Chapter 1

Introduction

Fisheries is recognized as a strong and effective employment and income generator to large sections of the society. Fisheries provide cheap animal protein to the people, particularly to the poorer sections in the society. Fishing is an ancient occupation. A diverse range of fishing gears and practices from small-scale artisanal to large-scale industrial systems are used for fish capture. About 200 million people in the world directly or indirectly depend on the fisheries industry. Of this about 50 million people directly depends on fishing for their livelihood and the rest is involved in ancillary activities such as processing, marketing, and supporting activities (FAO, 1995). Development in craft technology, mechanization, introduction of synthetic materials, acoustic fish detection, electronic navigation, and remote sensing are the major developments that has taken place in the historical evolution of fishing methods and practices (Hameed and Boopendranath, 2000). The world capture fishery production raised from 25 million tonnes in 1955 to 133 million in 2002, of which 71.5 million was contributed by marine capture fisheries (FAO, 2004). The most important commercially used capture methods in the world are trawling and purse seining (Sainsbury, 1971).

The trawl net is a conical bag with two wings and a codend, operated by towing horizontally from one or two boats (Hameed and Boopendranath,
Trawls are mainly operated from surface to bottom to harvest crustaceans, cephalopods, elasmobranchs, molluscs and finfishes, in different parts of the world (Boopendranath, 2000). Trawls are mainly classified into bottom trawl and midwater or pelagic trawl depending on the position in the water column, during operation. Bottom trawling, which is known to be the most effective method for shrimp capture, is widely accepted in the world. Bottom trawl is rather heavily rigged, with two otter boards provided to open the mouth horizontally and enough weight in the footrope to keep the trawl in contact with the bottom, during towing (Sainsbury, 1971; Hameed and Boopendranath, 2000; Misund et al., 2002). Incidental catching of non-target resources is a serious problem facing trawl fisheries in the world. Some part of the catch may be retained for sale or use, while others are discarded back into the sea because of a number of reasons like fish of wrong species, size, sex, damaged fish, lack of space for storage, prohibited species, etc. (Clucas, 1997). Discarding is a serious conservation problem because valuable living resources are wasted and populations of endangered and rare species are threatened (Harrington et al., 2005; Alverson and Hughes., 1996).

United Nations Convention on Law of the Sea adopted in 1982 provided a new framework for the effective management of marine resources. Exclusive Economic Zones (EEZs) of the coastal states provide 90% of the world’s marine fisheries resources. In 1992, International Conference on Responsible Fishing in Cancun (Mexico), requested FAO to prepare Code of Conduct for Responsible Fisheries. The code was unanimously adopted on 31st October 1995 and it provides the principles and
codes of practices for sustainable exploitation of aquatic resources, protection of aquatic environment, maintenance of biodiversity and conservation of energy (FAO, 1995).

1.1 Marine Fisheries of India

India is having a coastline of about 8128 km, an exclusive economic zone of 2.02 million sq. km and a continental shelf area of 0.5 million sq.km (Ayyappan and Diwan., 2007). The total fishermen population of India is about 3.57 million, with an active fishermen population of 0.81 million (CMFRI, 2006b). The fisheries sector contributed 1.08 % to the Gross Domestic Product (GDP) and 5.34% to the agricultural component during 2004 (GOI, 2006).

Fish production from India increased from 0.73 million tonnes in 1950 to 6.57 million tonnes in 2005-06. Marine capture fisheries production also increased from 0.5 million tonnes to 2.97 million tonnes during the above period (GOI, 2007). The number of trawlers operating in Indian waters has been recently estimated at 29,241 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 (CMFRI, 2006b). According to the recent estimate by CMFRI, the marine fish landing during the 2006-07 period is provisionally 2.71 million tonnes, of which 55% is contributed by pelagic species, 24% by demersal fishes, 16% by crustaceans and 5% by molluscs.
Major share (71%) of the total landings is contributed by mechanized sector, 24% by motorized sector and 5% by artisanal sector (CMFRI, 2006a).

