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Research Article

OFFSHORE DIEL VERTICAL DISTRIBUTION OF MESO/MACRO-HOLO/MERO ZOOPLANKTON IN THE SOUTHERN BLACK SEA

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ABSTRACT. Diel vertical distribution and migration (DVM) of meso and macro zooplankton in the Black Sea were studied at one constant station using plankton net in April 1995 and macro zooplankton in August 1993. Five common copepod species were found during the studies. *Acartia clausi* was distributed in the uppermost layers, *Pseudocalanus elongatus* within layer with temperature < 8 °C (the CIL), *Calanus euxinus* throughout the oxygenated layer, *Oithana similis* above the CIL in summer but in both the CIL and the upper mixed layer in spring and autumn, and *Paracalanus parvus* mostly in the upper layers. Additionally, eight taxa belonging to non-copepods were evaluated in the present work; namely, Appendicularia (*Oikopleura dioica*), Cladocera (*Pleopis polyphemoides, Podon leucarti, P. intermedius, Evadne spinifera,* and *E. nordmanni*), Cirripedia larvae, Polychaete larvae, Bivalvia larvae, Chaetognatha (*Sagitta setosa*), Scyphozoa (*Aurelia aurita*), and Ctenophora (*Mnemiopsis leidyi* and *Pleurobrachia pileus*). Three different groups were observed in regard to their vertical distribution layers: the uppermost layer inhabitants (Cladocera, Bivalvia and cirriped larvae, *Aurelia* and *Mnemiopsis*) that were distributed in correlation with the chlorophyll-*a* and fluorescence within a narrow depth range; the second group, appendicularians formed patch in both the upper layer with high Chl-*a* and fluorescence, and the deep water characterized with fine-particle maxima whereas *Pleurobrachia* and *Sagitta* were found within the CIL; deep layer dweller (Polychaete larvae) migrated within the deep homogenous layer in reverse relation to *Pleurobrachia* migration. *Mnemiopsis* extended over a narrow range of vertical depth by day and night being confined to the upper part of the mixed layer. Few individuals were localized below thermocline at night. *Pleurobrachia* was found mostly beneath the thermocline down to the anoxic layer. The vertical distribution of *Pleurobrachia* was manifested by a two-maximum structure at night. Upper maximum was less pronounced than the lower maximum during the day time. *Aurelia* was strictly associated to the upper mixed layer and layer above seasonal pycnocline.

Keywords: *zooplankton, diel vertical distribution, DVM, marine snows, Black Sea*

INTRODUCTION

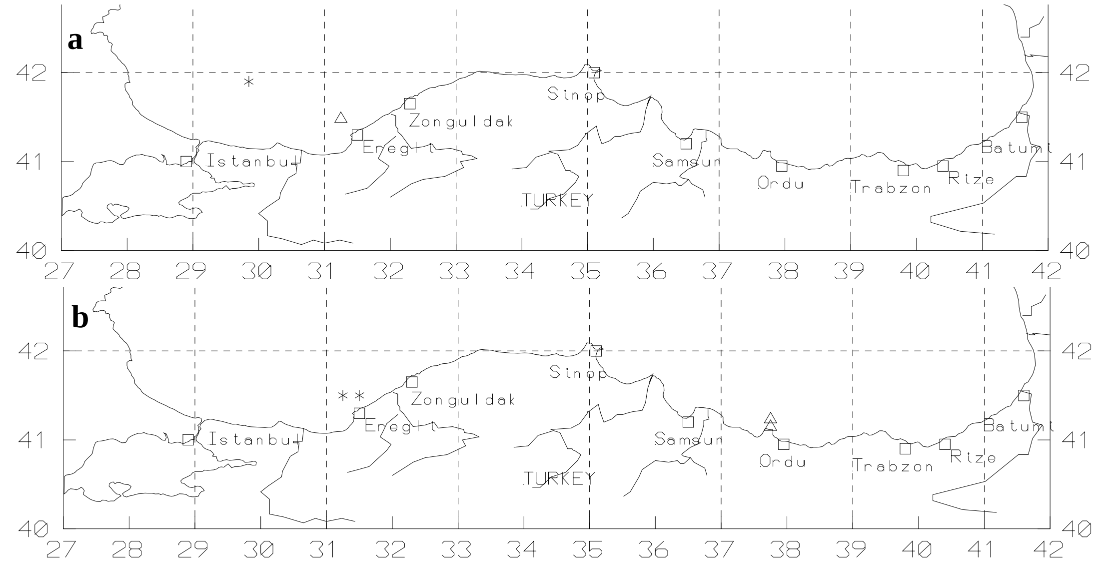
The Black Sea has a wide spectrum of hydrographic features (sharp seasonal and permanent stratification layered with changing condition vertically in salinity, temperature, density, dissolved oxygen, and hydrogen sulfur, currents, aerobic and anaerobic zone). Vertical distribution and diel migration (DVM) of the zooplankton occurred within the oxygenated zone of the water column. The vertical distribution was restricted to the depth until H_2S present at about a depth corresponding to sigma theta equal to 16.2. Tiselius [1] showed variations in the diel vertical distribution under the different physical conditions with regard to their sex, stages, and size of the species. The first extensive study on the vertical distribution of the mesozooplanktonic multiple-species in the Black Sea was represented by Vinogradov et al. [2]. There are a few studies on vertical distribution of the meso and macro zooplankton in the southern Black Sea -

Turkish Economical Exclusive Zone. But the studies focused on some certain group of the zooplankton without including all at the same sampling and daily hour time series at one station [3-10].

The present study was aimed to show the diel vertical distribution and migration patterns of mero/holo meso/macrozooplankton in the southern Black Sea in spring (April 1995) and summer (July 1992 and August 1993) with respect to the biological, chemical and physical peculiarities of the water column.

MATERIALS AND METHODS

Samples for studying the vertical distribution and daily migration of the zooplankton were taken with a standard opening-closing Nansen net (0.7 m net diameter, 120 μm mesh) at one station in offshore waters of the western Black Sea in late April 1995 and at one station in August 1993 (00:00, 05:00, 10:00 and 19:00 h). for only gelatinous organisms (Fig.1a). A series of discrete vertical hauls was made at a speed of 1 cm s^{-1} from the top of the anoxic layer to the surface (0 to 150 m) at 15-m intervals over a times series (00:30-01:30, 01:30-02:30, 09:30-10:30, 17:30-18:30, 20:30-21:30, and 21:30-22:30 h in April 1995). The depth of the H_2S layer (according to sigma theta=16.2; [11]) was determined with a SeaBird CTD (Fig. 1c, d). On board ship, gelatinous macrozooplankton organisms were separated from the mesozooplankton using a 2 mm mesh sieve and sized. In the laboratory, specimens of copepods from the mesozooplankton were identified at the species level and enumerated. Vertical distribution was calculated from abundance data standardized on percent base.



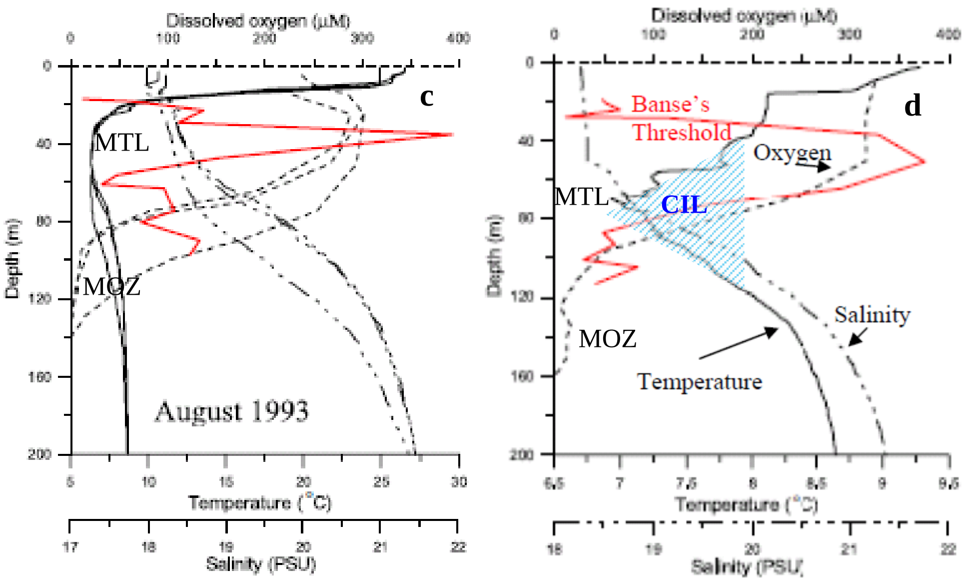


Fig.1. *Sampling stations for the vertical distribution of the zooplankton by net in the Black Sea in August 1993 (*, asterisk) and in April 1995 (open triangle) (a) and for the visual inspections of the gelatinous organisms by ROV in the Black Sea in July 1992 (*, asterisk) and in August 1993 (open triangle) (b). Profiles of the physical parameters and measurements across the water column depth casted at a DVM station in August 1993 (c) and April 1995 (d) by CTD.*

