Acoustical implication and innovations on distributions of a copepod species, *Calanus euxinus*, in the Black Sea

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Abstract- Swimming trajectories of *Calanus euxinus* Hulsemann, were studied using an echosounder with 120 and 200 kHz in the Black Sea. *Calanus* were acoustically discriminated respecting to vertical migration and swimming speed with DO and timing of their migrations. Species became torpid in water with DO<0.5 mg/l. The time spent swimming under DO condition between 2 and 5 mg/l was insignificant and varied widely from 10-25% of the total time spent under the normal oxic conditions (5-10 mg/l). *Calanus* formed concentration layer in thickness of 1-3 m in water. Upward migration was completed in about 3.5 h starting at time 2.5 h earlier and ending at time 1 h later than sunset (average 0.95 cm/s) in summer. Species ascended discretely from suboxic to lower end of CIL at 0.82 cm s^{-1} and passed up CIL and thermocline fast at 2.3 cm/s. Downward migration took shorter (2 h) starting ~1 h earlier and ending ~1 h later than sunrise. Swimming speed within thermocline and CIL was 2.7 cm/s and then it returned to daylight depth at a sinking speed of 0.57 cm/s. Total time in order for the *Calanus* to settle their nocturnal depth layer was about 5 hours. *Calanus* spend the daytime just above the suboxic zone where the upper end of suboxic zone was at depth deeper than 100 m (sigma-theta=15.2-15.4) if shallower (15.8-16.2).

Keywords- Zooplankton, distribution, acoustics, the Black Sea

Introduction

The acoustical studies have recorded progress for the mesozooplankton and gelatinous macrozooplankton. Direct identification of the organisms has seemed presently not to be impractical with present acoustical knowledge and techniques even though the bioacoustics have visualized well under water (Wiebe and Greene 1994; Mutlu 1996; David et al. 1999). Using background knowledge about characteristics identical to the organisms ought to be the most relevant approach to assess species of organisms. For instance, *Calanus euxinus* has generalized pattern for its vertical migration and time spend swimming in response to dissolved oxygen of the water column in the Black Sea as Svetlichny et al. (2000) described well. The present work was aimed to show ability of recognizing concentration layer of *Calanus euxinus* in the Black Sea from the acoustical records with respect to swimming behavior in response to dissolved oxygen during the vertical migration. Therefore, *in situ* monitoring of the species could be possible and then estimation of biomass and spatio-temporal distributional pattern during the day would be considered for the future works.

Material and Methods

Acoustical data collected from the Black Sea in June 1991, October 1999, and July 2000 (Fig. 2e) were evaluated to discriminate and identify a copepod, *Calanus euxinus* Hulsemann, concentration layer during their vertical migratory loops in response to dissolved oxygen of the water columns. Acoustic data were collected with a scientific echosounder (BioSonic, Model 102) at 120 kHz (October 1999, July 2000) and 200 kHz (June 1991, October 1999, and July 2000). During the acoustical records, Nansen Rosette and CTD probe (SeaBird) were casted to measure physical parameters and take water samples for measuring the dissolve oxygen with winkler titration method. Layered samples of meso and macro zooplankton were collected at some stations with a Nansen opening and closing net (112 µm mesh size and 0.7 m diameter mouth opening).

Results

Calanus' time spend for swimming through water with <0.5 dissolved oxygen (DO) mg/l comprised more than 50% of total time needed to complete either upward or downward migration of the species. *Calanus* looked like torpid or motionless at that time. This was occasionally true somewhere in water with DO up to 1 mg l^{-1}. The time varied between 15% and 25% where the DO was between 1 and 5 mg l^{-1}. When the DO reached a concentration of more than 5 mg l^{-1}, the time was less than 10%, resulting in that *Calanus* swims at maximum speed of 2.8 and 3.0 cm s^{-1} (Fig. 1b). According to the descriptions above on *Calanus*' swimming behavior through water with different concentrations of DO and using the acoustic records, *Calanus* formed a concentration layer in a thickness of 2-3 m in the water. Overall, upward migration of the species was completed in about 3.5 h starting at 17:30 and ending at 21:00 (0.95 cm s^{-1}) in summer. The species ascended discretely taking long time from the suboxic zone to lower end of the Cold Intermediate Layer (CIL) at an ascending speed of 0.82 cm s^{-1} and passed up the CIL and the thermocline very fast within a very short time of 45 min. at a speed of 2.3 cm s^{-1}. Downward migration took approximately shorter time about the 2 hours starting at 04:15 and ending at 06:13. Swimming speed within thermocline and the CIL was 2.7 cm s^{-1} (60 m for 37 min.) and thereafter it returned to daylight depth at a real sinking speed of 0.57 cm s^{-1}. Total time in order for the *Calanus* to settle their nocturnal depth layer was about 5 hours (Figs. 1c,d and 2g).