1.2 Bycatch and Discards

1.2.1 Bycatch definitions

There are a number of definitions available regarding the term, bycatch. 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 bycatch as “that part of the catch 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”. Clucas, (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”. Pillai, (1998) defined the term bycatch as “the portion of catch other than the target species caught while fishing for a particular species”. Hameed and Boopendranath (2000) stated that “bycatch includes undersized fish, non-targeted fish species, birds, mammals and other organisms encountered during fishing operations”.

Alverson et al. (1994) reviewed the literature on bycatch and concluded that there are mainly three accepted definitions of bycatch. In some areas, bycatch is the catch, which is retained and sold, that is not target species. In some other areas, bycatch means species or sizes and sexes of fish which are discarded. The term bycatch is also known to include all non-target fish species retained, sold or discarded.
Alverson et al. (1994) defined bycatch, based on recommendations of the Newport Workshop, Oregon (USA), as discarded catch plus incidental catch. Discarded catch means catch returned to the sea due to economic, legal, or personal considerations. Incidental catch means retained catch of non-targeted species. Definition of bycatch as advocated by Alverson et al. (1994) is followed, in this study, and includes both discarded catch and incidental catch.

1.2.2 Bycatch and discards - World scenario

A preliminary assessment of bycatch in world fisheries was made by Saila (1983). According to Saila (1983), the discards were 6.72 million tonnes in shrimp fisheries. Later, Andrew and Pepperell (1992) estimated global bycatch in shrimp fisheries at 16.7 million tonnes. In the year 1994, Alverson et al. (1994) estimated that annual bycatch in the world fisheries as 28.7 million tonnes of which an estimated 27.0 million tonnes were discarded. Shrimp trawling accounted for 37.2\% (9.5 million tonnes) of the total world bycatch. According to this data, much of the discard in shrimp fisheries is comprised of small tropical fishes. In temperate and sub-arctic waters, main portion of the discards are juveniles and adults of fishes of commercial value. Shrimp fisheries of India and Pakistan were contributing major share of discards in West Indian ocean (Alverson et al., 1994). In 1998, FAO estimated a global discard level of 20 million tonnes (FAO 1999). Average annual global discards, has been re-estimated to be 7.3 million tonnes, based on a weighted discard rate of 8\%, during 1992-2001 period (Kelleher, 2004). Decline in discards, may be due to a number of reasons such as stock depletion, strict regulations in some fisheries in the form of
improved fishing selectivity, anti-discard regulations and increased use of bycatch reduction devices. Globally, shrimp trawling contributes to the highest level of discard/catch ratios of any fisheries, ranging from about 3:1 to 15:1, and the amount of bycatch varies in relation to target species, seasons and areas (EJF, 2003). Trawl fisheries for shrimp and demersal finfish account for over 50% of the total estimated global discards (Kelleher, 2004).

1.2.3 Bycatch and discards - Indian scenario

In India, the bycatch problem is more due to the multi-species nature of the tropical fisheries. During shrimp trawling large quantities of finfish bycatch including significant amount of juveniles are also landed. The preliminary assessment of bycatch and discards in India by Central Marine Fisheries Research Institute, Cochin in 1979, has given 79.18% (3,15,902 tonnes) of total shrimp trawl landings as bycatch in India, maximum being in Gujarat (92.58%), followed by Tamil Nadu (91.04%) and Pondicherry (86.52%) and was utilized either for human consumption or as fish meal and fish manure (George et al., 1981). During 1980-82, trawl bycatch was estimated at 85% of the trawl landings off Mangalore and Malpe in Karnataka (Sukumaran et al., 1982). According to Gordon (1981), bycatch landing in east coast of India was 90,000 to 130,000 tonnes per annum. Gordon (1991) estimated that juvenile discards from trawling operations, off Visakhapatnam was 25 to 30%. Rao (1998) re-assessed the estimate of bycatch by the fleet based at Visakhapatnam at 40,410 tonnes, of which 32,421 tonnes was discarded and 8258 tonnes was retained.
A study conducted along the states of Kerala, Karnataka and Tamil Nadu by Menon in 1996 observed that target groups such as shrimp (16%) and cephalopods (4%) together constituted only 20% and others such as finfishes (65%) and benthic organisms 15% constituted the rest of the trawl landings. The quantity of bycatch landed by trawlers in the above states during 1985-90, was estimated as 43,000 t, of which 81% was constituted by stomatopods, and another 87,000 t of unmarketable benthic organisms is estimated to be discarded (Menon, 1996). Bycatch landings along Cochin, Visakhapatnam and in Saurashtra region (Gujarat), was about 70 to 90% and average discards was 15 to 20% from shrimp trawling (Pillai, 1998). Bycatch landing was maximum in Gujarat (90 to 95%), followed by Tamil Nadu (80 to 90%), Andhra pradesh (80 to 85%), Karnataka (80 to 85%), Orrisa (75 to 80%), Mahahrashtra (70 to 75%) and Kerala (65 to 70%). It is significant to note that among the bycatch, about 40% consisted of juveniles (Pillai, 1998).