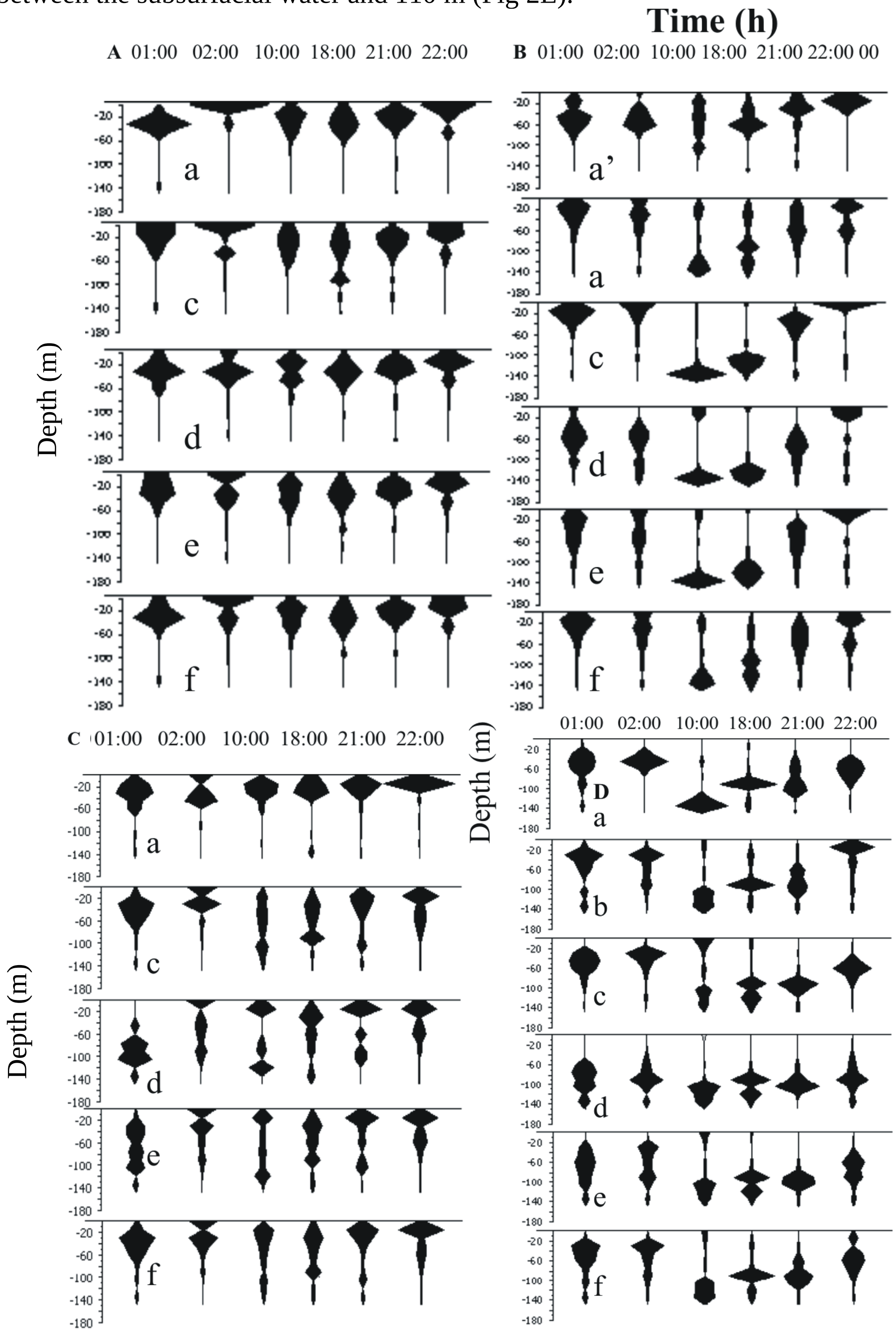
Furthermore, in order to visualize the natural aspects of macro-gelatinous organisms the Remotely Operated Vehicle (ROV) was casted through the water column from the surface water to a depth where H_2S started in July 1992 and August 1993 (Fig. 1b). The video data were converted to a schematic distribution of the jellies by the depth and temperature profile.

RESULTS

Appendicularia (*Oikopleura dioica*), Cladocera (*Pleopis polyphemoides, Podon leucarti, P. intermedius, Evadne spinifera,* and *E. nordmanni*), Cirripedia larvae, Polychaete larvae, Bivalvia larvae, Chaetognatha (*Sagitta setosa*), Scyphozoa (*Aurelia aurita*), and Ctenophora (*Mnemiopsis leidyi* and *Pleurobrachia pileus*) were additionally recorded for the diel vertical migration (DVM) besides the copepod species.

All specimens of *A. clausi* performed diel migration in the uppermost layer by staying above the pycnocline during the day and in the subsurface water at night (Fig 2A). Banse [12] showed that a salinity gradient of more than 0.3%o m-1 in 10 m prevented the vertical migration of small copepods as Bautista & Harris [13] also expressed that smaller neritic copepods migrate slightly in the upper layer.

Calanus euxinus migrated vertically through the entire oxygenated layer and did not however perform the diapause in April (Fig. 2B). The females started migrating up earlier from the deep layer to the surface by dusk and stayed longer in the mixed layer at night than the male individuals did. Downward migration was the reverse. Vertical distribution of *O. similis* appeared in two different layers: One was above the core of the Cold Intermediate Layer (CIL) and the other below the core that acted (Fig. 2C). *P. elongatus* was a calanoid species that generally migrated and was distributed within the CIL profiled with a temperature less than 8 °C (Fig. 2D). Distribution of the male individuals below the Minimum Temperature Layer (MTL, Fig 1c, d) could be due to representation of the MTL to the maximum Banse's threshold with a value of 2%o throughout the 20-m layer what created a very effective barrier for the migration of small-sized male individuals (Fig. 2D, F). Copepodites and adult females of *P. parvus* were distributed above the CIL, and above the MTL, respectively while the males underwent regular diel migrations between the subsurfacial water and 110 m (Fig 2E).



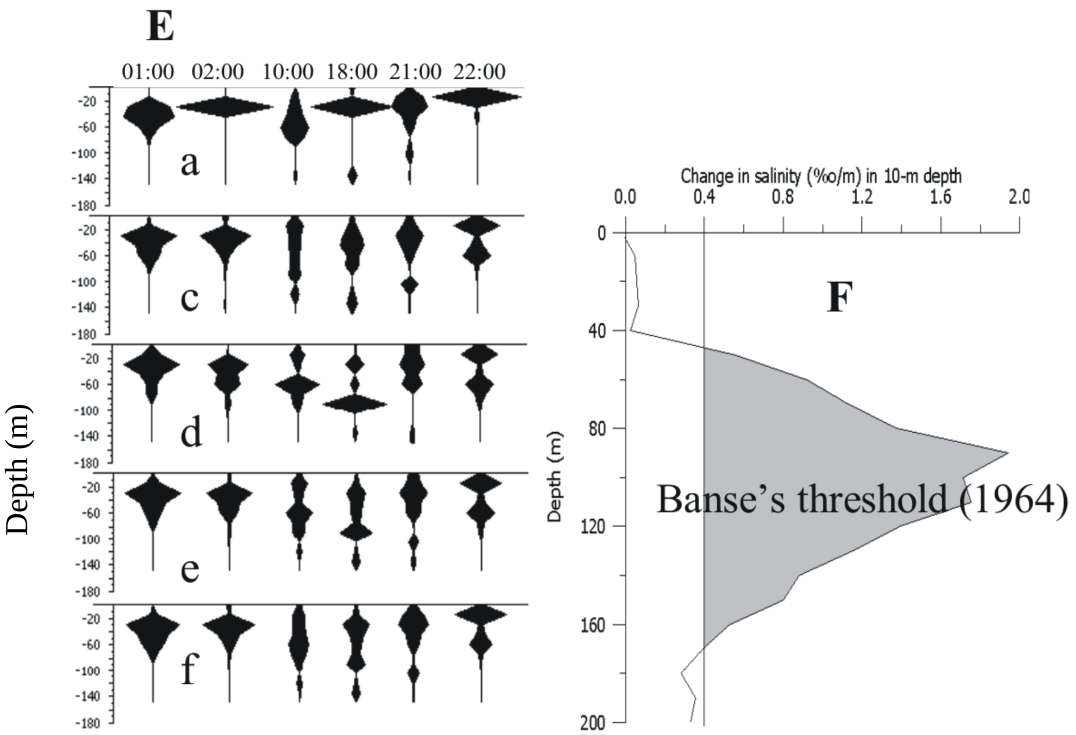


Fig. 2. *Pattern of vertical percent distribution of the copepod species (A; A. clausi. B; C. euxinus. C; O. similis. D; P. elongatus. and E; P. parvus). and F; Banse's threshold simulated to data of the present work. (a'; Calanus nauplii. a; copepodites. b; copepodid female. c; female. d; male. e; adults. and f; total).*

Aurelia aurita were distributed over a narrow depth range in and above the thermocline both day and night. *M. leidyi* showed a similar pattern to *A. aurita* occupying the same layer (Fig. 3).

