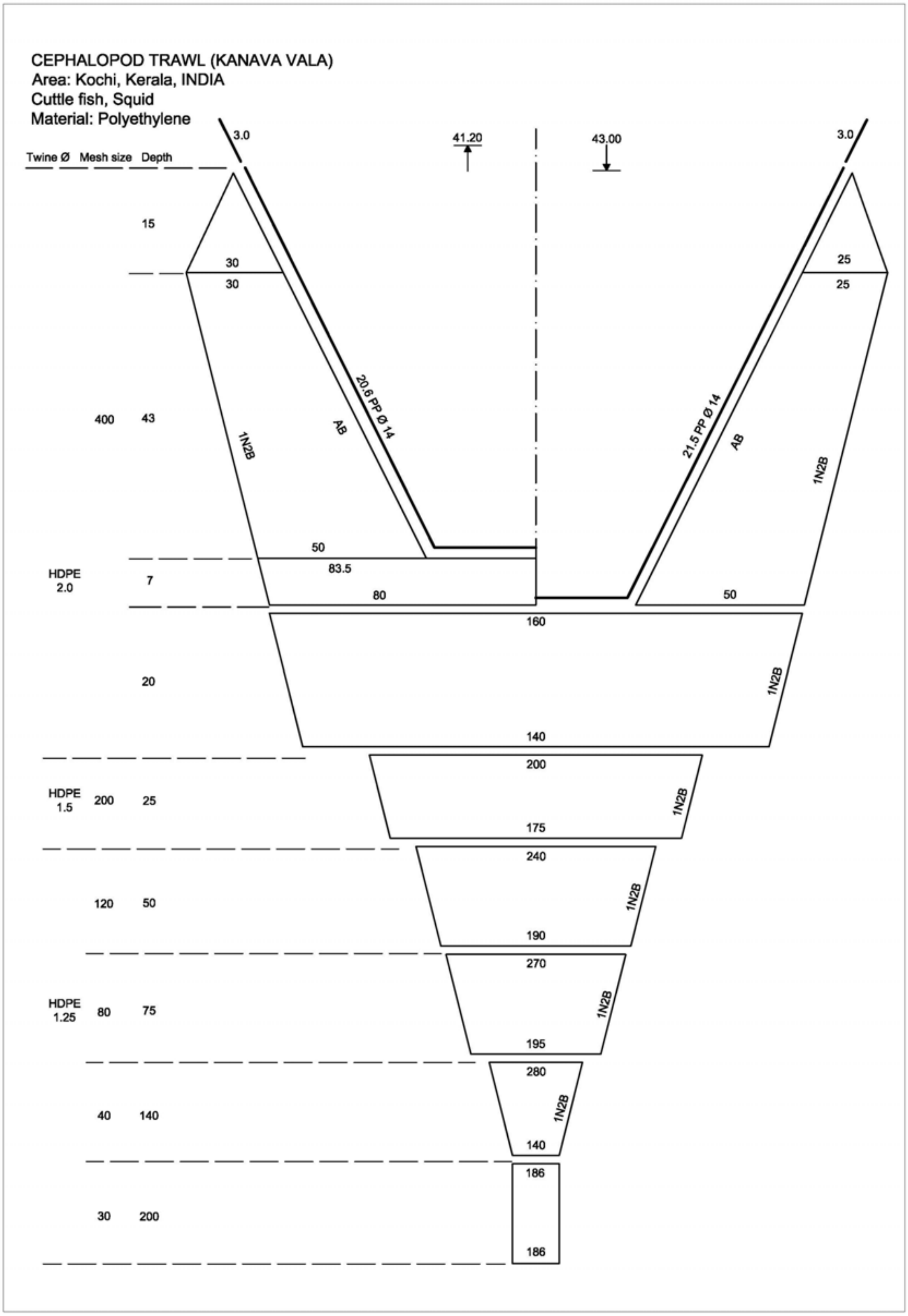


Fig. 4.22. Design of 35.0 m cephalopod trawl (Cochin center)

4.4.3. Materials and accessories used in trawl net

The important materials used for making trawl net are High Density Polyethylene (HDPE) netting. Steel wire ropes (SWR) are used as towing warps. Aluminuim floats earlier preferred by the trawlers are now replaced almost entirely by HDPE floats. Earlier single eyed floats are used in trawl nets. Currently 2-eyed floats are used, which is manufactured by a number of Indian Companies. Floats having various diameters (15 cm, 20 cm, 25 cm, 30 cm, 35 cm) are used in trawl nets.

Sinkers are usually made of lead and are available in 25 g, 30 g, 50 g, 100 g and 200 g. Cast iron is also used in some cases. Chain is not preferred by most of the net makers since it corrodes rapidly and the corrosion products can cause damage to the netting. During operation fishermen adjust the weight of the foot rope by tying iron link chains, if found necessary depending on depth of fishing and species targeted. For deep-sea trawling tickler chain is invariably used. Currently heavy duty rubber sinkers or bushes, each weighing about 650 g, are commonly used in bottom trawls. A commercial retail outlet for trawl accessories is shown in Fig. 4.23.

Polypropylene ropes are commonly used for bridles, hauling rope, centre rope, head and foot-ropes etc. Views of net making centers and net making materials are given in Fig. 4.24 and Fig. 4.25.

4.5. Discussion and Conclusion

The trawl fisheries in the central Kerala has developed greatly in recent years and in density it has got second position next to Kollam area (Gibinkumar et al., 2005; Sabu et al., 2005; Kurup and Rajasree, 2007). Due to diminishing returns from the traditional fishing grounds, the trawler owners were compelled to construct larger trawlers to explore deeper waters and for conducting multiday fishing. During the period of study, most of the trawlers in central Kerala were engaged in multi-day and multi-species fishing, using diverse designs of trawl nets. A gradual shift in the selection of boat materials was also observed and the most preferred boat building material is steel rather than wood for all the new constructions.

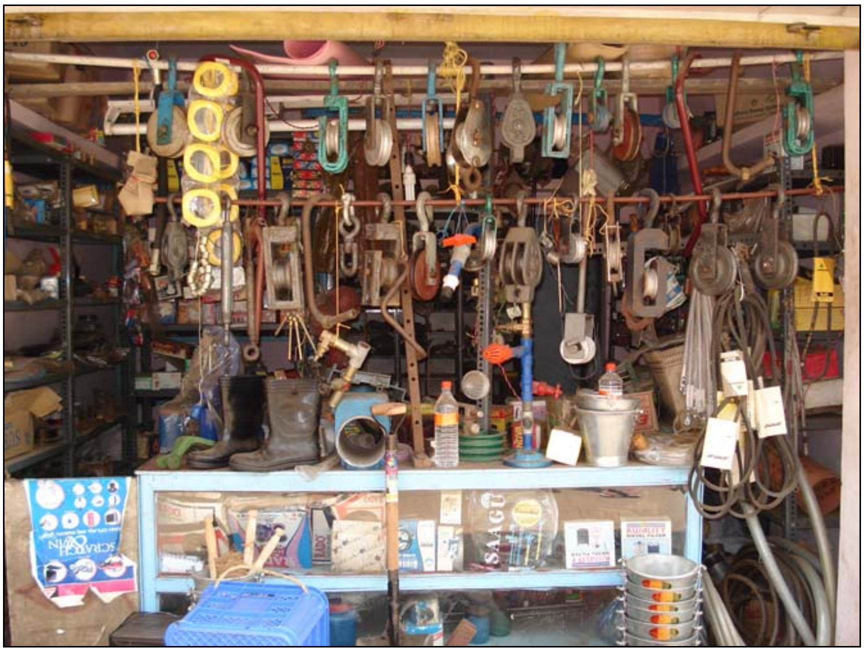


Fig. 4.23. A view of the retail outlet for trawl accessories

Fig. 4.24. Views of net making

Fig. 4.25. HDPE netting and Polypropylene ropes

Significant changes have been observed in the designs and diversity of trawl nets compared to earlier studies (Mukundan and Hameed, 1993). The mouth opening of the nets has increased and netting with larger meshes was used in the front panel sections of the fish trawls. The trawlers used to carry a wide variety of trawl nets (about 8-15 nets) during their fishing trips with an intention to catch all available and commercially important species.

During the study, 13 different designs of trawl nets were observed. These included 12 two-seam designs and one four-seam fish trawl design. Multi-seam designs are gaining popularity among the fishermen in central Kerala, especially in Munambam for targeting fishes. Bycatch tended to contribute a reasonable share in the income of the trawlers. Many industries utilizing the bycatch have been established in Cochin and adjacent areas. Small and medium trawler are bringing some part of their bycatch for the raw material suppliers of fish meal factories located in other states. Certain bycatch species such as Japanese threadfin bream, lizard fishes and some deep sea fishes are gaining market due to their demand in surimi plants. Bycatch may result in many biological, ecological, environmental and economic problems mainly because of the fact that about 40% of the bycatch in this area is comprised of juveniles and sub-adults (Pillai, 1998). The use of bycatch reduction devices is non-existent among the trawl fishermen of central Kerala. Since trawlers are the major contributors of bycatch in India, a combined effort on the part of research institutions, industry and Government must be focused on this issue in order to accelerate the efforts towards its mitigation.

Chapter 5

Bycatch Characterisation of Trawl Catch off Cochin

5.1. Introduction

Bycatch and discards are the common problem faced by all fisheries globally and it is a major component of impact of fisheries on marine ecosystems. Bycatch was closely associated with fishing from the very beginning of the commercial fishing operations and it presented some unique problems to the fishery managers. The changing perspective of bycatch itself offers the greatest challenge, as yesterday's bycatch becomes today's target catch (Boyce, 1996).

5.2.Bycatch in Indian fisheries

In tropical countries like India, bycatch issue is more complex due to the multi-species nature of the fisheries. Central Marine Fisheries Research Institute attempted to estimate bycatch associated with shrimp trawling in 1979-80 period and showed that 79.18% of total landings are represented as bycatch (George et al., 1981). In 1980, the bycatches formed about 55% of the total trawl landings at Shakthikulangara and 56% at Cochin (George et al., 1981). According to Sukumaran et al. (1982) shrimps contribute only 13% of average annual trawl catches from Malpe and Mangalore in Karnataka state (India) during 1980-82 and the trawl bycatch was as high as 85% during this period. Rao (1988) reported that the quantity of bycatch discarded in Visakhapatnam (India) depends on the demand for finfishes in the external and domestic markets. Gordon (1991) estimated the bycatch levels in India as part of Bay of Bengal Programme of FAO. He estimated the bycatch level in east-coast shrimp trawlers at about 90% of total catch and the quantity of bycatch being discarded by the trawlers was estimated to be 100,000-130,000 tonnes in 1988. Menon (1996) estimated a quantity of 43,000 tonnes of bycatch has been landed by trawlers in Kerala, Karnataka and Tamil Nadu states (India). Further studies conducted by CMFRI in 1999 revealed that the bycatch ratios along the southwest and southeast regions of India are 1:4.6 and 1:2.6 respectively (Menon et al., 2000).

In 2001-02 estimates of bycatch by Zacharia et al. (2005) in Karnataka state (India), quantity of trawler bycatch is 56,083 t (54.4% of total catch) in 2001 and 52,380 t (47.9%) in 2002. The quantity of discards was 34,958 t (33.9%) in 2001 and 38,318 t (35.1%) in 2002. In Kerala state (India), quantity of discards was estimated at 2,62,000 t during 2000-2001 and 2,25,000 t during 2001-2002 (Kurup et al., 2003; 2004).

The diversity of species found in tropical waters is the main cause of the higher magnitude of discards found there and in tropical regions the trawl nets used to catch over 400 species in their nets (EJF, 2003). Menon (1996) studied the bycatch landings of trawlers in Karnataka, Kerala and Tamil Nadu during 1985-90 and recorded 20 genera of fishes, 26 genera of crustaceans, 23 genera of gastropods, 15 genera of bivalves, 10 genera of echinoderms, polychaetes, anemones, sponges, gorgonids, ascidians and echiuroids, besides a large number of juveniles of fishes and cephalopods. Studies on the impact of bottom trawling on the ecology of fishing grounds and living resources of the Palk Bay and the Gulf of Mannar have shown the presence of 185 species in the bycatch, represented mainly by ground fish, stomatopods, shrimps, gastropods, bivalves, crabs, echinoderms, sea weeds and sea grass (CMFRI, 2002). Kurup et al. (2003) observed that the discards from bottom trawlers of Kerala coast were represented mainly by epifaunal species and juveniles of commercially valuable species and the discards were represented by 103 species of finfishes, 65 gastropods, 12 bivalves, 8 shrimps, 2 stomatopods, 12 crabs, 5 cephalopods, 3 echinoderms and 4 jellyfishes. Though discarding of bycatch is practiced in the case of multi day trawling, its magnitude and species composition is not properly assessed. A comprehensive study that includes landed bycatch and at-sea discards will only reveal the complete picture of the impact on the biodiversity caused by the bottom trawling.

With the decline of the shrimp catch the bycatches began to contribute significantly to the overall income of the shrimp trawlers (Clucas, 1998). Along the west-coast of India, especially in Gujarat, most of the bycatch is landed and utilized for fishmeal and manure production (IIM, 2003; Zynudheen et al., 2004;

Kumar and Deepthi, 2006). It is significant to note that among the bycatch about 40% consisted of juveniles and those in the early stages of development, which are invariably discarded leading to the depletion of the resources (Pillai, 1998; Pillai et al., 2004).

5.3. Objectives of the Study

Checklist on bycatch constituents is helpful in improving the knowledge regarding the biodiversity of the region and is an important tool for fisheries management. It also contributes to knowledge of distribution of non-conventional species, which are poorly represented in the catch statistics based on commercial landings (Sujatha, 1995). Greater efforts have occurred in recent years, to document the body of scientific data concerning quantities of bycatch, levels of discards, survival of discards, impacts of losses resulting from discards on target and non-target marine populations and bycatch mitigation measures. However, still there is a paucity of information on bycatch and bycatch reduction technologies in the context of Indian fisheries. In this study, a detailed investigation on the bycatch issues and concerns in trawl fishing, off Central Kerala (India) was attempted.

5.4. Materials and Methods

The study was conducted for a period one year from January 2006 to December 2006. Samples of bycatch were collected from the traditional trawling areas in coastal waters off Cochin at a depth ranging between 9 - 32 m (Fig. 3.1). The shrimp trawls were fabricated according to the traditional designs prevailing in the area and trawling operations were conducted from research vessels of Central Institute of Fisheries Technology, MFB Matsyakumari (17.5 m L_{OA}; 277 bhp @ 1000 rpm) and MFV Sagar Shakti (15.24 m L_{OA}; 223 bhp @ 1800 rpm). The duration of trawling varied from 0.75 to 2.0 h.

Catch components were identified up to species level using recent fish taxonomic works and revisions (Allen and Steene, 1987; Allen and Steene, 1994; Apte, 1998; Day, 1958a; Day, 1958b; Fernando and Fernando, 2002; Migdalski and Ficher, 1977; MPEDA, 1998; Wheeler, 1985), FAO species identification sheets (FAO, 1984) and online species identification websites (www.fishbase.org; www.cephbase.org, www.indian-ocean.org, www.gastopods.com, www.shellmuseum.org and www.seashells.org). After sorting the catch to the species level, weight and numbers were noted. In the case of large quantities sub-samples were used for analysis. The quantity of bycatch was obtained after subtracting the quantity of commercial size groups of shrimps from the total catch.

PRIMER software package (Version 5.2.9; Plymouth marine Laboratory, Plymouth, UK) was used for SIMPER analysis, plotting k-dominance curves, and estimating diversity indices such as total number of species (S), Margalef richness (d), Pielou's evenness (J'), Brillouin index (H), Shannon index (H'), Simpson's dominance index (λ'), Hill number (N1), taxonomic diversity (Δ), taxonomic distinctness (Δ*) average phylogenetic diversity index (Phi+) and total phylogenetic diversity index (sPhi+). Simpson's evenness measure ($E_{1/D}$) was calculated using MS Excel by dividing reciprocal of Simpson's dominance index with total number of species (S) in the sample.

5.5. Results and Discussion

In Central Kerala small trawlers (<12 m L_{OA}) generally do not operate beyond 50 m depth because they are interested mainly in the exploitation of the penaeid shrimps available in the coastal waters. Trawlers above 12 m L_{OA} are operated in deeper waters for upto 300 m and do multi-day fishing with trip duration up to 15 days. Most of the species occurring in this region are represented in the low value bycatch landed by the trawlers. Views of unsorted catch, targeted catch and incidental catch are presented in Fig. 5.1, Fig. 5.2 and Fig. 5.3 respectively. Views of bycatch of finfishes, juveniles, shells and miscellaneous species are presented in Fig. 5.4, Fig. 5.5, Fig. 5.6 and Fig. 5.7 respectively.

5.5.1. Bycatch characterisation

During the period observations, 282 species of marine organisms were encountered in the trawl nets (Table. 5.1). The catches includes 191 species of finfishes, 11 species of shrimps, 3 species of lobsters, 13 species of crabs, 11 species of cephalopods, 45 species of molluscan shells, 2 species of echinoderms, 2 species jellyfishes, 2 species stomatopods and one species each sea snake and sea turtle. Finfishes belonged to 12 orders and 59 families and 109 genera. 11 shrimp species belonged to 4 families and 13 crab species belonged to 4 families. 11 cephalopod species belonged to 3 orders and 3 families. Molluscan shells comprised of 45 species belonged to 22 families and jellyfishes belonged to 2 families. Results of studies on bycatch characterisation are summarized in Fig. 5.8 to 5.14 and Tables 5.1 to 5.3

The catch per unit effort was found to be higher before monsoon in the month of March and after monsoon during the months of September, October and November (Fig. 5.8). The CPUE was found to be low after March and throughout the monsoon periods. Monthly variation in number of species constituting the trawl bycatch is given in Fig. 5.9. The percentage of shrimp, which was the targeted catch of trawl fishing showed wide variations in landing from month to month. On an average shrimps constituted about 13% of total trawl catch, with a wide fluctuation between 0.04% and 48% (Fig. 5.10). Highest percentage of shrimp catch was recorded in the month of May and lowest catch was recorded in the month of July. Shrimp catch was comparatively low during the monsoon months of June, July and August. *Metapenaeus dobsoni* was available throughout the year except in July and *Parapenaeopsis stylifera* was available during April-May and September-December. The occurrence of jellyfishes was noticed from July onwards, with a peak period in September which then gradually diminished in the landings and disappeared after December. The occurrence of jellyfishes caused difficulties in trawling during these months and in heavily infested waters the nets would be filled within fifteen minutes of tow and causes damage to the fishing gear. The average bycatch percentage in Cochin waters during the year 2006 was about 87%. The lowest bycatch percentage was observed in the month of May and bycatch percentage as high as 99% was observed in the month of July.

Fig. 5.1. Views of unsorted catches from shrimp trawls

Fig. 5.2. Views of target catch of shrimp trawls

Fig. 5.3. Views of incidental bycatch of shrimp trawls

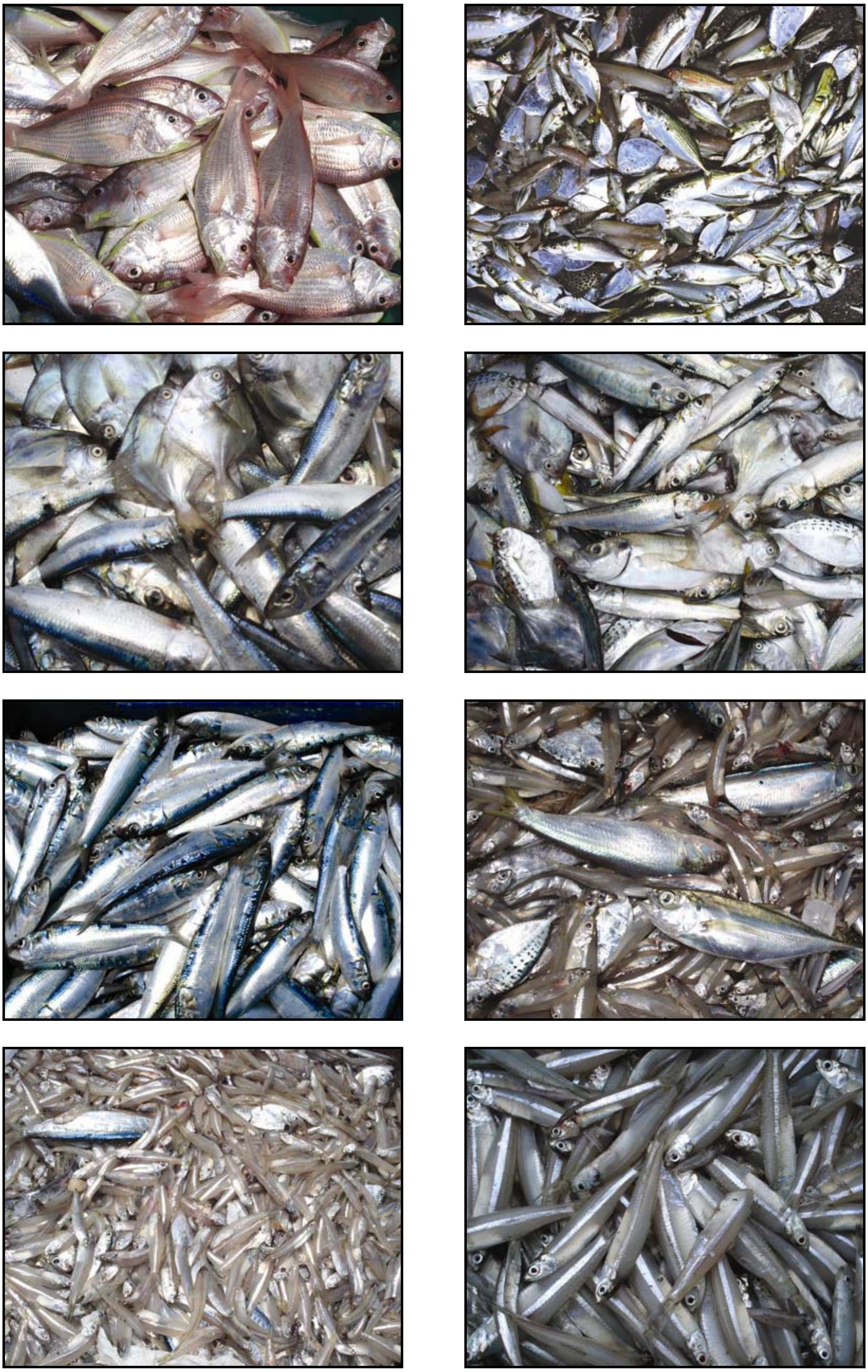
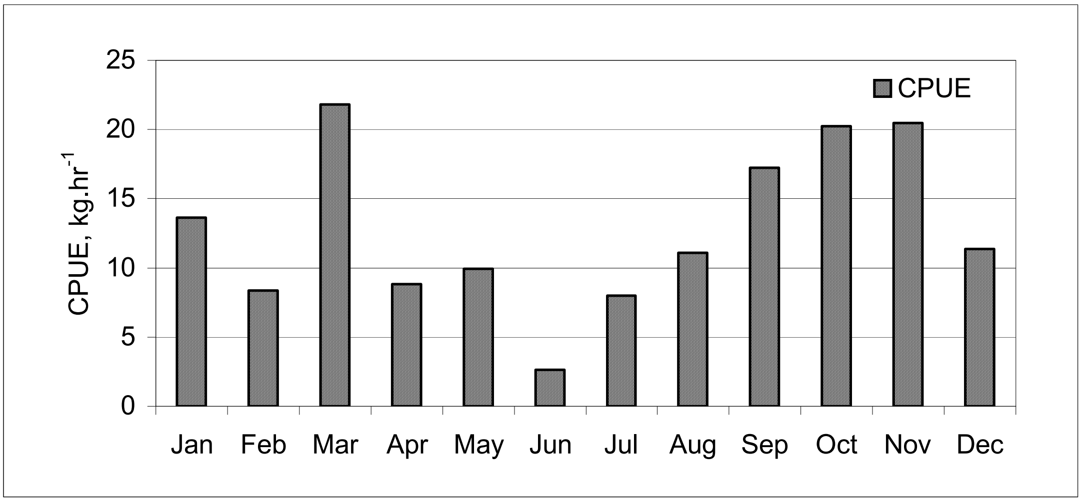


Fig. 5.4. Views of finfish bycatch of shrimp trawls

Fig. 5.5. Views of bycatch of juveniles

Fig. 5.6. Views of shell bycatch of shrimp trawls

Fig. 5.7. Views of bycatch of miscellaneous species



5.8. Monthly variation in CPUE of total catch (kg.h^{-1})

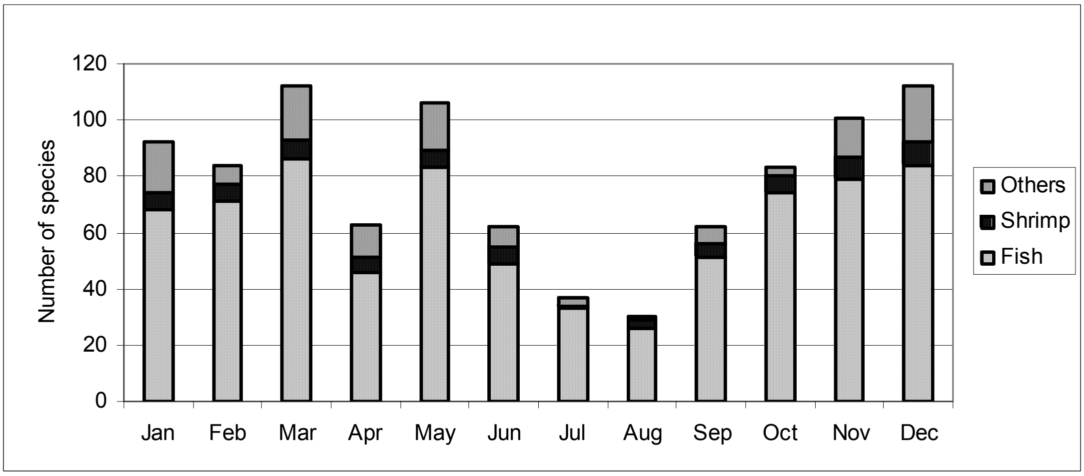


Fig. 5.9. Monthly variation in number of species in trawl landings

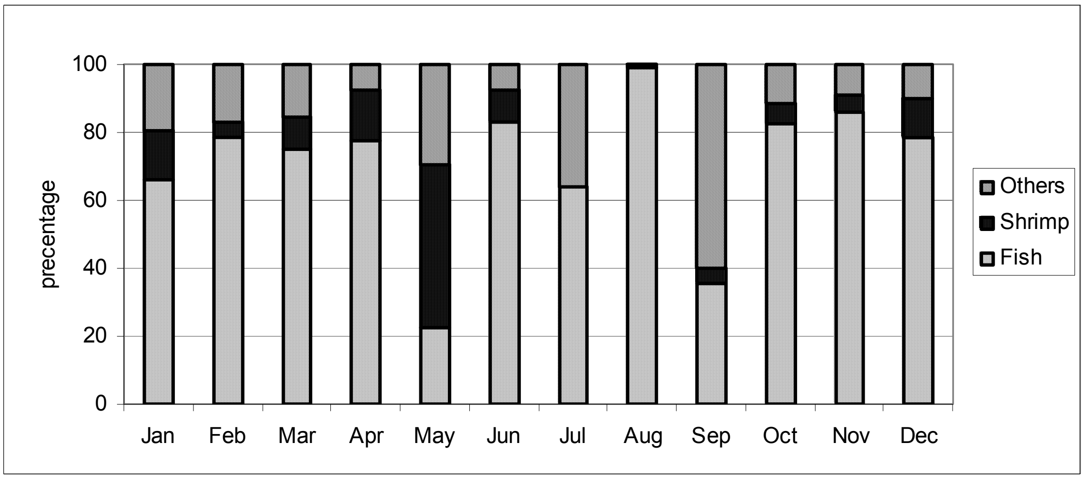


Fig. 5.10. Monthly variation in catch composition of trawl landings

Table. 5.1. List of species occurring in trawl catches in Cochin area

FINFISHES

Order : **RAJIFORMES**

Family : **Dasyatidae**

1. *Dasyatis kuhlii* (Muller & Henle, 1841)
2. *Himantura bleekeri* (Blyth, 1860)
3. *Himantura uarnak* (Forsskal, 1775)
4. *Himantura gerrardi* (Gray, 1851)

Family : **Myliobatidae**

5. *Aetobatus narinari* (Euphrasen, 1790)

Order : **CARCHARHINIFORMES**

Family : **Carcharhinidae**

6. *Rhizoprionodon acutus* (Ruppell, 1837)
7. *Scoliodon laticaudus* (Muller & Henle, 1838)

Family : **Sphyrnidae**

8. *Eusphyra blochii* (Cuvier, 1816)
9. *Sphyrna zygaena* (Linnaeus, 1758)

Order : **ANGUILLIFORMES**

Family : **Congridae**

10. *Uroconger lepturus* (Richardson, 1845)

Family : **Ophichthidae**

11. *Pisodonophis cancrivorus* (Richardson, 1848)
12. *Leiuranus semicinctus* (Lay & Bennett, 1839)
13. *Lamnostoma orientalis* (Mc Clelland, 1844)

Family : **Muraenesocidae**

14. *Congresox talabonoides* (Bleeker, 1853)

Order : **CLUPEIFORMES**

Family : **Chirocentridae**

15. *Chirocentrus dorab* (Forsskal, 1775)
16. *Chirocentrus nudus* (Swainson, 1839)

Family : **Clupeidae**

17. *Anodontostoma chacunda* (Hamilton, 1822)
18. *Dussumieria acuta* (Valenciennes, 1847)
19. *Escualosa thoracata* (Valenciennes, 1847)
20. *Opisthopterus tardoore* (Cuvier, 1829)
21. *Sardinella albella* (Valenciennes, 1847)
22. *Sardinella fimbriata* (Valenciennes, 1847)
23. *Sardinella gibbosa* (Bleeker, 1849)

24. *Sardinella longiceps* (Valenciennes, 1847)

Family : **Pristigasteridae**

25. *Ilisha elongate* (Anonymous [Bennett], 1830)
26. *Ilisha filigera* (Valenciennes, 1847)
27. *Pellona ditchella* (Valenciennes, 1847)

Family : **Engraulidae**

28. *Encrasicholina devisi* (Whitley, 1940)
29. *Encrasicholina heteroloba* (Ruppell, 1837)
30. *Encrasicholina punctifer* (Fowler, 1938)
31. *Stolephorus commersonnii* (Lacepede, 1803)
32. *Stolephorus indicus* (Van Hasselt, 1823)
33. *Stolephorus insularis* (Hardenberg, 1933)
34. *Stolephorus waitei* (Jordan & Seale, 1926)
35. *Thryssa dussumieri* (Valenciennes, 1848)
36. *Thryssa kammalensis* (Bleeker, 1849)
37. *Thryssa malabarica* (Bloch, 1795)
38. *Thryssa mystax* (Bloch & Schneider, 1801)
39. *Thryssa purava* (Hamilton, 1822)
40. *Thryssa setirostris* (Broussonet, 1782)

Order : **SILURIFORMES**

Family : **Ariidae**

41. *Arius arius* (Hamilton, 1822)
42. *Arius jella* (Day, 1877)
43. *Arius sona* (Hamilton, 1822)
44. *Arius maculatus* (Thunberg, 1792)
45. *Arius caelatus* (Valenciennes, 1840)
46. *Arius thalasinus* (Ruppell, 1837)

Family : **Plotosidae**

47. *Plotosus lineatus* (Thunberg, 1787)

Family : **Synodontidae**

48. *Saurida undosquamis* (Richardson, 1848)
49. *Saurida tumbil* (Bloch, 1795)

Order : **SYNGNATHIFORMES**

Family : **Fistularidae**

50. *Fistularia petimba* (Lacepede, 1803)

Order **SCORPAENIFORMES**

Family : **Scorpaenidae**

51. *Pterois volitans* (Linnaeus, 1758)
52. *Pterois russelli* (Bennett, 1831)

Family : **Platycephalidae**

53. *Platycephalus indicus* (Linnaeus, 1978)

54. *Grammoplites scaber* (Linnaeus, 1758)
55. *Thysanophrys celebica* (Bleeker, 1854)
56. *Cociella crocodila* (Tilesius, 1812)

Family : **Dactylopteridae**

57. *Dactyloptena macracantha* (Bleeker, 1854)

Family : **Synanceiidae**

58. *Minous monodactylus* (Bloch & Schneider, 1801)
59. *Minous dempsterae* (Eschmeyer, Hallacher & Rama-Rao, 1979)
60. *Synanceia horrida* (Linnaeus, 1766)
61. *Leptosynanceia asteroblepa* (Richardson, 1844)

Order : **BERYCIFORMES**

Family : **Holocentridae**

62. *Myripristis adusta* (Bleeker, 1853)

Order : **PERCIFORMES**

Family : **Teraponidae**

63. *Terapon jarbua* (Forsskal, 1775)
64. *Terapon theraps* (Cuvier, 1829)
65. *Terapon puta* (Cuvier, 1829)
66. *Pelates quadrilineatus* (Bloch, 1790)

Family : **Serranidae**

67. *Epinephelus latifasciatus* (Temminck & Schlegel, 1842)
68. *Epinephelus diacanthus* (Valenciennes, 1828)
69. *Epinephelus merra* (Bloch, 1793)
70. *Epinephelus tauvina* (Forsskal, 1775)
71. *Epinephelus areolatus* (Forsskal, 1775)
72. *Epinephelus chlorostigma* (Valenciennes, 1828)

Family : **Priacanthidae**

73. *Priacanthus hamrur* (Forsskal, 1775)

Family : **Apogonidae**

74. *Apogon aureus* (Lacepede, 1802)
75. *Apogon fasciatus* (White, 1790)

Family : **Pomacentridae**

76. *Neopomacentrus sindensis* (Day, 1873)

Family : **Haemulidae**

77. *Pomadasys maculatum* (Bloch, 1793)

Family : **Lutjanidae**

78. *Lutjanus malabaricus* (Bloch & Schneider, 1801)
79. *Pinjalo pinjalo* (Bleeker, 1850)
80. *Lutjanus argentimaculatus* (Forsskal ,1975)

81. *Lutjanus lutjanus* (Bloch ,1790)

Family : **Lethrinidae**

82. *Lethrinus nebulosus* (Forsskal, 1775)
83. *Lethrinus ornatus* (Valenciennes, 1830)
84. *Lethrinus miniatus* (Bloch & Schneider, 1801)

Family : **Nemipteridae**

85. *Nemipterus japonicus* (Bloch, 1791)
86. *Nemipterus mesoprion* (Bleeker, 1853)

Family : **Gerreidae**

87. *Gerres oyena* (Forsskal, 1775)
88. *Gerres filamentosus* (Cuvier, 1829)
89. *Gerres erythrourus* (Bloch, 1791)
90. *Gerres limbatus* (Cuvier, 1830)

Family : **Mullidae**

91. *Upeneus sulphureus* (Cuvier, 1829)
92. *Upeneus vittatus* (Forsskal, 1775)
93. *Upeneus tragula* (Richardson, 1846)

Family : **Sillaginidae**

94. *Sillago sihama* (Forsskal, 1775)

Family : **Lactariidae**

95. *Lactarius lactarius* (Bloch & Schneider, 1801)

Family : **Sciaenidae**

96. *Johnius amblycephalus* (Bleeker, 1855)
97. *Johnius borneensis* (Bleeker, 1851)
98. *Johnius carouna* (Cuvier, 1830)
99. *Johnius carutta* (Bloch, 1793)
100. *Johnius dussumieri* (Cuvier, 1830)
101. *Kathala axillaris* (Cuvier, 1830)
102. *Nibea maculata* (Bloch & Schneider, 1801)
103. *Otolithes cuvieri* (Trewavas, 1974)
104. *Otolithes ruber* (Bloch & Schneider, 1801)
105. *Otolithoides biauritus* (Cantor, 1849)
106. *Protonibea diacanthus* (Lacepede, 1802)
107. *Daysciaena albida* (Cuvier, 1830)

Family : **Leiognathidae**

108. *Gazza minuta* (Bloch, 1795)
109. *Leiognathus bindus* (Valenciennes, 1835)
110. *Leiognathus brevirostris* (Valenciennes, 1835)
111. *Leiognathus daura* (Cuvier, 1829)
112. *Leiognathus dussumieri* (Valenciennes, 1835)
113. *Leiognathus elongatus* (Gunther, 1874)
114. *Leiognathus equlus* (Forsskal, 1775)
115. *Leiognathus splendens* (Cuvier, 1829)

116. *Secutor insidiator* (Bloch, 1787)
117. *Secutor ruconius* (Hamilton, 1822)

Family : **Carangidae**

118. *Alectis ciliaris* (Bloch, 1787)
119. *Alectis indicus* (Ruppell, 1830)
120. *Alepes djedaba* (Forsskal, 1775)
121. *Alepes kleinii* (Bloch, 1793)
122. *Atropus atropus* (Bloch & Schneider, 1801)
123. *Atule mate* (Cuvier, 1833)
124. *Carangoides armatus* (Ruppell, 1830)
125. *Carangoides malabaricus* (Bloch & Schneider, 1801)
126. *Carangoides oblongus* (Cuvier, 1833)
127. *Carangoides praeustus* (Anonymous [Bennett], 1830)
128. *Caranx ignobilis* (Forsskal, 1775)
129. *Caranx sexfasciatus* (Quoy & Gaimard, 1825)
130. *Decapterus russelli* (Ruppell, 1830)
131. *Gnathanodon speciosus* (Forsskal, 1775)
132. *Megalaspis cordyla* (Linnaeus, 1758)
133. *Parastromateus niger* (Bloch, 1795)
134. *Scomberoides lysan* (Forsskal, 1775)
135. *Scomberoides tala* (Cuvier, 1832)
136. *Scomberoides tol* (Cuvier, 1832)
137. *Selar crumenophthalmus* (Bloch, 1793)
138. *Trachinotus blochii* (Lacepede, 1801)
139. *Uraspis uraspis* (Gunther, 1860)

Family : **Polynemidae**

140. *Leptomelanosoma indicum* (Shaw, 1804)
141. *Eleutheronema tetradactylum* (Shaw, 1804)
142. *Filimanus heptadactyla* (Cuvier, 1829)
143. *Filimanus similis* (Feltes, 1991)

Family : **Sphyraenidae**

144. *Sphyraena forsteri* (Cuvier, 1829)
145. *Sphyraena jello* (Cuvier, 1829)
146. *Sphyraena obtusata* (Cuvier, 1829)
147. *Sphyraena barracuda* (Walbaum, 1792)

Family : **Gobiidae**

148. *Oxyurichthys paulae* (Pezold, 1998)
149. *Trypauchen vagina* (Bloch & Schneider, 1801)

Family : **Trichiuridae**

150. *Trichiurus lepturus* (Linnaeus, 1758)
151. *Lepturacanthus savala* (Cuvier, 1829)

Family : **Stromateidae**

152. *Pampus argenteus* (Euphrasen, 1788)
153. *Pampus chinensis* (Euphrasen, 1788)

Family : **Ambassidae**

154. *Ambassis ambassis* (Lacepede, 1802)
155. *Ambassis gymnocephalus* (Bloch, 1790)
156. *Ambassis commersonnii* (Cuvier, 1828)

Family : **Mugilidae**

157. *Mugil cephalus* (Linnaeus, 1758)
158. *Liza subviridis* (Valenciennes, 1835)
159. *Liza parsia* (Hamilton, 1822)
160. *Liza tade* (Forsskal, 1775)
161. *Valamugil speigleri* (Bleeker, 1858-59)
162. *Valamugil cunnesius* (Valenciennes, 1836)
163. *Chelon microlepis* (Smith, 1846)

Family : **Menidae**

164. *Mene maculata* (Bloch & Schneider, 1801)

Family : **Scatophagidae**

165. *Sactophagus argus* (Linnaeus, 1766)

Family : **Scombridae**

166. *Rastrelliger kanagurta* (Cuvier, 1816)
167. *Scomberomorus commerson* (Lacepede, 1800)
168. *Scomberomorus lineolatus* (Cuvier, 1829)
169. *Scomberomorus guttatus* (Bloch & Schneider, 1801)

Family : **Siganidae**

170. *Siganus canaliculatus* (Richardson, 1845)
171. *Siganus javus* (Linnaeus, 1766)

Family : **Acanthuridae**

172. *Acanthurus mata* (Cuvier, 1829)

Family : **Uranoscopidae**

173. *Uranoscopus marmoratus* (Cuvier, 1829)

Family : **Drepaneidae**

174. *Drepane punctata* (Linnaeus, 1758)

Family : **Pempheridae**

175. *Pempheris mangula* (Cuvier, 1829)
176. *Pempheris oualensis* (Cuvier, 1831)

Order : **BELONIFORMES**

Family : **Hemirhamphidae**

177. *Rhynchorhamphus georgii* (Valenciennes, 1847)

Order : **PLEURONECTIFORMES**

Family : **Samaridae**

178. *Samaris cristatus* (Gray, 1931)

Family : **Cynoglossidae**

179. *Cynoglossus arel* (Schneider, 1801)
180. *Cynoglossus bilineatus* (Lacepede, 1802)
181. *Cynoglossus macrostomus* (Norman, 1928)
182. *Cynoglossus dubius* (Day, 1873)

Family : **Soleidae**

183. *Zebrias quagga* (Kaup, 1858)

Family : **Paralichthyidae**

184. *Pseudorhombus arsius* (Hamilton, 1822)

Order : **TETRAODONTIFORMES**

Family : **Triacanthidae**

185. *Triacanthus biaculeatus* (Bloch, 1786)
186. *Triacanthus nieuhofii* (Bleeker, 1852)
187. *Pseudotriacanthus strigilifer* (Cantor, 1849)

Family : **Diodontidae**

188. *Cyclichthys orbicularis* (Boch, 1785)

Family : **Tetraodontidae**

189. *Lagocephalus spadiceus* (Richardson, 1845)
190. *Lagocephalus inermis* (Temminck & Schlegel, 1850)
191. *Chelonodon patoca* (Hamilton, 1822)

SHRIMPS

Order**: DECAPODA**

Family : **Penaeidae**

192. *Penaeus (penaeus) monodon* (Fabricus, 1798)
193. *Penaeus (penaeus) semisulcatus* (De Hann, 1844)
194. *Penaeus (Fenneropenaeus) indicus* (H Milne Edwards, 1837)
195. *Metapenaeus dobsoni* (Miers, 1878)
196. *Metapenaeus monoceros* (Fabricus, 1798)
197. *Metapenaeus affinis* (H Milne Edwards, 1837)
198. *Parapenaeopsis stylifera* (H Milne Edwards, 1837)
199. *Trachypenaeus curvirostris* (Stimpson, 1860)

Family : **Hippolytidae**

200. *Exhippolysmata ensirostris* (Kemp, 1914)

Family : **Sergestidae**

201. *Acetes indicus* (H Milne Edwards, 1830)

Family : **Alphidae**
202. *Alpheus malabaricus* (Fabricus, 1798)

LOBSTERS

Family : **Palinuridae**
203. *Palinurus homarus* (Linnaeus, 1758)
204. *Palinurus ornatus* (Fabricus)

Family : **Scyllaridae**
205. *Thenus orientalis* (Lund, 1793)

CRABS

Order **: DECAPODA**

Family **: Lucosidae**
206. *Philyra scabriuscula* (Fabricus, 1798)

Family **: Portunidae**
207. *Scylla serrata* (Forskal, 1775)
208. *Portunus sanguinolentus* (Herbst, 1783)
209. *Portunus pelagicus* (Linnaeus, 1766)
210. *Charybdis feriatus* (Linnaeus, 1758)
211. *Charybdis lucifeara* (Fabricus, 1798)
212. *Charybdis natator* (Herbst, 1789)
213. *Callapha lophos* (Herbst, 1782)
214. *Podophthalmus vigil* (Fabricus, 1798)

Family **: Calappidae**
215. *Matuta lunaris* (Fabricus, 1798)
216. *Matuta planipes* (Forskal, 1775)

Family **: Majidae**
217. *Dolcea ovis* (Herbst)
218. *Dolcea gracilipes* (Stimpson)

CEPHALOPODS

Order **: SEPIIDA**

Family **: Sepiidae**
219. *Sepia pharonis* (Ehrenberg, 1831)
220. *Sepiella inermis* (Van Hasselt, 1835)
221. *Sepia aculeata* (Orbigny, 1848)

Order : **TEUTHIDA**

Family : **Loliginidae**
222. *Uroteuthis (Photololigo) duvauceli* (Orbigny, 1835)
223. *Doryteuthis singalensis* (Ortmann, 1891)

Order : **OCTOPODA**

Family : **Octopodidae**

224. *Cistopus indicus* (Orbigny, 1848)
225. *Octopus dollfusi* (Robinson, 1928)
226. *Octopus membranaceous* (Quoy & Gaimard, 1832)
227. *Octopus globosus* (Appelof, 1886)
228. *Octopus vulgaris* (Lamark, 1798)
229. *Octopus aegina* (Gray, 1849)

STOMATOPODS

230. *Oratosquilla nepa* (Muller, 1994)
231. Squilla sp.

