

Author version: *Rev. Fish Biol. Fish.*, vol.21; 2011; 339–354

A Review on Mesopelagic Fishes belonging to family Myctophidae

^{1*}Ms.Venecia Catul, ^{2*}Dr. Mangesh Gauns, ³Dr. P.K Karuppasamy

^{1*}veneciacatul@rediffmail.com; Tel: 91-9890618568, Fax: 91-0832-2450217

National Institute of Oceanography, Dona Paula, Goa, India

^{2*}gmangesh@nio.org; Tel: 91-0832-2450217

National Institute of Oceanography, Dona Paula, Goa, India

³saams2007@gmail.com; Tel: 91- 9447607809

National Institute of Oceanography, Regional Centre, Kochi, India

*- Corresponding authors

Abstract

Myctophids are mesopelagic fishes belonging to family Myctophidae. They are represented by approx. 250 species in 33 genera. Called as “Lanternfishes”, they inhabit all oceans except the Arctic. They are well-known for exhibiting adaptations to oxygen minimum zones (OMZ- in the upper 2000m) and also performing diel vertical migration between the meso- and epipelagic regions. True to their name, lanternfishes possess glowing effect due to the presence of the photophores systematically arranged on their body, one of the important characteristic adding to their unique ecological features.

Mid-water trawling is a conventional method of catching these fishes which usually accounts for biomass approx. in million tones as seen in Arabian Sea (20-100 million) or Southern ocean (70-200 million). Ecologically, myctophids link primary consumers like copepods, euphausiids and top predators like squids, whales and penguins in a typical food web. Lantern fishes become a major part of deep scattering layers (DSL) during migration along with other fauna such as euphausiids, medusae, fish juveniles, etc. Like any other marine organisms, Myctophids are susceptible to parasites like siphonostomatoid copepods, nematode larvae etc in natural habitats. They are important contributors of organic carbon in the form of their remnants and fast sinking faeces, which get deposited on ocean beds. Economically, they are a good source of protein, lipids and minerals, which is used as fishmeal for poultry and animal feed and as crop fertilizers. Few species are considered edible, but proper processing difficulties on a higher scale limit myctophids as human food.

Myctophids have a life span of approx. 1-5 years and low fecundity rates (100-2000 eggs per spawn). This trait is a disadvantage, if continuous utilization of their population, for e.g. for fish meal industries etc, occurs without giving them a chance to revive and recover. Hence, research in this area also should be given utmost importance.

In this paper, we have tried to compile information and ideas from various sources of myctophid research around the world, particularly from the Indian Ocean, to understand their ecological and economic importance and also to put forth new ideas to bring about conservation and restoration of this vulnerable resource.

Keywords: Lanternfishes, bioluminescence, deep scattering layers, oxygen minimum zone, vertical migration

Introduction

Mesopelagic fishes are among the most abundant marine organisms that are least studied and hence underutilized by mankind. They are small and usually found at depths between 100 and 1000 meters. Most mesopelagic species make extensive upward migration into the epipelagic zone during the night and thereafter migrate down several hundred meters to their daytime depths (Salvanes and Kristoffersen 2001). Because they can swim in directed paths and are small, they are sometimes termed as micronekton. The most common and abundant among the mesopelagic fishes are the lanternfishes of the family Myctophidae, characterized by approx. 250 species in 33 genera. It is one of the most abundant families of deep sea fishes, comprising at least 20% of the oceanic ichthyofauna (McGinnis 1974).

The Myctophidae are believed to be derived from the neoscopelids (the other family from the order: Myctophiformes) and have inhabited this planet a million years ago and are continuing to do so. A characteristic that makes them unique marine inhabitants are the presence of luminescent photophores arranged systematically on their bodies. They perform diel vertical migrations between the meso-(200-2000m) and epi-pelagic (10-100m) regions and show various adaptations to oxygen minimum waters (100-1000mts). They also form an important part of deep scattering layers. Myctophids play an important role in open oceanic energy dynamics, by forming an important link in the food web between primary consumers like zooplankton and tertiary consumers and commercially targeted fishes like tuna, sharks as well as cetaceans (Whales, Dolphins), pinnepeds (Seals, Sea-Lions), diving seabirds in the pelagic region and also for grenadiers in the demersal areas (Kozlov 1995; FAO 1997; Balu et al. 2006; Karuppasamy et al. 2007a; Cherel et al. 2010). They represent a pathway for substantial export of organic carbon between surface and deep ocean through diel vertical migration and production of large fast sinking faeces (Moku et al. 2008). Determining their feeding habits and trophic positions are thus essential for a better understanding of the functioning of the pelagic ecosystem (Cherel et al. 2010). The adaptations these fishes exhibit, during vertical migration especially through the OMZ, as seen in the northern Indian Ocean, need investigation.

Myctophids are economically important to world fisheries by way of providing raw material to fish meal industry and also for human consumption by proper processing (see below). Because of their importance and commercial

demands their stock is likely to decline if timely conservation efforts are not carried out. This will also have adverse effect on the food web structure of the region. This concern is the motivation of the present work.

The aim of this study is to summarize work carried out by researchers around the world and to bring awareness about lanternfishes and emphasize the importance of this rich, highly diverse group living in the mesopelagic region. Issues pertaining to myctophid future research and conservation are also addressed so that students, ecologists, fisheries managers, policy-makers and ecosystem modelers are benefited from in this review paper.

Discussion

History

Myctophids have been in this world since time immemorial. They lived, evolved and adapted to the earth's ever-changing environment. Fossilization of their relics occurred eventually which gave an indication about them being present during evolution of life on earth. Remnants in the form of isolated otoliths, teeth and scales from sedimentary rocks were found by Miller et al (2002). According to these authors fossils belonging to *Diaphus* and *Ceratoscopelus* genera were from the cretaceous period (145 million years ago). Fossilized myctophids, *Eomyctophum koraense* and *Oligophus moravicus* were found from the Paleocene (65 million), Eocene (54 million years ago) and Oligocene (33 million years ago) deposits of Russia and adjacent regions of Thetys and Parathetys basins (Prokofiev 2006). The genus *Eomyctophum* was separated into the subfamily Eomyctophinae, differing from other myctophiform fishes by the absence of lens-like thickenings of the photophores. Fossil records are also reported from the Miocene epoch of the upper tertiary period approximately 23 million years ago. Fossil findings can thus help to understand the type of climate, hydrography and habitats these fishes lived in and also their evolution and adaptations, similar to foraminiferans which has been studied by geologists to understand the environment during evolution.