A few small-sized individuals were observed below the thermocline in April while *M. leidyi* was confined to a layer above the thermocline in August. *P. pileus* was distributed below the CIL but most of them performed diel migrations between the MTL and suboxic zone in spring while it was vertically distributed below the thermocline in summer resulting in two maxima just below the thermocline and just below the CIL during the day and night. *A. aurita* performed midnight sinking in August (00:00 hr) and April (22:00) (Fig. 1, 3).

Most specimens of Appendicularia were generally distributed above the MTL and showed an inconsistent migration pattern during both day and night (Fig. 3). Appendicularia peaked in the subsurface water where Chl-*a* displayed its highest value at a depth of 50 m where the pycnocline started, at a depth of 100 m where NO_2 + NO_3 levels peaked, and at a depth of 150 m where the light transmission dropped suddenly. The second accumulation layer of Appendicularia was a depth where the light transmission dropped to a minimum value of 80s% (Fig. 3).

Sagitta setosa was vertically distributed from the surface to the upper limit of the anoxic zone, but they accumulated mainly in the pycnocline and halocline during the day and by twilight the specimens were concentrated in the deepest of their distribution (Fig. 3). The species appeared in two main aggregations during the nighttime: One was just above the permanent halocline, the other was at a depth where NO_2 + NO_3 corresponded to the fine particle maxima displaying a peak in concentration. By day the chaetognaths were entirely absent in the upper waters but were concentrated within the lower part of the oxycline, where the oxygen content was 0.5-0.8 ml l^{-1} as was repeatedly observed in this study in the Oxygen Minimum Layer (OML) (Fig. 1, 3).

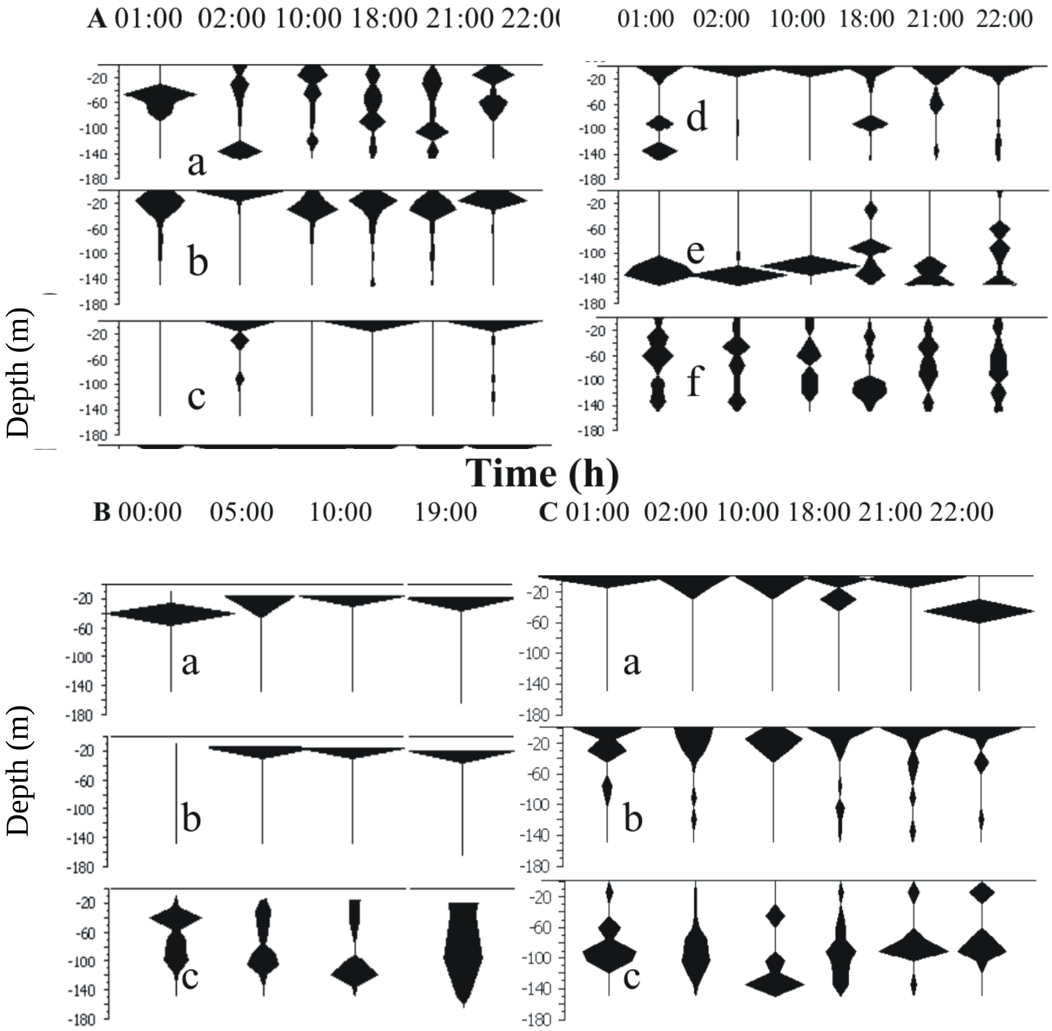


Fig. 3. *Pattern of vertical percent distribution of the taxa (**A**; a; Appendicularia. b; Bivalvia larvae. c; Cirriped larvae. d; Cladocera. e; Polycheate larvae. and f; Chaetognatha) in April 1995 and gelatinous organisms (a; A. aurita, b; M. leidyi and c; P. pileus) in summer (**B**, August 1993) and spring (**C**, April 1995) in response to the daylight.*

The aggregation was observed between 00:30 and 02:00 in a layer where the temperature ranged from about 7-to-11 °C (MTL). The present work showed that this species started to ascend after 18:00. Juvenile bivalves were found in the upper warm water above the permanent pycnocline, halocline, and the CIL, generally characterized by having a high Chl-*a* concentration depicting the presence of phytoplankton that the Bivalvia filter as food. Barnacle nauplii remained completely unchanged as to their inhabitance of surface waters during the day (Fig. 3).

Total mesozooplankton appeared with two maximum abundance concentrations in the water column during the day: The lower concentration occurred in the daytime and early nighttime while they yielded only a peak at surface around midnight. The upper concentration was above about 75 m, which was the area above the MTL extended to the thermocline and the lower concentration was found below 100 m where the microbial loop started and where the Dissolved Oxygen (DO) dropped to less than 150 μM l^{-1} (3.36 ml/l = 4.8 mg/l) (Fig. 1-3) The remaining intermediate layers constituted the transition layer which the zooplankton used for the immigration. The subsurfacial maximum was composed of *Noctiluca, Paracalanus, Oithana, Pseudocalanus*, *Acartia,* and sometimes *Calanus* species. In general, the cladoceran species were found in the uppermost layer situated above the pycnocline. The Polychaete larvae showed negative geotaxis in response to daylight between the anoxic and the MTL layer. They settled down to the suboxic zone during the nighttime and during the daytime, rose up to the MTL corresponding to the mid-part of the oxycline where the NO_2 + NO_3 and Particulate Organic Carbon peaked. The larvae were found in the Oxygenated Zone (OZM) during the night when the other mesozooplankton and a gelatinous species, *P. pileus* deserted the OML. This suggests that the larvae could avoid others during the daytime by rising to the upper layers (100 m). Actually *P. pileus* captures fast moving organisms to eat. The larvae of benthic animals were one of the food items of this ctenophoran species (Fig 3).

Marine snow particles (stringers and globular aggregates) were observed at all depths. Certain layers showed higher concentration than others. *Aurelia* and *Mnemiopsis* inhabited the same layer while the preference of *Pleurobrachia* extended from the lower limit of *Aurelia* to the layer where the oxygen is almost depleted. *Pleurobrachia* was observed to possess two different appearances, namely, individuals with and without tentacles i.e. the individuals retracted the tentacles into its sheaths (Fig.4). Visual *in situ* inspection using Mini-ROVER (Mini-Remote operated vehicle, BENTHOS), ROV was carried out at two stations in July 1992 during which the organisms were observed throughout the water column. At station 41° 30’ N 31° 15’ E at noon (12:10 p.m.), while *Aurelia* seemed to share accompanying the upper mixed layer with *Mnemiopsis*, *Aurelia* was found to extend further down to the upper part of cold intermediate layer (25 m). *Mnemiopsis* was homogeneously distributed in the mixed layer (12-15 m) whereas *Aurelia* formed aggregations at 10 and 17 m depths. Overall, *Pleurobrachia* was first observed at the beginning of the thermocline (10-12 m), down to 20-25 m depth, where scattered individuals without tentacles were common. At the upper layer of cold intermediate layer, less abundant individuals of *Pleurobrachia* were delicate with the tentacles. On the pycnocline at 70-110 m, mass aggregations of *Pleurobrachia* with protracted tentacles were observed, below this depth down to the lower limit of inspection by Mini-ROVER (140 m), individuals of *Pleurobrachia* with retracted tentacles were found very rarely (Fig.4a). Marine particles (marine snows) was apparently observed at two layers. One was at 3 m and other was found at 30-40 m depth, with very high concentrations. The second layer of marine snow was well overlapped with the upper depth of the cold intermediate layer (Fig.4a).