SHELLS

Family : **Arcidae**

232. *Barbatia (Merocibota) bistrigata* (Dunker, 1866)
233. *Anadara granosa* (Linnaeus, 1758)
234. *Anadara rhombea* (Born, 1780)
235. *Anadara inaequivalvis* (Bruguire, 1789)
236. *Scarpha inequalis*
237. *Trisodus turtuosa* (Linnaeus)

Family : **Babyloniidae**

238. *Babylonia spirata* (Linnaeus, 1758)
239. *Babylonia zeylanica* (Bruguire, 1789)

Family : **Bursidae**

240. *Bufonaria echinata* (Link, 1807)

Family : **Buccinidae**

241. *Cantharus spiratus* (Gray)

Family : **Turridae**

242. *Lophitoma indica* (Roding, 1798)
243. *Surcula amicta* (Smith)
244. *Surcula javana* (Linnaeus)

Family : **Veneridae**

245. *Marcia opima* (Gmelin, 1791)
246. *Meretrix casta* (Chemnitz)
247. *Meretrix meretrix* (Linnaeus, 1758)
248. *Paphia malabarica* (Chemnitz)
249. *Paphia textile* (Gmelin, 1798)
250. *Dosinia cretacea* (Reeve, 1851)
251. *Sonnata scripta* (Linnaeus, 1758)

Family : **Donacidae**

252. *Donax scrotum* (Linnaeus)

Family : **Ficidae**
253. *Ficus ficucs* (Linnaeus, 1758)
254. *Ficus gracilis* (Sowerby, G. B. I, 1825)

Family : **Harpidae**
255. *Harpa conoidalis* (Lamarck, 1843)

Family : **Muricidae**
256. *Murex carbonnieri* (Jousseaume, 1881)
257. *Murex virgineus* (Roding)

Family : **Fasciolariidae**
258. *Fusinus nicobaricus*

Family : **Naticidae**
259. *Natica lineata* (Roding, 1798)
260. *Natica vitellus* (Linnaeus, 1758)
261. *Natica didyma* (Roding, 1798)

Family : **Cassidae**
262. *Phalium canaliculatum* (Bruguire, 1792)
263. *Phalium bisulcatum* (Schubert & Wagner)

Family : **Pholadidae**
264. *Pholas orientalis* (Gmelin)

Family : **Cardiidae**
265. *Cardium flavum* (Linne)

Family : **Muricidae**
266. *Rapana rapiformis* (Born, 1778)
267. *Rapana bulbosa* (Born, 1778)

Family : **Strombidae**
268. *Tibia curta* (Sowerby)
269. *Strombus plicatus sibbaldi* (Sowerby)

Family : **Tonnidae**
270. *Tona dolium* (Linnaeus, 1758)

Family : **Turritellidae**
271. *Turitella acutangula* (Linnaeus)
272. *Turritella attenuata* (Reeve, 1849)

Family : **Volemidae**
273. *Hemifusus cochlidium* (Linnaeus)
274. *Hemifusus pulgilinus* (Born)

Family : **Patellidae**

275. *Umbonium vestiarium* (Linne)

Family : **Dentaliidae**
276. *Dentalium octangulatum* (Donovan)

ECHINODERMS

277. *Astropecten* spp
278. *Laganum depressum* (Lesson)

JELLYFISH

Family : **Catostylidae**
279. *Crambionella stulhamanni* (Chun)

Family : **Pelagidae**
280. *Aurelia solida* (Browne)

TURTLES

281. *Lepidochelus olivacea*

SEA SNAKES

282. *Aipysurus laevis*

5.5.2. Biodiversity analysis

The results of various diversity indices calculated are given in Table 5.2. All the indices showed highly significant differences among the various months. Indices regarding higher number of species (S) showed wide fluctuations among different months, but in general higher numbers of species were found during October-March. Maximum number of species was observed during the month of March (123) and the minimum number of species was observed during the month of April followed by July (36 and 37 respectively). The Margalef species richness (d) showed highest value (15.78) during March and due to the highest number of species observed in March, the Brillouin index was also found to be the maximum during this month. Comparatively species rich months were October, November, December and June with Margalef species richness value ranged between 12.2 and 13.4. It was also observed that in the monsoon months except in June species richness was low when compared to other seasons.

High values for Pieulou’s evenness (J’), Simpson’s evenness ($E_{1/D}$), Shannon-Wiener diversity index (H’ for log_2), Hill value (N1) and Taxonomic diversity (Δ) and low dominance index (λ') in the month of June, indicated highest biodiversity. The month of April was found to have the lowest biodiversity with lowest values for S, d, J', H, H'(log_2) and N1 and high dominance (λ') was also observed in this month.

Phylogenetic diversity index, which represents the taxonomic breadth of species present in various months, was calculated using the cumulative branch length of the full taxonomic tree drawn using Linnaean classification. Total Phylogenetic diversity index value, which is a modification of species richness indicates the species inter-relatedness and was found to be higher during March and minimum during July.

Table 5.2. Mean diversity indices of species during the year 2006

Month	S	d	J'	H	H'	N1	λ'	$E_{1/D}$	Δ	Δ*	Phi+	sPhi+
Jan	86	11.79	0.58	2.49	3.71	13.06	0.13	0.09	61.85	71.22	35.55	3057.14
Feb	77	10.80	0.41	1.72	2.58	5.97	0.29	0.04	52.72	74.51	31.91	2457.14
Mar	123	15.78	0.58	2.74	4.05	16.57	0.11	0.07	56.59	63.57	34.15	4200.00
Apr	36	4.59	0.24	0.83	1.24	2.36	0.70	0.04	23.26	76.47	39.29	1414.29
May	90	11.57	0.31	1.36	2.02	4.06	0.42	0.03	26.06	44.88	32.54	2928.57
Jun	64	13.41	0.78	2.72	4.67	25.41	0.06	0.28	63.18	66.98	34.60	2214.29
Jul	37	5.51	0.48	1.66	2.49	5.63	0.29	0.10	36.09	50.97	38.89	1400.00
Aug	42	5.29	0.28	1.04	1.53	2.89	0.60	0.04	21.64	53.51	35.71	1500.00
Sep	66	9.56	0.52	2.11	3.16	8.96	0.23	0.07	47.97	62.15	36.15	2385.71
Oct	85	12.25	0.63	2.71	4.06	16.72	0.11	0.11	59.25	66.21	34.29	2914.29
Nov	101	13.40	0.54	2.44	3.61	12.25	0.14	0.07	60.09	69.71	33.52	3385.71
Dec	92	13.31	0.45	1.94	2.95	7.71	0.25	0.04	52.13	69.08	34.63	3185.71

Highest values
Lowest values

In the dominance plot, in which the cumulative ranked abundances of species obtained in different months was plotted against species rank. The curve for June was lying on the lower side along with October, November, January and

March, which indicated comparatively higher biodiversity. The curves for April, May and August were more elevated indicating lower biodiversity during these months (Fig 5.11).

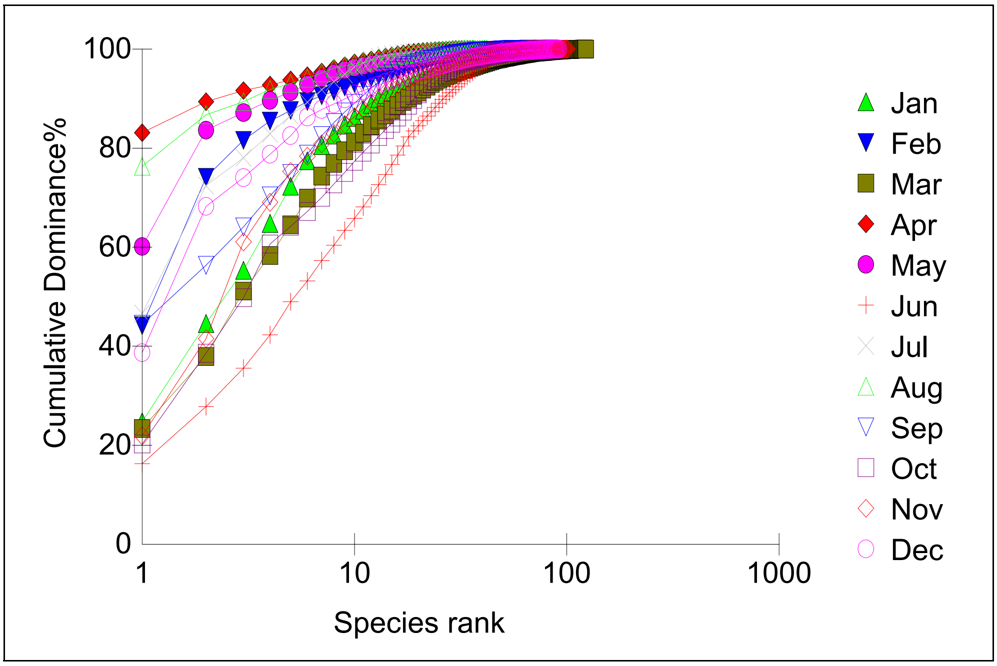


Fig 5.11. Month wise k-dominance plot for bycatch species in trawl landings

The similarity of species composition in different months was calculated by estimating the Bray-Curtis coefficient followed by the derivation of similarity matrix given as Table 5.3. Taking this matrix as the starting point a dendrogram in which the species in different months were clustered based on their similarity level was constructed (Fig 5.12). This type of hierarchical clustering was done by taking months representing the *x*-axis and *y*-axis defining the similarity level, which is used to group samples into discrete clusters. The dendrogram clearly revealed the separate grouping among different months but it did not reveal their interrelations on a continuous scale. The clustering of months into four distinct groups are clearly visible from the dendrogram, *viz*., [September, October], [April, May], [January, November] and [June, September, October]. July and August, with an average similarity of only 31.24% were the least bio-diverse months during the monsoon period and richest biodiversity was found during June, September and October months with similarities ranging from 36.81 to 56.38%. Apart from monsoon months, least biodiversity was found during the months of February, April and May with similarities ranging from 51.23 to 62.5%

and comparatively higher biodiversity was observed during January, March, November and December with similarities ranging from 44.5 to 63.57%.

Table 5.3. Bray-Curtis similarity for bycatch in trawl landings in various months

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	0	0	0	0	0	0	0	0	0	0	0	0
Feb	61.91	0	0	0	0	0	0	0	0	0	0	0
Mar	53.33	47.44	0	0	0	0	0	0	0	0	0	0
Apr	45.93	55.33	43.44	0	0	0	0	0	0	0	0	0
May	50.33	51.23	46.29	62.50	0	0	0	0	0	0	0	0
Jun	34.20	39.28	28.91	35.46	41.51	0	0	0	0	0	0	0
Jul	25.59	33.93	25.63	25.04	26.36	31.27	0	0	0	0	0	0
Aug	40.56	36.75	31.33	22.90	27.86	29.35	31.24	0	0	0	0	0
Sep	46.54	37.20	33.45	31.87	42.80	41.42	25.55	43.24	0	0	0	0
Oct	45.09	40.28	38.67	34.54	47.24	36.81	17.70	30.41	56.38	0	0	0
Nov	63.57	50.68	49.13	38.56	52.03	35.78	19.56	43.82	54.93	59.15	0	0
Dec	56.15	52.18	44.55	50.63	53.50	40.02	23.00	27.47	44.21	48.00	59.80	0

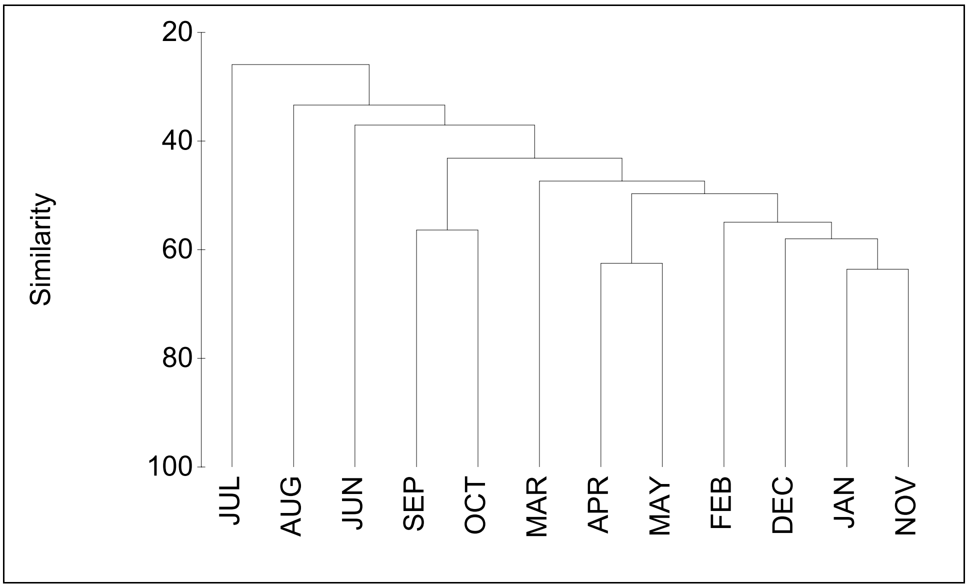


Fig. 5.12. Dendrogram showing the similarity grouping of months

This type of pattern was also evident in the MDS (non metric multi-dimensional scaling) plot (Fig 5.13) in which the samples are represented as points in two dimensional space such that the relative distances of all points are in the same rank order as the relative dissimilarities of the samples. The points that are close together represent samples that are similar in species composition and points that are far apart corresponds to different communities. The stress values were provided with the MDS corresponding to the ordination level of plot and amount of misleading interpretation. A MDS plot with stress value less than 0.05 can be considered for the most reliable interpretation of data and plots with stress values less than 0.2 can be considered to be potentially useful.

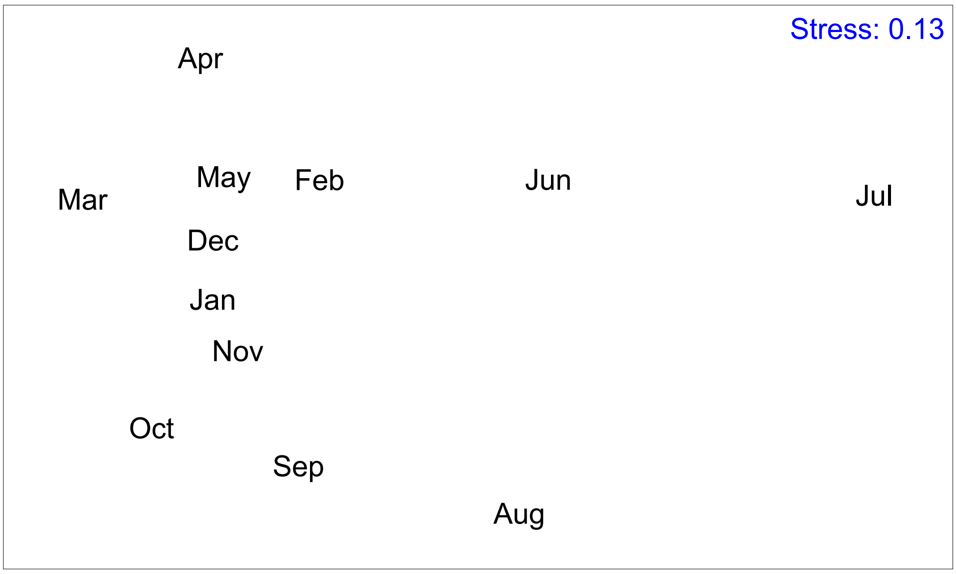


Fig. 5.13. MDS plot showing the similarity grouping of months

Bubble plots were obtained by superimposing the abundance data of a particular species in the MDS plot, and the abundance of that species in a particular sample can be directly understood by the size of the bubble. Bubble plots of some discriminating species such as *Metapenaeus dobsoni, Parapenaeopsis stylifera, Sardinella longiceps, Uroteuthis (Photololigo) duvauceli, Oratosquilla nepa* and jellyfish are given in Fig 5.14. From these plots it was clear that the *Metapenaeus dobsoni* showed abundance during April-May months and *Parapenaeopsis stylifera* showed abundance in May. *Sardinella longiceps* showed somewhat uniform distribution but showed abundance in the months of January, February, March, August and November. Jellyfish and squilla showed maximum abundance during September and December, respectively.

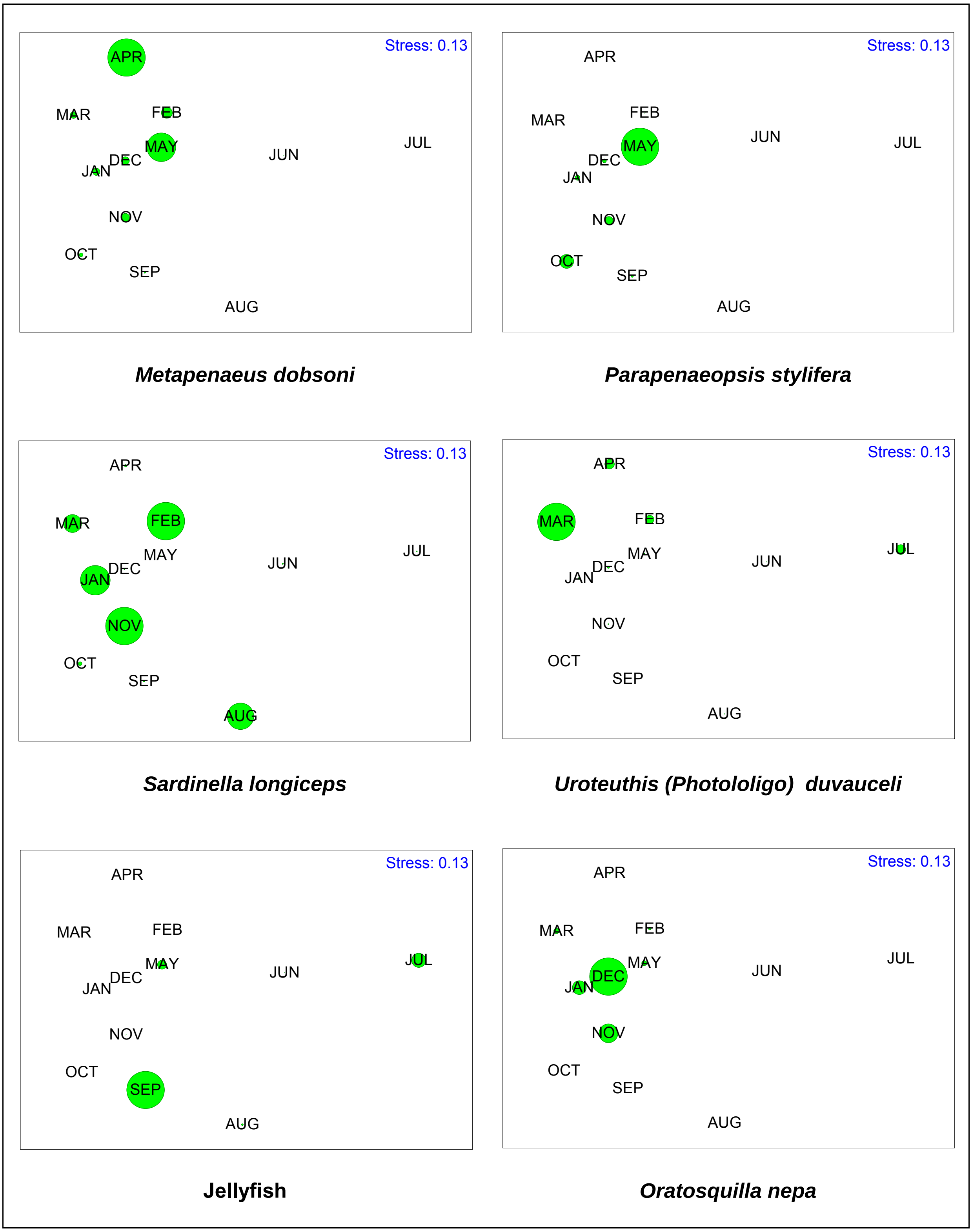


Fig. 5.14. Bubble plot of selected species showing abundance in various months

5.5. Conclusions

During this study conducted from January to December 2006 period, on trawl bycatch components off Cochin, 282 species of marine species were encountered in the trawl nets. The bycatch included 191 species of fishes, 11 species of shrimps, 3 species of lobsters, 13 species of crabs, 11 species of cephalopods, 45 species of molluscs, 2 species of echinoderms, 2 species jellyfish, 2 species stomatopods, 1 species sea snake and 1 species of sea turtle. The fishes belonged to 12 orders and 59 families and 109 genera. The shrimp species belonged to 4 families and crabs to 4 families, cephalopod species to 3 orders and 3 families, molluscan species to 22 families and jelly fishes to 2 families. The catch per unit effort (CPUE, $kg.h^{-1}$) was found to be higher before monsoon in the month of March and in the months of September, October and November. The CPUE was found to be low after March and throughout the monsoon periods. The percentage of shrimp, which is the targeted catch of trawl fishing showed wide variations in the landings from month to month.

The average bycatch percentage in Cochin waters during the year 2006 was about 87%. The lowest bycatch percentage was observed in the month of May and bycatch percentage as high as 99% was observed in the month of July. Although bycatch problem exists, it tends to contribute a significant share in the income of the trawlers. Many industries utilizing the bycatch have been evolved in Cochin and adjacent areas. Small and medium trawlers are bringing some part of their bycatch for the raw material suppliers of fish meal factories located in other states. Bycatch may result in many biological, ecological, environmental and economic problems mainly because of the fact that about 40-50 % of the bycatch in this area is comprised of juveniles and sub-adults. The use of bycatch reduction devices is not known among the trawl fishermen of central Kerala.

Chapter 6

Experiments with Fisheye BRD Designs

6.1. Introduction

Fisheye is an important bycatch reduction device facilitating the escapement of fish especially those undersized, from the codend (Pillai, 1998; Pillai et al., 2004). It consists of an oval shaped rigid structure with 8-15 cm height and 30-40 cm width with supporting frames and made of stainless steel/aluminium rods having at least ¼ inch diameter. This BRD is installed at specific areas of the codend, which facilitates the escape of the fish, which try to swim backward from the codend. Device is suitable for excluding actively swimming juveniles and young ones while retaining the big ones (Pillai, 1998; Brewer et al., 1998; Gregor and Wang, 2002).

Fisheye is known by different names in different geographical areas where it is used. It is known as Florida Fish Eye (FFE) in the Southeast US Atlantic and in the Gulf of Mexico (Steele, et al., 2002). It is also called Florida Fish Excluder (FFE) (Anon, 1997). In North Carolina Bay it is called Snake eye BRD (Fuls and McEachron, 1997). Fisheyes of different sizes and shapes are used in south Atlantic and in the Gulf of Mexico. Fisheye can be used as a single device or in combination with other BRDs such as Nordmore grid, super shooter, square mesh window, radial escape section etc. These combinations are found to be effective in improving the efficiency of the BRDs (Brewer et al., 1998; Broadhurst et al., 2002; Steele, et al., 2002).

6.1.1. Literature Review

Experiments conducted by Oregon Department of Fish and Wildlife showed the efficiency of fisheye BRD when positioned at different locations on a codend. Optimum efficiency was shown when the BRD was placed at 82 meshes in front of the pursing rings. Bycatch reduction is found to be 65.6% and shrimp loss is found to be 8.7% (Anon, 2004a). Similar results were obtained from the studies conducted in the Gulf of Mexico and South Atlantic shrimp fisheries. In another experiment conducted in the Australian Northern prawn fishery showed a bycatch reduction and shrimp loss ranged between 17.8-21.25% and 0.88-5.12% respectively (Gregor and Wang, 2002; AFMA, 2002). Experiments conducted by Brewer et al (1998) showed that the fisheye when used in combination with Nordmore grid excluded more than 25% of the small fish bycatch and when used in combination with super-shooter excluded about 12.5% of small fish bycatch. Experiments conducted in the Florida shrimp fishery showed 20-60% reduction in finfish bycatch when fisheye was combined with super-shooter (Steele, et al., 2002). Pillai et al. (2004) conducted experiments during 1997 for the first time in India and found 22% reduction in the fish capture. From the above experiments it was evident that the high bycatch exclusion characteristics and low target catch loss make fisheye an important hard BRD. The important advantages of fisheye BRD are (i) It is not expensive (ii) easy to fabricate (iii) easy to incorporate on to the trawl net (iv) maintenance required is minimum and (v) it will not interfere with normal operation of the net. The main disadvantage of this BRD is that it can be easily disabled at sea.

6.2. Objectives of the Study

Fisheye BRDs are not adequately evaluated in Indian fishery conditions, though it is found appropriate for other fisheries elsewhere. The objective of the study was to evaluate the bycatch reduction characteristics of three different designs of fisheye BRD.

6.3. Materials and Methods

6.3.1. The Fisheye BRDs

The following designs of fisheye BRDs with different exit configurations and orientations were used to conduct the experimental trials*:*

i. 300 x 200 mm Semicircular Fisheye with horizontally orientated exit (Fig. 6.1 and 6.4)
ii. 300 x 200 mm Oval Fisheye with vertically orientated exit (Fig. 6.2 and 6.5)
iii. 300 x 200 mm Oval Fisheye with horizontally orientated exit (Fig. 6.3 and 6.6)

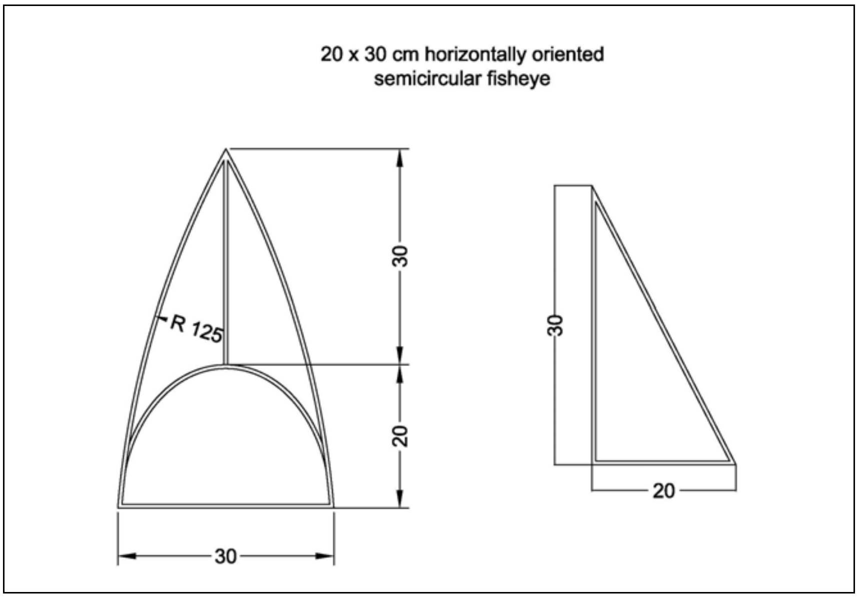


Fig. 6.1. 300 x 200 mm Semicircular Fisheye with horizontally orientated exit

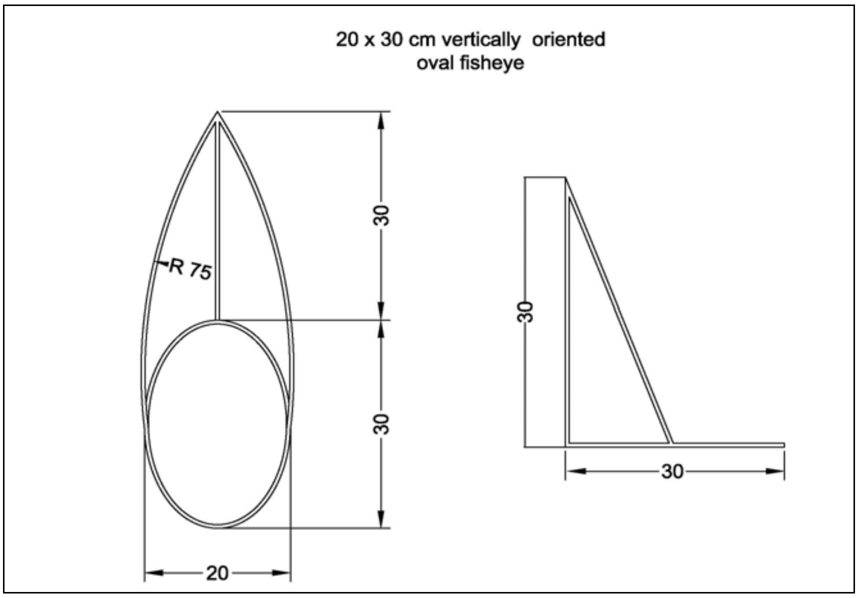


Fig. 6.2. 300 x 200 mm Oval Fisheye with vertically orientated exit

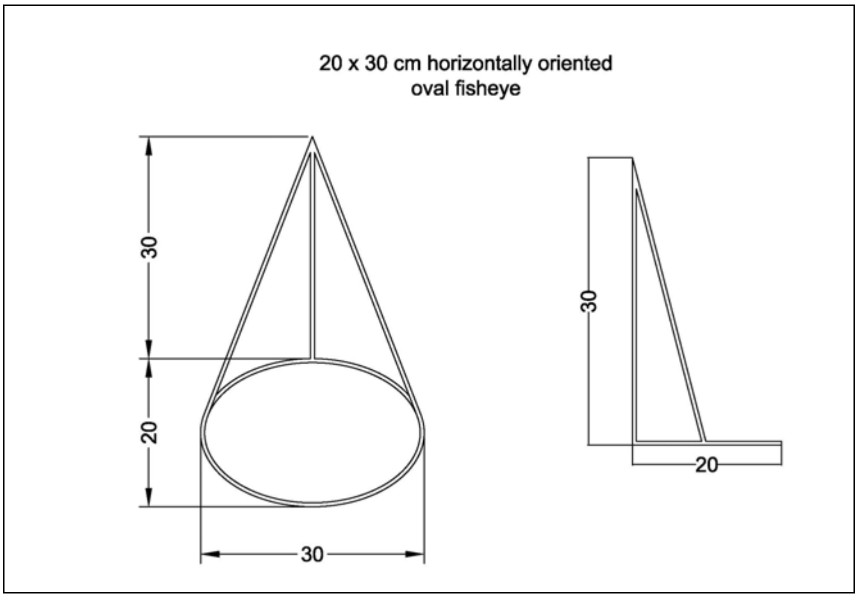


Fig. 6.3. 300 x 200 mm Oval Fisheye with horizontally orientated exit

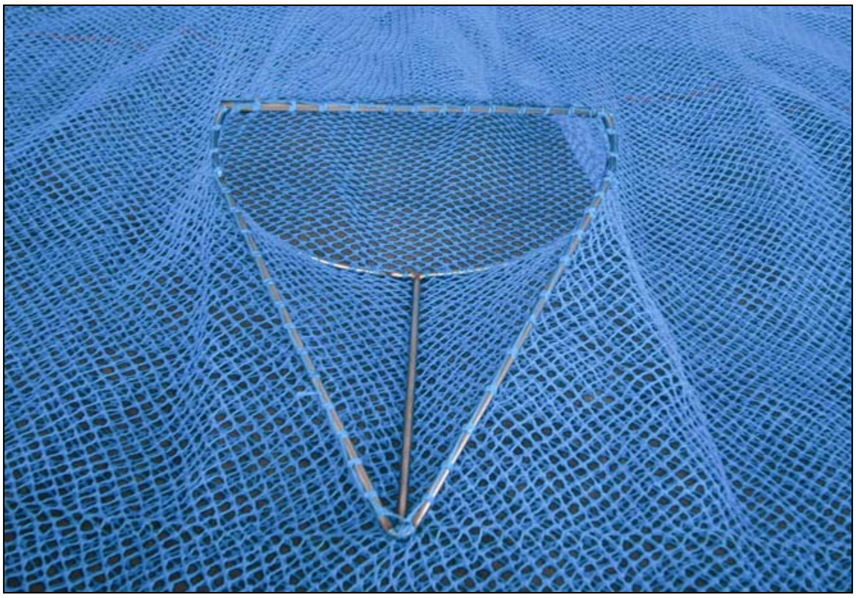


Fig. 6.4. 300 x 200 mm Semicircular Fisheye with horizontally orientated exit

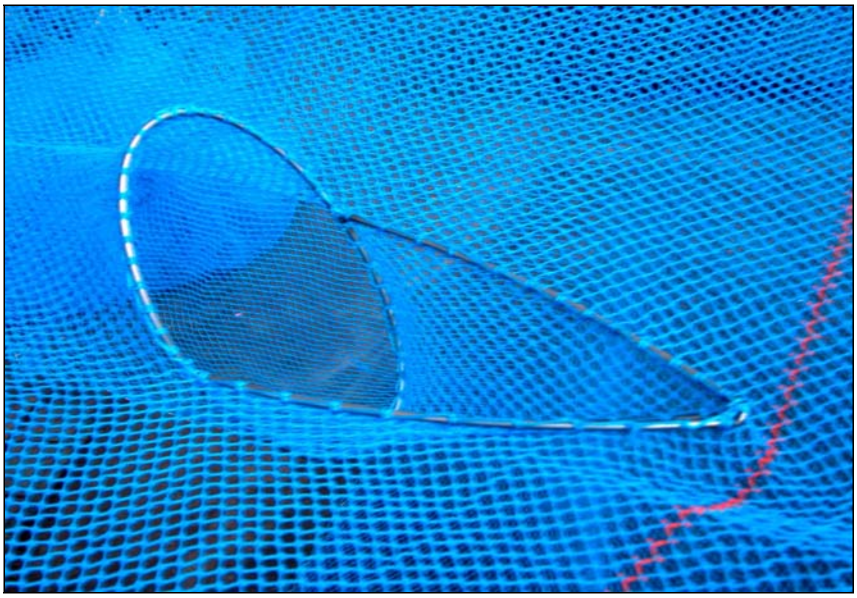


Fig. 6.5. 300 x 200 mm Oval Fisheye with vertically orientated exit

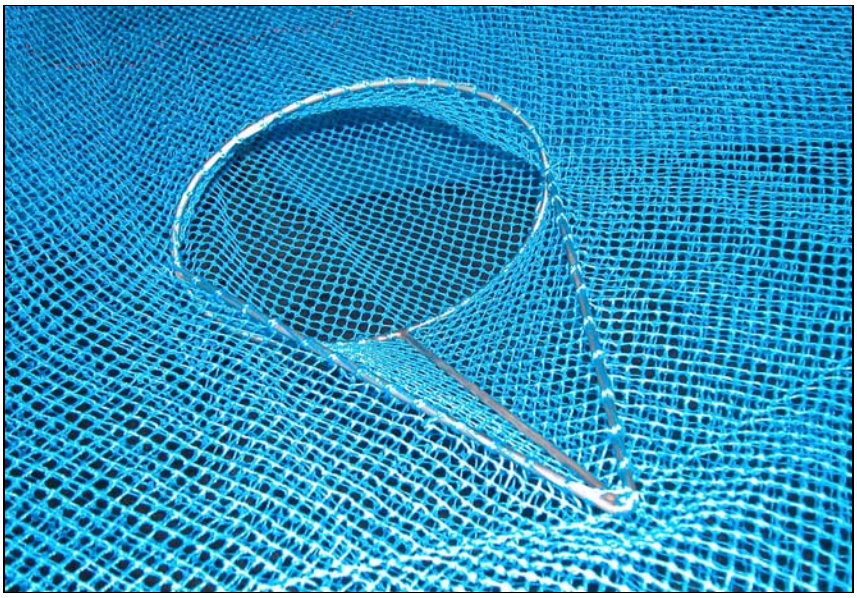


Fig. 6.6. 300 x 200 mm Oval Fisheye with horizontally orientated exit

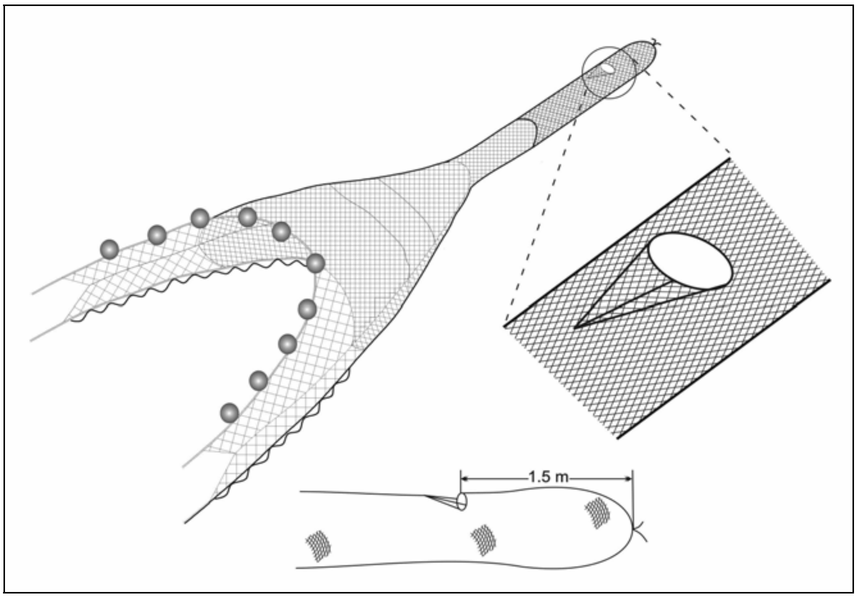


Fig. 6.7. Trawl net showing position of fisheye

The fisheye BRDs used in this experiment were fabricated in the CIFT gear fabrication laboratory. The supporting rods extend up to 300 mm and the BRD was made entirely of stainless steel rods of 6 mm dia. All fisheyes were fitted on the top side of the trawl codend at a distance of 4.5 m (225 meshes) from the fore end and 1.5 m (75 meshes) from the rear end of a codend of 6 m length (Fig. 6.7).

6.3.2. The trawl gear

The gear used for the operation of fisheye was a 29.0 m shrimp trawl with 20 mm diamond mesh codend (Fig. 3.4). The trawl was made entirely of twisted polyethylene. V-type otter boards of 80 kg each were used as the sheer device.

6.3.3. Vessels used for the experiment

Two research vessels of Central Institute of Fisheries Technology were used for conducting the field trials. First one was a steel trawler MFB Matsyakumari (17.5 m LOA and 57.17 GRT) having 277 bhp @ 1000 rpm Kirloskar Mann engine and the second one was a wooden trawler MFV Sagar Shakti (15.24 m LOA and 30 GRT) having 223 bhp @ 1800 rpm Ruston MWM engine.

6.3.4. The area of fishing operation

The experimental fishing operations were conducted during daytime, in the traditional shrimp fishing grounds at a depth ranging between 9 and 32 m off Cochin (Fig. 3.1).

6.3.5. Experimental fishing trials and catch handling

Covered codend method was adopted to conduct the study. Catch from the codend and the cover were separately sorted and identified up to species level. Weight of each species was taken and for large quantities sub samples were taken. In the case of fishes and shrimps total length was taken and for cephalopods the mantle length was measured.

6.4. Results and Discussion

Results of experiments conducted using 3 different designs of fisheye BRD, off Cochin between March 2005 and September 2006 are presented in Tables 6.1 to 6.9 and Fig. 6.8 to 6.13.

6.4.1. 300 x 200 mm Semicircular Fisheye with horizontally orientated exit

Results of performance evaluation of 300 x 200 mm Semicircular Fisheye with horizontally orientated exit in terms of bycatch exclusion and target catch retention are given in Tables 6.1 and 6.2. The experiment with fisheye BRD with 300 x 200 mm semicircular opening aligned horizontally was carried out during January-February 2006.

The experiment consisted of 17 hauls that were taken during 15 fishing days and the overall catch during this period was about 277.71 kg, of which 52.02% retained in the codend and about 47.98% escaped through the fisheye. Catch consisted of 75 species (59 species of teleosts, 5 species of shrimps, 1 species of lobster, 6 species of crabs, 1 species of cephalopods, 2 species of molluscs, 1 species of stomatopod and occasional catches of sea-snakes and plastic refuse). The shrimp loss was found to be very low, about 0.04% of the total catch and about 0.83% of total shrimp catch. The overall bycatch reduction was found to be about 50.58%.

Sardinella longiceps dominated among finfishes comprised 62.19% of the total catch during the experiment period followed by *Encrasicholina devisi* contributed 5.53% of total catch. Among cephalopods *Uroteuthis (Photololigo) duvauceli* contributed 3.31% of the total catch. Crabs contributed only 0.45% of the total catch. Shells contributed 0.02% of total catch. Shrimps contributed 5.23% of total catch and *Metapenaeus dobsonii* was the dominant species contributing 94.2% of total shrimp catch. *Oratosquilla nepa* contributed 2.29% of the total catch.

Among the species that escaped through the fish eye, only two species of finfishes showed 100% escapement they were *Caranx sexfasciatus and Secutor ruconius*. Another eight species including *Leiognathus dussumieri*, *Liza parsia*, *Sardinella longiceps*, *Lactarius lactarius, Ambassis ambassis, Megalaspis cordyla, Rastrelliger kanagurta* and *Mugil cephalus* showed escapement more than 50%. Among 75 species 31 species showed 0% escapement, consisted 19 species of teleosts, 4 species of shrimps, 2 species cephalopods, 5 species of crabs, 1 species of elasmobranch and 7 species of molluscan shells.

It was significant to note that the target catch loss was very low in the tune of 0.04% of total catch and 0.83% of shrimp catch and *Metapenaeus dobsonii* dominated the shrimp landing which contributed 94.21% of total shrimp catch. Another target catch *Uroteuthis (Photololigo) duvauceli* showed 100% retention.

Table. 6.1. Bycatch exclusion effect on species groups due to the installation of 200 x 300 mm semicircular fisheye

Species groups	Encountered catch, kg	Retained, %	Excluded, %
All species	277.71	52.02	47.98
Shrimp species	14.51	99.17	0.83
Non-shrimp species	263.2	49.42	50.58

Table. 6.2. Species-wise exclusion rates in 200x300 mm semicircular fisheye

Species	Encountered catch, kg	Retained, %	Excluded, %
Caranx sexfasciatus	0.200	0.00	100.00
Secutor ruconius	0.010	0.00	100.00
Leiognathus dussumieri	0.020	25.00	75.00
Liza parsia	0.225	31.11	68.89
Sardinella longiceps	172.700	31.22	68.78
Lactarius lactarius	0.320	31.25	68.75
Ambassis ambassis	0.835	38.32	61.68
Megalaspis cordyla	6.260	42.09	57.91
Rastrelliger kanagurta	2.360	48.94	51.06
Mugil cephalus	0.120	50.00	50.00
Sardinella fimbriatus	3.105	67.31	32.69
Johnius dussumieri.	0.460	67.39	32.61
Valamugil speigleri	0.215	69.77	30.23
Gerres limbatus	0.100	70.00	30.00
Sardinella albella	2.580	72.09	27.91
Alepes kleinii	0.255	72.55	27.45
Portunus sanguinolentus	0.765	73.20	26.80
Leiognathus brevirostris	1.175	74.47	25.53
Leiognathus equulus	1.400	78.57	21.43
Lagocephalus spadiceus	5.200	79.52	20.48
Alepes djedaba	1.120	80.36	19.64
Caranx ignobilis	0.110	81.82	18.18
Epinephelus diacanthus	0.110	81.82	18.18
Upeneus vittatus	0.110	81.82	18.18
Anadontostoma chacunda	0.660	83.33	16.67
Secutor insidiator	5.455	83.87	16.13
Dussumieria acuta	2.185	84.44	15.56
Scomberomorus commerson	0.350	85.71	14.29
Nibea maculata	0.215	86.05	13.95
Thryssa malabarica	1.120	86.61	13.39
Encrasicholina devisi	15.525	89.86	10.14
Stolephorus commersonnii	3.890	90.23	9.77
Leiognathus splendens	2.585	90.72	9.28
Johnius borneensis	0.810	91.98	8.02
Carangoides armatus	0.345	92.75	7.25
Otolithes ruber	1.095	95.89	4.11

Thryssa mystax	2.275	96.26	3.74
Stolephorus waitei	0.385	97.40	2.60
Stolephorus indicus	1.660	98.19	1.81
Oratosquilla nepa.	6.350	98.43	1.57
Johnius carouna	0.670	98.51	1.49
Thryssa puruva	1.095	99.09	0.91
Metapenaeus dobsoni	13.673	99.16	0.84
Parapenaeopsis stylifera	0.615	99.19	0.81
Miscellaneous species	16.995	100.00	0.00
All species	277.708	52.02	47.98

6.4.2. 300 x 200 mm Oval Fisheye with vertically orientated exit

The experiment with fisheye BRD with 300 x 200 mm oval opening aligned vertically was carried out during March 2006. The experiment consisted of 14 hauls that were taken during 14 fishing days and the overall catch during this period was about 343.89 kg, of which 57.19% retained in the codend and about 42.81% escaped through the fisheye. Results of performance evaluation of 300 x 200 mm Oval Fisheye with vertically orientated exit in terms of bycatch exclusion and target catch retention are given in Tables 6.3 and 6.4. Catch consisted of 110 species (83 species of teleosts, 1 species of elasmobranches, 6 species of shrimps, 1 species of lobster, 7 species of crabs, 4 species of cephalopods, 8 species of molluscan shells, 1 species of stomatopod and occasional catches of sea-snakes and plastic refuse). The shrimp loss was found to be very high which came to about 2.89% of total catch and 26.17% of shrimp catch, when compared with other designs of fisheye BRD. The overall bycatch reduction was found to be about 44.88%.

Fishes consisted 73.7% of the total catch and among fin fishes *Sardinella longiceps* was found to be the most dominant species contributing 11.44% of the total catch during the experiment period followed by *Sphyraena obtusata* (9.87%), *Encrasicholina devisi* (6.17%), *Rastrelliger kanagurta* (5.54%), *and Secutor insidiator* (5.45%). Shrimps was the next dominant group consisted 11.02% of total catch and *Metapenaeus affinis and Metapenaeus dobsoni* were the dominant species forming 41.64% and 33.54% respectively of total shrimp catch. Cephalopods contributed 8.95% of total catch. *Uroteuthis (photololigo) duvauceli* contributed 84.45% and *Sepiella inermis* contributed 11.23% of the total cephalopod landings. Crabs formed 3.6% of total landings, of which *Charybdis natator* formed 31.65%. Stomatopods comprised 1.62% and molluscan shells contributed 1.4% of total catch. Among shells *Turritella attenuata* contributed 36.3%.