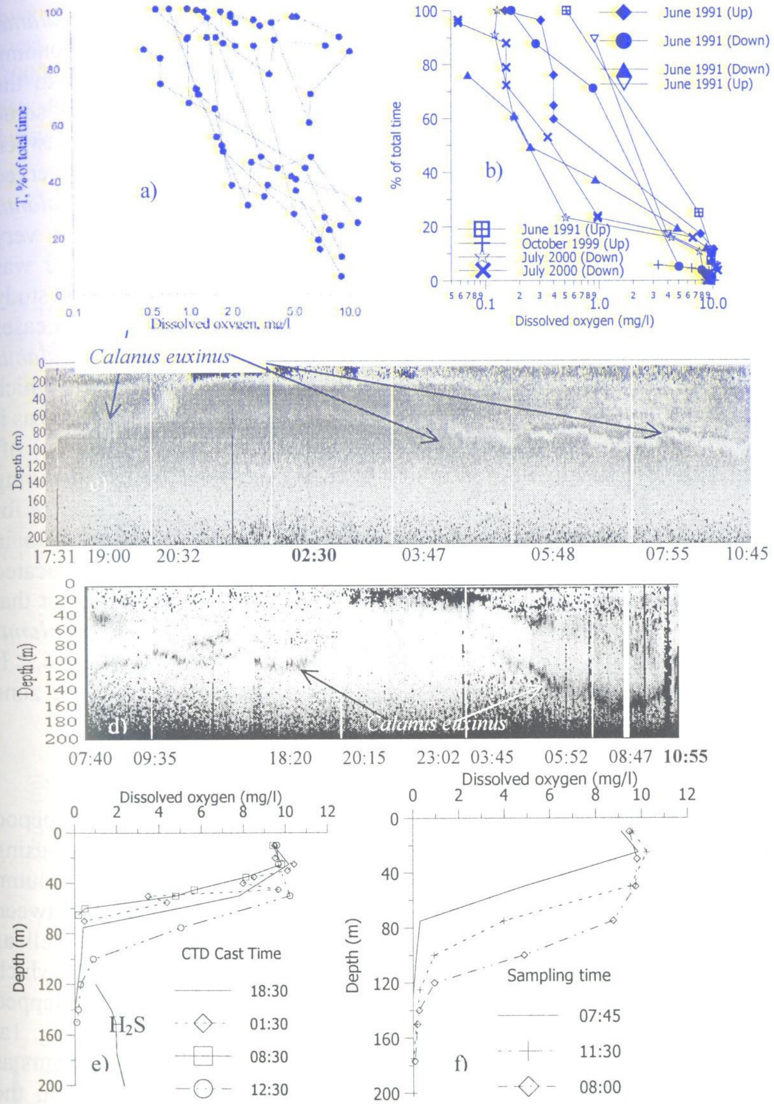


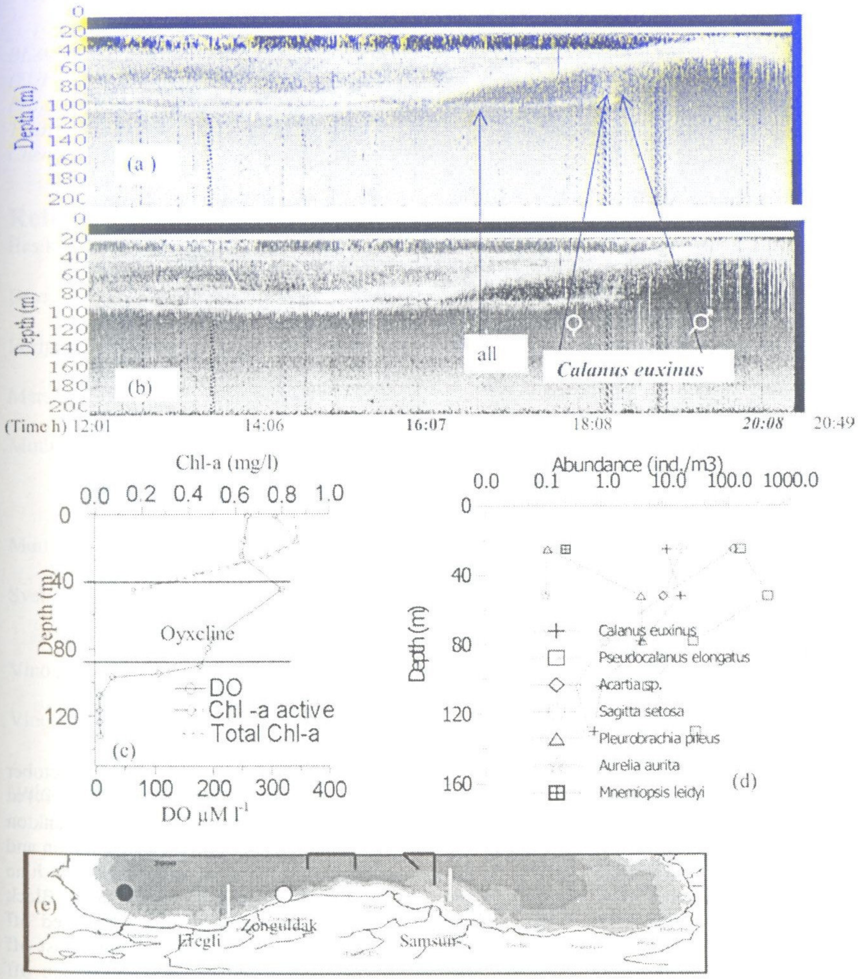
Fig. 1. Dissolved oxygen-dependent swimming speed of *Calanus euxinus*, (a; From Svetlichny *et al*, 2000 and b; from the present study), Acoustical observation of upward and downward migrations of *Calanus euxinus* in June 1991 in southwestern (c) and in southeastern (d, see Fig. 2e for the locations). Profiles of dissolved oxygen in the different time of acoustical records in Fig. 1c (e), and in Fig. 1d (f).

The case was the same in the examples of October 1999. At that time, *Calanus* spent the daytime preferring well-oxygenated layer (O_2 > 6 mg l^{-1}) corresponding to lower and the halocline and started migrating upward from the layer to the surface by the twilight (Fig. 2a,b,c). Fig. 2d shows that vertical distribution of some meso and macro zooplanktonic species from the layered samples collected between 19:49 and 20:08 (Fig. 2a,b) in October 1999. No acoustical scattering was observed below 30m depth at that time whereas most of the species especially *Calanus euxinus, Sagitta setosa, Pseudocalanus elongatus* and *Acartia* sp. were very abundant within the upper 25 m. At the same time, *Pleurobrachia pileus* was mostly found below the 30 m where the no scattering was observed. Another study conducted in July 2000 showed similar migratory behavior of the species to cases in both June 1991 and October 1999. With both 120 and 200 kHz, the *Calanus* daylight scattering layer was observed in water with DO more than 4 mg/l to which lower limit of permanent halocline corresponded off Zonguldak (Fig. 2f) whereas it was within suboxic zone characterized with DO less than 1 mg l^{-1} (Fig. 2h) off Samsun (Fig. 2g). However, two successive ascendances were observed during *Calanus*' upward migration (Figs. 2a,b,f). This could be due to time difference for female and male specimens to start the migrations separately as referred to in Enright and Honegerr (1977). The daytime concentration was however located either within suboxic zone or just above the zone