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Review Article

A Review on Techniques and Challenges in the Harvest of Mesopelagics

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Abstract

Harvesting of underutilized mesopelagic resources is among the possible solutions to increase capture fish production, which will also facilitate recovery of overexploited fish resources. Mesopelagics can be a source for fish meal, which is in great demand from the growing aquaculture and animal feed industry and will find applications in areas like nutraceutical and cosmetic industries. Recent estimates based on acoustic data, put the biomass of mesopelagic fishes between 11,000 and 15,000 million tonnes in the world oceans. Even though there is a large potential for developing a fishery for mesopelagics, very little information is available on the appropriate commercial harvesting systems. About 75% of total global catch of small mesopelagic fishes is accounted by myctophids. Average world annual production of myctophids between 1970 and 2015 has been 10,640 tonnes, with a maximum of 74,751 tonnes in 1990. Aimed midwater trawling and pair trawling with appropriate trawl designs have been considered suitable for harvesting mesopelagic resources. An overview of the study is the mesopelagics in the Indian Ocean and its availability in the deep sea shrimp trawl bycatch. Sampling gears and commercial fishing techniques targeting mesopelagics are discussed along with details of experimental aimed midwater trawling conducted in Arabian Sea, targeting mesopelagic resources.

Keywords: Mesopelagic resources, myctophids, harvesting techniques, aimed midwater trawling, pair trawling.

Introduction

Mesopelagics are small fishes in the size range of 3 to 30 cm inhabiting the disphotic oxygen minimum zone in world oceans in the depth range of 200 to 1000 m. The community include the adults and juveniles of finfishes (mainly myctophids), crustaceans and molluscs along with other organisms. Mesopelagic fishes in the world oceans have been estimated at about 1000 million tonnes by Lam & Pauly (2005), of which 365 million tonnes is in the Indian Ocean. Recently, Irigoien et al. (2014) based on acoustic data, estimated median values of mesopelagic fishes biomass between 11,000 and 15,000 million tonnes in the world oceans (40° N and 40° S). Harvesting of mesopelagics in the world oceans would be a boon for the ailing capture fisheries sector, if suitable harvest technologies are evolved. The striking importance of these resources at present is that the supply of edible fishes and juveniles for the fishmeal industry can be stopped and the raw materials can be responsibly sourced from mesopelagics. FAO (2001) reported to enhance production of capture fisheries, harvesting of underutilized fish resources are one of the possible solutions, which will also assist recovery of overexploited fish resources. Mesopelagics can be a source for fish meal, which is in great demand from the

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growing aquaculture and animal feed industry. Similarly, body oil will find applications in areas like nutraceutical and cosmetic industries.

Only very limited information on the commercial harvesting systems are available for mesopelagics fishery, despite of their large harvesting potential. Myctophids contribute about 75% of total global catch of small mesopelagic fishes (Vipin et al., 2012). World annual production of myctophids between 1970 and 2015 varied from 5 tonnes (1999) to 74,751 tonnes (1990) (FAO, 2017) with a mean production of 10,640 tonnes per year (Fig. 1). The fishing gears for harvesting of myctophids are not precisely designed for the targeted species. Commercial fishery for the same is restricted to countries like Oman and Africa. Vertical migration of the shoal during sunset and sunrise at a considerable speed for feeding zooplankton, need to be taken into account for successful harvesting. Possible reasons for underutilisation could be their smaller size, unpleasant appearance, wax content in the meat, difficulty in locating the shoal and hitches in harvesting from the deep sea.

The identified Diurnal Vertical Migration (DVM) of mesopelagics is mainly of two types: ascent of organisms to the surface at the onset of night (dusk) and down to daytime depths with day break (dawn) is one type and in other the process takes place in reverse order (Neilson & Perry, 1990) under low or absent light conditions, normally between dusk and dawn the nocturnal vertical relocations like midnight sinking, can take place (Giske et al., 1990; Tarling et al., 2002; Benoit-Bird et al., 2009). Light is known an one of the important proximate factor in DVM, with changes in light intensity advised to determine the depth distribution of mesopelagics and also the timing of ascent to surface and vice-versa (Neilson & Perry, 1990; Baliño & Aksnes, 1993; Widder & Frank, 2001; Hays, 2003; Cohen & Forward, 2009). At higher latitudes, light regimes and intensity vary noticeably with season, fishes which are influenced by light are adapted new behaviour accordingly. Several hypotheses for vertical migrations on a population level have been proposed. Eggers (1978) reported that the adaptiv value of vertical migrations is a measure to avoid predation, so mortality. Later it was extended to a hypothesis which includes the optimization of foraging in the anti-predation window (Clark & Levy, 1988; Scheuerell & Schindler, 2003).

