CHAPTER-III
3. REVIEW OF LITERATURE

Trawling is an important technique of fishing methods, coming under the category of dragged gear. In this method a bag-shaped net is towed through water with its mouth kept open by a frame, a beam, otter boards, floats, sinkers, kites etc. Sometimes, it is kept opened by being towed by two vessels moving at a distance from each other in the same direction. Based on the position in the water column where the trawl is dragged, trawls can be categorized into bottom trawl or demersal trawl and mid-water or pelagic trawl (Brandt, 1972). Mid-water trawl, though can give very high catch in a short time, is an aimed trawling and needs a fish shoal to be detected first before operating the gear skillfully. However, this is not popular in India. On the other hand, bottom trawling is a blind trawling, which does not need much of instrumentation and thus, is the only widely accepted method of commercial fishing practiced in India. There have been continuous developments in demersal trawl nets and their accessories to reach the present status. A brief review of different studies done on demersal trawling with special reference to the effect on trawl net mouth opening is summarized below.

3.1. Trawl gear performance

The suitability and acceptability of any gear depends on its satisfactory performance in a specific location. Therefore, several studies have been conducted to find out the relative gear performance in different locations.

3.1. 1. Aspects of general trawl designs

Designing fishing gear is the process of preparing technical specifications and drawings for the fishing gear, which meets the operational benefits and satisfies gear (Fridman, 1986). The key to successful development of selective gear designs is the understanding of the behaviour of the individual species to various environmental stimuli (Watson, 1989). Buckingham (1972) stated that the factors to be considered while designing a gear include engine power of vessel, length of belly, head line height, mesh size and its shape, netting material used and the overall resistance. Lonnevik (1989) stated that the hanging ratio of netting affects its overall shape, vertical and horizontal openings and stability. Adoption of standard design
and modern fabrication methods in anchored bag net results in better catchability (Kunjipalu et al., 1993).

Some characteristics of netting and twine material have significant hydrodynamic, behavioral and mechanical effects on gear selectivity (Ferro and Neill, 1994). The major factors influencing on the fish catch is the vertical opening of the net (Takayama and Koyam, 1959 and Parrish 1959). In a known fishing ground the quantity of fish caught by trawl gear has direct bearing on the volume of water filtered during a certain period of operation and depends on the both the horizontal and vertical opening of the net while in operation (Deshpande, 1960). It has been mentioned by Hridayanathan and Hameed (1990) that the catch of stake net (bag net) is highly influenced by its design besides the lunar cycle and operation methods. Trawl design should be made in such away that it offers minimum resistance. The behavior of the fish to be caught, technical characteristics of the vessel and condition of the ground are some of the important factors to be considered while designing a trawl (Sreekrishna and Shenoy, 2000).

The braided polyester netting and the new generation spectra fiber ropes for trawls give superior strength and abrasion resistance with very low elongation (Stone, 1989). The use of monofilament netting in otter trawls would reduce the total drag significantly compared to multifilament one (Sumpton et al., 1989). Kartha et al.(1977 stated that trawl made up of tape twine has increased the catch compared to poly amide and polyethylene monofilament material. The substitution of netting in the fore parts of the trawl by ropes would reduce the drag (Rao et al., 1994). Mounsey and Prado (1997) analysed three net designs for ecofriendly demersal fish trawling systems. Neethiselvan and Brucelee (2003) have analyzed the design features of fish trawl and shrimp trawls of Thoothukkudi coast with those of standard FAO fish cum shrimp trawls. Manikandan (2005) designed the big mesh trawl to reduce the by-catch in bottom trawling.

3.1.2. Design of efficient trawl gear

Fridman (1969) described the general principles involved in the theory and design of trawl gear and the several traditional and scientific methods of evaluating the efficiency of the gear. The efficiency of trawling operation can be improved by
increasing fishing time using two trawls alternatively - hauling one and shooting one (Anon., 1969). Nair et al., (1966) from their study to judge the most suitable size of trawl that can be economically operated in shallow waters, reported that towing two or more small trawls by a vessel is more advantageous than a single large trawl. Bigger trawl catches more, but at the cost of higher hydrodynamic drag and increased difficulty in gear handling (Dickson, 1959). Chandrapal (1975) opined that success of trawling operation depends on the proper matching between the gear and the trawler. Miyamoto (1959) studied the relationship between the size of trawl gear and the vessel towing power and formulated several equations for finding out the size of trawl net and otter board along with its weight in relation to the horsepower of the engine. Nair and George (1964) also came out with similar relationships between horsepower of the vessel and the size of the trawl gear and its accessories. Pradhan (1965) had given a preliminary account and review of the simple methods for determining the operational parameters of fishing gears.

3.1.3. Fish behaviour with respect to gears

Knowledge of fish behavior and its reaction to fishing gear forms the basis for the development of the efficient gears and the energy efficient fishing methods with good selectivity (Anon 1980). Mous et al., (2002) have reported that fish that are encountered by the net tend to keep a constant position relative to the net, even if the net tend to be towed at a speed of lower than its maximum swimming speed and, the fish that gets exhausted end up in the codend. The need to understand the fish reaction to gear for the development of efficient gear has been stressed by Parrish and Blaxter (1963) and Fridman (1969). Fish arriving at the trawl mouth may enter it and continue swimming towards the codend but it turns in the trawl mouth and continues swimming in the towing direction. Depending on the towing speed and the size of the gear the fish become exhausted after some period of time and drop back towards codend (Main and Sangster, 1981)

Chikimasa (1964) and Garner (1967) stated that pressure build up inside a tapering gear could have a frightening effect on fish. Arimoto et al., (1989) have observed with the help of underwater cameras, more fish reach near the net mouth and throat part of the net. Fridman (1986) noticed that the swimming speed of fish, to large extent, determines the required operation speed and gear size. Dickson
(1959) had stated that the most commonly observed reaction of fish is to swim perpendicular to moving wire rope. Suueronen (1989) observed that avoidance and escapement of herring (*Clupea harengus*) is dependent on the swimming patterns of this fish during trawl operation. Bottom trawl efficiency is function of horizontal herding ability of the gear so as to enable the fish towards the centre of the path in response to stimuli provided by sand cloud and bridles (Engas and Godo, 1989a; Ramm & Xiao, 1995; Dahm, 2000 and Somerton & Munro, 2001).

Sreekrishna (1995) reported that mullets are known to have the habits of jumping out of water when encountered with obstacles and when disturbed. The flying fish, pomfrets and sardines are known to take shelter around the bundles of vegetation for breeding. Main and Sangster (1983) compared heavy rigged trawl with light rigged trawl and observed the reaction of fish to the trawls. Haddock, sardine and mackerel were found to swim straight to light rigged trawl while they turned away from the path much ahead of heavily rigged trawl. Goeden *et al.*, (1990) observed in large low tanks through video and formed that 65% of shrimps escaped under net because of the insufficiency of the foot rope in containing their escape jumps. Variation in footrope contact with the bottom could impact the capture efficiency of the trawl (Weinberg *et al.*, 2002).

Main and Sangster (1981) stated that behavioral studies can be best observed by divers directly than the photographic or video cameras due to their limited vision. Amos (1984b) had communicated on the use of vertical echo sounders and sector scanning to monitor the action acoustically tagged fish. Ona *et al* (1999) reported that high frequency scanning sonar could be used to study the fish behaviour to trawls. Turbidity of water and the visibility have great effect on fish behaviour to the gear and its selectivity (Wardle, 1989). Farmer *et al.* (1998) analysed the behaviour of the fishes and noticed that prawn escaping through 45mm codend have minimum damage. The size of the trawl depends on the towing speed of the vessel and towing speed should be proportional to the swimming speed of the fish (Srikrishna and Shenoy, 2000). Glass *et al.*, (1993) observed that the fish reacts more in small mesh narrowing funnel netting when compared to large mesh netting panels. Walsh (1992) and Ona (1999) have observed the behavior of fish in small codend and noticed that
most escapements occurs by fish passing underneath the footrope, especially near its centre where fish are concentrate by herding.

3.1.4. Selection of trawl depending on the ground

The selection of trawl type for a particular region has profound influence on the trawl efficiency. Nakamura (1971) is of the view that the type of trawl net to be used should depend upon the fishing ground and the fish to be caught. Prado (1977) opined that muddy bottom allows the trawl to slide more freely than the one, which is hard or uneven. Buckingham (1972) suggested the use of a four-panel trawl without wings for fishing on hard grounds. Foster (1976) reported that a four-panel trawl developed at the Aberdeen Laboratory had improved fishing performance on rough grounds than a two seam trawl. The fishing grounds off Mangalore are an important trawling ground along the Western coast of India. Several workers have studied the efficiency of different types of trawls on this fishing ground (Mathew, 1978; Puthran, 1981; Mohankrishna, 1985; Ashok, 1989; Nayak, 1991; Talwar, 1997; Girish, 1999; Jayanaik, 2002 and Manikandan, 2005).