Table. 6.3. Bycatch exclusion effect on species groups due to the installation of 200 x 300 mm oval vertical fisheye

Species groups	Encountered catch, kg	Retained, %	Excluded, %
All species	343.89	57.19	42.81
Shrimp species	37.89	73.83	26.17
Non-shrimp species	306.00	55.12	44.88

Table. 6.4. Species-wise exclusion rates in 200 x 300 mm oval vertical fisheye

Species	Encountered catch, kg	Retained, %	Excluded, %
Epinephelus diacanthus	1.870	0.00	100.00
Johnius carouna	0.340	0.00	100.00
Congresox talabonoides	0.320	0.00	100.00
Sardinella fimbriatus	0.200	0.00	100.00
Stolephorus waitei	0.160	0.00	100.00
Leiuranus semicinctus	0.150	0.00	100.00
Gerres oyena	0.060	0.00	100.00
Kathala axillaris	0.060	0.00	100.00
Mugil cephalus	0.035	0.00	100.00
Samaris cristatus	0.025	0.00	100.00
Thenus orientalis	0.020	0.00	100.00
Scomberoides tala	0.015	0.00	100.00
Caranx sexfasciatus	0.010	0.00	100.00
Scomberoides tol	0.010	0.00	100.00
Caranx ignobilis	3.400	1.47	98.53
Nibea maculata	0.530	4.72	95.28
Gazza minuta	0.445	8.99	91.01
Platycephalus indicus	0.640	12.50	87.50
Anadontostoma chacunda	0.580	13.79	86.21
Gerres limbatus	0.240	16.67	83.33
Rastrelliger kanagurta	19.040	19.01	80.99

Alepes djedaba	1.880	19.68	80.32
Sphyraena obtusata	33.950	21.80	78.20
Valamugil speigleri	2.840	23.24	76.76
Sillago sihama	0.415	25.30	74.70
Decapterus russelli	1.800	26.67	73.33
Alectis ciliaris	0.070	28.57	71.43
Megalaspis cordyla	14.050	30.82	69.18
Parastromateus niger	1.710	32.16	67.84
Ficus gracilis	0.030	33.33	66.67
Nemipterus mesoprion	0.850	35.29	64.71
Sphyraena jello	2.620	36.64	63.36
Alectis indicus	0.080	37.50	62.50
Apogon fasciatus	1.220	37.70	62.30
Johnius carutta	0.365	39.73	60.27
Sardinella gibbosa	9.750	41.03	58.97
Scomberomorus guttatus	0.990	45.45	54.55
Liza parsia	1.810	49.72	50.28
Lactarius lactarius	0.450	51.11	48.89
Dussumieria acuta	0.720	55.56	44.44
Oxyurichthys paulae	0.270	55.56	44.44
Filimanus heptadactylus	0.215	55.81	44.19
Penaeus monodon	1.730	56.07	43.93
Pseudorhombus arsius	0.175	57.14	42.86
Sardinella albella	0.545	58.72	41.28
Pisidonophis cancrivorus	2.700	59.26	40.74
Metapenaeus monoceros	2.860	59.44	40.56
Secutor insidiator	18.755	59.85	40.15
Charybdis feriatus	1.920	60.42	39.58
Penaeus (Fenneropenaeus) indicus	4.040	60.64	39.36
Sardinella longiceps	39.330	61.33	38.67
Nemipterus japonicus	10.070	62.26	37.74
Otolithes ruber	1.420	64.08	35.92
Encrasicholina devisi	21.215	64.29	35.71
Cynoglossus macrostomus	0.275	65.45	34.55
Leiognathus splendens	1.755	66.38	33.62
Upeneus vittatus	0.180	66.67	33.33
Mene maculata	2.800	67.14	32.86
Uroteuthis (Photololigo)duvauceli	25.980	67.90	32.10
Sepiella inermis	3.455	69.61	30.39
Thryssa mystax	0.615	69.92	30.08
Opisthopterus tardore	0.380	71.05	28.95
Oratosquilla nepa.	5.560	71.94	28.06
Leiognathus dussumieri	0.220	72.73	27.27
Johnius borneensis	2.980	73.15	26.85

Leiognathus equulus	0.365	73.97	26.03
Selar crumenophthalmus	0.160	75.00	25.00
Parapenaeopsis stylifera	0.760	76.32	23.68
Ambassis ambassis	0.655	76.34	23.66
Alepes kleinii	1.380	76.81	23.19
Marcia opima	0.520	76.92	23.08
Saurida undosquamis	7.630	77.06	22.94
Lagocephalus spadiceus	6.375	77.49	22.51
Metapenaeus dobsoni	12.715	77.62	22.38
Saurida tumbil	0.920	78.26	21.74
Lepturacanthus savala	1.200	78.33	21.67
Metapenaeus affinis	15.785	78.59	21.41
Cynoglossus arel	1.510	78.81	21.19
Terapon jarbua	2.850	81.40	18.60
Leiognathus brevirostris	0.870	81.61	18.39
Callapha lophos	0.600	83.33	16.67
Encrasicholina punctifer	10.830	84.12	15.88
Babylonia spirata	0.650	84.62	15.38
Stolephorus indicus	4.920	87.40	12.60
Charybdis natator	3.920	89.80	10.20
Gerres filamentosus	0.660	90.91	9.09
Carangoides armatus	0.550	90.91	9.09
Terapon theraps	0.835	92.81	7.19
Portunus sanguinolentus	2.920	95.89	4.11
Scylla serrata	1.355	95.94	4.06
Thryssa malabarica	1.210	99.17	0.83
Miscellaneous species	8.535	100.00	0.00
All species	343.890	55.12	44.88

Among the species that escaped through the fish eye, 24 species showed escapement above 50%. 13 species of fin fishes and one lobster species showed 100% escapement they were *Epinephelus diacanthus, Johnius carouna, Congresox talabonoides, Sardinella fimbriatus, Stolephorus waitei, Leiuranus semicinctus, Gerres oyena, Kathala axillaris, Mugil cephalus, Samaris cristatus, Scomberoides tala, Caranx sexfasciatus, Scomberoides tol and Thenus orientalis.*

Among 110 species 19 species of finfishes showed 0% escapement. Shrimps contributed 11.03% of total catch and the target catch loss was 2.88% of the total catch and about 26.17% of total shrimp catch. Cephalopods were also lost considerably which was about 2.73% of total catch and 31.53% of total cephalopod catch. This high target catch loss was attributed to the larger exit opening and also the vertical orientation of the opening, which created more turbulence. The occurrence of smaller shrimps and cephalopods that get carried out of the trawl through fisheye due to water currents was also assumed to be a reason for the high target catch loss.

6.4.3. 300 x 200 mm Oval Fisheye with horizontally orientated exit

The experiment with fisheye BRD with 300 x 200 mm oval opening aligned horizontally was carried out during the months of March, April and May of 2006. The experiment consisted of 22 hauls that were taken during 12 fishing days and the overall catch during this period was about 140.02 kg, of which 73.21% (102.51 kg) retained in the codend and about 26.79% (37.51 kg) escaped through the fisheye. Results of performance evaluation of 300 x 200 mm Oval Fisheye with horizontally orientated exit in terms of bycatch exclusion and target catch retention are given in Tables 6.5 and 6.6. Catch consisted of 80 species (62 species of teleosts, 7 species of shrimps, 6 species of crabs, 2 species of cephalopods, 1 species of molluscan shell, 1 species of stomatopod, one species of jelly fish and occasional catches of sea snake and plastic refuse). The shrimp loss was found to be high which came to about 4.87% of total shrimp catch and 2.26% of total catch, when compared with semicircular fisheye BRD but it was much lower than vertically oriented fisheye. The overall bycatch reduction was found to be about 45.79%.

Table. 6.5. Bycatch exclusion effect on species groups due to the installation of 200 x 300 mm oval horizontal fisheye

Species groups	Encountered catch, kg	Retained, %	Excluded, %
All species	140.02	73.21	26.79
Shrimp species	65.01	95.13	4.87
Non-shrimp species	75.01	54.21	45.79

Table. 6.6. Species-wise exclusion rates in 300 x 200 mm oval horizontal fisheye

Species	Encountered catch, kg	Retained, %	Excluded, %
Nemipterus japonicus	0.600	0.00	100.00
Penaeus semisulcatus	0.100	0.00	100.00
Scomberomorus guttatus	0.100	0.00	100.00
Valamugil speigleri	0.075	0.00	100.00
Johnius carutta	0.060	0.00	100.00
Carangoides armatus	0.040	0.00	100.00
Gerres filamentosus	0.030	0.00	100.00
Sardinella albella	0.020	0.00	100.00
Leiognathus dussumieri	0.018	0.00	100.00
Gnathodon speciosus	0.015	0.00	100.00
Liza parsia	0.015	0.00	100.00
Siganus canaliculatus	0.010	0.00	100.00
Sphyraena obtusata	0.005	0.00	100.00
Alepes djedaba	0.245	2.04	97.96
Johnius carouna	0.125	8.00	92.00
Scomberoides lysan	0.175	8.57	91.43
Megalaspis cordyla	18.680	10.01	89.99
Kathala axillaris	0.040	12.50	87.50
Rastrelliger kanagurta	0.150	23.33	76.67
Thryssa kammalensis	0.045	33.33	66.67
Lagocephalus spadiceus	0.867	35.18	64.82
Otolithes ruber	2.045	40.83	59.17
Dussumieria acuta	1.275	45.10	54.90
Decapterus russelli	0.020	50.00	50.00
Priacanthus hamrur	0.010	50.00	50.00
Lactarius lactarius	0.390	53.85	46.15
Sardinella longiceps	2.965	54.47	45.53
Anadontostoma chacunda	0.445	56.18	43.82
Mene maculata	0.220	59.09	40.91
Pampus argenteus	10.585	60.89	39.11
Caranx sexfasciatus	0.015	66.67	33.33
Nibea maculata	0.260	67.31	32.69
Leiognathus splendens	0.125	68.00	32.00
Jelly Fish	14.950	68.56	31.44
Stolephorus waitei	2.165	74.13	25.87
Secutor insidiator	0.465	76.34	23.66
Metapenaeus dobsoni	60.768	95.57	4.43
Thryssa mystax	0.350	77.14	22.86
Gazza minuta	0.045	77.78	22.22

Metapenaeus affinis	1.308	80.50	19.50
Stolephorus commersonnii	0.775	80.65	19.35
Ambassis ambassis	3.905	80.79	19.21
Opisthopterus tardore	0.055	81.82	18.18
Parastromateus niger	0.120	83.33	16.67
Lepturacanthus savala	0.695	85.61	14.39
Encrasicholina devisi	3.170	86.12	13.88
Oratosquilla nepa.	1.865	87.13	12.87
Trypauchen vagina	0.205	87.80	12.20
Leiognathus equulus	0.068	88.24	11.76
Stolephorus indicus	0.120	91.67	8.33
Johnius borneensis	0.085	94.12	5.88
Penaeus (Fenneropenaeus) indicus	1.305	95.02	4.98
Parapenaeopsis stylifera	1.238	95.72	4.28
Sepiella inermis	0.073	95.89	4.11
Portunus sanguinolentus	1.015	96.55	3.45
Cynoglossus macrostomus	0.270	98.15	1.85
Uroteuthis (Photololigo)duvauceli	4.105	99.51	0.49
Miscellaneous species	1.128	100.00	0.00
All species	140.018	73.21	26.79

Fishes consisted 37.45% of the total catch and among fin fishes *Megalaspis cordyla* was found to be the most dominant species contributing 13.34% of the total catch during the experiment period followed by *Pampus argenteus* 7.56%, *Ambassis ambassis* 2.79% and *Encrasicholina devisi* 6.17%. Shrimps consisted 46.43% of total catch and *Metapenaeus dobsoni* alone contributed 93.47% of total shrimp catch. Cephalopods contributed 2.98% of total catch. *Uroteuthis (Photololigo) duvauceli* contributed 98.25% and *Sepiella inermis* contributed 1.75% of the total cephalopod landings. Crabs formed 1.04% of total landings, of which *Portunus sanguinolentus* formed 70% of crab landings. Stomatopods comprised 1.33% and molluscan shells contributed 0.04% of total catch.

Among the species, which escaped through the fish eye, 13 species of fin fishes showed 100% escapement they are *Nemipterus japonicus, Penaeus semisulcatus, Scomberomorus guttatus, Valamugil speigleri, Johnius carutta, Carangoides armatus, Gerres filamentosus, Sardinella albella, Leiognathus dussumieri, Gnathodon speciosus, Liza parsia, Siganus canaliculatus and Sphyraena obtusata* and another 10 species showed escapement above 50%.

Among 80 species 24 species of finfishes showed 0% escapement. Shrimps contributed 46.43% of total catch and the target catch loss was 2.26% of the total catch and about 4.87% of total shrimp catch. Cephalopods were considerably retained by this design of fisheye, which is as high as 97.7% of total cephalopod catch. Considering the rate of shrimp loss and cephalopod retention 300 x 200 mm horizontally oriented fisheye has got a higher efficiency next to 300 x 200 mm semicircular fisheye. Summarised results of experiments of three different designs of fisheye are given in the Table 6.7.

Table. 6.7. Results of experiments with 3 different Fisheye BRD designs

	Fisheye BRD with 300x200 mm oval exit of horizontal orientation	Fisheye BRD with 300x200 mm oval exit of vertical orientation	Fisheye BRD with 300x200 mm semicircular exit of horizontal orientation
No. of hauls	22	14	17
Total catch (kg)	140.02	343.89	277.71
CPUE (kg/h)	6.36	24.56	16.34
Retained catch (kg)	102.506	196.645	144.468
Retained catch (%)	73.21	57.19	52.02
Excluded catch (kg)	37.512	147.23	133.24
Excluded catch (%)	26.79	42.81	47.98
Retained shrimp catch (kg)	61.848	27.975	14.393
Excluded shrimp catch (kg)	3.166	9.915	0.12
Total shrimp catch (kg)	65.014	37.89	14.513
Retained shrimp catch (%)	95.13	73.83	99.17
Excluded shrimp catch (%)	4.87	26.17	0.83
Retained bycatch (other than shrimps) (kg)	40.658	168.67	130.075
Retained bycatch (other than shrimps) (%)	54.21	55.12	49.42
Excluded bycatch (other than shrimps) (kg)	34.346	137.315	133.12
Excluded bycatch (other than shrimps) (%)	45.79	44.88	50.58
No. of species caught	80	110	75
Fish species	62	83	59
Shrimp species	7	6	5
Other species	11	21	11
100% exclusion (No. of species)	13	14	2
>50% exclusion (No. of species)	10	24	8
Up to 50% exclusion (No. of species)	33	53	34
0% exclusion (No. of species)	24	19	31

6.4.4. Selectivity studies

The selectivity of fisheye bycatch reduction device is more or less a new area where not much work has been conducted and published. As in the case of nets the shape and size of meshes and in the case of grid BRDs the bar-space dimensions determines the selectivity. The important principle behind being the physical separation, the grids and net devices show similar selectivity characteristics. In the case of fisheye BRD the behavioural aspects of the individual species mostly override the application of physical separation principle. In fisheye BRD, fishes are given a provision to escape by providing adequate openings at specific locations and those species that can swim actively could find this opening and escape out. Again it is well established that the swimming speed and ability of a particular species is directly proportional to its body size and this behavioural aspect was utilized to determine the selectivity of fisheye BRD, since larger individuals would swim actively and find the way to escape and this ability would be reduced as their size decreases. The main limitation was to determine the selectivity of passive organisms such as shrimps as the water current would mainly influence their escapement.

The selectivity analyses of three fisheye designs were performed and for five species *viz. Dussumieria acuta, Encrasicholina devisi, Megalaspis cordyla, Rastrelliger kanagurta* and *Sardinella longiceps,* significant values were obtained concurrently. Selectivity curves and selectivity parameters of these species are given in Figures 6.8 to 6.12 and in Table 6.8 respectively. Semicircular fisheye gave lowest L_{50} value for mackerel showing at a length of 39.53 mm 50% of mackerel were released. In all the other four cases the L_{50} values obtained for semicircular fisheye was found to be in between the values obtained for oval and vertical fisheyes. Oval horizontal fisheye has lowest L_{50} values for *Megalaspis cordyla* and *Sardinella longiceps* and for oval vertical fisheye lowest L_{50} values were found for *Dussumieria acuta* and *Encrasicholina devisi*. In the case of *Dussumieria acuta* L_{50} values obtained for semicircular fisheye and vertical fisheye were found to be lower than the length at first maturity, showing their better release of juveniles when compared to oval fisheye. For *Encrasicholina devisi* all the three fisheye obtained L_{50} value greater than their length at first maturity.

Table. 6.8. Selectivity parameters for three designs of fisheye

Species	Fisheye	$L_{25\%}$	$L_{50\%}$	$L_{75\%}$	Selection range, mm	Length at first maturity, mm
	Semi circular	112.01	116.40	120.79	8.79	
Dussumieria acuta	Oval horizontal	131.02	166.46	201.90	70.88	140-150
	Oval vertical	85.60	108.06	130.53	44.93	
	Semi circular	70.53	75.77	81.01	10.48	
Encrasicholina devisi	Oval horizontal	75.90	85.36	94.82	18.93	64.5
	Oval vertical	44.74	70.00	95.26	50.51	
	Semi circular	76.09	137.12	198.16	122.07	
Megalaspis cordyla	Oval horizontal	11.09	87.38	163.67	152.59	250
	Oval vertical	128.74	147.98	167.22	38.48	
	Semi circular		39.53	108.19	137.33	
Rastrelliger kanagurta	Oval horizontal	22.00	62.69	103.38	81.38	190-220
	Oval vertical	90.80	139.84	188.89	98.09	
	Semi circular	59.84	85.27	110.70	50.86	
Sardinella longiceps	Oval horizontal	62.86	80.00	97.14	34.28	150-162
	Oval vertical	139.98	167.45	194.92	54.93	

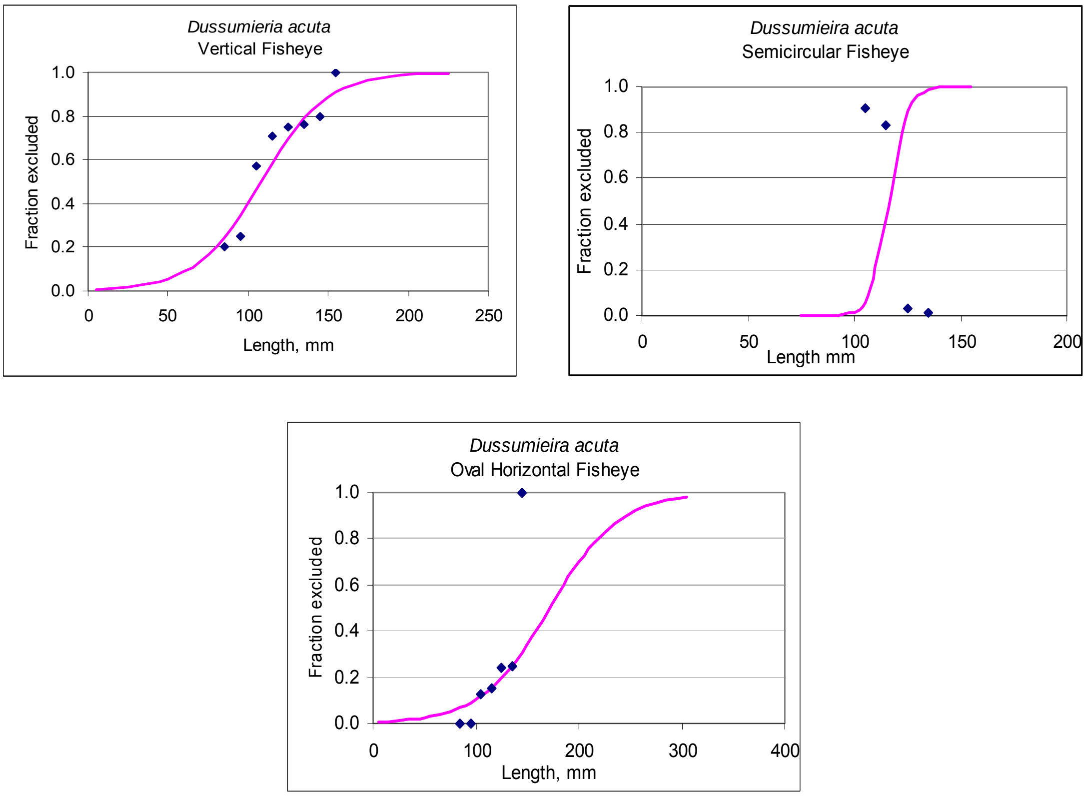


Fig. 6.8. Selectivity curves for *Dussumieria acuta*

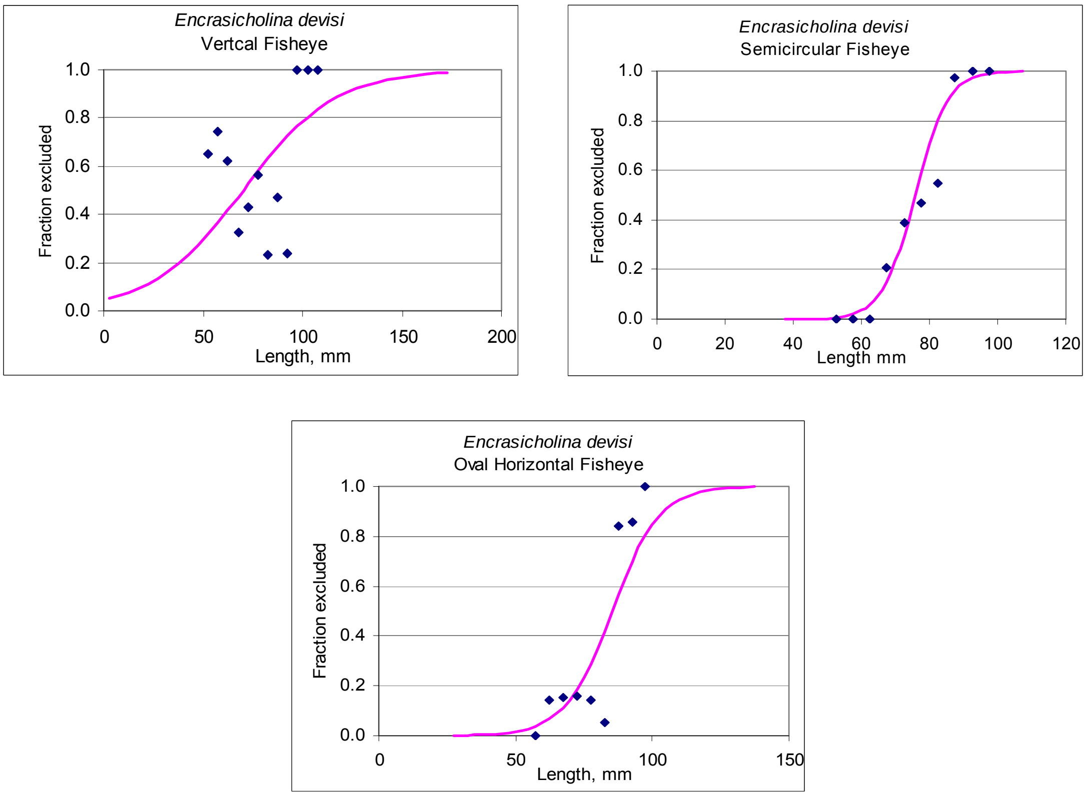


Fig. 6.9. Selectivity curves for *Encrasicholina devisi*

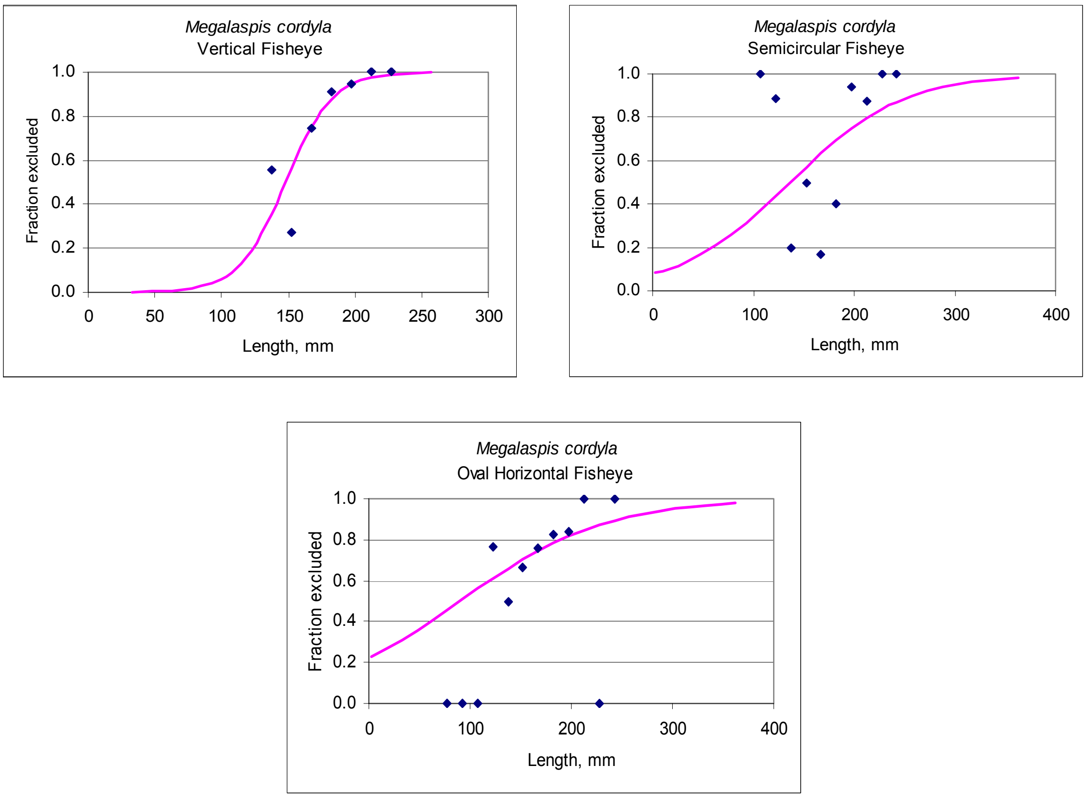


Fig. 6.10. Selectivity curves for *Megalaspis cordyla*

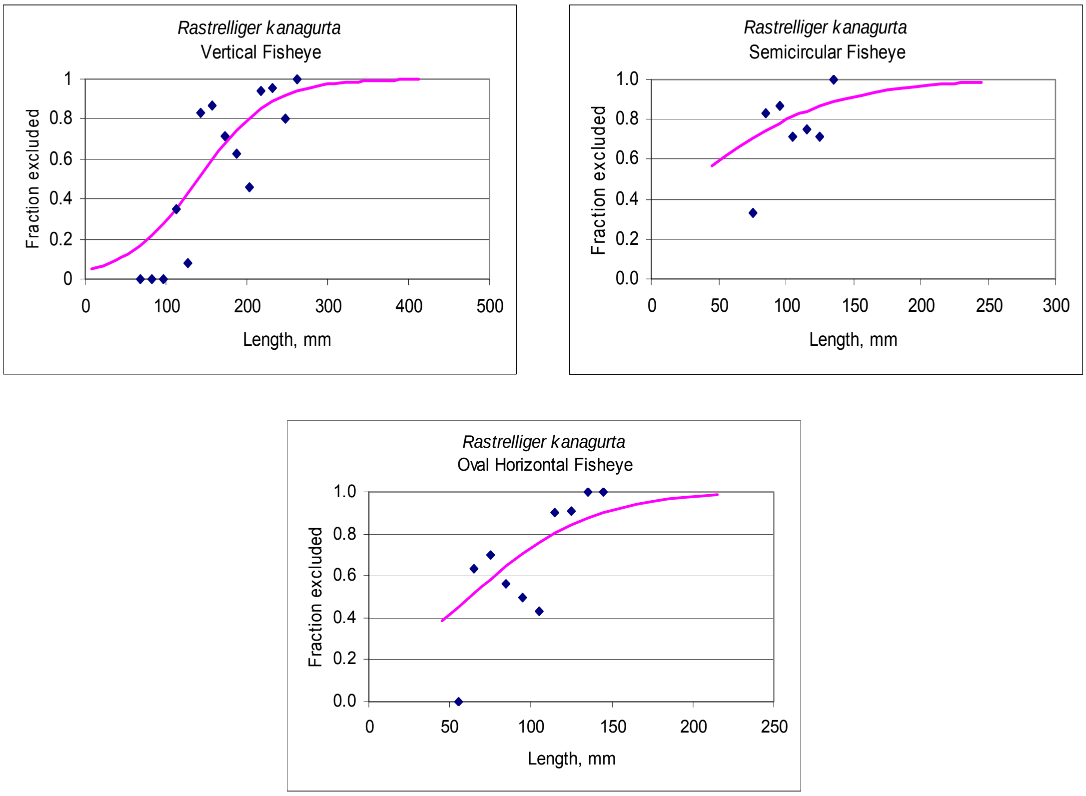


Fig. 6.11. Selectivity curves for *Rastrelliger kanagurta*

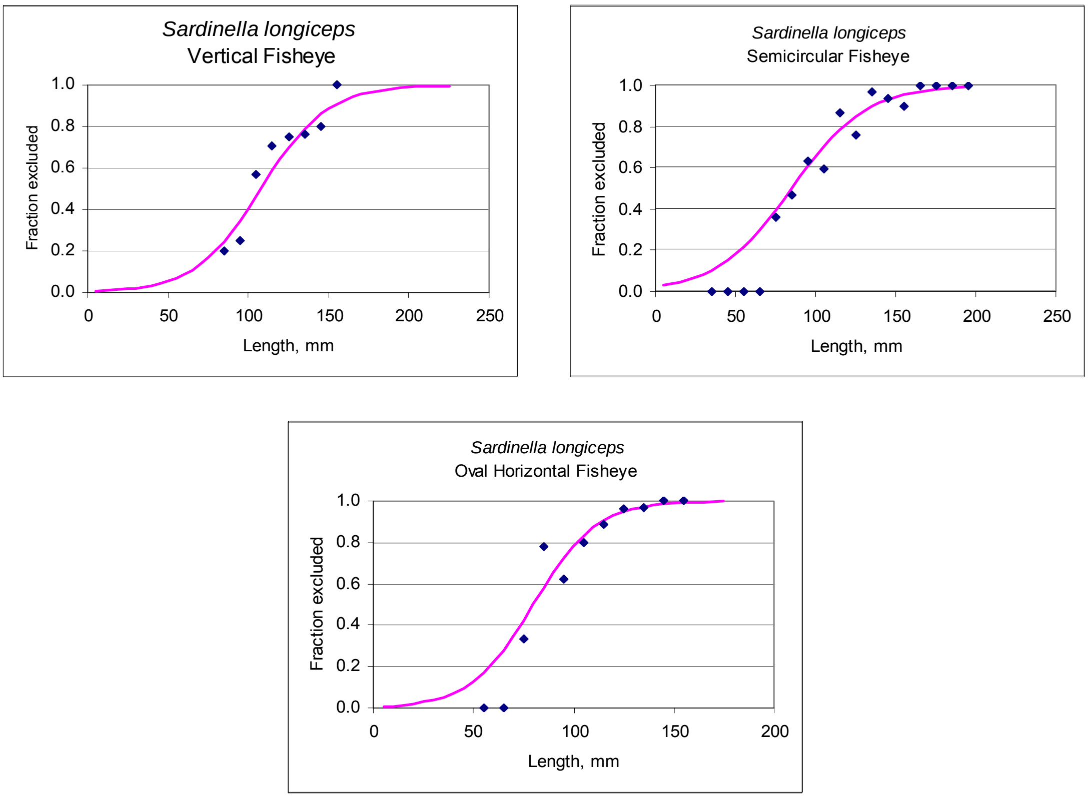


Fig. 6.12. Selectivity curves for *Sardinella longiceps*

6.4.5. PRIMER analysis

PRIMER software package (Version 5.2.9; Plymouth marine Laboratory, Plymouth, UK) was used for SIMPER analysis, plotting k-dominance curves, and estimating diversity indices such as total number of species (S), Margalef richness (d), Pielou's evenness (J'), Brillouin index (H), Shannon index (H'), Simpson's dominance index (λ'), Hill (N1), taxonomic diversity (Δ), taxonomic distinctness (Δ*) average phylogenetic diversity index (Phi+) and total phylogenetic diversity index (sPhi+). Simpson's evenness measure ($E_{1/D}$) was calculated using MS Excel by dividing reciprocal of Simpson's dominance index with total number of species (S) in the sample. The diversity indices were calculated for all the three fisheye BRDs and the results are given in the table 6.9.

Table. 6.9. Mean Diversity indices of species escaped from semicircular fisheye, oval vertical fisheye and oval horizontal fisheye

Fisheye	S	d	J'	H	H'	N1	λ'	$E_{1/D}$	Δ	Δ*	Phi+	sPhi+
SC	47	8.43	0.29	0.97	1.62	3.07	0.63	0.03	19.30	51.66	32.22	1514.3
OV	**88**	**13.78**	**0.68**	**2.89**	**4.42**	**21.34**	**0.08**	**0.15**	**58.30**	63.04	34.25	**3014.3**
OH	56	9.01	0.22	0.79	1.26	2.40	0.72	0.02	22.56	**79.32**	**37.24**	2085.7

SC=Semicircular fisheye, OV=Oval Vertical fisheye, OH=Oval Horizontal fisheye

From the results it was clear that the catch escaped from oval vertical fisheye was found to have more diversity in terms of S, d, J', H, H', N1, λ', $E_{1/D}$, Δ and sPhi+. The higher biodiversity of oval vertical fisheye was primarily due to the higher number of species and the richness observed among the species. A very low Simpson's dominance and very high Pielou's evenness and Simpson's evenness also attributed to the higher biodiversity of oval vertical fisheye.

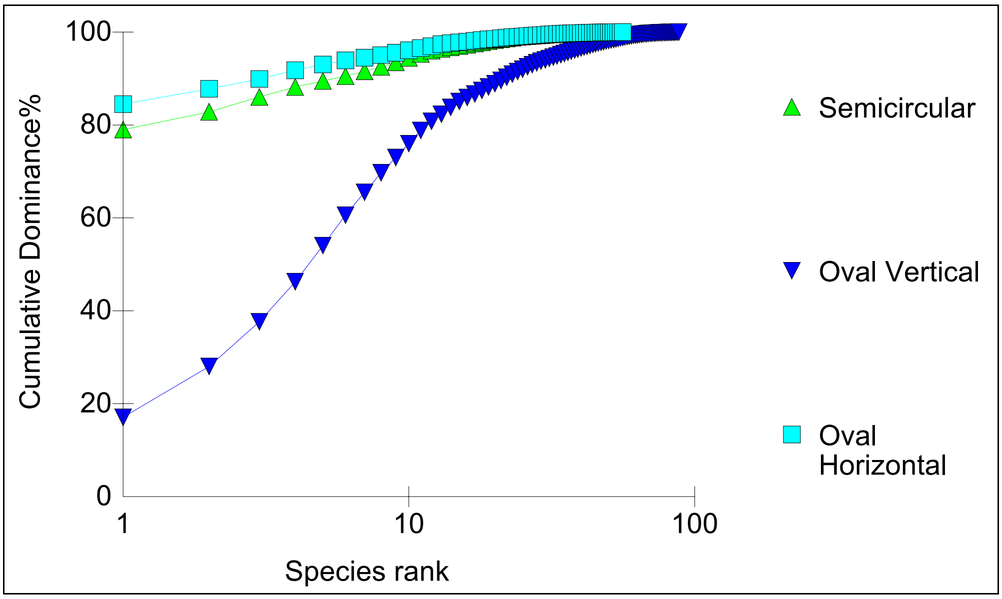


Fig. 6.13. Dominance plot for species escaped from three different fisheye BRDs

6.5. Conclusion

From the experiments conducted in the traditional fishing areas, the bycatch exclusion capability and target catch retention properties of three designs of fisheye *viz*, 300 x 200 mm oval exit with horizontal orientation, 300 x 200 mm oval exit with vertical orientation and 300 x 200 mm semicircular exit with horizontal orientation are found to be in par with the experiments conducted in different parts of the world (Brewer et al., 1998; Gregor and Wang, 2002; AFMA, 2002; Pillai, 2004)

Fisheye having 300 x 200 mm oval exit with vertical orientation showed poor performance and was not found suitable due to significant loss of target catch. On the other hand semicircular fisheye showed promising performance when experimented individually, in terms of higher target catch retention averaging at 99.17%. Higher bycatch exclusion of about 50.58% and lowest target catch loss of 0.83% was also observed with semicircular fisheye when operated individually. The selectivity studies showed that with all the three fisheye designs considerable amount of juveniles were found to be escaping from the trawls and for all species taken in to consideration for selectivity studies semicircular fisheye showed better performance except for *Rastrelliger kanagurta*. Considerable reduction in the quantity of larger individuals resulted in quality shrimps without damages. Comparatively better performance of semicircular fisheye in reducing the target catch loss is attributed to the low turbulence it produced as the design was not projecting out of the normal trawl codend design as in the case of other fisheye designs. The higher bycatch exclusion of semicircular fisheye was attributed to the higher area of the exit opening which has about 9.6% more than other oval designs. This experiment provided important information regarding the efficiency of various designs of fisheye BRDs. The 300 x 200 mm semicircular fisheye could be considered as a potential BRD for use in the shrimp trawling.

Chapter 7

Comparative Evaluation of Semicircular and Oval Fisheye BRDs

7.1. Introduction

The importance of fisheye BRDs is clear form discussions in Chapter 6 where three different designs of fisheye were evaluated individually, in terms of bycatch exclusion and shrimp retention characteristics. Among the three designs 300 x 200 mm semicircular fisheye with horizontally orientated exit performed much better followed by 300 x 200 mm oval fisheye with horizontally oriented exit. Fisheye is an important bycatch reduction device facilitating the escapement of fish especially those which are undersized from the codend (Pillai, 1998; Pillai et al., 2004) that could be successfully incorporated into a trawl codend for reducing the bycatch without compromising the target catch.

7.2. Objectives of the study

From the previous experiment with three fisheye BRDs, the designs that has given better performance *viz*, 300 x 200 mm semicircular fisheye and 300 x 200 mm oval fisheye with horizontally oriented exit were selected for comparative performance evaluation. The experiment was conducted in order to confirm the selectivity factors, bycatch exclusion and target catch retention characteristics of both designs of fisheye and thereby finding the optimum design that could be recommended for the trawling industry.

7.3. Materials and methods

7.3.1. Fisheye BRDs

300 x 200 mm Semicircular fisheye with horizontally orientated exit (Fig. 6.1 and 6.4) and 300 x 200 mm Oval Fisheye with horizontally orientated exit (Fig. 6.3 and 6.6) were used for the comparative analysis. The fisheye BRDs used for the experiment were fabricated in the CIFT gear fabrication laboratory.

The supporting rods extended up to 300 mm and the BRD was made entirely of stainless steel rods of 6 mm dia. All fisheyes were fitted on the topside of the trawl codend at a distance of 4.5 m (225 meshes) from the fore end and 1.5 m (75 meshes) from the rear end of the codend.

7.3.2. Experimental fishing trials and catch handling

The fisheye BRDs were operated using a 29.0 m shrimp trawl with 20 mm diamond mesh codend (Fig. 3.4) from the research vessels of Central Institute of Fisheries Technology. The experimental fishing operations were conducted during May-June 2006 in coastal waters off Cochin at a depth range of 9-32 m (Fig. 3.1). Alternate haul method with covered codends was adopted to conduct the study. Catch from the codend and the cover were separately sorted and identified up to species level. Weights of each species were taken and for large quantities sub samples were taken. In the case of fishes and shrimps total length was taken and for cephalopods the mantle length was measured.

7.4. Results and Discussion

7.4.1. Comparative evaluation of Oval and Semicircular fisheye

During 26 days of fishing operations in the traditional fishing grounds off Cochin 12 paired hauls were taken using the two designs and a total of 280.29 kg catch was obtained with an average CPUE of 9.12 kg/h. Trawl net with semicircular fisheye encountered 94.89 kg and that with oval fisheye encountered 185.4 kg of the catch. The exclusion percentages of the two designs were 28.44% and 31.81% respectively. 100% escapement was shown by 9 species each among 77 species encountered in the semicircular fisheye equipped trawl and among 70 species in the oval fisheye equipped trawl. While *Ilisha filigera, Johnius carutta, Johnius dussumieri, Liza subviridis, Penaeus monodon, Scomberoides tol, Scomberomorus guttatus, Selar crumenophthalmus* and *Valamugil speigleri* showed 100% escapement from oval horizontal fisheye, whereas *Caranx sexfasciatus, Decapterus russelli, Encrasicholina punctifer, Sardinella albella, Scomberoides lysan, Scomberoides tol, Scomberomorus guttatus, Scomberomorus lineolatus* and *Thryssa puruva* showed 100% escapement from semicircular fisheye and More than 50% escapement was shown by another 24 species from semicircular fisheye and 13 species in oval fisheye. 16 and 11 species respectively in semicircular and oval fisheye showed 0% escapement. Upto 50% escapement was shown by 28 and 37% respectively from semicircular and oval fisheye. Regarding target catch loss, semicircular fisheye performed much better than oval fisheye retaining 97.76% of shrimps (2.24% of shrimp loss), while oval fisheye retained only 86.8% of shrimp (13.2% shrimp loss). Results of comparative performance evaluation of 300 x 200 mm Semicircular Fisheye with horizontally orientated exit and 300 x 200 mm Oval Fisheye with horizontally orientated exit in terms of bycatch exclusion and target catch retention are given in Tables 7.1 and 7.2.

Table. 7.1. Bycatch exclusion effect on species groups due to the installation of Oval fisheye and Semicircular fisheye

Fisheye	Species groups	Encountered catch, kg	Retained, %	Excluded, %
200 x 300 mm Oval fisheye	All species	94.885	68.19	31.89
	Shrimp species	18.075	86.80	13.20
	Non-shrimp species	76.810	63.81	36.19
200 x 300 mm Semicircular fisheye	All species	185.400	71.56	28.44
	Shrimp species	36.665	97.76	2.24
	Non-shrimp species	148.735	65.10	34.90

Table. 7.2. Results of experiments with Oval fisheye and Semicircular fisheye

	Fisheye BRD with 300 x 200 mm oval exit	Fisheye BRD with 300 x 200 mm semicircular exit
No. of hauls	12	12
Total catch (kg)	94.885	185.4
CPUE (kg/h)	7.30	14.26
Retained catch (kg)	64.699	132.668
Retained catch (%)	68.19	71.56
Excluded catch (kg)	30.186	52.732
Excluded catch (%)	31.81	28.44
Retained shrimp catch (kg)	15.69	35.845
Excluded shrimp catch (kg)	2.385	0.82
Total shrimp catch (kg)	18.075	36.665
Retained shrimp catch (%)	86.80	97.76

Excluded shrimp catch (%)	13.20	2.24
Retained bycatch (other than shrimps) (kg)	49.009	96.823
Retained bycatch (other than shrimps) (%)	63.81	65.10
Excluded bycatch (other than shrimps) (kg)	27.801	51.912
Excluded bycatch (other than shrimps) (%)	36.19	34.90
No. of species caught	70	77
Fish species	57	61
Shrimp species	5	5
Other species	8	11
100% exclusion (No. of species)	9	9
>50% exclusion (No. of species)	13	24
Up to 50% exclusion (No. of species)	37	28
0% exclusion (No. of species)	11	16

7.4.2. Student's t-test

In the case of oval and semicircular fisheye Student's *t*-test for paired samples was conducted and statistically significant difference in bycatch exclusion was shown by five species which includes two shrimp species and one finfish species, in terms of higher exclusion from oval fisheye and two finfish species in favour of semicircular fisheye. *Secutor ruconius* (P=0.042) and *Thryssa mystax* (P=0.028) showed statistically significant exclusion from semicircular fisheye while form oval fisheye statistically significant exclusion was shown by *Secutor insidiator* (P=0.048), *Metapenaeus dobsoni* (P=0.011) and *Parapenaeopsis stylifera* (P=0.044). The significance found in the shrimp species clearly showed a significantly higher exclusion of targeted shrimp from oval fisheye when compared with semicircular fisheye. Though statistically insignificant 28 species showed higher exclusion characteristics from semicircular fisheye while from oval fisheye about 15 species showed better exclusion rates than from semicircular fisheye.

7.4.3. Selectivity studies

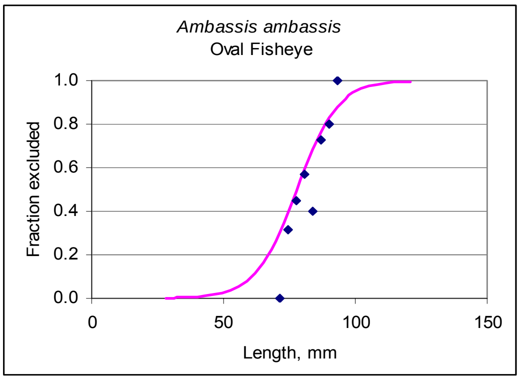
The selectivity of fisheye bycatch reduction device is more or less a new area where not much work has been conducted and published. As in the case of nets, the shape and size of meshes and in the case of grid BRDs the bar-space dimensions determines the selectivity. In the case of fisheye BRD the behavioural aspects of the individual species generally overrides the physical separation principle. In fisheye BRD, fishes are given a provision to escape by providing adequate openings at specific locations and those species that swim actively could find this opening and escape. Again it is well established that the swimming speed and ability of a particular species were directly proportional to its body size and this behavioural aspects were utilized to determine the selectivity of fisheye BRD, since larger individuals will swim actively and a find the way to escape and this ability will be reduced as their size decreases. The main limitation was to determine the selectivity of passive organisms such as shrimps as their escapement would be influenced mainly by the water current.