According to the bio-energetic efficiency hypothesis the organisms distributes at temperatures where maximize growth can occur (Wurtsbaugh & Neverman, 1988; Giske & Aksnes, 1992; Bevelhimer & Adams, 1993), whereas the foraging-opportunity hypothesis suggests that the depth distribution of the predator overlaps with depth changes of its prey (Levy, 1990a; Neilson & Perry, 1990). The hunger-satiation hypothesis assumes on an individual level that vertical movements of individuals are triggered by a change of its hunger or satiation state (Pearre, 2003).

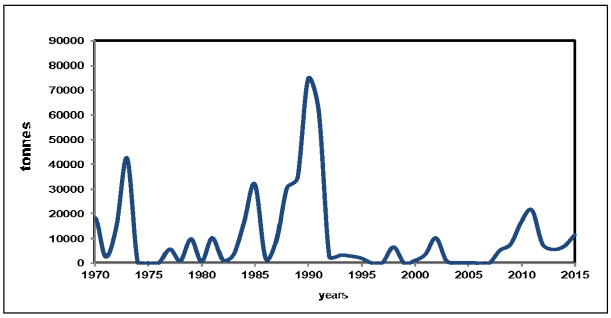

Fig. 1 World production of myctophids (source: FAO, 2017)

Mesopelagic resources in the Indian Ocean

Myctophids are among the most abundant group of mesopelagic fishes in the Indian Ocean and a total of 137 species of myctophids has been reported in the Indian Ocean (Boopendranath et al., 2012; Vipin et al., 2012). Eight species of myctophids were identified by Boopendranath et al. (2012) belonging to the genus, *Myctophum (Myctophum obtusirostre* and *M. spinosum*) *Benthosema* (*Benthosema fibulatum*) and *Diaphus* (*Diaphus watasei, D. dumerilli, D. hudsoni, D. luetkeni,* and *D. effulgens*) out of deep sea shrimp trawl bycatch, off southwest coast of India. Sebastine et al. (2013) estimated five species from the same fishery namely *D. watasei* (74.23%), *Neoscopilus microchir* (20.57%), *B. fibulatum* (1.94%), *Diaphus garmani* (1.69%) and *M. obtusirostre* (1.58%). Altogether nine species represent myctophids in the trawl bycatch off Kollam in which *D. watasei* is the dominant species. Gjosaetor & Kawaguchi, (1980) identified two most dominant genera in the Indian Ocean namely *Benthosema* and *Diaphus*. Occurrence of 11 species of myctophids from the Arabian Sea in which *Diaphus arabicus* was the dominant species was reported by Kinzer et al. (1993). Raman & James (1990) reported about 46% of the total fish biomass of the deep scattering layer (DSL) myctophids and they found maximum density along the continental slope waters near Mangalore and off Cochin areas off southwest coast.