3.1.5. On species depending trawl selection

Botha and Payne (1980) found beam trawl to be more efficient in catching soles in comparison to the otter trawls in their study off south West coast of Africa. Kurian (1965) in his comparative study found that bottom burrowing or resting species including shrimps prawns were more in the catches of beam trawl, while bottom swimmers dominated the catches of otter trawl. The author further reported a 50 per cent increase in shrimp catches in shrimp trawls by using long wings. Deshpande and George (1965) suggested that, in order to increase the effectiveness of shrimp otter trawls, heavy ground rope and less buoyancy on the head rope are necessary. Satyanarayana et al. (1970) developed shrimp trawls of wider horizontal spread at low towing speeds. Nair and George (1964) and Panicker et al. (1978) also worked on similar aspects.

Besides exploring the demersal resources, attempts were made for exploring off-bottom fishes. Kunjipalu et al. (1979) carried out comparative study of fishing efficiency of a bulged belly, a long wing and a four panel trawl and found that the bulged belly trawl had superiority over others in catching bottom and column fishes.
while the long wing trawl was found to be the best for catching shrimps. Similar results have also been reported by Pillai et al. (1979). Nair et al. (1971) have reported on the effect of over hang on increasing catch in a bulged belly trawl. The efficiency of a platform panel as a forward extension of lower belly in semi-pelagic trawls have been evaluated by Mathai et al. (1993). Mahalathkar et al. (1983) found that over hang trawl to be more efficient for the capture of off-bottom and column fishes than the non-over hang trawl. Nakamura (1971) found two-seam trawl to have greater vertical height than four-seam trawl. Contrary to this Deshpande et al., (1972 a) have reported that four-seam trawl had better catch efficiency when compared to a High Opening Bottom Trawl (HOBT) gear with bridles and a sweep line on each side with a greater efficiency in catching off-bottom fishes. Miyata (1977) has mentioned on the rapid increase in the use of HOBT in Malaysia over conventional bottom trawls. Pajot et al. (1982), Pandurangan and Ramamurthy (1983), Kunjipalu et al. (1984), Mohankrishna (1985), Pajot and Mohapatro (1986) and Raja (1987) found the HOBT to be superior to orthodox shrimps trawls in catching valuable pelagic and semi pelagic species. Brabant and Nedelec (1983) have reported on several HOBT for inshore waters and large lakes. Kunjipalu (1994) has given a brief account of the development of high opening trawls.

3.2. Mouth opening of the trawl

Mouth opening of the trawl refers to the trawl mouth geometry while towing. This is an important parameter of any dragged gear, which is directly related to the amount of water filtered and thus the fishing ability.

3.2.1. Importance of mouth opening of the trawl

There is an old and often quoted saying in trawling, “It all comes out of the codend”. Thus, it is the amount of fish in the codend that matters much to a fisherman. And so, what is more important is to discover how best to fill the cod-end in the shortest possible time with greater economy. Among the various factors concerning to this, trawl mouth opening, which depends on the spreading force and the lifting force of the gear commands immense importance. There exists certain definite inverse relationship between these two forces and for proper trawling operation, there should be a balance between them (Takayama and Koyama, 1959). The authors further stated that the major factors influencing the catch of trawl gear
are the horizontal spread of the net for bottom fish and its vertical opening for off-bottom fishes. Philips (1959) and Hamuro (1964) were of the same opinion. Deshpande (1960) stated that the quantity of fish caught by a trawl net has direct bearing on the volume of water filtered through it during a certain period of towing and in turn depends on both the vertical and horizontal opening of the net while in action. The area of net mouth is one of the factors that influence the drag of the net (Kwalski and Giannoli, 1974). Jayanaik, (2002) had reported that bridles and sweeps also influence the mouth opening of the trawl.

3.2.2. Horizontal mouth opening of the trawl

The horizontal mouth opening of a trawl usually refers to the door spread, though the wingspread is taken for consideration many a time. Importance of this for catching of fish has been widely studied.

3.2.2.1. Otter boards

3.2.2.2. History of the otter boards

Otter board was employed initially in line fishing at Ireland to keep the main line tight and is not an innovation of trawl fishery (Davis, 1958 and Brandt, 1972). Davis (1958) was of the opinion that the actual invention of otter boards must be credited to Hearder or Musgrave. He further stated that, though Danes were using a modern type of otter boards on their seine net way back in 1888; it was on 1892, the first successful otter board was made at Shields on the North East Coast of England. The otter board reached Germany through Holland in 1895. During the same year France completed successful experiments with the doors. After this, the otter boards became popular all over the world.

Before the introduction of otter boards, the trawl gear was kept open by a rigid self-supporting frame called ‘beam’. Introduction of otter boards coupled with the introduction of radical changes to trawl fishery as it has many advantages of easy handling, use of bigger nets, operation in deeper waters and larger coverage for the given net (FAO, 1974 and Baranov, 1976). The flat wooden plate was the type of otter board initially introduced, which has undergone many changes in size and shape to evolve into the present forms namely rectangular, oval, polyvalent, vee form, hydrofoil, suberkrub and saucer shaped, flat and cambered (horizontally or
vertically), with or without slot(s) and foil(s), at various aspect ratios, fabricated out of varied materials and rigged to provide various angles of attack.

3.2.2.3. Design and selection of otter boards

Design of more efficient otter boards is one important way to reduce net drag (Wray, 1986). FAO (1974) emphasized on the correct choice of otter board angle to reduce net drag. Pillai et al. (1973) have studied the effect of weight of otter boards on the horizontal opening of trawl net. Ben-Yami (1975) explained about how optimum size and setting can be calculated to avoid wastage of towing power and improve trawl performance. McLaughlin (1986) and Gabriel (1987) have emphasized on the selection of a correct trawl board shape and size to get best results. Mukundan (1970) has reviewed the design and construction of flat rectangular otter boards for bottom trawling. FAO (1974) has compiled the otter board types, their design and performance. Ashworth (1989) and Cheesley and Gates (1989) have described the history of developments of trawl doors. Anon (1995) has written a book on characteristics and functioning of otter boards.

3.2.2.4. Comparative studies between otter board types

Wide range of literature is available on the feasibility study of various types of otter boards. Mukundan et al. (1967) studied the relative efficiency of three different shaped otter boards on the basis of horizontal opening and towing tension. Narayanappa (1968) described different types of otter boards namely, flat rectangular, horizontally curved and oval single slotted rigged to a two seam trawl off Kakinada and found that the horizontally curved otter boards gave greater horizontal spread with high catch rate. Comparative fishing trials with flat rectangular and curved rectangular otter boards rigged to a four seam trawl showed higher catch rate with 13% more horizontal spread but with 10% higher towing resistance in the case of rectangular curved boards (Deshpande et al., 1970). Sreekrishna (1970) in his study off Kakinada found that a 12.96 m two seam trawl with rectangular curved doors and a 11.98 m two seam trawl door with oval boards were equally efficient. Deshpande et al. (1972) recorded better catch of fish and shrimp when trawls were rigged with rectangular otter boards than when rigged with oval doors. Lange and Steinberg (1989) studied the influence of size and form of otter boards on the opening area of a bottom trawl. Anon (1995a) evaluated six
different designs of cambered otter boards available in Australia in shrimp trawling. They also studied its effect on the performance such as total system drag, spreading capability, stability characteristics while on tow, shooting away characteristics, ease of handling etc. Anon (1991) developed a more fuel efficient environment friendly otter board. Jong and Marlen (1991) did model studies on use of single trawl door on the port side and Dan-leno on the star board side to catch pelagic fish closer to sea surface.

High aspect ratio otter boards for pelagic trawling called “Suberkrub” was first developed in Germany and later used in Japan with little modification for catching demersal fishes (Brandt, 1972). The author also reported on the use of “Tendem boards”, which consists of two smaller high aspect ratio boards instead of single suberkrub doors so as to overcome the problems of handling onboard while giving the same result. Development of spherical otter boards, called “Saucer boards or O-boards” by Russian was found suitable for rough fishing grounds as well as column water fishing by trawls (Brandt, 1972). Garner (1988) opined that the conventional boards with a flat surface present a high ratio of resistance and consequently good spreading force. Besides, the ground shear or friction along the seabed may be quite severe. On the other hand, in the case of oval boards the ground shear is much less and so also the spreading force and the board can easily clear obstacles on seabed. Further, oval boards with one slot, show a greater spreading force besides ease of riding over obstacles. Brandt (1972) reported that flat doors, Vee doors and spherical doors are associated with added advantages of interchangeability between starboard side and port side to avoid uneven wear of keel. Nair et al. (1973) reported that, though the Russian type oval boards are favourable on East Coast of India for the uneven rocky grounds and the superiority of the horizontal curved boards for bottom trawling has been proved, they were not popular due to the difficulty of manufacture and the cost compared to the flat rectangular type.

Brandt (1972) pointed out that, the simple flat rectangular wooden boards are less influenced by the hydrodynamic and hydrokinetic rules compared to the curved boards, thereby resulting in lesser efficiency of the conventional flat boards. Catasta (1959) designed two new otter boards of the shape of aeroplane wing section and
reported that, when compared to flat doors they offered lesser resistance, not falling flat, less liable to dig into the bottom and expected better durability. Mukundan (1970) reported that flat rectangular boards offered high resistance and spread force was not satisfactory. The new types of boards having good engineering/hydrodynamic performance are expensive to manufacture and difficult to handle as compared to conventional flat rectangular otter boards (FAO, 1974 and Ben-Yami, 1975). Garner (1988) substantiated that any trawl development must begin at otter board as it affects the rest of the gear in its performance.

