Indian Journal of Marine Sciences
Vol. 39 (2), June 2010, pp. 227-237

Distribution of mesopelagic micronekton in the Arabian Sea during the winter monsoon

P K Karuppasamy, K R Muraleedharan*, P K Dineshkumar & M Nair
National Institute of Oceanography, Regional Centre, Post Box No. 1913, Ernakulam North Post, Cochin – 682 018, Kerala, India
*[E-mail: muraleedharan@nio.org]

Received 5 February 2009; revised 24 June 2009

Response of micronekton to oxygen minimum zones in the Arabian Sea (AS) during winter monsoon period was investigated using data of 52 trawls deployed during four winter cruises between 1998 and 2000. Twenty-nine species, representing 19 groups were identified in the deep scattering layer (DSL). The mesopelagic community was dominated by shrimps, myctophids, fish larvae, phosichthyids and leptocephalus. Based on the distribution, two regions were distinguished: the southern Arabian Sea (sAS) and the northern Arabian Sea (nAS). Ceratoscopelus warmingii, Diogenichthys panurgus, Diaphus fragilis, Lampanyctus turneri, Thallasocaris carinata, Leptochela robusta, Oplophorus typus, Viniciguria nimbaria, V.leucita were dominant in the sAS; Benthosema pterotum, Bolinichthys longipes, Diogenichthys panurgus, D. fragilis, D. aliciae, V. nimbaria, V. leucita were dominant in the nAS. Most of these species were abundant in the upper 50 m during night, but were found in the oxygen minimum zone (OMZ) between 175 to 800 m north of 13oN during daytime. Fourteen of 29 species were detected within the OMZ during day time.

[**Keywords:** Oxygen minimum zone, Mesopelagic fishes, Shrimps, Myctophids, Arabian Sea]

Introduction

Mesopelagic fishes are commonly present in the world oceans[1]. They are main consumers of zooplankton, larvae, juvenile fish and are important prey for the higher producers such as tuna, squid and dolphin in the oceanic food webs, thus providing a link between top predators and zooplankton[2]. These fishes are small and usually found at depths between 100 and 1000 meters. Most of the mesopelagic species exhibit diel vertical migrations (DVM) from the mixed layer during night down to 1000-2000 meters during day[3]. Due to their small size and their ability to swim, they are termed micronekton[4]. The DVM is one of the most widespread behaviour in the mesopelagic zone which influences the life history of nonmigrating and migrating fishes[5]. Thus, the migrating animals influence the feeding behaviour and spatial distribution patterns of the predators[6].

In the mid-waters, sunlight is limited, temperature falls rapidly, salinity increases, oxygen decreases, and food availability dwindles. Despite the limited food availability, mesopelagic organisms thrive there. Mesopelagic fishes (Myctophidae, Gonostomatidae, Sternoptychidae, Phosichthyidae, Malacosteidae, Melanostomidae, Bregmacerotidae etc.), decapods (Sergestidae, Oplophoridae, Pasiphaeidae, Benthesicymidae, Thalassocarididae) and cephalopods[7,8,9] show a biogeographic distinctness of specific areas[10]. Many micronektonic species can be found near the sea surface, but most occur in the midwater at the edge of, or beyond the continental shelves[11]. Many species of myctophids, phosichthyids and gonostomatids together account to 75% of the mesopelagic fishes[12]. Through their DVM, they facilitate the transfer of carbon from the deep to higher trophic levels in the surface and transport carbon dioxide to deeper OMZ[13].

There are three regions in world oceans, where some unusual oceanographic processes cause the oxygen demand to exceed its supply, resulting in complete oxygen depletion at the intermediate depths[14]. Two of these sites are located in the eastern tropical north and south Pacific, while the third site is in the nAS[15], where the oxygen depletion is more pronounced during the winter monsoon[16,17]. Kamykowski and Zentara[18] opined that the midwater OMZ is found in all the world oceans, but is more prominent in the nAS. OMZs develop due to the degradation of organic matter by bacteria besides the sluggish horizontal mixing below the thermocline[19]. The US JGOFS study in the AS found a strong relationship between organisms and the oxygen concentrations, especially in the OMZ[20]. The species that live in the OMZ are typically vertical migrators, which rise to oxygenated waters during the night[21,9]. The objective of the present paper is to examine the composition of the AS mesopelagic micronekton fauna in relation to the OMZ during winter monsoon.

Materials and Methods

Mesopelagic fish samples were collected from 52 trawl stations using Isaacs Kidd Midwater Trawl (IKMT) during 4 cruises (October, 1998; November, 1998; December, 1999 and December, 2000) of Fisheries and Oceanographic Research Vessel (FORV) *Sagar Sampada* as part of the DSL programme in the AS from 1998 to 2000 in the area between 6-21°N and 66-77°E ((Fig. 1). Temperature and salinity were determined from Sea-Bird Electronics CTD (USA, model: SBE-911 plus) data and the sea surface temperature (SST) was measured using a bucket-thermometer. The salinity values from the CTD were corrected using the values obtained from Autosal (GuildLine, model, 8400 A) onboard. Water samples for dissolved oxygen (DO) were collected using a Rosette sampler fitted with Niskin samplers from 13 standard depths (viz., 0, 10, 20, 30, 50, 75, 100, 150, 200, 300, 500, 750 and 1000 m). DO was measured onboard using the Winkler method[22]. The concentration of nitrate and nitrite were obtained using an autoanalyser (SKALAR, Model 51001-1), following the principles of Grasshoff *et al*. 1983[22]. The acoustic detection of DSL was made by two scientific Echo sounders: Simrad, EK 400 and EK 200 (38 and 120 KHz).