Distinguishing Characteristics

Myctophids show the presence of non-bacterial bioluminescent organs known as "Photophores", which are ventrally arranged and species-specific. These are complex structures consisting of modified cup-like (lens) scales, containing photogenic tissue (fig.1). These organs emit a weak to bright blue-green-yellow light, which is a result of a chemical oxidation reaction, triggered and regulated by the nervous system. The compound luciferin is responsible for the

luminescence effect and the color (catalysed by enzyme luciferase). This compound is seen in many other marine and terrestrial bioluminescent groups with only differing chemical structures (Barnes et al. 1974; Stiasny 1997; Rees Jean-F et al. 1998; Balu et al. 2006; Moser et al. 2006; Campbell 2008). This adaptation could have evolved when these fishes started inhabiting the darker waters of the ocean. A function that may be needed to see in the dark in addition to their large photosensitive eyes and also to attract mates and mislead predators.

These delicate fishes perform daily diel vertical migration and accordingly occupy the bathypelagic (200-2000m) during the day and the epipelagic region (10-100m) at night (Nafpaktitis 1982; Gopakumar et al. 1983; Morrison et al. 1995; FAO 1997; Tsarin 2002; Balu et al. 2006). They are adapted to survive in low ambient oxygen layers (<0.1ml/L or 4.5 μ M), a characteristic feature of the northern Arabian Sea (fig.2) (Qasim 1982; Morrison et al. 1995; Nair et al. 1999; Naqvi et al. 2005; Hood et al. 2008) including the Bay of Bengal and continental margins along the eastern Pacific Ocean and off West Africa (Levin 2003). For instance, Kinzer et al (1993) understand that *Diaphus arabicus* and *Benthoosema pterotum* are adapted to low oxygen conditions in the northern Arabian Sea. In general, cold water at deeper depths lowers metabolic rates and possibly lowers oxygen consumption. Further, according to Levin (2003) these deep low oxygen layers may also limit entry of predator fish of higher order. These together with other adaptation (see below) may make OMZ's a safe niche for myctophids. Characteristics that make them so well adapted to extreme conditions and different from epipelagic fishes is one highlight of myctophid research.

Worldwide Distribution and Occurrence

Lanternfish distributions are circumglobal and are found in all oceans except the Arctic (fig.3 and table 1). They are highly diverse, which can be used as indicators of biogeographic distinctness of a specific area (Nafpaktitis 1982; Karuppasamy et al. 2008a). *Benthoosema pterotum* is the most common and numerous species in the western (Gulf of Oman-Somali region) and the eastern (along west coast of India) Arabian Sea and is also the largest single species stock of fish in the world (Gjøsæter 1984; U.S GLOBEC 1993; FAO 1997; Valinassab et al. 2007; Karuppasamy et al. 2008a) (fig.4). Other species like *Benthoosema fibulatum*, *Diaphus* spp., *Myctophum spinosum* and *Symbolophorus evermanni* were occasional in number, more common than *B. pterotum* in the Gulf of Aden (Gopakumar et al. 1983; Gjøsæter 1984; FAO 1997). Along the southern Omani and northeastern Somali coast, *B. fibulatum* dominated trawl collections and acoustic survey records. In the eastern Arabian Sea, *Diaphus arabicus* and *Hygophum proximum* are common forms (Gjøsæter 1984; Kinzer et al. 1993; FAO 1997). Along the coast of

Pakistan, Myctophids concentrations consist almost exclusively of *B. pterotum* with densities decreasing towards the west (FAO 1997). Survey in the western Indian Ocean estimated the presence of 97 species of myctophids belonging to 23 genera (Nafpaktitis 1982). *Stenobranchius leucopsarus* is one of the abundant and dominant non-airbladder lanternfish in the Subarctic Pacific including the Bering Sea and Sea of Okhotsk (Yasuma et al. 2006). Around 43 species belonging to 16 genera were recorded potentially in the southern ocean, out of which 7 species: *Electrona antarctica*, *Gymnoscopelus braueri*, *G. ophisthopetrus*, *G. nicholski*, *Krefflichthys anderssoni*, *Protomyctophum bolini* and *P. tensioni* were considered true representatives of regions of south of the Antarctic Polar Front (Hulley 1985; Kozlov 1995).

Biomass Catch Rate

Myctophids account for 75% of mesopelagic fish biomass caught by trawling, out of which majority are their larvae and/or juveniles (Gjøsæter 1984; Sassa et al. 2004; Moser et al. 2006) (fig.5), while the remaining biomass consist of bristlemouths (Gonostomidae), lightfishes (Phosichthyidae) and other fauna. The estimated global biomass via trawling method is about 550-600 million metric tones. The Arabian Sea alone supports around 100 million metric tones (Gopakumar et al. 1983; Gjøsæter 1984; Hussain et al. 1987; U.S GLOBEC 1993). However, recent estimates reported the number to be as low as approx 1.7-20 million (FAO 1997). Further, biomass estimates are approx 2.3 million in the Gulf of Oman (Gjøsæter 1984; Valinassab 2005 and 2007) and 70-200 million in the Southern ocean out of the 212-396 million mesopelagic fish biomass (Kozlov 1995; Pakhomov et al. 1996).

Methods of Biomass Estimation

The conventional methods of biomass estimation are mid-water and deep sea trawling. Mid-water trawling is considered ideal for mesopelagic fishes like myctophids (Gjøsæter 1984; FAO 2001). For example Karuppasamy et al (2007a, 2008a) in their survey cruise of 1998-2002 used the Isaac Kid-Mid water Trawl (IKMT) (fig.6) for collecting mesopelagic fishes from DSL regions in the Arabian Sea. However, acoustic methods are considered more reliable for biomass estimation. Some studies using acoustic surveys like High Sonar multibeam and Acoustics Doppler Current Profiler (ADCP) showed that trawl biomass usually did not match the acoustic data (Benoit-Bird et al. 2001; Yasuma et al. 2006). A reason could be that the fishes showed net avoidance by detecting the gear visually or by sensing turbulence in water. Gjøsæter (1984) used 38 kHz echosounders and electrical

integrators during the cruises between 1975-1983 for estimating lantern fish biomass and location. Swim bladders in these fishes provide high acoustic reflection in the form of scattered sound in the water column, which can be measured by acoustic devices (Moser et al. 2006; Yasuma et al. 2006). A split- or dual-beam echo sounder can measure the target strength, which in turn could be converted to fish biomass by measuring backscattered energy. Studies by Morrison et al (1995) explained that the diel vertical migration in Arabian Sea was very prominent in the backscatter intensity measured by the ADCP, which clearly pointed towards diel migration and movement into and out of the OMZ by organisms such as myctophid fish and euphausiids (especially *Euphausia diomedaea*).