Selectivity curves and selectivity parameters of dominant species *viz, Ambassis ambassis, Alepes djedaba, Dussumieria acuta, Encrasicholina devisi, Lepturacanthus savala, Megalaspis cordyla, Rastrelliger kanagurta, Sardinella longiceps, Stolephorus commersonnii* and *Thryssa mystax* are given in Figs. 7.1 to 7.10 and in Table. 7.3 respectively. Both fisheye showed some what similar selectivity patterns and the L_{50} values were found to be lower for six species each for both fisheye. Seven out of 10 species showed good escapement of juveniles form both fisheyes since the L_{50} values were found to be less than the length at first maturity of the species. For *Encrasicholina devisi* and *Stolephorus commersonnii* the L_{50} values were found to be higher than their length at first maturity for both fisheye, but the values were found to be lower for semicircular fisheye. For *Lepturacanthus savala* the L_{50} value was lower than L_m for semicircular fisheye.

Table. 7.3. Selectivity parameters for Semicircular fisheye and Oval horizontal fisheye

Species	Fisheye	$L_{25\%}$	$L_{50\%}$	$L_{75\%}$	Selection Range, mm	Length at first maturity, mm
Ambassis ambassis	Semicircular	77.74	89.93	77.74	102.13	55-75
	Oval horizontal	69.24	77.69	86.14	16.90	
Alepes djedaba	Semicircular	133.79	156.09	178.40	44.62	180-189
	Oval horizontal	57.21	109.52	161.84	104.63	
Dussumieria acuta	Semicircular	112.01	116.40	120.79	8.79	140-150
	Oval horizontal	131.02	166.46	201.90	70.88	

Encrasicholina devisi	Semicircular	70.53	75.77	81.01	10.48	64.5
	Oval horizontal	75.90	85.36	94.82	18.93	
Lepturacanthus savala	Semicircular	335.40	403.09	470.78	135.38	418-750
	Oval horizontal	420.46	786.67	1152.8	732.41	
Megalaspis cordyla	Semicircular	76.09	137.12	198.16	122.07	250
	Oval horizontal	11.09	87.38	163.67	152.59	
Rastrelliger kanagurta	Semicircular		39.53	108.19	137.33	190-220
	Oval horizontal	22.00	62.69	103.38	81.38	
Sardinella longiceps	Semicircular	59.84	85.27	110.70	50.86	150-162
	Oval horizontal	62.86	80.00	97.14	34.28	
Stolephorus commersonnii	Semicircular	90.47	101.22	111.97	21.50	74
	Oval horizontal	97.19	112.34	127.50	30.31	
Thryssa mystax	Semicircular	104.25	161.76	219.28	115.04	130
	Oval horizontal	93.56	103.55	113.53	19.97	



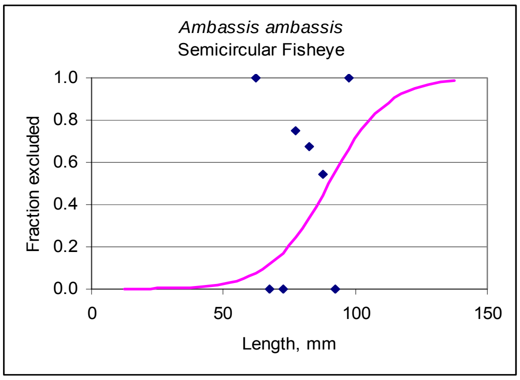
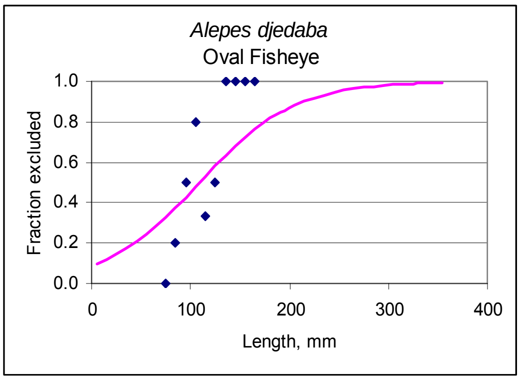


Fig. 7.1. Selectivity curves for *Ambassis ambassis*



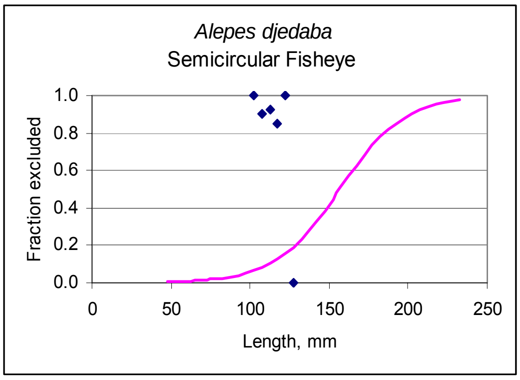


Fig. 7.2. Selectivity curves for *Alepes djedaba*

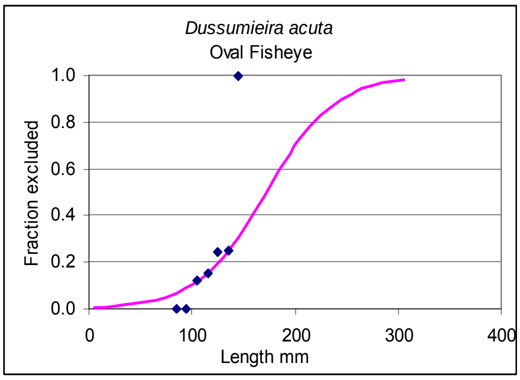


Fig. 7.3. Selectivity curves for *Dussumieria acuta*

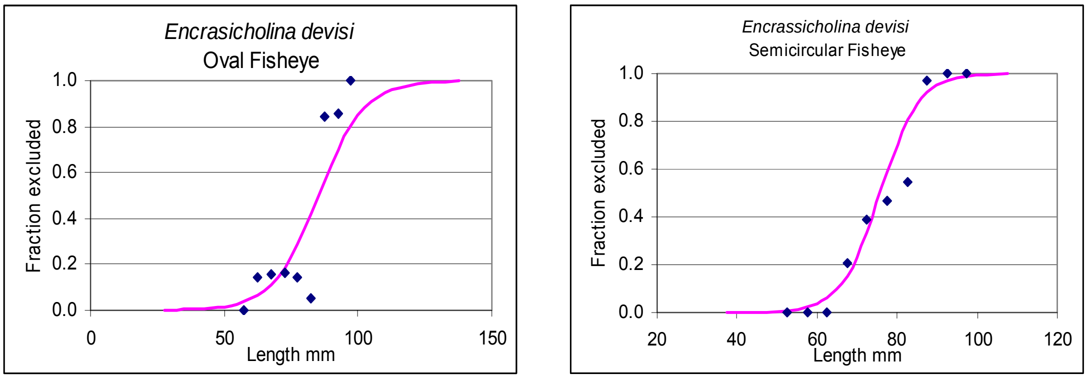


Fig. 7.4. Selectivity curves for *Encrasicholina devisi*

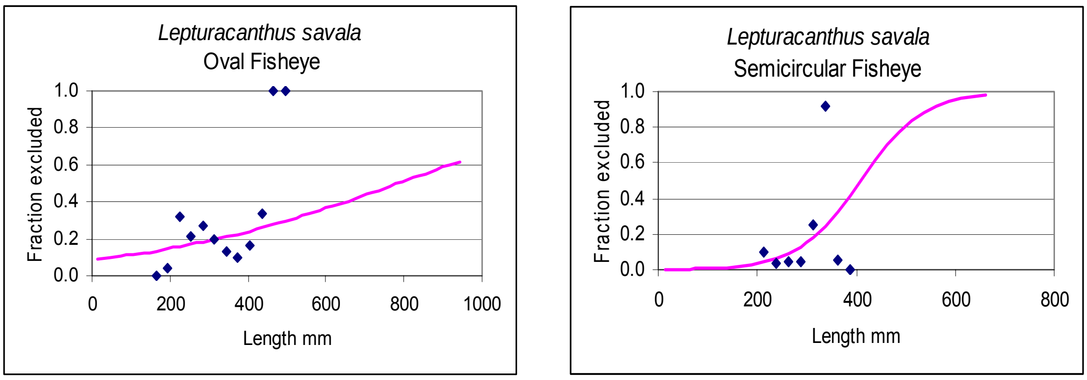


Fig. 7.5. Selectivity curves for *Lepturacanthus savala*

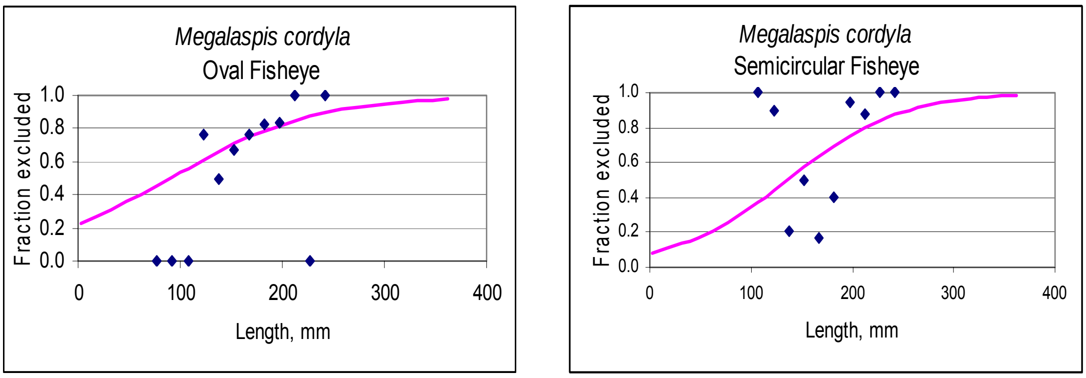


Fig. 7.6. Selectivity curves for *Megalaspis cordyla*

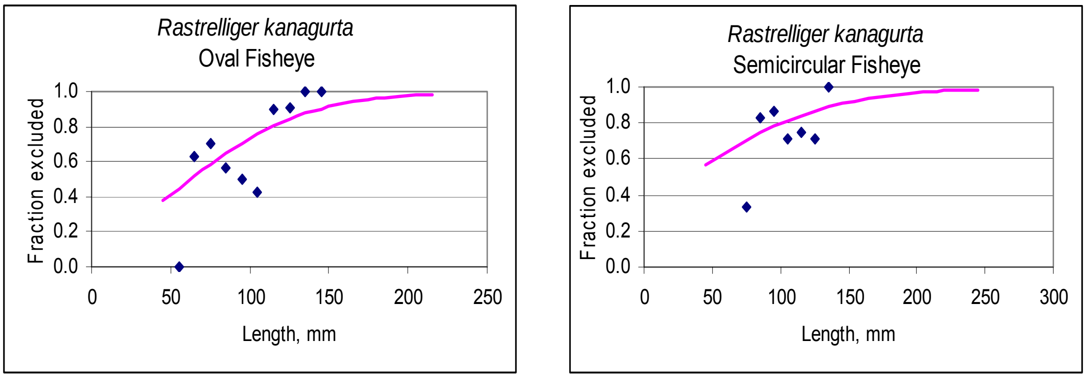


Fig. 7.7. Selectivity curves for *Rastrelliger kanagurta*

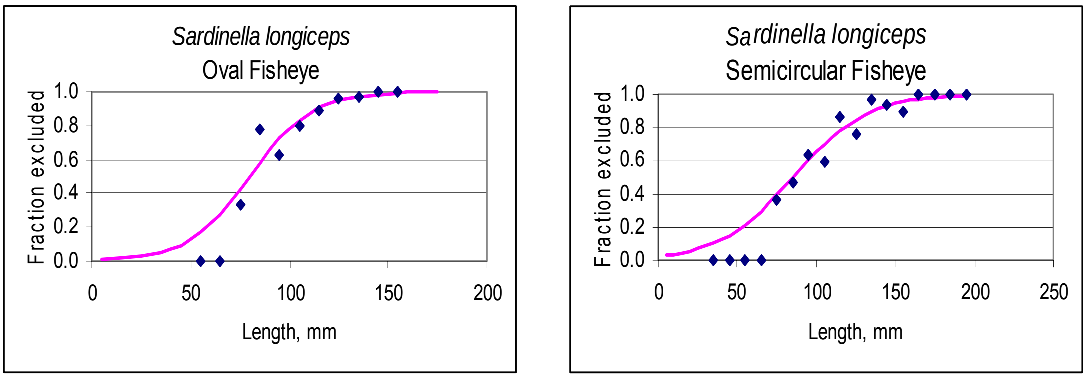


Fig. 7.8. Selectivity curves for *Sardinella longiceps*

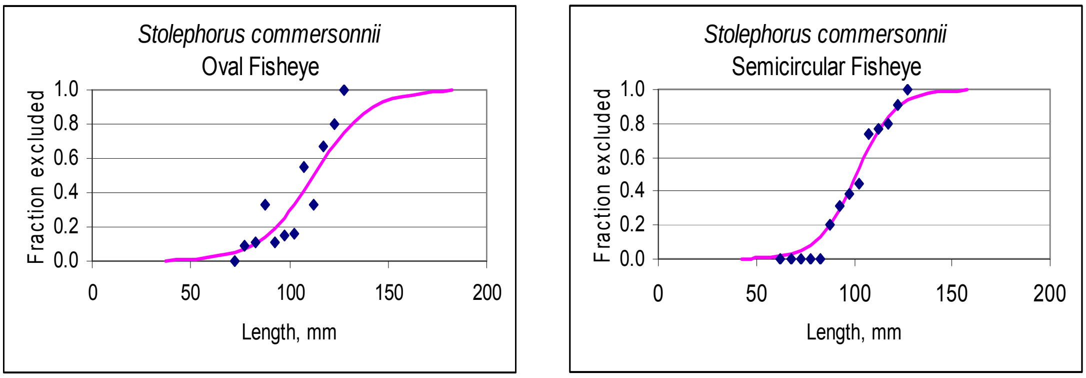


Fig. 7.9. Selectivity curves for *Stolephorus commersonnii*

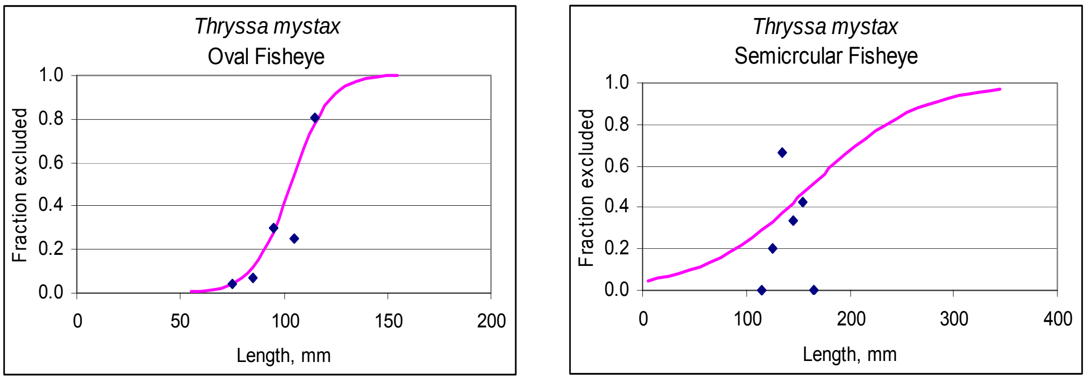


Fig. 7.10. Selectivity curves for *Thryssa mystax*

7.4.4. PRIMER Analysis

PRIMER software package (Version 5.2.9; Plymouth marine Laboratory, Plymouth, UK) was used for SIMPER analysis, plotting k-dominance curves, and estimating diversity indices such as total number of species (S), Margalef richness (d), Pielou's evenness (J'), Brillouin index (H), Shannon index (H'), Simpson's dominance index (λ'), Hill (N1), taxonomic diversity (Δ), taxonomic distinctness (Δ*) average phylogenetic diversity index (Phi+) and total phylogenetic diversity index (sPhi+). Simpson's evenness measure ($E_{1/D}$) was calculated using MS Excel by dividing reciprocal of Simpson's dominance index with total number of species (S) in the sample.

The diversity indices calculated for semicircular fisheye and oval horizontal fisheye are given in the table 7.4. From the results it was clear that the catch escaped from oval horizontal fisheye was found to have more diversity in terms of J’, H, H’, N1, $E_{1/D}$, Δ, Δ* and Phi+. Though the number of species and species richness index were found to be higher for semicircular fisheye, its higher dominance index was the cause for the lower biodiversity indices. In semicircular fisheye 78% of individuals were represented by only 3 species again showing higher dominance.

Table. 7.4. Mean Diversity indices of species escaped from Oval and semicircular fisheye

Fisheye	S	d	J'	H	H'	N1	λ'	$E_{1/D}$	Δ	Δ*	Phi+
Oval	53	8.64	**0.51**	**1.90**	**2.91**	**7.54**	0.22	**0.09**	**56.28**	**71.73**	**36.66**
Semicircular	**60**	**8.97**	0.45	1.76	2.65	6.30	**0.27**	0.06	50.03	68.42	35.48

In the k-dominance plot (Fig 7.11), in which the cumulative ranked abundances of species obtained in oval horizontal fisheye and semicircular fisheye was plotted against species rank and it was observed that the curve for oval horizontal fisheye lay on the lower side, extends further and raised slowly showed higher biodiversity in the catch excluded from oval horizontal fisheye.

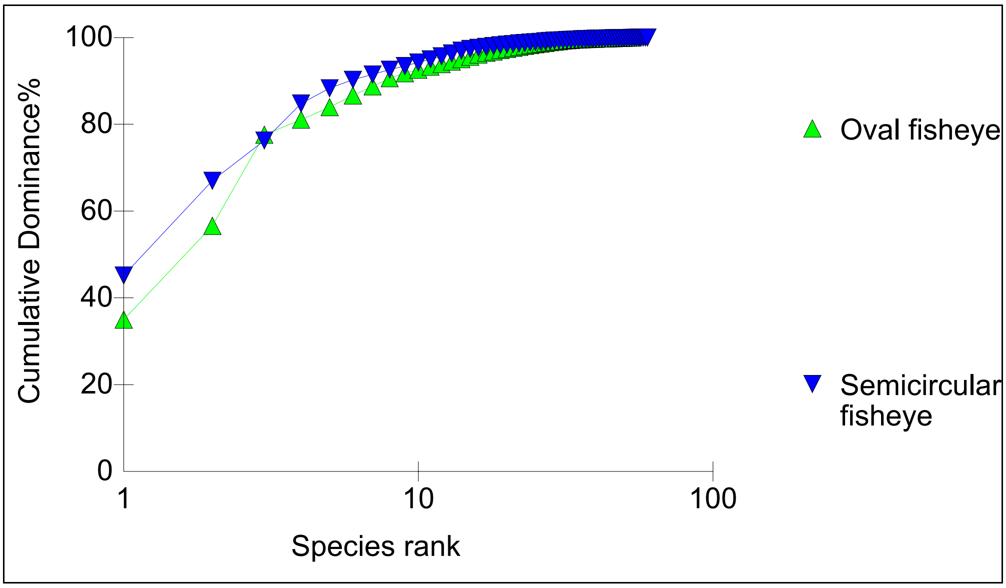


Fig. 7.11. k-dominance plot for species escaped from oval and semicircular fisheye

Bubble plots could be obtained by superimposing the abundance data of a particular species in the MDS plot, and the abundance of that species in a particular sample could be directly understood by the size of the bubble. Bubble plots of some discriminating species such as *Ambassis ambassis, Stolephorus* *commersonnii, Anadontostoma chacunda, Johnius carouna, Rastrelliger kanagurta and Uroteuthis (Photololigo) duvauceli,* are given in Fig. 7.12. The stress value (0.15), which overlying on the MDS plot showed an excellent ordination of the samples collected.

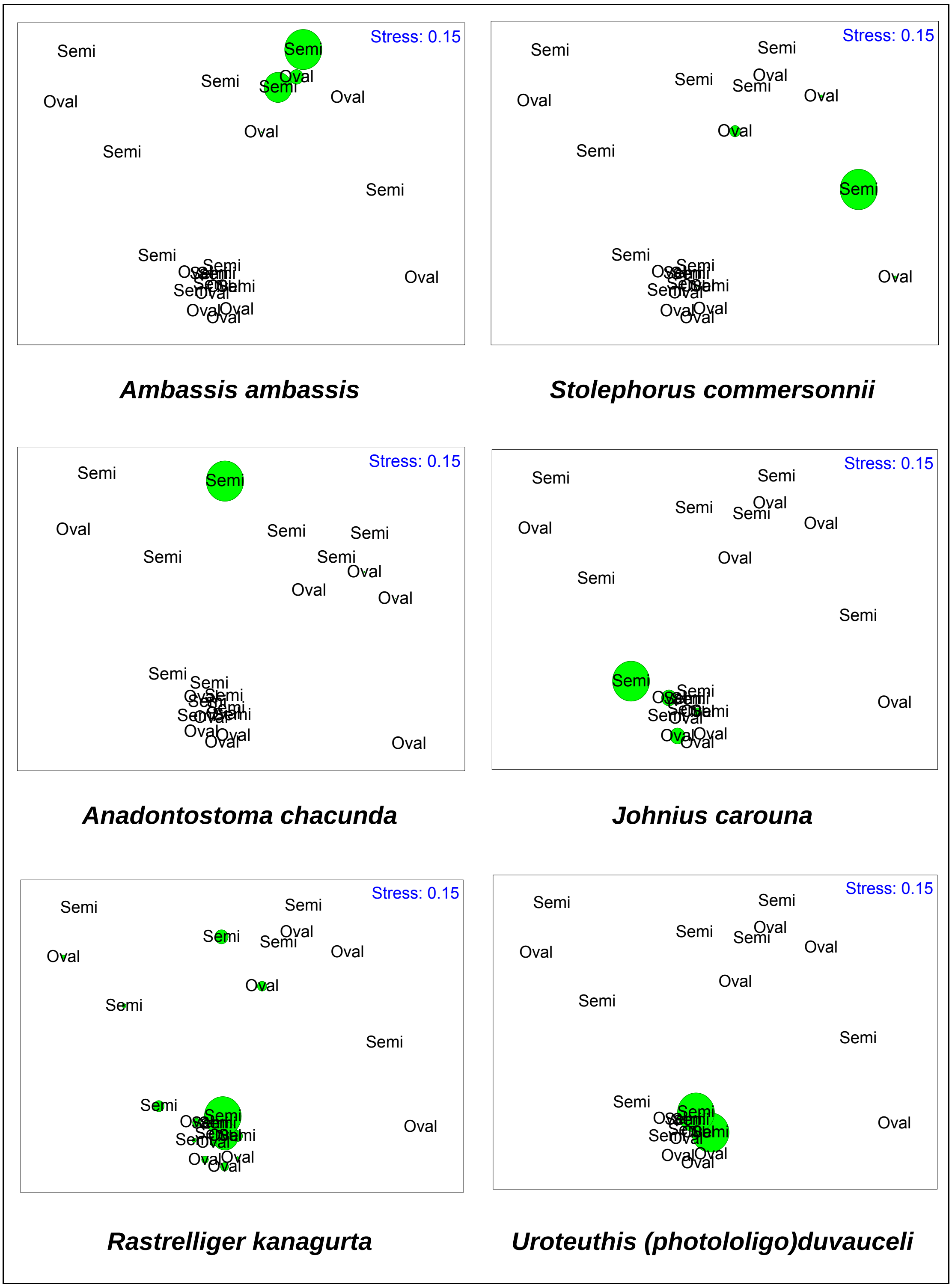


Fig. 7.12. Bubble plots showing abundance of escaped species from Oval and semicircular fisheye

7.5. Conclusion

Semicircular fisheye showed consistently better performance when experimented individually and also when compared with 300 x 200 mm oval fisheye with horizontal orientation, in terms of target catch retention which averaged at 99.17% and 97.76% respectively. Mean bycatch exclusion rates obtained by semicircular fisheye BRD were 50.58% and 34.90% respectively during individual and comparative trials. The selectivity studies showed that with both fisheye designs considerable amount of juveniles were found to be escaping from the trawls and for all species taken in to consideration semicircular fisheye showed better selectivity curves except for *Rastrelliger kanagurta*. Results of diversity analysis were better in respect of oval design, as indicated by the high evenness of the species that were excluded.

In view of its significantly high target catch retention properties and good bycatch exclusion characteristics 300 x 200 mm semicircular fisheye can be considered as a potential BRD suitable for adoption in the shrimp trawling.

Chapter 8

Comparative Evaluation of Rigid Oval and Rectangular Grid BRDs

8.1. Introduction

The complex management issues that arise during the simultaneous capture of commercial and bycatch species having different length ranges, body shapes and behavioural patterns towards the gear cannot be addressed only by controlling the codend mesh size (Fonseca et al., 2005a). This understanding led to the development of various types of sorting and separating devices which make use of soft devices such as nettings, ropes etc. The main disadvantage of these soft devices were the difficulty in maintaining shape underwater during fishing operations, which resulted in improper sorting and inadequate bycatch exclusion. This disadvantage could be minimized by using rigid structures in their construction. Bycatch reduction devices in the form of rigid separation grid were developed in Norway in 1980. The design was developed by the fishermen as a new concept primarily to avoid the bycatch of jellyfish in a shrimp trawl. This device was quite successful in eliminating bycatch and is popularly known as the Nordmore grid. Many later modifications of the device have shown varying degrees of success and several design variations are in vogue in fisheries elsewhere.

8.1.1. Literature review

Riedel and De Alteris (1995) described the ideal configuration for a sorting grid system that includes a funnel that accelerates the catch in conjunction with a sorting grate invisible to water (that does not disturb water passing through it) would better separate small animals from large and result in little or no loss of target species in trawls. The Nordmore grid system consisted of a rectangular or oval grid made of steel or aluminium provided with longitudinal bars with suitable bar-space. One or two horizontal bars would be attached to provide additional strength to the grid, which also reduces the flexibility of bars thereby maintaining constant bar-space. Bar-spacing of Nordmore grid varied from 10 to 100 mm.

This grid would act as a sieve or grate which facilitated the size separation of species with in a trawl net. The grids were usually installed in the extension piece between throat and codend of a trawl net. The angle of attack was usually between 45° to 60° from the horizontal. There would be a fish outlet either at the top or at the bottom in front of the grid. An accelerator funnel or guiding panels or flapper constructions would be mounted in front of the grid in order to guide the catch on to the grid (Isaksen et al., 1992; Crespi and Prado, 2002).

The bycatch reduction and sorting effect of the Nordmore system was effected by taking advantage mainly of the difference in size and to some extend the behaviour of shrimp and other animals caught in the trawl. Large animals and active swimmers were released out through the exit opening while the organisms that could pass through the grid were caught and retained in the codend. Matsushita et al. (2004) observed four different behaviours of fishes towards a grid during his experiments in Tokyo bay beam trawls. Fishes showed behaviours such as forward swimming in the towed direction, swimming over the grid, sticking on the grid, and passing through the grid. He also noticed that the reaction primarily depends on light and the penetration of some fishes through the bars was governed by voluntary action. Fishermen readily accepted the separator grid because of its shrimp / fish sorting efficiency and exclusion of large bycatch. The system also became popular in fishing areas that were normally closed due to high occurrence of bycatch (Isaksen et al., 1992).

In a study which assessed 16 different BRDs in Australian Northern prawn trawl fishery showed that inclined grids were extremely effective at excluding large bycatch such as sharks, rays and turtles. They were also effective in reducing non targeted fish up to 39% especially when used in combination with other BRDs (Brewer et al., 1998). Halliday and Cooper (1999) conducted experiments in Scotian shelf with Nordmore grid having 40 mm bar-space showed 48-98% bycatch reduction with less than 5% target catch loss. Similar experiments conducted by Graham (2003) with rigid grid in the English east-coast showed significant reduction in bycatch up to 94% with no significant loss of shrimp. Kvalsvik et al., 2006 conducted studies in the North Sea Norway pout fishery showed 62.4-94.6% bycatch reduction but also caused target catch loss ranged between 22-32.8%. He also stated that 100% sorting of target catch from non-target catch is practically impossible. In a comparative study made by Broadhurst and Kennelly (1996) in the Clarence River prawn-trawl fishery using Nordmore grid, modified Nordmore grid and blubber chute showed 75-90% bycatch reduction by all the three BRDs at the same time only Nordmore grid retained maximum target catch.

Many modifications have been made by researchers and the industry in order to improve the performance of Nordmore grid in varying fishing conditions (Grimaldo and Larsen, 2005). Fonseca et al. (2005a) tested a modified Nordmore grid in Portuguese continental waters showed non-target catch reduction between 48-74% but it also resulted in target catch loss between 4-15%. Grimaldo (2006) experimented a new version of Nordmore grid with tear-drop shaped bars showed 72% bycatch reduction along with 5.6% loss of shrimps. He also reported that at lower inclination angles, shrimp loss increased to 12.3% and fish exclusion increased to 86% and at higher inclination angles, shrimp loss was 4.2% and fish exclusion was 73% with out significant variation in the selectivity curves. Studies on sorting grids conducted by Maartens et al. (2002) showed that the grids with circular openings showed better exclusion of juveniles. AusTED was a modified flexible grid device fabricated by the combination of the principles of various BRDs. Experiments conducted with AusTED in Australian waters showed promising results in terms of bycatch reduction, shrimp retention and exclusion of turtles and large animals (McGilvray et al., 1999, Robins et al., 1999, Mounsey et al., 1995, Robins-Troeger et al., 1995, Brewer et al., 1998, Robins and McGilvray, 1999). Experiments with flexible grids were conducted by many researchers in Denmark and Norway which gave better results in terms of bycatch reduction, target catch retention and ease of handling on board (Madsen and Hanson, 2001; Polet, 2002).

Certain experiments conducted with grids and square mesh windows showed similar selectivity characteristics at the same time when grids used in combination with other BRDs showed better efficiency in terms of bycatch exclusion and target catch retention (Eigaard and Holst, 2002; Graham et al 2004b; Fonseca et al., 2005b). An industry modified Nordmore grid with composite square mesh panel was tested in Shark Bay prawn-trawl fishery of Western Australia reduced bycatch by 49% and several non-targeted and incidental catches by 75.7% (Broadhurst et al., 2002). Research trials conducted by Eigaard and Holst (2004) using sorting grid in combination with square mesh window to reduce the juvenile gadoids in the Norway pout fishery showed promising results. The system reduced 37-57% of bycatch at the same time square mesh window retained large marketable fishes. Fonseca et al (2005a) done experiments with Nordmore grid having 30 mm bar-space in combination with square mesh window in Portuguese waters showed considerable escapement of bycatch. He also noticed the contrasting behaviour displayed by demersal and pelagic species towards the grid.

Even though the bycatch exclusion characteristic of a BRD was promising fishers would have more concern regarding the short-term loss of target catches (Fonseca et al., 2005a). Prawn loss occurs primarily due to incorrect grid angle, grid blockage or poor performance of the accelerator funnels / guiding panels. High grid angle may increase the distance between the guiding panel and grid that could result in shrimp loss. Increasing the length of the panel or adding weights to the end of the panel may prevent shrimp loss. Grid blockage to a certain extend could be reduced by increasing the size of the exit opening (Epperly and Teas, 1999; Epperly and Teas, 2002; Crespi and Prado, 2002).

8.2. Objectives of the study

The main objective of this comparative study was to evaluate the effect of grid shape in the bycatch exclusion and shrimp retention characteristics in order to determine optimum grid shape suitable for incorporating in the shrimp trawl.

8.3. Materials and Methods

8.3.1. Rectangular grid

The dimensions of the rectangular grid used for the experiments were 1000 mm in height and 800 mm in width and had a bar spacing of 22 mm. It was fabricated out of stainless steel rods, outer frame diameter 8 mm and bar diameter 4 mm. The grid was kept at an angle of 45° from horizontal. Two floats were provided on the top of the grid on either side, to compensate the weight of the grid and also to keep the grid always in the upright position by providing some extra buoyancy (Isaksen et al., 1992; Brewer et al., 1998).

A triangular exit opening with dimensions of 600 mm at base and 450 mm at sides was provided at the top of the trawl extension in front of the grid made by cutting all bars from the upper corners of the grid. The opening was reinforced by a 4 mm rope at its edges. An accelerator or guiding funnel was provided in front of the grid at a distance of 0.5 m from the bottom of the grid. The funnel was inclined towards the bottom so that the water flow would be directed towards the bottom of the grid.

8.3.2. Oval grid

This was an oval shaped inclined grid design had dimensions of 1000 mm in height and 800 mm in width and having 22 mm bar-space. It was fabricated out of stainless steel rods with outer frame diameter 8 mm and bar diameter 4 mm. The grid was kept at an angle 45° from horizontal. Two floats were provided on the top of the grid on either side, to compensate the weight of the grid and also to keep the grid always in the upright position by providing some extra buoyancy (Mitchell et al., 1995; Dawson and Boopendranath, 2001; Boopendranath, 2003; Hannah et al., 2003).

A triangular opening having dimensions 600 mm at base and 450 mm at sides was provided at the top of the trawl extension in front of the grid made by cutting all bars from the upper sides of the grid. The exit opening was reinforced by a 4 mm rope at its edges. An accelerator or guiding funnel was provided in front of the grid at a distance of 0.5 m from the bottom of the grid. The funnel was inclined towards the bottom so that the water flow would be directed towards the bottom of the grid. A sketch of flat rectangular and oval grid is given in Fig. 8.1. Graphical representations of the installation of rectangular grid and oval grid were given in Fig. 8.2 and Fig. 8.3 respectively. Shrimp trawl codends incorporated with rectangular and oval grids are shown in Fig. 8.4 and exit openings before rectangular and oval grid are shown in Fig. 8.5.

8.3.3. The gear

The gear used for the operation of fisheye was a 29.0 m shrimp trawl with 20 mm diamond mesh codend (Fig. 3.4). The trawl was made entirely of twisted polyethylene. V-type otter boards of 80 kg each were used as the sheer device.

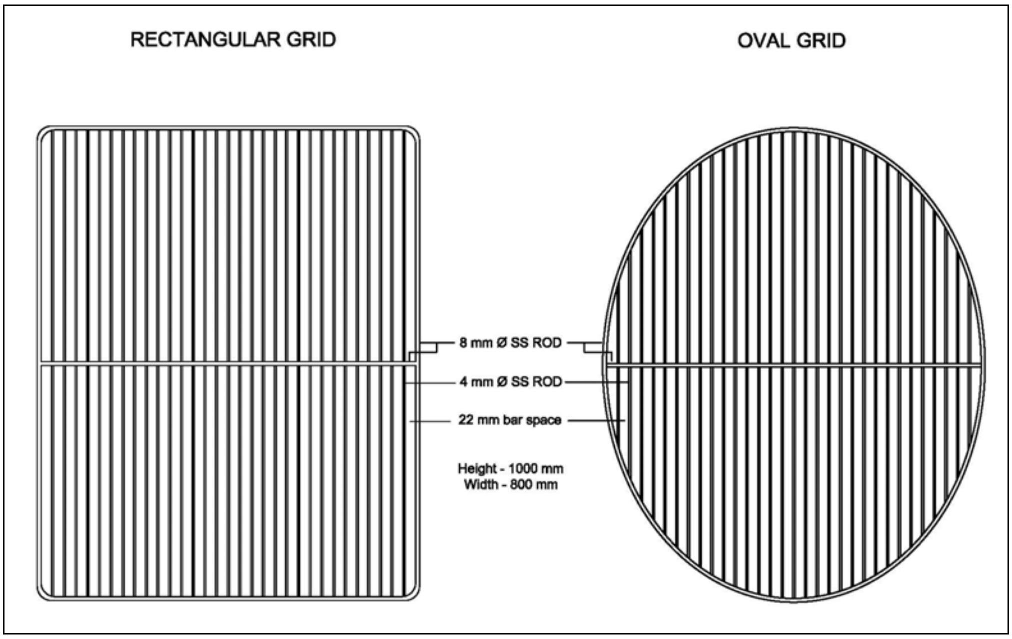


Fig. 8.1. A sketch of flat rectangular and oval grid

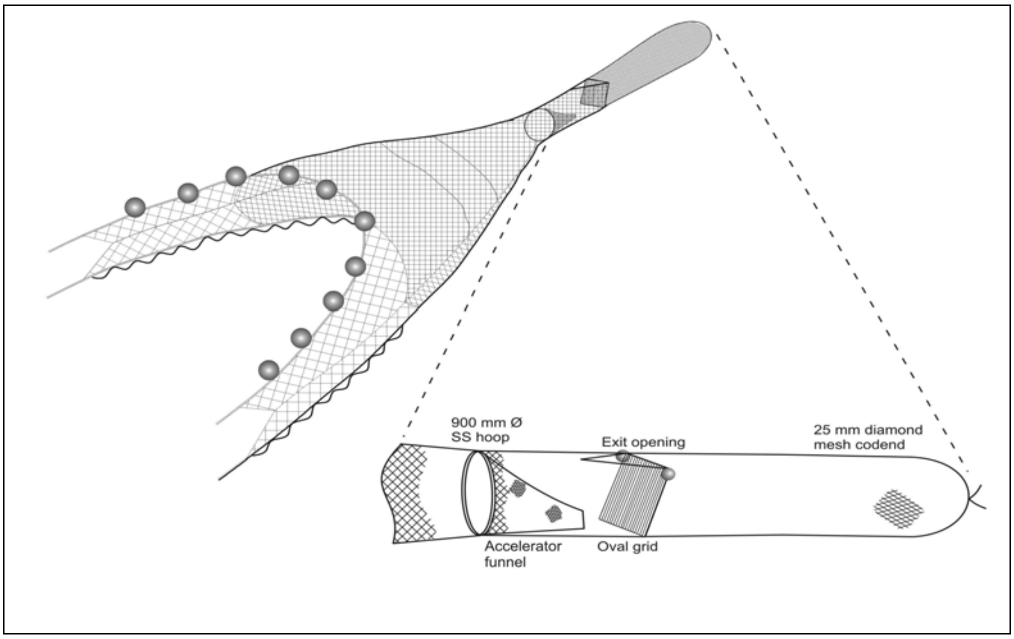


Fig. 8.2. Graphical representation showing installation of flat rectangular grid

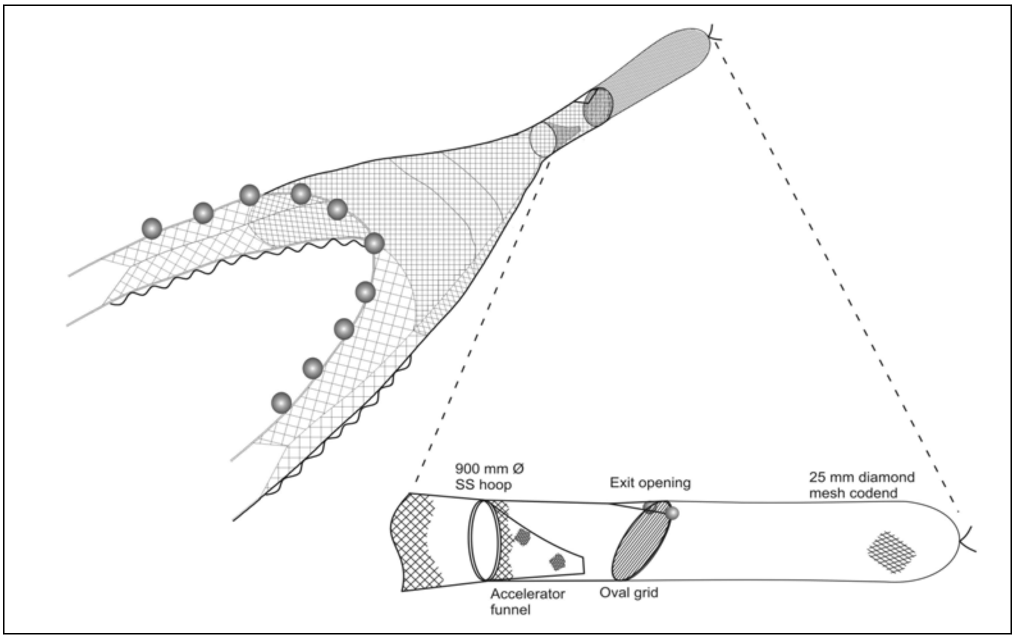


Fig. 8.3. Graphical representation showing installation of oval grid

Fig. 8.4. Shrimp trawl codends incorporated with rectangular grid and oval grid

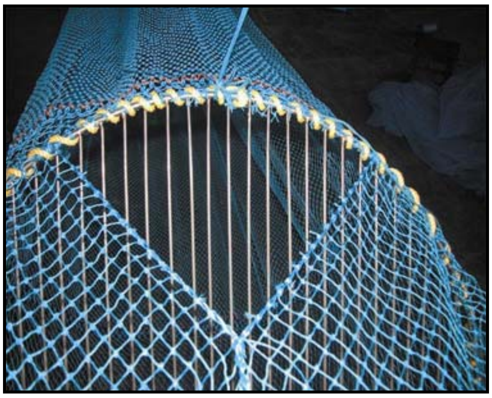


Fig. 8.5. Exit openings before rectangular and oval grid

8.3.4. Vessels used for the experiment

Two research vessels of Central Institute of Fisheries Technology were used for conducting the field trials. First one is a steel trawler MFB Matsyakumari (17.5 m LOA and 57.17 GRT) having 277 bhp @ 1000 rpm Kirloskar Mann engine and the second one is a wooden trawler MFV Sagar Shakti (15.24 m LOA and 30 GRT) having 223 bhp @ 1800 rpm Ruston MWM engine.

8.3.5. Area of study

The experimental fishing operations were conducted in coastal waters off Cochin at depths ranging between 9 and 32 m (Fig. 3.1).

8.3.6. Experimental fishing trials and catch handling

During the period, a total of 13 pairs of alternate hauls were taken during 12 fishing days on board MFV Sagar Shakti, using 29.0 m shrimp trawl with a single grid positioned in the extension piece in front of the codend. Experiment was conducted in order to study the fish behaviour and escapement of non-target groups from the shrimp trawl and there by analyse the bycatch exclusion characteristics of hard grids having different shapes.

Both rectangular and oval grids were hauled alternatively and covered codend method was adopted to conduct the study. Catch from the codend and the cover were separately sorted and identified up to species level. Weight of each species was taken and for large quantities sub samples were taken. In the case of fishes and shrimps total length was taken and for cephalopods the mantle length was measured.

8.4. Results and Discussion

Results of experiments with oval and rectangular grid having dimensions 1000 mm x 800 mm with 22 mm bar-space are given the table 8.1 and 8.2.

Table. 8.1. Results of experiments with Oval x Rectangular grid BRDs

	Oval grid BRD	Rectangular grid BRD
No. of hauls	13	13
Total catch (kg)	136.66	168.5
CPUE (kg/h)	10.79	12.79
Retained catch (kg)	60.025	86.845
Retained catch (%)	43.92	51.54
Excluded catch (kg)	76.63	81.625
Excluded catch (%)	56.08	48.44
Retained shrimp catch (kg)	18.265	19.645
Excluded shrimp catch (kg)	2.1	3
Total shrimp catch (kg)	20.365	22.645
Retained shrimp catch (%)	89.69	86.75
Excluded shrimp catch (%)	10.31	13.25
Retained bycatch (other than shrimps) (kg)	41.76	67.2
Retained bycatch (other than shrimps) (%)	35.91	46.10
Excluded bycatch (other than shrimps) (kg)	74.53	78.575
Excluded bycatch (other than shrimps) (%)	64.09	53.90
No. of species caught	63	54
Fish species	54	46
Shrimp species	6	6
Other species	3	2
100% exclusion (No. of species)	16	5
>50% exclusion (No. of species)	27	26
Up to 50% exclusion (No. of species)	14	16
0% exclusion (No. of species)	6	7

Table 8.2. Bycatch exclusion effect on species groups due to the installation of Oval grid and Rectangular grid

Grid type	Species groups	Encountered catch, kg	Retained, %	Excluded, %
Oval grid	All species	136.660	43.32	56.08
	Shrimp species	20.365	89.69	10.31
	Non-shrimp species	116.295	35.91	64.09
Rectangular grid	All species	168.500	51.54	48.44
	Shrimp species	22.645	86.75	13.25
	Non-shrimp species	145.855	46.10	53.90

8.4.1. Comparative evaluation of Oval and Rectangular grids

During 12 days of fishing operations in the traditional fishing grounds off Cochin a total of 304.855 kg catch was obtained with an average CPUE of 11.79 kg / hr. The trawl net fitted with rectangular grid caught 168.5 kg and those fitted with oval grid caught 136.655 kg with an average CPUE 12.790 kg and 10.786 kg respectively. Oval grid retained 60.025 kg in the codend and 76.63 kg in the cover, which showed an overall exclusion rate of 56% and rectangular grid, retained 86.845 kg in the codend and 81.625 kg in the cover, showed 48.44% overall catch exclusion. The overall bycatch reduction calculated after deducting the quantity of shrimps were about 64.09 and 53.9% respectively for oval and rectangular grid. 63 and 54 species respectively encountered oval and rectangular grids and among this 100% escapement was shown by 16 species in oval grid (*Arius jella, Cynoglossus arel, Gerres filamentosus, Johnius carouna, Johnius dussumieri, Megalaspis cordyla, Himantura uarnak, Nibea maculata, Opisthopterus tardore, Penaeus monodon, Pisodonophis cancrivorus, Scatophagus argus, Selar crumenophthalmus, Sepiella inermis, Terapon theraps and Valamugil cunnesius*) and 5 species (*Anadontostoma chacunda, Caranx ignobilis, Esculosa thoracata, Penaeus monodon and Scomberoides tol*) in rectangular grid. More than 50% escapement was shown by 27 species in the oval grid and 26 species in the rectangular grid. Regarding the target catch loss, rectangular grid lost about 13.0 % of shrimp catch (1.7% of total catch) oval grid showed slightly less shrimp loss of about 10% (1.3% of total catch).