Mesopelagics in the bycatch of deep sea shrimp trawlers

There is no commercial fishery for mesopelagics in India except the bycatch in the deep sea shrimp trawls operated off southwest coasts (Boopendranath et al., 2009; Pillai et al., 2009; Sebastine et al., 2013, Jose Fernandez, 2015). About 400 trawlers of LOA ranging from 10-20 m fitted with diesel engine of 175-411 hp operate shrimp trawls off Kollam, between 300-400 m depth, during September to May (Jos Fernandez et al., 2015). They operate mostly 32.2 m shrimp trawl with 30-50 mm mesh size for the trawl body and 26 mm for the codend. They target mainly five species of shrimps namely *Aristeus alcoki, Plesionika quasigrandis, Heterocarpus gibbosus, H. woodmasoni* and *Metapenaeopsis andamanensis.* During 2009-2010 the total bycatch in deep sea trawlers was 11,488 t with catch rate during peak season around 62.1 kg h^{-1} (Boopendranath et al., 2012). In the catch myctophids contributed about 32% (3,676 t) of the bycatch discards, with catch rate of 19.9 kg h^{-1}. Sebastine et al. (2013) estimated annual average landings of myctophids at 2667 t, during 2009-2011. Bineesh et al. (2010) and Jose Fernandez et al. (2015) reported that bycatch in deep sea shrimp trawlers formed around 61% of the total catch, of which myctophids contributed 32-35%.These fishes were discarded until recently due to low value and limitations in the fish hold capacity of the trawlers.

Sampling gears for mesopelagics

Several types of sampling gears like small micro-nekton nets to large commercial trawls have been used to catch mesopelagic fishes (Gjosaeter & Kawaguchi, 1980; Watanabe & Kawaguchi, 2003; Sassa et al., 2007; Collins et al., 2008; Boopendranath et al., 2012). International Young Gadoid Pelagic Trawl (IYGPT) used by Duhamel et al. (2000) is a type of successful sampling gear with a mouth dimension of 12x7 m, and 10 mm mesh size in the codend, operates in Southern Ocean (Williams & Koslov, 1997). This sampling gear is seems well adapted to catch mesopelagics. Takagi et al. (2006) reported mesopelagics were collected using Issac-Kidd Md-water Trawl (IKMT) with codend mesh size of 1.0 mm at a depth of 30 m in horizontal tows and with 0.5 mm codend mesh size at depths of 208–286 m in oblique tows from the western North Pacific Ocean on board RV Hakuho-Maru. A MTD-net (Motoda-type multi-layer net) (Motoda, 1971) was towed at a speed of 1.5 kn for catching the larvae of myctophids. The mouth diameter and mesh size of MTD-net were 56 cm and 0.33 x 0.33 mm respectively (Sassa & Kawaguchi, 2006). Myctophid species were also collected with trawl net on board training ship Tanshu Maru (GRT: 499; 1900 hp) of National Research Institute of Fisheries Science, at Kuroshio–Oyashio Transition Zone, at 3.8-4.7 kn speed for 30–50 min. The operated trawl net had head rope length of 73 m with 8 mm codend mesh size and total mouth opening of about 480 m^2 (Yatsu et al., 2005). At King George Island, for mesopelagic sampling a pelagic trawl PT-1088, with mouth opening of 200 m^2 (width 20 m; height: 10–12 m), with codend mesh size of 12 mm was used (Pusch et al., 2004). According to Dalpadado (1988) and Gjosaeter & Tilseth (1988), *Benthosema pterotum* was harvested with pelagic trawl with mouth opening of 250 m^2. The large mesh was in the wing part (e” 200 mm stretched) which decreased gradually towards codend part to 9 mm. The trawling speed was usually between 2 and 3 kn. During 1975-83 RV Dr. Fridtjof Nansen had conducted a systematic survey in Gulf of Oman and Arabian Sea. During this survey whole Gulf of Oman and Gulf of Aden were sampled 1979, 1981 and 1983. In 1975-76 alone 5 cruises were conducted in Gulf of Oman and it was estimated that total abundance of mesopelagic fish in the Gulf of Oman ranged from 8 to 20 million tonnes (FAO, 2001). To determine vertical distribution of mesopelagic component and other zooplankton found in top layer of 440 m, a set of five separate trawl nets was operated at Canadian weather station of subarctic North Pacific Ocean (Frost McCrone, 1974). Rectangular midwater trawl nets (RMT438+1), containing of RMT 1 mounted above RMT 8 with mouth area of 1 and 8 m^2 and codend mesh size of 0.33 and 0.85 mm respectively was used for mesopelagic collection on-board RV Polarstern (ANTXXI/4) during the autumn cruise of in the Lazarev Sea (Putte et al., 2006). In this case each haul consisted with standard double oblique tow from the surface to 200 m down and again back to the surface at towing speed 2.5 kn. Nakatani (1987) reported about mesopelagic collection by using horizontal tows with a 2.0 x 2.5 m which was a non-closing rectangular mid-water trawl on board TS Oshoro-Maru, in southern Bering