A recent study conducted in Karnataka (India) revealed that bycatch quantity from trawlers is 56,083 tonnes in 2001 and 52,380 tonnes in 2002, forming 54.4% and 47.9% of total trawl catch, respectively. The quantity of discards was 34,958 tonnes (33.9%) in 2001 and 38.318 tonnes (35.1% of total catch) in 2002. Discards were more in post-monsoon months. During single day fishing, stomatopods formed the most dominant component among discards (over 52%) but in multi-day fishing various finfishes dominated the discards. In Karnataka, juveniles contributed 36% of discards (15.9% of total catch) in single day fishing and 78% (23.5% of total catch) in multi-day fishing (Zacharia et al., 2005).
The characterization and quantification of bycatch and discards along Kerala coast, during 2000-2002, was done by Kurup et al. (2003). The discarded quantity estimated during 2000-2001 was 2,62,000 tonnes and during 2001-2002 it was 2,25,000 tonnes. The dominant varieties among the discards were finfishes, crabs and stomatopods. The group wise average discards during the study period were finfishes (95,000 tonnes), crabs (68,000 tonnes), stomatopods (40,000 tonnes), gastropods (22,000 tonnes), juvenile shrimps (5,000 tonnes), soles (3,000 tonnes), jelly fishes (3,000 t), cephalopods (2,900 tonnes), echinoderms (1,800 tonnes), sea snakes (1000 tonnes), and eggs (890 tonnes) (Kurup et al., 2003; 2004).

Kelleher (2004) has estimated total bycatch discards in Indian fisheries at 57917 t, which formed 2.03% of the total landings. Kumar and Deepthi (2006) have discussed the implications of trawl bycatch on marine ecosystem.

1.3 Bycatch Reduction Devices

Several approaches have been proposed and undertaken for bycatch reduction in trawling (Hall, 1996; Hall et al., 2000; EJF, 2003). Bycatch reduction has been attempted in several areas by reduction in the overall fishing effort, reduction in bycatch per unit effort by technological interventions and management actions like setting bycatch limits for individual vessels. Bycatch reduction through technological intervention (modification of fishing gears, installing Bycatch Reduction Devices and Turtle Excluder Devices) is considered as the prime approach for shrimp trawling industry around the world.
Bycatch Reduction Devices (BRDs) is 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. Bycatch Reduction Devices are physical modifications to trawls designed to reduce the catches of unwanted organisms, while maintaining catches of prawns (Broadhurst, 2000; Mitchell et al., 1995). BRDs are also known as trawl efficiency devices or trash excluder devices (Robins-Toeger., 1994). TED or turtle excluder devices are a specific type of BRD design designed to exclude large animals such as sea turtles, sting rays, sharks, sponges, etc. There is a widespread and increasing requirement for using bycatch reduction devices in trawl fisheries throughout the world. Efforts towards reducing bycatch take advantage of the variation in size of the species and their differential behaviour within and in the proximity of fishing gear.