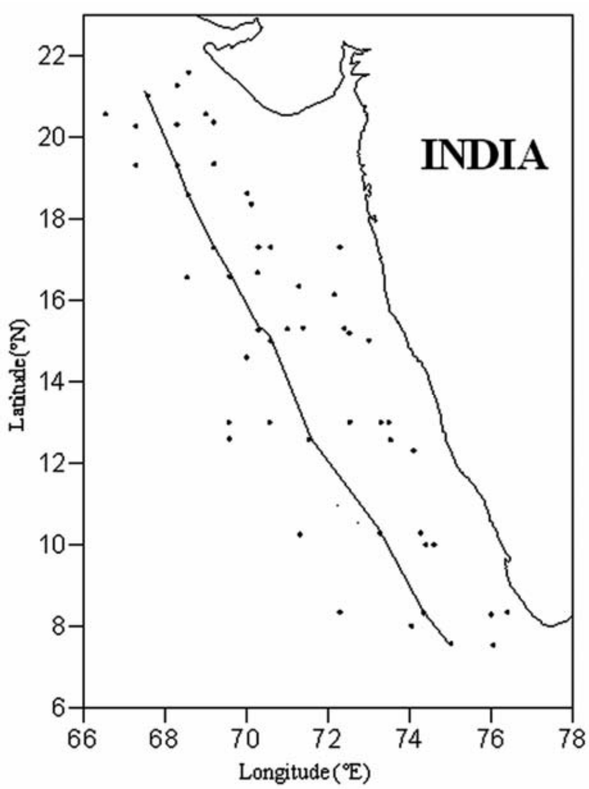

Fig. 1—Sampling locations of mesopelagic micronekton from the Arabian Sea. The straight line shows the stations selected for the temperature, salinity, dissolved oxygen, nitrate and nitrite contour.

The gear for the collection of mesopelagics, the IKMT, designed to collect meso/bathy pelagic organisms, which are larger and more active than the specimens caught by plankton net[23]. The net had an opening of 10 m^2 and a cod end (collecting cone) with a lining of 1.5 mm square mesh (0.25 mm twine thickness) (for more details, refer Karuppasamy[9]). The sample was collected in a 5 litter bucket attached to the cod end. The net was lowered and retrieved open, and its depth was measured by a transducer mounted at the head rope. The towing speed was 3 knots and 30 minutes was the towing time. The catches were preserved in 10% buffered formalin, noting the volume immediately after the haul. On shore, the organisms were sorted into groups, and their number and wet weight recorded. The sampling depth varied between the surface and 750 m, and the hauling depth depended on the concentration of DSL thickness as evidenced from echograms. The catch per unit area was estimated using the swept area method[24]. Taxonomic criteria and diagnosis for mesopelagic micronekton identification mainly relied on Holthuis[25] and Perez Perfante & Hensely[26].

The catch per unit area was estimated, using the equation:

$$B = \frac{(CW/a) * A}{x_1}$$

Where,

CW = Catch in weight of a haul

a = The area Swept by the gear during one unit of effort computed from the equation

$a = t * v * h * x_2$

Where,

t = time equal for trawling

v = velocity of trawling

h = average head rope length of IKMT (10 foot IKMT)

x_2 = effective net opening which was taken as 0.5

A = total area swept

X_1 = portion of catch actually retained by the gear (taken as 0.5 here)

Biodiversity indices

Diversity is a concise expression of how individuals of a community are distributed in subsets of groups. Diversity decreases when one or a few groups dominate in a community, when individuals of a more common group replace individuals of a rare group or when one or a few groups rapidly reproduce. To mathematically analyze and compare changes in aquatic communities due to environmental influence, diversity indices can be used as one of the tools.

Shannon and Weaver diversity index[27]

$H(S) = -\Sigma [p_i (\log_2 p_i)]$

$P_i = n_i/n$ (proportion of the sample belonging to the i^{th} species).

Margalef's richness index[28]

$D = (S-1)/\log_e^N$

S = number of species

N = total number of individuals of all the species in the sample.

Heips evenness index[29]

$E = e\,(H(S) - 1/S-1)$

H = species diversity in bits of information per individual

S = the number of species

Results

Environmental characteristics

The vertical temperature profile during this season along different transects are given in Fig. 2a. In the sAS, the 28°C contour spread around 50 m, indicating the homogenous character of the water column. Below 50 m depth the isotherms were well stratified. Along the nAS, 1°C decrease in temperature is noticed indicating the effect of winter cooling. The surface temperature showed marked differences of 1.5°C between sAS and nAS. The mixed layer was deep (60 m) and the sAS showed comparatively less salinity (36 psu) than the nAS (>36.5 psu). Intrusion of high saline water (> 36.5 psu) waters was evident between 20 to 75 m in the nAS. Along the 22°N transect, a sharp vertical mixing was evident making it homogenously distributed in salinity (~36.5 psu) (Fig. 2b).

Exceedingly low oxygen concentrations were found within a large body of intermediate waters. The OMZ, defined by the DO < 20 µM, was prominent in the intermediate layers (175-800 m) from 12°N to northward (Fig. 2c). Distribution of nitrate in nAS characterise greater enrichment due to convective mixing than the sAS (Fig. 2d). During the season, a secondary nitrite maximum was observed in nAS in the intermediater waters between 200-800 m, with increased in width towards north. The secondary nitrite maximum is associated with low oxygen and results from the reduction of nitrate during the oxidation of sinking organic matter. The secondary nitrite gradually decreased to the south (0.5 µM). The secondary nitrite maxima (> 1 µM) was identified in the nAS at 200-800 m, but was restricted to a limited area between 19 to 21°N (Fig. 2e).

The distribution of mesopelagic fishes

There is a distinct resident community in the DSL biocomposition (Fig. 3). The north (15-22°N)–south (06-15°N) comparison showed an increasing catch towards north (55.80%). The numerical catch ranged from 0.8 to 70 Nos./1000 m^3. Along the nAS, the maximum catch was at 18.35°N, 70.12°E (52 Nos./1000 m^3), 17.3°N, 70.29°E (44 Nos./1000 m^3), 16.14°N, 72.15°E (41 Nos./1000 m^3), and 17.29°N, 69.2°E (37 Nos./1000 m^3), whereas along the sAS high catches were recorded at 08.33°N, 74.134°E (70 Nos./1000 m^3), 10.29°N, 73.26°E (64 Nos./1000 m^3), 10.00°N, 74.59°E (47 Nos./1000 m^3), and 12.56°N, 71.52°E (34 Nos./1000 m^3).

Biocomposition

The mesopelagic fishes comprised 19 groups. Pelagic shrimps (3.66 Nos./1000 m^3), myctophids (2.17 Nos./1000 m^3), fish juveniles (1.03 Nos./ 1000 m^3) and phosichthyids (0.93 Nos./1000 m^3) were abundant. During day, leptocephalus, cephalopods, *Bregmaceros* sp, gonostomatids etc. were lesser. During night, shrimps (16.58 Nos./1000 m^3), juvenile fishes (4.12 Nos./1000 m^3), phosichthyids (3.34 Nos./1000 m^3), myctophids (3.14 Nos./1000 m^3) and leptcephalus (1.38 Nos./1000 m^3) were dominant (Table 1).

