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Compared Studies on Recognition of Marine Underwater Biological Scattering Layers

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Abstract

Direct identification of organisms at species level, one of the major problems in bioacoustics, was reviewed with comparison between empirical/experimental and observatory acoustics on behavioral natures ascertained to the species (diel vertical migration, response to ambiance, school shapes). Next progresses in biacoustics promise surely gate soon to fulfill solution of the problems. Presently, current acoustical knowledge required behavioral characterization identical to organisms targeted for direct identification. Integrating such techniques with previously obtained background knowledge on characteristics specific to certain organisms, acoustic techniques allow a significantly larger area of the ocean interior to be surveyed at a quite finer resolution on ecology of the scatterers than conventional methods. For instance, *Calanus euxinus* (copepod) and *Sagitta setosa* (cheatognath) have distinct patterns of vertical migration and time spent swimming, depending on the DO concentration of the water column in the Black Sea.

Key words: Biacoustics, fish, zooplankton, Turkish seas.

INTRODUCTION

Acoustical studies have been used to record the progress of mesozooplankton and gelatinous macrozooplankton. Direct identification of organisms, however, appears impractical with present acoustical knowledge and techniques, even though bioacoustics have functioned well in visualizing movement under water [3, 4, 14, 19-21] (Fig. 1).

Acoustic surveys conducted at sea provide data horizontally and vertically in a distance of large area (10s to 100s kilometers) and in range near-surface to hundred meters [5]. Thus, acoustic techniques allow a significantly larger area of the ocean interior to be surveyed at a finer resolution than traditional methods of surveying biomass such as net tows, video (which has high resolution but low sampling volume), or diver observations [5]. There are other objects such detectable amounts of sound as suspended sediments, air bubles, and even gradients of temperature, salinity, and the velocity of the water column, which could cause difficulty in interpreting the acoustic data (Fig. 1) [1,5]. Acoustic data alone are inherently ambiguous with regard to the identities of the scatterers. With few exceptions the identity of the taxonomy of scatterers must be verified by supplementary information, such as nets, pumps or optical plankton counters [2]. Nevertheless, some progress has

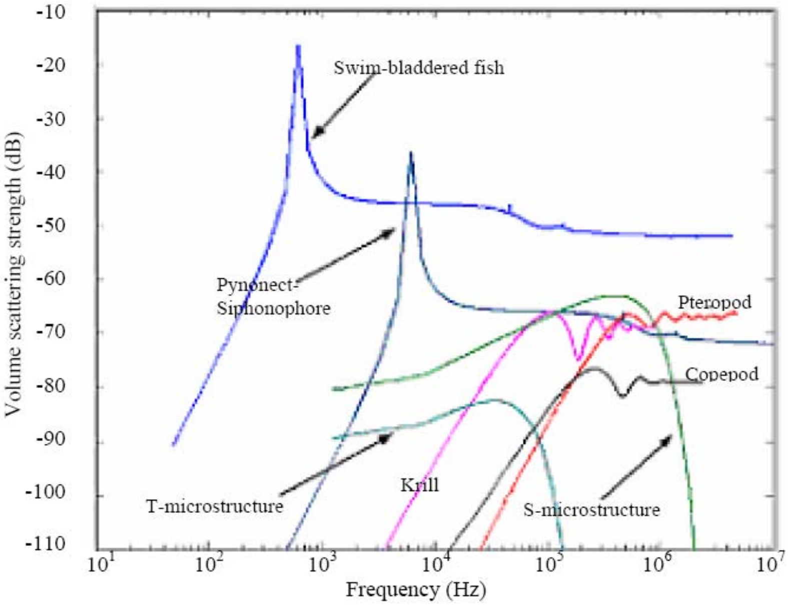

Figure 1. The most important biological and physical ocean acoustics scatterers (adapted from [6]).

been made in classifying organisms acoustically. [3] modeled acoustical scattering of organisms, producing calculations for organisms dominated by three different significant types of scattering: fluid-like, elastic shells, and gas inclusions (Fig. 1). Field studies have recently demonstrated that signals from Antarctic krill *Euphausia superba* and the mysid *Antarctomysis maxima* can be separated using multi-frequency acoustic data alone (Fig. 1) [4] Field bioacoustical studies focused mainly on stock assessment of fish and spatial zooplankton mapping besides vegetation and seabed classification. [5-6] summarized discrimination of physical induced scattering from planktonic biological scattering with the multi-frequencies system and the models (Fig. 1).