8.4.2. Stundent's t-test

Oval and rectangular grids showed significant difference in their exclusion characteristics for three species when conducted Student's *t*-test for paired samples. *Ambassis ambassis* (P=0.045) and *Epinephelus diacanthus* (P=0.041) showed significantly higher exclusion from the oval grid. Considering target catch oval grid performed better than rectangular grid showing significant shrimp (*Parapenaeopsis stylifera*) loss form rectangular grid system (P=0.043) and though statistically insignificant 62% of *Metapenaeus dobsoni* was also lost from the rectangular grid system. Among other species encountered the gear, 23 species showed comparatively higher exclusion from oval grid while 15 species showed comparatively higher exclusion from rectangular grid, though the values were not statistically significant.

8.4.3. Selectivity studies

The selectivity of grid devices were found to be determined by the shape and dimensions of grids and their bar-spacing. As in the case of net devices the physical separation based on size was taking place at the grids. The main difference between grid selectivity and net selectivity was that in the case the case of nets the physical sorting would retain the larger individuals while releasing the smaller individuals. In the case of grids, which were usually positioned in front of the codend with an opening either at top or bottom for the exit of organisms or objects which were larger than the bar-space, so that smaller individuals pass through the grid and get accumulated in the codend while larger ones get sorted out of the trawl net. Consequently in net selectivity the graph was plotted by taking length against fraction retained in codend and in grid selectivity the graph was plotted by taking length against fraction escaped from the gear.

The selectivity analysis of oval grid and rectangular grids were performed and for nine species *viz. Alepes kleini, Cynoglossus macrostomus, Lactarius lactarius, Leiognathus splendens, Lepturacanthus savala, Sardinella longiceps,* *Metapenaeus dobsoni, Parapenaeopsis stylifera* and *Penaeus (Fenneropenaeus) indicus* significant values were obtained concurrently. Selectivity curves and selectivity parameters of these species were given in Figures 8.6 to 8.14 and in Table 8.3 respectively. Out of nine species seven species showed results favourable to oval grid. For *Lactarius lactarius, Leiognathus splendens, Sardinella longiceps, Metapenaeus dobsoni,* and *Parapenaeopsis stylifera* the L_{50} values were found to be lesser than the length at first maturity for the concerned species. For *Cynoglossus macrostomus* and *Penaeus (Fenneropenaeus) indicus* rectangular and oval grids gave L_{50} values higher than their length at first maturity but comparatively lower vales was showed by oval grid. In the case of *Alepes kleini* though the L_{50} values for rectangular and oval grids were lesser than L_m the difference in their L_{50} were not significant.

Table. 8.3 Selectivity parameters for Oval grid and Rectangular grid

Species	Grid type	$L_{25\%}$	$L_{50\%}$	$L_{75\%}$	Selection range, mm	Length at first maturity, mm
Alepes kleini	Oval	75.74	88.52	101.30	25.56	129
	Rectangular	71.53	86.73	101.92	30.39	
Cynoglossus macrostomus	Oval	124.04	137.64	151.24	17.19	100-120
	Rectangular	128.18	140.95	153.73	25.55	
Lactarius lactarius	Oval	69.46	84.31	99.15	29.69	135
	Rectangular	78.24	102.83	127.42	49.18	
Leiognathus splendens	Oval	29.63	77.71	125.79	96.16	60-94
	Rectangular	82.13	90.32	98.50	16.37	
Lepturacanthus savala	Oval	332.52	410.99	489.46	156.94	418-750
	Rectangular	234.71	351.83	468.96	234.25	
Sardinella longiceps	Oval	79.46	122.04	164.63	85.16	150-162
	Rectangular	136.60	154.91	173.22	36.62	
Metapenaeus dobsoni	Oval		82.87	199.06	232.39	88.6
	Rectangular	94.17	113.45	132.72	38.55	
Parapenaeopsis stylifera	Oval	35.98	53.42	70.86	34.88	63.2
	Rectangular	14.90	76.55	138.20	123.30	
Penaeus (F) indicus	Oval	122.90	150.37	177.83	54.93	130.2
	Rectangular	145.48	170.91	196.34	50.86	

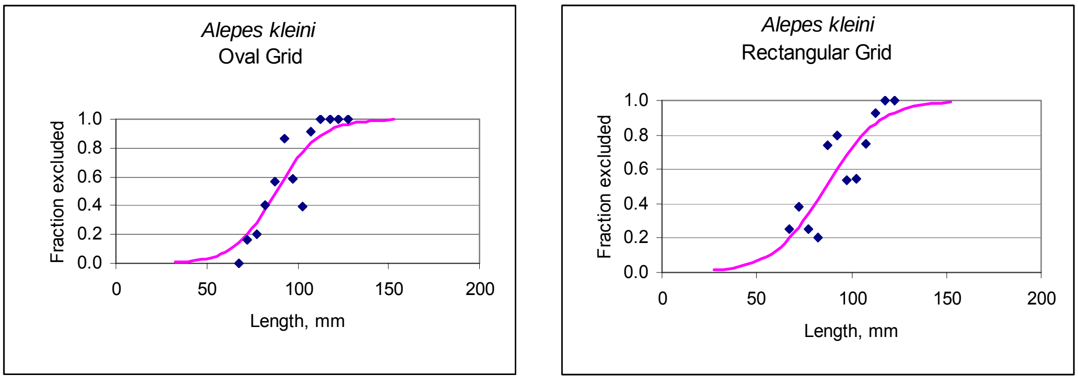


Fig. 8.6. Selectivity curves for *Alepes kleini*

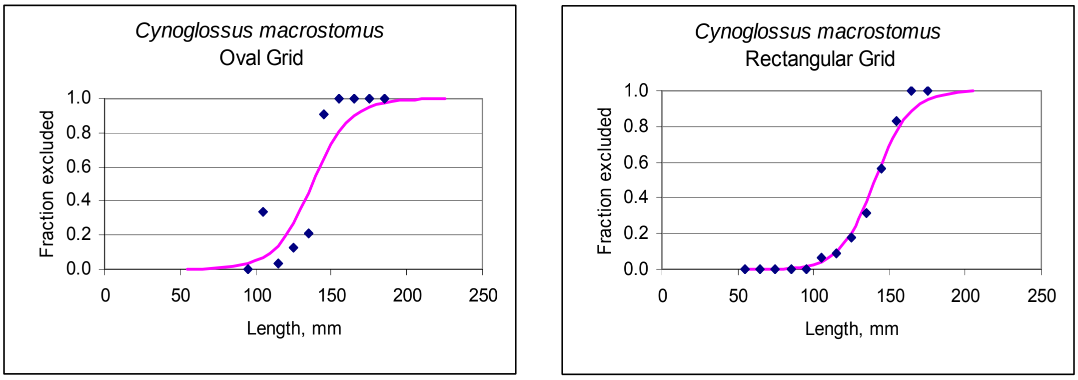


Fig. 8.7. Selectivity curves for *Cynoglossus macrostomus*

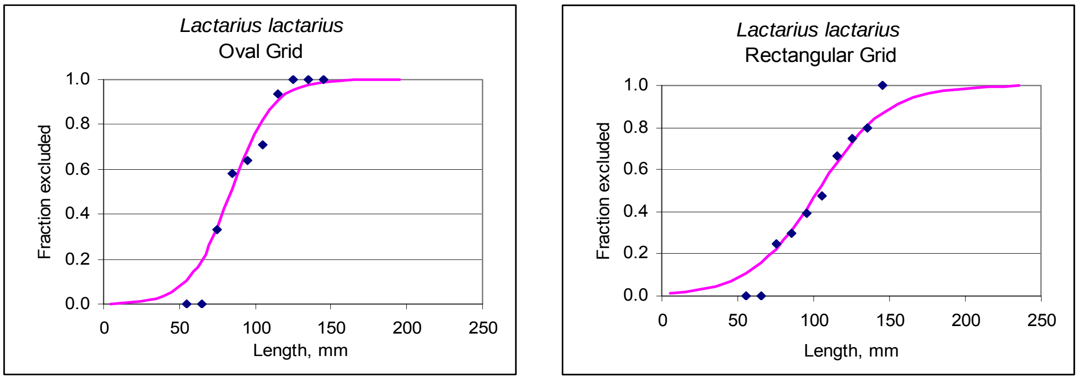


Fig. 8.8. Selectivity curves for *Lactarius lactarius*

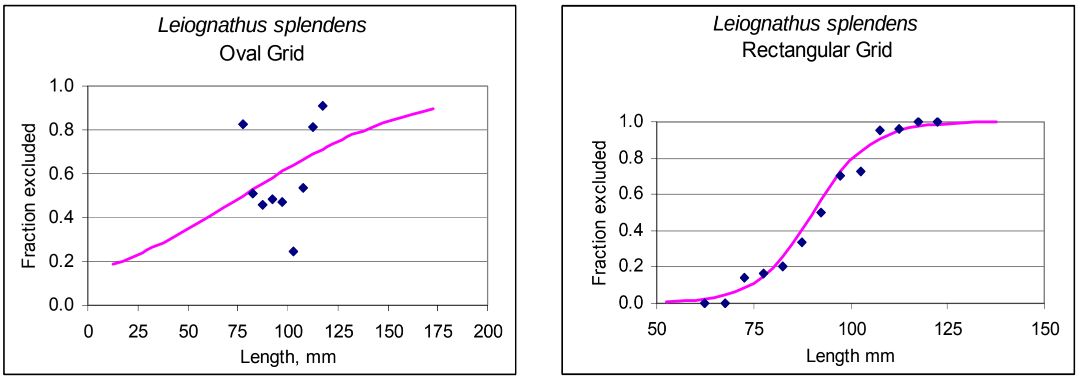


Fig. 8.9. Selectivity curves for *Leiognathus splendens*

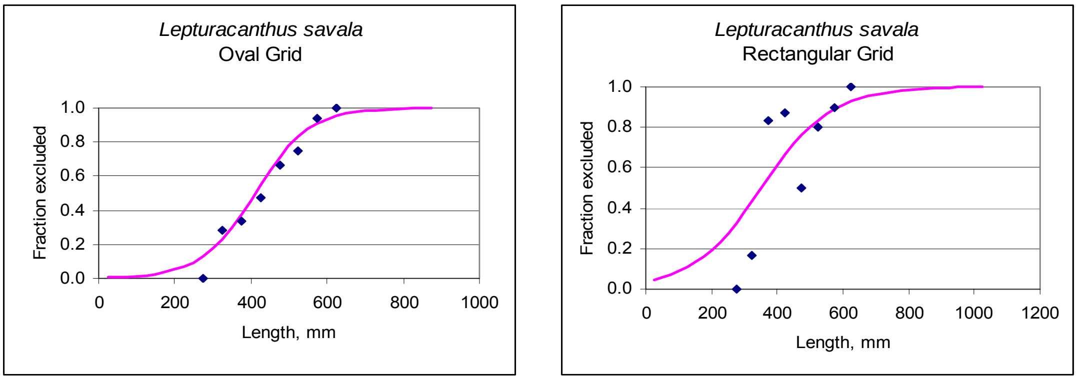


Fig. 8.10. Selectivity curves for *Lepturacanthus savala*

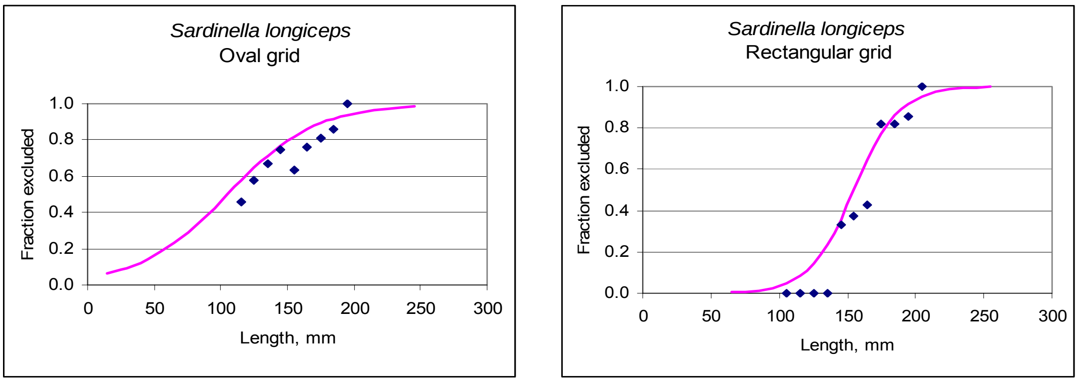
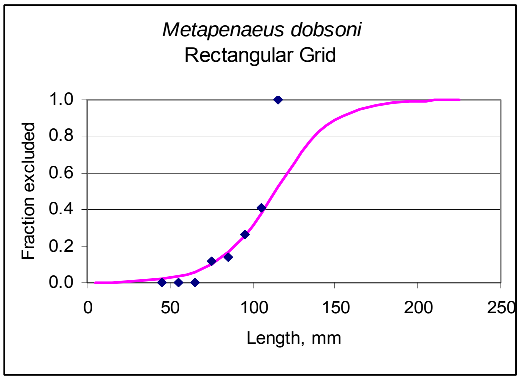


Fig. 8.11. Selectivity curves for *Sardinella longiceps*



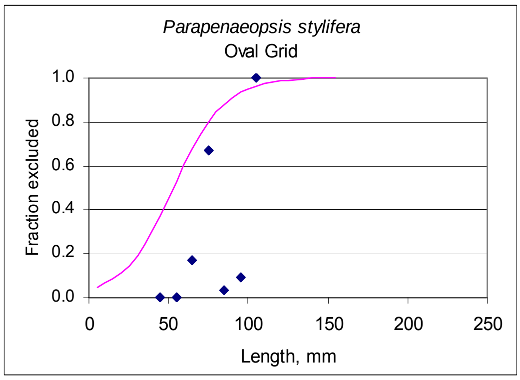
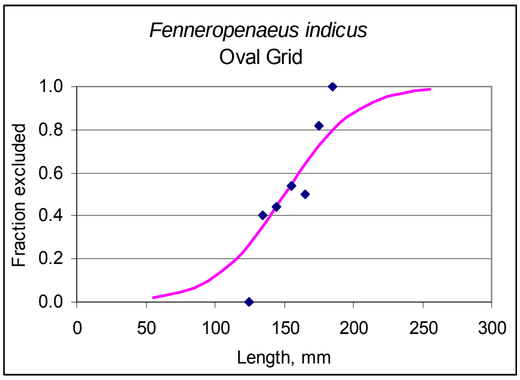


Fig. 8.12. Selectivity curve for *Metapenaeus dobsoni*

Fig. 8.13. Selectivity curve for *Parapenaeopsis stylifera*



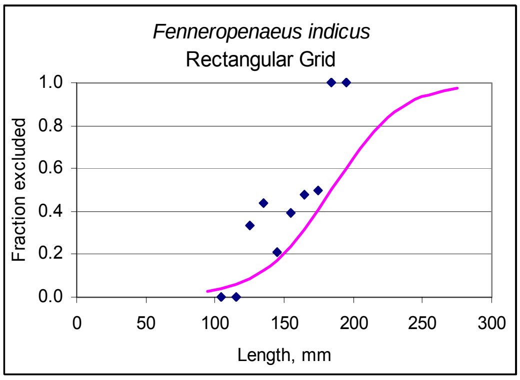


Fig. 8.14 Selectivity curves for *Penaeus* (*Fenneropenaeus) indicus*

8.4.4. PRIMER analysis

PRIMER software package (Version 5.2.9; Plymouth marine Laboratory, Plymouth, UK) was used for SIMPER analysis, plotting k-dominance curves, and estimating diversity indices such as total number of species (S), Margalef richness (d), Pielou's evenness (J'), Brillouin index (H), Shannon index (H'), Simpson's dominance index (λ'), Hill (N1), taxonomic diversity (Δ), taxonomic distinctness (Δ*) average phylogenetic diversity index (Phi+) and total phylogenetic diversity index (sPhi+). Simpson's evenness measure ($E_{1/D}$) was calculated using MS Excel by dividing reciprocal of Simpson's dominance index with total number of species (S) in the sample. The diversity indices of the excluded catch from rectangular and oval grid incorporated trawls were analysed. Views of excluded catch from rectangular grid and oval grid incorporated trawls are shown in Fig. 8.15.

The various diversity indices calculated for both rectangular gird and oval grid are given in table 8.4. From these indices it was clearly assumed that the biodiversity of species escaped from rectangular grid was found to be more diverse in terms of J', H, H', N1, $E_{1/D}$, Δ and Δ*. The high evenness values given by J' and $E_{1/D}$ and lower dominance value for λ' confirms the higher biodiversity of catch excluded from rectangular grid.

Fig. 8.15.Views of excluded catch from rectangular grid and oval grid incorporated trawls

Table. 8.4. Mean Diversity indices of species escaped from rectangular and oval grids

Grid	S	d	J'	H	H'	N1	λ'	$E_{1/D}$	Δ	Δ*	Phi+	sPhi+
Rectangular	52	8.65	**0.73**	**2.72**	**4.14**	**17.66**	0.08	**0.23**	**54.55**	**59.36**	35.44	1842.86
Oval	**56**	**9.32**	0.71	2.69	4.12	17.41	**0.09**	0.19	46.02	50.75	**36.48**	**2042.86**

In the k-dominance plot (Fig. 8.16), in which the cumulative ranked abundances of species obtained in rectangular and oval grids was plotted against species rank and it was observed that the curve for rectangular grid lay on the lower side, extended further and raised slowly showed higher biodiversity in the catch excluded from rectangular grid.

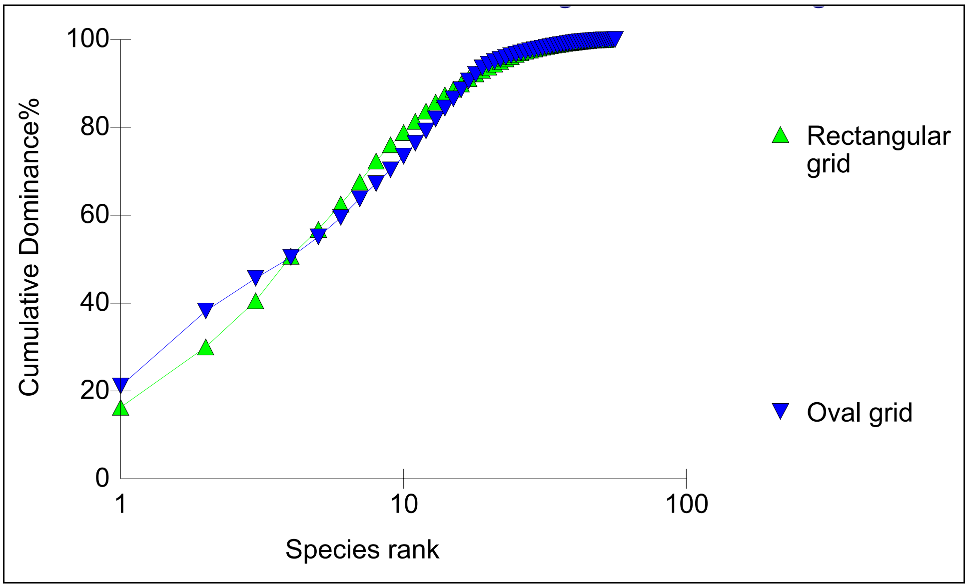


Fig. 8.16. k-dominance plot for species escaped from rectangular and oval grids

Bubble plots could be obtained by superimposing the abundance data of a particular species in the MDS plot, and the abundance of that species in a particular sample could be directly understood by the size of the bubble. The stress value (0.18), which overlying on the MDS plot showed a good ordination with no real prospect of a misleading interpretation of the samples collected. Bubble plots of some discriminating species such as *Metapenaeus dobsoni, Parapenaeopsis stylifera, Ambassis ambassis, Lactarius lactarius, Sardinella longiceps and Uroteuthis duvauceli* are given in the Fig. 8.17. *Metapenaeus dobsoni* and *Parapenaeopsis stylifera* showed higher escapement from rectangular grid and all other discriminating fish species and squid species showed higher escapement from oval grid. This confirms the better exclusion characteristics and target catch retention properties of oval grid.

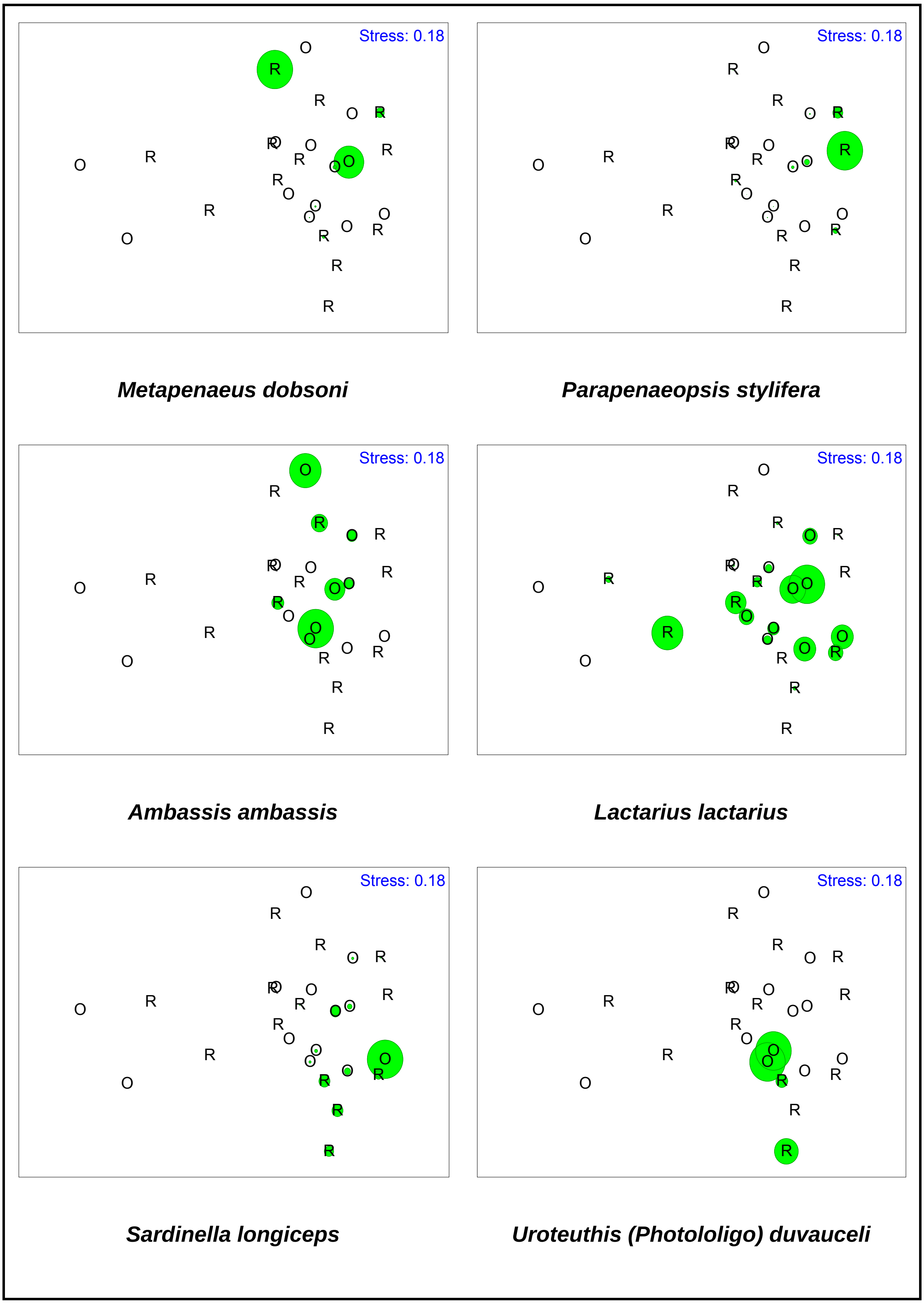


Fig 8.17. Bubble plot shows abundance of escaped species from rectangular and oval grids

8.5. Conclusion

Experiments with flat and oval sorting grids have given promising results. Use of sorting grids is emerging as a popular bycatch reduction device due to comparative effectiveness as a solution for bycatch reduction and target catch retention. Oval grid showed higher bycatch exclusion rate of about 64% and showed exclusion of more number of species at 100% and 50% levels. In addition, oval grid performed better than rectangular grid, in respect of target catch retention. The higher target catch loss and lower bycatch exclusion of rectangular grid could be attributed to the higher turbulence created by its projecting corners during trawling operation.

The results of Student's *t*-test confirmed that the bycatch exclusion and shrimp retention rates are significantly higher through oval grid compared to rectangular grid. Though statistically insignificant, 50% more species showed comparatively higher exclusion rate from oval grid compared to rectangular grid. Selectivity results have also indicated better performance of oval grid as about 78% of species considered for selectivity studies showed better selectivity characteristics with oval grid. Larger fish species and jellyfishes were invariably excluded from the trawl net through both the grid BRDs. The higher exclusion rate of shrimps which was in the range of 10-13% was primarily due to the clogging of the grids by debris, inadequacy of the bar-space, incorrect grid angle, inappropriate shape and size of the exit opening. Variation in the abundance of shrimp and bycatch species during different season also could be influencing the exclusion characteristics of the BRDs. It is necessary to conduct additional observations to evaluate the effect of bar-spacing on the size selectivity and shrimp retention characteristics of grids as it is considered to be a major factor influencing their performance.

Chapter 9

Comparative Performance of Rigid Oval grids with Different Bar-spacing

9.1. Introduction

Bycatch reduction devices in the form of rigid separation grid were developed in Norway in 1980. The design which was developed by the fishermen as a new concept primarily to avoid the bycatch of jellyfish in a shrimp trawl turned out to be quite successful in eliminating bycatch. The main disadvantage of sorting and separating devices which made use of netting, ropes etc. was the difficulty in maintaining shape underwater during fishing operations, which resulted in improper functioning and inadequate bycatch exclusion. This disadvantage could be minimized by using rigid structures. From the previous experiment with oval and rectangular flat grids, in order to determine the difference in selectivity patterns of grid BRDs based on their shape, 1000 x 800 mm oval grid preformed much better than rectangular grid of similar dimensions. Oval grid outperformed rectangular grid in terms of higher bycatch exclusion and comparatively higher target catch retention. Though the bycatch exclusion was excellent the target catch retention was not satisfactory, that recorded about 10% of total shrimp catch in oval grid

9.2. Objectives of the study

The bycatch reduction and sorting effect of the Nordmore system was effected by taking advantage mainly the difference in size and to some extend the behaviour of shrimp and other animals caught in the trawl. Large animals and active swimmers are released out through the exit opening while the organisms that can pass through the grid was caught and retained in the codend. Even though the bycatch exclusion characteristics of a BRD were promising fishers would have more concern regarding the short-term loss of target catches. Higher shrimp loss could be attributed to incorrect grid angle, grid blockage or poor performance of the accelerator funnels / guiding panels. High grid angle would increase the distance between the guiding panel and grid that could result in shrimp loss. Increasing the length of the panel or adding weights to the end of the panel could prevent shrimp loss. Grid blockage could be reduced to a great extend by increasing the size of the exit opening. Another important factor that governed the performance of grid devices was their bar-space. In order to study the effect of bar-spacing another set of experiments was conducted using oval grids with two different bar-spacing. The main objective of this comparative study was to evaluate the effect of bar-space in the bycatch exclusion and shrimp retention characteristics in order to determine optimum bar-space for oval grids.

9.3. Materials and methods

9.3.1. Oval Grids with different bar-spacing

The oval grid designs with dimensions of 1000 mm in height and 800 mm in width and with different bar-spacings *viz*., 20 mm and 26 mm were used for the comparative field trials. It was fabricated out of stainless steel rods of 8 mm dia for outer frames and 4 mm dia for bars. The grid was kept at an angle 45° from the horizontal. Two floats were provided on the top at either side of the grid, to compensate the weight of the grid and also to keep the grid always in the upright position.

A triangular opening having dimensions 600 mm at base and 450 mm at sides was provided at the top of the trawl extension in front of the grid made by cutting all bars from the upper side of the grid. The exit opening was reinforced by a 4 mm rope at its edges. An accelerator or guiding funnel was provided in front of the grid at a distance of 0.5 m from the bottom of the grid. The funnel was inclined towards the bottom so that the water flow would be directed towards the bottom of the grid. (Mitchell et al*.,* 1995; Dawson and Boopendranath, 2001; Boopendranath, 2003; Hannah et al., 2003).

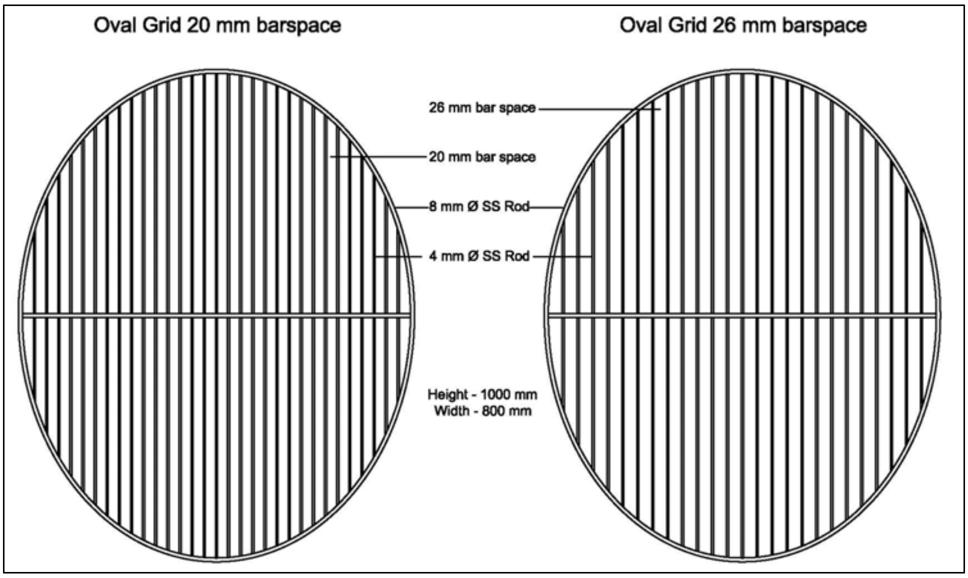


Fig. 9.1. Oval grids with 20 mm and 26 mm bar-spacings

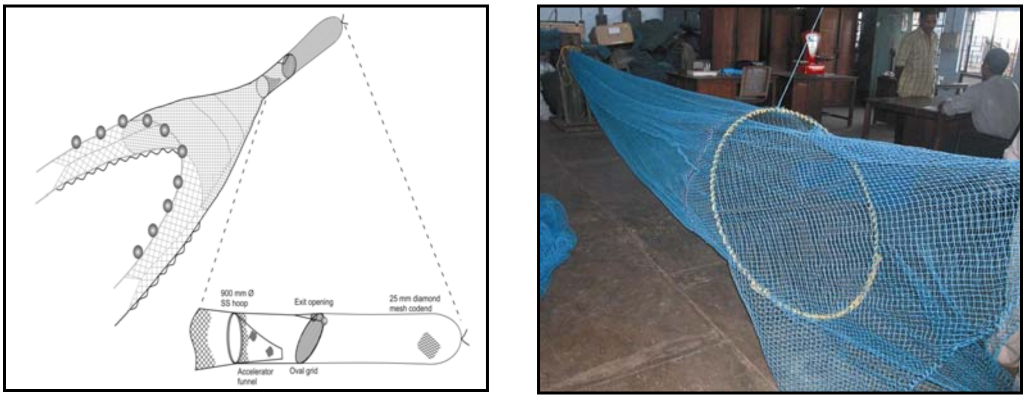


Fig. 9.2. Trawl net showing installation of oval grids

Fig. 9.3. Trawl operation with Oval grid

9.3.2. The gear, vessels used for the experiment and area of study

The gear used for the operation of fisheye was a 29.0 m shrimp trawl with 20 mm diamond mesh codend (Fig. 3.4). The trawl was made entirely of twisted polyethylene. V-type otter boards of 80 kg each were used as the sheer device. Two research vessels of Central Institute of Fisheries Technology are used for conducting the field trials (i) steel trawler MFB Matsyakumari (17.5 m L_{OA} and 57.17 GRT) having 277 bhp @ 1000 rpm Kirloskar Mann engine (ii) wooden trawler MFV Sagar Shakti (15.24 m L_{OA} and 30 GRT) having 223 bhp @ 1800 rpm Ruston MWM engine. The experimental fishing operations were conducted in coastal waters off Cochin at depths ranging between 9 and 32 m (Fig. 3.1).

9.3.3. Experimental fishing trials and catch handling

Both 20 mm and 26 mm oval grids were hauled alternatively and covered codend method was adopted to conduct the study. Catch from the codend and the cover were separately sorted and identified up to species level. Weight of each species was taken and for large quantities sub samples were taken. In the case of fishes and shrimps total length was taken and for cephalopods the mantle length was measured.

9.4. Results and Discussion

Results of experiments with flat oval grids having 20 mm and 26 bar-spaces are summarized in the Table. 9.1 and Table. 9.2.

Table. 9.1. Bycatch exclusion effect on species groups due to the installation of Oval grid having 20 and 26 mm bar-space

Grid type	Species groups	Encountered catch, kg	Retained, %	Excluded, %
Oval grid with 20 mm bar-space	All species	46.732	63.73	36.27
	Shrimp species	13.447	86.21	13.79
	Non-shrimp species	33.285	54.65	45.35
Oval grid with 26 mm bar-space	All species	52.942	52.59	47.41
	Shrimp species	11.355	93.88	6.12
	Non-shrimp species	41.587	41.32	58.68

Table. 9.2. Results of experiments with Oval grid BRDs having 20 and 26 mm bar-space

	Oval grid BRD with 20 mm bar-space	Oval grid BRD with 26 mm bar-space
No. of hauls	11	11
Total catch (kg)	46.732	52.942
CPUE (kg/h)	4.06	4.6
Retained catch (kg)	29.782	27.844
Retained catch (%)	63.73	52.59
Excluded catch (kg)	16.95	25.098
Excluded catch (%)	36.27	47.41
Retained shrimp catch (kg)	11.592	10.66
Excluded shrimp catch (kg)	1.855	0.695
Total shrimp catch (kg)	13.447	11.355
Retained shrimp catch (%)	86.21	93.88
Excluded shrimp catch (%)	13.79	6.12
Retained bycatch (other than shrimps) (kg)	18.19	17.184
Retained bycatch (other than shrimps) (%)	54.65	41.32
Excluded bycatch (other than shrimps) (kg)	15.095	24.403
Excluded bycatch (other than shrimps) (%)	45.35	58.68
No. of species caught	87	90
Fish species	64	65
Shrimp species	7	7
Other species	16	18
100% exclusion (No. of species)	10	13
>50% exclusion (No. of species)	17	24
Up to 50% exclusion (No. of species)	31	28
0% exclusion (No. of species)	29	25

9.4.1. Comparative evaluation of grids with different bar spacing

In order to find the significance of bar-spacing in the selectivity and exclusion characteristics of oval grids a comparative analysis experiment was conducted with flat oval grids with different bar-spacings *viz*., 26 mm and 20 mm. Experiment conducted for 11 days and a total of 22 hauls were taken. Total catch was about 99.674 kg with an average CPUE of 4.334 kg/h. Trawl net fitted with Grid having 20 mm bar-space retained 63.73% of the catch encountered and excluded 36.27% where as the trawl net fitted with grid having 26 mm bar-space retained 52.59% of the catch encountered and excluded about 47.41%. The overall bycatch reduction calculated after deducting the quantity of shrimps were about 45.35 and 58.68% respectively for oval grids having 20 mm and 26 mm bar-space. Among 87 species encountered in the 20 mm grid incorporated trawl, 10 species *viz*, *Scylla serrata, Pampus argenteus, Charybdis feriatus, Thryssa kammalensis, Alectis indicus, Mugil cephalus, Johnius carutta, Leiognathus bindus, Oxyurichthys paulae* and *Mene maculata* showed 100% escapement and another 17 species showed more than 50% escapement. In the 26 mm grid incorporated trawl 13 species *viz*, *Pampus argenteus, Portunus pelagicus, Caranx ignobilis, Epinepheleus diacanthus, Scylla serrata, Thryssa kammalensis, Charybdis feriatus, Johnius carutta, Anadontostoma chacunda, Tonna dolium, Scomberoides tala, Alectis indicus and Scomberoides lysan* showed 100% escapement and another 24 species showed more than 50% escapement among a total of 88 species. Exclusion rate upto 50% were shown by 31 species in 20 mm grid and 28 species in 26 mm grid. 29 and 25 species respectively showed 0% escapement from 20 mm and 26 mm grid. Shrimp loss was about 13.8% for 20 mm grid and about 6.12% for 26 mm grid. A drastic 40% reduction in target catch loss was the result of increasing bar-space from 22 to 26 mm.

9.4.2. Student's t-test

Results of Student's *t*-test has shown exclusion rates were significantly different between the grids in respect of seven species. *Alepes kleini* (P=0.044), *Gazza minuta* (P=0.049), *Leiognathus bindus* (P=0.014), *Leiognathus brevirostris* (P=0.043) and *Opisthopterus tardoore* (P=0.046) showed significantly higher exclusion rate from 26 mm grid while shrimp (*Metapenaeus dobsoni*) loss was significantly higher (P=0.036) from 20 mm grid. Twenty-two species showed better exclusion rate from 26 mm grid while 20 species showed better exclusion in the case of 20 mm grid, however the difference exclusion rates were not statistically significant.

9.4.3. Selectivity studies

The selectivity analyses in respect of eleven species *viz. Alepes djedaba, Ambassis ambassis, Lagocephalus spadiceus, Leiognathus brevirostris, Lepturacanthus savala, Megalaspis cordyla, Opisthopterus tardore, Sardinella longiceps, Stolephorus commersonnii, Stolephorus waitei* and *Thryssa mystax* encountered in the two grids with 20 mm and 26 mm bar-spacing were performed. Selectivity curves and selectivity parameters of these species are given in Fig. 9.4 to 9.14 and in Table. 9.3 respectively. Among the eleven species studied five showed results in favour of oval grid with 26 mm bar-space. *Ambassis ambassis, Leiognathus brevirostris, Megalaspis cordyla, Sardinella longiceps* and *Stolephorus waitei* showed L_{50} values less than their length at first maturity and also in the case of *Alepes djedaba* and *Thryssa mystax*, the L_{50} values were below their length at first maturity and only slightly higher than the values obtained for 20 mm oval grid. For *Stolephorus commersonnii* 26 mm oval grid gave lower L_{50} value than 20 mm grid even though the values were above their length at first maturity and in the case of *Lepturacanthus savala* both grids gave more or less equal L_{50} values. Moreover in the case of 20 mm oval grid the selectivity curve were not fitting properly for the species *Ambassis ambassis, Lagocephalus spadiceus, Leiognathus brevirostris, Stolephorus commersonnii, Stolephorus waitei* and *Thryssa mystax.*

Table. 9.3. Selectivity parameters for Oval grids having 20 mm and 26 mm bar-space

Species	Grid type	$L_{25\%}$	$L_{50\%}$	$L_{75\%}$	Selection range, mm	Length at first maturity, mm
Alepes djedaba	20 mm	109.42	114.78	120.14	10.78	180-189
	26 mm	124.55	135.88	147.20	22.62	
Ambassis ambassis	20 mm	56.94	78.31	99.67	42.74	55-75
	26 mm	53.71	64.96	76.22	22.51	
Lagocephalus spadiceus	20 mm		53.85	269.26	430.83	-
	26 mm	66.15	82.81	99.46	33.32	
Leiognathus brevirostris	20 mm	60.37	157.59	254.81	194.44	181
	26 mm	63.85	76.06	88.26	24.41	
Lepturacanthus savala	20 mm	284.69	328.63	372.58	87.89	418-750
	26 mm	258.14	330.08	402.03	143.89	
Megalaspis cordyla	20 mm	87.04	109.88	132.72	45.68	250
	26 mm	80.00	99.71	119.42	39.43	
Opisthopterus tardore	20 mm	53.82	79.98	106.13	52.31	-
	26 mm	87.49	127.76	168.03	80.54	
Sardinella longiceps	20 mm	76.37	108.88	141.38	65.01	150-162
	26 mm	50.08	84.95	119.83	69.75	
Stolephorus commersonnii	20 mm	78.84	147.50	216.16	137.33	74
	26 mm	99.06	108.53	118.01	18.94	
Stolephorus waitei	20 mm	53.59	89.03	124.47	70.88	81-84
	26 mm	70.02	83.75	97.48	27.47	
Thryssa mystax	20 mm	24.73	106.72	188.70	163.97	130
	26 mm	74.86	118.80	162.74	87.89	