When samples are needed for identification, dissection for anatomical studies, biochemical studies etc, trawling can still be carried out. But continuous use of trawling by researchers especially deep sea trawling leads to irrevocable environmental damage due to scraping out of bottom-benthic dwellers (plants and animals) by the gear. Therefore care must be taken to hold organisms of interest and avoid bycatch.

Systematics

Morphology

Lanternfishes have a slender compressed body covered with deciduous, cycloid or ctenoid scales, which also cover the luminescent glands in some species. The fish's size varies from 2-30mm, which is a standard length, majority being under 15mm and weighing between 2 and 6gms (Nafpaktitis 1982; Hulley 1985; FAO 1997; Moser et al. 2006). A prominent, bluntly rounded head with large elliptical to round eye characterizes the Myctophids small body. The fins are of the type: single high dorsal fin, an adipose fin, pelvic fin and an anal fin supported by a cartilaginous plate at its base, originating under or slightly behind the posterior end of the dorsal fin. The pectoral fins generally have eight rays, small and reduced to large and well-developed in different species. The caudal fin is forked in emergence (Nafpaktitis 1982; Hulley 1985; Moser et al. 2006). The color of the myctophids varies from blue-green to silver in shallow dwelling species e.g. *Diaphus* sp., while deep water species are dark- brown to black e.g. *Lampanyctus* sp. and *Taaningichthys* sp. (Nafpaktitis 1982; Hulley 1985; Balu et al. 2006; Moser et al. 2006). The gills bear well developed enlarged blade-like gill rakers along the first gill arch except in *Centrobranchus* sp., the number of which is used as a taxonomic character for differentiating species (Hulley 1985).

Accessory luminous glands (luminous tissue patches) are also seen in some fishes. For instance, in headlight fish, *Diaphus* sp. the glands are in close proximity to the eyes or are supracaudal (dorsal) in males and infracaudal (ventral) in females of *Lobianchia gemellari*, suggesting their sexually dimorphic nature (fig.7). Some other species showing these patches are *Stenobranchius leucopsarus* and *Lampanyctus ritteri*, except *Symbolophorus californiensis* wherein they are absent (Barnes et al. 1974; Stiassny 1997). All species of Myctophidae show photophores with the exception of one i.e. *Taaningichthys paurolychnus* (found in Eastern Atlantic: Madeira and Cape Verde; Western Atlantic: near Bermuda and Jamaica; Western Indian Ocean) whereas all the other species of this genus are bioluminescent (Hulley 1985; Stiassny 1997) (fig.8). Is this some kind of adaptation or evolution that has taken place, because this particular species did not require bioluminescence? And started inhabiting upper illuminated depths due to intraspecies competition, has to be studied.

Another pattern of dimorphism in which males are markedly smaller than females at maximum size is found in some species such as *Ceratoscopelus warmingii* and *Electrona Antarctica* (Karuppasamy et al. 2008a).

Swim bladders facilitate buoyancy during juvenile stages, which then get filled with lipids or degenerate during maturation in most species. Larval gut is slightly sigmoid, extends to the mid-body and has transverse mucosal folds, which ranges from extremely short in *Lampanyctus* sp. to elongate and trailing free from the body in *Myctophum aurolaternatum* (Moser et al. 2006).

Reproductive Biology

Myctophids are characterized by rapid growth, early sexual maturity, life span of 1-5 years and high mortality rates (Childress et al. 1980; Gjøsaeter and Kawaguchi 1980; Karuppasamy et al. 2008a). Females are oviparous and both sexes are non-guarding pelagic spawners. They release eggs and seminal fluid into the water, where fertilization takes place. The tiny eggs (0.70-0.90 mm, with a segmented yolk, moderately perivitelline space, single oil globule and delicate chorion) are made buoyant by lipid droplets. The fertilized eggs (embryos) and then, the hatched larvae (~2.0 mm), drift at the mercy of the currents until they have developed. Spawning may continue year-round in some species, but have been reported during the winter to early spring season (Balu et al. 2006; Moser et al. 2006). All the lanternfishes have a low fecundity rate with females producing approx. 100-2000 unfertilized eggs per spawn, depending on the species and age of the fish. *Benthoosema pterotum*, one of dominant species is known to spawn

only once in its life time which is highly variable, usually occurring at 7 months age (Gjosæter 1984; Dalpadado 1988). Larger species such as *Benthoosema glaciale* (glacier lanternfish) may live for up to eight years, reaching maturity at 2-3 years, while smaller myctophids like the *Diogenichthys laternatus* (Diogenes lanternfish) tend to have higher resilience, doubling their populations within 15 months.

The study of lanternfish embryos is hindered by their extreme fragility because the chorion (outer membrane enclosing the embryo) often ruptures during sampling and the yolk is lost during towing. On the other hand, lanternfish are best-studied as larvae, which can be identified confidently by morphological characteristics e.g. head, gut and body shape and also based on pigment (melanophore or melanin) patterns with the exception of *Diaphus* sp. that are proven to be extremely difficult to identify. Most larvae possess branchiostegal photophores. Larvae of some species have stalked eyes, like the spotted lanternfish *Myctophum punctatum* (Moser et al. 2006). Further, during harvesting these tiny mesopelagic fishes are exposed drastically to different pressure zones in short time span due to which the organisms get damaged. Otherwise, these fishes get time to adjust their bodies to pressure change during vertical migration.