Acoustic-scattering methods offer biologists a useful tool in estimating the distribution and abundance of marine organisms that scatter a measurable amount of sound, such as fish and zooplankton. However, acoustical surveys measure the amount of scattered sound in the water column and are not a direct measure of the biological organisms present [5].

Identification of fish species was achieved involving a lot of environmental parameters into statistical multivariate analyses (e.g. [7-8]). These parameters identical to the species allow characterization of fish species. However, direct identification from acoustics without using the supplementary information is a rare achievement. It is believed that concentrated schools or layers formed by different fish even zooplankton species have not been found mixed during the day in marine nature as understood from visually inspected such as documented films, or field studies. This suggests environmental preference of the species in the water column that outlines their diel distinctive features of the layers that could be followed from the acoustical records with appropriate frequency and resolution. One of the goals must be direct identification of the species by bioacoustical studies, which is mostly interested by oceanographers. Total acoustical energy measured alone may be out of the interest because many oceanographers are considered to study marine pelagic biology at species level. Bioacousticians know that acoustic surveys of the water column can provide a wide range of spatio-temporal survey. [9] summarized current fisheries acoustics as follows: The **major problem** for estimating indices of abundance from such surveys is the correct allocation of observed echoes to species. The current solution to this problem employs trawl samples to provide ground-truth, but this is opportunistic and punctual, giving direct information for only a few kilometres of track. The information is then extrapolated to the surrounding area often in an ad hoc manner. There is a need to move this aspect of routine survey work forward to provide a well-founded identification procedure. Multi-frequency techniques alone have been shown to be successful for acoustic species identification particularly for distinguishing fish with a swimbladder (e.g., herring) from those without one (mackerel) [9]. Although this basic premise has been known for many years the equipment required for its practical application has not been generally available. This is required to be married to basic environmental data. This produces a database which for each species will contain measured extracted parameters (e.g. school height, width, average density, school depth, height above seabed, species composition, length-frequency, 4D position [time, latitude, longitude, depth], geographical coordinates, water temperature, density, salinity etc.) [8]. For all known traces of a particular species (contained in the echogram library) there is then probability of identification based on these criteria alone. This emulates the process whereby characteristics of certain types of echogram traces (e.g. herring from pillar schools) are recognised as being diagnostic of certain species, something that fishermen and scientists alike have always done subjectively. Such algorithm could be discussed for validation to other seas [9]. This limited succession and uncertainty in identification of the species always becomes a challenge in biacoustical studies. Present acoustical techniques with monochromatic or multifrequencies however do not allow identification of single species from composite diverse pelagic ecosystem. Requirements of many parameters on school types to resolve identification of fish species bring trawl or purse-seine surveys and environmental sensing systems.

