A Review of Trawl Selectivity Studies carried out along Indian Coast

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A Review of Trawl Selectivity Studies carried out along Indian Coast

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Abstract

Though trawling contributes significantly to landings in India, issues like bycatch which comprises of juveniles of commercially important species and impacts to the sea bottom are often implicated. There has been a significant increase in the capacity, both in terms of number and in terms of the size of trawlers during the last decade in India. Technical measures like closed season and gear modification are proposed in the Marine Fisheries Regulation Acts of different states. A large number of Bycatch Reduction Devices (BRDs) have been field tested along the Indian waters which have proven to be effective for exclusion of juveniles. Among the different BRDs, square mesh codends are the most popular, due to its conceptual simplicity and ease of modifications of the existing codends. A large number of studies related to the selection parameters for trawlnets of different mesh sizes, are reported from India. This study attempts to review the results of these studies with respect to methods used for deriving the selection parameters. It is observed that variation exists in the methodology adopted for deriving selection parameters among the reports. None of the studies have analyzed the operational factors that affect selectivity of the gear and similarly the survival of the escapees from the BRDs is not quantified. Though preliminary in nature, the selectivity estimates available now are good enough for coming out with proposals regarding the optimum mesh required for individual species. Inclusion of factors affecting selection into the studies, biological parameters of the targeted species and modeling approaches will help in refining the results already available and a development and adoption of a standard protocol for trawl selectivity studies will help significantly.

Keywords: Trawling, selectivity, square mesh, bycatch, cover codend, L_{50}

Introduction

India has a coastline of 8118 km and endowed with 2.02 million sq. km of Exclusive Economic Zone (EEZ) of which 0.5 million sq. kms is continental shelf. It has a catchable annual fisheries potential yield of 4.4 million tonnes, occupying third rank in world marine fish production (Anon, 2011). Marine fish production of India which was only 0.5 million tonnes in 1950, increased to 3.63 million tonnes in 2016 (CMFRI, 2017), due to rapid mechanization and developments in synthetic gear materials from late 1950s. The increasing export demand for shrimps gave a significant boost to mechanised fishing, particularly trawling. The uncontrolled increase in the capacity, in terms of number, size and the power of engines of fishing crafts have affected the sustainability of resources. The marine fisheries production started to stagnate from the late 90's, and the resultant changes that have occurred in the state of fisheries have become evident (Vivekanandan et al., 2005; Bhathal & Pauly, 2008).

Indian trawl fisheries

India has 71960 mechanized vessels operating from different landing centers. The total number of trawlers operating in India are 35228 of which 71.2% operate in the west coast and the rest along the east coast. The numbers of trawlers have increased by 20.5% during the last decade. Annual average fish landing from trawlers was 2.07 million tonnes which is more than 57% of the marine fisheries production of India. Out of the total landings, 64% of the catch was from the west coast and remaining from the east coast of India (CMFRI, 2017). There has been a steady increase in the vessel size and the installed

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engine capacity. Edwin et al. (2014) have given a detailed account of the history and changes in the trawling sector over the years. Renju et al. (2014) had described the structural changes in the marine mechanized trawling sector of India. The trend of decreasing profits of trawlers over the years was reported by Aswathy et al. (2011).

Though trawlnets are very efficient for the capture of shrimps, the targeted catch formed only 25-30% and the rest of the catch is either discarded or brought to the shore which forms the input for the fishmeal industry (Boopendranath et al., 2010; Dineshbabu et al., 2013). The discarded and the incidental catches consists of juveniles of commercially important fishes and other bottom biota (Boopendranath et al., 2008; Gibinkumar et al., 2012; Dineshbabu et al., 2013; Madhu et al., 2015).

Though a number of technical measures with regard to fishing gear, and spatial and temporal restrictions are proposed and mandated for reducing the negative impacts of trawling, the adoption of these technologies by the fishermen are often limited. Compliance to CCRF of FAO and legal instruments are poor and also Monitoring Control and Surveillance (MCS) measures by Indian maritime states indicates poor observance (Anon, 2003; Varkey et al., 2006; Pitcher et al., 2009). Reduction in bycatch is often a big problem, due to the scientific, socio-cultural and socio-economic components involved (Komoroske & Lewison, 2015)