Mukundan (1970) and Brandt (1972) gave an account of the different materials used for otter board construction. Originally the flat boards were made up of wooden planks or marine plywood strengthened by steel frame and iron struts. Catasta (1959) used iron and plastic material for his new aeroplane wing section type otter boards. However, nowadays steel is replacing the wood in the construction of most of the otter board types, especially used in deeper waters.

3.2.2.5. Vee otter boards

Many workers have studied the feasibility of vee boards in demersal trawling. Brandt (1972) reported that vee - shaped trawl doors (butterfly otter boards) became very popular in small scale inshore trawling and were designed by the Chinese captain Loo-Chi Hu in 1956/57. The author further adds that these boards claim a good performance on rough grounds. Although the vee doors are associated with low shearing power, successful fishermen prefer them Wray (1986) studied the performance of the varying type of vee doors such as standard vee doors, cambered and square vee doors and vee doors with or without slots. Satyanarayana et al. (1978) investigated the relative efficiency of different shaped otter boards under identical fishing conditions and found the gear fitted with vee shaped otter board performed well when compared to the gear fitted with horizontally curved and vertically curved boards. Main and Sangster (1979) found superior spreading force with rectangular cambered boards, whereas, vee doors were superior in terms of stability and clearing rough grounds. Kunjipalu et al. (1984a), in their comparative study found that 'V' shaped all-steel doors, with their inherent stability to ride over obstacles and mud and interchangeability of starboard side and port side boards, were superior to conventional flat rectangular otter boards for bottom trawling.
Matsuda et al. (1990) studied the hydrodynamic characteristics of a vertical V shaped otter board in model tank to determine the lift, drag and moment. Loverich and West (1989) designed high aspect ratio otter boards, called “fishbusters”, which was found successful for bottom trawling by increasing the catch rate significantly over those with conventional flat rectangular vee doors. Lange (1987) used 13% camber ratio in his new type of V door to get 70% higher lift coefficient. Le et al. (1987), in their model experiments observed that the simple cambered otter boards performed better than super V otter boards, even though same camber ratio was used. Lange (1989) conducted wind tunnel tests to develop vee form boards. Lange (1991, 1991a) did model tests to study the hydrodynamic characteristics of cambered V doors of high aspect ratio (1.0) and found that when compared to cambered vee doors of traditional aspect ratio (0.5) the new boards reduced the drag coefficient. Greening (1989) reported that, for deep sea fishing beyond 200 nautical mile high aspect ratio cambered vee doors were found suitable.

It has been mentioned that, poly ice vee doors had better spreading ability while shooting the gear (Anon 1996). Kunjipalu et al. (1984a) reported that flat rectangular otter boards of wood and steel construction are extensively used in commercial trawling along Sourastra coast but steel V boards were superior in terms of construction, durability, inherent stability and higher hydrodynamic efficiency. Sahu (1997) studied the efficiency of vee otter door in comparision to the conventional flat rectangular otter board for demersal trawling and concluded that vee type is better.

3.2.2.6. Otter board characteristics

The otter board attitudes such as angle of attack, heel, tilt, aspect ratio and hydrodynamic characteristics such as lift, drag, sheer, camber, slot etc. play an important role in the engineering performance of otter board (Mukundan, 1970). Effect of angle of attack on the performance of different types and shapes of boards have been reported by Blestikina (1962), Dale and Moller (1963), Mukundan (1970), FAO (1974), Lin et al. (1989, 1989a), Ko et al. (1990), Matsuda et al. (1990) and Mukundan and Hameed (1994). With his studies on flat rectangular otter boards, Crewe (1964) got maximum sheer at 30°. Angle of attack ranging from 30° to 39° has been suggested for trawling with flat rectangular boards (Ben-Yami,
The effect of heel of boards has been reported by Crewe (1964), Ben-Yami (1963), Mukundan (1970), Lin et al. (1989, 1989a) and Mukundan and Hameed (1994). Mukundan (1970) discussed the effect of tilt of otter board on the ground performance. The ratio lift to drag, which is an important characteristic of an otter board has been studied (FAO, 1974 and Mukundan, 1970).

Gabriel (1987) compiled the general criteria and various hydrodynamic coefficients for most common type of otter boards to help selecting otter board type. Kim and Ko (1987) studied the sheering characteristics of simple cambered and super V otter board attached with a flat plate at the trailing edge. Daartz et al. (1987) investigated the dynamic behaviour of otter boards. Ibrahim (1988) and Park et al. (1993) studied the effect of ground touching on the hydrodynamic efficiency of otter boards. Ben-Yami (1995) has reviewed the hydrodynamic behaviour of otter boards, the influence of ground touch and speed and other aspects that influence the performance of otter boards in action.

Lin et al. (1988, 1989, 1989a) studied the hydrodynamic characteristics of lift and drag of saucer shaped otter boards of different camber ratios. Matuda et al. (1989) reported on the hydrodynamic characteristics of wing parakite, a net mouth-opening device made of canvas and found its performance to be comparable to an ordinary cambered upright otter board. Jo et al. (1991) studied the sheering ability of a newly designed canvas net sheering device.

3.3. Importance of horizontal mouth opening of trawl

Horizontal opening of the trawl net mouth is a key factor in the efficient operation of all the demersal trawls (Okonski, 1972). Narayanappa (1972) and Satyanarayana et al. (1978) found that catch per trawling hour increased with increase in lateral spread of the net up to a certain range beyond which the rate declined. Levi et al. (1989) measured the horizontal distance between otter boards to study the biomass abundance in the Sicillian channel. Kunjipalu et al. (1992) established relationship between the size and type of net and its optimum horizontal opening, which is suitable to catch a particular fish resource. Rose and Walters (1990 and 1991) reported that variation in the horizontal opening of bottom trawls at
different depths gave varied and biased results in the catch of ground fish fishery in USA due to the changes in the length of warp required at different depths.

### 3.3.1. Factors influencing horizontal mouth opening of trawl

Mukundan (1970) summarized that the lateral opening of trawl depends on the type of gear used, nature of bottom, length of warp released during operation and towing speed and more particularly the type of board and the position of the door assumes during fishing. Kotsyunin and Nikonorov (1971) is of the opinion that the horizontal spread between the otter boards depends on the size of trawl, quality of trawl board (i.e. the ratio of spread to resistance), length of sweep line or bridles, warp scope etc. Pillai et al. (1979) recorded significant increase of otter boards horizontal opening in the large mesh trawl. Kunjipalu et al. (1989) recorded 7.9% more horizontal opening between the otter boards of a 25 m large mesh two seam demersal trawl than that of a 25.6 m two seam trawl developed by BOBP (Bay of Bengal Programme). Several authors have reported a higher horizontal opening in large mesh trawls (Anon., 1973 and Naidu et al., 1987). Nair et al. (1973) suggested that horizontal opening can be improved with long sweep lines and extension wings, which in combination with tickler chain yields better prawn landings. Satyanarayana and Nair (1964) had stated that shrimp trawls with 35-60 ft head rope had a horizontal spread of 50-60% of the total length of the head rope including sweeps. Satyanaryana et al. (1972) related a relationship of horizontal spread of the otter boards to the total length of head rope. The methods for theoretical calculation of wing and door spreads for bottom trawls have been given by Ben-Yami (1959), Deshpande (1960) and Dalmendray and Valdes (1984). Hagstroem (1987) described the method of measuring the door spread and headline height of trawl net. Marteinsson (1992) measured the wingspread, door spread and trawl height by acoustic instruments.

Otter boards trawl doors or doors as they are frequently called are the devices to keep trawl net horizontally open while towing. They account for approximately one fourth to one fifth of the total drag of trawl gear, and also directly influence the geometry of a trawl and consequently the overall drag of the gear (Anon, 1974). Each door is connected with towing brackets for attachment of warp on one side and the bridles of the net on the other side, so that the boards keep obliquely to the
direction of motion due to the forces from flow of water (Hodson, 1942 and Brandt, 1972). The two doors on either side in a trawl net are working on the same principle as that of a kite, causing the shearing effect in the water (Mukundan, 1970). The most recently developed methods of keeping the horizontal opening of the net are canvas mouth opening devices and wing parakites (Jo, 1985; Matuda et al. 1989; Ko et al. 1988 and Jo et al. 1991).

3.3.2. Vertical mouth opening of the trawl

Vertical mouth opening of a trawl refers to the maximum height to which the head rope is lifted while towing. This is considered important for catching certain fish resources by trawls.