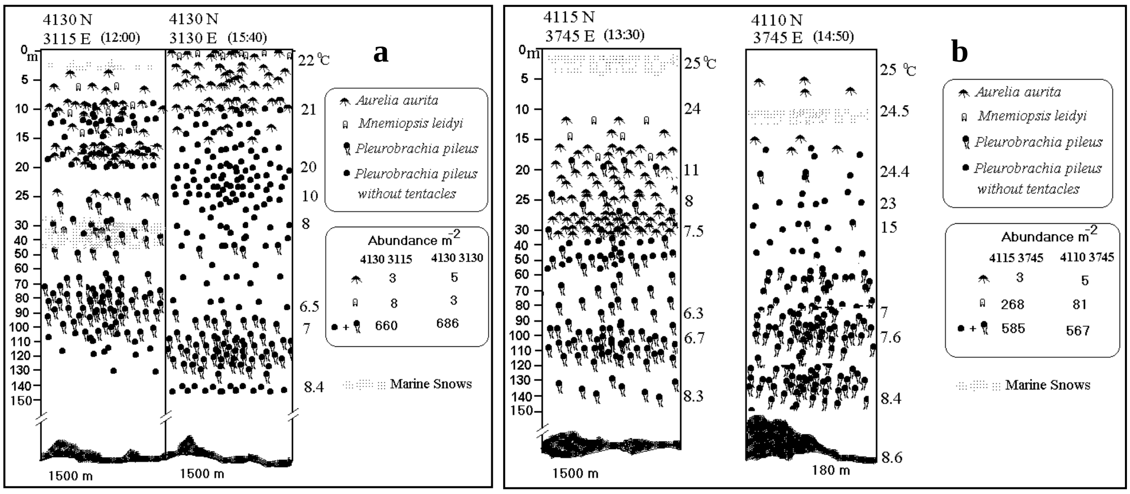


Fig.4. Vertical structure of the planktonic gelatinous community (Mnemiopsis leidyi, Aurelia aurita and Pleurobrachia pileus) at stations 41^{o} 30' N 31^{o} 15' E and 41^{o} 30' N 31^{o} 30' E in July 1992 (a), and at stations 41^{o} 15' N 37^{o} 45' E and 41^{o} 10' N 37^{o} 45' E in August 1993 (b), visually inspected from video records.

At station 41^{o} 30' N 31^{o} 30' E at 03:40 p.m., all organisms displayed the same vertical distribution as mentioned before, i.e. the main layer of *Aurelia* and *Mnemiopsis* shifted upwards towards the surface. *Pleurobrachia* without tentacles formed aggregations more in the upper layer than that observed at station 41^{o} 30' N 31^{o} 15' E (12:10 p.m.). *Pleurobrachia* with the tentacles kept its position constant in the deep layer (Fig.4b). Apart from the visual observation by Mini-ROVER in July 1992 in the western Black Sea, two stations (41^{o} 15' N 37^{o} 45' E at 13:30 p.m. and 41^{o} 10' N 37^{o} 45' E at 14:50 p.m.) in the eastern Black Sea were also visually inspected for these organisms in August 1993. The surface waters were warmer in that period (25^{-}26 ^{o}C) compared to that measured in July. Individuals of *Aurelia* and *Mnemiopsis* were found in the lower depths. At station 41^{o} 15' N 37^{o} 45' E (13:30), *Aurelia* was found from 10 m down to 30-35 m depths. However, none of the individuals of *Mnemiopsis* and *Aurelia* were observed above the thermocline. Swarm of *Aurelia* was observed at a depth range of 5 m thickness in the upper part of the cold intermediate layer. Abundance of individuals with and without tentacles increased homogeneously with depth down to 60 m. The first visual detection of *Pleurobrachia* with tentacles started below 60 m depth reached a maximum concentration between 95 and 115 meters where the pycnocline occurred, and then decreased towards 140-145 m depth, below which none of individuals of *Pleurobrachia* existed. Higher concentrations of marine snow were found in the upper 5 m (Fig.4b). At the station 41^{o} 10' N 37^{o} 45' E (14:50), individuals of *Aurelia* were found in the mixed layer of the water column while few individuals were observed above the layer of marine snows (10 m). However, specimens of *Mnemiopsis* were not observed at this station. In the thermocline layer (20^{-}22 m) *Pleurobrachia* with retracted tentacles exhibited homogeneous distributions. Individuals which outstretched the tentacles were observed at 60-70 m depths. Their abundance increased throughout the cold intermediate layer in which temperature varied between 7 ^{o}C and 8 ^{o}C (Fig.4b).

The zooplankton was numerically dominated by the copepods in the Black Sea. More than half of the abundance of the copepod was composed of a moderate sized-copepod, *Pseudocalanus elongatus* (Fig.5).

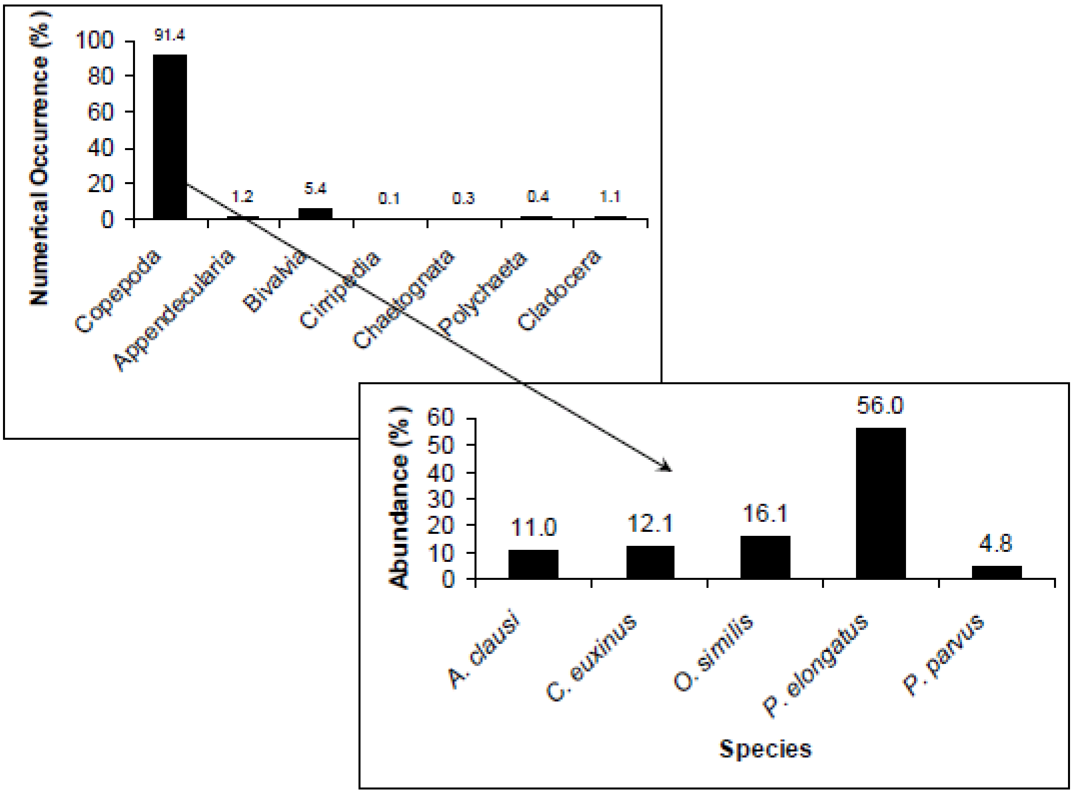


Fig. 5. *Percent numerical occurrence of the zooplanktoon and abundance of the copepods in April 1995.*

DISCUSSION

The organisms which migrated daily in a narrow layer of the upper waters were featured with remarkable adaptation to a depth range from 0-15 to 50 m, slightly affected by variation in temperature and light intensity, correlated with primary production, and the chl-*a* maximum layer, less than 7% of the variation in the vertical distribution due to variation in primary production, confined to the upper warmer layer, survival rate declined sharply in severely depleted oxygen-condition, do not stay outside the limits of the phytoplankton, inhibited by temperatures below 10 ^{o}C and growth and reproduction rates decreased with decreasing temperatures, a salinity gradient of more than 0.3‰/m in 10 m prevented vertical migration of small copepods, smaller neritic copepods migrate slightly in the upper layer (Fig 6) [12, 15, 16, 20, 31, 37, 38, 39, 40].