Issue of bycatch in trawl fisheries

Generation of bycatch, which affects the ecosystem either directly or indirectly at different trophic levels, is a serious issue in commercial fishing around the world (Andrew & Pepperell, 1992; Goñi, 1998; Pauly et al., 1998; Hall, 2000; Pauly et al., 2002; Worm et al., 2006; Komoroske & Lewiser, 2015; McCauley et al., 2015). Kelleher (2005) using the premise that discards are a function of the fishery of a region and using a large geographical coverage, had arrived at an average global figure of 7.3 million tonnes of discards, which was approximately 8% of the total landed catch. Davies et al. (2009) estimated the quantity of discards at 38.5 million tonnes. The reports on the decline in the discard quantity as a result of increased utilization of the non-targeted component by Kelleher (2005), was countered by an equally disturbing finding that the world catches are also decreasing proportionately (Zeller & Pauly, 2005). Seines, followed by midwater and bottom trawls were responsible for the major catches in the world Watson et al. (2006). Trawl nets due to their low selectivity and high efficiency are often implicated with generation of large quantities of bycatch (Kennelly, 1995; Hill & Wassenberg, 2000; Ye et al., 2000; Gamito & Cabral, 2003; Heales et al., 2007; Boopendranath et al. 2008). The estimates by Kelleher (2005) quantified the discards generated by shrimp trawling as 18.6 million tonnes, accounting for 27.3% of the total estimated discards. Midwater trawl fisheries targeting small pelagics are reported to have the least discards among the different trawling systems. The bycatch generated by multigear and multispecies fisheries that deploy many gears during the same trip is often difficult to assess. These fisheries are often without a target species, and all species are targets and are typical of the tropical countries including India.

The first study on the fisheries bycatch along Indian waters by George et al. (1981) reported that bycatch formed about 55% of the total trawl landings along two harbours in Kerala. Sukumaran et al. (1982) had reported that shrimps contribute only 13% of average annual trawl catches from Malpe and Mangalore during 1980-82 and the trawl bycatch was as high as 85% during this period. The total bycatch generated along the east coast of India by shrimp fisheries was reported by Gordon (1991) to vary between 99–130 thousand tonnes annually. Rao (1988), reported total bycatch generated by shrimp trawlers along Vishakhapatnam coast as 40410 t, of which 32420 t was discarded and the rest landed. Sujatha (1995) had characterized the bycatch constituents of shrimp trawlers off Vishakhapatnam. Pravin & Manohardoss, (1996), reported constituents of low value bycatch generated by commercial trawlers operating from Veraval coast. Pillai (1998) reported that Gujarat coast generated the highest bycatch of 40% mostly comprising of juveniles. Dixitulu (2003) and Prabhu (2013), described bycatch of shrimp trawlers along the upper east coast of India. The constituents of the trawl bycatch along the south east coast was studied by Jagadis et al. (2003). The quantity of bycatch off Kerala coast was estimated at 262000 t during 2000-2001 and 225000 t during 2001-2002 (Kurup et al., 2003; 2004). Kelleher (2004) had estimated total bycatch discards in Indian fisheries at 58000 t, which formed about 2% of the total landings. Constituents of the bycatch generated along Veraval coast Gujarat was reported by Zynudheen et al. (2004). Zacharia et al. (2005), studied the quantitative and qualitative assessment of bycatch and discards generated by trawlers along Mangalore coast during 2001–2002. Bhathal (2005) in her historical reconstruction of Indian marine fisheries catches (1950-2000) observed that discards from Indian fisheries had a heavy impact on the marine trophic structure. Kumar & Deepthi, (2006) reviewed the bycatch problem in the Indian context and different steps available for bycatch mitigation. The juveniles generated by different gear-craft combinations and the amount of loss due to catch of juveniles in the fishery along Kerala coast were estimated by Najmudeen & Sathiadhas, (2008). The bycatch produced by shrimp trawling along central Kerala coast was reported by Boopendranath et al. (2008). The bycatch issues of central Kerala were described by Gibinkumar et al. (2008). Mohamed et al. (2009) have shown that the percentage of juveniles exploited by trawl ranges from 20 to 60% in case of seer fishes and groupers and as 12% in case of squids. Based on interviews, reports and direct field observations, during 2008-09, Pramod (2010) estimated the bycatch discards from mechanised trawlers operating in Indian EEZ at 1.2 million tonnes. The same study estimated 56.3% of the total catch of shrimp trawlers as bycatch. Recent estimate by Dineshbabu et al. (2013), showed that landing of low value bycatch (LVB) in trawl fisheries, increased from 14% in 2008 to 25% in 2011, which is reflected as reduction in discard volume by trawlers.