There are several advantages in using BRDs in shrimp trawling (Brewer et al., 1998). BRDs reduce the negative impacts of shrimp trawling on marine community. Fishers could benefit economically from higher catch value due to improved catch quality, shorter sorting time, lower fuel costs, and longer tow duration. Adoption of BRDs by fishers would forestall any criticism by conservation groups against trawling. Recreational and non-shrimp commercial fisheries would also benefit due to a reduced impact on the species targeted by them.

1.3.1 Classification of Bycatch Reduction Devices

BRDs have been developed based on the differential behavior patterns such as differences in swimming speed, vertical distribution or size.
of shrimp and fish inside the net and size selectivity. 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. Shrimp is unable to swim against the water flow and carried away with the flow of water up to the cod end. (Broadhurst and Kennelly, 1994; 1996; Brewer et al., 1998; Pillai, 1998; Broadhurst, 2000; Hameed and Boopendranath, 2000). A standard classification for BRDs is found unavailable while a generalized categorization was observed in some literature (Mitchell et al., 1995; Talavera, 1997; Pillai, 1998; Broadhurst, 2000). BRDs can be broadly classified into three categories based on the type of materials used for their construction, viz., Soft BRDs, Hard BRDs, and Combination BRDs. Soft BRDs make use of soft materials like netting and rope frames for separating and excluding bycatch. Hard BRDs are those, which use hard or semi-flexible grids and structures for separating and excluding bycatch (Mitchell et al., 1995). Combination BRDs use more than one BRD, usually hard BRD in combination with soft BRD, integrated to a single system (Boopendranath et al., 2006; Boopendranath, 2007).

1.3.2 Soft Bycatch Reduction Devices

The soft Bycatch Reduction Devices use soft structures made of netting and rope frames instead of rigid grids, prevalent in hard BRDs, for separating and excluding bycatch. Based on the structure and principles of operation they are classified into five categories viz., (i) Escape windows, (ii) Radial Escapement Section without Funnel, (iii) Radial Escapement Section with Funnel, (iv) BRDs with differently shaped slits and (v) BRDs with guiding/separator panel. Soft BRDs have advantages such as ease of
handling, low weight, simplicity in construction and low cost, compared to hard BRDs.

1.4 Review of Literature

One of the greatest challenges before modern fisheries, in recent times, is to develop and implement selective fishing, in order to minimize ecological and environmental impacts of fishing. The importance of reducing bycatch and minimizing ecological impacts of fishing operations have been emphasized by a number of authors in the world (Andrew and Pepperell, 1992; Alverson et al., 1994, FAO, 1995; FAO, 1996; Kennelly, 1995; Mitchell et al., 1995; Hall, 1996; Clucas, 1997; Kaiser and de Groot., 2000; Broadhurst, 2000; Hameed and Boopendranath, 2000; Boopendranath et al., 2006; Boopendranath, 2007). FAO code of conduct for responsible fisheries has given priority status to development and for improvement of fishing technology that eliminates bycatch or selectively target fish in a way promotes long-term sustainability and protection of biodiversity (FAO, 1995). One of the approaches in the responsible fishing practices is to reduce the negative impacts of a fishing gear by improving the selectivity and incorporation of bycatch reduction devices.

1.4.1 Historical evolution

Good fisheries management and responsible fishing regimes requires that fishing gear should preferentially catch the adult fish at a particular age, which would maximize yield while permitting the juveniles and sub-adults to escape. Earlier works on gear selectivity are by Todd (1911), Davis (1929; 1934), Clark (1952), Graham (1954) and others. Mesh size of the netting has the greatest influence on selectivity. Among other intrinsic design features
which influence selectivity of trawls are mesh configuration, load on twine, material and thickness of twine, hanging ratio, towing speed, towing duration, use of lastridge ropes in codend and type of ground rig (Brandt, 1963; Clark, 1963; Briggs, 1986). Most of the size selection occurs in the codend and escape of fish also takes place through forward net panels (Ellis, 1963; Clark, 1963; Bennett, 1984). Shrimp mesh selectivity studies have been carried out with the objective of allowing greater escapement of undersized shrimps (Valdemarsen, 1989).