Sea. Similarly Myctophids were collected from the upper surface of 1,000 m to 1,500 m in water column by using modified Tucker trawls which had mouth area of 3.2 m^2 or 6.5 m^2, 1.1 cm stretch mesh in the body and 505 ì mesh in the codend operated in the Eastern Gulf of Mexico, (Gartner et al., 1987; Hopkins et al., 1973. Clarke (1973) reported collection of Lantern fishes with modified CPT, 10 ft IKMT and 6-ft Issac-Kidd (IK) mid-water trawl, in the Pacific Ocean near Hawaii. The 10 ft IKMT and the 6 ft IKMT terminated with 1.0 and 0.5 m dia plankton net respectively. It was of standard dimensions which anteriorly and posteriorly lined with 6.35 and 4.75 mm knotless nylon mesh respectively. CPT made up with 19 and 6.35 mm stretched mesh in the main body and codend respectively (Higgins, 1970). Collection of Lantern fishes was done with open RMT-8 which is rectangular midwater trawl with total mouth area of 8 m^2 at night with a warm-core eddy (Baker et al., 1973; Brandt, 1983). RM trawls with 4.5 mm mesh and codend lined with 300 ìm mesh netting towed horizontally for 60 min at a speed of 1.5 m s^{-1} and collected mesopelagic samples (Brandt, 1983). Similar work was reported by Evseenko (2006) where larvae of Lantern fish were collected using net BR 80/113 with mesh size of 0.7 mm in the Eastern South Pacific. Bottom trawl of mouth opening 3 x 20 m towing time 15–30 min at 3 kn. Uchikawa et al. (2008) reported over the continental slope off Tohoku myctophid landing during day time. Sameoto (1989). Used BIONESS Zooplankton Multiple Net Sampling System at a speed of 3 kn at Davis Strait and northern Baffin Bay and reported presence of myctophid in the sample collected. Jakupsstovu (2004) designed trawl for myctophid sampling which had small meshes in belly and codend with mouth opening between 50 and 100 m^2

Commercial harvesting of mesopelagics

Currently a few commercial myctophid fishery exists, which comprise partial operations in the Gulf of Oman, the sub-Antarctic and off South Africa (Hulley, 1996). A fishery for *Lampanyetodes heotoris* has been reported off South Africa using purse seines used for anchovy, with the catches fluctuating between 87 and 42,400 t during 1969-1977 (Newman, 1977; Gjosaeter, 1984). The Soviet Union conducted a trawl fishery for *Electrona carlsbergi* in the Southern Ocean, during 1980-1993, with catches/yr. between 500 and 23,000 t (ASOC, 1996; Kock, 2000). Hulley (1996) reported average catch of *Electrona carlsbergi* about 20,000 t per year between 1988 and 1990 around South Georgia and Shag Rocks, which further increased to78,488 t in 1991. Published literature on commercial fishing gears and operation for catching mesopelagics is scarce. A few studies have been done in Omani waters (Gjosæter & Myrseth 1979; Aglen et al 1982; Gjøsæter & Tilseth 1983; Shilat & Valinassab, 1998.) and in the North Atlantic (Gjøsæter & Kawaguchi, 1980; Poletaev et al., 1991; Lamhauge et al., 2008). Pair trawling is considered as a promising option for harvesting myctophids from the Gulf of Oman (Anon, 2001). A large net with wider mouth opening can be towed using two vessels of similar specifications, which can facilitate better catch rate, even for shoals with less density. Based on the habitat and ecology of the resources Midwater trawls with large mouth area and codend mesh size of 9-10 mm were found more appropriate for harvesting myctophids (Gjosaeter, 1984; Shilat & Valinassab, 1998; FAO, 2001). It has proven that success of myctophid harvesting is mainly depends upon mouth opening of trawl and appropriate mesh size of the netting (Shilat & Valinassab, 1998). In case of dense and large shoal, Midwater trawling is more appropriate whereas in case of less active fish, which cause fish to react slowly and poor visibility the advancing trawl system is more suitable. The sensors of net sonde attached to the head rope and other part of trawl provides idea about fishing depth, vertical opening of the net catch incoming to net, all are required for successful catching operation (Hameed & Boopendranath, 2000). Horizontal spread of mouth opening of net could be obtained by a pair of vertically cambered Suberkrub otter boards during aimed midwater trawling which will further leads to precise the position of trawl net while targeting myctophids and other resources (Hameed & Boopendranath, 2000; Gabriel et al., 2005). Sonar could keep exact and desired position of the trawl relative in terms to schools of fishes (Misund, 1994). To get size and swimming behaviour of shoals, multi-beam, true-motion sonars are most appropriate (Bodholt & Olsen, 1977). The Catch Per Unit Effort (CPUE) also depends upon shape of the net its rigging and the behaviour of the fishes. In addition to that local fish abundance and dragged area sampled by the trawl is also important (Engas, 1994). Shilat & Valinassab (1998) recommended codend mesh size and hauling speed, 9 mm and 2.2-2.8 kn respectively for harvesting myctophids with midwater trawling. Smaller mesh size and wide