3.3.2.1. Kites and gussets

Takayama and Koyama (1959) suggested the use of kites and gussets. Burgess (1967) reported that a kite attached to the float line gave a higher headline height in a trawl. Cerdic (1978) had commented on the use of a canvas sail kite to double the mouth opening of a trawl net. Ben-Yami (1979a) did flume tank tests and confirmed the benefits of using sail kites. Ben-Yami (1979) stated that sail kite gave 120% increase in fishing height while fishing spread was reduced by about 10%. He also reported that increasing the fishing height affects the bottom contact of the footrope. Successful use of sail kite by Russian, Polish and Burmese fishermen were mentioned by Ben-Yam (1979). Lange (1989) has discussed the simple method of designing and rigging flexible sail kite to a trawl mouth. A strip of canvas was fixed to the trawl mouth to attain higher headline height by Day (1978). Ben-Yami (1979) studied the feasibility of using a sail kite to achieve more vertical opening.

3.3.2.2. Floats

Floats are widely used devices for lifting the headline. Catasta (1959) used plastic floats with a hydrodynamic section and an elevating hood to lift headline. Satyanarayana et al. (1970) employed different methods to increase the vertical height in an otter trawl and found that the trawl with additional float line gave better catch when compared to the nets with triangular gussets or with rectangular kite. Studies at Aberdeen Laboratory showed that the floats of squashed sphere were efficient to spherical floats (Anon., 1973). Chen (1989) got encouraging results with
the use of flexible hydrofoil wing float for lifting the headline of a trawl. Kunjipalu and Boopendranath (1993) developed a flexible float made of canvas and their investigation resulted in a significant improvement in the yield of finfish and total catch besides many other advantages.

3.3.2.3. Sinkers and tickler chain

Use of sinkers is of prime requisite to pull the lower lip of the net mouth down. Many references are available on the use of tickler chain for the dual job of sinker and tickling the ground to catch burrowing variety of fish and crustaceans (Deshpande and George, 1965 and Beardsley, 1973). At the same time many workers have discussed the adverse impact of using heavy tickler chain in damaging the bottom fauna as well as the ecosystem (Anon, 1971 and Manoharados et al., 1993). The use of heavy chain had been mentioned (Anon, 1971).

3.3.3. Importance of vertical mouth opening of trawl

Takayama and Koyama (1959) stressed the importance of vertical opening of the net for catching demersal fishes. Philips (1959) has indicated the effect of increase in headline height on the catching power of the net. He has emphasized the importance of headline height over the horizontal spread by otter boards in catching high swimming fish. Hamuro and Ishii (1959) found that, by increasing the headline height by 1.5m the catch could be increased by 50% in a two-boat trawl. Verghese et al. (1968) reported that a high opening bulged belly trawl gave higher catch rate of 31.8% than an identical conventional bottom trawl. George (1978) examined the superiority of a 4 – 4.5 m high opening trawl over that of a Mediterranean trawl of Tunissian design with a vertical opening of only 0.9 – 1.2 m. Lan (1980) had reported that with large mesh in the trawl could get higher net mouth and more catch besides less resistance. Boopendranath et al. (1986) had mentioned that a 25 m high opening bottom trawl with sail kite landed 54.4% more catch with 13.2% reduction in by-catch than a trawl without sail kite.

3.4. Factors influencing the mouth opening of the trawl

Factor affecting the successful spreading of the trawl should be controlled properly so as to produce an effective fishing gear (Binns, 1959). Okonski (1972)
stated that the type of net construction, the speed of towing, current speed, rigging of ground rope and sea bed condition influence the mouth opening of a trawl net.

3.4.1. Towing speed

Carrothers and Foulkers (1972) studied the effect of towing speed on the net mouth opening and found that, at higher towing speeds the head line height and wing spread were reduced while its drag increased. On the contrary, Perumal et al. (1973) reported that both during the model and full-scale experiments, the trawl showed increased horizontal spread and warp tension and reduced vertical opening due to the increase in towing speed. Further increase in towing speed causes the net spread and start flying finally foul net on other hand speed is too slow boards welcome together and entangled (Koyama, 1984).

3.4.2. Gear design

The designs of trawl gear do have influence on the trawl mouth opening. The design of a new large bottom trawl by increasing the headline length was found to be to give greater spread and lift to the trawl mouth (Anon., 1974). Satyanarayana et al. (1972) designed a four-seam trawl net and compared its performance with conventional two seam net. The new gear had lesser horizontal spread and more vertical height, but both had almost the same warp tension. It has been suggested that greater spread and higher headline height could be obtained by increasing the number of meshes in the square piece and top wing of the trawl (Anon., 1974). Wray (1990) is of the opinion that Y-type trawl design seems to give better horizontal and vertical spread. Panicker et al. (1978) did comparative studies on parallel twin body trawl with bulged belly trawl off Cochin. They found that twin body trawl had 28% higher fishing efficiency and about 9% less resistance due to 26.6% extra wide mouth opening than the other. San and Fuwa (1975), in their model experiment found that the height of the trawl mouth of six-seam trawl was much higher than shrimp trawl under normal towing speed. Okonski (1972) from his long experience reported that different type of fishing and nets need different proportions of horizontal opening in the trawl. Experiments on the modifications in the gear design to achieve greater trawl height have been tried by many scientists (Verghese et al., 1968; Satyanarayana and Narayanappa, 1976; Pajot et al., 1982).
3.4.3. Others

Okonski and Sadowski (1959) studied the effect of length of headline and footrope on the vertical mouth opening of the trawl gear. Fujushi and Taniguchi (1976) tried using bottom curtain to increase the trawl net height. Fuwa (1979) described a method to decide the height of a trawl net mouth directly from the net plan. He also noted the relationship between the height of net mouth corresponding to the length of warp released and the distance between the two trawls. Wan and Hou (1992) changed the wing tip into double shallow tailed construction to give better vertical mouth opening and better trawl geometry under normal towing speed. Kotsyumin and Nikonorov (1971) described a method to measure fishing height of a trawl net. Mouri et al. (1976) elaborated on a theoretical equation to measure the central height of net mouth of a four-panel bottom trawl.

Narayanapa and Satyanarayana (1973) studied the optimum buoyancy-weight relationship for bottom trawl. Dickson (1959) suggested for a critical balance of sinkers and floats in order to reduce fish escape below the ground rope without sacrificing headline height.

3.4.4. Other factors influencing trawl performance

Besides the above, so many other factors influence the performance of trawl gear in their own way. A few of such factors have been described below.

3.4.4.1. Warp – depth relationship (scope ratio)

The fishing spread of the gear and the behaviour of otter board depends on the length of warp payout for that depth (Mukundan, 1970). Miyamoto (1959) proposed a formula and Johnstons (1950) prepared graph to decide the length of warp to be released. Nair et al. (1966) summarized the factors influencing the minimum length of warp paid out for bottom trawling. The authors have studied on the scope ratio based on the net size and water depth for small shrimp trawls. Mukundan (1970) had discussed in detail the effect of different warp scope ratios at the same depth and same warp scope ratio for different depths on horizontal mouth opening. Nair et al. (1966), Chandrapal (1975) and Ercoli (1986) studied the effect of scope ratio on gear efficiency.
3.4.2. Effect of bridle/sweep line on mouth opening

The importance of bridles and sweeps to improve the performance of trawl system herding fish in the direction of trawl has been reported (Chapman, 1964, Crewe, 1964, Blaxter et al., 1964 and Narayanappa 1968). Scharfe (1959), from his study with Mediterranean type of trawl, observed that the sweep lines, particularly the mud ropes used for herding fish into the net, play an important role in its catching ability though the resistance due to this part of the net is only 8 % of the total gear resistance. Kuriyan (1965) and Gabriel (1978) reported that the method of rigging of a trawl net also influences its functioning. Kuriyan (1965) got more catch when he used single sweep line in between the net and the otter boards than the otter boards were attached directly with the net. Satyanarayana and Mukundan (1963) stated that the angle of attachment of bridles with otter boards influence its functioning. Use of longer bridles to catch more fish in bottom trawls has been reported by several authors (Deshpande et al., 1972 and Roberts, 1964). It has been that the size distribution of fish caught in a trawl is affected by sweep lines (Anon., 1974). Dickson (1959) said that the gap between spreading wires or sweep lines is a potential place for fish escape. Narayanappa (1972) studied on optimizing the length of single sweep wire for an otter trawl. Rajendran (1982) could adjust the headline height and wing spread of a butterfly trawl by changing the bridle length. Mathai et al. (1984) and Rajan et al. (1990) undertook studies on optimization of bridle lengths for demersal trawls. Rajan et al. (1990) reported that several demersal species excluding crustaceans are known to respond to herding by sweeps and bridles crossing the seabed. Fish also respond to the noise and vibration of the otter board and to the clouds of mud and sand generated by them. The herding effect is maximized when the trail of sand and the cloud is positioned in alignment along the bridles and sweeps (Main and Sangster, 1981). According to Sainsbury (1996) the otter boards are usually separated from the forward end of each wing by a length of wire and the sweep line. Hanumanthappa and Radcliffe (1998) have conducted model testing two bridle and three bridles rigs arrangements in wing trawl and recorded the vertical height and wingspread. Paine and Gruver (1996) have found that the design of trawl bridle rigging and foot rope attachment technique enable the net to fish slightly above the bottom. Hameed and Boopendranath (2000) have reported the rigging of two bridle and three bridles arrangement in bottom trawling.
based on the bottom conditions where trawl is to be operated. Jayanaik et al. (2004) have conducted the bottom trawl with variation in bridle length and found that 19-20 meter bridle length had an optimum mouth opening during bottom trawling. Further, they also reported the highest catch in the above bridles arrangement when compared to other combinations.