Biochemical Studies

Mesopelagic fishes are reported to contain high amounts of wax esters which when consumed in large quantities cause diarrhoea and seborrhoea in animals (Lekshmy et al. 1983). Myctophids are high in proteins and mineral content, variably lower in lipids and uniformly low in carbohydrates (Neighbors et al. 1982; Lekshmy et al. 1983; FAO 1997; Phleger et al. 1999; Lea et al. 2002), which indicates its nutritional importance. A number of studies have evaluated the lipid content of vertically migrating myctophids and found that they include triglycerides, believed to serve primarily as an energy store and wax esters, mainly used for buoyancy. Gopakumar et al (1983) reported that lanternfishes are a good source of potassium, sodium and calcium. They also did not find any harmful bacteria like coliforms, faecal streptococci and coagulase positive staphylococci. They concluded from the above biochemical and pathological findings that lanternfishes are good enough as palatable food for human and animal consumption after proper processing. A study on myctophid, *Electrona Antarctica* showed the presence of 86.2-90.5% of wax esters of the total lipids (Neighbors et al. 1982; FAO 1997; Phleger et al. 1999).

Ecology

The lanternfish are thought to perform migration as they follow zooplankton on which they feed and also to avoid predation by camouflaging themselves. They regulate the brightness of the photophores to match the downwelling light which effectively disguises the lanternfish's shape. When viewed from below it appears as an outline making it difficult to identify the myctophids. This phenomenon is called as "Counter-Illumination" or "Counter-shading" (fig.9). Since the photophores are arranged differently for each species and also different in males and females, their bioluminescence can therefore, play a role in intraspecies communication, specifically in shoaling and courtship behavior.

Migrational Behaviour

There is also great variability seen in migration patterns within the family. Some deeper-living species may not migrate at all while others may do so only at irregular intervals. Vertical migration at night usually starts about one hour prior to sunset and is essentially complete between one-half to one hour after sunset. The migrational patterns may also be dependent on life history stage, sex, latitude, hydrography, topography and season (Nafpaktitis 1982; Hulley 1985; Tsarin 2002; Sassa et al. 2004). As per a study carried out by Watanabe et al (1999), myctophids show four kinds of migrational patterns which are (1) Migrants showing clear day-night habitat separation with peak abundance above 200m at night: *Symbolophorus californiensis*, *Tarletonbeania taylori*, *Notoscopelus japonicus*, *Diaphus theta*, *Ceratoscopelus warmingi*, and *Diaphus gigas*. (2) Semi-migrants, in which part of the population often remains in the daytime habitat at night. The distribution depths of migratory and nonmigratory individuals do not overlap: *Stenobrachius leucopsarus*. (3) Passive-migrants, in which there is no separation of day-night habitats, but the upper limit of daytime distribution depth shifts to a shallower layer at night, probably as the fish follow migratory prey: *Lampanyctus jordani*. (4) Nonmigrants: *Stenobrachius nannochir*, *Lampanyctus regalis* (>140mm SL), and *Protomyctophum thompsoni*. Smaller forms travel a distance of 10-170m/h while larger taxa journey a distance of 100-200m/h one-way. According to Sassa et al (2004), myctophid larvae remain in the epipelagic zone (<200m) and then move to relatively deeper depth to adapt to their later adult life in the mesopelagic zones, after which most species start diel vertical migration. They are also capable of crossing density gradients such as thermocline and halocline that generally inhibit mixing by physical processes (Nafpaktitis and Nafpaktitis 1969).

Observed swimming behavior among myctophids takes two forms depending on the body type. Robust-bodied species swim in short bursts, propelled by a rapid closing of the tail fin rays and flick of the tail. In general, these are the strongest migrators, with the widest difference in day and night vertical distribution. The flabby-bodied forms tend to move with a slow eel-like wriggling of the entire body.

Findings of Gartner (1991) highlight the epipelagic zone as the responsible area in shaping Myctophids development; it is in this area that these fishes carry out most of their activities like feeding, reproduction and development. Ropke (1993) and Sassa et al (2004) are of the belief that vertical distribution of potential prey is more important than just physical stratification in determining the vertical distribution of most mesopelagic larvae in subtropical-tropical region. This daily vertical migration is connected with nutrition and energy exchange between lower and higher trophic levels (Tsarin 2002). Therefore, it is important to understand their prey items like copepods, euphausiids through gut content analyses which in turn will highlight their feeding ecology and community structure. Further, vertical migration is also controlled by light intensity, for e.g. an experiment carried out by Gjesæter (1984) onboard RV 'Dr. Fridtjof Nansen', inferred that maximum lanternfishes are sensitive (repel) to bright light. This could be because they are adapted to low light conditions in deep waters and yet could be another reason for their migration to the surface after dusk. The scientist used the fish's migratory behaviour as an advantage for catching near surface concentrated fish during trawling. Fishermen could use this method during commercial fishing for maximum catch.

Deep Scattering Layer members

Echo sounder records show that many myctophid species like *Benthosema pterotum*, aggregate in compact layers, and contribute abundantly to the micronektonic biomass of the acoustically dense "Deep Scattering layer" (DSL) or "false bottom", especially during the daytime when they are relatively inactive (Bekker 1967; Oven et al. 1984; FAO 1997; Karuppasamy et al. 2006, 2007a, 2008a). They are predominant in most regions among the fish fauna of sound scattering layers of the open seas (Bekker 1967; Oven et al. 1984; Balu et al. 2006; Karuppasamy et al. 2006, 2008a) mostly along with other fauna like amphipods, chaetognaths, copepods, doliolids, euphausiids, isopods, lucifers, medusae, ostracods, pteropods, salps, siphonophores, jelly like substances, larval forms like alima larvae, decapod larvae, phyllosoma larvae, micronektons such as pelagic shrimps, crabs, cephalopods, leptocephalus, fish juveniles and other mesopelagic fishes belonging to families photichthyidae, gonostomatidae, sternophychidae,

bregmacerotidae, melanostomiidae, stomiidae, astronesthidae, nemichthyidae, trichiuridae and idiacanthidae (Auster et al. 1992; Morrison et al. 1995; Karuppasamy et al. 2006). These layers are found in depths ranging from 200 to 750m during the day and between surface and 200m at night (Karuppasamy et al. 2006).

When alone, myctophids have a higher probability of getting noticed by a predator than if in aggregates. Therefore, myctophids selectively occur with other pelagic fauna such as amphipods, euphausiids, sergestids and ctenophores, to reduce the chances of coming in contact with predators (Auster et al. 1992) and also to take advantage of aggregate search abilities for common prey such as copepods. Another reason for aggregate formation is high production due nutrients supply brought in by upwelling (coastal and open-ocean) as seen in the Arabian Sea (Hulley 1985; U.S GLOBEC 1993).