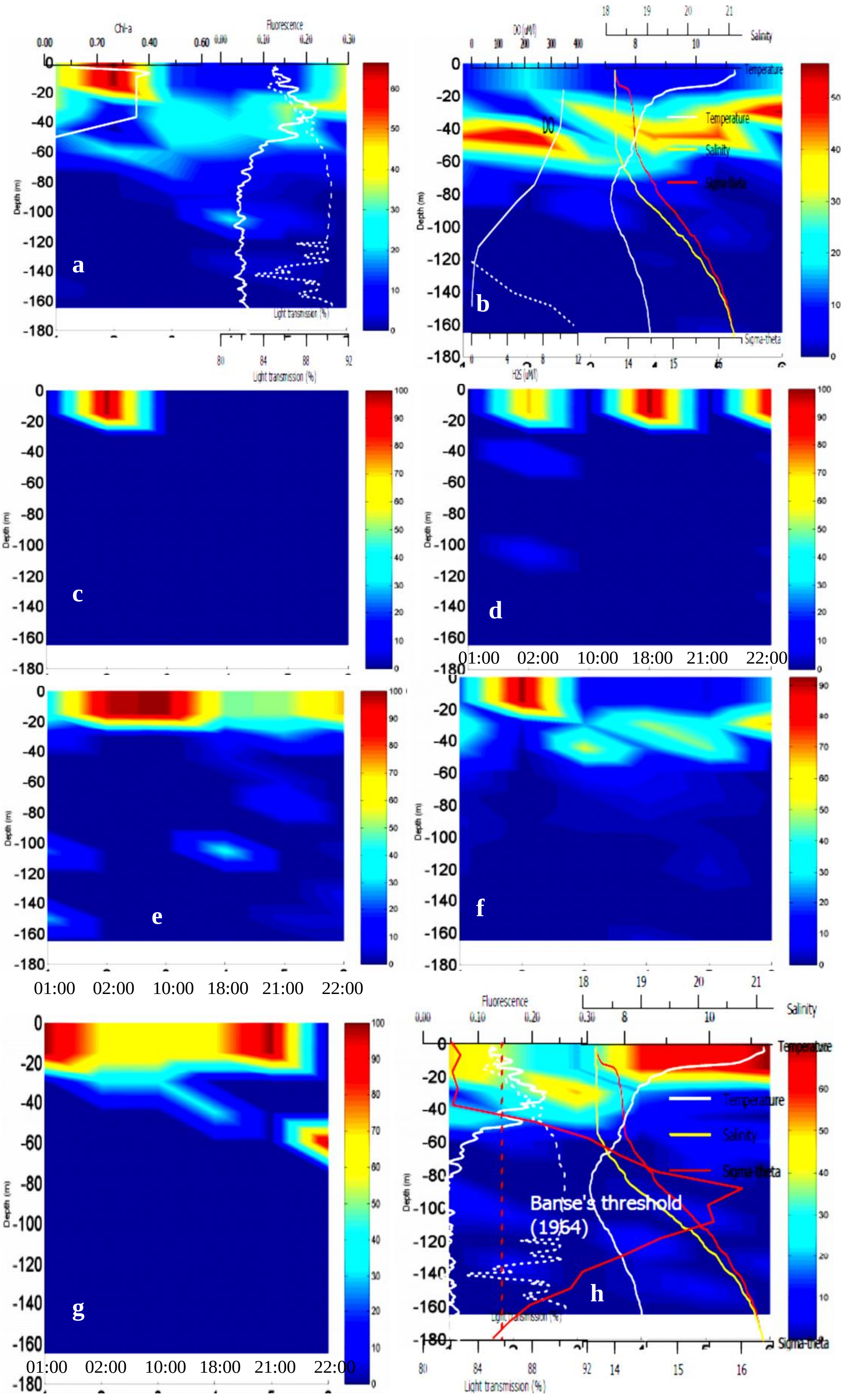
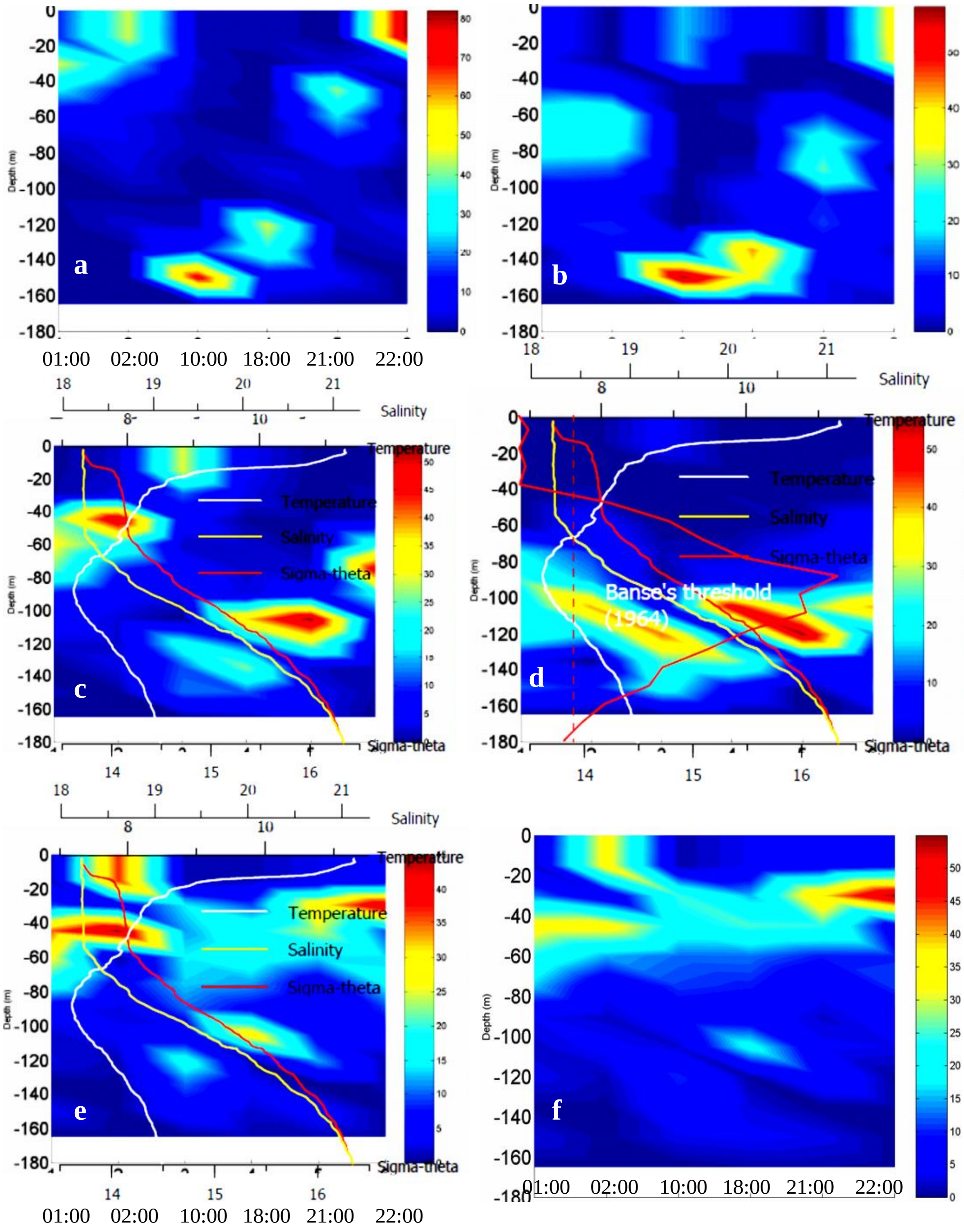

a
b
c
d
e
f
g
h
Chl-a
Fluorescence
Light transmission (%)
Depth (m)
DO (uM)
H2S (uM)
Salinity
Temperature
Sigma-theta
DO
Banse's threshold (1964)
01:00 02:00 10:00 18:00 21:00 22:00
0
-20
-40
-60
-80
-100
-120
-140
-160
-180

Fig.6. *Diel vertical migration of the upper layer zooplankton with percent numerical (abundance) distribution with the environmental parameter profiles. a) Acartia spp, female, b) Acartia spp, male, c) gastropod larvae, d) Cirriped larvae, e) Cladoceran larvae, f) bivalve larvae, g) Aurelia aurita and h) Mnemiopsis leidyi in April 1995.*

All specimens of *A. clausi* performed diel migration in the uppermost layer by staying above the pycnocline during the day and in the subsurface water at night. Fulton [14] showed that *A. tonsa* was found to be a strong nocturnal migratory species. Bautista & Harris [13] also expressed that smaller neritic copepods migrate slightly in the upper layer. Stalder & Marcus [15] showed that adults of *A. tonsa* declined sharply in survival with DO=0.9 to 0.6 ml l^{-1}. Petipa et al. [16] determined that *A. clausi*, a mixed food consumer does not stay outside the limits of the phytoplankton as observed in the present work. Petipa et al. [17] ascertained that the vertical range of *C. euxinus* was restricted to a lower depth characterized with oxygen deficiency and the appearance of H_2S [2, 5, 6]. Enright & Honegger [18] determined that the females of *C. euxinus* started migrating up earlier from the deep layer to the surface by dusk and stayed longer in the mixed layer at night than the male individuals did [19] as observed in the present study. Erkan *et al.* [5] and Besiktepe [6] gave the conclusion of inconsistent and unclear vertical migration of *O. similis*. Zenkevitch [20] classified *P. elongatus* as a cold water stenothermal form and Vinogradov et al. [2] concluded that the species did not reach the OML, which was below the CIL, during the daytime by downward migration and did not penetrate the upper mixed layer above the CIL during the night time migration [5, 6]. Distribution of the male individuals below the MTL could be due to representation of the MTL to the maximum Banse’s threshold with a value of 2‰ throughout the 20-m layer what created a very effective barrier for the migration of small-sized male individuals. Besiktepe (2001) observed a peak in abundance of copepodites and adult females of *P. parvus* in the CIL in spring whilst the highest density of individuals was reported to be above the CIL in September and June.