3.5. Gear resistance and economy in fishing

The water through which the trawl is dragged offers a great resistance to the forward movement of the gear, which necessitates greater power requirement, more fuel consumption and ultimately greater cost. Therefore, many a study in trawl gear also focused on reducing gear resistance and obtaining the economy in fishing operation. Buckingham (1972) found that a HOBT with large mesh netting not only had reduced water resistance but also had greater mouth area. Naidu et al. (1987) studied the effect of variation in mesh size and found that trawls with bigger sized mesh gave better horizontal spread at low resistance and thus saving fuel. Prado (1977) reported that a long narrow net has a lower drag than a broad barrel like net. Two small trawls joined side by side with a shared head rope and foot rope and fished between a single pair of doors resulted in reduced towing resistance for the same catch as obtained by the trawl towed separately (Charles, 1986). Panicker et al. (1977) on their comparative study between parallel twin body trawl and bulged belly trawl of identical size, conducted off Cochin, found the former to have better catching efficiency than the latter. The parallel twin body trawl had about 28% higher catch rate with 20% increase in horizontal spread and about 9% reduction in resistance than the bulged belly trawl. Yang (1988) discussed the energy saving measures of bottom otter trawls in consideration to the drag from the net, trawl door, foot rope, warp, lazy line and floats. Hanumanthappa and Radcliffe (1998) have conducted flume tank experiments and recorded the resistance at various towing speed. Nayak (1991) and Manikandan (2005) have reported the resistance of big mesh trawl, considerably lower than that of HOBT.

3.6. Exploratory fishing

According to Baragi and James (1984) who studied the fishery and bionomics of sciaenids off South Kanara coast, it is reported that fourteen species of sciaenids contribute to the fishery along the coast, of which Johnius aneus, Otolithus
ruber and *O. Cuvieri* were abundant. Two survey vessels conducted survey in the area between latitude 14° N and 18° N using demersal trawl up to 300 m depth to study the distribution and abundance of the demersal fishery resources of the Karnataka-Konkan coast and found high concentration of *Nemipterids* and *Priacanthids* in this region throughout the year except in July. About 46% of the total landings were contributed by these two species alone. The next dominant species were catfish and ribbonfish, constituting about one fourth of the catch. Other important varieties recorded in this region were perches, elasmobranchs, decapterids, cephalopods, carangids and lizardfish. Abundance of *Serranids* was observed in the depth up to 100 m in this region (Anon., 1986a). Sivaprakasam (1986) elaborated the results of the intensive survey conducted by the vessel *Matsya Shakthi* and *Matsya Vishwa* along the Karnataka coast upto a depth of 500 m. He stated that the catch rates in the three latitudes, 12° N, 13° N and 14° N were comparatively low ranging from 89 to 134 kg/hr. The catch composition in various depths ranges indicated that coastal waters up to 70 m were dominated by catfish followed by *Nemipterus*, *Decapterus* and *Priacanthus*. However considerable concentration of squids and cuttlefish at 70m to 150 m depth, *Priacanthus* at 150 m to 200 m depth, *centrolophus* and deep shrimp at 200 m to 500 m depth range were recorded, while the lizard fish was distributed widely at all depths. Sukumaran et al. (1986) recorded the decrease in the catch of *Portunus sanguinolentus* from 102.30 ton to 27.0 ton during 1979-78 to 1981-82 along the Mangalore coast and from 65.9 ton to 44.1 ton during 1980-81 to 1981-82 along the Malpe Coast.

According to the survey conducted to study, the distribution and abundance pattern of demersal fishery resources in the area between 14° N and 18° N, high concentration of bull’s eyes was observed in 100-300 m depth range with peak abundance during September. Threadfin breams were more concentrated in the depth range of 100-200 m with higher catch rates during December-May contributing up to 40% of catch during February. During this survey, squids were also reported in significant quantities all along North Karnataka-Konkan coast (Anon., 1987). Studies conducted on Macrobenthos in the Arabian sea, off Manjeshwar up to 50 m depth for a period of one year revealed that molluscs, echiruids, polychaetes, brittle star and starfish were the main components of benthic fauna and also revealed that higher trawl catches were directly correlated to higher...
standing crop of macro benthos (Nathaniel et al. 1988). Syda Rao (1988) had stated that *Loligo duvaucelli* was emerging as one of the important by-catch of trawl landings at Mangalore operated up to 50 m depth. The largest size of male and female of this species were 355mm and 228mm respectively, which were the largest so far caught from the Indian coast.

According to the demersal resource survey conducted along Karnataka and South Maharashtra coasts between latitude 11° N and 18° N, the maximum catch rate of 1153.5kg/hr was registered from the depth between 200-300 m at 11° N off Kerala coast followed by lat 12° N off South Kanara coast (847.6kg/hr). Thread fin bream dominated the catches in 50-100 m and 100-200 m depth range as well as in the shallow regions of 30-50 m depth followed by catfish and ribbon fish. There was a progressive increase in catch rates obtained in depth range below 50 m from lat. 13° N towards North and highest catch rates was recorded from lat. 17° N. Bulls eye contributed to about 62% of the total catch recorded from above 100 m depth. *Priacanthus* species was observed between September -October in the Northern latitude, highest being at 16° N in zone 0-50 m depth in the month of September but size of which was small being 120-160mm. Squids and cuttle fish formed 8% and 12% of the catch in the depth below 50 M and 50-100 m depth respectively (Anon., 1990a; 1991 and 1992).

According to the preliminary survey conducted for neretic and oceanic squid resources along the west coast, large quantities of squids captured by jigging were from the shallow areas (Anon., 1992). Demersal resources survey and monitoring along Karnataka -Goa-South Maharashtra coast between latitude 11 N° and 18 N° Anon., (1994) showed that the highest catch rate was recorded in the deeper section and the important resources being bulls eye, scads, squids and mackerel. Similar results were obtained by the survey conducted for demersal resources and monitoring along Karnataka coast between latitude 10° N and 15° N. Experimental squid jigging along the southwest coast (Anon., 1995) showed that a high yield of squids was recorded during the month of September.

Biological data on the mackerel, based on its heavy landings in trawler at Mangalore have been documented (Prathiba and Kemparaju, 1995). Based on the exploration of juveniles of the spiny cheek grouper, by multi-day trawlers along
Dakshina Kannada coast. Zacharia et al. (1995) gave details stating that the size range of 9 to 24 mm were in sizeable quantities during Oct-May at Mangalore and Malpe landing centres. Prathiba Rohit et al. (1996) have given information regarding Mackerel fishery during the monsoon period by indigenous gears along the South Kanara coast.

According to the demersal resource survey (Anon., 1997a) along the south west coast between latitude 11° N and 18° N, deeper zones of latitude 15° N and latitude 12° N were found to be more productive. It has also been suggested that the months of July, August and September to be more productive for squid jigging (Anon., 1997a). Zacharia at al. (1997) have provided information on the abundance of large size rock cods off Karnataka coast during the post monsoon months of September based on the survey conducted by R.V. Varuna. Premalatha (1997) has provided information on the availability and biological characteristics of Priacanthus hamrur based on trawling operations of F.V. Samudrika and F.V. Sagarika of the Integrated Fishery Project, Government of India. Biological characteristics, length -weight relationship and occurrence of Sepia aculeata along the Mangalore coast have been studied (Syda Rao, 1997). Sukumaran et.al. (1998) has studied the potential new resources of penaeid shrimps off Mangalore coast. A fishery and population characteristic of mackerel landed by trawlers along the Dakshina Kannada coast has been extensively studied by Prathiba Rohith et al. (1998). Nandakumar et al. (2001) have reported the deep sea shrimp fishery first along the Kerala and Karnataka coast with 505 kg. per boat off Mangalore coast.

Kaikini (1974) studied the regional and seasonal abundance of white fish (Lactarius) in the trawling grounds off Bombay -Saurashtra coasts and found that the fish was concentrated in the depth range of 20-45 m. The biology and distribution of Nemipterus caught from Bombay waters was reported by Muthiah and Pillai (1979). Sivakumaran (1984) recorded the landing of oil Sardine (Sardinella longiceps) along Parangipettai (Porto Novo), South east coast of India. The catch and size composition of Carrangid fishery, the fishing ground, the craft and gears used and its economic importance in Porto Nova were discussed by Venkataramaji (1983). He recorded 29 different species of Carrangid in the inshore waters of Porto Nova. Kurup and Surendranath (1985) observed decline in the catch
of *Penaeus indicus* from 29% to 6% against an unusual increase in *Metapenaeus dobsoni* from 52% to 72%. Khan and Zafar (1985) reported that the fishing season for Bombay duck (*Harpodon neherus*) fishery along the Saurashtra coast varied from September to January.