Feeding Behaviour

Myctophids are known to be opportunistic predators on copepods, ostracods, euphausiids, hyperiid amphipods, chaetognaths, pteropods, fish eggs and fish larvae (Hulley 1985; Dalpadado et al. 1988; Kinzer et al. 1993; Pakhomov et al. 1996) based on their wide range of food choices. They exhibit predominant night time feeding ~ 8-10hrs. Finding of Dalpadado et al (1988) on *Benthoosema pterotum* infer that these fishes indeed show diel vertical migration as the copepods found in the gut contents are epipelagic. But studies by Robison (1984) showed that a tropical-subtropical species, *Ceratoscopelus warmingii* fed on mats of *Rhizosolenia* sp. (diatom) which is considered occasional herbivory in times of food crisis even though the fish feeds on zooplankton religiously. Results of studies carried out by Pakhomov et al (1996) do not support the hypothesis that Antarctic krill plays a major role in feeding ecology of myctophids. Maybe the diets of myctophid species tend to overlap during periods of abundant food, also when the food is less the diet differs (Pakhomov et al. 1996; Rodriguez-Grana et al. 2005). Post-metamorphic and adult myctophids are mainly nocturnal feeders in contrast to larvae who feed during the day in most species.

Parasitic Infection

Like any other marine organisms, myctophids are also subjected to parasitic infection in natural habitats. Some of the common parasites affecting some myctophid species include siphonostomatoid copepod like *Sarcotretes* sp., which attach to muscles and kidneys of the fishes (Cherel et al. 2004; Karlsbakk 2007) and *Cardiodectes medusaeus*, which penetrates its head into the heart of the myctophids (Perkins 1983; Sakuma et al. 1999).

Nematodes like *Diphyllobothrium* larva (Karlsbakk 2007; Klimpel et al. 2008) and Tetracyllidea larva *Scolex pleuronectis* were found on *Lampanyctus macdonaldi* (Klimpel et al. 2006) and a hydroid parasite *Hydrichthys* sp. was found to infest *Diaphus theta*, *Tarletonbeania crenularis* and *Lampanyctus* sp. (McCormick et al. 1967).

Ecological Importance

The caloric content of high lipids in myctophids forms a significant source of energy for top predators especially during breeding season (Phleger et al. 1997; Lea et al. 2002). Studies carried out on mesopelagic fishes by Butler et al (2001) in the Arabian Sea suggest that myctophids form an important part of the diets of predatory fishes like *Chauliodus pammelas*, *C. sloani*, *Stomias affinis* and *S. nebulosus*.

A number of cetacean species and penguins prey on myctophids and are among the non-mesopelagic animals that may be affected by commercial fishing of myctophids. In the Gulf of Oman, northern Arabian Sea regions, eastern Pacific Ocean, off West Africa and the Bay of Bengal, where the oxygen content of the water has limited or eliminated the presence of other small fish species, lanternfishes may be a more significant component of the diet for at least scombrid fishes like tunas, mackerels (FAO 1997). Findings by Lea et al (2002) highlight trophic links between high-latitude fish and their prey and emphasise the importance of myctophids as a significant energy source for marine predators foraging in the Polar Frontal Zone. Recently, Fatty acid analyses have been used to resolve trophic interactions of myctophids in Antarctic marine food webs (Stowasser et al. 2009). Myctophids are usually not accessible to flying seabirds like seagulls as the fish are not found near surface (0-5m) and these birds usually do not dive. Myctophid biomass can reach them only when these birds consume their primary prey like squids, nototheniids (endemic fishes of Antarctic region, also called as “Ice fish”) and channichthyid (“crocodile icefish or white-blood fish”) fish, who feed on myctophids (Kozlov 1995). When not consumed by predators (non-predator mortality), myctophid decomposing biomass ends up contributing to benthic nutrition (U.S GLOBEC 1993). According to Nair et al (1999), myctophids bring both nutrients and carbon dioxide to the deeper layers (500-1000m) in or near the oxygen minimum regions.

Economic/ Commercial Importance

Commercial lanternfish fisheries include limited operations off South Africa, in the sub-Antarctic and in the Gulf of Oman (Gopakumar et al. 1983; Gjøesæter 1984; Moser et al. 2006; Valinassab et al. 2007). But majority of the

myctophids are not used for direct human consumption owing to their high lipid or wax ester content, therefore they are used as predator fish feed, poultry feed, animal feed and crop fertilizers (Lekshmy et al. 1983; Balu et al. 2006). Exceptions to this are *Diaphus coeruleus*, *Gymnoscopelus nicholski* and *G. bolini* which were considered edible in the Southwest Indian Ocean and Southern Atlantic in the late 1970's (Nafpaktitis 1982; Hulley 1985; FAO 1997; Balu et al. 2006). There are no reports of human consumption of myctophids in India (FAO 1997; Balu et al 2006). Lekshmy et al (1983) have carried out various methods for processing and utilization of *Benthoosema pterotum*. They have also carried out nutritional evaluation of fish meal, dry fish and fish hydrolysate using casein protein as reference on rats for palability. However, one cannot ignore the processing difficulties on a large scale. An industrial fishery for *Lampanyctodes hectoris* in South African waters closed in the mid-1980s due to processing difficulties caused by the high oil content of the fish (FAO 1997). Interestingly, in eastern South Atlantic, this particular species accounted for around 42,560 tones (10.45%) of pelagic catch in 1973 (Hulley 1985).

However, considering their large biomass, efforts are needed to conceive ideas and to come out with a cost effective processing technology.

Conclusion

Future research

Considering the large standing stocks of myctophids in some parts of the world ocean and its fishery potential, research is necessary to understand the role of myctophids in the oceanic food web (pelagic ecosystem). According to Moku et al (2008), carbon and nitrogen cycling are common indicators of energy flow between the trophic levels. So studies related to carbon and nitrogen content of myctophids together with biochemical measurement can help to understand the dynamics of nutrient cycling in a food web.

Myctophids luminescence and behaviour can also be studied by using deep sea submersibles or deep water visual system in live habitats in addition to finding out biomass rates. Fish that are caught live/swimming or show some viability during trawling can be carefully placed in an artificial medium mimicking the natural habitat and then investigated as per the aim of research. But maintaining them in workable conditions for a long time can be difficult (Barnes et al. 1974; Johnsen et al. 2004).

