ACOUSTICAL (ECHOSOUNDER AND ADCP) OBSERVATION OF *CALANUS EUXINUS* AND *SAGITTA SETOSA* IN THE BLACK

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Since direct acoustical recognition of concentration layer of copepods C. euxinus, *swimming trajectories of chaetognaths* S. setosa *in the Black Sea were studied using an echosounder at 120 and 200 kHz and ADCP (Acoustic Doppler Current Profiler) at 150 kHz.* Sagitta setosa *were acoustically discriminated with respect to vertical migration and vertical distributional range depending on stage status in months.* C. euxinus *were acoustically discriminated with respect to vertical migration and swimming speed, according to dissolved oxygen (DO) concentration and the timing of migrations. Upward migration was completed in about 3.5 h, starting 2.5 h before and ending 1h after sunset (average rate: 0.95 cm s^{-1}) in summer. Species ascended discretely from the suboxic to the lower boundry of the cold intermediate layer (CIL) at 0.82 cm s^{-1}, and passed up the CIL and thermocline fast (2.3 cm s^{-1}). Downward migration took less time (2 h), starting ~1 h before and ending ~1 h after sunrise. Swimming speed within the thermocline and CIL was 2.7 cm s^{-1}; copepods subsequently returned to daylight depth at a sinking speed of 0.57 cm s^{-1}. Chaetognaths were migrated daily between subsurface and oxycline or suboxic zone (OMZ). The lower limits changed to be the oxycline and OMZ depending on abundance of adult and immature (young) individuals in the concentration layer. In July and September, individuals of a new generation did not migrate and stayed in subsurface water. During January through May, all adults exhibited diel vertical migration and co-existed with the copepod* C. euxinus *during the day time in the OMZ while during June through October, two different layers of* S. setosa *underwent during their diel vertical migration: The upper layer was immature individuals and the lower layer was mature individuals.*

INTRODUCTION

Sagitta setosa migrates between the anoxic zone or oxycline and surface layers [1-4]. Limits of vertical distribution of *S. setosa* depended on stage composition and body length [2]. The variation appeared to be related to the body length (maturity status) of the individuals. Core populations of juveniles (<5 mm) were distributed generally above the thermocline.

Diel vertical migration in the adult was observed from the upper layers down to the oxygen minimum zone (OMZ; [5] in April when the entire population was made up of adults longer than 10 mm. In June, almost half of the adults migrated down to the OMZ during day, whereas the other half showed limited vertical migration down to the third (oxycline; σ_θ=14.6-15.4) or fourth layers (just above anoxic layer; σ_θ=15.4-15.8; [2, 4]. In September, when the entire population consisted of individuals from the new generation and of these, almost 20% were adults (from 6 to 10 mm long). In April, May, and December, the population comprised mainly adults (> 5 mm long). Juveniles (< 5mm long) predominated in June, September and November, accounting for almost 60% of the population [2]. Their muscle fiber formation might not have been completed sufficiently to allow the individuals to swim down to the depth of the OMZ [2]. In May when the population was generally represented by nearly mature individuals of 16 to 22 mm in length, emigrational rearrangements from OMZ to surface layers took 4 h: from 20:00 to 00:00 hrs. The maximum rate of the individuals' movement upwards was about 1 cm s^{-1}. In other words, assuming the average length of chaetognaths within concentrations to be about 17 mm this rate comprised 0.6 body length s^{-1}. Usually, the layer of chaetognath concentration was clearly separated from the layer of maximal *Calanus* concentration and was more extended vertically and *C. euxinus* lagged behind the chaetognaths that ascended from the deeper layers during the evening migration at nightfall in May [1]. In September, most of the individuals were juveniles of new generation as [2] found. A study conducted between January and August showed that in the Black Sea the peak of the *S. setosa* bloom occurred in July/August [6].

Calanus euxinus have distinct patterns of vertical migration and time spent swimming, depending on the DO concentration of the water column, as described by [7] and [8] for Black Sea copepods. [8] found that time spent swimming (*T*, %) did not depend on water temperature. Under normoxic conditions *T* varied widely from 15–20% to 90–95%. However, when oxygen concentration declined to the values characterizing *C. euxinus*' daytime habitat at depth (0.8–1.15 mg O$_2$ l^{-1}), *T* of all investigated animals increased to 80–100% [9].

Presently, direct identification from acoustics without using supplementary information remains generally impractical. Integrating such techniques with previously obtained background knowledge on characteristics specific to certain organisms may, therefore, be the most fruitful strategy for species identification.

The aim of the present work was to be able to identify the composition of unknown scattering layers in the Black Sea from monthly acoustical records, based on daily behavior of *S. setosa* and to observe spatio-temporal distribution of *S. setosa* and *C. euxinus*.