Aurelia aurita were distributed over a narrow depth range in and above the thermocline both day and night. Shushkina & Musayeva [21] first observed a similar vertical distribution in late September 1987; this pattern has been repeatedly observed [9, 22]. *M. leidyi* showed a similar pattern to *A. aurita* occupying the same layer; it was repeatedly observed [8, 22, 23]. A few small sized individuals were observed below the thermocline in April (present work) while *M. leidyi* was confined to a layer above the thermocline in August 1993 [8, 9, 24]. Mutlu & Bingel [7] reported that most *P. pileus* were observed below the thermocline in summer with two distinct depth maxima at 20 - 40 m and 90 - 120 m, where relatively cold waters occur. Kideys & Romanova [24] observed a similar pattern in June-July of summer 1996. Vinogradov et al. [2] found similar trends in April-May of spring 1984 with respect to the spring distribution detailed here.

The zooplanktoon which migrate through the water column were characterized with vertical distribution within a certain physicochemical condition, vertical range restricted to a lower depth characterized with oxygen deficiency and the appearance of H_2S, inconsistent and unclear vertical migration but were in agreement that the species were distributed in the *Calanus* layer, feeding depends on time: being uneaten in deep layers during daytime, and eaten in upper layers during nighttime, copepodites always in the upper layers, avoidance from predation, carnivorous feeding on nauplii as well, migration related with lipid content stored in the body, vertical migration differed between sex of specimens, Banse's threshold valid particularly for males of small-sized copepods (Fig. 7) [2, 5, 6, 12, 17, 18, 31, 34, 41, 42, 43, 44, 45, 46, 47].



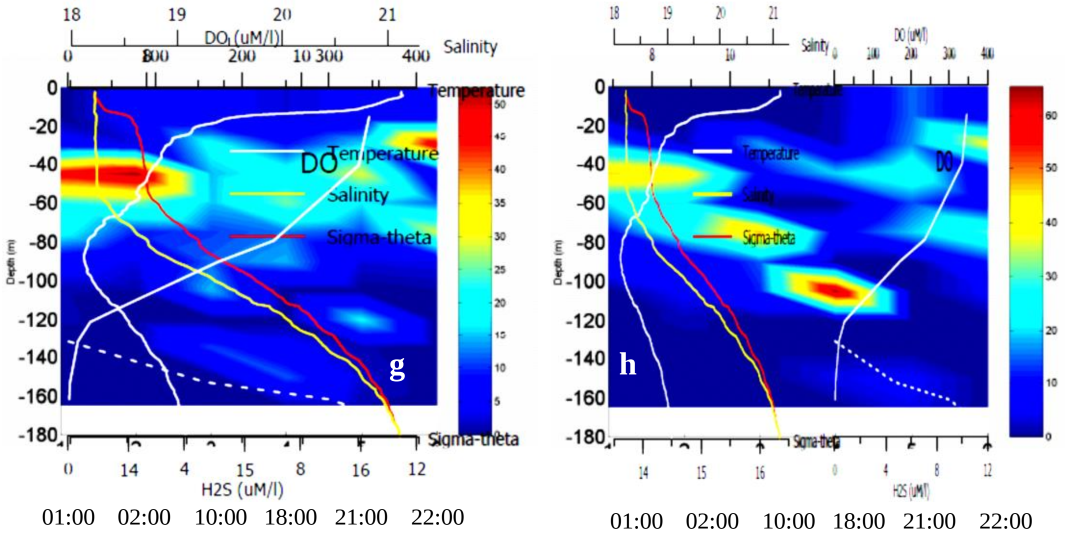


Fig.7. *Diel vertical migration of the zooplankton migrating daily through the water column with percent numerical (abundance) distribution with the environmental parameter profiles. a) Calanus euxinus, female, b) Calanus euxinus, male, c) Pseudocalanus elongatus, female, d) Pseudocalanus elongatus, male, e) Oithana spp, female, f) Oithana spp, male, g) Paracalanus parvus, female and h) Paracalanus parvus, male, in April 1995*

Erkan et al. [5] reported that Appendicularia were found in the upper layer above the thermocline in summer while they were observed throughout the oxygenated water in autumn. Acuna [25] related the population dynamics of these gelatinous tunicates to the phytoplankton bloom that occurred in early spring and early autumn in the Black Sea [26].

All these depths of occurrence of Appendicularia could carry the fine scale living and non-living particles on which Appendicularia feed indifferently [27]. Flood [28] reported that even more remarkable is the accumulating body of evidence suggesting that, in addition to consuming submicron particulate matter, appendicularians seem capable of filtering and ingesting colloidal dissolved organic carbon (DOC). The subsurface accumulation was related to the presence of a high concentration of DOC between the surface and a depth where $NO_2 + NO_3$ levels peaked [29]. The second accumulation layer of Appendicularia was a depth where the light transmission dropped to a minimum value of 80s%. Mopper & Kieber [30] reported the layer as fine particle maxima, which the Appendicularia could feed intensively on.

Sagitta setosa appeared in two main aggregations during the nighttime: One was just above the permanent halocline, the other was at a depth where $NO_2 + NO_3$ corresponded to the fine particle maxima [30] displaying a peak in concentration. Besiktepe & Unsal [4] showed similar findings on the vertical distribution of this species. Erkan et al. [5] concluded that this species did not exhibit a clear migratory pattern in October 1996 and July 1997. Vinogradov et al. [2] found that by day the chaetognaths were entirely absent in the upper waters but were concentrated within the lower part of the oxycline, where the oxygen content was 0.5-0.8 ml l^{-1} as was repeatedly observed in this study in the OML. Vinogradov et al. [2] found the main bulk of this species within the thermocline characterized with temperatures varying between 9 - 15 ^{o}C in late April-May 1984. Vinogradov et al. [2] observed onset and completion of migration to be between 20:00 and 00:00 with the most rapid phase of migration occurring between 21:00 and 22:00.

Inconsistent distribution; continuation of organisms through the water column was related for the DVM-environmental parameter relation with interest to the phytoplankton bloom, peak in subsurface water where chl-*a* displayed its highest value, consuming microbes, submicron particulate matter, colloidal dissolved organic carbon (DOC), fine particle, exhibition of an unclear migratory pattern, and DO content and profile of the water playing a crucial role in triggering and initializing the upward vertical migration (Fig. 8a-b) [2, 4, 5, 25, 26, 27, 28, 29, 30, 43, 48, 49].

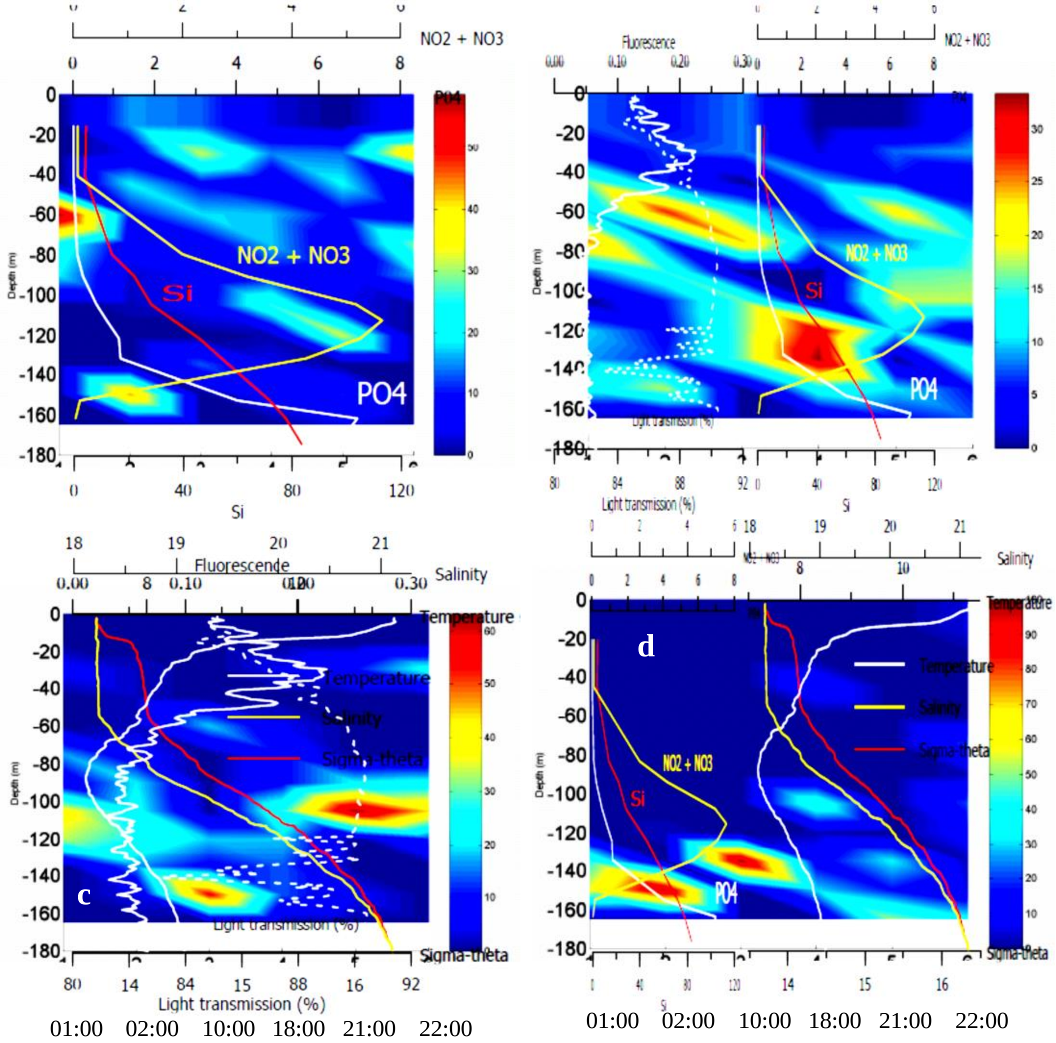


Fig.8. *Diel vertical migration of the zooplankton migrating daily with inconsistent distribution through the water column and deep water dwellers with percent numerical (abundance) distribution with environmental parameter profiles. a) Appendicularia, b) Sagitta setosa, c) Pleurobrachia pileus and d) Polychaetea larvae in April 1995.*

The deep water dwellers, zooplankton which migrated in the deep water were typified with the features of cold water groups, distribution below thermocline or Minimum Temperature Depth (MTD), vertical range in difference depending on seasons, overwhelming majority of individuals migrated vertically upward at night. A second group did not migrate and remained at depth (Fig. 8c-e) [2, 7, 24, 50].