Table 1: Catch rates for myctophids during commercial fishing trials in the Oman Sea

Location	Vessel	Year	No. of hauls	Catch/day (t)
Iranian waters	Jihad-Fanoos (112 m L_{OA})	1995	184	22-25
	Ferdows-I (45.4 m L_{OA})	1996; 1998	101	24-28
Oman waters	Oman-Pride (92 m L_{OA})	1996	279	20

(Source: Valinassab et al., 2007)

mouth opening required for myctophid harvesting because swimming ability is least and herding effect due to wing portion of trawl is also very weak. Mesopelagic trawl net (head rope length: 98 m, mouth opening area: 381 m^2, vertical opening: 23 m and net weight: 800 kg) was used for harvesting lantern fishes in the Gulf of Oman (Shilat & Valinassab, 1998). Valinassab et al. (2007) reported catch rates of 20-28 t day^{-1} for myctophid trawling operations in Iranian and Oman waters. For efficient myctophid capture Valdemarsen (2004) suggested a trawl net specification which comprised with minimum of 20 m vertical opening, codend mesh size should be less than 10 mm, 1000 mm mesh sizes in the front part, and less than 30 mm behind the belly section which should have diameter of 8 m. Shilat & Valinassab (1998) reported CPUE depends on towing speed of trawl net and most appropriate speed is about 2.5 kn, as myctophids have low swimming speed and small in size. Design development of trawl net specially mesh size in belly portion should have input from behavioural observation during catching process. It was also seen that the mesh size of netting between codend and aft belly is important while designing mesopelagic trawls. (Jakupsstovu, 2004). CPUE of mesopelagic is directly proportional to coincident of vertical opening of trawl with vertical range of the layer of maximum fish abundance, which is mainly in (DSL) (Shilat & Valinassab, 1998). Higher towing speed and mouth opening will leads to land higher catch (McNeely, 1971). Medium and high speed towing land larger *Diaphus* spp. than to low speed towing (Itaya et al., 2007). Adjustment of trawl net to the depth of the fish distribution (DSL) is one of the vital issues pertinent to midwater trawling which needs to properly addressed while fishing operation. This is utmost important because of diurnal vertical migration of myctophids. Addressing this issue is difficult while targeting shoals of lantern fishes especially during morning and evening when fishes change their depth distribution at higher speed (Shilat & Valinassab, 1998). Though there are very less report about effect of pressure variations on mesopelagic as such but it seems it might not affect myctophids at larger extent as they demonstrate daily vertical migration. It is also known that the noise of the vessel and gear might heard before visual contact by fishes so it is potential cause to move away fishes from trawl net, which further leads to effective reaction when gear arrives Light is one of the cause to change escape behaviour of fishes, fish orientation in depth and reaction distance, so the catching efficiency of trawl net may vary throughout the day with light concentration (Engas, 1994). Myctophids are possessing bioluminescent light organ which emits light resulting enable fishes to sense and react with gear. The presence of lateral line system helps them to detect low frequency vibrations & pressure waves (Glass & Wardle, 1989; Wardle, 1993). Valinassab et al. (2007) reported average landings of myctophids by pelagic trawl nets had codend mesh size of 10 mm was between 24-28 t day^{-1} during 1995-98 in Iranian waters (Table 1). Authors also reported 20 t day^{-1} landings of myctophids in Oman waters during 1996. When pelagic trawl net fitted with 10 mm codend mesh was used, average catches by FV Jihad-Fanoos were 24–25 t day^{-1}.