Rajyalakshmi and Reddy (1985) observed the dispersal and recruitment of fry and juveniles of *Chanos chanos* in Kakinada Bay area. Studies conducted by Rao *et al.* (1985) on the commercial trawl fishery off Veraval during 1979-82 showed the demersal fishery resources off Veraval, particularly shrimps were under a strain of over fishing due to the year-to-year increase in shrimp trawlers and the fishery was becoming increasingly uneconomical. Vivekanandan and James (1986) reported that the maturity size of *Nemipterus japonicus* off Madras was 145 mm length and the spawning period ranged from June to March. Observation of the fish landings at Sassoon dock during the year 1971 and 1981 showed that there was a continuous decline in the landings of pelagic fishes from 31.4% to 18.1% (Pillai and Krishna, 1986). Studies were made on the growth, maturity, seasonal abundance and distribution of *Decapterus dayi* along west coast of India by Premalatha (1986a). She observed that larval abundance was more from May to November with a peak in July and September in the Capecomorin region. The fishery of *Alepes kalla* and its distribution in relation to environmental parameters were discussed by Premalatha (1986b). Sivaprakasam (1986b) has documented on the various deep-sea fishery resources of the Indian waters beyond 70 m to 500 m zone. The threadfin bream fishery off Cochin was studied by Nair *et al.* (1986) who observed that their migration during Southwest monsoon from 75-100 m depth to 35-40 m depth coincided with upwelling due to the change in hydrographic conditions. The demersal fishery resource of Wedge Bank up to a depth of 73 m was discussed by Joseph *et al.* (1987). Premalatha (1988) studied on the carrangid fishery (*Megalaspis cardyla*) along the south west coast of India and found out that the contribution of this fish larvae to the total Carrangid landings was about 20%.

Fishery resources of the Exclusive Economic Zone (E.E.Z.) of North-West coast of India was estimated by Bapat *et al.* (1982). He has estimated the potential yield of standing stock of pelagic and demersal fishes to be 2,47,000 ton in the depth zone of 55-360 m. Silas (1985) studied the cephalopod resources of the E.E.Z. off
Mangalore and found that 70% of Loligo duvaucelii landed at Mangalore were from the inshore region. Lolignid squid (Doryteuthis sibogae) was described for the first time by Silas et al. (1985) from Indian seas. He reported the occurrence of this species in commercial quantities along South-West coast of India. The occurrence of oil sardine (Sardinella longiceps) along the Orissa coast was confirmed by Ramasomayajula and Dhana Raju (1985). Occurrence of large shoals of Elagatis bipinnulata (Carrangidae) at 50-60 m depth off Cape Comorin was reported by Sivaprakasam and Nagarajan (1986). Shivaprakasam (1986b) has studied the fishery resources of Cape Comorin and has given the composition of catch and their depth-wise and month wise distribution. The contribution of cephalopods to the country's total marine fish production during 1984-85 was about 24,000 ton (Anon., 1986b). Raje and Savaria (1987) recorded the occurrence of Oceanic Squid (Symplectoteuthis oulaniensis) at 80 m depth along Saurashtra coast. Further they found that this species carried out diurnal vertical migration from surface at night to deeper layer during day. Sudhakar Rao (1987) made a preliminary study on the shrimps fishery along north east coast of India and estimated the potential yield of shrimps between Pentakota and Sunderbans to be 6559 ton. Exploratory survey of shrimps resources off Kakinada conducted by Sudhakara Rao (1988) indicated that almost all the penaeid species were being harvested at the optimum level. He further indicated that any further increase in fishing effort might lead to over fishing of the stock. Najah and Thamer (1988) in their study conducted during 1975 and 1976 on the demersal fish resources of the northern part of the Arabian Sea, found the highest catch rate to occur in April.

Radhakrishnan et al., (1990) reported the occurrence of Spiny lobster (Panulirus penicillatus) for the first time off Madras. A study on the shrimps fishery of the mouth of Gulf of Kutch by Antony and Soni (1990) showed that Metapenaeus kutchensis was the most prominent species representing the fishery, in substantial quantities, throughout the season. During the study conducted from 1986-87, Rajamani and Manickaraja (1990) noted that the seasonal prawn fishery along the Periathalai coast, in the Gulf of Mannar was constituted exclusively by Panaeus indicus with the maximum catches during the month of July. Sivaprakasam et al. (1991) conducted studies on the marine fishery resources off the lower east coast of India. According to his study the depth range of 50-100 m was found to be more
productive for demeral resources such as perches, pomfrets, carrangids, ribbon fish, barracuda and mackerel. As per the demersal trawl survey conducted along the Northern east coast of India between latitude 18° N and 21° N, it was found that the depth zone of 50-100 m was dominated by clupenoids, cat fish and leiognathids. According to James et al. (1994) stated that perches dominated the catch in Indian waters, the peak fishing season extending between October and April. Kripa et al. (1995) working on the cephalopod fishery at Cochin found Kerala to rank first among all the maritime states of India in cephalapod production. Kunjipalu et al. (1994) in his study conducted in September 1992 reported on the occurrence of African black mouth Croaker (Arrobucca marleyi) off North West coast of India with the catch rates varying between 500 kg/hr to 1000 kg/hr An account of the fishery of green tiger prawn (Penaeus semisulcatus) off Tuticorin, during the five year period from 1986 to 1991, was discussed by Rajamani and Manickaraja (1995). They found that 59.6% of this species contributed to the total average annual catch of shrimps estimated to be 251 tonnes. Meiyappan et al. (1995) studied the stock assessment of Indian Squid (Loligo desvauceli) along Kerala, Maharashtra and Gujarat and found out they account for 80% of the all India squid production (23, 941 ton) during 1989.

The status of non-penaeid shrimps fishery of India off Maharashtra coast was given by Deshmukh (1995) according to him an average annual catch of 57,000 ton of non-penaeid shrimps formed 3.7% of total marine fish production in India. Sukumaran et al., (1995) in their study during the year 1985-89 estimated the potential stock for Metapenaeus dobsoni for the whole country to be 25,000 ton. Crustacean fishery resources of India were studied by Suseelan and Pillai (1995). They reported that during 1995 average production of shrimps obtained from 0-50 m depth zone was 2,25,000 ton. According to the study on the reproductive biology of the sand lobster (Thenus orientalis) Kagwade and Kabli (1996) found that the maturity sizes of both males and females were about 107 mm, which spawned between September and April with a peak in November. Further, they also reported that female lobster spawned twice in a year. Penaeid shrimps resources in the Palk Bay off Mandapam was studied during 1986-93 by Maheshwarudu et al. (1996) who informed that it contributed 16.70% of the total trawl landings of that area. According to postlarvae of Chanos chanos collected in April 1985 by Bensam
(1996), it was found that the spawning grounds of this fish can extend to deeper depths off 1,125 m. Chandra Kumar (1996), in the study on the sardine fishery resources along Srikakulam coast, reported that the peak landings occurred in the month of February with 200-205 mm size group fishes predominating the fishery. Four species of full beak (Belonids) and two species of half beaks (Hemiramphids) contributed to good fishery in Gulf of Mannar (Kasim et al. 1996). Fernandez et al., (1996a) with the help of the prediction model estimated the total catch of *Coilia dussumieri* as 22,540 ton in the year 2000 provided the efforts remained constant. The Bombay duck fishery along the northwest coast of India was studied by Fernandez et al. (1996b) for the period 1947 to 1986. They made use of prediction model to describe the state of the stock. Details on the status of trawl fishery from 1990 to 1994 and catches has been given by Joel et al. (1996). In the basis of observation on the oil sardine landings along the Tuticorin coast during 1996 Arumugam (1997) found that fishes with a size range of 120-185mm dominated the catch. Annam (1997) studied the status of Sciaenid fishery along Orissa coast during 1983-95 and noted an increase in the catch from 1983 to 1993 and the fishing season was between October to March. Observations on the landings of Ribbon fishes at Vishakapatnam during October 1997 was done by Satya Rao et al. (1998). They found that fishes with a size range of 540-560 mm dominated the catch. Exploratory analysis on the predictability of oil sardine landings in Kerala was given by Srinath (2004). Yohannan and Abdurahiman (1988) found that the upwelling phenomenon along the Malabar Coast that normally occurs during March to October period produced plankton bloom, which helped in increasing the reproductive output of mackerel. Further, he found that mackerel preferred a temperature of 27° C and hence they remain immediately above the thermo cline. Scariah et al. (1999) revealed that there was a tangible change in the composition of the total marine fish landings in Maharashtra. This was attributed to the gradual decline in the dolnet fishing and increase in case of trawl fishing. There was decrease of production of elasmobranchs, crustaceans along north west coast., perches and croakers along south west coast., silver belly along south east coast and cat fish along north east coast (Anon., 2000). However, north west cost contributed to 40% of country’s marine fish production followed by south west coast (32%), south east (22%) and north east coast (6%). Highest catch rate of 75.16 kg. was recorded from the 50-100 m depth zone of at 16° N, followed by 47.90 kg/hr from 30-50 m depth zone of
latitude 15° N, 38.92 kg/hr from 50-100 m depth zone of latitude 17° N and 34.43 kg/hr from 50-100 m depth zone of latitude 15° N. (Anon., 2005). The survey vessels of Fishery Survey of India surveyed along the south south Maharastra, Goa, Karnataka and north Kerala between 11° N to 18° N from 20-200 m depth zone and resources found to be more in lat. 15° followed by lat. 17° N lat. 12° N and 13° N (Anon., 2006).