Shrimps, myctophids, phosichthyids and fish juveniles formed the major composition of the micronekton (Fig. 4), although their catch varied considerably in individual hauls. Shrimp was recorded in maximum at 8.33°N, 74.34°E (303 Nos./1000 m^3) and 10.24°N, 73.26°E (54 Nos./1000 m^3) (Fig. 4a). Myctophid catch showed a different trend, the most of their catch was recorded at 21° 00°N, 67.58°E (23 Nos./1000 m^3), 19.33°N, 69.20°E (20 Nos./1000 m^3) and 15.00°N, 73.00°E (19 Nos./1000 m^3) (Fig. 4b). The group, Phosichthyids enjoys wide distribution and occupies most parts of the central and nAS with maximum at 18.35°N, 70.17°E (26 Nos./1000 m^3) and

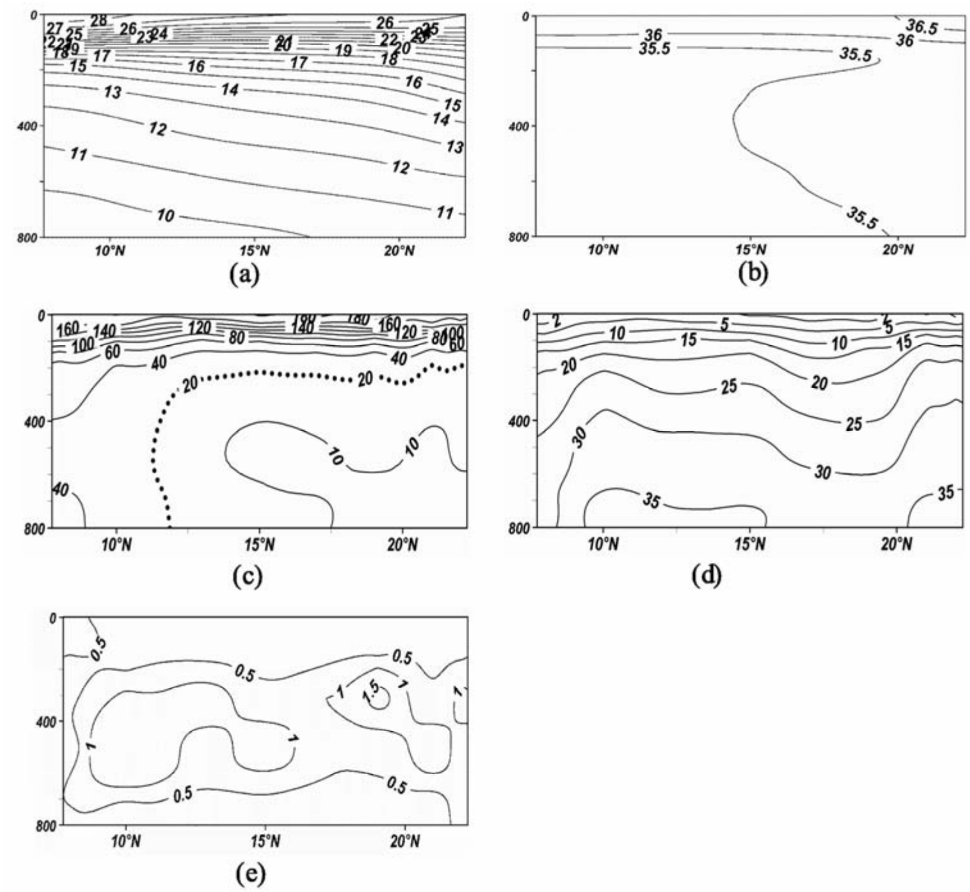

Fig. 2—Vertical distribution of temperature (a), salinity (b), dissolved oxygen (c), nitrate (d), nitrite (e), in the Arabian Sea during the winter monsoon of 1998-2000

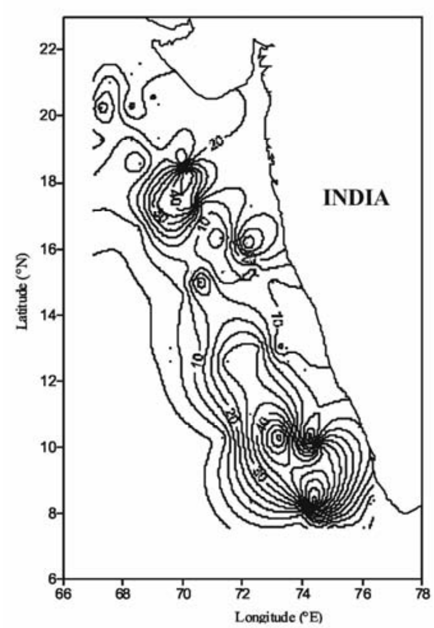

Fig. 3—Distribution of mesopelagic micronekton (Nos./1000 m^3) in the Arabian Sea

Table 1— Abundance and composition of mesopelagic micronekton in the Arabian Sea in the day and night trawls

Mesopelagic groups	Day (Nos./1000m^3)	Night (Nos./1000m^3)	Composition (% of total)
Shrimps	3.66	16.58	53.29
Crabs	0.002	0.01	0.03
Cephalopods	0.19	0.23	1.10
Leptocephalus	0.57	1.38	5.15
Bregmaceros	0.08	0.48	1.48
Fish juvenile	1.03	4.12	13.56
Myctophidae	2.17	3.14	13.97
Phosichthytidae	0.93	3.31	11.17
Chauliodontidae	0.004	0.02	0.06
Nemichthyidae	0.002	0.001	0.01
Trichuridae	0.01	-	0.02
Tricanthidae	0.002		0.01
Gonostomatidae	0.04	-	0.10
Sternoptychidae	0.01	-	0.03
Stomiidae	-	0.002	0.01
Melanostomiidae	-	0.003	0.01
Champsodontidae	-	0.002	0.01
Astronesthidae		0.002	0.01
Carangidae	-	0.001	0.003