Studies on selectivity

Estimates of the selectivity of fishing gears used in a fishery is important, since this is one of the many management options available for sustaining or improving the state of resources. Accurate estimates of the selectivity of gears will help in yield- per-recruit analysis, optimizing the ideal mesh size in a multi-species fishery, estimation of length frequencies of the stock, suggesting catch quotas and stipulating minimum landing size for a fishery and assessing the effect of mesh sizes on the yield (Bennett, 1984; Broadhurst et al., 2006; Gray et al., 2005; Kuikka et al., 1996; Millar & Fryer, 1999). Changes in the mesh size is the most commonly used management tool (Millar & Fryer, 1999), due to conceptual simplicity and ease of modifying the existing gear system (Ragonese & Bianchini, 2006). A large number of studies have shown improvements in selectivity by using larger meshes or square meshes in the codend (Varghese et al., 1988; Casey et al., 1992; Fonteyne & M'Rabet, 1992; Ju-Hee Lee et al., 1994; Lowry et al., 1995; Stergiou et al., 1997; Tokaç et al., 1998; Graham & Kynoch, 2001; Campos et al., 2002; 2003; Broadhurst et al., 2004; Bahamon et al., 2006; Guijjarro & Massuti, 2006; Bullough et al., 2007; He, 2007; Raghu Prakash et al., 2008; Sala et al., 2008; Tosunoglu et al., 2009; Broadhurst et al., 2010; Sala et al., 2015). Insertion of escape panels (windows) made of larger meshes or square meshes in the codend and mounting grids or combination of both, is another strategy that improves both size and species selection in trawls (Isaksen et al., 1992; Rogers et al., 1997; Brewer et al., 1998; Madsen et al., 1999; García-Caudillo et al., 2000; Salini et al., 2000; Graham & Kynoch, 2001; Broadhurst et al., 2002; Eigaard & Holst, 2004; Graham et al., 2004; Fonseca et al., 2005a; Fonseca et al., 2005b; Madsen & Stæhr, 2005; Brewer et al., 2006; Courtney et al., 2006; Criales- Hernandez et al., 2006; O'Neill et al., 2006; Bahamon et al., 2007; Eayrs et al., 2007; Revill et al., 2007; Boopendranath et al., 2008; Heales et al., 2008; Krag et al., 2008; Valentinsson & Ulmestrand, 2008; Frandsen et al., 2009; Briggs, 2010; Madsen et al., 2010; Brèiæ et al., 2016). Alternate methods to achieve balanced harvesting in sigmoid shaped selection processes, was discussed and demonstrated by Stepputtis et al. (2016).

Factors affecting selection process in trawls

Use of small mesh sizes and operating in the near shore areas, is reported to be the main reason for the disproportionately high quantities of bycatch in shimp trawls world over (Andrew & Pepperell, 1992; Kelleher, 2005). The other factors that affect the codend selectivity of trawls are the size of the mesh openings of the codend and the probability that the fishes come across these openings (MacLennan, 1992; Wileman et al., 1996). Selection parameters of the trawl codend are also affected by the twine diameter (Sala et al., 2007), material used for fabrication of the codend (Tokaç et al., 2004), speed of the tow (Dahm et al., 2002), seasonal changes (Özbilgin & Wardle, 2002), codend circumference (Broadhurst & Kennelly, 1996; Broadhurst & Millar, 2009; Graham et al., 2009; Reeves et al., 1992), codend catch weight (Erickson et al., 1996; Madsen et al., 1999) and shape of the mesh opening (Broadhurst & Kennelly, 1996; He, 2007; Tosunoglu et al., 2009). Since codend is the portion of the net where the fishes aggregate and try to escape, changes made to this part of the net, will offer better escape opportunity for juveniles and non-target species and thereby improving the selectivity of the trawl net (Reeves et al., 1992; Robertson & Stewart, 1988; Macbeth et al., 2005b; Bellarmine et al., 2009). Square meshes are found to maintain their shapes during towing and are hence found to be more selective than diamond mesh codend with same or even larger meshsizes (Robertson & Stewart, 1988; Walsh et al., 1992; Casey et al., 1992; Kennelly, 1994; Halliday et al., 1999; Halliday & Cooper, 2000; Broadhurst et al., 2004; Macbeth et al., 2005a; Bahamon et al., 2006; Guijjarro & Massuti, 2006; He, 2007; Macbeth et al., 2007; Sala et al., 2008; Tosunoglu et al., 2009; Sala et al., 2015) . However, few works have reported that the selectivity of square-mesh codends for dorso-ventrally flattened fishes to be poor (Fonteyne & M'Rabet, 1992; Perez-Comas et al., 1998; Sala et al., 2008).

Gear based technical measures use the inherent capabilities of the interventions like having larger and sustained mesh opening during towing as seen in the case of square mesh codends or by exploiting the behaviour pattern of the target and non-target species for separation of the catches (Thorsteinsson, 1992; Broadhurst et al., 2000; Boopendranath et al., 2008; Winger et al., 2010; Madhu et al., 2015; Sistiaga et al., 2016). Though, theoretically it would be possible to make a 100% selective gear, it would mean that a large portion of the targeted catch will escape, which will result in loss of revenue and hence will not be adopted by the fishers (Broadhurst et al., 2007). Therefore, the mesh size and shape used in a fishery is often a trade-off between maximizing profits and conservation targets.