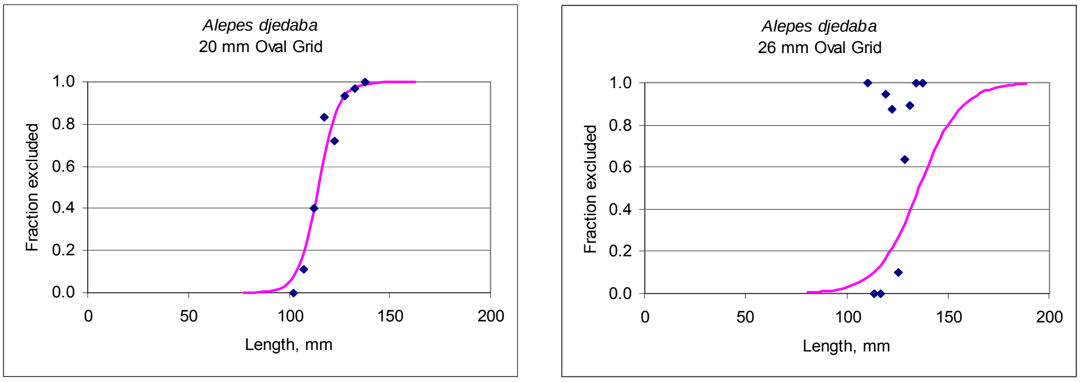


Fig. 9.4. Selectivity curves for *Alepes djedaba*

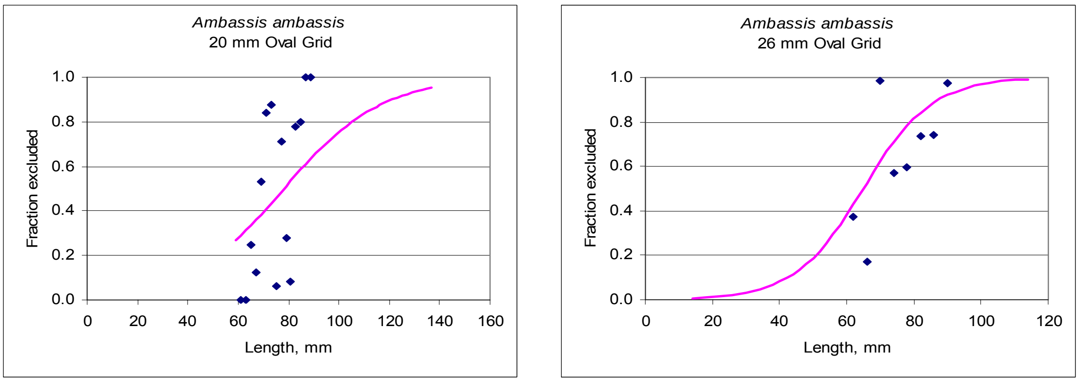


Fig. 9.5. Selectivity curves for *Ambassis ambassis*

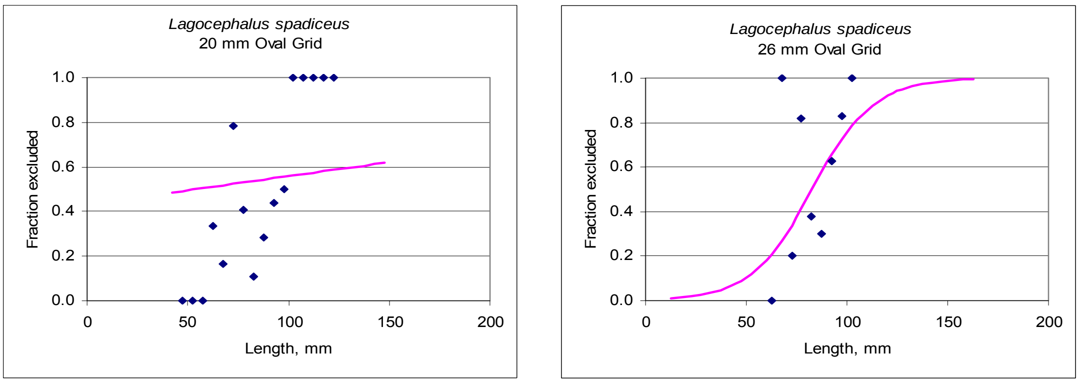


Fig. 9.6. Selectivity curves for *Lagocephalus spadiceus*

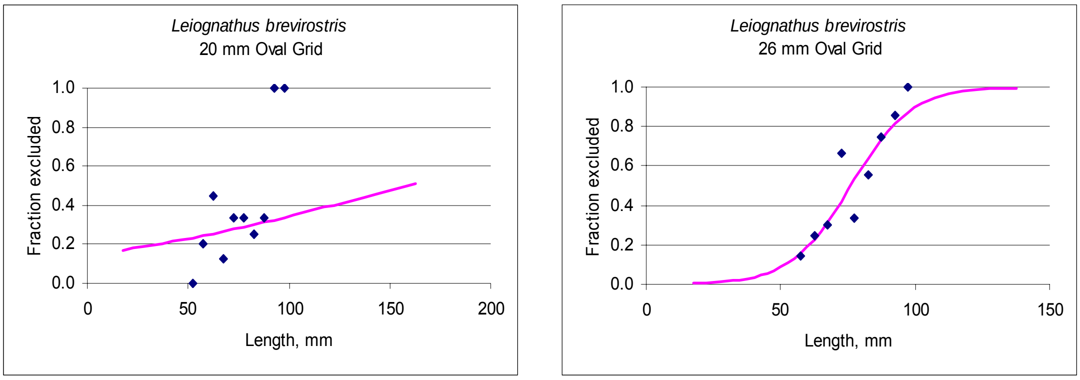


Fig. 9.7. Selectivity curves for *Leiognathus brevirostris*

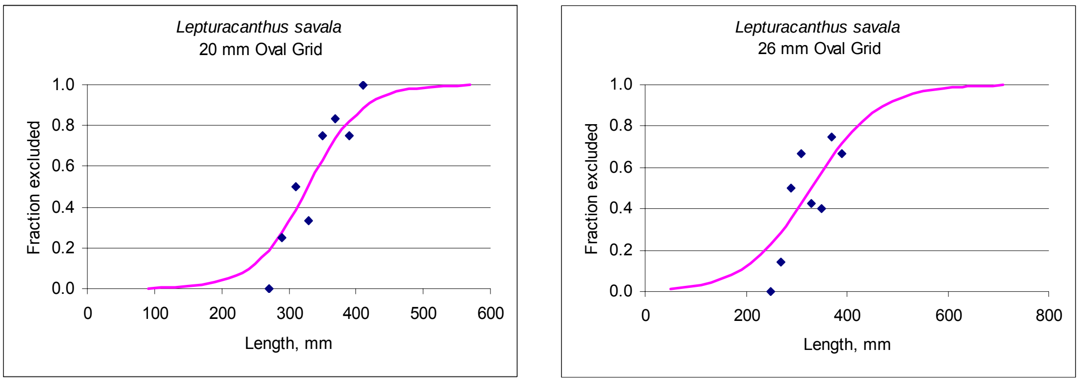


Fig. 9.8. Selectivity curves for *Lepturacanthus savala*

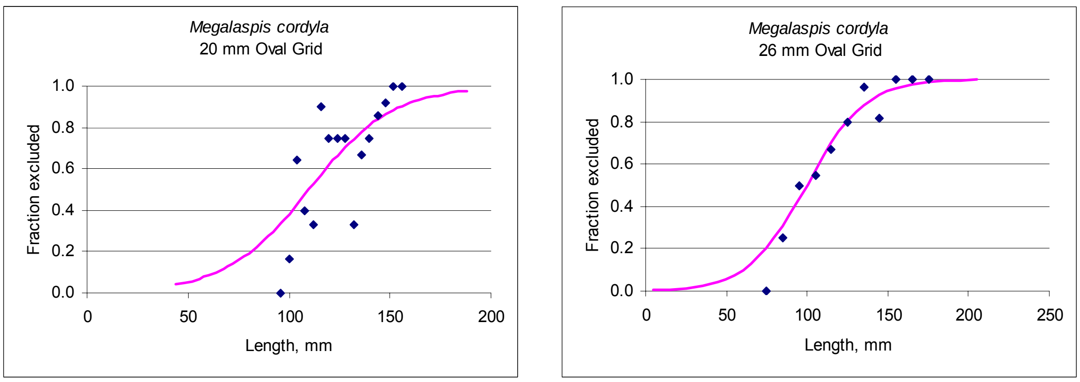


Fig. 9.9. Selectivity curves for *Megalaspis cordyla*

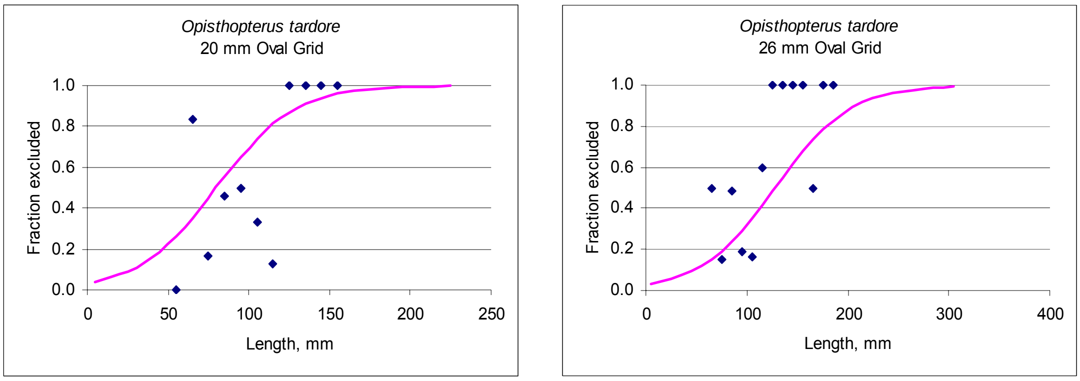


Fig. 9.10. Selectivity curves for *Opisthopterus tardoore*

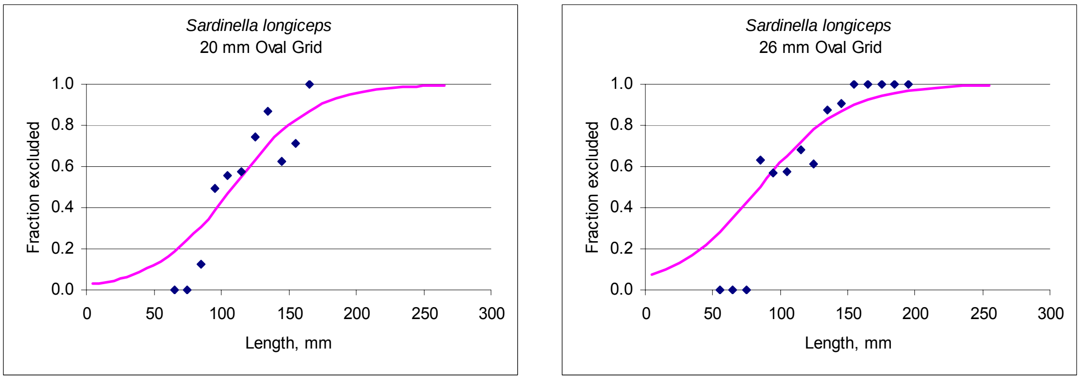


Fig. 9.11. Selectivity curves for *Sardinella longiceps*

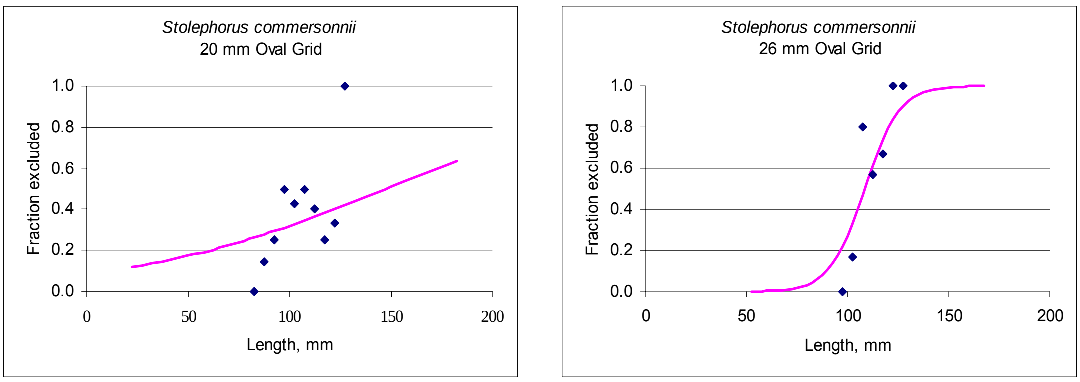


Fig. 9.12. Selectivity curves for *Stolephorus commersonnii*

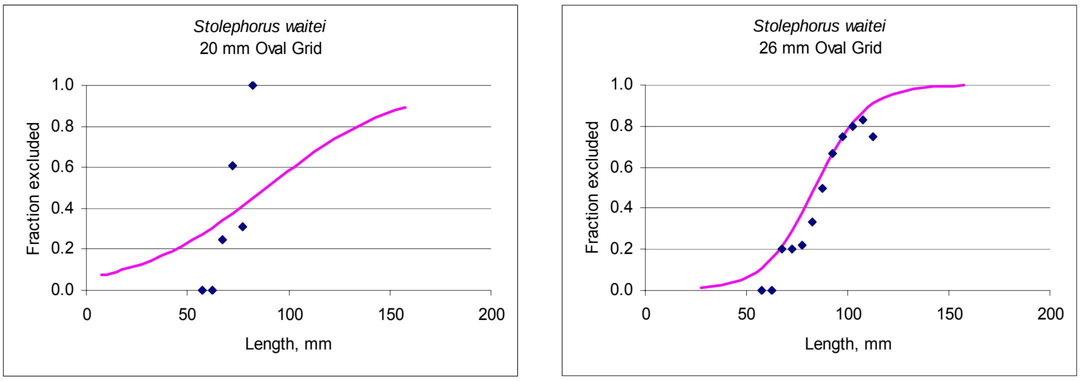


Fig. 9.13. Selectivity curves for *Stolephorus waitei*

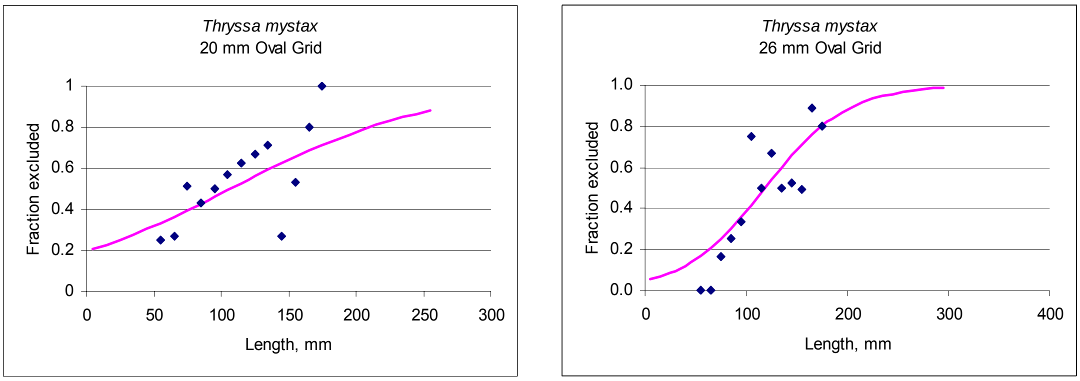


Fig. 9.14 Selectivity curves for *Thryssa mystax*

9.4.4. PRIMER analysis

PRIMER software package (Version 5.2.9; Plymouth marine Laboratory, Plymouth, UK) was used for SIMPER analysis, plotting k-dominance curves, and estimating diversity indices such as total number of species (S), Margalef richness (d), Pielou's evenness (J'), Brillouin index (H), Shannon index (H'), Simpson's dominance index (λ'), Hill (N1), taxonomic diversity (Δ), taxonomic distinctness (Δ*) average phylogenetic diversity index (Phi+) and total phylogenetic diversity index (sPhi+). Simpson's evenness measure ($E_{1/D}$) was calculated using MS Excel by dividing reciprocal of Simpson's dominance index with total number of species (S) in the sample. The diversity indices calculated for 20 mm and 26 mm oval grids are given in the table 9.4. From the results it was clear that the catch escaped from 20 mm grid was found to have more diversity in terms of S, d, J', H, H', N1, $E_{1/D}$, Δ, and Δ*. Higher dominance was observed in 26 mm grid in terms of Simpson's dominance index (λ') as 50% of the total number of species was represented by only 5 species. Phi+ and sPhi+ was found to be higher in the 26 mm grid showing that the taxonomic breadth of species represented in the 26 mm grid was more than that of 20 mm grid since in 26 mm grid 35 species were represented by 22 families and in 20 mm grid 38 species were represented by only 19 families.

Table. 9.4. Mean Diversity indices of species escaped from oval grids having 26 mm and 20 mm bar-space

Grid	S	d	J'	H	H'	N1	λ'	$E_{1/D}$	Δ	Δ*	Phi+	sPhi+
26 mm	35	6.68	0.54	1.72	2.75	6.71	**0.27**	0.11	52.59	71.66	**42.04**	**1471.43**
20 mm	**38**	**7.03**	**0.59**	**1.92**	**3.08**	**8.46**	0.22	**0.12**	**57.89**	**74.10**	37.97	1442.86

In the k-dominance plot (Fig. 9.15), in which the cumulative ranked abundances of species obtained in 20 mm and 26 mm grid was plotted against species rank and it was observed that the curve for 20 mm grid lay on the lower side, extended further and raised slowly showed higher biodiversity in the catch excluded from 20 mm grid.

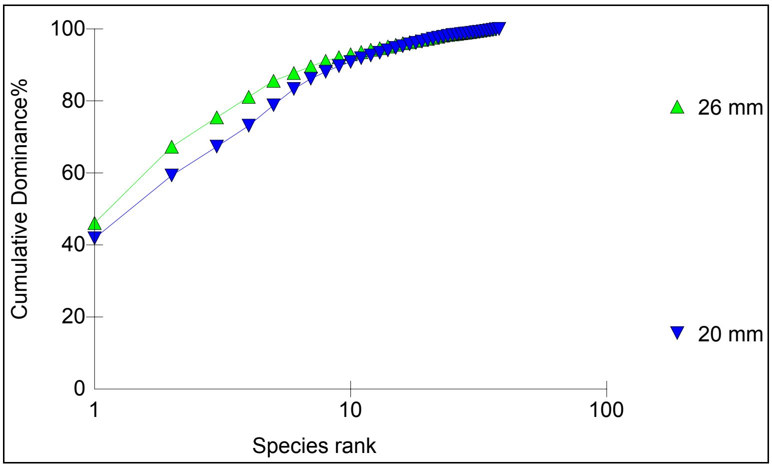


Fig. 9.15. k-dominance plot for species excluded from oval grids having 20 and 22 mm bar-space

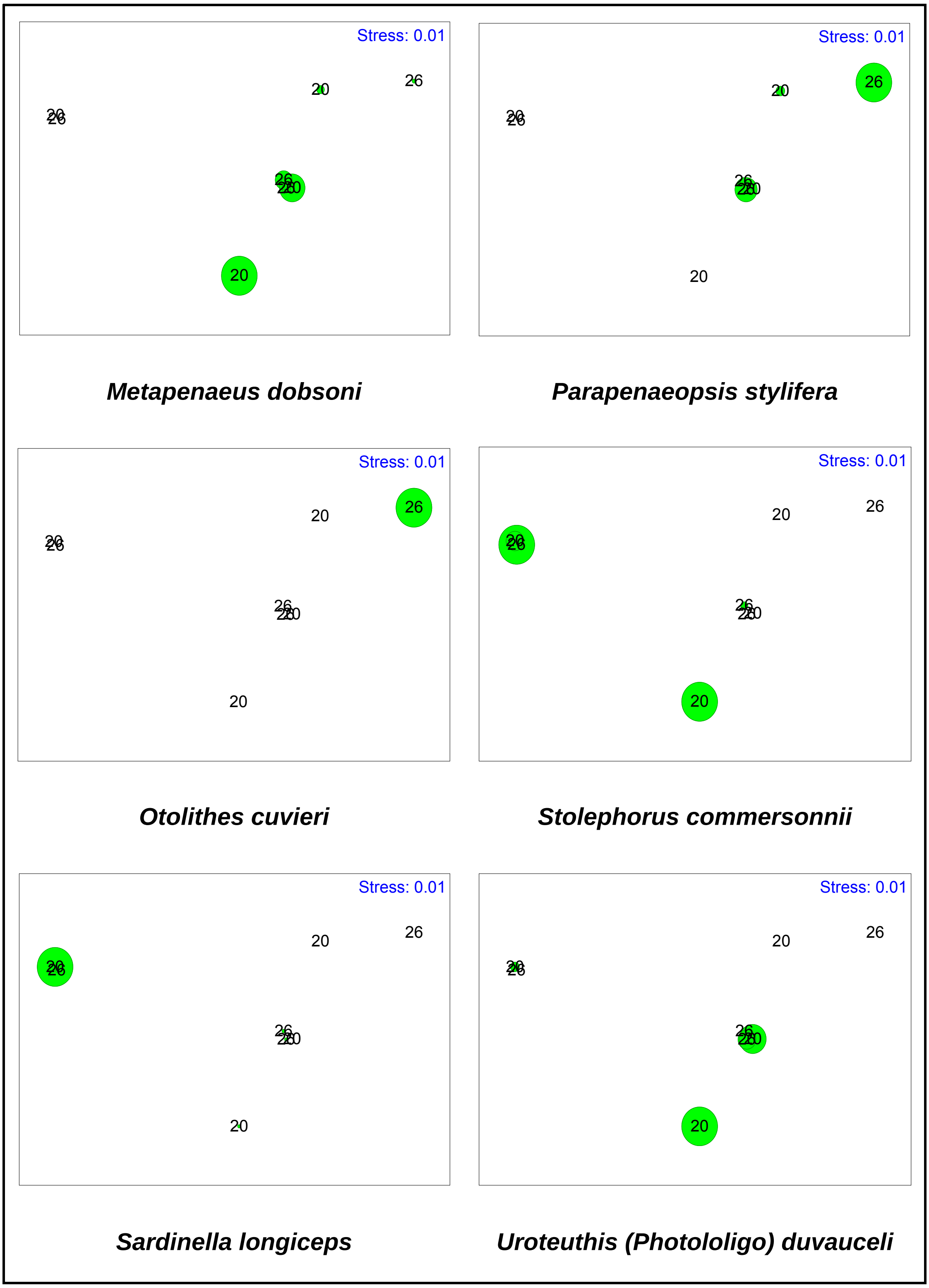


Fig. 9.16. Bubble plot showing abundance of escaped species from oval grids having 20 and 22 mm bar-space

Bubble plots could be obtained by superimposing the abundance data of a particular species in the MDS plot, and the abundance of that species in a particular sample could be directly understood by the size of the bubble. Bubble plots of some discriminating species such as *Metapenaeus dobsoni, Parapenaeopsis stylifera, Otolithes cuvieri, Stolephorus commersonnii, Sardinella longiceps* and *Uroteuthis* (*Photololigo*) *duvauceli* are given in figure 9.16. The stress value (0.01), which overlying on the MDS plot showed an excellent ordination of the samples collected. The bubble plot of *Metapenaeus dobsoni* showed its comparatively high escapement through 20 mm grid and regarding *Parapenaeopsis stylifera* more escapements was found from 26 mm grid. *Sardinella longiceps* showed comparatively similar escapement form both grids.

9.5. Conclusion

The performance of 26 mm flat oval grid as a bycatch reduction device was comparable with the earlier works done in other fisheries (Isaksen et al, 1992; Brewer et al., 1998; Halliday and Cooper, 1999; Graham, 2003). More over 26 mm oval grid performed much better showing the effect of bar-space in determining the efficiency of the grids. The efficiency shown by the 26 mm oval grid in retaining target catch was remarkable as there was a 40% reduction in the target catch loss when the bar-space was increased from 22 mm to 26 mm. When the bar-space was reduced from 22 mm to 20 mm the target catch loss increased from 10% to 13.8%. Apart from this, 26 mm oval grid excluded 58.68% of bycatch out of which 13 species showed 100% escapement and another 24 species showed more than 50% escapement. In the case of 20 mm grid bycatch exclusion rate was 45.35% and only 10 and 17 species showed 100% and more than 50% escapement respectively. Student's *t*-test has indicated significantly higher exclusion rates in respect of five out of seven species and significantly lower shrimp loss from 26 mm oval grid compared to 20 mm grid. Even though the target catch retention properties was not up to the mark the 26 mm bar-spaced oval grid can be considered as a potential bycatch reduction device that could be recommended for adoption by the trawling industry.

Chapter 10

Comparative Performance of Rigid Oval Grid and Semicircular Fisheye

10.1. Introduction

In the previous experiments different designs of grid devices and different configurations of fisheye BRDs were experimented. Among grid devices 1000 x 800 mm oval grid with 26 mm bar-space showed better performance in terms of higher target catch retention and higher bycatch exclusion. Among fisheye designs 300 x 200 mm semicircular design performed better in terms of lower target catch loss and higher bycatch reduction. Though these two designs of BRDs were having different principles of operation, as the grid worked on the principle of physical separation and the fisheye worked on the behavioral aspects of the fishes and shrimps, an experiment that compares these two designs would be helpful in many aspects. Firstly it would be helpful in determining the most effective BRD for the Indian trawl fishing conditions, which is in par with most of the tropical fisheries of the world. Secondly it could pave way to further experiments in Indian waters in which these two designs could be combined in a single trawl net in order to improve the efficiency in terms of target catch retention and bycatch reduction. In certain instances, two or more BRDs were combined in a single gear to enhance the efficiency. BRDs having different principles that were installed at different regions of a gear work in combination for improving bycatch exclusion properties.

10.2. Objectives of the study

Among rigid grid designs, flat oval grid of 1000 x 800 mm size with 26 mm bar-spacing and among fisheye BRDs, 300 x 200 mm semicircular BRD have given relatively better performance in terms of target catch retention and bycatch reduction, as discussed in previous chapters. The objective of this study has been to evaluate the performance of rigid grid BRD and fisheye BRD which has shown potential during earlier experiments, through comparative field trials, in order to determine the most suitable BRD in terms of bycatch reduction in and ease of handling.

10.3. Materials and methods

10.3.1. Oval Grid with 26 mm bar-spacing

The oval grid design having dimensions of 1000 mm in height and 800 mm in width and having different bar-spacing 26 mm was used for the comparative analysis (Fig. 10.1). It was fabricated out of stainless steel rods with outer frame diameter 8 mm and bar diameter 4 mm. The grid was kept at an angle 45° from horizontal. Two floats were provided on the top at either side of the grid, to compensate the weight of the grid and also to keep the grid always in the upright position by providing some extra buoyancy.

A triangular opening having dimensions 600 mm at base and 450 mm at sides was provided at the top of the trawl extension in front of the grid made by cutting all bars from the upper sides of the grid. The exit opening was reinforced by a 4 mm rope at its edges. An accelerator or guiding funnel was provided in front of the grid at a distance of 0.5 m from the bottom of the grid. The funnel was inclined towards the bottom so that the water flow would be directed towards the bottom of the grid. (Mitchell et al*.,* 1995; Epperly and Teas, 1999; Dawson and Boopendranath, 2001; Boopendranath, 2003; Hannah et al., 2003)

10.3.2. Semicircular Fisheye BRD

Semicircular fisheye with 300 x 200 mm horizontally orientated exit was used for the comparative analysis with oval grid. The fisheye BRD used in this experiment were fabricated in the CIFT gear fabrication laboratory with supporting rods extend up to 300 mm and the BRD was made entirely of stainless steel rods of 6 mm dia (Fig. 10.2). The fisheye was fitted on the topside of the trawl codend at a distance of 4.5 m (225 meshes) from the fore end and 1.5 m (75 meshes) from the rear end of the codend.

10.3.3. The gear, vessels used for the experiment and area of study

The gear used for the operation of fisheye was a 29.0 m shrimp trawl with 20 mm diamond mesh codend (Fig. 3.4). The trawl was made entirely of twisted polyethylene. V-type otter boards of 80 kg each were used as the sheer device. Two research vessels of Central Institute of Fisheries Technology are used for conducting the field trials, (i) steel trawler MFB Matsyakumari (17.5 m LOA and 57.17 GRT) having 277 bhp @ 1000 rpm Kirloskar Mann engine and (ii) wooden trawler MFV Sagar Shakti (15.24 m LOA and 30 GRT) having 223 bhp @ 1800 rpm Ruston MWM engine. The experimental fishing operations were conducted during October-November 2006 in the traditional coastal waters off Cochin at depths ranging between 9 and 32 m (Fig. 3.1).

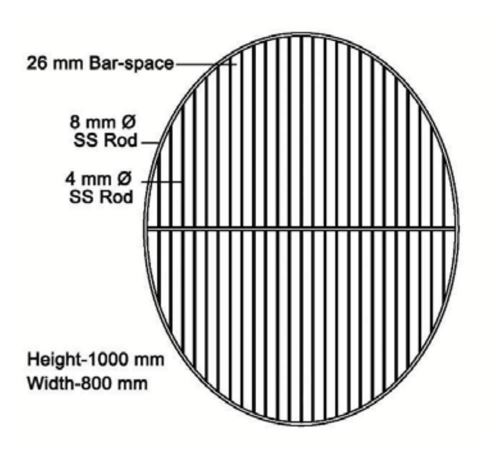


Fig. 10.1. Flat Oval grid with 26 mm bar-space

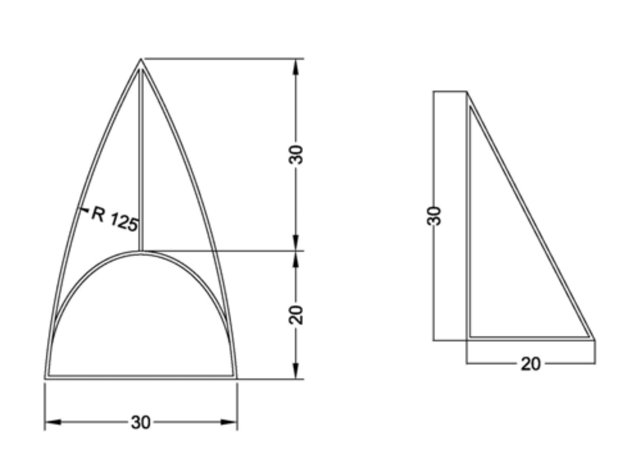


Fig. 10.2. 300 x 200 mm Semicircular fisheye

10.3.4. Experimental fishing trials and catch handling

Both 20 mm and 26 mm oval grids were hauled alternatively and covered codend method was adopted to conduct the study. Catch from the codend and the cover were separately sorted and identified up to species level. Weights of each species were taken and for large quantities sub samples were taken. In the case of fishes and shrimps total length was taken and for cephalopods the mantle length was measured.

10.4. Results and Discussion

Results of the comparative experiments with 1000 x 800 mm oval grid and 300 x 200 mm fisheye with semicircular exit are given the Table. 10.1 and Table. 10.2.

10.4.1. Comparative evaluation of grid and fisheye

During 11 days period, a total of 11 pairs of alternate hauls were taken on board MFV Sagarshakti, using 29.0 m shrimp trawl with a flat oval grid positioned in the extension piece in front of the codend and one semicircular fisheye positioned on topside of the codend. Comparative experiments were conducted in order to study the fish behaviour and escapement of non-target groups from the shrimp trawl and there by analyse the variations in the bycatch exclusion and target catch retention of characteristics of flat oval grid and fisheye.

Table. 10.1. Bycatch exclusion effect on species groups due to the installation of 300 x 200 mm Semicircular fisheye and Oval grid

Grid type	Species groups	Encountered catch, kg	Retained, %	Excluded, %
300 x 200 mm Semicircular fisheye	All species	56.239	57.63	42.37
	Shrimp species	5.330	98.41	1.59
	Non-shrimp species	50.909	53.36	46.64
Oval grid with 26 mm bar-space	All species	35.171	49.65	50.35
	Shrimp species	5.253	92.00	8.00
	Non-shrimp species	29.918	42.21	57.79

Table. 10.2. Results of experiments with oval grid and semicircular fisheye BRDs

	Semicircular fisheye BRD	26 mm Oval grid BRD
No. of hauls	11	11
Total catch (kg)	56.239	35.171
CPUE (kg/h)	4.72	2.95

Retained catch (kg)	32.408	17.461
Retained catch (%)	57.63	49.65
Excluded catch (kg)	23.831	17.71
Excluded catch (%)	42.37	50.35
Retained shrimp catch (kg)	5.245	4.833
Excluded shrimp catch (kg)	0.085	0.42
Total shrimp catch (kg)	5.33	5.253
Retained shrimp catch (%)	98.41	92.00
Excluded shrimp catch (%)	1.59	8.00
Retained bycatch (other than shrimps) (kg)	27.163	12.628
Retained bycatch (other than shrimps) (%)	53.36	42.21
Excluded bycatch (other than shrimps) (kg)	23.745	17.29
Excluded bycatch (other than shrimps) (%)	46.64	57.79
No. of species caught	80	89
Fish species	66	66
Shrimp species	4	5
Other species	10	18
100% exclusion (No. of species)	6	16
>50% exclusion (No. of species)	9	22
Up to 50% exclusion (No. of species)	26	24
0% exclusion (No. of species)	39	27

During 11 days of fishing operations in the traditional fishing grounds off Cochin, eleven hauls each were taken for each design and a total of 91.410 kg catch was obtained with an average CPUE of 3.83 kg / hr. The trawl net fitted with flat oval grid caught 35.171 kg and those fitted with fisheye caught 56.239 kg with an average CPUE 2.95 kg/h and 4.7 kg/hr respectively. Oval grid retained 17.461 kg in the codend and 17.71 kg in the cover, which showed an overall catch exclusion rate of 49.65% and fisheye retained 32.408 kg in the codend and 23.831 kg in the cover, showed 42.37% overall catch exclusion. Regarding bycatch exclusion which was the percentage of catch excluded after deducting the percentage of shrimps, the oval grid performed better showed 57.79% bycatch exclusion and fisheye showed about 46.64% bycatch exclusion.

80 and 89 species respectively encountered the fisheye and oval grid incorporated trawl systems and among this 100% escapement was shown by 16 species in oval grid (*Thryssa kammalensis, Chirocentrus nudus, Chirocentrus dorab, Scomberoides lysan, Siganus canaliculatus, Liza parsia, Dasciaena albida, Sardinella fimbriatus, Alepes kleinii, Charybdis natator, Ilisha melanostoma, Johnius borneensis, Johnius dussumieri, Pempheris mangula, Parastromateus niger* and *Scomberoides tol*) and 6 species (*Valamugil cunnesius, Liza parsia, Thryssa kammalensis, Atule mate, Caranx sexfasciatus* and *Lagocephalus inermis*) in the semicircular fisheye. More than 50% escapement is shown by 22 species in the oval grid and 9 species in the semicircular fisheye. Regarding the target catch loss, oval grid lost about 8% of shrimp catch and semicircular fisheye performed much better in this aspect losing only 1.59% of total shrimp catch. Zero percentage escape was shown by 39 and 27 species respectively from semicircular fisheye and oval grid BRD.

10.4.2. Student's t-test

In the case of flat oval grid and semicircular fisheye statistically significant difference in the bycatch exclusion was observed for 10 species in favour of flat oval grid, showing higher bycatch exclusion efficiency of flat grid. Bycatch exclusion of about 58% was given by the flat oval grid while semicircular fisheye excluded about 47% of bycatch. *Lepturacanthus savala* (P=0.034), *Opisthopterus tardore* (P=0.041), *Otolithes cuvieri* (P=0.048), *Otolithes ruber* (P=0.048), *Pampus argenteus* (P=0.043), *Portunus sanguinolntus* (P=0.032), *Stolephorus commersonnii* (P=0.003), *Thryssa malabarica* (P=0.047), *Thryssa mystax* (P=0.009), *Thryssa purava* (P=0.042) and *Uroteuthis* (*Photololigo*) *duvauceli* (P=0.026) showed significantly higher exclusion from flat oval grid. But when the aspect of target catch retention was taken semicircular fisheye performed much better. Loss of targeted shrimp species *Metapenaeus dobsoni* was significantly higher (P=0.006) from oval grid compared to fisheye. Loss of *Parapenaeopsis stylifera* was also higher from the grid BRD; however the difference was not statistically significant. About 15 species have shown higher exclusion from the grid system and about 12 species higher exclusion from the fisheye; however the differences were not found to be statistically significant.

10.4.3. Selectivity studies

The selectivity analyses of 26 mm oval grid and semicircular fisheye were performed and for nine species *viz. Alepes djedaba, Ambassis ambassis, Lagocephalus spadiceus, Lepturacanthus savala, Megalaspis cordyla, Sardinella longiceps, Stolephorus commersonnii, Stolephorus waitei* and *Thryssa mystax* significant values were obtained concurrently. Selectivity curves and selectivity parameters of these species were given in Figures 10.3 to 10.11 and in Table 10.3 respectively. Six species out of nine showed significant results in favour of flat oval grid with 26 mm bar-space. The L_{50} values of *Alepes djedaba, Ambassis ambassis, Lepturacanthus savala, Megalaspis cordyla, Stolephorus waitei* and *Thryssa mystax* were found to be lower than their length at first maturity. Moreover *Sardinella longiceps* and *Stolephorus commersonnii* showed almost similar results.

Table. 10.3 Selectivity parameters for 26 mm oval grid and semicircular fisheye

Species	BRD type	$L_{25\%}$	$L_{50\%}$	$L_{75\%}$	Selection range, mm	Length at first maturity, mm
Alepes djedaba	Semicircular	133.79	156.09	178.40	44.62	180-189
	26 mm	124.55	135.88	147.20	22.62	
Ambassis ambassis	Semicircular	77.74	89.93	77.74	102.13	55-75
	26 mm	53.71	64.96	76.22	22.51	
Lagocephalus spadiceus	Semicircular	83.57	75.72	91.42	15.69	-
	26 mm	66.15	82.81	99.46	33.32	
Lepturacanthus savala	Semicircular	335.40	403.09	470.78	135.38	418-750
	26 mm	258.14	330.08	402.03	143.89	
Megalaspis cordyla	Semicircular	76.09	137.12	198.16	122.07	250
	26 mm	80.00	99.71	119.42	39.43	
Sardinella longiceps	Semicircular	59.84	85.27	110.70	50.86	150-162
	26 mm	50.08	84.95	119.83	69.75	
Stolephorus commersonnii	Semicircular	90.47	101.22	111.97	21.50	74
	26 mm	99.06	108.53	118.01	18.94	
Stolephorus waitei	Semicircular	90.82	109.54	128.25	37.43	81-84
	26 mm	70.02	83.75	97.48	27.47	
Thryssa mystax	Semicircular	104.25	161.76	219.28	115.04	130
	26 mm	74.86	118.80	162.74	87.89	

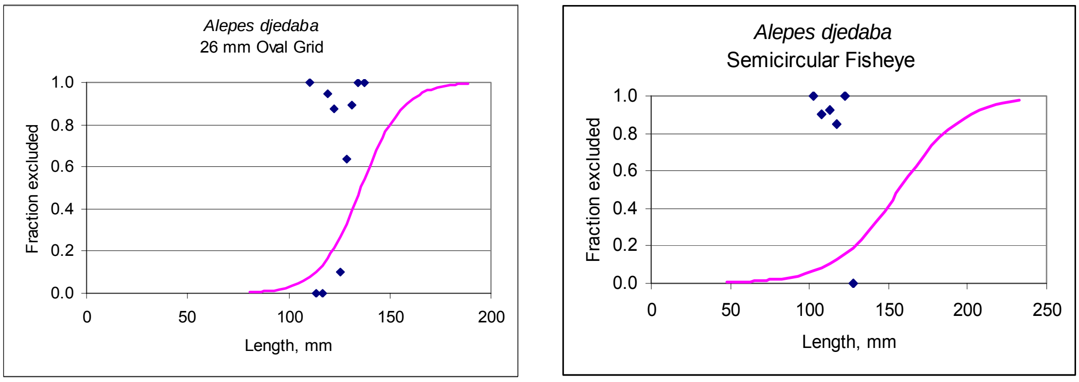


Fig. 10.3. Selectivity curves for *Alepes djedaba*

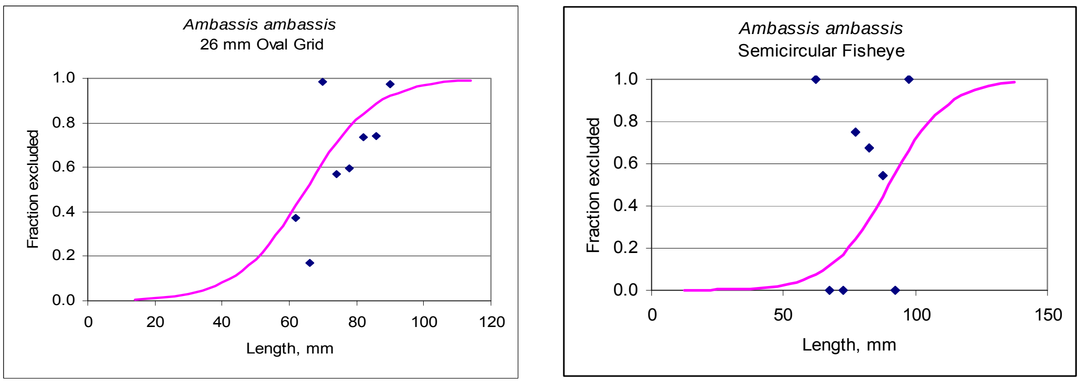


Fig. 10.4. Selectivity curves for *Ambassis ambassis*

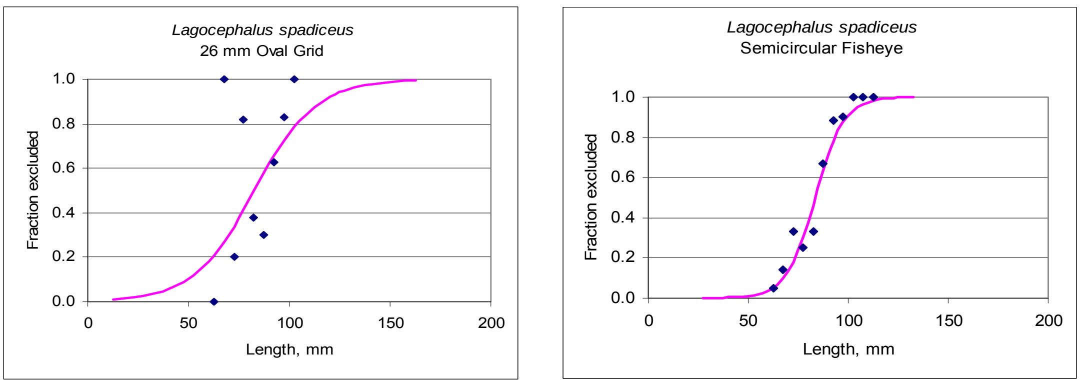


Fig. 10.5. Selectivity curves for *Lagocephalus spadiceus*

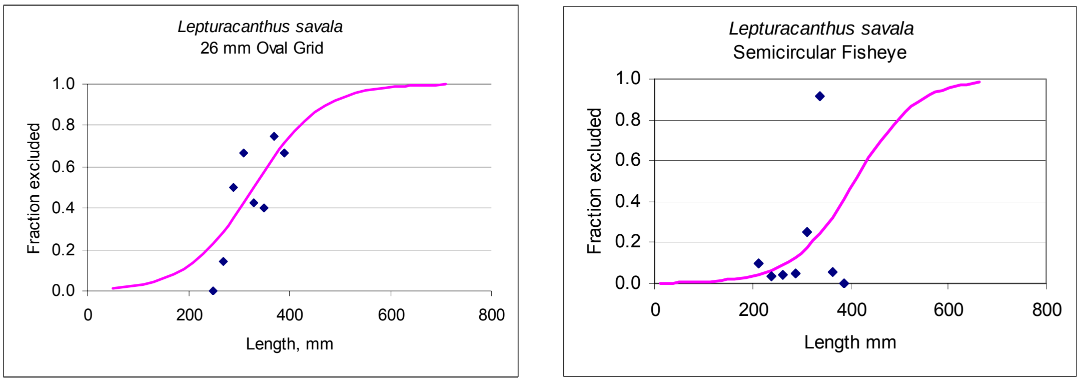


Fig. 10.6. Selectivity curves for *Lepturacanthus savala*

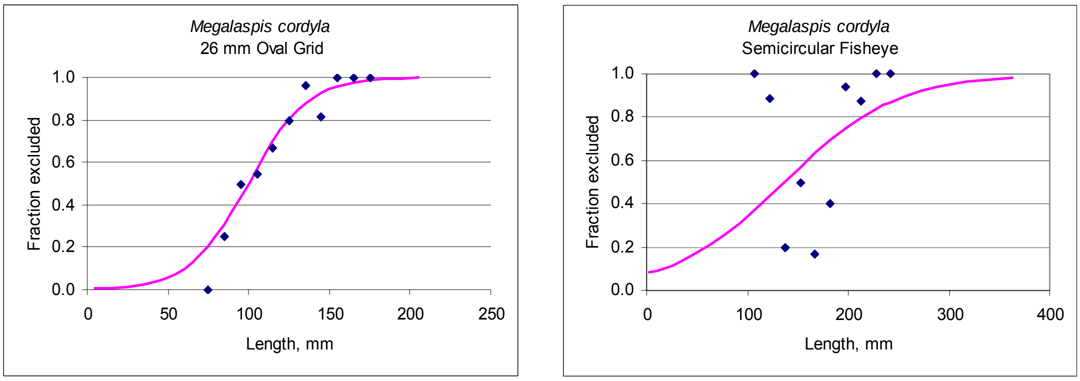


Fig. 10.7. Selectivity curves for *Megalaspis cordyla*

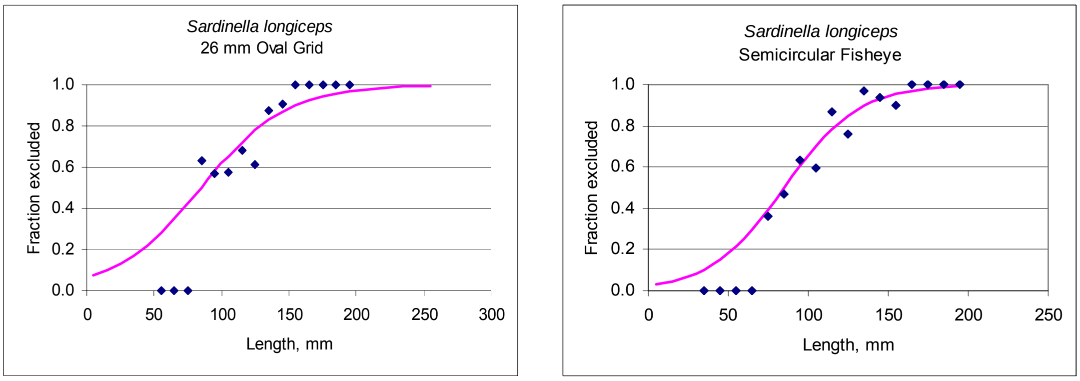
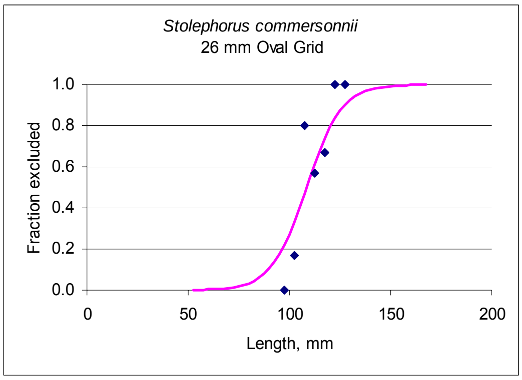


Fig. 10.8. Selectivity curves for *Sardinella longiceps*



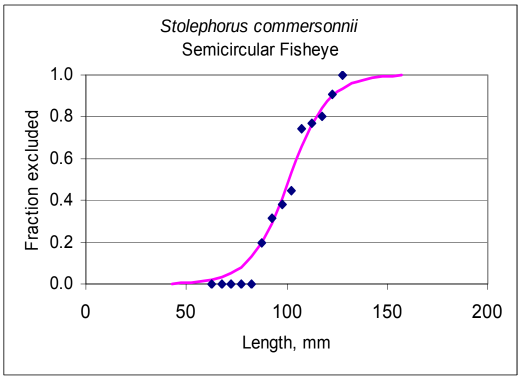
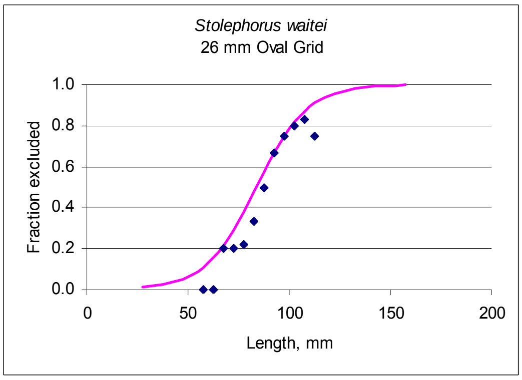


Fig. 10.9. Selectivity curves for *Stolephorus commersonnii*



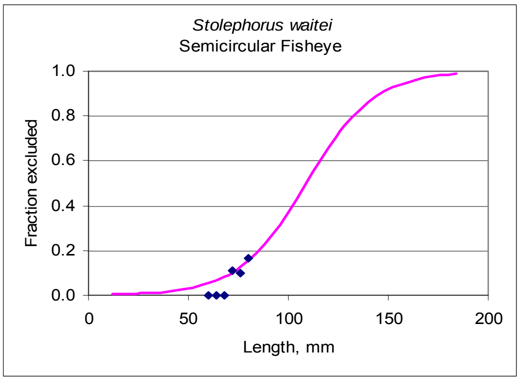
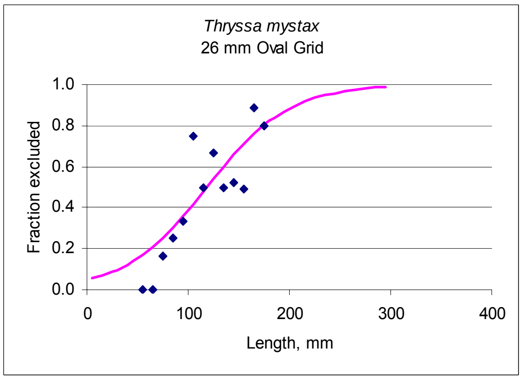


Fig. 10.10. Selectivity curves for *Stolephorus waitei*



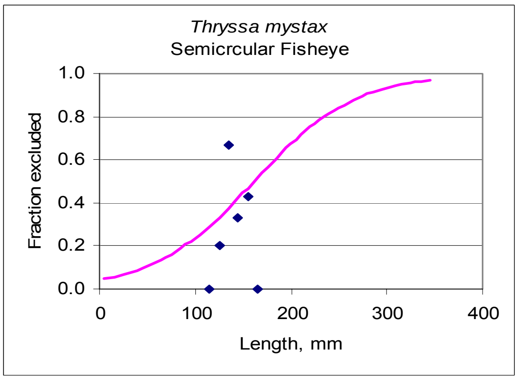


Fig. 10.11. Selectivity curves for *Thryssa mystax*

10.4.4. PRIMER analysis

PRIMER software package (Version 5.2.9; Plymouth marine Laboratory, Plymouth, UK) was used for SIMPER analysis, plotting k-dominance curves, and estimating diversity indices such as total number of species (S), Margalef richness (d), Pielou's evenness (J'), Brillouin index (H), Shannon index (H'), Simpson's dominance index (λ'), Hill (N1), taxonomic diversity (Δ), taxonomic distinctness (Δ*) average phylogenetic diversity index (Phi+) and total phylogenetic diversity index (sPhi+). Simpson's evenness measure ($E_{1/D}$) was calculated using MS Excel by dividing reciprocal of Simpson's dominance index with total number of species (S) in the sample

The diversity indices calculated for semicircular fisheye and 26 mm oval grid are given in the Table. 10.4. From the results it was clear that the catch escaped from 26 mm oval grid was found to have more diversity in terms of S, d, J', H, H', N1, $E_{1/D}$, Δ, Δ*, Phi+ and sPhi+. Higher dominance was observed in semicircular grid in terms of Simpson's dominance index (λ') as 70% of the total number of individuals was represented *Sardinella longiceps*. Phi+ and sPhi+ was also found to be higher in the 26 mm oval grid showed that the taxonomic breadth of species represented in the 26 mm grid was more than that of semicircular fisheye since in 26 mm oval grid bycatch consisted 60 species, that were represented by 26 families and in semicircular fisheye 49 bycatch species of were represented by only 19 families.