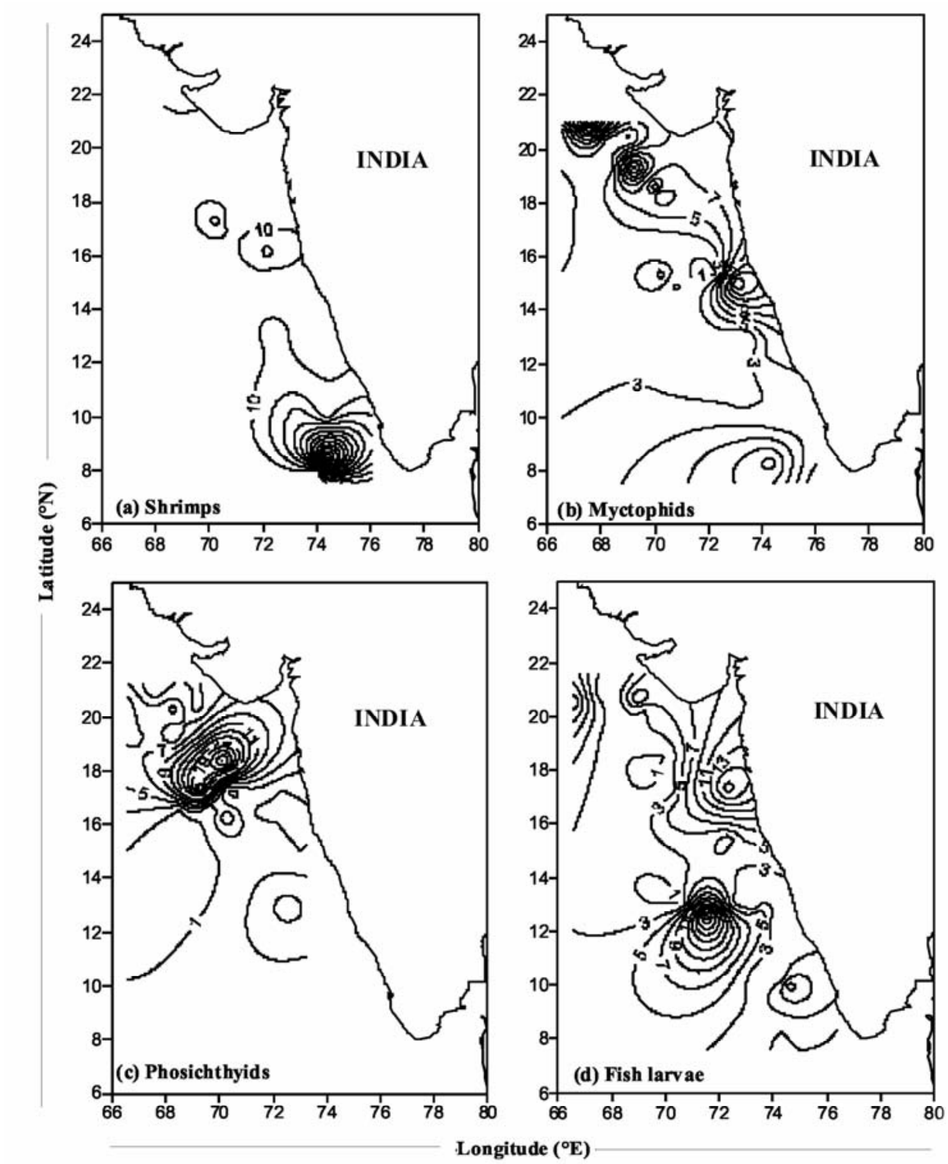

Fig. 4—The distribution of (Nos./1000 m^3) of mesopelagic major micronekton in the Arabian Sea

17.29°N, 69.2°E (22 Nos./1000 m^3) (Fig. 4c). Another important group of fish larvae is found to occur between 08.00°N, 22.00°E with maximum at 12.56°N, 71.52°E (25 Nos./1000 m^3) and 17.29°N, 72.2°E (18 Nos./1000 m^3) (Fig. 4d).

Species composition and vertical migration of mesopelagic fishes

Table 2 shows the list of mesopelagics in the sAS and nAS. A total of 29 species representing 15 families (fishes, pelagic shrimps and crabs) were recorded. Among the mesopelagics, the myctophids were the most diverse (13 species), followed by shrimps (4 species) and phosichthyids (2 species). The distribution of these species in relation to depth in the day and night collections are furnished at Table. 3. In the sAS (6-15° N), during night, most of the species occurred at 0-50 and 50-100 m depths. *Vincigurria leucita*, *V.nimbaria*, *Diogenichthys panurgus*, *D.fragilis, Leptochela robusta*, *Diaphus alicia*, and *Bolinichthys longipes* were the major contributors from 0-50 m depth and *Thallassocaris carinata*, *L.turneri*, *V.nimbaria*, *V.leucita* and *D.panurgus* were dominant in the 50-100 m depths. During day, the majority of catches were from 100-300 m and > 300 m depths showing that most of the mesopelagic fishes were found in deeper waters. The species that dominated the collections from 100-300 m depth were

Table 2—Mesopelagic micronekton species occurrence in the southern Arabian Sea and northern Arabian Sea during the winter monsoon

Species Name	Total Nos.	Length range (mm)	sAS	nAS
Family: Myctophidae				
Benthesema pterotum	526	20-62	√	√
B.fibulatum	58	34-45	√	√
Bolinichthys longipes	284	17-45	√	√
Ceratoscopelus warmingii	61	40-70	√	√
Diaphus fragilis	1238	20-58	√	√
D.aliciae	729	16-43	√	√
D.signatus	50	38-57	√	–
D.fulgens	10	25-46	√	√
D.lucidus	234	40-71	√	√
Hygopum proximum	42	20-47	√	√
Myctophum aurolaternum	3	25-104	–	√
Lampanyctus turneri	183	37-86	√	√
Diogenichthys panurgus	232	31-60	√	√
Family: Phosichthyidae				
Vincigurria nimbaria	1130	15-45	√	√
V.leucita	1772	75-46	√	√
Family: Stomidae				
Stomias boa boa	206	60-76	√	√
Family: Trichiuridae				
Trichiurus sp.	24	22-54	√	√
Family: Tricanthodidae				
Macrorhamphosoe sp.	4	60	√	–
Family: Nemichthyidae				
Nemichthys sp.	2	36-87	√	–
Family: Melanostomidae				
Bathophilus sp.	8	44-90	√	–
Family: Chauliodontidae				
Chauliodus sp.	2	80-203	√	√
Family: Astronesthidae				
Astronesthesus sp.	14	28-58	√	–
Family: Bregmacerotidae				
Bregmaceros sp	2	46-48	√	–
Pelagic shrimps				
Family: Thalassocridae				
Thalassocaris carinata	10183	5-15	√	–
Family: Phasiphaeidae				
Leptochela robusta	118	10-35	√	–
Family: Sergestidae				
Sergestes seminudus	97	26-46	√	√
Family:Benthysicymidae				
Gennadas sordidus	1	36	√	–
Family: Oplophoridae				
Oplophorus typus	224	40-60	√	–
Crabs				
Family:				
Charybdis (G) smithii	15	40-60	–	√

