

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 time (Besiktepe *et al.* 1998, Besiktepe & Unsal 2000, Erkan *et al.* 2000, Besiktepe 2001, Kideys & Romanova, 2001; Mutlu & Bingel, 1999; Mutlu, 1999; Mutlu, 2001a,b). The present study was aimed to show the diel vertical distribution and migration patterns of mero and holo zooplankton in the southern Black Sea in spring (April 1995) with respect to the biological, chemical and physical peculiarities of the water column.

### Material 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  $\mu$ m mesh) at one station in offshore waters of the western Black Sea in late April 1995. A series of discrete vertical hauls was made at a speed of 1 cm s<sup>-1</sup> 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). The depth of the H<sub>2</sub>S layer (according to sigma theta=16.2; Tugrul *et al.*, 1992) was determined with a SeaBird CTD. 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.

### Results and Discussion

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 1A). Fulton (1984) showed that *A. tonsa* was found to be a strong nocturnal migratory species. Banse (1964) showed that a salinity gradient of more than 0.3‰ m<sup>-1</sup> in 10 m prevented the vertical migration of small copepods as Bautista & Harris (1992) also expressed that smaller neritic copepods migrate slightly in the upper layer. Stalder & Marcus (1997) showed that adults of *A. tonsa* declined sharply in survival with DO=0.9 to 0.6 ml l<sup>-1</sup>. Petipa *et al.* (1970) determined that *A. clausi*, a mixed food consumer does not stay outside the limits of the phytoplankton as observed in the present work. *C. euxinus* migrated vertically through the entire oxygenated layer (Fig 1B). Petipa *et al.* (1963) ascertained that the vertical range of the species was restricted to a lower depth characterized with oxygen deficiency and the appearance of H<sub>2</sub>S (Vinogradov *et al.* 1985; Besiktepe 2001, Erkan *et al.* 2000). 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 as Enright & Honegger (1977) determined (Dagg *et al.* 1989). 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 (Fig 1C). Erkan *et al.* (2000) and Besiktepe (2001) gave the conclusion of

inconsistent and unclear vertical migration. *P. elongatus* was a calanoid species that generally migrated and was distributed within the CIL profiled with a temperature less than 8 °C (Fig 1D). Zenkevitch (1963) classified the species as a cold water stenothermal form and Vinogradov *et al.* (1985) 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 (Besiktepe 2001, Erkan *et al.* 2000). 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 (Fig. 5D,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 subsurface water and 110 m (Fig 1E). Besiktepe (2001) observed a peak in abundance of the species in the CIL in spring whilst the highest density of individuals was reported to be above the CIL in September and June.

*A. aurita* were distributed over a narrow depth range in and above the thermocline both day and night. Shushkina & Musayeva (1983) first observed a similar vertical distribution in late September 1987; this pattern has been repeatedly observed (Vinogradov *et al.* 1989; Mutlu 2001a). *M. leidyi* showed a similar pattern to *A. aurita* occupying the same layer; it was repeatedly observed (Vinogradov *et al.* 1989; Bogdanova & Konsoulov, 1993; Mutlu, 1999). A few small sizes individuals were observed below the thermocline in April (present work) while *M. leidyi* was confined to a layer above the thermocline in August 1993 (Mutlu 1999, 2001a; Kideys & Romanova, 2001). *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. Mutlu & Bingel (1999) 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 (2001) observed a similar pattern in June-July of summer 1996. Vinogradov *et al.* (1985) found similar trends in April-May of spring 1984 with respect to the spring distribution detailed here (Fig 2B and C).

Most specimens of Appendicularia were generally distributed above the MTL and showed an inconsistent migration pattern during both day and night. Erkan *et al.* (2000) 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 (2001) related the population dynamics of these gelatinous tunicates to the phytoplankton bloom that occurred in early spring and early autumn in the Black Sea (Oguz *et al.* 2001).