For zooplankton, direct identification remained at higher taxa level rather than species level. Sound scattering models depend highly on detectable size of the target that is actually a very complex subject and depends on many things. The important factors include diameter of the animal relative to the acoustic wavelength (hence wavenumber, “ka” value), orientation, material properties, numbers of animals per unit volume, sensitivity of the echosounder, and distance from the transducer. Also, it is important to understand that even if an animal is detectable while isolated, once it is near another animal that has a greater target strength, the latter animal is the one that is detected. Thus, accuracy of comparison of measured volume backscatering with expected (models) one is related to the following instances: [10] showed that some acoustic predictions were more sensitive to animal shape and orientation than others. Thus for elongated animals, the pattern of backscattering vs. angle of orientation at a fixed frequency is strongly dependent upon shape. Recently [11] reported the orientation distribution of copepods freely swimming to be peaked at about 90^o (i.e. the animal body axis was vertical with the head up) with a standard deviation of 30^o. This offset could be due to a combination of factors including system calibration, animal avoidance of net (particularly for the macrozoogelatinous organisms), accuracy of acoustic models, accuracy of input parameters into the models, and the failure of the frequencies to detect mesozooplankton. [10] concluded that the scattering predictions showed a very strong dependence upon shape, orientation, and frequency for the euphausiids and copepods. For the models and ground-truthing, net towing is always necessary to measure density of individuals in a unit volume. The density depends primarily on thickness of layer towed. In nature, measurement of real thickness of the concentration layer of zooplankton could be possible with visual inspection and are variable in time and space. [12] showed that thickness of concentration layer in the Black Sea was variable in time: 3 m in summer, but 1 m in October. This example variation was completely reflected to the estimated volume backscattering strength and detection limits as well.

Presently, *in situ* observatory bioacoustics on spatio-temporal natural behaviors of animals purposed could be much helpful to recognize concentration layers of zooplankton and fish schools. For instance, the Black Sea is very good target for direct identification of species from the acoustical surveys since the Sea is less diversified in pelagic fish and zooplankton composition as compared with other Turkish Seas. For instance, *Calanus euxinus* (copepod) have distinct patterns of vertical migration and time spent swimming, depending on the DO concentration of the water column, as described by [13] for Black Sea copepods: the 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%. Besides their natural behaviors, detection limits and ambient noise of the frequencies allow acoustical selectivity of the species. For instance, the dominant sources of acoustical scattering at 120, 150 and 200 kHz in the surface waters of the Black Sea found here are the pelagic fish (anchovy and sprats) and zooplankton: the chaetognath *Sagitta setosa* and *C. euxinus*. There are three species (*Pleurobrachia pileus* Ctenophora; *S. setosa*, and *C. euxinus*) of adult zooplankton that are >2 mm long (~minimum detectable size at 200 kHz) [14] and migrate through the water column from the deep to the surface in the Black Sea [15-17]. Other larger species (*Aurelia*, *Mnemiopsis* and *Bereo*) do not penetrate beneath the thermocline during their daily migrations in the Black Sea [18]. *Aurelia* is a significant sound scatterer [19] but its vertical depth ranges are restricted to the upper waters. *P. pileus* and *Mnemiopsis* are very similar in acoustical properties to *Bolinopsis* (-75.9 dB at 200-1000 kHz; -80 dB at 420 kHz) are very weak scatterers owing to the high water content in the body [20-21]). Individuals of *P. pileus* were distributed throughout almost the entire water column and had two concentration maxima [15]. [12] acoustically identified *C. euxinus* in the Black Sea in June/July and October. Background noise levels (the minimum threshold in Sv) of the 120 kHz were -78.5 ± 0.8 (SD) dB in the Black Sea and the noise levels of the 200 kHz were 4 dB lower than those of 120 kHz (Fig. 2d) [22], which is almost equal to target strength of gelatinous *P. pileus*. [12] showed that *P. pileus* formed very weak scattering as not observed at 120 and 200 kHz in October 1999. At the same time, *P. pileus* was mostly found below 30 m, where no scattering was observed. The rest of the gelatinous organisms were found at the surface in low abundances.

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 identify the composition of the unknown scattering layers targeted in three Turkish Sea. This ability would allow *in situ* monitoring of the species; estimation of biomass and better understanding of spatio-temporal distributional patterns.