T.carinata, *O.typus*, *V.leucita*, *D.fragilis*. *T.carinata*, *V.leucita*, *L.robusta* were the predominant species caught from > 300 m. In the nAS (17-22° N), during night, the catches from 0-50 were dominated by *D.aliciae*, *V.leucita*, *B.longipes*, *V.nimbaria*, *Stomias boa boa* and at 50-100 m were *D.panurgus*, *D.aliciae*, *V.leucita*, *N.nimbaria* and *B.pterotum*. During day, the abundant species that were recorded from 100-300 m were *T.carinata*, *B.pterotum*. The species that were dominant at depths below 300 m were *D.fragilis*. *D.lucidus* and *V.leucita*. The species diversity (H′=2.237) and richness (d=2.813) were higher in the depth range of 150-300 m, where as the evenness (J′=0.7393) was comparatively higher in the 0-50 m depth (Table 4).

Discussion

Mesopelagic fishes are the major pelagic community linking to zooplankton with higher trophic groups. In the present survey nineteen groups were found in the upper 800 m during winter monsoon. Among the mesopelagics, the most dominant groups were the myctophids (13 species) and shrimps (4 species). The striking feature was the abundance of mesopelagics in the nAS than in the sAS. The northwestern AS is relatively rich in fisheries resources, with considerable quantities of mesopelagics occurring on, and seaward of the continental slope and through the deep zone of Oman Sea waters[30]. A study revealed pronounced vertical migration in night than in the day. During the day, they stay below 200 m, while during night they rise to the surface. One of the behavioral characteristics of the mesopelagics is their DVM; from below 500 m during the day into surface layers at night[31,32]. The DVM contribute significantly to the vertical transport of organic material from epipelagic to mesopelagic zoes (biological pump;[33]). These groups play a major role as the diet of fishes like tuna and squids [34,35]. Shrimps are the dominant group among the mesopelagic micronekton. Among the pelagic crustaceans, shrimps occupy a prime position[36,8]. Their abundance increases from the north to south, as the sAS is more productive than the nAS. The myctophids were concentrated more in the nAS than in the sAS.

Winter monsoon season is characterised by cooling (< 26°C) of surface waters in the north. Towards the south, the SST gradually increases (>28°C). Vertical structure of salinity shows two maxima during winter. The Arabian Sea High Salinity Water mass (ASHSW)

Table 3—Vertical distribution (Numbers) of mesopelagic micronekton species from the Arabian Sea

Latitude (°N)e	Day and Night	Depth in (m)	*Benthosema pterotum*	*Benthosema fibulatum*	*Bolinichthys longipes*	*Ceratoscopelus warmingii*	*Diogenichthys panurgus*	*Diaphus fragilis*	*Diaphus aliciae*	Diaphus signatus	*Diaphus fulgens*	*Diaphus lucidus*	*Hygophum proximum*	*Myctophum aurolaternum*	*Lampanyctus turneri*	*Vincigurria nimbaria*	*Vincigurria leucita*	*Stomias boa boa*	*Trichiurus sp*	*Macrorhamphosoe sp*	*Nemichthys sp*	*Bathophilus sp*	*Chauliodus sp*	*Astronesthesus sp*	*Bergmaceros sp*	*Thallassocaris carinata*	*Leptochela robusta*	*Sergestes seminudus*	*Gennadas sordidus*	*Oplophorus typus*	*Charybdis (G) smithii*
		0-50	–	–	–	–	–	–	–	–	–	–	–	–	–	–	50	–	–	–	1	–	–	–	–	–	–	–	–	–	1
		50-100	–	13	2	4	72	–	4	13	–	–	–	–	59		2	1	–	–	–	–	2	7	–	8388	–	–	–	–	1
	N	100-300	–	–	1	–	4	–	6	7	3	23	4		27	64	–	–	–	–	–	1	–	–	–	–	–	–	–	–	2
8		>300	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	D	100-300	–	1	–	2	–	–	–	–	–	1	–	–	–	–	–	–	4	4	–	–	–	–	–	100	–	–	–	150	1
		>300	–	6	–	–	12	–	–	30	–	16	–	–	–	10	–	–	–	–	–	–	–	–	–	120	–	–	–	12	–
		0-50	–	–	–	–	–	–	–	–	–	–	–	–	–	34	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		50-100	–	–	5	20	–	4	15	–	–	–	1	–	79	116	77	–	–	–	–	–	–	7	–	–	–	–	–	–	2
	N	100-300	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7	–	–	–	–	–	–	–	–	–
10		>300	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
	D	100-300	–	–	–	7	–	1	–	–	–	–	–	–	–	–	56	–	–	–	–	–	–	–	–	165	–	–	–	2	3
		>300	–	–	3	25	–	–	7	–	–	–	–	–	11	15	–	–	–	–	–	–	–	–	–	1303	–	–	–	60	–
		0-50	–	9	2	–	60	20	–	–	–	–	–	–	5	18	80	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		50-100	–	7	7	–	32	5	–	–	–	–	6	–	–	–	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–
13	N	100-300	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		>300	–	–	–	–	–	–	–	–	–	–	–	–	–	–	400	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	D	100-300	–	–	–	–	–	9	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		>300	–	1	–	–	23	27	7	–	–	–	1	–	–	122	158	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		0-50	2	–	48	–	2	374	103	–	–	–	24	–	–	27	108	–	–	–	–	–	–	–	–	–	80	5	–	–	–
	N	50-100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
15		100-300	–	–	–	–	–	–	–	–	–	–	–	–	–	19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		>300	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	D	100-300	–	1	–	–	–	121	30	–	–	–	–	–	–	7	30	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		>300	–	–	–	–	–	33	–	–	–	–	–	–	–	31	35	–	–	–	–	–	–	–	–	–	37	–	1	–	–