3.7. Selectivity of trawl

3.7.1. Size selectivity

Selectivity can be considered as the factors that causes the size composition of the catch to be different from that of the population or that causes fishing mortality to vary with size of the fish (Pope et. al. 1975). The size and shape of codend meshes are main factors, which determine its selectivity (Pope, 1966). Mesh size and gear operation pattern are the factors, which affect size selectivity (Karlsen, 1985). Reeves et. al. (1992) and Galbraith et al. (1994) noticed that the mesh size and codend diameter have a greater influence on selectivity. The chief area of size selection of P. borealis was the codend; negligible loss of fish occurred through wing and belly (Nilssen and Larsen, 1986a).

As early fishing experiment (1910) was to study the relative escapement of fish from codends (Todd 1911). The use of large mesh sizes to reduce juvenile catch was recommended by the International Council for the Exploration of the sea (ICES) for the fisheries of Northern Europe (Great Britain Parliament, 1933). FAO recommended that to catch fish of certain size, the selection of mesh size should be such that it retains half of the fish of critical size (FAO, 1968). Panicker and Sivan (1965) suggested an increase in codend mesh size to capture larger shrimps and to reduce depletion of bottom fauna. Alagaraja et. al. (1986) noticed the instance of heavy landings of undersized shrimps along the coast of Kerala due to the use of small meshed trawls.

International Council for Exploration of Sea (ICES) has recommended an increase in the mesh size from 105 mm to 120 mm for the cod (Gadus morhua) fishery in the Baltic Sea (Lowry et. al. 1994). The larger mesh size (40 mm) in codend of dol net (Bag net) has an adverse effect on the catch of secondary species
like non-penaeid shrimps and total catch (Kunjipalu et al. 1993). George et al. (1974) suggested suitable mesh size for the codend of the stake nets. Valdemarssen (1988) showed that size selectivity of shrimp (Sandalus borealis) has little effects due to increased mesh sizes in codend. Armstrong et al. (1998) have observed the few small fishes retained in the large mesh sized codend. Lehman et al. (1993) reported significant reduction of small shrimp in 60 mm mesh codend than codend with mesh size of 45 mm. Kunjipalu et al. (1993) found that the Bombay duck catch was consistently better in experimental bagnet with 30 mm and 40 mm codend meshes.

Swan (1989) stated that, the very large meshes (up to 25.6m) in trawls are seen to be effective in herring fish and very large catches may be taken when fishes are light in weight, i.e., buoyant with high oil content. Lhomme (1978) compared the results of shrimps catches of trawls of different mesh sizes in the body of the net and found that average size of shrimp caught in 80 mm size was greater than 60 mm size.

The larger size shrimp would be caught only if a much larger mesh size was adopted and the immediate effects would be loss, which could not be economically endured (Lindner, 1966). After an underwater observation of haddock trawling, Serebrove (1989) concluded that increasing mesh size cannot be an effective method of protecting young fish, since the hydrodynamic conditions of catch formation traumatize a considerable part of the fish of any size. Fujishi (1974) discussed the difficulties in developing a criterion for mesh size of gears engaged in multi species fishery. Hoidal et al. (1982) presented a model using “Von Bertalanffy and Beverlon and Holt equation” to estimate effective mesh sizes and suggested that this model can be used to estimate the stock.

Fridman (1986) defined the selection factor as the ratio of fish length to mesh lumen length at which 50% of the fish escape and 50% do not. Goni (1985) found out that, increase in mesh size has increased the selection factor in selectivity experiments for European hake and rose shrimp. The selection factors of 0.85 and 0.84 were estimated for the two species of sepiidae (Pereira, 1993). The selection factor for the 34 mm mesh codend for species of Cypris was in the range of 2.80 to 3.75 (Livadas, 1989).
Walsh et al. (1989) found that, selection factors were higher for American plaice (*Hippoglossoides platessoides*) in diamond meshed codend. The 50% retention lengths for *Penaeus semisulcatus* were 1.96 and 2.27 cm for 30mm and 40 mm codend of high opening bottom trawl respectively (Siddeek, 1986). Underwater observation conducted by Stewart and Robertson (1985a) showed that covered codend causes obstruction for fish escape. Vooren (1985) compared the selection factors and escapement with respect to different mesh sizes for three different species namely castanha (*Umbrina canosai*), Pescada (*Cynoscion strialus*) and Pescadinha (*Macroden anaylodon*) by means of regression analysis.

Polet and Redant (1994) noticed that the 90 mm mesh size codend is less selective for nephrops and whittings. Hickey et al. (1993a) found that 155 mm diamond mesh codend produces better selection for Atlantic cod (*Gadus morhua*). The simple way to improve size selectivity in existing trawl is to shorten the lace rope in the codend that catches fewer small fishes (Jacobson 1991). A codend of 135 mm meshes with lastrich ropes has selectivity comparable to a 150 mm conventional codend (Isaksen and Valdemarson, 1990). Armstrong et al. (1989) noticed that the length of the extension piece and codend diameter also influence codend selectivity. Matsushita Yoshiki et al. (1996) have suggested that the over-lapped meshes decrease the mesh area, resulting in the low efficiency of mesh selection. Campos et al. (2003) have reported that the effect of an increased results in codend 20 – 50% escapement through the mesh.

### 3.7.1.1. Influence of square mesh on size selectivity

Mesh shape also influences the gear design parameters in the same way as mesh sizes. Several scientists have worked on trawls with different mesh shapes and studied their influence on selectivity. Fish size selectivity is related not only to the mesh size of codend but also to the shape of the mesh as determined by rigging of the codend webbing (Robertson, 1982; Robertson and Stewart, 1988; Casey and Warnes, 1987). As the codend gets progressively filled up, the drag of the catch close up the diamond shaped meshes preventing under sized fish from wriggling through and jumping them in the mass of the catch. Further, it is found that even if small fish do escape, a large proportion are likely to die because of damage while passing through a mesh where as damage is minimum in square mesh codend. Further,
square mesh panels in the top of the trawl in the extension ahead of the codend do not close together when under load and have been found effective in allowing many undersized fish to swim, through them and escape (Sainsbury, 1996). Robertson (1983) compared fish escape rates of square mesh and diamond mesh codends and concluded that square mesh codends had higher escape rates of juveniles because of larger mesh opening and caused less damage to fish. Isaksen and Larsen (1988) found that square mesh codends gave improved selectivity for cod and haddock and considerable reduction of undersized fish.

Cooper and Hickey (1987) observed the reduction of haddock and cod by about 25% in square meshed codend while comparing with that of diamond meshed codend and observed higher value of 50% retention length (L₅₀) of the fish. Averill and Carr (1987) indicated that square mesh sections in trawl, not only improves the catch rates but also reduce the discard rates. Larsen et al. (1988) compared the proportion of undersized cod caught by 95mm square meshed codend with that of diamond-meshed codend. Diamond mesh seems to catch 48% more of undersized fish in terms of number and 10.4% by weight. Robertson (1986a) discussed the design and construction of square meshed codends. Robertson (1986b) in another experiment concluded the selection ranges of square meshed codend. Robertson and Stewart (1988) found that L₅₀ values for square mesh codends were larger than for diamond mesh codend of same mesh size for, whittings. Thorsteinsson (1989) noticed a drastic reduction of 0 group of fish and catch of undersized shrimps in square meshed netting. Suuronen (1990) compared the size selectivity of 36 mm square meshed codend with that of diamond meshed codend of same mesh size and concluded that square mesh codend will have a sharper selectivity and will retain fewer juveniles of herring (*Clupia harengus*).

Square mesh netting provides an adequate escape route for all undersized fishes before they are trapped in the codend (Sterling, 1991). Whittings have better escapement from the net with the square panel than from the conventional diamond net (Briggs, 1991 and Moth-Poulsen, 1994). The conventional codend retained all sizes of fish and 135 mm and 110 mm knotless square meshed codends had a tendency to free small fish of walleys Pollack *Theragra chalcogramma* (Matsushita et al. 1993). The mean selection lengths with respect to *Sarida tumbil* and
Dussumieria acuta were greater in 30 mm square meshed codend than in diamond-meshed codend (Kunjipalu et al., 1994). Amos (1984a) suggested that square mesh in throat would be useful in allowing small and unwanted fish to escape from the trawl. Hillis et al. (1991) inserted square mesh panels on the front part of the codend and observed a substantial reduction in both undersized and commercial sized whittings. Briggs (1992) observed in the Irish sea nephrops fishery that, the square meshed codend in nephrops trawl yielded very good escapement of whittings than the conventional diamond net and thus could be used as conservation tool in whiting fishery. Ulmestrand and Lareson (1991) tested with 70 mm square mesh window in the top panel of a Nephrops Trawl and noticed a significance difference in the size of whiting (Micromesistius poutassov). Robertson and Shanks (1994) observed a significant increase in the escape of juveniles of haddock and whiting in nephrops trawls with 80 mm square mesh window on top panel and 70 mm square meshed codend and extension. Kunjipalu and Varghese (1989) have suggested that square meshed codend in demersal trawls could be used as a tool for conservation and management of fishery resources.