in space. This is very clear that when the suboxic zone is located in layer shallower than 100 m, the *Calanus* concentration layer is within suboxic with sigma-theta in a range of 15.8 to 16.2. If the suboxic is deeper than 100 m, *Calanus* will stay just above the suboxic zone where sigma-theta varied between 15.2 and 15.4.

Discussion

120 kHz and 200 kHz were used for evaluating *in situ* recognition of a copepod layer as *Calanus euxinus* by looking at acoustical records directly and by using time spend swimming behavior of the species in response to DO of water column in the Black Sea. Wiebe and Greene (1994) determined relationship between minimum detectable size of the target and the acoustical frequency as well as David et al. (1999) determined. Time spend swimming as function of DO which was Fig.d out from the acoustical records of the present work overlapped significantly with experimental results made by Svetlichny et al. (2000) (Fig. 1a, b). Net samples collected in April 1995 (Mutlu 2002) showed that slope of hours as a function of depth where *Calanus* concentration was observed changed in the different layers with different DO concentrations. The slope increased with the DO. Swimming speed of *Calanus* during migration varied from a passive sinking speed of ~0.57 cm s^{-1} within suboxic zone to an active speed of 2-3 (upward)-2.7 cm s^{-1} (downward) through well-oxygenated water. Svetlichny et al. (2000) showed that the speed of active swimming of the species was equal to 2.8 cm s-1 in aerated water and passive swimming to 0.54 cm s^{-1} under hypoxia. Similar migration speeds (2.8 and 0.94 cm s-1) for the species were obtained by a series of vertical

tows (Besiktepe 2001). Overall, the species completed its upward migration for 3 hours while its downward migration lasted shorter (2 hours). Svetlichny et al. (2000) concluded that migration downwards takes 2.0 h and movement upwards lasts for 3.0 h. The present study showed also that two successive movements during the downward and upward migrations were observed.