Selectivity experiments

A selectivity experiment is called direct, when the length frequencies of the population is known and when fishing is done with a particular gear in this known population (Millar & Fryer, 1999). However, estimating the population length frequency is impossible and hence all studies are indirect, involving repeated fishing in the area with different variants of the gear (mesh and shape variants) to know the population structure and the study retention characteristics (Casey et al., 1992; Zaucha et al., 1995; Perez-Comas & Skalski, 1996; Moderhak, 1997). There are different methods for estimating the population that had entered the net and detailed reviews are available (Pope et al., 1975; Wileman et al., 1996; Boopendranath & Pravin, 2005). Trouser trawls having two codends in one trawlnet, one with the experimental mesh size and the other with small meshes to estimate of the population available to the gear is used (Millar & Walsh, 1992; Walsh et al., 1992; Mous et al., 2002). The twin trawl method uses two trawl nets, in a single vessel, in which one of trawlnet carries the experimental codend and the other a small meshed codend used to estimate available population (Cotter et al., 1997; Deval et al., 2006). However, the assumption of equal split of fish between these codends is often not followed and above method depends on assuming equal splits, which have sometimes shown to affect the parameters estimates (Sistiaga et al., 2009). The most used and reliable method is the covered codend method which has a small mesh cover around the experimental codend which retains all fish that escapes the codend and thus represents the population encountered by the gear (Herrmann et al., 2007; Madsen, 2007). However the cover can affect the behaviour of the fishes by masking the mesh opening which influences selectivity (Pope et al., 1975; Madsen & Holst, 2002). Besides, different methods like the use of long and wider covers, hoops and kites attached to the cover, are found to reduce masking (Main & Sangster, 1985; Stewart & Robertson, 1985; Robertson & Leaver, 1989; Robertson et al., 1995; Wileman et al., 1996; Madsen et al., 2001). Among the methods, covered-codend method was found to give results that are well defined and more stable than the other methods. Madsen et al. (2002), observe that this could due to codend and cover stabilization during the fishing operations and also because the total population estimates using covered codend method is more precise.

Size selection quantifies the relative capture probability of a size class of fish, usually represented in terms of length of the fish, since length is the easiest measurable quantity that is related to gape or girth of fish (Wileman et al., 1996; Millar & Fryer, 1999). The logistic curve which represents the probability of retention of a length class of fish in the codend, is commonly used to describe the selection curves for towed gears and found to fit the selection curves in most of the cases (Wileman et al., 1996). The selectivity parameters are derived from the intercept and the slope values of the fitted model. The detailed review of the methods used is given in Boopendranath & Pravin, (2005). The SELECT (Select Each LEngth's Catch Total) method is now acknowledged as the standard for estimating the selectivity parameters for both towed and other static gears (Millar, 1992; Millar & Holst, 1997;

Millar & Fryer, 1999). This method does not require the quantification of the length frequency of the population and is dependent on the proportion of catch of a particular length class retained by the experimental gear. The expected value of a particular length class in different hauls can be modeled and by maximizing the log-likelihood, the selectivity parameters can be derived (Millar & Walsh, 1992; Wileman et al., 1996; Millar & Fryer, 1999; Millar et al., 2004). In case of covered codend method, the SELECT methodology corresponds to a standard binomial regression and the parameter estimates for the regression can be derived using generalized linear modeling (Millar & Fryer, 1999).

Selection curve

"Size selection encapsulates all the processes that cause the probability of capture to vary with fish size" (Millar & Fryer, 1999). The selection process can be partitioned into three definitions based on the population from which the fishes are being selected. Millar & Fryer (1999), describe these as

1. Population-selection curve: This is the relative probability of capture of a fish of a particular length from the entire population.
2. Available-selection curve: is the relative probability of capture of total fish of a given length that was available to the gear.
3. Contact-selection curve: is the relative capture probability of capture of a given length of fish that encounters the gear. This curve is often defined as the selection curve, since it is this curve that quantifies the difference in length distribution between the fish populations that comes into contact with the gear.

There are a set of assumptions made for estimating the contact selection curve and the factors that affect the selection curve can be modeled. The general model for analyzing data for all comparative selection studies is by Millar & Fryer, (1999). In case of covered codend method, two gear variants have to be considered, one is the codend and the other is the cover. The relative fishing intensity of the codend is the total catch entering the codend and simultaneously the fishing intensity of the cover will be the value minus the retention probability of the codend. However, the retention probability of the cover also needs to be taken into account. The general model can take into account the different variants of the gears and model accordingly, but it is necessary to make assumptions regarding the population length frequency, selection properties of the codend and cover, fishing intensity, and then fit the model and select the best fit by comparing the residual plot and goodness-of-fit statistics (Millar & Fryer, 1999).

The maximum likelihood method is used for all the parameter estimation since the approximate unbiasedness and the variance of the parameter estimates can also be worked out (Cadigan & Millar, 1992). However due to the over parameterization it may not always be possible to find values for the parameters. However, by specifying the population length distribution and by using different classes of models, the parameters of the selection curve can be estimated (Wileman et al., 1996; Millar & Fryer, 1999).