1. MATERIAL AND METHODS

Acoustical data were examined to discriminate and identify the concentration layer of *S. setosa* in the Black Sea. Acoustical data were collected with a scientific echosounder data (BioSonics Model 120) at 120 kHz (October 1999, July 2000) and 200 kHz (June 1991, January 1992, February 1994, October 1999 and July 2000) and an acoustic Doppler current profiler (ADCP, RD broadband) at 150 kHz (March 1995, April 1993, May 1994, August 1993, September 1995, October 1999, December 1993). The echosounder parameters were calibrated with a spherical ball of tungsten, and the transmitter of the echosounder was disabled to estimate the background noise that would be used to set the signal-to-noise threshold during post-processing of the data. Acoustical data of the echosounder were converted to volume backscattering strength (dB) and those of ADCP to echo intensity (dB) and were plotted as enhanced echograms. Echo intensity as relative biomass of only *C. euxinus* and *S. setosa* concentration layers was vertically integrated and averaged by giving a

certain thresholds recognizing the species. There was no significant difference in echo intensity measurements between echosounder and ADCP (Fig. 2b and c; Fig. 2m and n). During acoustical recording, Nansen rosette water samples and CTD profiles (Sea Bird Electronics, Model 9/11) were collected to measure physical hydrography and to determine dissolved oxygen using the Winkler titration method. Stratified and whole water column net samples of meso- and macrozooplankton were examined for indications of vertical migration by *S. setosa* [1-4, 9-10, unpublished data IMS-METU]. Corrected biomass (wet weight mg m^{-2}) of both species were summed up after biomass collected by vertical hauls of Nansen plankton nets for *S. setosa* was multiplied by its acoustical reflection coefficient of 0.058 and *C. euxinus'* by 0.015.

2. RESULTS AND DISCUSSION

The dominant sources of acoustical scattering at 120, 150 and 200 kHz in the surface waters of the Black Sea were the chaetognath *Sagitta setosa* and the copepod *Calanus euxinus* (Fig. 1). Each species exhibited a distinct daily migrational path that appeared to reflect its hydrographic preference. Their vertical range as well as timing of their migrations changed depending upon their developmental stage and the season. In general, the range of vertical migration was restricted to within a layer between the OMZ and subsurface water. Distinctive main feature of the species was response of their swimming speed to the dissolved oxygen. *Calanus euxinus* accelerated the speed immediately within oxygenated water column while *Sagitta setosa* accelerated that within subsurface maxima of the oxygen during the migration time. Meanwhile, vertical distribution of the species was variable in time depending on their stage composition, generation time besides diapausing features of *C. euxinus* (Figs. 1 and 2).