Juvenile bivalves were found in the upper warm water above the permanent pycnocline, halocline, and the CIL, generally characterized by having a high Chl-*a* concentration depicting the presence of phytoplankton that the Bivalvia filter as food. Magnesen et al. [31] showed that less than 7% of the variation in the vertical distribution was due to variation in primary production. Barnacle nauplii remained completely unchanged as to their inhabitance of surface waters during the day.

Total mesozooplankton appeared with two maximum abundance concentrations in the water column during the day. Vinogradov et al. [2] determined that the distributional pattern of the total mesozooplankton biomass in the whole oxygen zone had a two-maximum structure clearly manifested during the daytime. Erkan et al. [5] found that the cladoceran specimens, regardless of species, were observed only in the mixed layer in October 1996 with exception of a few individuals found in the deeper layer while they were irregularly distributed in the oxic zone in July 1997. The Polychaete larvae settled down to the suboxic zone during the nighttime and during the daytime, rose up to the MTL corresponding to the mid-part of the oxycline where the $NO_2 + NO_3$ and Particulate Organic Carbon (POC; [32]) peaked. Wishner et al. [33] observed that the polychaetes peaked in a layer where the POC peaked around 750 m depth in the Eastern Pacific OZM. This suggests that the larvae could avoid others during the daytime by rising to the upper layers (100 m). Actually *P. pileus* captures fast moving organisms to eat. As Vinogradov & Shushkina [34] and Mutlu & Bingel [7] stated, the larvae of benthic animals were one of the food items of this ctenophoran species.

Marine particles called marine snow were apparently observed with very high concentrations at two layers. One was at 3 m and other was found around 30-40 m depth. The deeper layer of marine snow overlapped with the upper depth of the cold intermediate layer. Visual inspections made by Diercks and Kempe [35] showed that marine snow particles exist at all depths of the mixed layer of the Black Sea with occasionally higher concentrations at 20-30 and 70-80 m depths. Although *Aurelia* shares the upper mixed layer with *Mnemiopsis* they may extend further down to the upper layer of cold intermediate layer (25 m).The *Mnemiopsis* was confined to the mixed layer (12-15 m) of the Black Sea and homogeneously distributed whereas *Aurelia* formed aggregations at 10 and 17 m depth. Similarly, observations from the submersible revealed that in spring and early summer the medusae inhabit the upper mixed layer, the thermocline and down to the core of cold intermediate layer in the open sea areas, i.e. they occur down to a depth of 70-80 m in the meandering rim current and to 55-60 m over the domes of gyres [34]. *Pleurobrachia* was inspected first in the upper edge of the thermocline (10-12 m) where its individuals were delicate with the tentacles and not abundant. From this layer down to 20-25 m, there were non-aggregating individuals without tentacles. *Aurelia* and *Pleurobrachia* were observed together at 10-20 m depths. On the pycnocline (70-110 m), high aggregations of *Pleurobrachia* with protracted tentacles were observed. Vinogradov et al. [2] observed that in the layer of deep ctenophore maxima they were suspended inactive in the water with widely outstretched tentacles. This inactive appearance of *Pleurobrachia* with outstretched tentacles may suggest that individuals were able to gather the prey. *Pleurobrachia* picks up the food with their tentacles using it as flagellate. Then the tentacles were rolled, leading to an appearance of helix. It directs the attached preys on the tentacles to its mouth and grazes them at the edge of mouth (visual inspection from available records in IMS-METU, 1996). Below this depth (70-110 m) down to 140 m, *Pleurobrachia* was found very rarely and all individuals retracted its tentacles. During in situ visual inspection, Kempe et al. [36] found three zones of macro-plankton. A top zone dominated by coelenterate (medusae), *Aurelia aurita*; these animals appeared during both daytime and nighttime at the surface of the Black Sea. Below this zone a layer dominated by ctenophora, *Pleurobrachia* is located. A transition zone located between these two zones was occupied by both species occurred.

CONCLUSION

In general, *Pleurobrachia* was found mostly beneath the thermocline down to the anoxic layer in the CIL where the temperature is less than 8 ^{o}C. *Aurelia* was strictly associated with the upper mixed layer and the layer above the seasonal pycnocline. *Aurelia* has moved down to a maximum depth of 60 m nearly at midnight and was confined to the upper layer of seasonal halocline within the cold intermediate layer. *Mnemiopsis* extended over a narrow range in the water column during the day and night. No individuals of *Mnemiopsis* were observed below the thermocline in summer; however, a few individuals were localized at around 60-80 m below thermocline at night in spring. All specimens of *A. clausi* performed diel migration in the uppermost layer by staying above the pycnocline during the day and in the subsurface water at night *C. euxinus* migrated vertically trough the entire oxygenated layer and did not however perform the diapause in spring. The females of *C. euxinus* started migrating up earlier from the deep layer to the surface by dusk and stayed longer in the mixed layer at night than the male individuals did and downward migration was the reverse. Vertical distribution of *O. similis* appeared in two different layers: One was above the core of the CIL and the other below the core that acted. *P. elongatus* was a calanoid species that generally migrated and was distributed within the CIL. Total mesozooplankton appeared with two maximum abundance concentrations in the water column during the day: The lower concentration occurred in the daytime and early nighttime while they yielded only a peak at surface around midnight. The subsurfacial maximum was composed of *Noctiluca, Paracalanus, Oithana, Pseudocalanus, Acartia,* and sometimes *Calanus* species. In general, the cladoceran species were found in the uppermost layer situated above the pycnocline. The Polychaete larvae showed negative geotaxis in response to daylight between the anoxic and the MTL layer contrasted to *P. pileus* in the CIL.

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REFERENCES

[1] Tiselius, P. T. (1988): Effects of diurnal feeding rhythms species composition and vertical migration on the grazing impact of calanoid copepods in the Skagerrak and Kattegat. *Ophelia,* 28: 215-230.

[2] Vinogradov, M. Ye., Flint, M.V. & Shushkina E.A. (1985): Vertical distribution of mesoplankton in the open area of the Black Sea. *Marine Biology,* 89: 95-107.

[3] Besiktepe, B., Kideys, A. E. & Unsal, M. (1998): In situ grazing pressure and diel vertical migration of female *Calanus euxinus* in the Black Sea. *Hydrobiologia,* 363: 323-332.

[4] Besiktepe, B & Unsal, M. (2000): Population structure, vertical distribution and diel migration of *Sagitta setosa* (Chaetognatha) in the south-western part of the Black Sea. *Journal of Plankton Research,* 22(4): 669-683.

[5] Erkan, F., Gucu, A.C. & Zagorodnyaya, J. (2000): The diel vertical distribution of zooplankton in the southeast Black Sea. *Turkish Journal of Zoology,* 24: 417-427.

[6] Besiktepe, S. (2001): Diel vertical distribution, and herbivory of copepods in the south-western part of the Black Sea. *Journal of Marine Systems*, 28: 281-301.

[7] Mutlu, E, & Bingel, F. (1999): Distribution and abundance of ctenophores and their zooplankton food in the Black Sea. I. *Pleurobrachia pileus*. *Marine Biology,* 135(4): 589-601.

[8] Mutlu, E. (1999): Distribution and abundance of ctenophores and their zooplankton food in the Black Sea. II. *Mnemiopsis leidyi*. *Marine Biology,* 135(4): 603-613.

[9] Mutlu, E. (2001a): Distribution and abundance of moon jellyfish (*Aurelia aurita*) and its zooplankton food in the Black Sea *Marine Biology,* 138(2): 329-339.

[10] Mutlu, E. (2001b): Distribution of gelatinous macrozooplankton and ecosystem change in the Black Sea. In: Gelatinous zooplankton outbreaks: theory and practice. *CIESM Workshop Series, Monaco,* 14: 75-80.

[11] Tugrul, S., Basturk O., Saydam C. & Yilmaz A. (1992): Changes in the hydrochemistry of the Black Sea inferred from the water density profiles. *Nature,* 359: 137-139.