Between haul variability

Usually selectivity estimates of trawls are derived from multiple tows and considerable between-haul variations in the size selectivity for different species are reported (Fryer, 1991; Reeves et al., 1992; Millar et al., 2004). The reason for the variation in the selectivity are due to factors like the towing speed, towing direction, water depth, and the spatial structure of the population coming into contact with the net vary with hauls (Fryer, 1991; Millar & Fryer, 1999). This between haul variability should be taken into consideration for valid conclusion regarding the selectivity estimates (Millar et al., 2004). There are different approaches to deal and estimate the between haul variability in the towed gear experiments. Combined haul analysis is one method, which assumes that all the data for a particular gear has come from a single haul and the mean selection curve is used to provide the expected catch for individual hauls. Replication estimation of Dispersion (REP) and bootstrapping methods are carried out to infer the between-haul variation (Millar, 1993; Millar & Fryer, 1999). Fixed and random effects model by Fryer (1991), model the between-haul variation by analysis of individual haul data. This model estimates a mean selection curve by allowing the selection curve of the individual hauls to vary randomly about it. This model gives more realistic variance estimates by incorporating random and fixed effects (Wileman et al., 1996; Millar & Fryer, 1999; Madsen, 2007). The fixed effects can be the codend mesh size, colour of the codend twine, thickness of the twine, codend extension length, vessel type etc. that are controllable technical parameters and some of the random factors that affect selectivity include the codend catch weight, sea conditions etc. (Wileman et al., 1996; Madsen et al., 1998).

Gear based technical measures in India

Since the last two decades, the major challenge in fishing technology has shifted from increasing the production of the target species (with least concern for bycatch) to improving the selectivity, both in terms of species and their sizes (Valdemarsen & Suuronen, 2003). There is a large body of literature that deals with improving the size and species selectivity of the fishing gears and among these improving the selectivity of towed gears, which are found to be the least selective have received the most attention in India (Boopendranth & Pravin, 2005).

The most important technical measure in the trawling sector in India includes the trawling ban imposed by the Governments of all the maritime states of India. The ban on using motorized and mechanized fishing vessels for 61 days of ban, is scrupulously followed along the maritime states (Anon, 2014). Gujarat, Maharashtra and Kerala have made square mesh codends mandatory in the codends of trawls. The legal mesh size for codends in the states of Gujarat and Maharashtra is 40 mm square mesh (Anon, 2003). In Kerala, a comprehensive set of regulations with regard to control of vessel size, engine power and legal mesh sizes to be used in different gears in the traditional and mechanized sector was promulgated (Anon, 2017a). Bull trawling and light assisted fishing is also now banned along the Indian coast (Anon, 2017b). Minimum legal sizes for 58 species were recommended for Kerala in 2014 (Mohamed et al., 2014). Aswathy et al. (2011) worked out the economics of mechanized fishing vessels with respect to the trawling ban along Kerala coast.

Studies carried out on trawl gear selectivity in India

The first report in India on selection properties of codend was by Panicker & Sivan (1965), who had studied the effect of seven different codends varying in mesh sizes from 1 inch to 2.5 inches on shrimp and fishes. Covered codend method using trouser trawls were used to derive the split between the different codends. Though selection factor for the different codends were derived, the method is not mentioned in the report. Sathyanarayana, (1965) has studied the size groups of prawns landed by four shrimp trawls having different different mesh sizes. Kunjipalu et al. (1991) reported that larger mesh size (40 mm) in the codend of Dol net (Bag net) had an adverse effect on the catch of secondary species like non-penaeid prawns and total catch. Kunjipalu et al. (1996) have studied the impact of using squaremesh codends of 20 mm in place of conventional codends of the same mesh size. The selection curves of six species, including two shrimps were deduced and the L_{25}, L_{50} and L_{75} values and selection factor was derived in this study. Kunjipalu et al. (1998) have reported the escapement pattern from 20 mm and 30 mm square and diamond mesh codends using cover codend method using a trouser trawl. The percentage escapement of two species of prawn, two cephalopods and three species of fish were reported in the study. Varghese et al. (1998) had studied the impact of square mesh and diamond mesh codends of three mesh sizes (20, 30 and 40 mm) on the conservation of resources using cover codend method. The mean selection lengths, range and selection factors with respect of three species were determined in the study. Pillai et al. (1996) have showed that 50 mm square mesh codend released more juveniles than 40 mm mesh size for six species studied. Trouser trawls were used in the above study, but parameters of the curve, were not estimated. The studies that have derived the selectivity estimates based on least square regression fit, are by Varghese et al., 1996; Prakash et al., 2008; Prakash et al., 2010; Pravin et al., 2010; Rajeswari et al., 2010; Remesan et al., 2010; Boopendranath et al., 2012; Edwin et al., 2013 and Rajeswari et al., 2013.

Thomas et al. (2008) have used SELECT methodology for estimating the parameters of stakenet codends for *Metapeneaus dobsoni* along Cochin waters. Prakash et al. (2013) have also used the SELECT methodology and have reported standard errors for the parameter estimates. The studies by Madhu et al., 2010; 2011; 2013; 2016 have used Replication Estimation of Dispersion (REP) (Millar et al., 2004), for taking into account the variation in the selection parameters due to multiple hauls. A detailed list of the different studies related to square mesh codends and their selection parameters for different species are given in Table 1.