From the history, fishery managers attempted to minimize pre-recruit mortality through the use of mesh sizes in trawls (Armstrong et al., 1990). The first separator trawls were developed in France and the Netherlands in 1964 (FAO, 1973). Selective trawls were used in Belgium, Norway, Iceland and in the Northwestern United States on crangonid and pandalid shrimp in the 1960’s (Watson et al., 1986). Selective shrimp trawl experiments were conducted in Europe during the mid 1960s followed by experiments in West coast of US (FAO, 1973; Alverson et al., 1994). The need for selective shrimp trawling gear was first discussed by Seidel in 1975. The earlier method for the reduction of bycatch from shrimp trawl begins with the incorporation square mesh in codends (Averill and Carr 1987; Averill 1990; Isaksen and Valdemarsen 1986; Walsh et al. 1989). Greater efforts have been directed towards reducing bycatch by taking advantage of the differential behaviour of species in the fishing gear employed (Watson, 1989; Laevestu and Alverson 1992).

Species behaviour in trawls nets leads to the introduction of separator panels. The separator trawl designs used panels of webbing placed in the
mouth, throat or along the wings of the trawl to lead the fish toward escape
openings, allowing shrimp to pass through panel meshes into the codends.
Other designs divided the trawl into upper and lower halves with separate
codends (FAO, 1973; Watson and Taylor, 1986; Andrew and Pepperell,
1992; Prado, 1993). During 1980s experiments using sorting trawls spread
world wide (Valdemarsen, 1986; Isaksen and Valdemarsen, 1986) and as a
result, number of panel separators and funnel excluders and other soft
devices for sorting catch from top to bottom or bottom to top or having
vertical separating qualities emerged for use in different waters and for
different species (FAO, 1973; Watson et al., 1986). Based on the separation
concept, development of Radial Escapement Section took place in 1980s in
Norway (West et al., 1984; Watson et al., 1986; Valdemarsen, 1986). After
the series of experiments and evaluation with earlier soft devices, hard turtle
excluder device was developed in United States of America in 1980s

Linnane et al. (2000) reviewed potential gear modifications in beam
and otter trawl nets and they discussed the importance of mesh size, square
mesh codends, separator panels and the incorporation of sieve net in the
demersal trawls. Van Marlen (2000) discussed the importance of technical
modifications in trawl such as square mesh codends, square mesh panels
and windows, separator panels, escape openings in trawl and optimum mesh
size for codends to reduce the capture of undersized fish and discards.
Glass (2000) reviewed methods like square mesh codends, square mesh
window, separator panels, composite codends and escape panels in trawl
net for the conservation of fish stock. He described the methods of bycatch
reduction based on the differential behavioral principle and mechanical sorting principle. Need for responsible fishing through the effective use of selectivity devices in ASEAN member countries were discussed by Chokesanguan (2002).

1.4.2 Development of hard BRDs

Research has been done on concepts or devices for shrimp trawling all over the world (Prado, 1993). Research on hard bycatch reduction device started only after 1980s, after the innovation of hard Turtle Excluder Device by National Marine Fisheries Service, US (Watson et al., 1986; Harrington, 1992; Isaksen et al., 1992; Prado, 1993). The important hard TEDs like NMFS hooped TED, Fixed angle TED and Cameron TED (Oravetz and Grant, 1986; Prado, 1993; Mitchell et al., 1995; Talavera, 1997, Rogers et al., 1997), Matagorda TED, Georgia-Jumper, Super Shooter, Anthony Weedless, Jones TED and Flounder TED (Talavera, 1997; Mitchell et al., 1995; Dawson, 2000; Belcher et al., 2001; CIFT, 2003) were developed under the category of hard TEDs for the conservation of Sea turtles.