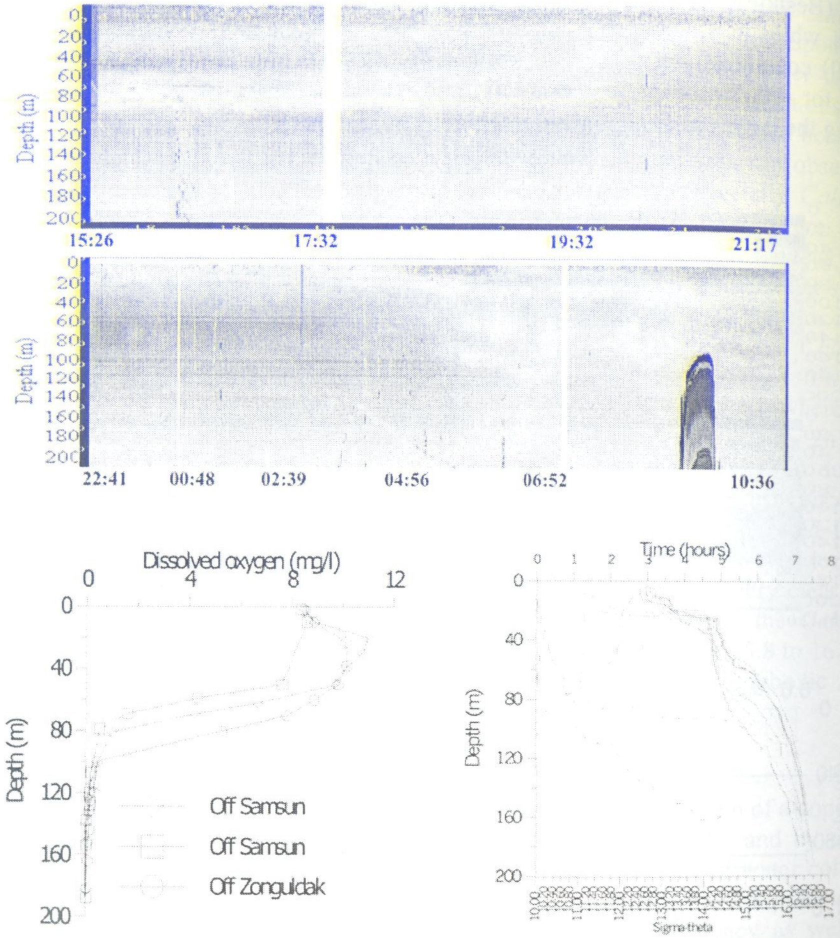


Fig. 2. Acoustical observation of upward and downward migrations of *Calanus euxinus* in October 1999 at 120 kHz (a) and 200 kHz (b). Profiles of dissolved oxygen (μM l^{-1}; 100 μM l^{-1}=3.2 mg l^{-1}) at **16:07** h of acoustical records in Fig. 2a,b (c), and vertical distribution of meso and macro zooplankton abundances between 19:49 and ***20:08*** h in Fig. 2a,b (d) (sunrise at 07:09, mid-time between noon and dusk at 16:00, and sunset at 18:32; see Fig. 2e for the locations). Locations (e; thick black line: June 1991, black circle: October 1999; white circle and lines; July 2000) of acoustic studies in the Black Sea, acoustic records (200 kHz) at the stations, acoustical cross-section at a station stayed off Zonguldak (f; dawn at 04:47 and dusk at 21:41), and on the trackline from offshore to coast off Samsun (g) in July 2000 (dawn at 04:32 and dusk at 20:47) and vertical DO distribution off Zonguldak and Samsun (h), relation of depth of daytime concentration to sigma-theta (m; dashed line: swimming paths and solid line: sigma-theta).

This could be postulated to the observations on timing of separate migration of female and male specimens as referred to in (Marshall and Orr 1955; Enright and

Honegger 1977; Mutlu 2002). As the present work showed, thickness of the species diurnal concentration layer varied between 1 in October 1999 and 3 m in June 1991 and July 2000. Vinogradov et al. (1985) showed that hemipopulation of the species formed a narrow concentration layer that did not exceed 2 m thickness in water with a DO concentration of 0.4 to 0.5 ml l^{-3} during the daytime. The thickness was narrowed to be 1 m in October (Vinogradov and Shushkina 1982).

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