There are a few studies that have derived the length-frequencies of different species in the codend and the cover, without modeling the selection curve (Pillai et al., 1996; Boopendranath et al., 2013; Hanumanthappa et al., 2013). The results of experiments including the length frequencies of commercial species, using Bycatch Reduction Devices (BRDs) other than square mesh codends, like CIFT-Turtle Excluder Device (CIFT-TED), Juvenile Fish Excluder cum Shrimp Sorting Device (JFE-SSD), Sieve net BRD, Big eye BRD etc. along Indian coast are also reported (Kumar & Deepthi, 2006; Boopendranath et al., 2008; Boopendranath et al., 2013; Prakash et al., 2016). Commercial trials using square mesh codends are reported from Gujarat (Mohamed et al., 2010) and Maharashtra (Madhu et al., 2017). Boopendranath et al. (2008) have reported the results of the trials using different BRDs along Kerala coast.

Most of the works on trawl selectivity in India have reported the parameters for species that belong to the "round" category and the square meshes are found to be very effective for this shape (Table 1). There are reports that square mesh codends are not very selective in case of flat-bodied fishes (Sala et al. 2008). Kunjipalu et al. (1996), have report the selection parameters of flat fish (*Cynoglossus* sp.) and this is the only study in the "flat" fish category from the Indian waters.

The review shows that there are a large number of studies on trawl selectivity in India, but the method adopted for deriving the selection parameters is not consistent throughout. Many of these studies have derived the parameters based on the least square method and visual fitting and do not use any recognized models for optimization. This is often a drawback, since it affects the derivation of the best mesh size for use in codends (Millar & Fryer, 1999).

A large numbers of operational factors like the speed of the vessel, the codend catch, twine thickness, circumference of the codend etc. which is described earlier in this text, affect the selection properties of trawlnet. Studies on the variation in selection properties due to influence of different operational variables, is not reported from the Indian waters.

The optimum mesh size recommended for different species in studies ranged from 40 to 150 mm. A wafer plot of the optimum mesh size against L_{50} values and selection factor (SF) is shown in Fig. 1. The graph highlights the optimum mesh size estimates in case of all the studies carried out from which the selection factor of the codends are available. This graph also highlights the requirement of mesh sizes to be between 40-60 mm for the diamond and square mesh codends. The relation between the L50 values and the optimum mesh size for all the species is shown in Fig. 2. The optimum mesh size required for particular length of a fish is always smaller in case of square mesh than the diamond mesh codends.

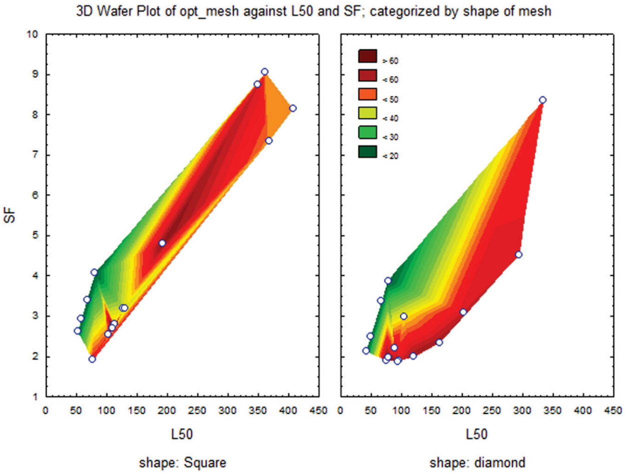

Fig. 1. 3D wafer plot of optimum mesh size derived from different reports against L50 and selection factors; categorized by shape of mesh (The actual data points are overlaid on the graph)

Two studies carried out along Gujarat and Maharashtra, have worked out the economics of using square mesh codends along the Indian coast. Mohammed et al. (2009a), based on their studies onboard commercial vessels along Gujarat, showed that the loss in terms of value of escaped catch was only 1.3% with a concurrent increase in the unit value of catch, by replacing traditional codends with 40 mm square mesh. Madhu et al. (2017) have reported the rate of escapement of juveniles from 30 mm square mesh codend as 0.76 kg h^{-1}, which was 3.9% of the total catch retained in the codend and valued in monetary terms at INR 29. Though the value was negligible in the studies, the value if the escapees are allowed to grow to optimum length would be much higher (Mohamed et al., 2009b).