RESULTS and DISCUSSION

There are significant differences in overall levels of acoustic volume backscattering among the Seas; on this occasion, Sea of Marmara and Black Sea had higher values. The acoustic patchiness structure differed among the Seas due to obvious difference in hydrographic peculiarities of the Seas. Large sized meso and macrozooplanktons (jellyfish, chaetognaths, ctenophores) contributed most to the total volume backscattering strength. The enhanced echograms were very different among the Seas. There were obvious changes in the composition of the plankton and hydrography among the Seas as well, which caused the differences in the acoustic levels. The regions that were acoustically tracked in the Seas (Fig. 2) were biologically very productive and were associated with divergence zones due to the upwelling of the waters. Biological scattering was

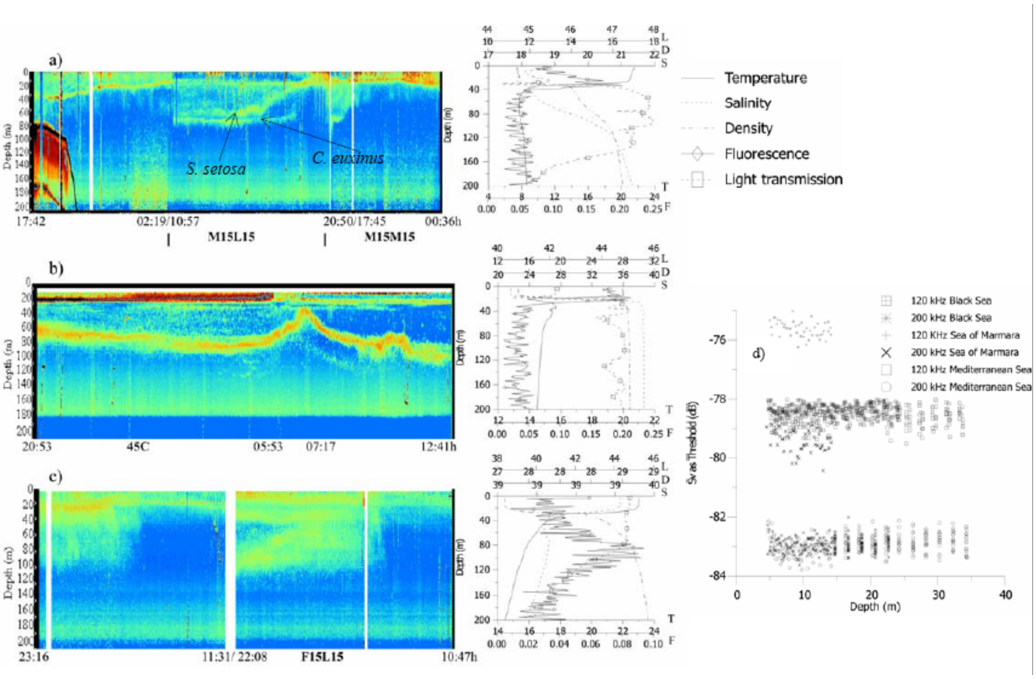

Figure 2. Enhanced echograms of sound scatterers around the study areas at 200 kHz in the Black Sea (a), at 120 kHz in the Sea of Marmara (b), at 200 kHz in the Mediterranean Sea (c), and vertical profiles of the hydrography (T: Temperature in oC; S: Salinity in ppt; D: density in sigmatheta; F: Fluorescence in Volts; L: Light transmission in %), and background noise (d) as function of depth in the Seas (from [22]).

vertically distributed between surface and suboxic zone (here 120 m) in the Black Sea (Fig. 2a), whereas it was confined to a narrow layer in a range of surface to the interface at 20 m formed between waters of the Black Sea and Mediterranean Sea in the Sea of Marmara (Fig. 2b). The Mediterranean Sea was very different in terms of the volume backscattering due to absence of shallow interface (Fig. 2c). Acoustical scattering was layered in and above the suboxic zone during the daytime in offshore waters of the Black Sea, while it was aggregated in the mixed layer at night hours. As the bottom depth was shoaled, the volume backscattering strength became homogenous (Fig. 2a). In the Sea of Marmara, the scattering was much intensified and layered just above the interface during the daytime, whereas it was homogenously distributed within the mixed water characterized with the Black Sea above the interface. During daytime, the layer between interface and transducer depth was deserted by the plankton. Aggregations by the scatterers were observed just underneath the transducers (Fig. 2b). Moderately high scattering was observed in the upper 100 m in the Mediterranean Sea at night, while the scattering observed in the upper 60 m layer during the day was less intense since vertical migratory species deserted the upper layers (Fig. 2c).