Patterns of time spent swimming of *C. euxinus* as a function of DO, as determined from acoustical records in the present study, showed trends similar to the experimental results of [8, 9]; both showed a similar relation between the time spent swimming (5 h of total time) and oxygen concentration. Net samples, collected in April 1995 [10], showed that the slope of the function of time in hours versus the depth where the *C. euxinus* concentration was observed changed in the different layers with different DO concentrations. The slope increased with the DO concentration. Swimming speed of *C. euxinus* during migration varied from a passive sinking speed of ~0.57 cm s^{-1} within the suboxic zone to an active speed of 2–3 cm s^{-1} (upward) and to 2.7 cm s^{-1} (downward) through well-oxygenated water. [8] showed that the speed of active swimming of the species was equal to 2.8 cm s^{-1} in aerated water and of passive swimming was equal 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 [3]. Overall, the species completed its upward migration in 3 h, while its downward migration lasted less time (2 h). In some cases, downward migration could last longer (5–7 h) than usual, depending on location of the suboxic zone. In some cases, where the suboxic zone was located in a layer deeper than 100 m and where its daylight concentration layer remained just above the suboxic zone, the species' upward migration was completed in a very short time (~1 h), at its highest speed. [8] concluded that migration downwards takes 2.0 h and movement upwards lasts for 3.0 h. The present study also showed that two successive movements during the downward and upward migrations took place. This could be due to the timing of separate migrations of female and male specimens, as postulated by [11-12]. [12] determined that males returned