Various designs of hard BRDs are in operation either experimentally or commercially around the world which includes (i) Oval grids, oval shaped metallic grid with exit opening like Georgia-Jumper (Mitchell et al., 1995), Galvanisada (Talavera, 1997), Saunders grid (Talavera, 1997), Thai Turtle Free Device (TTFD) (Chokesanguan, 1996); Oregon grate (Hannah et al., 2003), CIFT-TED (Dawson and Boopendranath, 2001), Seal Excluder Device (AFMA, 2008) and Halibut Excluder Grate (Rose, 2000); (ii) Slotted grid BRDs which provide slots for the passage of non-targeted organisms such as Hinged grid (Eigaard and Holst, 2004) and Anthony Weedless (Talavera,
(iii) Bent grids in which grid bars and grid frame are bent at one end near the opening such as Juvenile and Trash Excluder Device (JTED) (Chokesanguan et al., 2000), NAFTED (Brewer et al., 1998; Eayrs, 2004); (iv) Flat grid BRDs such as Nordmore grid (Isaksen et al., 1992), Wicks TED (Robins et al., 1999), Kelly-Girourard grid (Morris, 2001), and EX-it grid (Maartens et al., 2002). Fisheye BRD is considered as an important hard BRD around the world (Pillai, 1998; Brewer et al., 1998; Hannah et al., 2003; Burrage, 2004). There are several design variations of fisheye BRD such as Florida Fish Eye (FFE) used in the Southeast US Atlantic (NCDMF, 1997) and in the Gulf of Mexico (Wallace and Robinson, 1994). Other designs in this categories are Snake-eye BRD used in North Carolina Bay (Fuls and McEachron, 1997), Fish slot (Morris, 2001), Sea eagle BRD (NCDMF, 1997) and Popeye Fish excluder or Fishbox BRD (Anon, 2004c).

1.4.3 Development of Semi-flexible BRDs

Semi-flexible BRDs made of semi-flexible or flexible materials such as polyethylene, polyamide and FRP are used in the North Sea brown shrimp fishery (Polet, 2002), Polyamide grid devices provided with hinges to facilitates operation from net drums have been used in the Danish experiments in the North Sea shrimp fishery (Madsen and Hanson, 2001) and Polyamide-rubber grid design are used in Denmark (Anon, 2002a).

1.4.4 Development of Soft BRDs

Based on the structure and principles of operation soft BRDs are classified into five categories viz., (i) Escape windows, (ii) Radial Escapement Section without Funnel, (iii) Radial Escapement Section with
Funnel, (iv) BRDs with differently shaped slits and (v) BRDs with guiding/separator panel.

1.4.4.1 Escape windows

Escape windows function based on the differential behaviour of fishes and shrimps. Fishes that have entered the codend tend to swim back and escape when suitable escape windows provided, at the top in the front section of the codend. Square mesh window, square mesh panels and rope BRD are the examples of this category (Broadhurst and Kennely, 1994; 1996; Brewer et al., 1998; Eayrs and Prado., 1998; 1998b; Pillai, 1998; Pillai et al., 2004). Studies carried out using square mesh windows have indicated their effectiveness in reducing bycatch by 30 to 40% in Northern prawn trawl fisheries (Broadhurst and Kennely, 1994; 1996; Brewer et al., 1998). Square mesh has the advantage that the mesh opening is not distorted while under operation, unlike diamond meshes (Broadhurst and Kennely, 1994; 1996; Brewer et al., 1998; FAO, 1997; Robins et al., 1999; Kunjipalu et al., 1994). Experiments conducted in Persian Gulf waters has shown that Rope BRD is effective in excluding 25% of the bycatch with no loss of shrimp or commercial fish species (Eayrs and Prado., 1998). Use of square mesh panels has been found to reduce the bycatch, particularly juveniles and young ones, by about 20% in Indian waters (Kunjipalu et al., 1994; 1997; Pillai, 1998; Pillai et al., 2004).

1.4.4.2 Radial Escapement Section without Funnel

In Radial Escapement Section without Funnel, a radial section of netting with large meshes is provided between hind belly and codend. Small
sized fishes, jellyfish and other bycatch components, which have low swimming ability, are expelled due to enhanced water flow through large mesh section. Based on this principle Fuwa et al. (2002) described a Trawl flow Regulative Ecological Friendly Netting Device (TREND). Experiments in Japanese waters, using TREND has been shown to give safe escapement to juvenile fish, with better opportunity for survival (Fuwa et al., 2002).