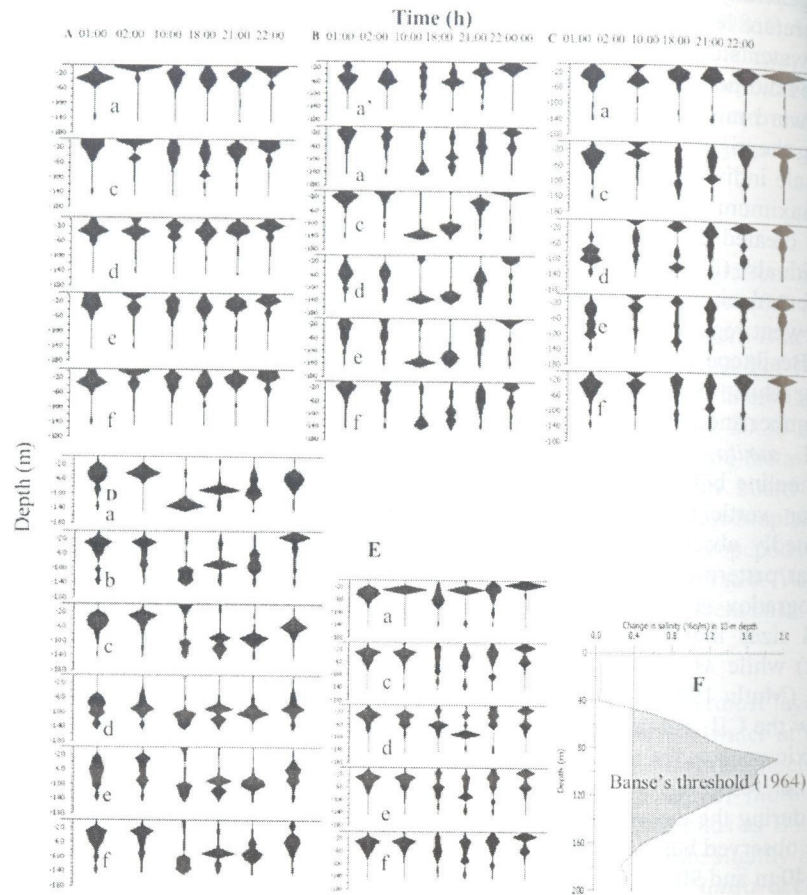


Fig. 1. Pattern of vertical percent distribution of the copepod species (A; *A. clausi*. B; *C. euxinus*. C; *O. similis*. D; *P. elongatus*. and E; *P. parvus*). and F; Banse's threshold simulated to data of the present work. (a'; *Calanus* nauplii. a; copepodites. b; copepodid female. c; female. d; male. e; adults. and f; total).

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  $\text{NO}_2 + \text{NO}_3$  levels peaked, and at a depth of 150 m where the light transmission dropped suddenly. All these depths could carry the fine scale living and non-living particles on which Appendicularia feed indifferently (Gorsky *et al* 2001). Flood (2001) 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  $\text{NO}_2 + \text{NO}_3$  levels peaked (Karl & Knauer 1991). The second accumulation layer of Appendicularia was a depth where the light transmission dropped to a minimum value of 80s%. Mopper & Kieber (1991) reported the layer as fine particle maxima, which the Appendicularia could feed intensively on.

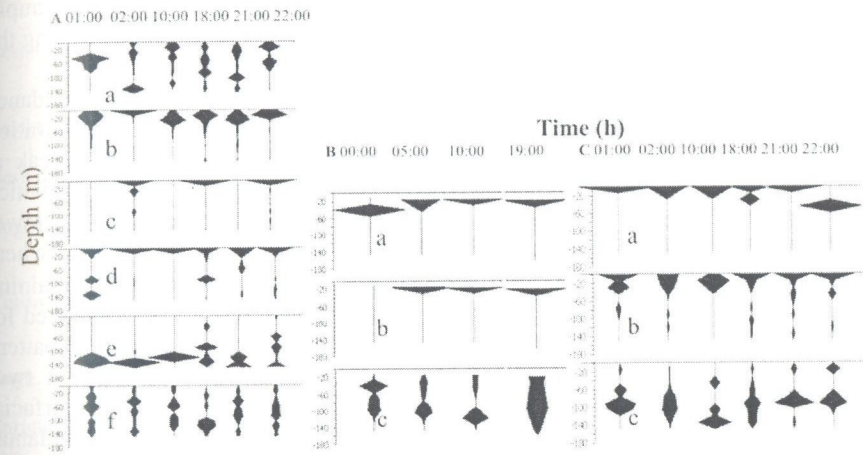


Fig. 2. Pattern of vertical percent distribution of the taxa (A; a; Appendicularia. b; Bivalvia larvae. c; Cirriped larvae. d; Cladocera. e; Polychaete larvae. and f; Chaetognatha) in April 1995 and gelatinous organisms (a; *A. aurita*, b; *M. leidy* and c; *P. pileus*) in summer (B, August 1993) and spring (C, April 1995) in response to the daylight.

*S. 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. The species appeared in two main aggregations during the nighttime: One was just above the permanent halocline, the other was at a depth where  $\text{NO}_2 + \text{NO}_3$  corresponded to the fine particle maxima (Mopper & Kieber, 1991) displaying a peak in concentration. Besiktepe & Unsal (2000) showed similar findings on the vertical distribution of this species. Erkan *et al* (2000) concluded that this species did not exhibit a clear migratory pattern in October 1996 and July 1997. Vinogradov *et al* (1985) 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  $\text{l}^{-1}$  as was repeatedly observed in this study in the OML (Fig. 5). The aggregation was observed between 00:30 and 02:00 in a layer where the temperature ranged from about 7-11 °C (MTL). Vinogradov *et al* (1985) found the main bulk of this species within the thermocline characterized with temperatures varying between 9 - 15 °C in late April-May 1984. The present



work showed that this species started to ascend after 18:00 as Vinogradov *et al* (1985) 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. 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* (1989) 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 inhabitation of surface waters during the day.

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 DO dropped to less than  $150 \mu\text{M l}^{-1}$  ( $3.36 \text{ ml/l} = 4.8 \text{ mg/l}$ ). The remaining intermediate layers constituted the transition layer which the zooplankton used for the immigration. Vinogradov *et al* (1985) 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. The subsurface maximum was composed of Noctiluca, Paracalanus, Oithona, Pseudocalanus, Acartia, and sometimes Calanus species. In general, the cladoceran species were found in the uppermost layer situated above the pycnocline. Erkan *et al* (2000) 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 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  $\text{NO}_2 + \text{NO}_3$  and Particulate Organic Carbon (POC; Coban-Yildiz *et al* 2000) peaked. Wishner *et al.* (1995) observed that the polychaetes peaked in a layer where the POC peaked around 750 m depth in the Eastern Pacific OZM. The larvae were found in the 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. As Vinogradov & Shushkina (1992) and Mutlu & Bingel (1999) stated, the larvae of benthic animals were one of the food items of this ctenophoran species (Fig 2A).

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## Acoustic copepod

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## Abstract

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