Taking the minimum background noise threshold and detection limit of acoustical frequencies (120, 150 and 200 kHz) into account, minimum threshold in Sv was measured by switching transmitter of the echosounder off and measuring the received sound. Background noise levels of the 120 kHz were -78.5 ± 0.8 (SD), -75.5 ± 1.2 and -78.5 ± 0.8 dB in the Black Sea, Sea of Marmara, and the Mediterranean Sea, respectively. The noise levels of the 200 kHz were 4 dB lower than those of 120 kHz. However, the noises were 3-4 dB higher in the Sea of Marmara than those in the other Seas (Fig. 2d).

The Black Sea

There are two pelagic fish species (anchovy and sprat) schooling in large biomas. Acoustical records showed that two types of the schools were formed: large compact, and small and dispersed schools (Fig. 3). Appearance of the two types was related to diel periods: daylight and dark times. Large compact schools occurred always getting close to or standing at the shelf slope in the dark period whereas the latter was suspended in the water column and never penetrated down to layer below the thermocline during the daylight (Fig. 3b). This structure was repeatedly observed in three days. Because of insufficient trawling for the fish schools, i*n situ* direct identification on fish species could not be performed even though presumably only two fish species exist here. There are two possible explanations on presences of the two types: small-dispersed schools (Fig. 3a) could belong to sprat and compact schools (Fig. 3b) to anchovy; catch composition of trawling during the daylight was due to sprat and that afternoon was enhanced with anchovy together with appearance of compact school, or the two types could belong to sprat that could yield different types of schools between daylight and dark periods. During the daylight, deep-scattering layers of zooplankton behaved an unusual vertical migration when the dispersed schools seemed to graze on the zooplankton. This is true only in winter. Appearance of compact schools suggests also another approach for the belongings of the school: These might be anchovy school but they could be found in different location during the day.

There are two dominant zooplankters that could be acoustically discriminated: *C. euxinus* and *S. setosa* (Fig. 2a). *C. euxinus* were acoustically discriminated with respect to vertical migration and swimming speed, according to dissolved oxygen (DO) concentration and the timing of migrations. Species became torpid in water with DO values <0.5mg l^{-1}. The time spent swimming under DO conditions between 2 and 5mg l^{-1} was insignificant, and varied greatly from the 10% to 25% of total time spent swimming under normoxic conditions (5-10mg l^{-1}). *C. euxinus* formed a concentration layer in the water