Degree	Day and Night	Depth in Meter	*Benthosema pterotum*	*Benthosema fibulatum*	*Bolinichthys longipes*	*Ceratoscopelus warmingii*	*Diogenichthys panurgus*	*Diaphus fragilis*	*Diaphus aliciae*	*Diaphus signatus*	*Diaphus fulgens*	*Diaphus lucidus*	*Hygophum proximum*	*Myctophum aurolaternum*	*Lampanyctus turneri*	*Vincigurria nimbaria*	*Vincigurria leucita*	*Stomias boa boa*	*Trichiurus sp*	*Macrorhamphosoe sp*	*Nemichthys sp*	*Bathophilus sp*	*Chauliodus sp*	*Astronesthesus sp*	*Bergmaceros sp*	*Thallassocaris carinata*	*Leptochela robusta*	*Sergestes seminudus*	*Gennadas sordidus*	*Oplophorus typus*	*Charybdis (G) smithii*
		0-50	—	1	—	—	3	17	150	—	—	—	2	3	2	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
		50-100	—	—	29	—	93	8	—	—	—	—	—	—	—	380	287	—	—	—	—	1	—	—	—	—	—	—	—	—	—
	N	100-300	—	—	—	—	—	—	—	—	—	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17		>300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	D	100-300	—	3	—	—	—	—	—	—	—	—	—	—	—	9	16	—	—	—	—	—	—	—	—	105	—	92	—	—	—
		>300	—	—	—	—	—	431	—	—	—	194	2	—	—	2	30	—	—	—	—	—	—	—	—	2	—	—	—	—	—
		0-50	4	—	—	—	4	7	143	—	—	—	1	—	—	—	158	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		50-100	—	—	—	—	7	—	119	—	—	—	1	—	—	—	51	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N	100-300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19		>300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	D	100-300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		>300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		0-50	52	—	165	—	—	—	—	—	—	—	—	—	—	139	30	205	—	—	—	—	—	—	—	—	—	—	—	—	4
		50-100	—	—	15	—	—	4	108	—	—	—	—	—	—	123	98	—	—	—	—	—	—	—	—	—	1	—	—	—	—
21	N	100-300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		>300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	D	100-300	47	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		>300	—	11	—	—	—	151	35	—	—	—	1	—	—	4	76	—	20	—	—	—	—	—	—	—	—	—	—	—	—
		0-50	12	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N	50-100	360	—	7	2	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
22		100-300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		>300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	D	100-300	49	5	—	1	—	17	—	—	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		>300	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

In the day collections, mesopelagics were not found at 0-50, 50-100 m depths in many transects

Table 4—Diversity, richness (parenthesis) and evenness (J′) of mesopelagic micronekton species

Depth range (m)	Total number of species (S)	Total number of Individuals (N)	Species richness (d)	Species evenness (J′)	Species diversity (H′)
0-50	17	2283	2.069	0.7393	2.095
50-150	19	10564	1.943	0.3088	0.9092
150-300	21	1224	2.813	0.7348	2.237
300-800	18	3435	2.088	0.5873	1.698

originating from the north penetrates to south (10°N), through the upper 100 m. Another salinity maxima (35.6-35.0 psu) associated with the OMZ is trapped between 150-800 m. The DO concentration in the AS decreased sharply to the suboxic level below 175 m depth range and the intense OMZ was observed in the north of 13°N. The secondary nitrite maxima and its thickness during this season was more (~500 m). The OMZ was influenced by the oxygen supply and consumption, because of more vigorous dentrification[15].

The high biological production in surface layers causes high oxygen demand at intermediate depths and is primarily responsible for the development of oxygen minimum conditions (150-1000 m) in the AS[37]. The high salinity watermass, originally from the north penetrate to the south and reaches far beyond 10°N through the subsurface layers[38]. It is known that oxygen is not distributed uniformly in the oceans[39]. The AS has been recognized as a region of intense O_2 deficient zone. The mid depth O_2 deficiency in the AS is perhaps the most significant in the world oceans, as the concentration within 150-1000 m is less than 20 µM in a vast central and northeastern area[40]. Significantly, the AS contains huge stocks of (~100 million tons) of myctophids[36], which are specially adapted to low (<10 µM) ambient O_2 levels[41]. The JGOFS study showed a strong relationship between the distribution of organisms and the oxygen profiles in the AS, especially in locations where the OMZ was pronounced. Anyway, the response to the OMZ varied with the type of organisms[42].

Among 13 species of myctohids, the predominant species were *B.pterotum, B. longipes, D. panurgus, D.fragilis,* and *D. aliciae*. Gjosaeter[43] reported *B. pterotum* as the dominant species of the area off the coast of Pakistan. This corresponds roughly with our sampling stations along 22°N. In contrast, *B. pterotum,* which were absent in the southern area (8°-15°N), became increasingly abundant to the north. Among the myctophid species, *D. fragilis, D. aliciae* and *B. longipes,* relatively more number of specimens were caught, particularly in the region of nAS. Most of the species showed a primary maximum within the OMZ. Some species like *B.fibulatum, B.longipes, D.fragilis, D.aliciae, H.proximum, G.sordidus, T.carinata, O.typus, C.smithii, V.nimbaria, V.leucita, Trichiurus* sp, *Macrorhamphosodes* sp, *Nemichthys* sp occurred mostly within the OMZ during day. Possibly a lethargic behaviour of mesopelagic fish especially myctophids, particularly at oxygen deficient depths, could have contributed to a reduced net avoidance during daytime. Barhame[44] documented lethargy in myctophid fishes to drift. Similar avoidance by some myctophid species in the OMZ was noted by Wisner[45] from the eastern Pacific Ocean. Although abundant in other parts of the Pacific Ocean, *Diogenichthys atlanticus* and *Centrobranchus* sp were absent in a OMZ of ~1.0 ml/l. Hopkins and Gartner[46] from a trawl collection of over 50 myctophid species suggested niche separation as a means to reduce competition. According to the literature, 55 species of myctophids are known from AS[47]. Tsarin and Boltacher[48] recently recorded 16 species of myctophid in the OMZ of nAS. It is interesting to note that the *B.bifulatum*, are of major specimens in the study regions.