Table. 10.4. Mean Diversity indices of species escaped from Semicircular fisheye and Oval grid

	S	d	J'	H	H'	N1	λ'	$E_{1/D}$	Δ	Δ*	Phi+	sPhi+
Fisheye	49	8.76	0.38	1.29	2.12	4.35	**0.50**	0.04	27.51	54.91	34.69	1700
Oval Grid	**60**	**12.45**	**0.71**	**2.47**	**4.21**	**18.46**	0.09	**0.18**	**59.84**	**65.83**	**34.76**	**2086**

In the k-dominance plot (Fig. 10.12), in which the cumulative ranked abundances of species obtained in 26 mm oval grid and semicircular fisheye was plotted against species rank and it was observed that the curve for 26 mm oval grid lay on the lower side, extended further and raised slowly showed higher biodiversity in the catch excluded from 26 mm grid.

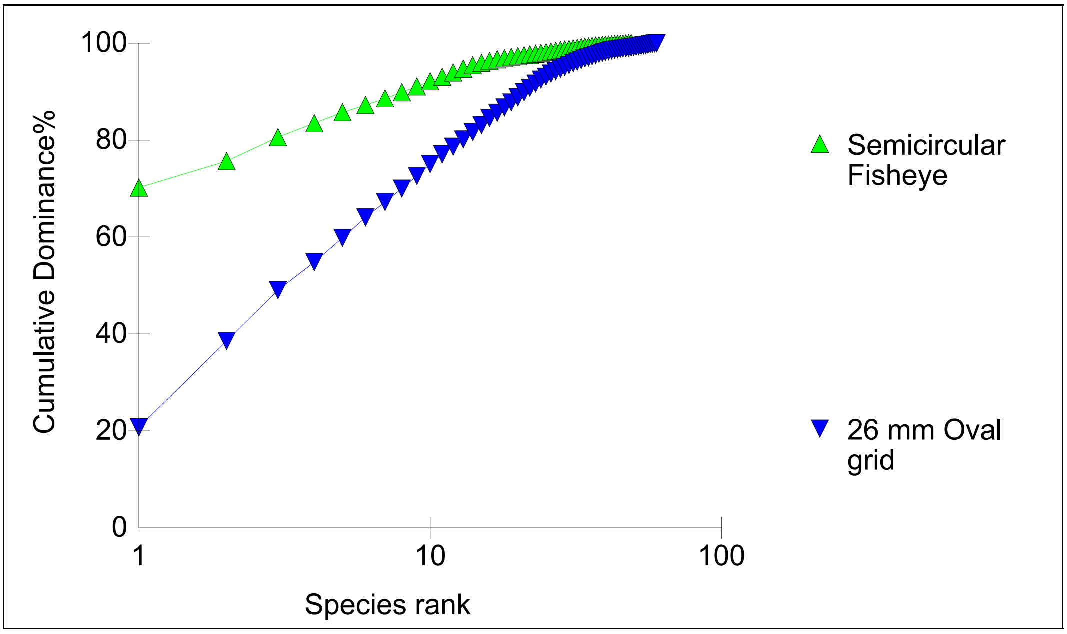
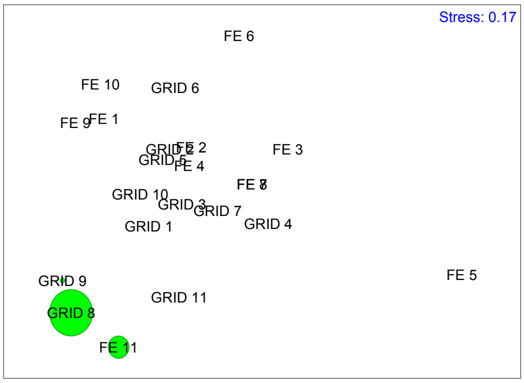
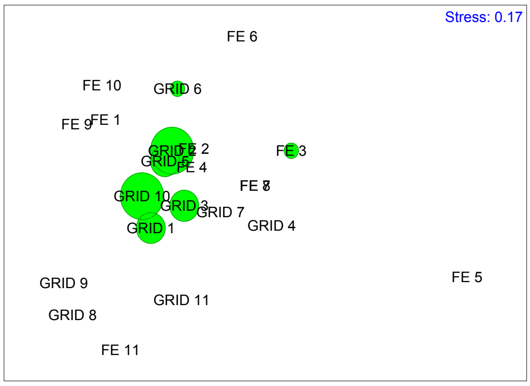


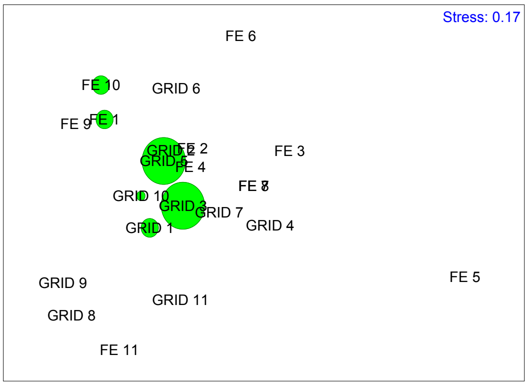
Fig. 10.12. Dominance plot for species escaped from Oval grid having 26 mm bar-space and Semicircular fisheye

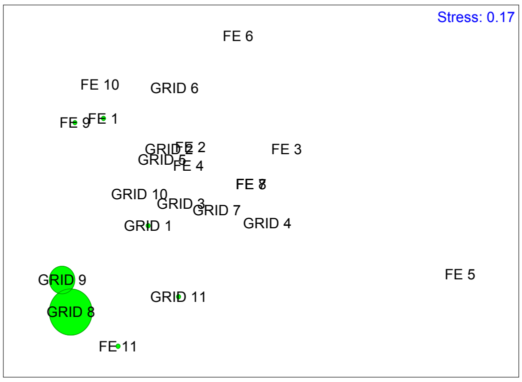
Bubble plots could be obtained by superimposing the abundance data of a particular species in the MDS plot, and the abundance of that species in a particular sample could be directly understood by the size of the bubble. Bubble plots of some discriminating species such as *Ambassis ambassis, Otolithes ruber, Stolephorus commersonnii, Encrasicholina devisi, Srolephorus waitei, Johnius amblycephalus, Meagalaspis cordyla, Secutor insidiator, Sardinella longiceps, Thryssa mystax, Metapenaeus dobsoni* and *Parapenaeopsis stylifera,* are given in Fig. 10.13a & 10.13b. The stress value (0.17), which overlying on the MDS plot showed a good ordination of the samples collected. The bubble plot of *Metapenaeus dobsoni* and *Parapenaeopsis stylifera* showed its comparatively high escapement through 26 mm oval grid. All other species except *Sardinella longiceps* and *Stolephorus waitei* showed higher escapement form 26 mm grid.



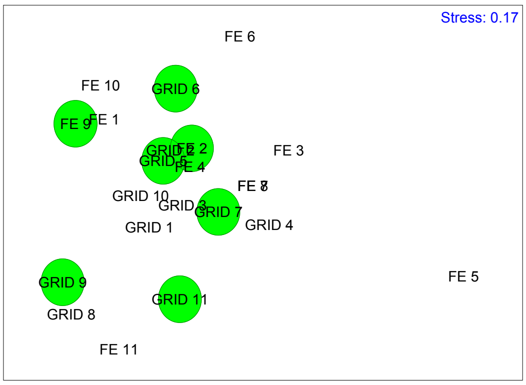


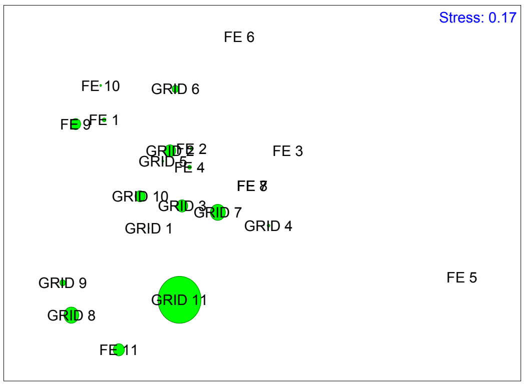
Ambassis ambassis ***Stolephorus commersonnii***





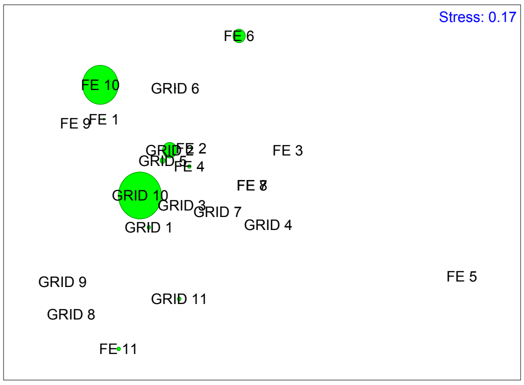
Encrasicholina devisi ***Otolithes ruber***



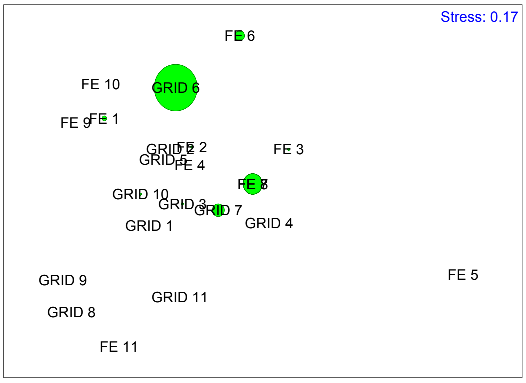


Johnius amblycephalus ***Thryssa mystax***

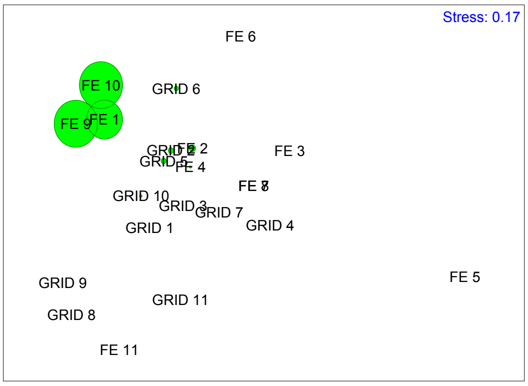
Fig 10.13a. Bubble plots showing abundance of escaped species from oval grid and semicircular fisheye



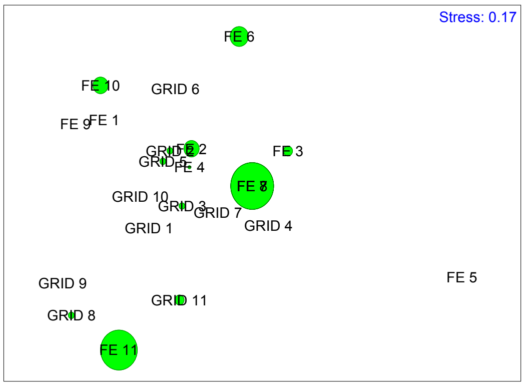
Meagalaspis cordyla



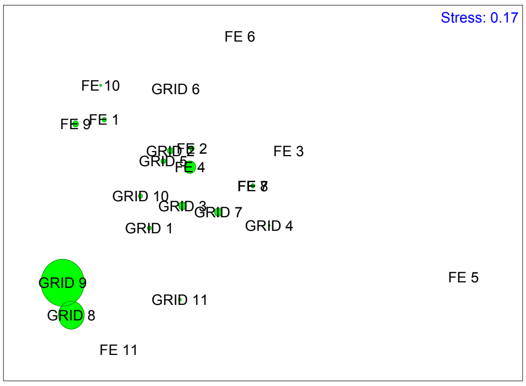
Secutor insidiator



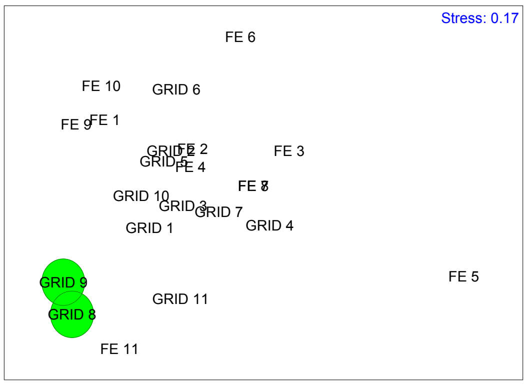
Sardinella longiceps



Stolephorus waitei



Metapenaeus dobsoni



Parapenaeopsis stylifera

Fig 10.13b. Bubble plots showing abundance of escaped species from oval grid and semicircular fisheye

10.5. Conclusion

Comparative evaluation of 26 mm oval grid and semicircular fisheye was conducted and produced differing results in respect of bycatch exclusion and target catch retention. While grid showed excellent results in terms of bycatch exclusion, fisheye showed promising results in target catch retention. Bycatch exclusion shown by 26 mm oval grid was about 58% and that by semicircular fisheye was about 47%. About 16 species showed 100% exclusion from 26 mm oval grid while semicircular fisheye showed 100% escapement for only six species. More than 50% escapement was shown by 22 and 9 species for 26 mm oval grid and semicircular fisheye respectively. Diversity analysis results were favourable to 26 mm oval grid which excluded about 60 species belonging to 26 families. Shrimp loss was comparatively high (about 8%) in 26 mm oval grid. In the selectivity analysis that six out of nine species showed favorable results for 26 mm oval grid and in another two species both grid and fisheye produced similar results.

Oval grid with 26 mm bar-space showed better bycatch exclusion characteristics during different set of experiments (about 58%); however shrimp loss was 6-8%. In the case of semicircular fisheye, bycatch exclusion was in the range 35% to 51% target catch retention was excellent (>98%). BRDs with bycatch exclusion above 35% have been considered for certification of BRDs for use in shrimp fisheries elsewhere. In view of this, both the oval grid BRD and semicircular fisheye BRD could be considered as appropriate for adoption for commercial shrimp trawling in Indian waters, for mitigation of bycatch problem and protection of biodiversity.

Chapter 11

Summary and Recommendations

Bycatch and discards are common problems faced by all fisheries globally and it is a major component of impact of fisheries on marine ecosystems. They are extremely complex and ecosystem-wide issues, which include many economic, political and moral factors. Bycatch is unavoidable in any kind of fishing but the quantity varies according to the type of gear operated. Bycatch refers to non-targeted species retained, sold or discarded for any reason and can be defined as discarded catch plus incidental catch.

An estimated 27.0 million tonnes (range: 17.9-39.5 million t) of bycatch were discarded annually by the world's marine fishing fleets and shrimp trawling alone accounted for 9.5 million tonnes (35 %) of discard annually, in 1994. FAO estimated a global discard level of 20 million tonnes in 1998, which was re-assessed at 7.3 million tonnes, for the 1992-2001 period. The FAO Code of Conduct for Responsible Fisheries adopted in 1995, gives emphasis to responsible practices in order to ensure long-term sustainability of the aquatic fishery resources, protection of biodiversity, energy conservation and environmental safety.

Commercial trawling in India is mainly targeted on shrimp and during their operation large quantities of bycatch, which include finfish, crustaceans, molluscs etc, are captured. Non-economic components of the bycatch are generally discarded back to the sea and wasted, which is not acceptable in the context of responsible fishing. In India, the bycatch in shrimp trawling is a serious problem accounting for 70-90% of the total catch of which about 40% consisted of juveniles, which implicate severity of the issue. In order to minimize this loss trawling has to be made more selective and environment friendly by incorporating Bycatch Reduction Devices (BRDs).

In the context of Indian fisheries there is a paucity of information on bycatch, in general, and bycatch reduction technologies, in particular. In this study, a detailed investigation on trawl bycatch and bycatch reduction measures is attempted with a view to evolve optimized BRDs for improving selectivity of commercial shrimp trawls. The main objectives of the study include:

i. Design and development of hard bycatch reduction devices, incorporating rigid materials for trawling;

ii. Comparative evaluation of hard bycatch reduction devices, for selective trawling appropriate for small scale mechanized sector;

iii. Conduct a bycatch characterisation study of trawl catch, off Central Kerala; and

iv. Characterisation of the existing trawling systems operated off Central Kerala.

Review of Hard Bycatch Reduction Devices

BRDs can be broadly classified into two categories based on the type of materials used for their construction, as Hard BRDs and Soft BRDs. Hard BRDs are those, which use hard grids or solid separating devices. The materials used for making Hard BRDs include solid steel rods, aluminium rods, fibreglass rods, steel or aluminium tubing. Hard BRDs can be broadly classified into Flat grid BRDs (e.g. Nordmore grid), Bent grid BRDs (e.g. Super shooter), Oval grid BRDs (e.g. Matagorda and CIFT-TED), Slotted grid BRDs (e.g. Flounder TED), Hooped and fixed angle BRDs (e.g. NMFS TED), BRDs with rigid escape slots (e.g. Fisheye BRD), Semi-flexible BRDs (e.g. Polyamide grid) and Combination BRDs (e.g. AusTED).

Materials and Methods

Studies were conducted using the following BRD designs:

(a) A rectangular grid having dimensions of 1000 mm in height and 800 mm in width and having bar-spacing of 22 mm;

(b) Oval grids having dimensions of 1000 mm in height and 800 mm in width and having bar-spacings of 20 mm, 22 mm and 26 mm;

(c) Three designs of fisheye BRD having different exit opening configurations such as oval horizontal, oval vertical and semi circular.

A 29.0 m commercial shrimp trawl design with 20 mm diamond mesh codend, rigged with V-form otter boards of 80 kg each, was used for comparative evaluations of BRDs. Experimental fishing operations were conducted from research vessels *MFB Matsyakumari* (17.5 m LOA; 57.17 GRT;

277 bhp @ 1000 rpm Kirloskar Mann engine) and *MFV Sagar Shakti* (15.24 m LOA; 30 GRT; 223 bhp @ 1800 rpm Ruston MWM engine), belonging to Central Institute of Fisheries Technology, Cochin, in the traditional fishing grounds off Cochin at a depth range of 9-32 m.

Comparative evaluation of prototypes of hard BRDs was conducted using statistically designed trawling experiments. Species level data was used to determine grid selectivity and exclusion characteristics of BRDs and bycatch characterisation. BRD-wise catch diversity analysis was carried using PRIMER 5.2.9 (Plymouth Routines In Multivariate Ecological Research).

The details of bycatch issues and concerns were collected by making field visits and using structured interview schedules. Details of vessel, gear and accessories were collected by direct observation of a stratified random sample of trawl systems, operated off Central Kerala.

The study was conducted at Central Institute of Fisheries Technology (CIFT), Cochin which has adequate facilities such as fully equipped research vessels, gear fabrication and testing laboratories.

Trawl Systems of Central Kerala

The trawl fisheries in the central Kerala has developed significantly and in density it got second position in Kerala state next to Kollam area. Due to the unbridled expansion in fleet size and indiscriminate fishing operations, has affected the catch rate and the returns drastically. The boat owners were compelled to construct larger trawlers with higher capacities and endurance to explore deeper waters and for conducting multiday fishing. In central Kerala, most of the trawlers are engaged in multi-day and multi-species fishing. A gradual shift in the selection of boat materials is observed and for new constructions steel is the preferred boat building material rather than wood.

Changes have been observed in the trawl designs. The mouth opening of the nets has increased and use of larger meshes in the front sections is observed in fish trawl designs. The trawlers carry 8-15 trawl nets during the fishing trips, with the intention of catching all available and commercially important aquatic organisms in the sea.

During the study 13 different designs of trawl nets were observed. These include 12 two-seam designs and one four-seam fish trawl design. Multi-seam designs targeting fishes are gaining popularity among fishermen in central Kerala, especially in Munambam.

Bycatch characterization of trawl catch off Cochin

During this study conducted from January to December 2006 period, on trawl bycatch components off Cochin, 282 species of marine species were encountered in the trawl nets. The bycatch included 191 species of fishes, 11 species of shrimps, 3 species of lobsters, 13 species of crabs, 11 species of cephalopods, 45 species of molluscs, 2 species of echinoderms, 2 species jellyfish, 2 species stomatopods, 1 species sea snake and 1 species of sea turtle. The fishes belonged to 12 orders and 59 families and 109 genera. The shrimp species belonged to 4 families and crabs to 4 families, cephalopod species to 3 orders and 3 families, molluscan species to 22 families and jelly fishes to 2 families.

The catch per unit effort (CPUE, $kg.h^{-1}$) was found to be higher before monsoon in the month of March and in the months of September, October and November. The CPUE was found to be low after March and throughout the monsoon periods. The percentage of shrimp, which is the targeted catch of trawl fishing showed wide variations in the landings from month to month. On an average shrimps constitute about 13% of the total trawl catch, with a wide fluctuation between 0.04% and 48%. Highest percentage of shrimp catch was recorded in the month of May and lowest catch was recorded in the month of July. *Metapenaeus dobsoni* was available throughout the year except in July and *Parapenaeopsis stylifera* was available during April - May and also from September to December. The occurrence of jellyfish began in July, peaked in September, gradually reduced and disappeared after December. The occurrence of jellyfish caused difficulties in trawling and damage to the fishing gear and during periods of heavy infestation, the trawl nets will be filled with in fifteen minutes after shooting.

The bycatch percentage was obtained after subtracting the percentage of shrimps from the total catch. The average bycatch percentage in Cochin waters during the year 2006 was about 87%. The lowest bycatch percentage was observed in the month of May and bycatch percentage as high as 99% was observed in the month of July. Although bycatch problem exists, it tends to contribute a significant share in the income of the trawlers. Many industries utilizing the bycatch have been evolved in Cochin and adjacent areas. Small and medium trawlers are bringing some part of their bycatch for the raw material suppliers of fish meal factories located in other states. Certain bycatches like Japanese threadfin bream, lizard fishes and some deep sea fishes already gained market due to their higher demand in *surimi* plants. Bycatch may result in many biological, ecological, environmental and economic problems mainly because of the fact that about 40-50 % of the bycatch in this area is comprised of juveniles and sub-adults. The use of bycatch reduction devices is not known among the trawl fishermen of central Kerala.

Experiments with Fisheye BRD designs

Fishing experiments were conducted to study the bycatch exclusion and target catch retention characteristics of three different design variations of fisheye BRD *viz*, (i) 300x200 mm oval exit with horizontal orientation, (ii) 300x200 mm oval exit with vertical orientation and (iii) 300x200 mm semicircular exit with horizontal orientation BRD.

Fisheye BRD with oval exit and vertical orientation showed poor performance. Though it showed excellent bycatch reduction characteristics, the design also showed considerable amount of shrimp loss. On the other hand, semicircular fisheye BRD showed promising performance; in terms of bycatch exclusion (50.58%) and lowest target catch loss (0.83%). The selectivity studies showed that with all the three fisheye designs significant number of juveniles were escaping from the trawls and for all species taken in to consideration semicircular fisheye showed better selectivity curves except for *Rastrelliger kanagurta*. Quality of shrimp retained in he codend was better and free from physical damages, due to the exclusion of large fish species through the BRD. The main advantage of semicircular fisheye in reducing the target catch loss is attributed to the low turbulence due to design features compared to the other fisheye BRD designs. The higher bycatch exclusion of semicircular fisheye BRD is attributed to the larger area of the exit opening, which has about 9.6% more than the other designs. The Fisheye BRD with 300x200 mm semicircular exit and horizontal orientation has shown potential for introduction in commercial shrimp trawls.

Comparative evaluation of Semicircular and Oval Fisheye BRDs

Comparative fishing experiments were conducted using Fisheye BRD with 300x200 mm semicircular exit and horizontal orientation and Fisheye BRD with 300x200 mm oval exit and horizontal orientation. During the experiments, the former performed better than the latter; in terms of target catch retention, which averaged at 99.17% and 97.76%, respectively. Bycatch exclusion of semicircular fisheye BRD was slightly lower than Fisheye BRD with oval exit and horizontal orientation and averaged at 34.9% and 36.19% respectively. The selectivity analysis showed that with both Fisheye BRD designs facilitated the release of significant number of juveniles. When all species are taken in to consideration, Fisheye BRD with semicircular exit showed better selectivity characteristics except for *Rastrelliger kanagurta*. Results of diversity analysis of the excluded bycatch have shown higher evenness of the individual species, in the case of Fisheye BRD with oval exit.

Comparative evaluation of Rigid Oval and Rectangular Grid BRDs

Flat rectangular and oval sorting grids have shown potential for bycatch reduction in many fisheries. Larger organisms entering the trawl are excluded through the exit opening by the grid BRD by the physical sorting action and smaller organisms such as shrimps and small-sized fishes goes through the grid bar spacing to the codend. Comparative field evaluation of Rectangular and Oval Grid BRDs of 1000x800 mm size with 22 mm grid bar spacing was conducted using commercial shrimp trawl design. Oval grid BRD performed better than Rectangular grid BRD both in terms of bycatch exclusion and target catch retention rates. Average bycatch exclusion was 64% for the former and 54% for the latter design while target catch retention was 90% and 87%, respectively. The difference in performance was statistically significant ($p<0.05$). The better performance of Oval grid BRD is attributed to lower turbulence due to its streamlined form compared to rectangular grid BRD that has angularities in the BRD section. Selectivity analysis has shown better performance of Oval grid BRD. About 78% of the species considered for selectivity studies showed better selectivity characteristics, compared to Rectangular grid BRD.

The shrimp loss of more than 5% was observed in both the grid BRDs and has been attributed to the clogging of the grid by debris due to inadequate bar spacing, incorrect grid angle or the inappropriate shape and size of the exit opening. Further, seasonal variation in relative abundance of the shrimp and bycatch species may also influence rate of bycatch exclusion. Further studies were conducted on the effect of grid bar-spacing on the size selectivity with respect to shrimp species, as it is a major factor affecting the performance of grid BRDs.

Comparative Evaluation of Rigid Oval Grid BRDs with Different Bar-spacing

In order to determine the effect of bar-spacing on the efficiency of grids, comparative performance trials were conducted using Oval grid BRDs with 26 mm and 20 mm bar-spacing. The performance of Oval grid BRD with 26 mm bar-spacing was comparable to earlier works done in other fisheries. The improvement in efficiency in Oval grid BRD with 26 mm bar-spacing was remarkable as there was a 40% reduction in the shrimp loss when the bar-spacing increased from 22 mm to 26 mm. When the bar-spacing was reduced from 22 mm to 20 mm the shrimp loss increased from 10% to 13.8%. Apart from this 26 mm oval grid excluded 59% of bycatch out of which 13 species have shown 100% escapement and an additional 26 species have shown more than 50% escapement. In the case of 20 mm grid, bycatch exclusion was 45% and only 10 showed 100% and 13 species >50% escapement.

Five out of seven species showed higher exclusion rate from 26 mm oval grid which was statistically significant ($p<0.5$) indicating its better exclusion efficiency. Shrimp loss was significantly higher in 20 mm grid.

Even though higher biodiversity indices were obtained for the bycatch excluded from 20 mm oval grid, selectivity analysis and Student's *t*-test indicate better performance of 26 oval mm grid. Though the target catch retention properties was not up to the mark the 26 mm bar-spaced oval grid can be considered as a potential bycatch reduction device that can be recommended to the trawling industry. Further studies were conducted on the comparative performance of the Oval grid BRD and Fisheye BRD semicircular exit.

Comparative Evaluation of Rigid Oval Grid BRD and Semicircular Fisheye

Comparative performance of 26 mm Oval grid BRD and semicircular Fisheye BRD was evaluated. While Oval grid BRD showed excellent results in terms of bycatch exclusion, Fisheye BRD showed promising results in target catch retention. Bycatch exclusion shown by 26 mm Oval grid BRD was about 58% and that by semicircular Fisheye BRD was about 47%. About 16 species showed 100% escapement from 26 mm Oval grid BRD while semicircular Fisheye BRD showed 100% escapement for only six species. More than 50% escapement was shown by 22 and 9 species for 26 mm Oval grid BRD and semicircular Fisheye BRD, respectively. Diversity analysis of the excluded catch indicated that 60 species belonging to 26 families were excluded by Oval grid BRD. Statistical analysis showed favourable results for 26 mm oval grid when bycatch exclusion was considered. About 10 species showed statistically significant higher exclusion from 26 mm oval grid and other 15 species also showed higher exclusion from the same device though it was not statistically significant. The shrimp loss was highly significant ($p<0.01$) for 26 mm oval grid, which was about 7.9% of the total shrimp catch. In the selectivity analysis, six out of nine species showed favorable results (L_{50} values were greater than the length at first maturity) for 26 mm oval grid and in another two species both grid and fisheye produced similar results.

Oval grid BRD with 26 mm bar-spacing showed better bycatch exclusion characteristics consistently (59% and 58% respectively in the first and second set of experiments). However, the shrimp loss was about 6.12% and 8% in the first and second set of experiments respectively. The semicircular Fisheye BRD, showed bycatch exclusion in the range of 35% to 51% and at the same time showed excellent target catch retention properties above 98%. BRDs with bycatch exclusion above 35% can be considered for certification as approved BRDs for shrimp fisheries elsewhere. In view of this 300 x 200 mm semicircular fisheye can be considered as the optimum design that can be recommended as the potential BRD for commercial trawling.

Conclusions

i. A review of literature has indicated that about thirty-three hard BRD designs, which comes under 8 broad classes, have been found operated either experimentally or commercially in different fishing areas with promising results.

ii. Bycatch characterisation of the trawl fishery off central Kerala, India, has revealed 282 species including 191 species of fishes, 11 species of shrimps, 3 species of lobsters, 13 species of crabs, 11 species of cephalopods, 45 species of molluscs, 2 species of echinoderms, 2 species jellyfish, 2 species stomatopods, 1 species sea snake and 1 species of sea turtle.

iii. Bycatch problem exists in the trawl fishery of Central Kerala, but it contributes a significant share in the income of the trawler fishermen. The use of bycatch reduction devices is non-existent among the trawl fishermen.

iv. 13 different designs of trawl nets were observed and the prevailing codend mesh size for shrimp trawls was 20 mm which is below the regulated mesh size (35 mm) under KMFR Act

v. Among the three Fisheye BRD designs evaluated semicircular Fisheye BRD with 300x200 mm semicircular exit opening showed better performance with a bycatch exclusion ranged between 35 and 51% and shrimp loss ranging between 0.83% and 2.24%.

vi. Among the two rigid grid BRDs evaluated, Oval grid BRD showed better performance in terms of higher bycatch exclusion (64%) and lower shrimp loss (10%) compared to the rectangular grid BRD with a bycatch exclusion of 54% and shrimp loss of 13%. The shape and orientation of the exit openings has been observed to affect the bycatch exclusion and target catch retention characteristics of Fisheye BRDs.

vii. Bar-spacing was observed to influence on the performance and selectivity characteristics of rigid grid BRD. The grid with larger bar-space of 26 mm showed better performance than the grid with smaller bar-spacing of 20 mm, in terms of higher bycatch exclusion and lower shrimp loss.

viii. Oval grid BRD with 26 mm bar-spacing has shown higher bycatch exclusion compared to Fisheye BRD with 300x200 mm semicircular exit and horizontal orientation, while Fisheye BRD performed better in terms of shrimp retention.

ix. The performance of Fisheye BRD with 300x200 mm semicircular exit and horizontal orientation has indicated its potential for adoption as bycatch reduction device appropriate for mitigating the bycatch problem in the trawl sector. Another promising design is Oval grid BRD, though it has disadvantages of comparatively higher shrimp loss.

x. Experiments with fisheye BRDs clearly shows that the shape and orientation of the exit openings directly affect the bycatch exclusion and target catch retention characteristics and similarly the shape of the grid and the bar-spacing affects the efficiency of the rigid grid BRDs

Recommendations

i. Bycatch Reduction Devices (BRDs) are essential for reducing the negative impacts of trawling on sustainability of marine resources and biodiversity

ii. Use of BRDs should be made mandatory in shrimp trawl nets and proper awareness should be generated in trawling industry

iii. Fisheye BRD with 300x200 mm semicircular exit opening and rigid Oval grid BRD with 26 mm bar-spacings performed better in terms of bycatch exclusion and target catch retention and hence can be recommended for use in shrimp trawling

iv. Monitoring of fishing activities and catch characterisation should be built into the fishery management system for facilitating interventions where needed

v. Mesh size regulation for codend of the commercial trawls need to be rigorously enforced.

References

Adlerstein, S.A., Trumble, R.J., 1998. Pacific halibut bycatch in Pacific cod fisheries in the Bering Sea: An analysis to evaluate area-time management. *Journal of Sea Research*. 39,153-166.

Allen, G.R., Steene, R.C., 1987. *Reef fishes of the Indian Ocean*. T.F.H. Publications. NJ. 240 p.

Allen, G.R., Steene, R.C., 1994. *Indo-Pacific coral reef field guide*. Tropical Reef Research. 378 p.

Alverson, D.L., Freeberg, M.H., Murawski, S.A., Pope. J.G., 1994. A Global assessment of fisheries bycatch and discards. *FAO Fish. Tech. Pap*. no. 339. Rome, FAO, 233 p.

Alverson, D.L., Larkin, P., 1992. Fisheries: Fisheries Science And Management: Century 21. In: Proceedings of the World Fisheries Congress, Athens, Greece, May 3–8, 1992.

Alverson, D.L., 1997. Global assessment of fisheries bycatch and discards: A summary overview. Global Trends: Fisheries Management. *Am. Fish. Soc. Symp*. 20, 115-125.

Alverson, D.L., 1998. Discarding practices and unobserved fishing mortality in marine fisheries: an update. Washington Sea Grant Programme. University of Washington. 82 p.

Alverson, D.L., 1999. Some Observations on the Science of Bycatch. *Mar. Technol. Soc. J*. 33(2), 6-12.

Alverson, D.L., 1999. Some Observations on the Science of Bycatch. *Mar. Technol. Soc. J*. 33(2), 6-12.

Andrew, N.L., Pepperell, J.G., 1992. The bycatch of shrimp trawl fisheries. In: Ansell, A.D., Gibson, R.N., (Eds.), *Oceanography and Marine Biology Annual Review*, 30, 527-565.

Anon, 1997. Proclamation Re: Shrimp Trawling, Division of Marine fisheries. (www.ncfisheries.net/content/brd.)

Anon, 2004. Popeye fish excluder . Queensland Government Department of Primary Industries and Fisheries. *Trawl fishery newsletter*. July 2004, Issue #5.

Apte, D., 1998. *The Book of Indian Shells*. Bombay Natural History Society. Oxford University Press. 113 p.

Armstrong, D.W., Ferro, R.S.T., MacLennan, D.N., Reeves, S.A., 1990. Gear selectivity and the conservation of fish. *J. Fish. Biol*. Vol. 37, Suppl A: 261-262.

Averill, P.H., 1990. Improved trawl selectivity through strategic use of colored twine. In: Proceedings of the Fisheries Conservation Engineering Workshop, Rhode Island, April 1990.

Averill, P.H., Carr. H.A., 1987. Use of square mesh in New England's ground fishery. In: Proceedings of Oceans 87: The Ocean, an International Workplace. Vol.2: 649-651.

Ball, B., Munday, B., Tuck,T., 2000. Effects of otter trawling on the benthos and environment in muddy sediments. In: Kaiser, M.J., de Groot, S.J., (Eds.), The Effects of Fishing on Non- target Species and Habitats: Biological, Conservation and Socio-economic Issues. Blackwell Science Ltd. pp 69-72.

Belcher, C., Vendetti, R., Gaddis, G., Parker, L., 2001. Results of Gear Testing to Reduce Turtle Capture in the Whelk Trawl Fishery. Issued by the Georgia Seagrant College Program, The University of Georgia Marine Extension service. Bulletin No. 23, 28 p.

Bergmann, M., Wieczorek, S.K., Moore, P.G., Atkinson, R.J.A., 2002. Discard composition of the Nephrops fishery in the Clyde sea area, *Scotland. Fish. Res*. 57, 169-183.

Bjordal, A., 1999. Bycatch control through technical regulations and fisheries monitoring. In: Nolan, C.P., (Ed.). Proceedings of the International conference on Integrated Fisheries Monioring. Sydney, Australia, 1-5 February 1999. Rome, FAO, 378 p.

Bonfil, R., 2000. The problem of incidental catches of sharks and rays, its likely consequences, and some possible solutions. Shark Conference 2000 - Online Documents. Honolulu, Hawaii February 21-24.

Boopendranath, M.R., 2003. CIFT-TED for Turtle-safe Trawl fisheries. *CIFT Special Bulletin* No. 12, 40 p.

Boyce, J.R., 1996. An Economic Analysis of the Fisheries Bycatch Problem. *Journal Of Environmental Economics And Management* 31, 314-336.

Branch, T.A., Rutherford, K., Hilborn, R., 2006. Replacing trip limits with individual transferable quotas: implications for discarding. *Marine Policy*, 30, 281–292.

Brandt, A.V., 1984. *Fish Catching Methods of the World*. Fishing News Books Ltd., London, 432 p.

Brewer, D., Eayrs, S., Rawlinson, N., 1995. Bycatch reduction devices show promise in the NPF [northern prawn fishery]. *Aust. Fish*, 54(5), 24-26.

Brewer, D., Rawlnison, N., Eayrs, S., Burridge, C., 1998. An assessment of bycatch reduction devices in tropical Australian Prawn trawl fishery. *Fish. Res*. 36, 196-215.

Brewer, D.T., Eayrs, S.J., Rawlinson, N.J.F., Salini, J.P., Farmer, M., Blaber, S.J.M., Ramm, D.C., Cartwright, I., Poiner, I.R., 1997. Recent advancements in environmentally friendly trawl gear research in Australia. Developing and sustaining world fisheries resources. The state of science and management. pp. 537-543.

Briggs, R.P., Armstrong, M.J., Rihad, D., 1999. The consequences of an increase in mesh size in the Irish Sea Nephrops fishery: an experimental approach. *Fish. Res*. 40 (1), 43–53.

Broadhurst, M.K., 2000. Modifications to reduce bycatch in prawn trawls: A review and frame work for development. *Reviews in Fish Biology and Fisheries*. 10(1), 27-60.

Broadhurst, M.K., Larsen, R.B., Kennelly, S.J., McShane, P.E., 1999. Use and success of composite square-mesh codends in reducing bycatch and in improving size-selectivity of shrimps in Gulf St. Vincent, South Australia. *Fish.Bull*. 97,434–448.

Broadhurst, M.K., Kangas, M.I., Damiano, C., Bickford, S.A., Kennelly, S.J., 2002. Using composite square-mesh panels and the Nordmøre-grid to reduce bycatch in the Shark Bay prawn-trawl fishery, Western Australia. *Fish. Res.* 58, 349–365

Broadhurst, M.K., Kennelly, S.J., 1996. Rigid and flexible separator trawls that reduce the by-catch of small fish in the Clarence River prawn-trawl fishery, Australia. *Mar. Freshw. Res*. 47, 991-998.

Broadhurst, M.K., Young, D., Damiano, C., 2004. Effects of Nordmore grid angles, profiles and other industry developed modifications on catches in an Australian penaeid-trawl fishery. *Ciencias Marinas*. 30(1B), 155-168.

Burrage, D.D., 2004. Evaluation of the "Gulf Fisheye" Bycatch Reduction Device in the Northern Gulf Inshore Shrimp Fishery. *Gulf Mex. Sci*. 22(1), 85-95.

Burridge, C.Y., Pitcher, C.R., Wassenberg, T.J., Poiner, I.R., Hill, B.J., 2003. Measurement of the rate of depletion of benthic fauna by prawn (shrimp) otter trawls: an experiment in the Great Barrier Reef, Australia. *Fish. Res*. 60, 237-253.

Caddy, J.F. 1989. Species selectivity of fishing gear: an optimal criterion for management of stocks. National reports and selected papers presented at the Sixth Session of the Working Party on Assessment of Marine Fishery Resources, St. George's, Grenada, May 15–19, 1989. Western Central Atlantic Fishery Commission, UN/FAO, Rome, Italy.

Casale, P., Laurent, L., De Metrio G., 2004. Incidental capture of marine turtles by the Italian trawl shery in the north Adriatic Sea. *Biological Conservation* 119, 287-295.

Casey, J., Warnes, S., 1987. Selectivity of square mesh pelagic trawls for mackerel: preliminary results. ICES C.M. 1987/B:23.

Cedrola, P.V., Gonz´alez, A.M., Pettovello, A.D., 2005. Bycatch of skates (Elasmobranchii: Arhynchobatidae, Rajidae) in the Patagonian red shrimp fishery. *Fish. Res*. 71, 141–150.

CEFAS, 2003, A study on the consequences of technological innovations in the capture fishing industry and the likely effects upon environmental impacts. Final Report. Royal Commission on Environmental pollution, 181 p.

Chidambaram, K., 1952. The experimental introduction of powered fishing vessels in India and Ceyon, *Proc. IPFC* 4(2), 225-233 pp.

Chokesnguan, B., Ananpongsuk, S., Siriraksophon, S., Podapol, L., 2000. Study on Juvenile and Trash Excluder Devices (JTEDs) in Thailand. Southeast

Asian Fisheries Development Center Training Department (SEAFDEC). Thailand, TD/RES/47, 8 p.

Chuenpagdee, R., Morgan, L.E., Maxwell, S.M., Norse, E.A., Pauly, D., 2003. Shifting gears: assessing collateral impacts of fishing methods in US waters. *Front. Ecol. Envir.* 1(10), 517-524.

CIFT, 2003. CIFT-TED for Turtle-safe Trawl Fisheries - A Success Story in Responsible Fisheries), *CIFT Special Bulletin* No. 12 (English): ii+40 p.

Clarence, P., 1997. A Brief History of Bycatch Management Measures for Eastern Bering Sea Groundfish Fisheries. *Marine Fisheries Review*. 59(4), 15-22.

Clarke, K. R., Warwick, R.M., 1994. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 1st edition: Plymouth Marine Laboratory, Plymouth, UK, 144 p.

Clarke, K. R., Warwick, R.M., 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2nd edition: PRIMER-E, Plymouth, UK, 172 p.

Clarke, K.R., Gorley, R.N., 2001. PRIMER v5: User manual, PRIMER-E, Plymouth UK, 91 p.

Clucas, I.J., 1997. Study of the options for utilization of bycatch and discards from marine capture fisheries. FAO Fisheries circular No-928, Rome, FAO, 59 p.

Clucas, I.J., James, D.G., (Eds.) 1997. The utilisation of bycatch/discards. In: Papers presented at the technical consultation on Reduction of Wastage in Fisheries, Tokyo, Japan, 28 October 1 November 1996, FAO Fisheries Report, No. 547, Supplement, Rome, FAO, pp. 59-67.

Clucas, I., 1998. Bycatch - is it a bonus from the Sea? Infofish International. 3, 24-28.

CMFRI, 2002. Annual Report 2001-2002, Central Marine Fisheries Research Institute, Cochin, pp. 96-99.

CMFRI 2006b. Marine Fisheries Census 2005 Part-1, CMFRI, Cochin: 97 p.

CMFRI. 2006a. Annual Report 2006-2007. Central Marine Fisheries Research Institute, Cochin, 126 p.

Cook, R., 2001. The magnitude and impact of bycatch mortality by fishing gear. In: Sinclair, M., Valdemarson, G., (Eds.), Proceedings of the Reykjavik Conference on Responsible Fisheries in the Marine ecosystem. Reykjavik, Iceland. October 1-4, 2001. 18 pp.

Costa, M. E., Olim, S., Paris, C., Borges, T.C., 2001. The Importance of By-catch From Commercial Trawl Fisheries Off the South Coast of Portugal. Northwest Atlantic Fisheries Organization, NAFO SCR Doc. 01/ 82, 6 p.

Crespi, V., Prado, J., 2002. Equipment fact sheet. Fishing Technology Equipment. Fishing technology series. FAO, Rome, 7-12pp.

Criales-Hernandez, M.I., Duarte, L.O., Garcia, C.B., Manjarres, L., 2006. Ecosystem impacts of the introduction of bycatch reduction devices in a tropical shrimp trawl fishery: Insights through simulation. *Fish. Res*. 77, 333–342.

Cryer, M., Hartill, B., O'Shea, S., 2002. Modification of marine benthos by trawling: toward a generalization for the deep ocean? *Ecological Applications*. 12(6), 1824-1839.

Davis, M.W., Ryer, C.H., 2003. Understanding Fish Bycatch Discard And Escapee Mortality. AFSC Quarterly Report. 9 p.

Dawson, P., 2000. Use of BRDs and TEDs in Shrimp Trawling. In: Advances in Harvest Technology. *ICAR Winter School Manual*. CIFT, Cochin, pp. 424-433.