Due to strong vertical migration behaviour, can myctophids help in carbon mitigation and thus reduce global warming? What is the fate of the lighter organic carbon particles (scales, faecal pellets) between the euphotic zone and deep layers? Is it recycled or consumed as marine snow by other fishes and crustaceans? Do they show any interaction with other fishes especially in deep scattering layers other than prey-predator relationship? These are some of the questions that need attention.

The northwestern Indian Ocean holds one of the three major OMZ's of the open oceans, with a very wide depth range (100-1000 m), particularly in the Arabian Sea (Naqvi et al. 2005). Strong OMZ's have substantial impacts on the abundance and distribution of mesopelagic organisms. The US JGOFS study in the Arabian Sea found a strong relationship between organisms and the oxygen concentrations especially in the OMZ (Morrison et al. 1999). Biology of the OMZ needs to be studied in detail to understand this unique niche.

Further, benthic forms like calcareous foraminiferans, nematodes and annelids show adaptations to OMZ regions. They have small, thin bodies, enhanced respiratory surface area and blood pigments such as haemoglobin. They also show biogenic structure formation for stability, an increased number of pyruvate oxidoreductases, and the presence of sulphide-oxidising symbionts (Levin 2003). Do myctophid also show similar adaptations to survive in low oxygen regions? This topic needs detailed investigation. Further, how do they adapt to pressure change during vertical migration in a matter of few hours in the oceans has to be studied. Animals living at higher altitudes on terrestrial habitats also experience such low oxygen conditions. However, they have adaptations to store more oxygen due to their high haemoglobin level. Do myctophids also show similar physiological adaptations? Can we learn something from these low-oxygen survival adaptations that will benefit human beings, especially during diving or when in submarines or submersibles?

Literature on genetic studies of lanternfishes is limited. From biodiversity view point these types of studies are needed to understand differences, similarity between different genera and species from different parts of the world oceans.

A study of biology, ecology, distribution and systematics of dominant and endemic myctophid species in the various regions of occurrence will also help to understand the dynamics of these organisms.

Conservation Status

As Myctophids have a low fecundity rate, they are prone to survival threats. Exploitation in the form of extensive conventional fishing can reduce the lanternfish stocks in easily accessible areas, without giving them a chance to revive and recover. Studies in the Arabian Sea have already shown that the biomass catch rate has reduced drastically (around 100 million metric tones as shown by Gopakumar et al. 1983; Gjøsaeter 1984, Hussain et al. 1987; U.S GLOBEC 1993 to recent estimates of approx 1.7-20 million as shown by FAO 1997; Valinassab et al. 2007). Research to understand the life cycle of myctophids, their adaptations to various stresses etc, is looked for so that the dwindling stocks in natural environments can be revived using artificial habitats. These artificially bred stocks can cater to production of fishmeal, fish oil etc rather than stressing the reserves from the oceans. Damage to, or loss of myctophid populations could have serious impact for many other organisms' especially top predators and other commercially important fish in open ocean food webs.

The biodiversity of this fish community has to be conserved by means of protecting their habitats that also include a detailed survey and inventory of existing bio-resources (Karuppasamy et al. 2007a).

The possibility exists that lanternfish populations could support globally significant fisheries. Many species of myctophids and gonostomatids together account for around 75% of the total potential global catch of small mesopelagic oceanic fishes (FAO 1997) in the Indian Ocean, especially Arabian Sea. Myctophid fishes, particularly *Benthoosema pterotum*, are among the most exciting target species available in the world for research in pelagic biology on many different levels (Valinassab et al. 2007).

Acknowledgements

Authors are grateful to Dr. S.R. Shetye, Director, National Institute of Oceanography and Council for Scientific and Industrial Research, India for facilities and encouragement. Thanks are due to Drs. Z. A. Ansari and S. Prasanna Kumar of National Institute of Oceanography for critically going through the manuscript and suggesting improvements. Authors are also thankful to Drs. Melanie L J. Stiassny and Edith Widder for granting permission to use figures in this MS. Authors also sincerely thank Ms. Nandini Sahai, Director, The International Centre Goa for correcting grammatical errors in the manuscript. This study forms a part of the project entitled "Environmental studies for assessment of myctophid resources in the Arabian Sea", funded by CMLRE and MOES. This is NIO's contribution number _____

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Figure Legends

Fig. 1 Photophore arrangement in California headlight fish, *Diaphus lucidus* (Stiassny MLJ 1997- used with permission)

Fig. 2 Region of hypoxia in the northern Arabian Sea (Redrawn using Paint) (Morrison et al. 1999)

Fig. 3 World map of possible global distribution of myctophids species (marked as numbers) based on literature survey- Refer Table 1 for serial numbers against each species (Created using Adobe Illustrator)

Fig. 4 *Benthoosema pterotum*- one of the most dominant species in the world (Karuppasamy et al. 2007a- used with permission)

Fig. 5 Larvae of some of the myctophid genera (Stiassny MLJ 1997- used with permission)

Fig. 6 Isaac Kid-Mid Trawl (Karuppasamy et al. 2007a – used with permission)

Fig. 7 Photophore arrangement in *Lobianchia gemellarii* showing sexual dimorphic nature (Stiassny 1997 – used with permission)

Fig. 8 *Taaningichthys paurolychnus*, a myctophid lacking photophores (Stiassny 1997 – used with permission)

Fig. 9 Counter-Illumination as seen in myctophids (Edith Widder/Ocean Research & Conservation Association www.biology.duke.edu/johnsenlab/links; www.teamorca.org- used with permission)

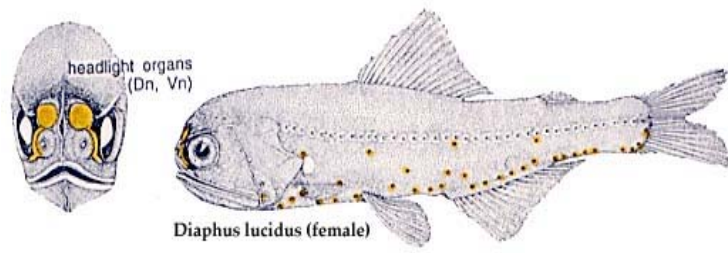


Fig1.