to depth earlier than females in the May samplings and also mentioned the early upward migration of females observed by [10] in the Black Sea in April 1995. As the present work showed, the thickness of the diurnal concentration layer of *C. euxinus* varied between 1 m in October 1999 and 3 m in June 1991 and July 2000.
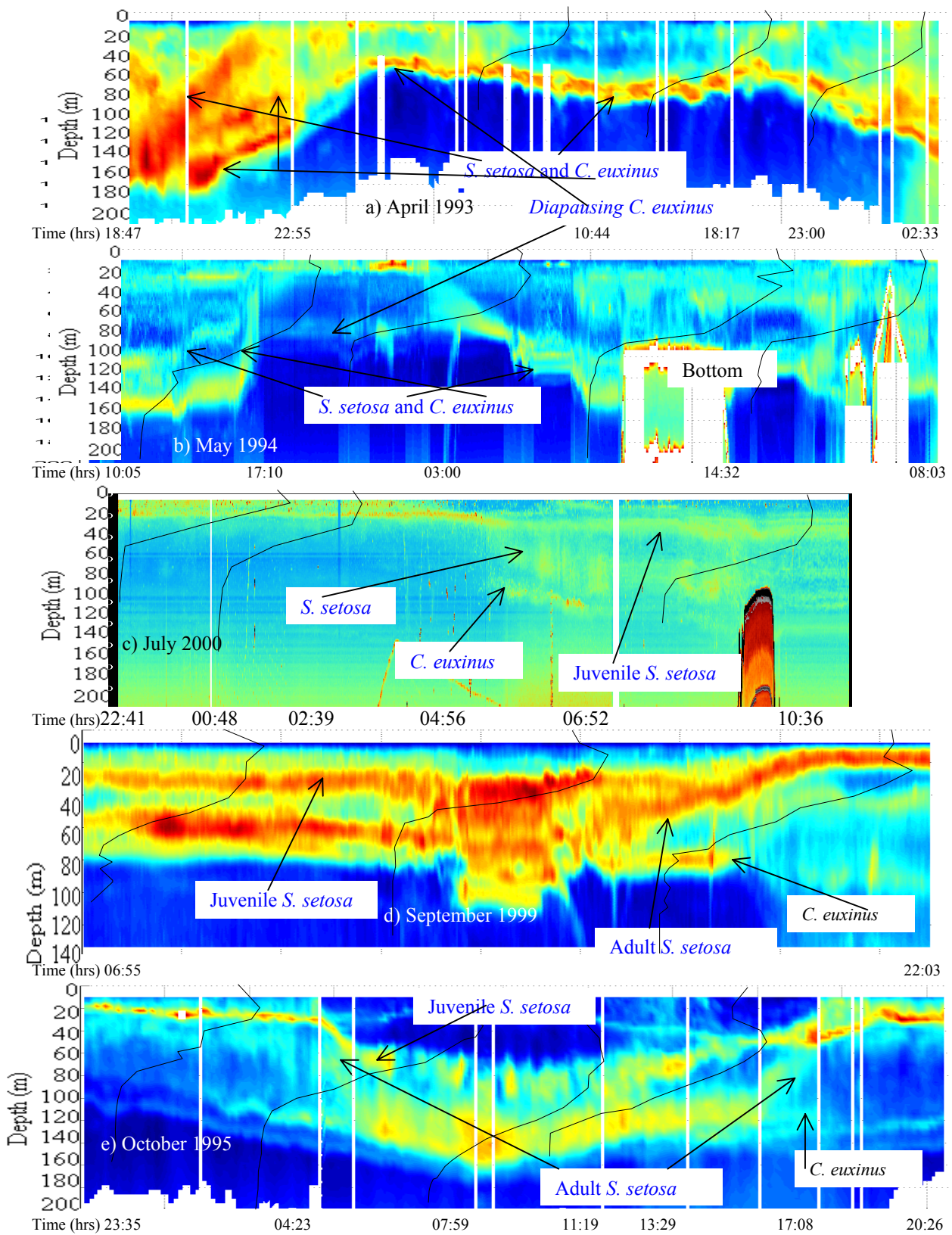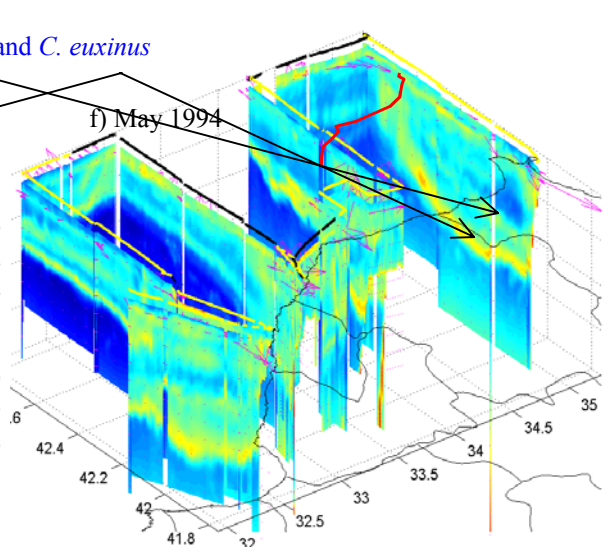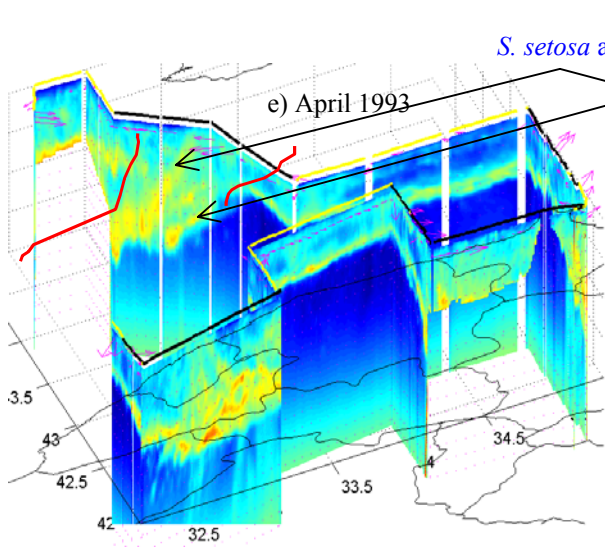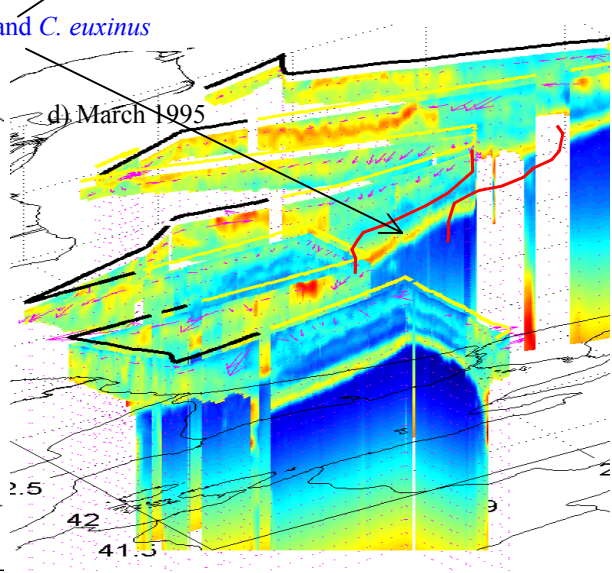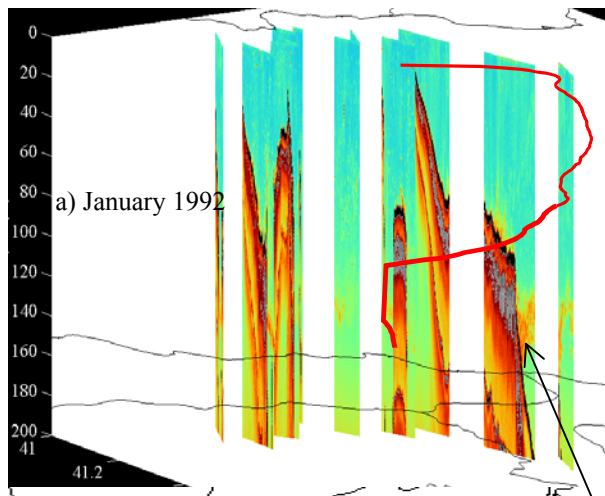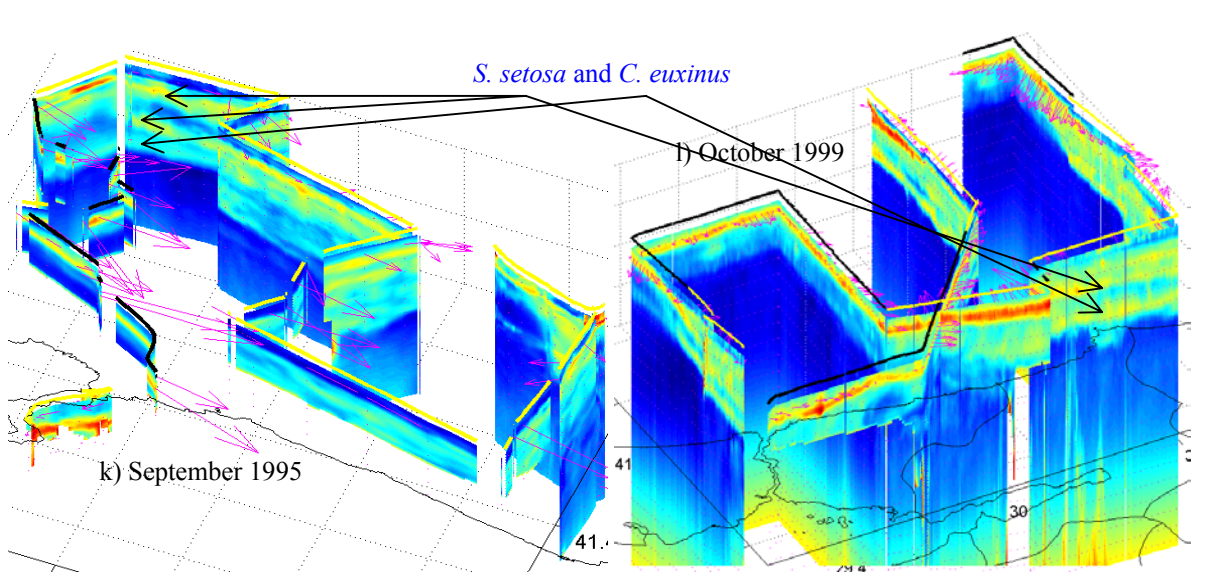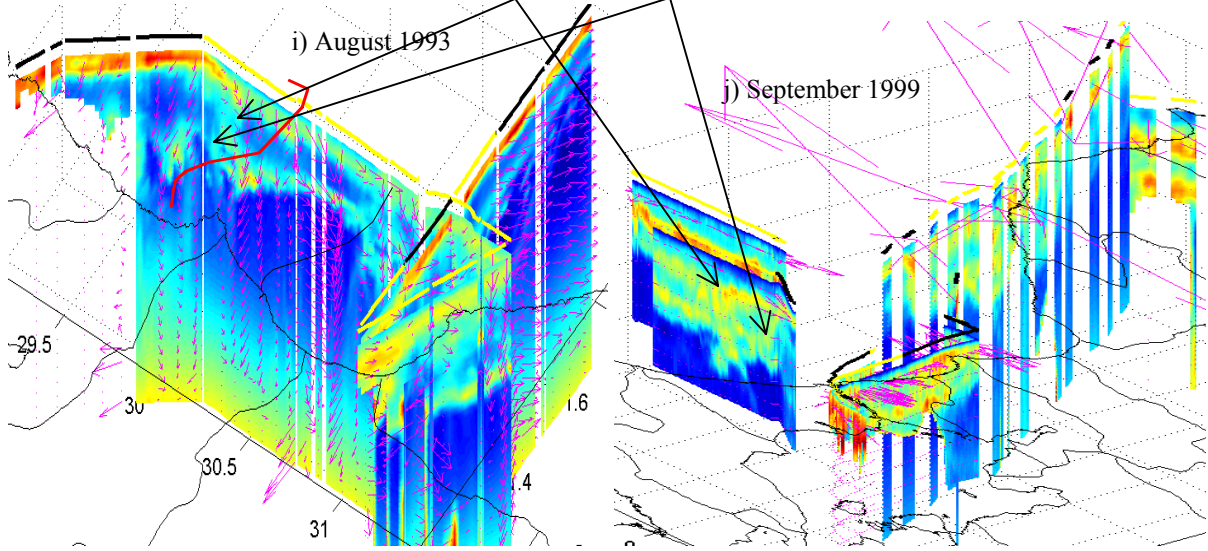
Fig. 1. Swimming behavior of *C. euxinus* and *S. setosa* with response to the dissolved oxygen in March 1995 (a), May 1994 (b), July 1992 (c), September 1999 (d), and October 1995 (e) in the Black Sea. All depthwise profiles are dissolved oxygen. Cast time of each profile corresponds to lower end of each profile.