Childress[49,50] found that oxygen consumption declines rapidly with depth in living pelagic crustaceans and fishes[51], which also varies with depth. Omori[52] stated that the distributions of many shrimps are patchy and probably shoaling might occur as a result of intraspecific interaction. Studies on midwater fish are limited to the O_2 minimum layer in the eastern tropical Pacific and/or morphological adaptations. Although the present study has highlighted the major micronektonic groups such as myctophid and shrimps within the OMZ, this mechanism involved and the physiological adaptation have not been understood. This would require detailed in-situ and in-vitro investigations so that the importance of the OMZ and its potential productivity in the mesopelagic depth zones in the AS can be well understood.

Acknowledgements

We are thankful to Director, National Institute of Oceanography, Goa, the Director, Central Marine Fisheries Research Institute, Cochin and the Scientist-in-Charge, Regional Centre, National Institute of Oceanography, Cochin, for encouragement and support. The lead author is grateful to the Council of Scientific Industrial Research (CSIR) for providing financial assistance in the form of a Senior Research Associateship (SRA). This is NIO contribution XXXX.

References

1 McClatchie S & Dunford A, Estimated biomass of vertically migrating mesopelagic fish of New Zealand, *Deep-Sea Research* I, 50 (2003), 1263-1281.

2 Williams A, Koslow J A, Terauds A & Haskard K M, Feeding ecology of the fishes from the mid slope micronekton community of southern Tasmania, Australia, *Marine Biology,* 139 (2001), 1177–1192.

3 Salvanes A G V & Kristoffersen J B, Mesopelagic fishes. *Encyclopedia of Ocean Sciences*, vol.3. Edited by J.Steele et al. Academic Press, (2001), 1711-1717.

4 Herring P, The biology of the deep ocean. In: Crawley et al.(eds) Biology of habitats. Oxford, 2002, pp 314

5 Willis J M & Pearcy W G, Vertical distribution and migration of fishes of the lower mesopelagic zone off Oregon, USA, *Marine Biology*, 70 (1982), 87-98.

6 Bertrand A, Bard F & Josse E, Tuna food habits related to the micronketon distribution in French Polynesia, *Marine Biology*, 140 (2002), 1023-1037.

7 Menon N G, Preliminary investigation of the Fish Biomass in the Deep Scattering Layer of the EEZ of India. *Proc. First Workshop Scientific Results FORV Sagar Sampada*, DOD/ICAR (CMFRI & CIFT), Cochin, 5-7 June, (1990), 273 - 280.

8 Karuppasamy P K, Menon N G, Nair K K C & Achuthankutty C T, Distribution and abundance of pelagic shrimps in the deep scattering layer of the Arabian Sea, *Journal of Shellfish Research*, 25 (2006), 1013-1019.

9 Karuppasamy P K, Balachandran K, Simmy George, Balu S, Vimala Persis & Menon N G, A check list of fishes collected by IKMT from the DSL survey in the Indian EEZ of Arabian Sea, *Indian Hydrobiology*, 9 (2007), 311-316.

10 Wienerroither R M, *Species composition of mesopelagic fishes in the area of the Canary Islands*, Eastern Central Atlantic. Fritz (ed.): 6th GFBS Annual Congress Abstracts. Org. Divers. Evol. 3, Electr. Suppl. 17 (2003).

11 Abookire A A, Piatt J F & Speckman S G, A nearsurface, daytime occurrence of two mesopelagic fish species (*Stenobrachius leucopsarus* and *Leuroglossus schmidti*) in a glacial fjord, *Fish Bulletin U.S*, 100 (2002), 376–380.

12 FAO, Review of the state of the world fishery resources: Marine Fihes 2. Lanternfishes-A potential fishery in the northern Arabian Sea. *FAO fisheries circular number*, 920 (1997).

13 Butler M, Bollens S.M., Burkhalter B., Madin L.P. & Horgan M., Mesopelagic fishes of the Arabian Sea: distribution, abundance and diet of *Chauliodus pammelas*, *Chauliodus sloani*, *Stomias avinis* and *Stomias nebulosus, Deep-Sea Research* II, 48 (2001), 1369-1383.

14 Deuser W G, Reducing environments, in Riley, J. P., & Skirrow, G. (eds) Chemical Oceanography, 2nd edn, Vol. 3, London, Academic Press, pp1-38 (1975).

15 Naqvi S W A, Naik H, Pratihary A, Souza1 W D, Narvekar P V, Jayakumar D A, Devol A H, Yoshinari T & Saino T, Coastal versus open-ocean denitrification in the Arabian Sea, *Biogeosciences,* 3 (2006), 665- 695.

16 Sen Gupta R, Caroline Morales, George M D, Kureishy T W, Noronha & Fouderkar, Chemistry and hydrography of the Andaman Sea, *Indian Journal of Marine Sciences* 10 (1981), 220-223.

17 Madhu N V, Jyothibabu R, Ramu L, Sunil V, Gopalakrishnan T C & Nair K K C, Vertical distribution of mesozooplankton biomass in relation to oxygen minimum layer in the Arabian Sea, *Indian Journal of Fish*, 50(4) (2003), 533-538.

18 Kamykowski D & Zentara S Hypoxia in the world ocean as recorded in the historical data set, *Deep Sea Research*, 37 (1990), 1861-1874.

19 Wyrtki K, The oxygen minimum in relation to ocean circulation, *Deep-Sea Research*, 9(1962), 11-23.

20 Morrison J M, Codispoti L A, Smith S L, Wishner K, Charles Flagg, Wilford D.Gardner, Steve Gaurin, Naqvi S W A, Vijayakumar Manghnani., Linda Prosperie. & Jan S.Gundersen., The oxygen minimum zone in the Arabian Sea during 1995, *Deep-Sea Research* II: Topical Studies in Oceanography 46 Issues 8-9, August 1999, (1999),1903-1931

21 Vinogradov M E & Voronina N M, Influence of the oxygen deficit on the distribution of plankton in the Arabian Sea. *Okeanologiya* 1 (1961), 670-678 (Eng. transl. in *Deep-Sea Research,* 9 (1962), 523-530.