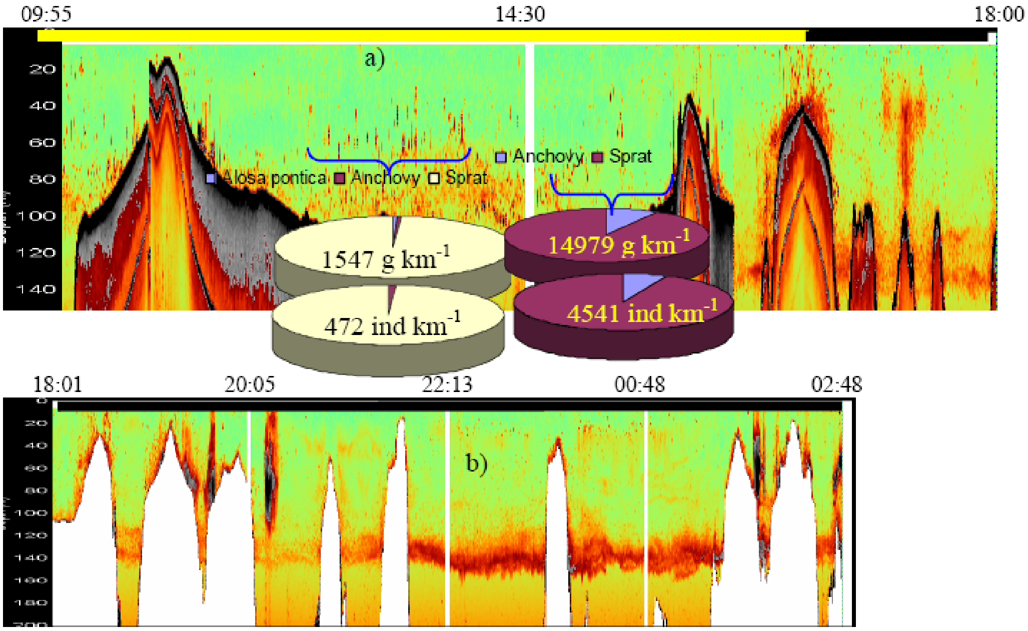

Figure 3. Two types of fish schools observed in the Black Sea: dispersed small (a) and compact schools (b) during wintering period of the anchovy.

of 1-3m thickness. Upward migration was completed in about 3.5h, starting 2.5h before and ending 1h after sunset (average rate: 0.95cm s^{-1}) in summer. Species ascended discretely from the suboxic to the lower boundary of the cold intermediate layer (CIL) at 0.82cm s^{-1}, and passed up the CIL and thermocline fast (2.3cm s^{-1}). Downward migration took less time (2h), starting ~1h before and ending ~1h after sunrise. Swimming speed within the thermocline and CIL was 2.7cm s^{-1}; copepods subsequently returned to daylight depth at a sinking speed of 0.57cm s^{-1}. Total time for *C. euxinus* to settle to their nocturnal depth layer was about 5h (Fig. 2a).

Sagitta setosa formed a concentration layer thicker than *C. euxinus* did (1-3 m). The migration was completed in about 2.5-4 h, upward migration starting before *C. euxinus* and downward migration after *C. euxinus*. Adult *Sagitta* swam fast only in the well-oxygenated layer (subsurface maximum DO). This feature was oxygen-dependent behavior of *S. setosa*'s vertical swimming and distinguished *S. setosa* from *C. euxinus*. Chaetognaths migrated daily between the nearsurface and the oxycline or suboxic zone (OMZ). Whether the deepest depth limit of migration was the oxycline or the OMZ depended on the relative abundance of adult and immature (young) individuals in the concentration layer. In July and September individuals belonging to a new generation did not migrate but stayed in subsurface water day and night (Fig. 2a).

Sea of Marmara

This might have been due to the presence of Black Sea water overlaying Mediterranean water (below 20 m depth) in the Sea of Marmara. The ambient noise may have been enhanced by reflection occurring between surface and the interface of the two water types in the Sea of Marmara. Individual calculated Sv less than the noise was not involved into the comparison between expected and measured Sv. Possible reasons of high ambient noise present in the Sea of Marmara are discussed later. The background noise and minimum Sv was, however, very high at 21:00 h in the Sea of Marmara. [23] showed that the noise is inherently frequency dependent and also depends on bottom depth. The water mass interface during nighttime reflected echo energy as much as the bottom did. Daytime Sv from the interface was very low compared to that of the nighttime because the biological scatterers around the interface changed with time (Fig. 2b and 4b). This could have changed the "hardness" of the interface and thus the noise increased due to the biological variations as [23] suggested that bottom variations. Hardness of the interface could be associated with density of jellyfish, *Aurelia aurita*. Although the jellyfishes avoided capture by the net, according to [19] their swimming rhythms showed that they could be jellyfish (Fig. 4). A variation of about 10-15 dB (dependent disc diameter of the jellyfish, Fig. 4a) and occurrence of a peak every 25-30 s due to swimming of the jellyfish were observed in individual scatterers rising from the interface (station 6 and 7; Fig. 2b and 4b). Acoustic records showed that there was no significant difference in the day and night vertical distribution of biological scatterers below the interface in contrast to layer above the interface. During the present work, at 12:30 the layered samples by the net showed that there were dead specimens between 80 and 150 m and between 20 and 80 m. The specimens were all alive above the interface. The water column below the interface has not, however, been well studied biologically. There was only one striking scattering layer between 40 and 80 m where the light transmission dropped to 44%. The physical parameters appeared to be homogenous beneath the interface. High abundance of dead chaetognaths (length >1.5 cm) and larger calanoid copepod (length>2 mm) predominated layer between 80 and 150 m. There were small sized copepods, larvae of polychaetes, cladocerans between 20 and 80 m in low numbers.