a) January 1992

b) February 1994

S. setosa and *C. euxinus*

c) February 1994

d) March 1995

S. setosa and *C. euxinus*

e) April 1993

f) May 1994

g) June 1991

h) July 2000

S. setosa an *. euxinus*

i) August 1993

j) September 1999

S. setosa and *C. euxinus*
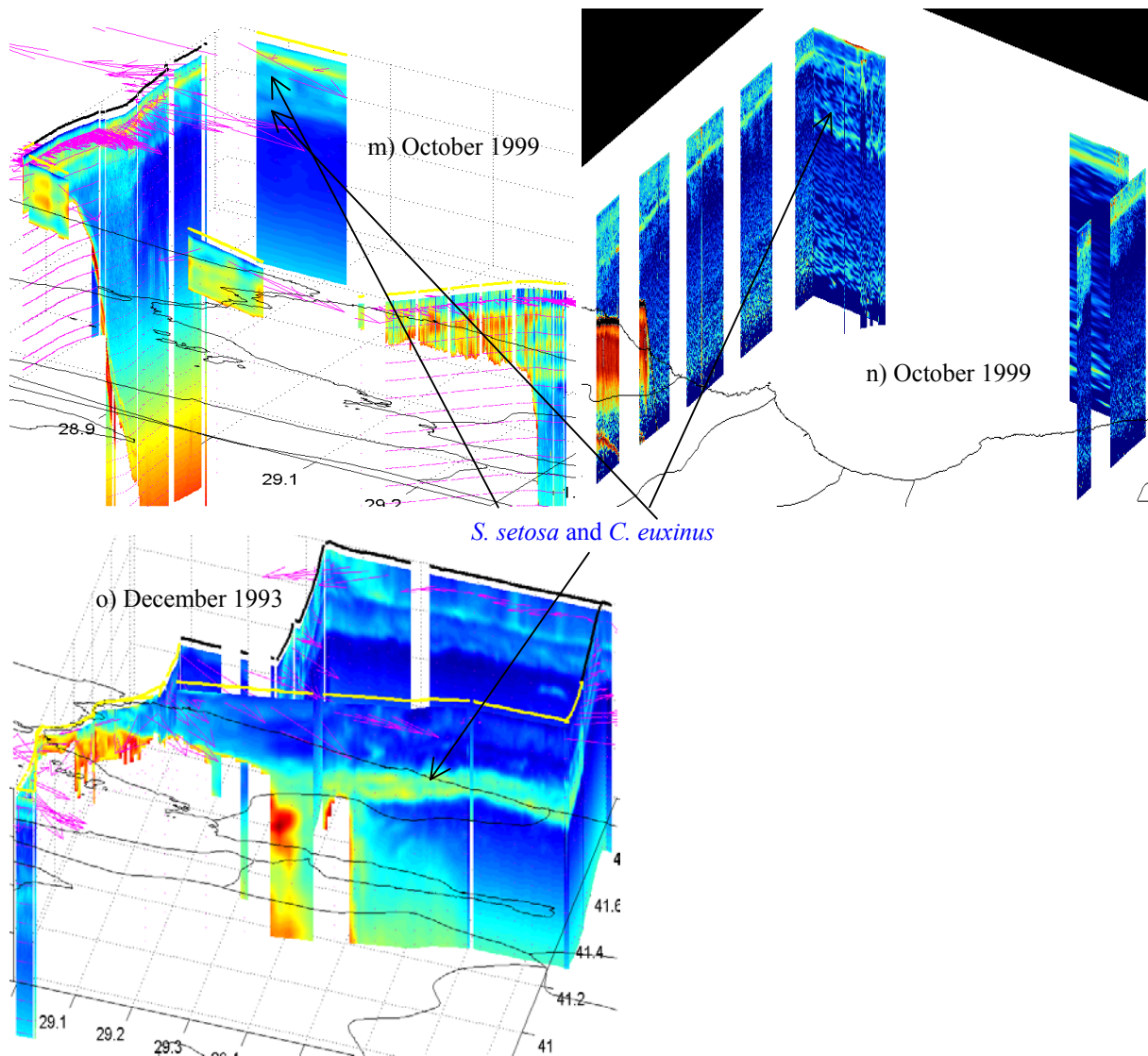
k) September 1995

l) October 1999
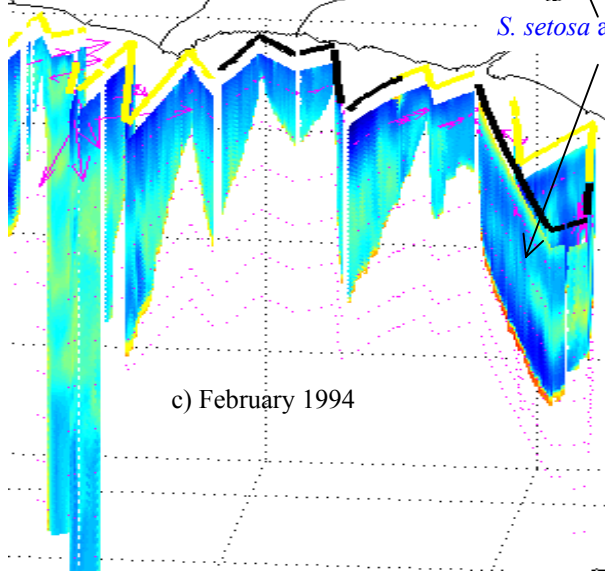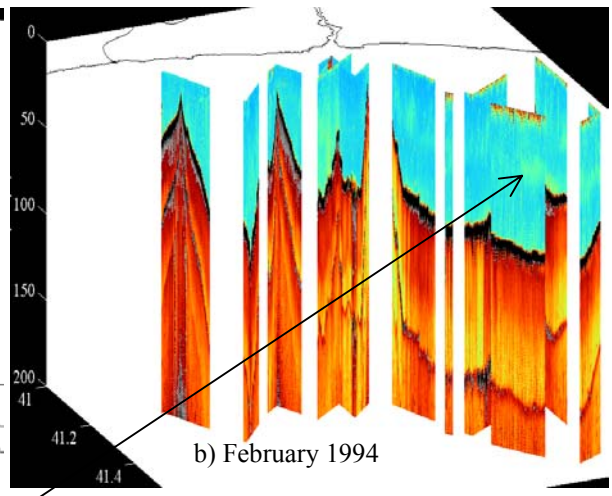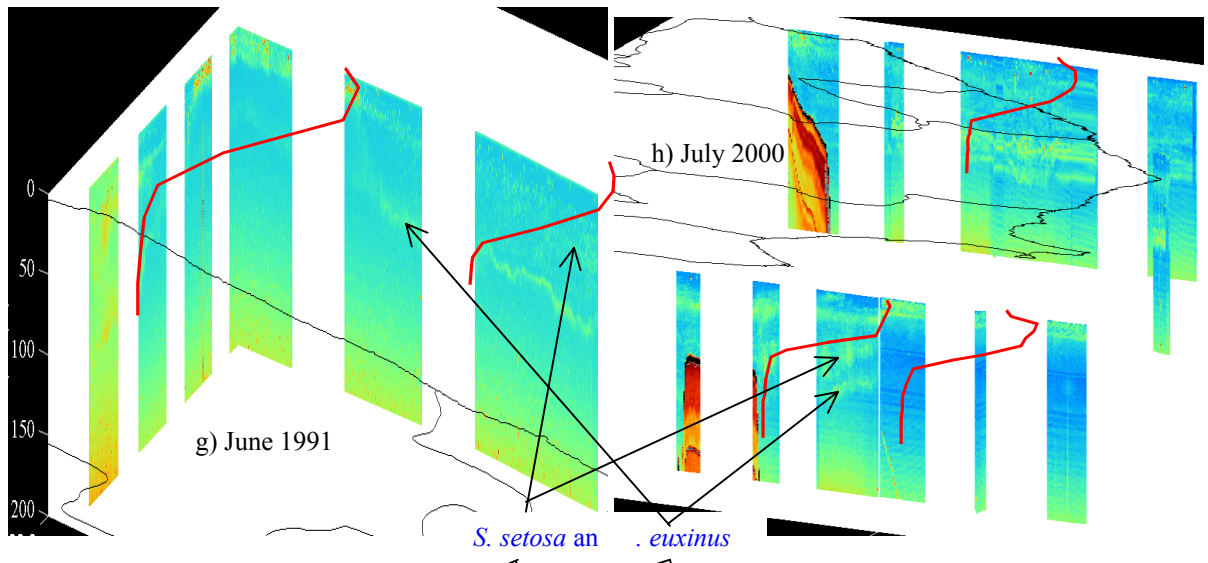
Fig. 2. 3D seasonal spatio-temporal distribution of *Calanus euxinus* and *Sagitta setosa* in different parts of the Black Sea. Yellow band over the enhanced echogram of acoustical data derived from only ADCP shows daytime and black nighttime. Arrows in magenta denotes water currents. Red profiles denote dissolved oxygen.

Two different concentration layers belonging to *S. setosa* were observed throughout the water column during the daily migration. Adults of *S. setosa* migrated between subsurface and a layer just above the OMZ while their juveniles could generally reach the oxycline. In July and September, a scattering layer that did not migrate during the day was observed and stayed in the thermocline. Most of the individuals were juveniles of new generation as [2] found. A study conducted between January and August showed that in the Black Sea the peak of the *S. setosa* bloom occurred in July/August [6]. [13] suggested that young stages might have higher specific metabolic demands and lower storage capability and hence, are tied to the surface because they need to feed more often. Adult individuals fed intensively in the subsurface water at night and then returned to their daytime depth to digest their prey.

The swimming ability of the *S. setosa* concentration layer depended on its size distribution and generation time. Young individuals from the new generation produced in July and September started a limited vertical migration between subsurface waters and the oxycline one month later (August and October). In the present study, a DSL overwintered