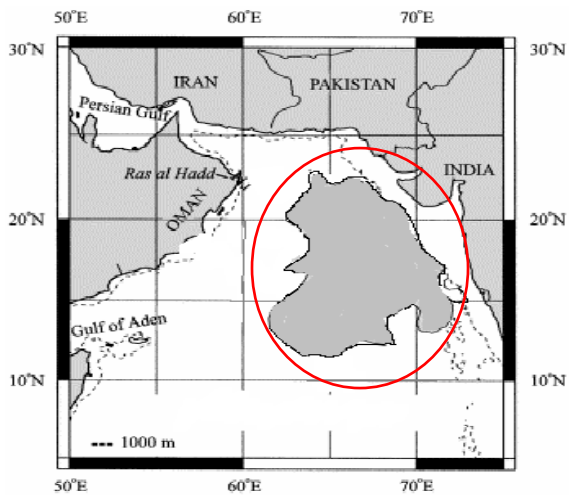


Fig2

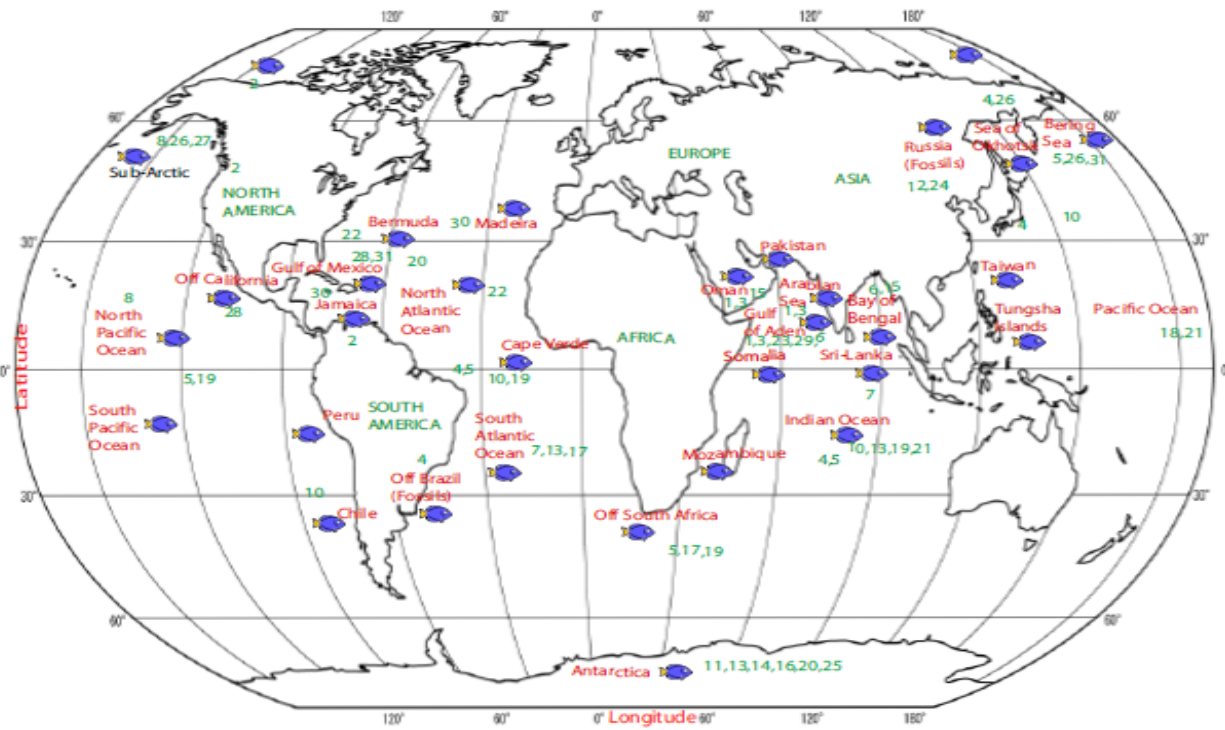


Fig3



Benthosema pterotum

Fig4

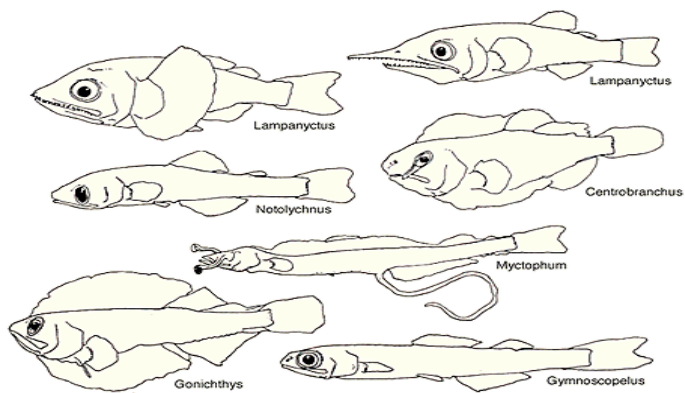


Fig5



Fig6

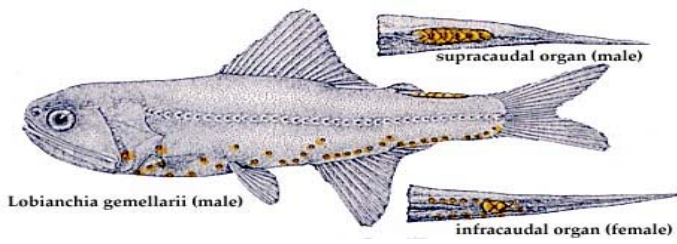


Fig7

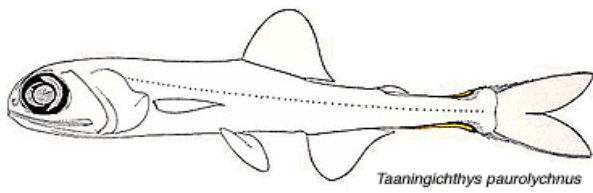


Fig8



Fig9

Table 1 Biogeographic regions of certain myctophid species* (Refer Fig.3 for distribution in the world oceans)