Dawson, P., Boopendranath, M.R., 2001. *CIFT-TED - construction, installation and operation*, CIFT Technology Advisory series – 5, CIFT, cochin:16p.

Dawson, S.M. 1991. Modifying gillnets to reduce entanglement of cetaceans. *Mar. Mamm. Sci.* Vol. 7(3): 274-282.

Day, F., 1958a. *The fishes of India*. Volume – I. William Dawson & Sons Ltd. London. 198 p.

Day, F., 1958b. *The fishes of India*. Volume – II. William Dawson & Sons Ltd. London. 778 p.

De Lancy, L.B., Whitaker, J.D., Egleston, Jr., Maddox, M.B., 1997. Testing of a Soft TED as a bycatch Reduction Device. *South Carolina Marine Resources Division Technical Report* No- 87; 16 p

Dealteris, J., Milliken, H., Morse, D., 1997. Bycatch reduction in the Northwest Atlantic small-mesh bottom-trawl fishery for silver hake (*Merluccius bilinearis*). Developing and sustaining world fisheries resources. The state of science and management. pp. 568-573.

Demetre, M., Sanchez, P., Kaiser, M.J., 2000. The behavioural response of benthic scavengers to the otter - trawling disturbance in the Mediterranean. In: Kaiser, M.J., de Groot, S.J., (Eds.), The Effects of Fishing on Non- target Species and Habitats: Biological, Conservation and Socio-economic Issues. Blackwell Science Ltd. pp 121-129.

Devaraj, M., Smita, P., 1998. Economic performance of mechanized trawlers in the state of Kerala, India. *Fish. Res*. 6, 271 – 286

Diamond, S.L., 2003. Estimation of bycatch in shrimp trawl fisheries: a comparison of estimation methods using field data and simulated data. *Fish. Bull*. 101, 484-500.

Dobrzynski, T.J., 2004. The National Marine Fisheries Service's National Bycatch Strategy. *Marine Fisheries Review*. 66, 1-8.

Duplisea, D.E., Jennings, S., Malcom. S.J., Parker, R., Sivyer, D.B., 2001. Modeling potential impacts of bottom trawl fisheries on soft sediment biogeochemistry in the North Sea, *Geochem. Trans*. 14, 1-6.

Duthie, A., 1997. Canadian efforts in responsible fishing operations: The impact in the Canadian Northern Shrimp Fishery and the success of bycatch devices in Canadian fisheries. Papers presented at the Technical

Consultation on Reduction of Wastage in Fisheries. Tokyo, Japan, 28 October-1 November 1996. FAO Fish. Rep. 547, pp. 99-116.

Eayrs, S., 2004. Reducing turtle mortality in shrimp-trawl fisheries in Australia, Kuwait and Iran. Papers presented at the Expert Consultation on interactions between Sea turtles and Fisheries within an Ecosystem context, 9-12 March, 2004. FAO Fisheries Report no. 728, Rome. FAO, 238 p.

Eayrs, S., Prado, J., 1998. Bycatch reduction devices show promise in the Persian Gulf. *INFOFISH International*. 3, 62-66.

Eigaard, O.R., Holst, R., 2004. The effective selectivity of a composite gear for industrial fishing: a sorting grid in combination with a square mesh window. *Fish. Res*. 68, 99-112.

EJF, 2003. Squandering the seas: How shrimp trawling is threatening ecological integrity and food security around the world. Report of the Environmental Justice Foundation, London, p. 45.

EJF, 2005. What's the Catch? Reducing Bytcatch in EU Distant Water Fisheries. Environmental Justice Foundation, London, UK. 16p.

EPA, 1998. Evaluation of Bycatch Reduction Devices in Texas Coastal Bend Waters. Demonstrating Practical Tools for Watershed Management through the National Estuary Program. United States Environmental Protection Agency. Washington DC. EPA842.F98.003N. 4 p.

Epperly, S.P., 2003. Fisheries-Related Mortality and Turtle Excluder Devices (TEDs). In: Lutz, P.L., Musick, J.A., Wyneken, J., (Eds.), The Biology of Sea Turtles -Vol II. CRC Press. 339-353 pp.

Epperly, S.P., W.G. Teas. 1999. Evaluation of TED opening dimensions relative to size of turtles stranding in the Western North Atlantic. U.S. Dep. Commerce, National Marine Fisheries Service SEFSC Contribution PRD-98/99-08, 31 p.

Epperly, S.P., Teas, W.G., 2002. Turtle Excluder Devices – are the escape openings large enough? Fisheries Bulletin 100:466-474.

European Communites, 2000. Fishing in Europe. A European Commission Publication – Directorate - General for Fisheries. 3, 12 p.

FAO, 1973. Report of the Expert Consultation on selective shrimp trawls, Ijmuiden (The Netherlands), June 1973. FAO Fish. Rpt. 139,73 p.

FAO, 1975. Catalogue of small-scale fishing gear, Fishing News Books Ltd., Farnham, 191 p.

FAO, 1978. FAO Catalogue of fishing gear designs, Fishing News Books Ltd., Farnham, 159 p.

FAO, 1984. FAO species identification sheets for fishery purposes. Western Indian Ocean (Fishing Area 51). FAO Fisheries Department. Rome.

FAO, 1995. Code of conduct for Responsible Fisheries. FAO, Rome, 41 p.

FAO, 1999. The state of World Fisheries and Aquaculture, 1998, FAO, Rome

FAO, 2004a. FAO year book, Fishery Statistics capture production. Vol-94/2002, FAO Fisheries Series No. 66, FAO Statistics Series No. 180. FAO, Rome. 642 p.

FAO, 2004b. The state of World Fisheries and Aquaculture, 2002, FAO, Rome

FAO. 2004c. Report of the Expert Consultation on Interactions between Sea Turtles and Fisheries within an Ecosystem Context. Rome, Italy, 9-12 March 2004. FAO Fisheries Report. No. 738. Rome, FAO. 2004. 37 p.

Farmer, M.J., Brewer, D.T., Blaber, S.J.M., 1998. Damage to selected Fish species escaping from shrimp trawl codends: a comparison between square-mesh and diamond-mesh 38, 73-81.

Federal Register, 2000, 2003, 2005

Fennessy, S., 2002. Reduction of bycatch in prawn trawl fisheries. Southern African Marine Science Symposium (SAMSS 2002): Currents Coasts Communities. Swakopmund (Namibia), 1-5 Jul 2002.

Fernando, S. A., Fernando, O. J., 2002. A field guide to the common invertebrates of the East coast of India. Centre of Advanced Study in Marine Biology. Annamalai University, Parangipettai. 265 p.

Fishing News International, 2002. Flexigrid beats problems, Tough grid fold on to net drum. *Fishing News International*. Vol – 41; No – 12, December – 2002. London, p. 1 & 12.

Fishing News International, 2003, Lighter nylon grid for Svalbard shrimping *Fishing News International*, Vol – 42; No – 5, May – 2003. London, p – 26

Fishing News International, 2004. Hoki Trawl exclude seals. *Fishing News International*. Vol – 43; No – 12, Feb – 2004. London, p 13.

Fletcher, K.M., 1998. Bycatch Reduction Device Rule in Gulf. In: Fletcher, K.M., (Ed.). Water Log, 18(2).

Fonds, M., Groenewold, S., 2000. Food subsidies generated by the beam- trawl fishery in the southern North Sea. In: Kaiser, M.J., de Groot, S.J., (Eds.), The Effects of Fishing on Non- target Species and Habitats: Biological, Conservation and Socio-economic Issues. Blackwell Science Ltd. pp 130-150.

Fonseca, P., Campos, A., Larsen, R.B., Borges, T.C., Erzini, K., 2005a. Using a modified Nordmore grid for by-catch reduction in the Portuguese crustacean- trawl fishery. *Fish. Res*. 71, 223-239.

Fonseca, P., Campos, A., Mendes, B., Larsen, R.B., 2005b. Potential use of a Nordmore grid for bycatch reduction in a Portuguese bottom- trawl multispecies fishery. *Fish. Res*. 73, 49-66.

Fuls, B.E., Mc Eachron, L.W., 1997. Evaluation of three bycatch reduction devices in Aransas Bay During the 1997 spring and Fall commercial Bay-shrimp seasons, *Fish. Bull.* 22 p.

Gallaway, B.J., Cole, J.G., 1998. Reduction of Juvenile Red Snapper Bycatch in the U.S. Gulf of Mexico Shrimp Trawl Fishery. *North American Journal of Fisheries Management*. 19(2), 342-355.

Gamito, R., Cabral, H., 2003. Mortality of brown-shrimp discards from the beam trawl fishery in the Tagus estuary, Portugal. *Fish. Res*. 63, 423-427.

Garcia-Caudillo, J.M., Cisneros-Mata, M.A., Balmori-Ramirez, A., 2000. Performance of a bycatch reduction device in the shrimp fishery of the Gulf of California, Mexico. *Biological Conservation*. 92, 199-205.

George, M. J., Suseelan, C., Thomas, M.M., Kurup, N. S., 1980. A case of over fishing: Depletion of shrimp resource along Neendakara coast, Kerala. *Mar. Fish. Infor. Serv*., T & E Ser., 18, 1-8.

George, M. J., Suseelan, C., Balan, K., 1981. By-catch of shrimp fisheries in India. *Mar. Fish. Inf. Serv*. Tech. Ext. Ser. 28, 3-13.

Gibinkumar, T.R., Sabu, S., Pravin. P., Boopendranath, M.R., 2005. Trawling systems operated off Quilon, Kerala, India. In: Kurup, B.M., Ravindran, K., (Eds.), International symposium on Improved sustainability of fish production systems and appropriate technologies for utilization. 16-18 March, 2005, Cochin, India. pp. 462-481.

Gislason, H., 2001. The effects of fishing on non- target species and ecosystem structure and function. In: Sinclair, M., Valdimarsson, G., (Eds.) Proceedings of the Reykjavik Conference on Responsible Fisheries in the Marine ecosystem. Reykjavik, Iceland. October 1-4, 2001. 18 pp.

Glass, C.W., Wardle, C.S., 1997. A review of fish behavior in relation to species separation and bycatch reduction in mixed fisheries. Proceedings Of The Solving Bycatch Workshop, September 25-27, 1995, Seattle, Washington., Alaska Sea Grant College Program, Fairbanks, AK (USA), 1996, pp. 243-250

Gnanadoss, D.A.S., 1977. Wither Mechanization? Silver Jubilee Souvenir of Integrated Fisheries Project, Cochin. 6-8.

Goni, R., 1998. Ecosystem effects of marine fisheries: an overview. *Ocean and Coastal Management*. 40, 37-64.

Gordon, A. 1991. The bycatch from Indian shrimp trawlers in the Bay of Bengal: the potential for its improved utilization. Bay of Bengal Programme, Natural Resources Institute, Overseas Development Administration, Madras, India. BOBP/WP/68, 32 p.

Graham, N., 2003. Bycatch reduction in the brown shrimp, *Crangon crangon*, fisheries using a rigid separation Nordmore grid (grate). *Fish. Res*. 59, 393-407.

Graham, N., Jones, E.G., Reid, D.G., 2004a. Review of technological advances for the study of fish behaviour in relation to demersal fishing trawls, *ICES Journal of Marine Science*, 61, 1036-1043.

Graham, N., O'Neill, F.G., Fryer, R.J., Galbraith, R.D., Myklebust, A., 2004b. Selectivity of a 120mm diamond cod-end and the effect of inserting a rigid grid or a square mesh panel. *Fish. Res*. 67, 151-161.

Gray, C.A., Kennelly, S.J., Hodgson, K.E., 2003. Low levels of bycatch from estuarine prawn seining in New South Wales, Australia. *Fish. Res*. 64, 37-54.

Gregor, R., Wang Y.G., 2002. An Observer Report: At Sea Testing and Assessment of a Modified Fisheye Bycatch Reduction Device Abroad the Rosen C for Approval in Australia's Northern Prawn Fishery. *Australian Fisheries Management Authority* (AFMA). Australia.

Grimaldo, E., 2006. The effects of grid angle on a modified Nordmøre-grid in the Nordic Shrimp Fishery. *Fish. Res*. 77, 53-59.

Grimaldo, E., Larsen. R.B., 2005. The cosmos grid: A new design for reducing by-catch in the Nordic shrimp fishery. *Fish. Res*. 76, 187-197.

Guijarro, B., Massuti, E., 2006. Selectivity of diamond- and square-mesh codends in the deepwater crustacean trawl fishery off the Balearic Islands (western Mediterranean). ICES Journal of Marine Science, 63, 52-67.

Gulbrandsen, O., Andersen, M. R., 1992. Introduction of small fishing craft in Kerala, India. BOBP/ REP/ 49, FAO/ IND/ 8852A. Madras. INDIA. 28 p

Gulbrandsen, O., 1984. Fishing craft development in Kerala: Evaluation report. FAO/ SIDA, Madras. INDIA. 23 p.

Hall, M. A., 1996. On bycatches. Review of Fish Biology and Fisheries 6, 319-352.

Hall, M.A., 1999. estimating he ecological impacts of fisheries: What data are needed to estimate bycatches. In: Nolan, C.P., (Ed.). Proceedings of the International conference on Integrated Fisheries Monioring. Sydney, Australia, 1-5 February 1999. Rome, FAO, 378 p.

Hall, M.A., Alverson, D.L., Metuzals, K.I., 2000. By-Catch: Problems and Solutions. *Marine Pollution Bulletin*. 41, 204-219.

Hall, S.J., Mainprize, B.M., 2005. Managing Bycatch and discards: how much progress are we making and how can we do better? *Fish and Fisheries*. 6(2), 134p.

Halliday, R.G., Cooper, C.G., 1999. Evaluation of separator grates for reduction of bycatch in the silver hake (*Merluccius bilinearis*) otter trawl fishery off Nova Scotia, Canada. *Fish. Res*. 40, 237-249.

Hameed, M.S., Boopendranath, M.R., 2000. *Modern fishing gear Technology*. Daya publishing house. Delhi, 186 p.

Hamer, D.J., Goldsworthy, S.D., 2006. Seal-fishery operational interactions: Identifying the environmental and operational aspects of a trawl fishery that contribute to by-catch and mortality of Australian fur seals (*Arctocephalus pusillus doriferus*). *Biological conservation*, 130, pp. 517-529.

Hannah, R.W., Jones, S.A., 2000. Bycatch reduction in an ocean shrimp trawl from a simple modification of the trawl footrope*. J. North W. Atl. Fish. Sci*. 27, 227-233.

Hannah, R.W., Jones, S.A., 2003. Measuring the height of the fishing line and its effect on shrimp catch and bycatch in an ocean shrimp (*Pandalus jordani*) trawl. *Fish. Res*. 60, 427-438.

Hannah, R.W., Jones, S.A., Matteson, K.M., 2003. Observations of fish and shrimp behaviour in ocean shrimp (*Pandalus jordani*) trawls. Oregon

Department of Fish and Wildlife Marine Recourses Program 2040 S.E. Marine Science Drive Newport, Oregon 97365, 28 p

Harrington, D.L., 1997. Finfish excluder devices in the South Atlantic shrimp fishery. Proceedings Of The East Coast Bycatch Conference., Rhode Island Sea Grant, Dec 1996, pp. 91-94.

Harrington, D.L., Vendetti Jr, R.A. 1997. Shrimp trawl bycatch reduction in the southeastern United States. Proceedings Of The Solving Bycatch Workshop, September 25-27, 1995, Seattle, Washington, Alaska Sea Grant College Program, Fairbanks, AK (USA), 1996, pp. 129-136.

Harrington, J.M., Myers, R.A., Rosenberg, A.A., 2005. Wasted fishery resources: discarded by-catch in the USA. *Fish and Fisheries*. 6, 350-361.

Heales, D.S., Brewer, D.T., Jones, P.N., 2003. Subsampling trawl catches from vessels using seawater hoppers: are catch composition estimates biased? *Fish. Res*. 63, 113–120.

Herrera, G.E., 2005. Stochastic bycatch, informational asymmetry, and discarding. *Journal of Environmental Economics and Management*. 49, 463–483

Hill, B.J., Wassenberg, T.J., 2000. The probable fate of discards from prawn trawlers fishing near coral reefs: A study in the northern Great Barrier Reef, Australia. *Fish. Res.* 48, 277-286.

Hjul. P., (Ed.)., 1972. *The stern Trawler*. Fishing News (Books) Ltd., Surrey, England, 221 p.

Hornell, J., 1916. Notes on the exploratory cruises in search of trawl grounds off the Indian and Ceylon coasts. *Madras Fish. Bull.* 87, 23-43.

Horsten. M.B., Kirkegaard, E., 2003. Bycatch from a Perspective of Sustainable Use. IUCN SSC European Sustainable Use Specialist Group: Fisheries Working Group.Comments on the European Commission Green Paper on the Common Fisheries Policy After 2002. Brussels. 16 p.

IMM, 2003. Major Trends in the Utilisation of Fish in India: Poverty- Policy Considerations. Output from the Post-Harvest Fisheries Research Programme Project R7799. IMM Ltd, Exeter, UK. 4 p.

Isaksen, B., 1997. The Norwegian approach to reduce bycatch and avoid discards. Papers presented at the Technical Consultation on Reduction of Wastage in Fisheries. Tokyo, Japan, 28 October-1 November 1996. FAO Fish. Rep. 547, pp. 89-93.

Isaksen, B., Valdemarsen, J.W., 1986. Selectivity experiments with square mesh codends in bottom trawls. *ICES C.M*. 1986/B:28.

Isaksen, B., Valdemarsen, J.W., Larson, R.B., Karlsen, L., 1992. Reduction of fish bycatch in shrimp trawl using a rigid separator grid in the aft belly. *Fish. Res*. 13, 335-352.

ISO, 1975. Fishing nets - drawings - general directives, International Standards Organization, DIS: 3169

Jennings, S., Dinmore, T.A., Duplisea, D.E., Warr, K.J., Lancaster, J.E., 2001. Trawling disturbance can modify benthic production processes. *Journel of Animal Ecology*. 70, 459-475.

Jennings, S., Nicholson, M.D., Dinmore, T. A., Lancaster, J.E., 2002. Effects of Chronic trawling disturbance on the production of infaunal communities. *Marine Ecology Progress series*, 243, 251-260.

Jennings, S., Reynolds, J.D., 2000. Impacts of fishing on diversity: from pattern to process. In: Kaiser, M.J., de Groot, S.J., (Eds.), The Effects of Fishing on Non- target Species and Habitats: Biological, Conservation and Socio-economic Issues. Blackwell Science Ltd. pp 235-250.

Kaiser, M., Cheney, K., Spence, F.E., Edwards, D.B., Radford, K., 1999, Fishing effects in the north east Atlantic shelf areas: patterns of fishing effort, diversity and community structure. VII. The effects of trawling disturbance on the fauna associated with the tubeheads of serpulid worms. *Fish. Res*. 40, 195-205.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., Poiner, I.R., 2001. Impacts of fishing gear on marine benthic habitats. In: Sinclair, M., Valdimarsson, G., (Eds.) Proceedings of the Reykjavik Conference on Responsible Fisheries in the Marine ecosystem. Reykjavik, Iceland. October 1-4, 2001. 18 pp.

Kaiser, M.J., Spence, F.E., Hart, P.J.B., 2000. Fishing – Gear Restrictions and Conservation of Benthic Habitat Complexity. *Conservation Biology*. 14(5), 1512-1525.

Kelleher, K., 2004. Discards in the world's marine fisheries. FAO Fisheries Technical Paper 470. Food and Agriculture Organisation of the United Nations, Rome.

Kennelly, S.J., 1999a. The Development and Introduction of By-catch Reducing Technologies in Three Australian Prawn-Trawl Fisheries. *Mar. Technol. Soc. J*. 33(2), 73-81.

Kennelly, S.J., 1999b. The role of fisheries monitoring programmes in identifying and reducing problematic bycatches. In: Nolan, C.P., (Ed.). Proceedings of the International conference on Integrated Fisheries Monioring. Sydney, Australia, 1-5 February 1999. Rome, FAO, 378 p.

Kennelly, S.J., Broadhurst, M.K., 2002. By-catch begone: changes in the philosophy of fishing technology. *Fish and Fisheries,* 3 (4), 340-355.

Kirubakaran, P., Neelakandan, M., Shaji, S., Rao, D.V., Venkateswarulu, N., Varghese, C.P., 2002. Preliminary observations on the operation of TED in bottom trawl. *Fishing chimes*. 21(12), 31-33.

Koch,V., Nichols, W.J., Peckham, H., de la Tobae, V., 2006. Estimates of sea turtle mortality from poaching and bycatch in Bah ́a Magdalena, Baja California Sur, Mexico. Biological Conservation. 128, 327 -334.

Koslow, J.A., Gowlett- Holmes, K., Lowry, J.K., O'Hara, T., Poore, G.C.B., Williams, A., 2001. seamount benthic macrofauna off southern Tasmania: community structures and impacts of trawling. *Marine Ecology Progress Series*. 213, 111-125.

Krapf, D., 1994, From TEDs to BRDs. Gulf and South Atlantic shrimp fishermen shift bycatch focus. In: Warren, B., (Ed.), Win-Win Bycatch Solutions. A Handbook For Collaboration., Natl. Fish. Conserv. Cent., Seattle, WA (USA), pp. 51-56.

Kraus, S.D., Read, A.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E., Williamson, J., 1997. Acoustic alarms reduce porpoise mortality. *Nature* 388:525.

Kristjonsson, H., 1967. Technique of finding and catching shrimp in commercial fishing. Proc. FAO World Scientific Conference on the Biology and Culture of Shrimps and Prawns. 12-24. June 1967, Cuidad de Mexico, 69 p.

Kumar, A.B., Deepthi, G. R., 2006. Trawling and by-catch: Implications on marine ecosystem. *Current Science*, 90(7), 922-931.

Kunjipalu, K.K, Varghese, M.D., Nair, A.K.K. 1994a. Studies on square mesh codend in trawls-I Studies with 30mm mesh size, *Fish.Technol*. 31(2), 112-117.

Kunjipalu, K.K, Varghese, M.D., Pillai, N.S., Boopendranath, M.R., Meenakumari, B., 1994b. Square Mesh Codends in Demersal Trawls: Fabrication Rigging and advantages, *Fish Technology Newsletter* 7 (3&4): 3

Kunjipalu, K.K, Varghese, M.D., Pillai, N.S., Boopendranath, M.R., Meenakumari, B., 1997. Results of fishing experiments with square mesh in the codend of demersal trawls. In: Hameed, M.S., Kurup, B.M., (Eds.) Proc. Technological Advancements in Fisheries, P.197, Publn. No. I-School of Industrial Fisheries, Cochin.

Kunjipalu,K.K, Meenakumari, B., Mathai, T.J., Boopendranath, M.R., Manoharadoss, R.S., 2001. Effect of mesh size on selectivity of square mesh codends, *Fish. Technol*.38(1),1-7.

Kurian, G.K., 1965. Trends in development in the prawn fishing techniques in India-a review, *Fish. Technol.* 2(1), 64-68.

Kurup, B. M., Premlal, P., Thomas, J.V., Anand, V., 2003. Bottom trawl discards along Kerala coast: A case study. *J. Mar. Biol.Assoc*. India, 2003, 45, 99-107.

Kurup. B.M, Premlal, P., Thomas. J.V., Anand. V., 2004. Status of Epifaunal Component in the Bottom Trawl Discards Along Kerala Coast (South India) *Fish. Technol*. 41(2), 101-108

Kurup, B.M., Rajasree, R., 2007. Status of bottom trawl fishery in Kerala (South India), Fish. Technol. 44, 99-108

Kvalsvik, K., Huse, I., Misund, O. A., Gamst, K., 2006. Grid selection in the North Sea industrial trawl fishery for Norway pout: Efficient size selection reduces bycatch. *Fish. Res*. 77, 248-263.

Laptikhovsky, V., Fetisov, A., 1999. Scavenging by fish of discards from the Patagonian squid fishery. *Fish. Res.* 41, 93-97

Laptikhovsky, V.V., 2004. Survival rates for rays discarded by the bottom trawl squid fishery off the Falkland Islands Fish. Bull. 102,757–759

Leadbitter, D. 1999. Bycatch Solutions: A handbook for fishers in non-trawl fisheries. FRDC Report No. 1998/201. Ocean Watch Australia Ltd., New South Wales 2009, Australia. 52 p.

Lewison, R.L., Crowder, L.B., Read, A.J., Freeman, S.A., 2004. Understanding impacts of fisheries bycatch on marine megafauna. TRENDS in Ecology and Evolution. 19(11), 598-604.

Linnane, A., Ball, B., Munday, B., van Marlen, B., Bergman, M., Fonteyne, R., 2000. A review of potential techniques to reduce the environmental impact of demersal trawl. Irish Fisheries Investigations (New Series) No. 7. 43p.

Liu, H.C., Sainsbury, K.J., Chiu, T.S., 1985. Trawl cod-end mesh selectivity for some fishes of north-western Australia. Fish. Res. 3 (2), 105-129.

Lousiana Fisheries, 2005. Management information: BRDs, specification for certified BRDs. (www.seagrantfish.1su.edu/management/TEDs&BRDs/brds_specc.htm).

Maartens, L., Gamst, K.A., Schneider, P.M., 2002. Size selection and release of juvenile monk fish Lophius vomerinus using rigid sorting grids. *Fish. Res*. 57, 75-88.

Macbeth, W,G., Broadhurst, M.K., Paterson, B.D., Wooden, M.E. L., 2006. Reducing the short-term mortality of juvenile school prawns (*Metapenaeus macleayi*) discarded during trawling. *ICES Journal of Marine Science*, 63, 831-839.

Machias, A., Vassilopoulou, V., Vatsos, D., Bekas, P., Kallianiotis, A., Papaconstantinou, C., Tsimenides, N., 2001. Bottom trawl discards in the north eastern Mediterranian Sea. *Fish. Res*. 53, 181-195.

Madsen, N., Hanson, K.E., 2001. Danish Experiments with a grid system tested in the North sea shrimp fishery. *Fish. Res*. 52, 203-216.

Madsen, N., Tschernij, V., Hansen, K., Larsson, P.O., 2006. Development and testing of a species-selective flatfish otter trawl to reduce cod bycatches. *Fish. Res*. 78, 298–308.

Matsuoka, T., 1999. Sampling and estimation of discards in multi-species fisheries. In: Nolan, C.P., (Ed.). Proceedings of the International conference on Integrated Fisheries Monioring. Sydney, Australia, 1-5 February 1999. Rome, FAO, 378 p.

Matsushita, Y., Fujita, K., Ikegami, N., Ohata, S., 2004. Reaction of juvenile ounder to grid separators. *ICES Journal of Marine Science*, 61, 1174-1178.

Matsushita., Y., 2000. Bycatch reduction technologies for towed fishing gears. Bulletin of the Japanese Society of Scientific Fisheries. Nippon Suisan Gakkaishi. 66(2), 261-268.

McCaughran, D.A., 1992. Standardized nomenclature and methods of defining bycatch levels and implications. In: Schoning, R.W., Jacobson, R.W., Alverson, D.L., Gentle, T.G., Auyong, J., (Eds.), Proceedings of the

National Industry Bycatch Workshop February 4–6, 1992. Newport, Oregon. Natural Resources Consultants, Inc., Seattle, Washington. pp. 200–201.

McGilvray, J., 1995. A summary of bycatch reduction devices. Department of Primary Industries. Queensland. 29 p.

McGilvray, J.G., Mounsey, R.P., MacCartie, J., 1999. The AusTED-II, An improved trawl efficiency device 1, Design theories. *Fish. Res*. 40, 17-27.

McKenna, S., 1997. Effectiveness of excluder devices on bycatch reduction and shrimp retention. Proceedings Of The East Coast Bycatch Conference., Rhode Island Sea Grant, Dec 1996, 107-112.

Menon, N. G., 1996. Impact of bottom trawling on exploited resources. In: Marine Biodiversity, Conservation and Management. Menon, N.G., Pillai, C.S.S., (Eds.), Central Marine Fisheries Research Institute, Cochin, pp. 97-102.

Menon, N.G., Nammalwar, P., Zachariah, P.U., Jagadis, I., 2000. Investigations on the impact of coastal bottom trawling on demersal fishes and macrobenthos. Central Marine Fisheries Research Institute, Annual Report 1999–2000, Cochin, pp. 55-57.

Migdalski, E. C., Ficher, G. S., 1977. *The fresh and salt water fishes of the world*. Octopus Books Ltd. London. 316 p.

Milton, D.A., 2001. Assessing the susceptibility to fishing of populations of rare trawl bycatch: sea snakes caught by Australia's Northern Prawn Fishery. *Biological Conservation*. 101, 281-290.

Mitchell, J.F, Watson, J.W., Foster, D.G., Taylor. R.E., 1995. The Turtle Excluder Device (TED): A Guide to better performance. *NOAA Technical Memorandum NMFS-SEFSC*-3-6, 35 p

Morgan, L.E., Chuenpagdee, R., 2003. Shifting gears: addressing the collateral impacts of fishing methods in U.S. waters. PEW Science Series. 42 p.

Morizur Y., B. Caillart, D. Tingley, 2004, The problem of discards in fisheries. In Safran, P., (Ed.), Fisheries and Aquaculture: Towards Sustainable Aquatic Living Resources Management, Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK, chapter 5.52.12, 17p.

Morris, B., 2001. Certification of bycatch reduction devices in North Carolina. Report to North Carolina Sea Grant. November 2001. Grant 99-FEG-33.

Mounsey, R.P., Baulch, G.A., Backworth, R.C., 1995. Development of a trawl efficiency device (TED) for Australia's Northern Prawn Fisheries I, The Aus TED Design. *Fish. Res*. 22, 99-105.

MPEDA, 1998. *Commercial fishes and shell fishes of India*. Marine Products Export Development Authority. Kochi. 177 p.

Mukundan, M., Hameed, M.S., 1993. Present status of Trawl Designs in Cochin area. *J. Mar. Biol. Ass. India*, 35 (1 & 2): 109 – 113

National Marine Fisheries Service, 1998. Managing the nation's bycatch: priorities, programs and actions for the National marine Fisheries Service. National Marine Fisheries Service, 192 p

National Marine Fisheries Service, 2003. Evaluating bycatch: a national approach to standardized bycatch monitoring programs. NOAA, NMFS, Silver Spring, MD. 88 p.

National Research Council, 1990. Decline of the Sea Turtles: Causes and Prevention. , Committee on Sea Turtle Conservation Commission on Life Sciences (CLS). National Academies Press. Washington, DC (USA). 259 p.

Nedlec, C., 1982. Definition and classification of fishing gear categories. *FAO Fish. Tech. Pap.* 222, 51p.

Norman, F.I., 2000. Preliminary investigation of the bycatch of marine birds and mammals in inshore commercial fisheries, Victoria, Australia. *Biological Conservation* 92, 217-226.

Oravetz, C.A., Grant, C.J., 1986. Trawl efficiency device shows promise, *Australian Fisheries*. February 1986, 37-41.

Ortiz, M., Legault, C.M., Ehrhardt. N.M., 2000. An alternative method for estimating bycatch from the U.S. shrimp trawl fishery in the Gulf of Mexico, 1972–1995. *Fish. Bull*. 98:583-599.

Pauly, D., Christensen, V., Froese, R., Palomares, M.L.D., 2000. Fishing down aquatic food webs. *American Scientist,* 88, 46-51.

Petruny-Parker, M.E., Castro, K.M., Schwartz, M.L., Skrobe, L.G., Somers, B., (Eds.), 2003. Proceedings of the New England Bycatch Workshop. Rhode Island Sea Grant, Narragansett, R.I. 52 p.

Pierre, J.P., Norden, W.S., 2006. Reducing seabird bycatch in longline fisheries using a natural olfactory deterrent. *Biological Conservation*. 130, 406-415.

Pillai, N.S., 1998. Bycatch Reduction devices in shrimp trawling. *Fishing Chimes* 18 (7), 45-47.

Pillai, N.S., Varghese, M.D., Mathai, T.J., 2004. Performance evaluation of different selective devices for the reduction of by-catch in shrimp trawls. In: Somvanshi, V.S., (Ed.), Large Marine Ecosystems: Exploration and exploitation for Sustainable Development and Conservation of Fish Stocks Fishery Survey of India. Mumbai, pp. 569-576.

Polet, H., 2002. Selectivity experiments with sorting grids in the North sea brown shrimp (*Crangon crangon*) fishery. *Fish. Res*. 54, 217-233.

Pollack, S., 1994. A bycatch success story. Nordmore grate cuts New England shrimpers' fish bycatch. In: Warren, B., (Ed.), Win-Win Bycatch Solutions. A Handbook For Collaboration., Natl. Fish. Conserv. Cent., Seattle, WA (USA), pp. 63-64.

Powell, E.N., Bonner, A.J., Muller, B., Bochenek, E.A., 2004. Assessment of the effectiveness of scup bycatch-reduction regulations in the Loligo squid fishery. *Journal of Environmental Management* 71, 155–167.

Prado, J., 1993. Selective shrimp catching devices: a review. *INFOFISH International*. Number 1/93, 54-60 pp.

Prado, J., 1997. Technical measures for bycatch reduction. Papers presented at the Technical Consultation on Reduction of Wastage in Fisheries. Tokyo, Japan, 28 October-1 November 1996. FAO Fish. Rep. 547, pp. 25-44.

Ramirez, D.A., 2001. Modified trawl net for selective capture of shrimp using small boats in Baja California Sur, Mexico. INFOFISH International. Number 6/2001, 60-62.

Rao, K. S., 1988. Ecological monitoring of trawling grounds. *J. Indian Fish. Assoc*., 18, 239–244.

Rester, J., De Silva, J., Condrey, R., 1997. Bycatch reduction in the gulf menhaden industry through gear modification. Fisheries Bycatch: Consequences & Management. pp. 111-114.

Rester, K.J., 1999. Characerisation and evaluation of Bycatch reduction devices in the Gulf of Manhaden fishery. North American Journal of Fisheries Mangement. 19, 42-50.

Revill, A.S., Jennings S., 2005. The capacity of benthos release panels to reduce the impacts of beam trawls on benthic communities. *Fish. Res*. 75, 73–85.

Riedel, R., DeAlteris, J., 1995. Factors affecting hydrodynamic performance of the Nordmore Grate System: a bycatch reduction device used in the Gulf of Maine shrimp fishery. *Fish. Res*. 24, 181-198.

Robertson, J.H.B., 1984. Square mesh codend selectivity for Haddock (*Melanogrammus aelgefinus* (L)) and whiting (*Merlangius merlangus* (L)) in a Scottish seine net. *Int. Counc. Explor. Sea. CM*. 1984/B:30, 4 p.

Robins, J.B., McGilvray, J.G., 1999. The Aus TED-II, an improved trawl efficiency device II commercial Performance. *Fish. Res*. 40, 29-41.

Robins,J.B., Campbell, M.J., McGilvrey, J.G., 1999. Reducing prawn trawl bycatch in Australia: An overview and an example from Queensland. Marine *Fisheries Review* 61(3), 46-55.

Robins-Troeger, J.B., Buckworth, R.C., Dredge, M.C.L., 1995. Development of a trawl efficiency device (TED) for Australian Prawn fisheries II. Field evaluations of the Aus TED. *Fish. Res*. 22, 107-117.

Rogers,D.R., Rogers,B.D., Desilva, J.A., Wright, V.L., Watson, J.W., 1997. Evaluation of shrimp trawls equipped with bycatch reduction devices in inshore waters of Louisiana. *Fish. Res*. 33, 55-72.

Rose, C.S., 1999. Initial Tests of a Flexible Grate for Size Selection of Trawl Caught Fish. *Mar. Technol. Soc. J*. 33(2), 57-60.

Rose, C.S., Gauvin, J.R., 2000. Effectiveness of a Rigid Grate for Excluding Pacific Halibut, *Hippoglossus stenolepis*, From Ground Fish Trawl Catches. Marine *Fisheries Review*. 62(2), 61-66.

Sabu, S., Gibinkumar, T.R., Pravin, P., Boopendranath, M.R., 2005. Trawl for whelk (*Babylonia spirata*) off Quilon, Kerala, India. In: Kurup, B.M., Ravindran, K., (Eds.), International symposium on Improved sustainability of fish production systems and appropriate technologies for utilization. 16-18 March, 2005, Cochin, India. pp. 496-501.

Gilman, E.L., Dalzell, P., Martin. S., 2006. Fleet communication to abate fisheries bycatch. *Marine Policy* 30, 360-366.

Saila, S.B. 1983. Importance and assessment of discards in commercial fisheries. FAO Fisheries Circular. 765, 62p.

Saillant, E., Bradfield, S.C., Gold, J,R., 2006. Genetic impacts of shrimp trawling on red snapper (*Lutjanus campechanus*) in the northern Gulf of Mexico. *ICES Journal of Marine Science.* (Article in press)

Sainsbury, J.C., 1996. *Commercial Fishing Methods – An Introduction to Vessels and Gear.* Fishing News Books Ltd., Farham, 352 p.

Salini, J., Brewer, D., Farmer, M., Rawlinson, N., 2000. Assessment and benefits of damage reduction in prawns due to use of different bycatch reduction devices in the Gulf of Carpentaria, Australia. *Fish. Res*. 45, 1-8.

Sanchez, P., Demestre, M., Martin, P., 2004. Characterization of the discards generated by bottom trawling in the north western Mediterranean. *Fish. Res*. 67, 71-80.

Sandra, L.D., 2003. Estimation of bycatch in shrimp trawl fisheries: a comparison of estimation methods using field data and simulated data. *Fish. Bull*. 101(3), 484-500.

Sandven, P., 1959. The Indo-Norwegian Project in Kerala. Norwegian foundation for assistance to under developed countries. Oslo, 152 p.

Sathiadhas, R., Venkataraman, G., 1981. Impact of Mechanized Fishing on the Socio – economic Conditions of the fishermen of Sakthikulangara– Neendakara, Kerala, *Mar. Fish. Infor. Serv*., T & E Ser., 29, 1 – 18

Schratzberger, M., Jennings. S., 2002. impacts of chronic trawling on meiofaunal communities. *Marine Biology*. 141, 991-1000.

Scofield, W.L., 1948. Trawling gear in California., State of California, Dept. of National Resources, Division of Fish and Game, *Fish. Bull.* 72, 60p.

Shaffer, G., 1999. United States-Import Prohibition of Certain Shrimp and Shrimp Products. WTO Doc. WT/DS58/AB/R. American Journal of International Law, Vol. 93, No. 2 (Apr.,) , pp. 507-514.

Sparre, P., Ursin, E., Venema, S.C., 1989. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fish.Tech.Pap., 306.1, 337 p.

Steele, P., Bert, T.M., Johnston, K.H., Levett, S., 2002. Efficiency of bycatch reduction devices in small otter trawls used in the Florida shrimp fishery. *Fish.Bull*. 100, 338-350.

Stobutzki, I.C., Miller, M.J., Jones, P., Salini, J.P., 2001. Bycatch diversity and variation in atropical Australian penaeid shrimp fishery: implications of monitoring. *Fish. Res*. 53, 283-301.

Stratoudakis, Y., Fryer, R.J., Cook, R.M., 1998. Discarding practices for commercial gadoids in the North Sea. *Can. J. Fish. Aquat. Sci*. 55(7), 1632- 1644.

Sudarsan, D., John, M.E., Somvanshi, V.S., 1990. Marine fishery resource potential in the Indian exclusive economic zone – an update, *Bull. Fish. Surv. India* 20: 27p.

Sujatha, K., 1995. Finfish Constituents of Trawl By-catch off Visakhapatnam. *Fish. Technol*. 32, 56 – 60.

Sukumaran, K. K., Telang, K. Y., Thippeswamy, O., 1982. Trawl fishery of south Kanara with special reference to prawns and bycatches. *Mar. Fish. Inf. Serv*. Tech. Ext. Ser. 44, 8–14.

Talavera, R.V., 1997. Dispositivos excluidores de tortugas marinas. FAO Documento Technico de Pesca, No. 372, Roma, FAO, 116 pp.

Tamini, L.L., Chiaramonte, G.E., Perez, J.E., Cappozzo, H.L., 2006. Batoids in a coastal trawl fishery of Argentina. *Fish. Res*. 77, 326–332.

Thankappan, T., 2000. Ban on Trawling: An Accepted Practice for Marine Fisheries Management in Kerala, *Kerala Calling*, Department of Public Relations, Government of Kerala, 20 (12) 11-14

Valdemarsen, J.W., Isaksen. B., 1986. Further experiments with radial escape section (RES) as fish-shrimp separator in trawl. ICES, Copenhagen, Denmark. ICES C.M. 1986/B29:17.

Valdemarsen, J.W., 2001. Technological trends in capture sheries. *Ocean & Coastal Management.* 44, 635–651.

Valdemarsen, J.W., Suuronen, P., 2003. Modifying fishing gear to achieve ecosystem objectives. In: Sinclair, M., Valdemarsson, G., (Eds.), Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem. Rome , FAO. pp 321-341

Van Marlen, B., 2000. Technical modifications to reduce the bycatches and impacts of bottom-fishing gears. In: Kaiser, M.J., de Groot, S.J., (Eds.), The Effects of Fishing on Non- target Species and Habitats: Biological, Conservation and Socio-economic Issues. Blackwell Science Ltd. pp 253-268.

Verghese, C. P., 1998. Capture Fishery Technology in India. In: Hameed, M. S., Kurup, B. M., (Eds.) Technological Advancements in Fisheries, Publn. No. 1. School Ind. Fish., Cochin University of Science and Technology, Cochin. pp 161-165.

Vincent, A.C.J.. 2003. Bycatch of lined seahorses (*Hippocompus erectus*) in a Gulf of Mexico shrimp trawl fishery. *Fish. Bull*. 101(4), 721-731.

Wallace, R.K., Robinson, C.L., 1994. Bycatch and bycatch reduction in recreational shrimping. *Northeast Gulf Sci*., 13(2), 139-144.

Warren, B., Ess, C., Swenson, E., 1997. Managing bycatch and discards: A review of progress and challenges in the United States. Papers presented at the Technical Consultation on Reduction of Wastage in Fisheries. Tokyo, Japan, 28 October-1 November 1996. FAO Fish. Rep. 547, pp. 69-88.

Wassenberg, T.J., Dews, G., Cook, S.D., 2002. The impact of fish trawls on megabenthos (sponges) on the north- west shelf of Australia. *Fish. Res*. 58, 141-151.

Wassenberg, T.J., Milton, D.A., Burridge, C.Y., 2001. Survival rates of sea snakes caught in demersal trawlers in northern and eastern Australia. *Biological Conservation*. 100, 271-280.

Watson, J., Workman, I., Foster, D., Taylor, C., Shah, A., Barbour, J., Hataway, D., 1993. Status report on the potential of gear modifications to reduce finfish bycatch in shrimp trawls in the southeastern United States. 1990-1992. NOAA Techn. Mem. NMFS SEFC 327.

Watson, J., Foster, D., Nichols, S., Shah, A., Scott-Denton, E., Nance, J., 1999. The Development of Bycatch Reduction Technology in the Southeastern United States Shrimp Fishery. *Mar. Technol. Soc. J*. 33(2), 51-56.

Watson, J.W., Jr., C. McVea. 1977. Development of a selective shrimp trawl for the southeastern United States penaeid shrimp fisheries. Mar. Fish. Rev. Vol. 39(10):18–24.

Watson, J.W., Jr., C.W. Taylor. 1991. Research on selective shrimp trawl designs for penaeid shrimp in the United States: A review of selective shrimp trawl research in the United States since 1973. NOAA/NMFS/SEFSC, Mississippi Laboratories, Pascagoula, Mississippi. PUBL. R.I. SEA GRANT COLL. PROGRAM. pp. 50-59.

Watson, J.W., Jr., Mitchell, J.F., Shah. A.K., 1986. Trawling efficiency device: a new concept for selective shrimp trawling gear. *Mar. Fish. Rev*. 48, 1-9.

Wheeler, A., 1985. The world encyclopedia of fishes. Mc Donald & Co. Ltd. London. 368 p.

Whitaker, J.D., DeLancey, L.B., Jenkins, J. E., 1992. A pilot study to examine the efficiency of finfish excluder devices in a shrimp trawl. Proj. Rep. No. F-47 to the US Fish and Wildlife Service. 45 pp.

Wienbeck, H., 1997. Sorting grids - first trials in the commercial brown shrimp fishery. *Inf. Fischwirtsch*. 44(1), 23-26.

Wienbeck, H., 1998. First trials on the selection of a sorting grid in commercial fishery for brown shrimps. *Anim. Res. Dev*. 47, 71-78.

Wienbeck, H., 1999. Analysis of the bycatch reduction by means of sorting grids in the commercial brown shrimp fishery. *Inf. Fischwirtsch. Fischereiforsch*. 46(1), 33-35.

Wileman, D.A., Ferro, R.S.T., Fonteyne, R., , Millar, R.B., (Eds.), 1996. Manual of methods of measuring the selectivity of towed fishing gears, ICES Cooperative Research Report 215: 126 p.

Wilson, T., 1998. U.S. ban on imported shrimp deemed illegal. In: Fletcher, K.M.,(Ed.). *Water Log,* 18(2).

Ye, Y., Alsaffar, A.H., Mohammed, H.M.A., 2000. Bycatch and discards of the Kuwait shrimp fishery. *Fish. Res*. 45, 9-19.

Zacharia, P. U., Krishnakumar, P.K., Muthiah, C., Krishnan, A.A. Durgekar, R.N, 2005. Quantitative and qualitative assessment of bycatch and discards associated with bottom trawling along Karnataka during 2001-2002, Paper presented at the International Symposium on Improved Sustainability of Fish Production Systems and Appropriate Technologies for Utilization, CUSAT, Kochi.

Zynudheen, A. A., Ninan, G., Sen, A. Badonia, R., 2004. Utilizationof by-catch in Gujarat (India). NAGA, World Fish Center Q. 27, 20–23.