Mediterranean Sea

The Mediterranean Sea exhibited rather different appearance of acoustic scatterings than the other Seas did. Two plankton concentration levels existed daily in epipelagic of the Mediterranean Sea. Plankton that ascended from deep layer towards surface at nighttime tended to reside at night in a layer between 40 and 80 m where the fluorescence peaked. Non-migrating plankton were distributed in the upper 40 m corresponding to depth of thermocline (Fig. 2c). [24] showed that some species of zooplankton ascended from deep layer towards surface at night while others stayed in epipelagic zone during the day. Moderately high scattering was observed in the upper 100 m in the Mediterranean Sea at night, while the scattering observed in the upper 60 m layer during the day was less intense since vertical migratory species deserted the upper layers (Fig. 2c). One of dominant DSL in Rhodes Gyres is European Flying squid. Target strengths of experimental squids individual with mantle length of 19, 17.5, and 10.5 cm were estimated as -53, -54, -57 dB at 200 kHz, respectively Table (1).

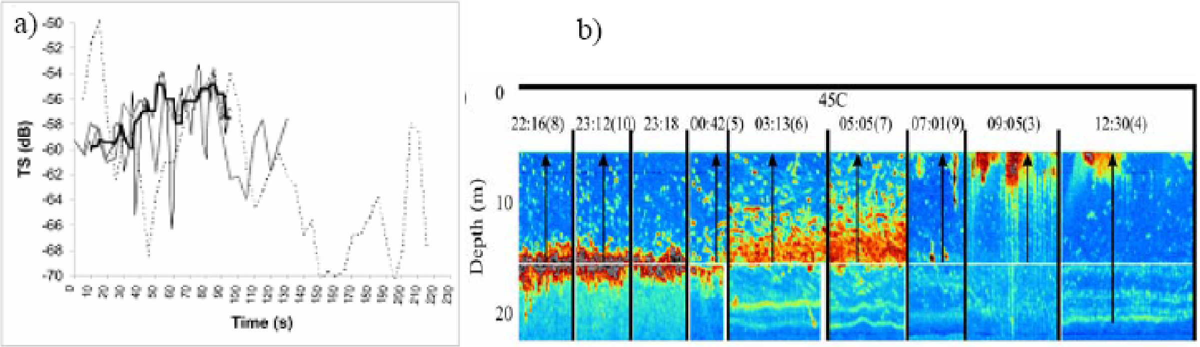

Figure 4. Comparison of swimming rhythm of *A. aurita* [19] with that obtained from the scatterers arising from the interface in the Sea of Marmara (a, b). Thin black line, variation of TS due to the swimming behavior of *A. aurita*; Thick black line, the variation averaged over 5 s [19]; variation of Sv of the individual scatterer observed for long time (a; gray line, station 6; dashed black line) at station 7 (b) (from [22]).

Table 1. Target strengths of the European flying squids (*Todarodes sagittatus*) at 200 kHz.