Sr. No.	Species	Area of Occurrence	Citations
1.	<i>Benthoosema fibulatum</i>	Gulf of Aden, southern Oman and northeast Somalian coasts.	Gopakumar et al. 1983; Gjesæter 1984; FAO 1997
2.	<i>Benthoosema glaciale</i>	Northwest Atlantic: Norway and Greenland, Mediterranean Sea, Western Atlantic: Baffin Bay and northwest Atlantic: Canada.	Gjesæter 1984; Dalpadado 1988
3.	<i>Benthoosema pterotum</i>	Gulf of Oman, Gulf of Aden, Somalia, eastern and northern Arabian Sea and Pakistan west coast.	Gjesæter 1984; Kinzer et al 1993; U.S GLOBEC 1993; FAO 1997; Valinassab et al. 2007; Karuppasamy et al. 2008a
4.	<i>Centrobranchus</i> spp.	Eastern Atlantic: Morocco to Senegal and from Gabon to Angola, western Atlantic: USA to about 14°N, and from Brazil to Argentina, northwest Atlantic: Canada, Indian Ocean: 8°S to 34°S, southwest Pacific: off New Zealand, southeast Pacific: northern section of the California Current region and off Chile, Hawaii and Japan and south China Sea.	Hulley 1985
5.	<i>Ceratoscopelus warmingii</i>	Atlantic Ocean: 35°N (eastern) and 42°N (western), Pacific Ocean, Indian Ocean: 20°N- 45°S, Reported to be common in southern Africa, south and east China Sea.	Hulley 1985; Kozlov 1995; Watanabe et al 1999
6.	<i>Diaphus arabicus</i>	Northern and eastern Arabian Sea.	Gjesæter 1984; Kinzer et al. 1993;

			FAO 1997
7.	<i>Diaphus coeruleus</i>	Southwest Indian Ocean and southern Atlantic.	Nafpaktitis 1982; Hulley 1985; FAO 1997; Balu et al. 2006
8.	<i>Diaphus theta</i> ,	Sub-Arctic and western north Pacific	Watanabe et al 1999
9.	<i>Diaphus</i> spp.	Gulf of Aden	Gopakumar et al. 1983; Gjosæter 1984; FAO 1997
10.	<i>Diogenichthys laternatus</i>	Eastern Pacific: California, USA and Mexico to Chile, Atlantic and Indian Oceans and south China Sea.	Gjosæter 1984; Dalpadado 1988
11.	<i>Electrona antarctica</i>	Antarctica Polar Front.	Neighbors et al. 1982; Hulley 1985; Kozlov 1995; FAO 1997; Phleger et al. 1999
12.	<i>Eomyctophum koraense</i>	Fossilized forms in Russia.	Prokofiev 2006
13.	<i>Gymnoscopelus bolini</i> and <i>G. nicholski</i>	Southwest Indian Ocean, southern Atlantic and Antarctica Polar Front	Nafpaktitis 1982; Hulley 1985; FAO 1997; Balu et al. 2006
14.	<i>Gymnoscopelus braueri</i> and <i>G. ophisthopterus</i>	Antarctica Polar Front	Hulley 1985; Kozlov 1995
15.	<i>Hygophum proximum</i>	Northern and eastern Arabian Sea	Gjosæter 1984; Kinzer et al. 1993; FAO 1997
16.	<i>Kreffichthys anderssoni</i>	Antarctica Polar Front	Hulley 1985; Kozlov 1995
17.	<i>Lampanyctodes hectoris</i>	South African waters and southern Atlantic	Hulley 1985; FAO 1997
18.	<i>Lampanyctus ritteri</i>	Eastern Pacific Ocean	Hulley 1985; Stiassny 1997

19.	<i>Lobianchia gemellari</i>	Pacific Ocean, Mediterranean and Black Sea, Indian Ocean and Atlantic Ocean: Madeira Islands and South Africa.	Hulley 1985; Stiassny 1997
20.	<i>Lampanyctus macdonaldi</i>	North Atlantic: between 65°N and 47°N, South Atlantic: Antarctic Polar Front and Southern Ocean: 60°-63°S, 90°-120°W	Hulley 1985
21.	<i>Myctophum aurolaternatum</i>	Pacific and Indian Ocean	Moser et al. 2006
22.	<i>Myctophum punctatum</i>	Eastern Atlantic: Mauritanian Upwelling Region (15°N-20°N), Mediterranean Sea, western Atlantic and Greenland to USA.	Moser et al. 2006
23.	<i>Myctophum spinosum</i> ,	Gulf of Aden	Gopakumar et al. 1983; Gjosæter 1984; FAO 1997
24.	<i>Oligophus moravicus</i>	Fossilized forms in Russia	Prokofiev 2006
25.	<i>Protomyctophum bolini</i> and <i>P. tensioni</i>	Antarctica Polar Front	Hulley 1985; Kozlov 1995; Watanabe et al 1999
26.	<i>Stenobranchius leucopsarus</i>	Sub-Arctic Pacific, western north Pacific: Bering Sea and Sea of Okhotsk.	Yasuma et al. 2006; Watanabe et al 1999
27.	<i>Stenobranchius nannochis</i>	Sub-Arctic and western north pacific	Watanabe et al 1999
28.	<i>Symbolophorus californiensis</i>	North Pacific: Japan and from Alaska to Baja California and Mexico.	Hulley 1985; Stiassny 1997; Watanabe et al 1999
29.	<i>Symbolophorus evermanni</i>	Gulf of Aden	Gopakumar et al. 1983; Gjosæter 1984; FAO 1997

30. *Taaningichthys paurolychnus* Eastern Atlantic: near Madeira islands and Cape Verde, western Atlantic: near Bermuda and Jamaica, Western Indian Ocean. Hulley 1985; Stiassny 1997
31. *Tarletonbeania crenularis* Eastern Pacific: southeastern Alaska to off Mexico, including the Gulf of Alaska and Bering Sea. McCormick et al. 1967; Yasuma et al. 2006

*The 33 Genera are: *Benthoosema*, *Bolinichthys*, *Centrobranchus*, *Ceratoscopelus*, *Diaphus*, *Diogenichthys*, *Electrona*, *Gonichthys*, *Gymnoscopelus*, *Hintonia*, *Hygophum*, *Idiolychnus*, *Krefflichthys*, *Lampadena*, *Lampanyctodes*, *Lampanyctus*, *Lampichthys*, *Lepidophanes*, *Lobianchia*, *Loweina*, *Metelectrona*, *Myctophum*, *Nannobranchium*, *Notolychnus*, *Notoscopelus*, *Parvilux*, *Protomyctophum*, *Scopelopsis*, *Stenobranchius*, *Symbolophorus*, *Taaningichthys*, *Tarletonbeania* and *Triphoturus*