Future areas of research in trawl selectivity in India

Benefits of using modified gear in the fisheries stock by using biological parameters, is worked for many species in different countries and the results show

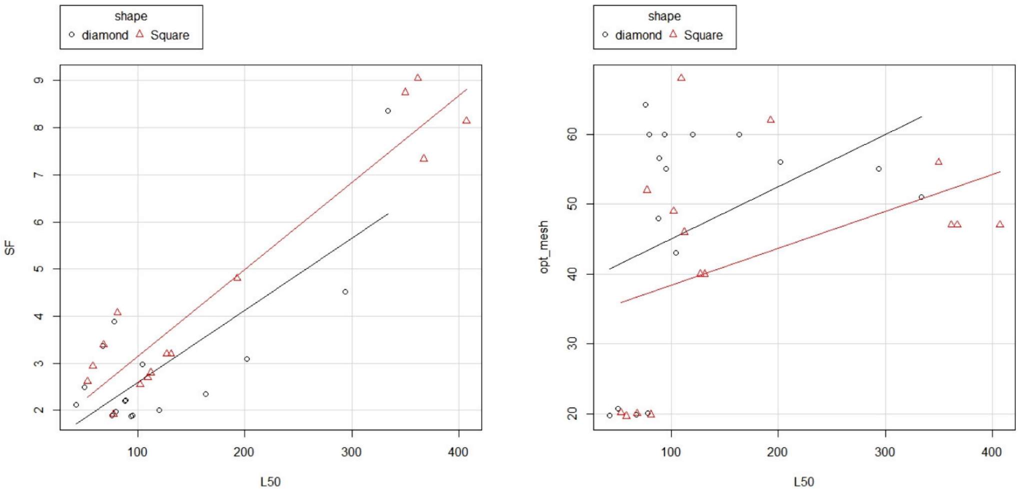

Fig. 2. The relationship between L50 and selection factor (SF) and Optimum mesh (opt_mesh) for the square and diamond mesh codends

the potential benefits of using square mesh and other BRDs in the long run, often after a brief decline in the catches (Bahamon et al., 2007a; Bahamon et al., 2007a; Gorelli et al., 2017). Works, which take into account the biological parameters in addition to the gear selectivity parameters for determining long-term benefits, are lacking in the Indian scenario. Methods that take into account the biological parameters for deriving the virtual population of the fishery by using square mesh codends are required for convincing benefits of the adoption of square mesh codends, both, for fishers and policy makers for better adoption of technology.

Though there are a large number of studies on selectivity estimates, a standard methodology needs to be developed taking into account the highly varied condition (Edwin et al., 2014), existing in the Indian trawl fisheries. This protocol should include all the components from design of experiments, data collection, standard models for deriving the selectivity estimates and regular updating based on recent techniques developed elsewhere. Studies based on the morphology of fishes and its penetration properties for evaluating the selection process by modeling can provide insights into the complex selection process happening in the trawl gear (Krag et al., 2011; Bayse et al., 2016)

Girth measurements are very important in selectivity studies and length is often taken as the proxy for girth (Matsushita & Rosidi, 1997). Works describing the length-girth measurements for trawl resources are rare in the Indian scenario. The traditional selectivity results when compared with the results from length-girth measurements of fish would further help to optimize mesh size in multispecies fisheries like in India.

Escapement of fishes are also known to take place through forward net panels and underneath the ground rope (Bennett, 1984; Godo & Walsh, 1992) indicating the importance of studies on whole trawl selection. Only one study by Bellarmine et al. (2009) describes whole trawl selectivity in Indian scenario. Works using wide-ranging designs of trawls for different species needs to be carried out for improving selection in trawls, which will help in designing better resource and size specific trawls.

In order for the gear based technical measures to be effective, the mortality of escapees from these devices, should be very low and quantifiable, and this will also help in stock assessment studies (Suuronen, 2005). Only one study by Jayasankar, (2006), reports survival of trawl caught resources along India coast. Detailed studies using equipment for survival studies and underwater monitoring can give important insights into escape mechanisms and mortality occurring during and after the process of escapement (Davis, 2009). In line with survival studies, development of gear designs, which can prevent the entry of non-targets into the gear, will help significantly towards the problem of escape mortality.

It is debated that introduction of highly selective gears may undermine the very objectives of sustainable fishing or stock sustenance (Cushing, 1984;

Table 1: Estimates of trawl selectivity based on studies carried out along Indian coast