Aimed midwater trawling experiments for mesopelagics in Indian Ocean

Aimed midwater trawling for mesopelagics was carried out onboard FORV Sagar Sampada (L_{OA} 72.5 m; 2285 hp) with stern trawling facility, during October 2013, between 8° to14° N lat and 72° to 77° E long, in 84-415 m depth in the Arabian

Sea (Remesan et al., 2016). A 45 m four equal panel midwater trawl designed at the ICAR-Central Institute of Fisheries Technology, Cochin (Boopendranath et al., 2012) (Fig. 2) and a 49.5 m krill midwater trawl of Danish origin (Cosmos Trawl, Hirtshals, Denmark) (Boopendranath et al., 2010) were used for harvesting the DSL components. Trawls were rigged with Thyboron otter boards (Type 7) of 5.57 m^2 each weighing 800 kg. Double sweep lines of about 100 m length and bunched iron link chain depressor weighing 150 kg each were used on both lower legs of the trawl. Trawling was carried out in 16 stations (45 m trawl at 6 stations and 49.5 m krill trawl at 10 stations). Simrad echo sounder EK60 (200, 120 and 38 KHz) was used for detecting DSL. Simrad ITI trawl monitoring system was used to measure vertical opening at trawl mouth and determine trawl depth to facilitate aimed mid water trawling. Trawls were dragged for one hour duration after determining the depth of the DSL using echosounder. The net was lowered to the DSL based on output of the ITI trawl monitoring system. Care was taken to drag the net in the DSL by adjusting the warp length. The speed of the vessel was 2.3 to 2.8 knots for dragging 45 m trawl and 1.8 to 2.2 for 49.5 m trawl.

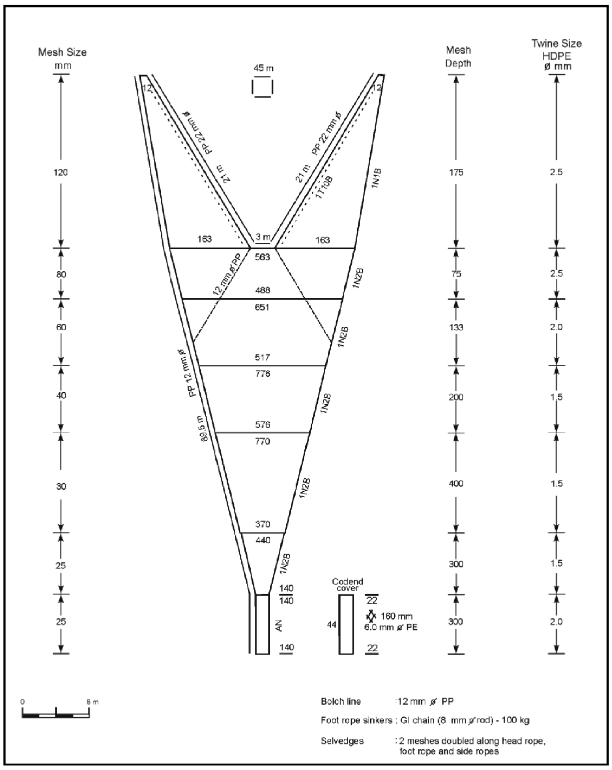

Fig. 2: 45 m four-panel myctophid trawl

In aimed mid water trawling for mesopelagics the net is towed in the DSL after the depth is ascertained using echosounder (Fig. 3). Ten hauls were taken using 49.5 m krill midwater trawl in Lakshadweep waters. The net was provided with small mesh knotless nylon inner layer with 10 mm mesh size from the mouth to the codend which led to increase in drag as evident in the low trawling speed realised (1.8-2.2 kn). Six hauls were taken with 45 m myctophid trawl, mostly off Kollam at a towing depth of 250-370 m (depth of DSL) (Fig. 3). According to Raman & James (1990) maximum density of catch was found in the depth range of 200-500 m during day and 20-90 m during night.