22 Grasoff H K & Kremling M, Methods of seawater analysis, Second Edition Weinheim, Deerfeild Beach. Florida Based, Vorlagchemic, 1986.

23 Isaacs J D & Kidd L W, Isaacs-Kidd Midwater Trawl. Final reports. Scripps Institute Oceanography, University of California (Reference 53) 3 (1951), 1-18.

24 Sparre P & Venema S L, Introduction to tropical fish stock assessment (Part 1), *FAO Technical Paper,* (1992) Rome.

25 Holthuis L B, The recent genera of the caridean and stenopodidean shrimps (Class Crustacea, order Decapoda, Supersection Natantia) with keys for their determination. *Zoologische verhandelingen.* Leiden, 26 (1955), 1 - 157.

26 Perez Farefante I & Kensley B, Penaeoid and Sergestoid shrimps and Prawns of the World. Keys and Diagnoses for the Families and genera. *Memoires du Museum Natonal, d'histoire Naturelle,* Tome 175 (1997), Zoologie, 233pp.

27 Shannon C E & Weaver W, *The mathematical theory of communication*, University of Illinois, 1963.

28 Margalef R, *Perspectives in ecological theory,* University of Chicago Press, (1968), pp111.

29 Heips C, A new index measuring evenness*, Marine Biology Association*, UK 54 (1974), 555-557.

30 Gartner Jr., Patterns of reproduction in the dominant lantern fish species of the eastern Gulf of Mexico. With a review of reproduction among tropical, subtropical Myctophidae, *Bulletin of Marine Science*, 52 (1993), 721-750.

31 Kinzer J, Schulz K, Vertical distribution and feeding patterns of midwater fish in the central Equatorial Atlantic I. Myctophidae, *Marine Biology,* 85(1985), 313-322.

32 Gartner J V Jr., Hopkins T L, Baird R C & Milliken D M, The lanternfishes (Pisces: Myctophidae) of the eastern Gulf of Mexico, *Fish Bulletin*, 85 (1987), 81-98.

33 Hidaka K, Kawaguchi K, Murakami M & Takahashi M, Downward transport of organic carbon by diel migratory micronekton in the western equatorial Pacific: its quantitative and qualitative importance, *Deep-Sea Research* I, 48 (2001), 1923-1939.

34 Alverson F G, The food of yellowfin and Skipjack tunas in the eastern tropical Pacific Ocean, *Inter America Tropical Tuna Commission Bulletin*, 7(1963), 295-396.

35 Gjosaeter J, Mesopelagic fish, a large potential resource in the Arabian Sea, *Deep-Sea Research*, 31 (1984), 1019-1035.

36 Couwelaar V M, Angel M V & Madin L P, The distribution and biology of the swimming crab *Charybdis smithii* McLeay, 1838 (Crustacea; Brachyura; Portunidae) in the NW Indian Ocean, *Deep-Sea Research* II, 44 (1997), 1251–1280.

37 Devol A H, Bacterial oxygen uptake kinetics as related to biological processes in oxygen deficient zones in the oceans, *Deep-Sea Research* 25 (1978), 137-146.

38 Vijay J G, *Nutrient dynamics in the EEZ of the west coast of India with special reference to the oxygen minimum zone and denitrification,* Ph.D Thesis, Cochin University of science and technology, Cochin, India (2006).Sewell R S S & Fage I, Minimum oxygen layer in the ocean, *Nature*, 162 (1948), 949-951.

40 Naqvi S W A & Jayakumar D A, Ocean biogeochemistry and atmospheric composition: Significance of the Arabian Sea, *Current Sciences*, 78(3) (2000), 289-299.

41 GLOBEC U S, *Implementation plan and workshop report for US GLOBEC studies in the Arabian Sea*. US GLOBEC Report, U.S.GLOBEC Division of Environmental Studies, University of California, Davis, California 9, (1993),pp 105.

42 JGOFS, Joint Global Ocean Flux Study: Report of the Indian Ocean synthesis group on the Arabian Sea process study, *JGFS Report* No.35 (2002).

43 Gjosæter J, Abundance and production of lanternfish (Myctophidae) in the western andnorthern Arabian Sea, *FiskDir. Skr. Ser. Hav Unders*, 17 (1981), 215-251.

44 Barhame G, Deep sea fishes: lethargy and vertical orientation. In: *Biological sound scattering in the ocean,* G. B. FARQUHAR editor, Maury Center for Ocean Science Report 005, U.S. Government Printing Office, Washington, D.C., (1971), 100-118.

45 Wisner R L, The taxonomy and distribution of lanternfishes (Family Myctophidae) of the Eastern Pacific Ocean, NORDA Report 3. Navy Ocean Research and Development Activity, Bay St Louis, Mississippi, (1974), 229 pp.

46 Hopkins T L & Gartner J H, Resources-partitioning and predation impact of a low-latitude myctophid community, *Marine Biology*, 114 (1992), 185-197.

47 Nafpaktitis B & Nafpaktitis M, Lanternfishes (Fam. Myctophidae) collected during cruises 3 and 6 of the R/V "Anton Bruun" in the Indian Ocean, *Bulletin of the Los Angeles County Museum National History of Science*, 5 (1969), 1-79.

48 Tsarin S A & Boltacher, *Mesopelagic fishes of the Arabian Sea*. Page 162-177. Book Title: The mesopelagic structure of the epipelagic ecosystem of the open Northern Arabian Sea," Editors: K.Banse and S.A. Piontkoski, University press (India) Private limited (2006).

49 Childress J J, Respiratory rate and depth of occurrence of midwater animals, *Limnology oceanography*, 16 (1971), 104-106.

50 Childress J J, The respiratory rate of midwater crustaceans as a function of depth occurrence and relation to oxygen minimum layer off Southern California, *Comparative Biochemistry and Physiology*, 50A, (1975), 187-799.

51 Drazen J C & Seibel B A, Depth-related trends in metabolism of benthic and benthopelagic deep-sea fishes*, Limnology and Oceanography*, 52(5) (2007), 2306-2316.

52 Omori M, The biology of pelagic shrimps in the Ocean. *Advanced in Marine Biology*, 12 (1974), 233-324.