[12] Banse, K. (1964). On the vertical distribution of zooplankton in the sea. *Prog. Oceanog.,* **2**, 53-125.

[13] Bautista, B. & Harris, R.P. (1992): Copepod gut contents, ingestion rate and grazing impact on phytoplankton in relation to size structure of zooplankton and, phytoplankton during a spring bloom. *Marine Ecology-Progress Series,* 82: 41-50.

[14] Fulton, R. S.III. (1984): Effects of chaetognath predation and nutrient enrichment on enclosed estuarine copepod communities. *Oecologia,* 62: 97-101.

[15] Stalder, I.C. & Marcus N.H. (1997): Zooplankton responses to hypoxia: behavioral patterns and survival of three species of calanoid copepods. *Marine Biology,* 127: 599-607.

[16] Petipa, T.S., Pavlova, E.V. & Mironov, G. N. (1970): On the efficiency of utilization of energy in pelagic ecosytems of the Black Sea. In: J. H. Steele (Ed.), Marine food chains. *University of California Press,* Berkeley and Los Angeles: 144-164.

[17] Petipa, T.S., Saginauku, L.I. & Delalo, E.P. (1963): Vertical distribution of zooplankton in the Black Sea. Transact. *Sebastopol. Biology. Station, Academy of Science, USSR,* 16: 119-137.

[18] Enright, J.T. & Honegger H.W. (1977): Diurnal vertical migration: adaptive significance and timimg, 2. Test of the model: details of timing. *Limnology and Oceanography,* 22: 873-886.

[19] Dagg, M.J., Frost B.W. & Walser W.E. (1989): Copepod diel migration, feeding and the vertical flux of pheopigments. *Limnology and Oceanography,* 34(6): 1062-1071.

[20] Zenkevitch, L. (1963): Biology of the Seas of the USSR. *George Allen & Unwin ltd., London,* 403-426.

[21] Shushkina, E.A. & Musayeva E.I. (1983): The role of jellyfish in the energy system of the Black Sea plankton communities. *Oceanology,* 23(1): 92-96.

[22] Vinogradov, M.Ye., Shushkina, E.A., Musayeva, E.I. & Sorokin, P.Yu. (1989): A newly acclimated species in the Black Sea: the ctenophore *Mnemiopsis leidyi* (Ctenophora: Lobata). *Oceanology*, 29(2): 220-224.

[23] Bogdanova, D.P. & Konsoulov, A.S. (1993): On the distribution of the new Ctenophora species *Mnemia mccradyi* in the Black Sea along the Bulgarian coastline in the summer of 1990. *Dokl B" Akad Nauk*, 46: 71-74.

[24] Kideys, A.E. & Romanova, Z. (2001): Distribution of gelatinous macrozooplankton in the southern Black Sea during 1996-1999". *Marine Biology*, 139: 535-547.

[25] Acuna, J.L. (2001): Appendicularian blooms: accident or rule. In: Gelatinous zooplankton outbreaks: theory and practice. *CIESM Workshop Series*, Monaco,14: 43-44

[26] Oguz, T., Ducklow, H.W., Purcel, J.E. & Malnotte-Rizzoli, P. (2001): Modelling the response of top-down control exerted by gelatinous carnivores on the Black Sea pelagic food web. *Journal of Geophysical Research*, 106(C3): 4543-4564.

[27] Gorksky, G., Miller, R.L. & Nival, P. (2001): Aggregations and blooms of appendicularians. In: Gelatinous zooplankton outbreaks: theory and practice. *CIESM Workshop Series*, Monaco, 14: 49-50.

[28] Flood, P. (2001): Drifting houses in the Gulf Stream. Focus on Appendicularia, Harbor Branch Oceanographic". http://www.at-sea.org/missions/append/append.html.

[29] Karl, D.M. & Knauer, G.A. (1991): Microbial production and particle flux in the upper 350 m of the Black Sea. In: J.W. Murray, (Ed.), Black Sea Oceanography. *Deep-Sea Research*, 38(2A): 921-942.

[30] Mopper, K. & Kieber, D.J. (1991): Distribution and biological turnover of the dissolved compounds in the water column of the Black Sea. In: J.W. Murray, (Ed.), Black Sea Oceanography. *Deep-Sea Research*, 38(2A): 1021-1047.

[31] Magnesen, T., Aksnes, D.L. & Skjoldal, H.R. (1989): Fine-scale vertical structure of a summer zooplankton community in Lindaspollene, western Norway. *Sarsia*, 74: 115-126.

[32] Coban-Yildiz, Y., Fabbri, D., Tartari, D., Tugrul, S. & Gaines, A.F. (2000): Application of pyrolysis-GC/MS for the characterization of suspended particulate organic matter in the Mediterranean Sea: a comparison with the Black Sea. *Organic Geochemistry*, 31: 1627-1639.

[33] Wishner, K.F., Ashjian, C.J., Gelfman, C., Gowing, M.M., Kann, L., Levin, L.A., Mullineaux, L.S. & Saltzman, J. (1995): Pelagic and benthic ecology of the lower interface of the Eastern Tropical Pacific oxygen minimum zone. *Deep-Sea Research, Part I*, 42(1): 93-115.

[34] Vinogradov, M.Ye. & Shushkina E.A. (1992): Temporal changes in community structure in the open Black Sea. *Oceanology*, 32(4): 485-491.

[35] Diercks, A. & Kempe, S., (1988): Visual inspection of the water column and sea bottom and microlplankton and macroflocs in the upper 200 m of the water with a video camera and photo camera equipped Mini-Rover. In. S. Hanjo, B.J. Hay and the members of the scientific shipboard party (Eds). Cruises report, R/V Knorr 134-8. Black Sea Leg1, April 16-May 7, 1988: Temporal and spatial variability in sedimentation in the Black Sea. *Piri Reis International Contr. Ser*, 6: 87-92.

[36] Kempe, S., Diercks, A.R., Liebezeth, G. & Prange, A. (1989): Geochemical and structural aspects of the pycnocline in the Black Sea (R/V Knorr 134-8, LEG1,

1988). In: Black Sea Oceanography, Izdar, E. and Murray, J., (Eds), *Kluwer Academic Publisher*, 351: 89-110.

[37] Herman, A.W., (1983). Vertical distribution patterns of copepods, chlorophyll, and production in northeastern Baffin Bay. *Limnology and Oceanography,* 28: 709-719.

[38] Falkowski, P.G., Vidal J., Hopkins T.S., Rowe G.T., Whitledge T.E. & Harrison, W.G. (1983): Summer nutrient dynamics in the Middle Atlantic Bight: primary production and utilization of phytoplankton carbon. *Journal of Plankton Research,* 5: 515-537.

[39] Dalton K, (2000): Fine Scale Vertical Distribution of Zooplankton in an Estuarine System. Student research abstracts University of Maryland Summer 2000 http://www.mdsg.umd.edu/Education/REU/2000Dalton.html.

[40] Heinle, D.R., (1966): Production of a calanoid copepod, *Acartia tonsa*, in the Patuxent River Estuary. *Chesapeake Science,* 7: 59-74.

[41] Marshall, S.M., Nicholss, A.G. & Orr, A.P. (1934): On the biology of *Calanus finmarchicus*. V. Seasonal distribution, size, weight and chemical composition in Loch Striven in 1933 and their relation to the phytoplankton. *Journal of Marine Biological Association in United Kingdom*, 19: 793-827.

[42] Rudjakov, J.A., 1970: The possible causes of diel vertical migrations of planktonic animals. *Marine Biology,* 6: 98-105.

[43] Lie, U., Magnesen, T., Tunberg, B. & Aksnes, D. (1983): Preliminary studies on the vertical distribution of size-fractions in the zooplankton community in Lindaspollene, Western Norway. *Sarsia,* 68: 65-80.

[44] Sabatini, M. & Kiorboe, T. (1994): Egg production, growth and development of the cyclopoid copepod *Oithana similis. Journal of Plankton Research,* 16: 1329-1351.

[45] Lampitt, R.S., (1978): Carnivorous feeding by a small marine copepod. *Limnology and Oceanography,* 23(6): 1228-1231.

[46] Balino, B.M. & Aksnes, D.L. (1993): Winter distribution and migration of the sound scattering layers, zooplankton and micronekton in Masfjorden, western Norway. *Marine Ecological Progress Series,* 102: 35-50.

[47] Marshall, S.M. & Orr, A.P. (1955): The biology of *Calanus finmarchicus* (Gunnerus). *Oliver & Boyd*, Edinburg : 188 pp.

[48] Sullivan, B.K. (1980): In situ feeding behavior of *Sagitta elegans* and *Eukrohnia hamata* (Chaetognatha) in relation to the vertical distribution and abundance of prey at Ocean station ‘P’. *Limnology and Oceanography,* 25(2): 317-326.

[49] McLaren, I.A. (1963): Effects of temperature on growth of zooplankton, and the adaptive value of vertical migration. *Journal of Fisheries Research Board Canada,* 20: 685-727.

[50] Vinogradov, M.Ye. & Nalbandov, R.Yu. (1990): Effects of changes in water density on the profiles of physicochemical and biological characteristics in the pelagic ecosystem. *Oceanology,* 30(5): 567-573.