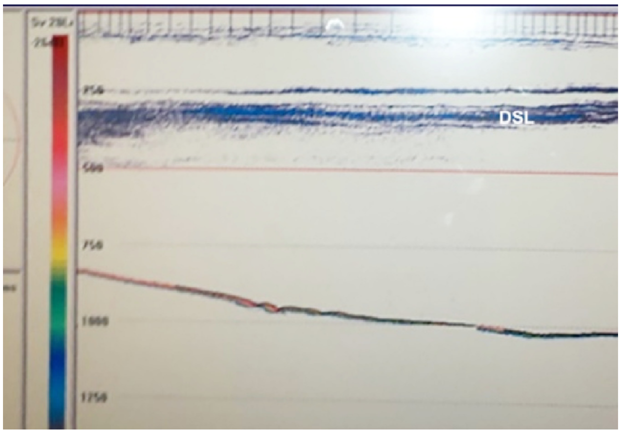

Fig. 3 Echosounder display of DSL

A view of the mesopelagic catch obtained from the 49.5 m krill trawl is shown in Fig. 4 and percentages of major categories in the pooled catch are given in Fig. 5. Total catch was constituted by 40 species of mesopelagics and some unidentified organisms. Catch included finfishes, crustaceans, molluscs and jellyfishes and two species of ribbonfishes (*Trichiurus lepturus* and *T. Auriga*). In the finfish component, Stomiforms contributed nearly 41%, which included *Argyropelecus affinis*, *Chauliodus sloani*, *A. boulengeri* and *A. martensii*. Crustaceans consisted of deep sea prawns (*Acanthephyra purpurea* and *Oplophorus typus*) and swimming crab (*Charybdis longicollis*).

Benthosema fibulatum (38.5%), *B. pterotum* (22.0%), *Myctophum spinosum* (15.5%), *M. nitidulum* (8.0%), *Diaphus jenseni* (5.2%), *D. watasei* (5.0%), *D. nielseni* (4.6%), *D. garmani* (2.0%), *D. lucidus* (1.0%), *Symbolophorus rufinus* (1.4%) and *S. evermanni*(1.2%) were the myctophid components present. Two species of genus *Benthosema* contributed about 60% of the myctophid catch (Fig. 6). Menon (1990)

Table 2. Details of aimed midwater trawling

Gear	Fishing depth (m)	No. of hauls	Towing speed (kn)	Vertical opening (m)	Fishing effort (h:min)	Total catch (kg)	Mean CPUE⁺SD (kgh^{-1})
45 m myctophid trawl	84-370	6	2.3-2.8	6.7-9.8	11:46	96.00	8.06^{+}4.17
49.5 m krill trawl	223-415	10	1.8-2.2	16.1-18.9	21:55	323.50	14.76^{+}5.06

(Source: Remesan et al., 2016)

Fig. 4. Mesopelagics caught in 49.5 m krill trawl

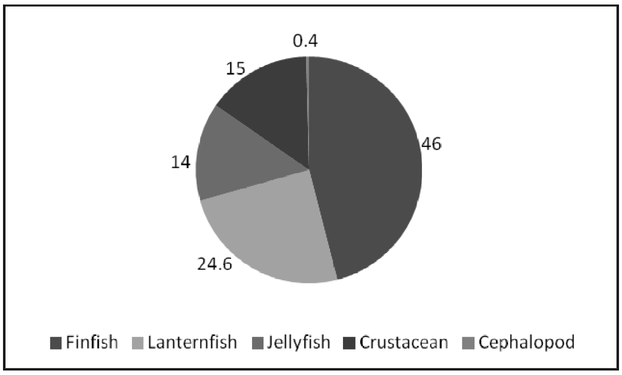

Fig. 5. Percentage contribution of major groups in the pooled catch

reported that the common genera in myctophids of Indian Ocean were Diaphus, Myctophum and Benthosema, which was evident from results of the present study. *Diaphus* was the predominant genus (Balu & Menon, 2006; Manju et al., 2013; Vipin, et al., 2012; Jose Fernadezet al., 2015) represented by five species in the catch, though the quantity was less.