1.4.4.3 Radial Escapement Section with Funnel

Radial Escapement Devices with funnel (Watson and Taylor.,1988) positioned between hind belly and codend of the trawl. A small meshed funnel accelerates the water flow inside the trawl and carries the catch towards the codend. Actively swimming fishes swim back and escape through the large mesh netting section surrounding the funnel, where the water flow rate is weak, while the shrimps are retained in the codend. Studies using Radial Escapement Device have shown 20-40% reduction in the fish bycatch in Australia’s Northern Prawn Fishery (Brewer et al., 1998). Studies in India have indicated of 18% reduction in fish bycatch by using a variation of Radial Escapement Device with 80 mm square meshes, surrounding the funnel (Pillai et al., 2004). Experiments in Louisiana have shown that Extended Funnel BRD and Skirted Extended Funnel BRDs caught less bycatch than the control nets (Rogers et al., 1997). The Extended Funnel BRD has provided 44% fish reduction with 5% shrimp loss. The Monofilament BRD, which is used in commercial trawling, has been reported to give 25-51% reduction in bycatch, without problems of clogging. Bycatch reduction by Neil-Olsen BRD has been reported to be 27-45%, in tropical coastal waters (Robins et al., 1999).
1.4.4.4 BRDs with differently shaped slits

BRDs with differently shaped slits utilized the behaviour of fish and shrimp. Fishes that entered the codend are given opportunity to swim back and escape by providing slits in the netting on the topside of the codend or hind belly, while shrimps are retained in the codend (Robins et al., 1999; Morris, 2001). Average bycatch reduction from V-cut BRD, operated in Queensland east coast trawl fishery has been reported to be 16%, with very low or no shrimp loss (DPI-QLD, 2004). The Lake Arthur BRD, widely used in shrimp trawling in Lake Arthur area of Western Louisiana, is one of the earliest BRDs. Lake Arthur BRD is reported to reduce the bycatch up to 34% (Morris, 2001). Big eye BRD reduce bycatch by 30 to 40%, in tropical coastal waters, commercially used by shrimp fleet in Queensland east coast waters. During 1998, 30% of the Queensland east coast trawl fleet used Big eye BRD in their penaeid fishery (Robins et al., 1996).

1.4.4.5 BRDs with guiding or separator panel

Guiding or separator panels are used to achieve separation of the bycatch by using differences in their behaviour or size. BRDs with guiding panels lead the fishes to escape openings, making use of the herding effect of the netting panels on finfishes. The shrimps are not subjected to herding effect and hence pass through the meshes towards the codend. BRDs with separator panels physically separate the catch according to the size, with the use of appropriate mesh size. Shrimps pass through the panels to the codend while bycatch such as fishes and sea turtles are directed towards the exit opening (Christian et al., 1988; Rogers et al., 1997; Polet et al., 2004). Separator panel BRD operations in New South Wales shrimp trawl fisheries
have indicated a shrimp loss of 2-30% and fish exclusion of 30-80% (Anon, 2004a). However, there is a chance for debris clogging the separator panel. Authement-Ledet BRD with bottom opening has been reported to give better exclusion of fishes, while top opening BRD entailed in minimum shrimp loss (Rogers et al., 1997).

The Morrison TED, Parker TED and Andrews TED are efficient soft TEDs, which are used to exclude sea turtles and large marine animals in many countries. Proper installation of the soft TEDs is essential in order to ensure their efficient performance. Morrison soft TED has been used successfully to exclude sea turtles in Gulf of Mexico. In addition to sea turtles, it reduced other bycatch species, particularly fish. The biggest drawback regarding this category of BRDs is the possibility of clogging with debris (Christian et al., 1988; Kendall, 1990). Studies in Moreton Bay, Queensland, Australia using Morrison soft TED has given reduction in bycatch by an average of 32% (Andrew et al., 1993; Robins-Troeger, 1994). Results of studies conducted in the Gulf of Mexico and South Atlantic shrimp fisheries has shown that Andrews soft TED is very effective in excluding the red snapper bycatch up to 77% with a shrimp loss of 16% and Morrison soft TED excluded 20 to 40% of fish bycatch with a shrimp loss of 13%. Andrews soft TED is successfully used in West Florida shelf area without excessive clogging (Anon, 2002b). Turtle exclusion rate from Parker soft TED, which is approved for use in US waters, has been reported to be 97% (Anon, 1998). Experiments using Sieve net in Belgium fishery has been bycatch exclusion rates of 29-50% in different seasons, with less than 15% loss of shrimps (Polet et al., 2004).
1.4.5 Development of Combination BRDs