Mantle length (cm)	Individual weight (g)	average TS (dB)	range in TS (dB)
19.0	200	-53	-56 to -50
17.5	130	-54	-56 to -52
10.5	30	-57	-60 to -54

Sound models and field detection of the scatterers depends mainly on material properties, densities (abundance or biomass), shape, dimensions, orientation of the animals apart from specification of the acoustics such as the wavenumber. The bioacoustics of upper waters of the Black Sea, Sea of Marmara, and the Mediterranean Sea were studied in October 1999 with an echosounder with 120 and 200 kHz dual-beam transducers. Net tows were taken to ground-truth the acoustic volume backscattering. A forward solution was applied to determine significant scatterers among 21 taxa of the Seas with regard to detection limits of the frequencies and background noise measured in each Sea. 200 kHz data showed significant correlation between measured Sv and calculated total Sv (AVBS) and density (biomass and abundance) of the taxa (Fig. 5).

Large-sized copepods and chaetognaths in the Black Sea, *Aurelia*, *Beroe* and chaetognaths and large sized and abundant appendicularians in Sea of Marmara and fish larvae in the Mediterranean Sea contributed most to the volume backscattering. The abundance and biomass of the composite taxa could not directly be proportional to the AVBS because of size (e.g. length, weight) distribution apart from their material properties (Fig. 5a). For instance, the common jellyfish are moderately strong scatterers [19] but ctenophores such as *Mnemiopsis*, *Bolinopsis, Pleurobrachia* or *Bereo* are not so such scatterers [12, 20, 22]. They can contribute higher biomass to the total densities rather than other small sized organisms but less acoustic intensity to the AVBS because of the reflection coefficient. Reflection coefficients (R) can correct biomass comparable with the AVBS and make them linear-proportional to AVBS. Relationship between biomass and AVBS can be improved by multiplying R with the biomass of the composite pelagics (Fig. 5b).

In conclusion, bioacoustics is powerful in sampling with high spatio-temporal resolution. More accurate data are obtained to characterize natural behaviors (thickness, diapuasing, swimming speed etc) of the organisms that could be followed from the acoustics. For instance, *C. euxinus* spent their daytime in different layers depending on the regions: downwelling where they stayed just above the OMZ and upwelling where they stayed within OMZ in the Black Sea. *Sagitta setosa* is known now to accelerate their swimming speeds only within subsurface maxima of the DO. All those knowledge on responses of two organisms to the DO can aid to profile physical properties of the Sea: continuous spatio-temporal lower limits of the DO, profiles of the DO, divergence or convergence zones.

Acknowledgments

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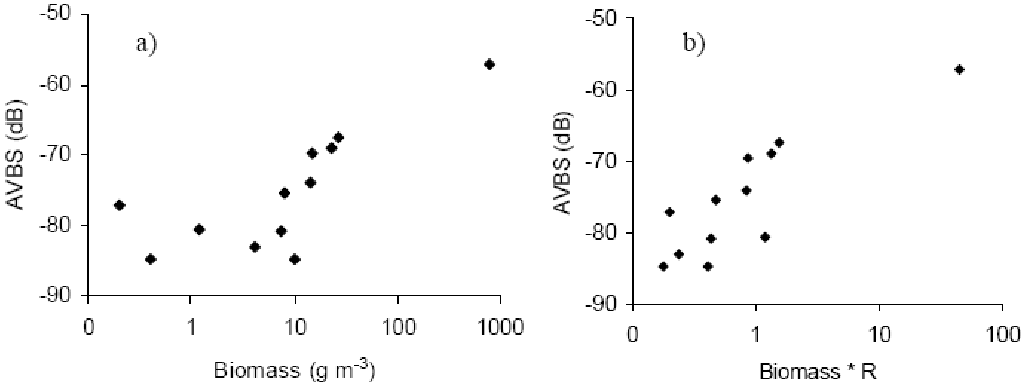

Figure 5. The relationship between volume backscattering (AVBS, 200 kHz) and (a) Nansen biomass (g m-3) and (b) corrected biomass (g m-3 * R).

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