Catch rate was low in all the hauls made with two nets, in spite of the effort taken to maintain the trawl in the ascending DSL till the end of the tow. Acoustic fish detection techniques with net monitoring equipment is one of the prime cause for successful midwater trawling, which requires to guide the net exactly into the position of fish shoals. The operational depth of the trawl is customised by changing vessel's speed along with length of the towing warps in combination. (Hameed & Boopendranath, 2000; Gabriel et al., 2005; Vijayan, 2009). Low density of DSL could be one of the reasons for the the low catch rate. The speed of trawling was 1.8-2.8 kn, which is below the optimum speed (2.5-3.0 kn) recommended for myctophid trawling (Shilat & Valinassab,1998; Boopendranath, et al., 2009; Uchikawa et al., 2008). Raman & James (1990) reported that catch of lantern fishes were always more in night hauls than day hauls possibly due to the migration to depths beyond the range of the net and also net avoidance and greater scatter during day time. Acoustic studies by Kaartvedt et al. (2012) revealed gear avoidance behavior of mesopelagic fish from a

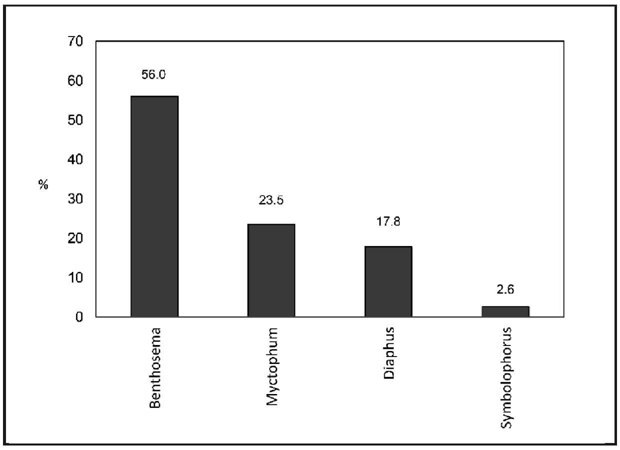

Fig. 6. Percentage contribution of different genera of myctophids in the pooled catch

pelagic trawl. During acoustic surveys with the help of multibeamsonar and acoustic doppler current profiler (ADCP) catch did not match the acoustic data (Benoit-Bird et al., 2001; Yasuma et al., 2006). Underwater camera studies are required to know the escapement behaviour of lanternfishes from the mouth of the trawl.

The recommended codend mesh size for mesopelagics was 10 mm or less, whereas it was 25 mm for the 45 m myctophid trawl, which would have excluded smaller sized catch (Remesan et al., 2013; 2016). Similarly, the vertical opening of the experimental nets were as low as 6.7 m with a maximum opening of 18.9 m for 49.5 m krill trawl. Valdemarsen (2004) and Shilat & Valinassab (1998) suggested that the trawl for efficient capture of myctophids should have relatively large vertical opening of 20 to 23 m. According to Dalpadado (1988) and Gjosaeter & Tilseth (1988), *Benthosema pterotum* was caught using pelagic trawls which had an estimated mouth area of 250 m^2, in Indian Ocean. Since the demand for fish protein for human beings, farmed fishes and other organisms are increasing and the fish oil based industry is also expanding, there is an urgent need to harvest the abundant mesopelagic resources in the region. Presicion equipment to continuously monitor the DSL and cost effective technology for aimed midwater trawling for mesopelagics and their onboard processing are urgently needed to make the operations economically viable. Introduction of seperator trawls to selectively harvest deep sea shrimps and mesopelagics in the lower and upper codends respectively would reduce the sorting time in deep sea shrimp trawl operations where mesopelagics are caught as bycatch. Govt. agency and the trawling industry should join hand to develop a commercially viable technology for harvesting mesopelagics.

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