Researchers has proposed different combinations of sorting grids, slotted BRDs such as fisheye and soft BRDs such a square mesh window and bigeye BRD in order to obtain higher bycatch exclusion efficiencies (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.

1.4.6 Development of bycatch reduction technologies in India

In India, Kunjipalu *et al.* (1994a;1994b; 2001), Varghese and Kunjipalu (1996), Varghese (1999) have reported results of trawl selectivity studies conducted using square mesh codends and panels. Their studies indicated that mesh size below 25 mm in square mesh codend provided very little chance of escapement for juveniles and sub-adults. Pillai *et al.* (1999) developed a new separator device with horizontally divided codend for separation of shrimp and fish during trawling. Pillai *et al.* (1998; 2004) has made preliminary observations on the bycatch and discards of shrimp trawls in India and described certain selective devices with potential for reduction of bycatch in trawls. This includes square mesh window attachment, Radial Escapement Devices, Fisheye, Grid devices in shrimp trawling. Varghese *et al.* (2000) has reported a method of separating jellyfish from target species in shrimp trawls, using inner square mesh filter. Shrimp trawling and bycatch issues associated with mini trawling along the coastal waters of Kerala and the need to reduce bycatch in mini-trawl nets were discussed by Thomas (2000). Regulation in mesh size for trawl nets and use of square mesh in
mini-trawl and other trawl nets used in inshore areas was proposed by Vijayan and Edwin (2001). Varghese et al. (2004) compared the selection pattern of diamond and square mesh codends in trawl. The effects of separator panel for bycatch separation in trawl codend were discussed by Vijayan et al. (2004). An indigenous Turtle Excluder Device (Hard TED) for use by the commercial trawling industry in order to prevent fishing induced mortality of sea turtles with minimum catch loss was developed by Central Institute of Fisheries Technology (CIFT) (Dawson & Boopendranath, 2001; CIFT, 2003).

1.5 Rationale and Objectives of the Study

Though trawling is an efficient method of fishing, it is known to be one of the most non-selective methods of fish capture. The bulk of the wild caught penaeid shrimps landed in India are caught by trawling. In addition to shrimps, the trawler fleet also catches considerable amount of non-shrimp resources. Bycatch discards is a serious problem leading to the depletion of the resources and biodiversity. In order to minimize these problems, trawling has to be made more selective by incorporating Bycatch Reduction Devices (BRDs). The soft BRDs use soft structures made of netting and rope frames instead of rigid grids prevalent in hard BRDs, for separating and excluding bycatch.

Studies regarding the technologies to reduce bycatch have been conducted in various fisheries in different parts of the world. In India not much work has been done in this regard even though the bycatch in the landings by shrimp trawlers in India is very significant. Under the Code of
Conduct for Responsible Fisheries (FAO, 1995) stress have been given to the design and development of fishing gear that are environment friendly which minimize negative impacts of fishing on long term sustainability and biodiversity. The present study aims to develop simple, efficient, cost-effective bycatch reduction devices using soft structures for the mechanized shrimp trawl fisheries sector of India.

The main objectives of the study have been:

- To design and develop soft bycatch reduction devices, incorporating flexible materials for selective trawling;
- To study the existing trawl systems (vessel, gear and accessories) and bycatch issues off south Kerala; and
- Comparative field evaluation using prototype BRDs and statistical analysis of data, in order to evolve the most appropriate BRD for the small-scale mechanized trawl sector.