Wray (1990b) concluded that, hexagonal meshes have better let-through characteristics of undersized fish than diamond meshes in the body of trawl. Suuronen et. al. (1991a) observed that the 50% retention length for the hexagonal mesh codend was considerably smaller for herring. Hameed and Boopendranath (2000) have reported that size selectivity in gear using netting for retention of the catch can be achieved by controlling mesh sizes and mesh shapes (square) optimized the target species or size group. Talwar and Hanumanthappa (2006) have shown that 50% of retention lengths of mackerel, pumfrets, soles and ribbon fishes were comparatively found better in HOBT with 28mm mesh size square meshed codend. They also reported that the average by-catch was about 5.5 times lesser in square meshed in the forward part of the trawl net than in the conventional trawl net.

3.7.2. Species selectivity:

Species selectivity in mobile gears such as trawl is achieved using separator panels or grid by making use of behavioral difference in species in the fishing area (Hameed and Boopendranath, 2000). Further they also stated that separation of species such as shrimps and fish is possible to some extent by reducing the length of
the trawl, adjusting the head rope height and controlling the towing speed, making use of principles of differences in the swimming speed and vertical distribution. Isaken et al. (1992) said that a new concept of separator panel, and grid installation was developed in Norway in order to have species selectivity by avoiding the by-catch of fish in a shrimp trawl. Design of trawl with separator panel terminating into two codends for dual purpose of fish conservation and effective separation of catch was discussed by Wray (1990a). He also reported that effective separation of fishes could be attained based on their behaviour, while the fish conservation could be effected by using large mesh in one of the codends or through escape catches. Main and Sangster (1982) noticed the separation of finfish from shellfish in trawl having a horizontal separator panel. William (1983) found that a successful separation of shrimpsprawns from red fish in Canadian separator trawl was possible by allowing the juveniles of red fish to escape. Chuck and Seidel (1984) found that the fish deflector has the ability to reduce the by-catch of jellyfish and finfish.

It has been reported that an effective separation of shrimps and whitings by using horizontal separating panel in trawl can be effective. Main and Sangster (1985) rigged the conventional fish or shrimp trawl with a horizontal separating panel dividing the codend into two compartments and were able to minimize the undersized Gadoid by-catch. Main and Sangster (1986) made underwater observations and indicated that the entry height of fishes into the trawl mouth differs from species to species and it is possible to have species separation by adjusting the height of separator panel. They also concluded that the smaller fishes could be released by keeping top codend open or providing it with large mesh. Friis and Yngvessen (1987) reported on the design and operation of a separation trawl used in Denmark. Hillis and Carrol (1988) and Hillis (1989) investigated vertical separation of whitings and Nephrops by two separator trawls, and found nephrops in a lower codend. Ashok and Sheshappa (1989) in their study on separator trawl experiment have observed total separation of crustaceans into the lower codend of trawl.

Moth-Poulsen (1994) has developed a trawl with separator panel with two compartments and found that upper compartment had gainful whitings. Among the horizontal separator panels, the square mesh panel and grid in trawls, the horizontal separation panel had less separation effect (Wileman and Main1994). Sujastani
(1984) reported that “By-catch Excluder Device” in shrimp trawls reduced the catch of unwanted fishes and can be helpful for conservation of fishery resources. Monintja and Sudjastani (1985) revealed that the implementation of BED on the standard commercial trawl shrimps had a by-catch reduction of 42.5%. Finfish (excluder) device installed in the codend of a shrimp trawl is reported to be very efficient in decreasing the by-catch of finfish (Anon, 1990). Olsen (1990) opined that the ‘shrimp grid’ developed at Norway is very effective in reducing by-catch. Valdemarsen (1990) could reduce juvenile by-catch of haddock in shrimp trawl by providing the codend with grid made of parallel bars. Wray (1990c) illustrated about the successful operation of Norwegian grid device “Troll X” which could release juveniles and undersized fish from trawl. Hickey et al. (1993a) have developed a shrimp trawl rigged with excluder device with different Nardmore Grates having 22 mm, 25 mm and 28 mm bar spacing and 43 mm square meshed codend and by-catch reduction of 60-90% depending on species. Marlen et al. (1994) made observation of large pelagic trawls through ‘RCTV’, and found that codend cover can have significant effect on the escapement behaviour of fish. Rulifson et al. (1992) showed the effectiveness of by-catch reduction devices (BRDS) in South Atlantic Coastal waters when compared to the unmodified nets. Matsuoka et al. (1991) carried out a series of experimental shrimps trawling tests with a simple Trawl Efficiency Devices (TED) and observed slight reduction in the catch of shrimps. Brewer et al. (1995) tested a trawl with by-catch reduction device called “Fish-Eye” and a square mesh window and observed higher shrimps yield with a reduced by-catch.

3.7.3. Catching efficiency

Catching efficiency of the gear is influenced by its design, mesh size, and mesh shape and other operational techniques. However, mesh size and mesh shape can be chosen so as to bring about a compromise between the conservation measures and catching efficiency.

3.7.3.1. Influence of mesh size and mesh shape

Large meshes in gear have a good guiding effect, but when fishing close to bottom, big meshes do not appear to have the same guiding effect (Anon., 1980). Lan (1989) reported from his experiment conducted in east China that, large meshed trawl had a higher mouth opening and higher catch than the conventional trawl.
Pinhorn (1970) has opined that, even though there will be immediate losses in the use of large mesh size, it will lead to potential benefit in the subsequent years. Lower average catch was obtained in large mesh size during a comparative experiment (Claesson, 1986). Nilssen and Larsen (1986b) compared catching efficiency of 20 mm codend mesh with and without fine meshed cover for lobster fishing. The net with fine meshed cover retained about 27 times more catch of lobster than the other one. Naidu et al. (1987) have reported the effect of the variation in the mesh size on the catching efficiency of trawl. Chen et al. (1987) compared the percentage retention of shrimps in different mesh sized codends by covered codend experiment. Fujishi (1985) also reported increased catch rate from a six-panel high opening bottom trawl with large meshes in the frontal body.

Larger meshes in the front part influence fishing efficiency, species selection and length of fish (Ji 1986). Chow et al. (1988) worked on optimizing mesh size for harvesting dominant species of demersal fish in the Taiwan strait. Andrew and Butter worth (1988) examined the effect of changes in mesh size of trawl on catchability co-efficient and sustainable yield of Southern African hake stock. Kondratyuk et al. (1988) have studied on the optimal mesh size of the trawl codend for direct beaked red fishery. Kunjipalu et al. (1989) have discussed the suitability of large mesh trawl for efficient harvesting of demersal fish resources in North West coast of India. Siddeek (1989) has stated that, the new fish-cum-shrimp trawl with large mesh size performed better by bringing a slightly larger amount of shrimp and a greater quantity of fish. Vijayan et al. (1990) observed 31.5% higher catch of shrimp and 37% more revenue using the improved gear in traditional motorized craft. Suuronen et al. (1991) observed that, in pelagic herring trawling, large numbers of juvenile herring were caught with 32 mm diamond meshed codend. Nayak (1991) investigated the effect of large meshes in the body of the newly developed four seam bottom trawl (NLMT) and found that, the average catch was about 37% higher in NLMT than that of HOBT. Vijayan et al. (1992) have got 29.6% increased fish catch in rectangular trawl with larger meshes in forward parts. Talwar (1997) reported that trawl gear with square mesh panels in the front and codend parts of the trawl gear had higher percentage of the commercially valuable fishes than conventional trawl. HOBT with square meshed codend invariably caught less number of under sized fish when compared to the diamond-meshed codend.
Lehmann et al. (1993) compared the catch results in 60 mm and 45 mm mesh sized codends and found that, 60 mm size codend yielded 40-50% reduction of small shrimp and 15-30% reduction of large shrimps. Lowery et al. (1994) found that, the catch of cod was reduced by approximately 40% in 120 mm mesh sized codend and total catch value was reduced by approximately 35%, when compared to the reference net having 105 mm in the codend.

Moth-Poulsen (1994) in his study on the selectivity of whiting trawl observed the whiting gaining access to upper codend while the cod in the bottom codend. An average separation of 50% of the whiting in the top codend was accompanied by only 19% of the haddock and the catch of number of unmarketable fish as a means of decreasing by-catch was reduced from 53.4% to 16.7% without reducing the catch of the main target species and small shrimps in Seto Sea of Japan (Tokai et al. 1994). Fonteyne and Rabet (1992) suggested that, application of square mesh might reduce the catch of small round fish. Broadhurst and Kennely (1996) reported while comparing the catch of the gear with conventional codend that, the catch of the trawl with codend made entirely of square meshes has shown a 52% reduction in the mean weight of shrimps prawns caught and 95% reduction in the number.