from March to April and in August. This layer could have been *C. euxinus* because the layer was separated from continuity of *C. euxinus* as recognized during the vertical migration.
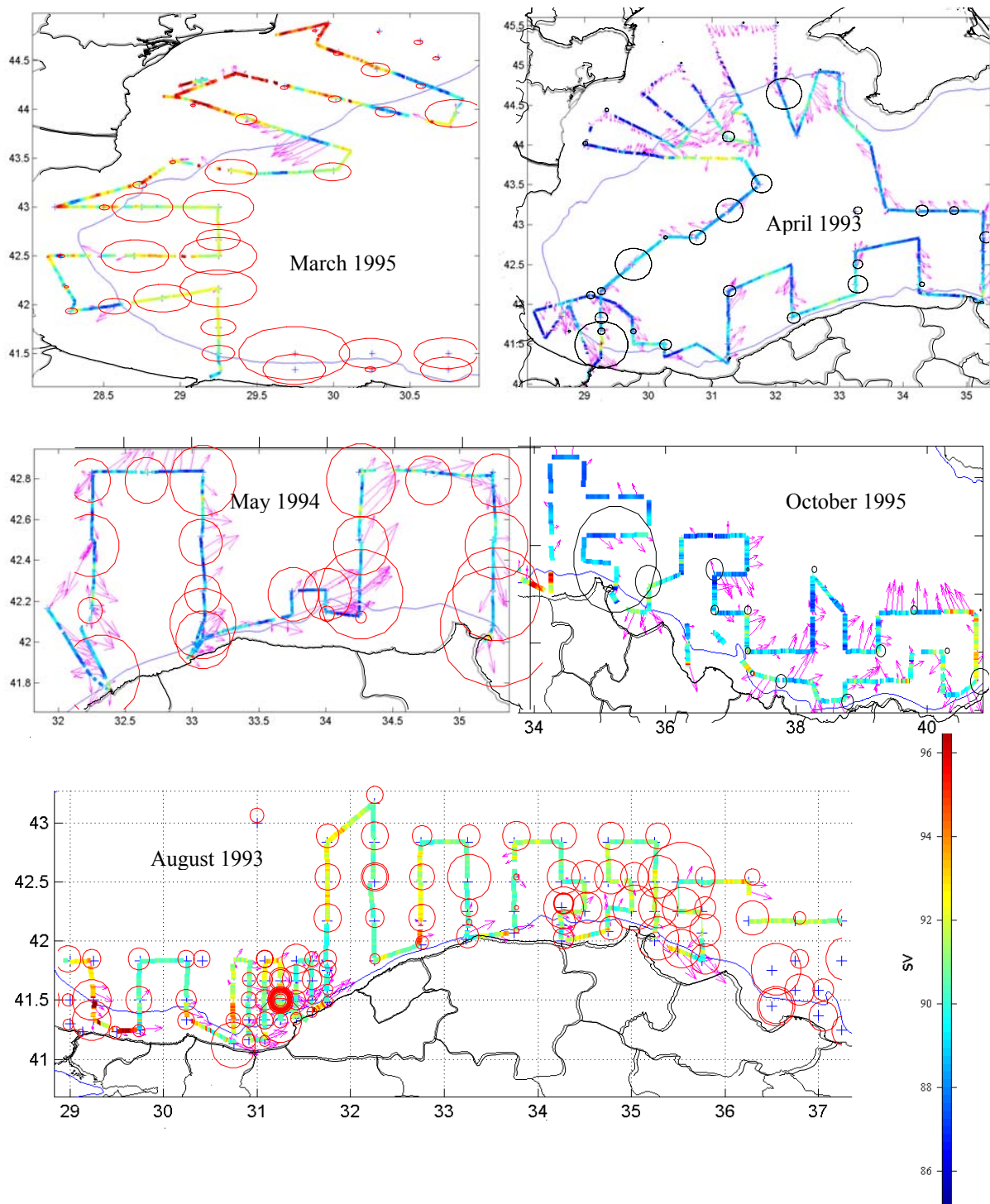

Fig. 3. Spatio-temporal echo intensity (dB; relative biomass) distribution of *Calanus euxinus* and *Sagitta setosa* in the Black Sea. Arrows in magenta denotes surface currents. Circles were corrected biomass. Blue line along the coast is depth contour of 200 m.

In contrast to the pattern observed during downward migration, *C. euxinus* lagged behind *S. setosa* during upward vertical migration. In general, *S. setosa* and *C. euxinus*

reached the subsurface water during nighttime at about the same time, however *S. setosa* started their migration before *C. euxinus* did. *S. setosa* migrated at an average constant speed of 0.38 cm s^{-1} until they reached the upper limit of oxycline. Then they speeded up through the maximally well-oxygenated subsurface water as highly as *C. euxinus* performed through the oxygenated water column. This pattern generally held in winter, spring and summer. In autumn, no acceleration in their swimming speed was and the chaetognath completed the migrations at a constant speed.

Distribution of biomass as echo intensity of only *C. euxinus* and *S. setosa* changed in time and space (Fig. 3). In contrast to the biomass distribution in April 1993, higher biomass were observed on the shelf water in March 1995. However, there was no perfect correlation between echo intensity and corrected biomass, many of the locations showed good the correlation. Some difference could come from strategy of net sampling; the nets were hauled from a depth above 5-10 m from bottom whilst the vertical hauls could trend to oblique offshore.

In conclusion, taking minimum background noise threshold and detection limit of acoustical frequencies (120, 150 and 200 kHz) into account, the concentration layer of *S. setosa* can acoustically be identified by observing their diel migrational pattern during different months in the Black Sea. *Sagitta setosa* showed different patterns in time depending on their generation time and stage composition. During the cold-water season when their population consisted mainly of adult individuals, their daytime concentration layer coexisted with that of *C. euxinus* in the OMZ whereas in warm-water season when the immature individuals (juveniles) comprised more 60% of the population, the concentration layer stayed in the oxycline. In July and September, individuals of new generation did not migrate during the day and stayed in subsurface water. *Calanus euxinus* started accelerating upon entering the oxycline while *S. setosa* accelerated after entering well-oxygenated subsurface water. *Sagitta setosa* completed its migration within 4 hrs at an average swimming speed of 0.38 cm s^{-1}.

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