Sl. No.	Species	Mesh type	Mesh size (mm)	L25 (SE) mm	L50 (SE) mm	L75 (SE) mm	Selection factor	Opt. mesh size	Reference
1	*Johnius* sp.	Diamond	30	76.3	99.2	121.5			Kunjipalu et al.(1994)
2	*Johnius* sp.	Square	30	82.6	97.5	115.3			Kunjipalu et al.(1994)
3	*Leognathus* sp.	Diamond	30	56.7	66.6	80			Kunjipalu et al.(1994)
4	*Leognathus* sp.	Square	30	53.9	64.1	77.8			Kunjipalu et al.(1994)
5	*Nemipterus japonicus*	Diamond	30	84.8	103.6	123.3			Kunjipalu et al.(1994)
6	*Nemipterus japonicus*	Square	30	84.3	100.6	117.6			Kunjipalu et al.(1994)
7	*Saurida tumbil*	Diamond	30	110	124.3	140			Kunjipalu et al.(1994)
8	*Saurida tumbil*	Square	30	114.8	131.5	150			Kunjipalu et al.(1994)
9	*Thryssa purava*	Diamond	30	102.8	113	128			Kunjipalu et al.(1994)
10	*Thryssa purava*	Square	30	96.7	106.9	118.9			Kunjipalu et al.(1994)
11	*Dussumieria acuta*	Diamond	20	63	78	94	3.88	20.1	Varghese et al. (1996)
12	*Dussumieria acuta*	Square	20	67	81	96	4.07	19.9	Varghese et al. (1996)
13	*Metapenaeus dobsoni*	Diamond	20	34	50	66	2.49	20.8	Varghese et al. (1996)
14	*Metapenaeus dobsoni*	Square	20	45	58	72	2.94	19.7	Varghese et al. (1996)
15	*Parapenaeopsis stylifera*	Diamond	20	33	42	55	2.12	19.8	Varghese et al. (1996)
16	*Parapenaeopsis stylifera*	Square	20	42	53	66	2.62	20.2	Varghese et al. (1996)
17	*Thryssa purava*	Diamond	20	52	67	79	3.37	19.9	Varghese et al. (1996)
18	*Thryssa purava*	Square	20	49	68	85	3.39	20.1	Varghese et al. (1996)

19	*Upeneus vittatus*	Square	40	100	112.2	124	2.8	46	Prakash et al. (2008)
20	*Leognathus bindus*	Square	40	55.2	77	98.8	1.92	52	Prakash et al. (2008)
21	*Upeneus moluccensis*	Diamond	40	60.2	88.1 (3.1)	103	2.2	48	Madhu et al .(2010)
22	*Upeneus moluccensis*	Diamond	50	60.6	94.9 (2.5)	120	1.9	55	Madhu et al .(2010)
23	*Nemipterus japonicus*	Square	40	93	127	162	3.2	40	Prakash et al.(2010)
24	*Thryssa mystax*	Square	40	126	131	169	3.2	40	Prakash et al.(2010)
25	*Rastrelliger kangurta*	Diamond	40	179	202	225	3.10	56	Pravin et al (2010)
27	*Trichiurus lepturus*	Square	50	335.1	407.1	479.1	8.14	47	Rajeswari et al. (2010)
28	*Leputracanthus savala*	Square	50	343.6	367.3	391	7.34	47	Rajeswari et al (2010)
29	*Leputracanthus savala*	Square	40	272.1	350	327.8	8.75	56	Rajeswari et al. (2010)
30	*Alepes kleinii*	Diamond	40	88	104	120	*2.98*	*43*	Remesan et al. (2010)
31	*Uroteuthis (P) duvauceli*	Diamond	40	59.8 (0.19)	79.0 (0.16)	98.3 (0.20)	1.98	60	Madhu et al. (2011)
32	*Uroteuthis (P) duvauceli*	Diamond	50	79.9 (0.19)	93.8 (0.12)	107.7 (0.15)	1.88	60	Madhu et al. (2011)
33	*Uroteuthis (P) duvauceli*	Diamond	60	97.8 (0.22)	120.2 (0.21)	142.7 (0.29)	2.00	60	Madhu et al. (2011)
34	*Uroteuthis (P) duvauceli*	Diamond	70	146.7 (0.18)	163.6 (0.19)	180.5 (0.26)	2.34	60	Madhu et al. (2011)
35	*Megalaspis cordyla*	Diamond	65	231	294	357	4.52	55	Leela et al. (2013)
36	*Saurida tumbil*	Square	40	162	193	225	4.8	62	Prakash et al. (2013)
37	*Nibea maculata*	Square	40	93	109	125	2.7	68	Prakash et al. (2013)
38	*Trichiurus lepturus*	Square	40	307.5	362	416.5	9.05	47	Rajeswari et al. (2013)
39	*Trichiurus lepturus*	Diamond	40	259.6	334	409.5	8.35	51	Rajeswari et al. (2013)
40	*Thryssa dussumieri*	Diamond	40	43	88.4 (0.16)	115	2.21	56.6	Madhu et al. (2016)
41	*Thryssa dussumieri*	Square	40	79	102.0 (0.12)	122	2.55	49.0	Madhu et al. (2016)

Zhou, 2008). Modeling and simulation approaches like by Criales-Hernandez et al. (2006), can help in understanding the ecosystem impacts of introduction of bycatch reduction devices in a fishery, which are essential in the Indian scenario.

Though preliminary in nature, the selectivity estimates available now in the Indian scenario are good enough for coming out with proposals regarding the optimum mesh required for individual species. Studies related to optimization of the mesh size taking the twin objective of conservation and monetary benefits into account are urgently required. Since these twin objectives often militate, deriving an optimum mesh size would be very catchy. Inclusion of factors affecting selection into the studies, biological parameters of the targeted species and modeling approaches will help in refining the results already available and development and adoption of a standard protocol for trawl selectivity studies will help significantly.

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