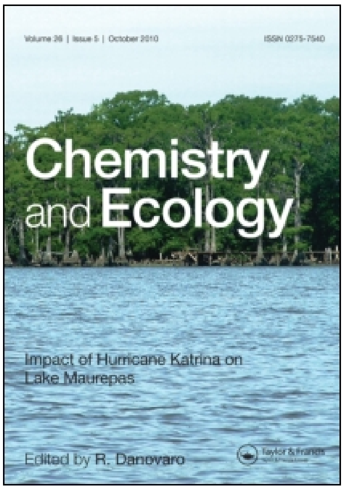

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Acoustic evaluation of anchovy larvae distribution in relation to oceanography in the Cape Passero area (Strait of Sicily)

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The aim of the paper is to present the results of a study on the relationship between ichthyoplanktonic distribution and the hydrographic features in the Cape Passero area (Strait of Sicily). Acoustic, physical, and biological data were collected during two multidisciplinary research surveys performed during the summer in 2002 and 2003 in the Strait of Sicily. The oceanographic surveys 'Ansic 02' and 'Ansic 03' were carried out on board the RV *Urania* in the framework of the work programme of the ASTAMAR research project. An accurate post-processing procedure was adopted to estimate anchovy larvae distribution in a sea area around Cape Passero, also taking into account the results of biological sampling. The analysis of acquired data has singled out a relationship between the acoustic-based ichthyoplanktonic distribution and the presence in both surveys of a thermohaline front positioned in the south-eastern part of the study area, which appears to be able to promote concentration processes.

Keywords: Acoustic estimate; Ichthyoplankton; Cape Passero; CTD data; Strait of Sicily

1. Introduction

The Strait of Sicily is very important from an oceanographic point of view, since it connects the two main basins of the Mediterranean sea. The water masses circulation has been largely studied in the central and northern areas of the Strait from both observations and models [1–5]. However, very few data have been collected in the south-western part of the Strait, so there is not the same detailed knowledge of water masses dynamics in Tunisian and Libyan waters [6]. The simplest circulation scheme in the area is a two-layer model with fresher Modified Atlantic Water (MAW) flowing eastward in the upper layer and relatively dense and salty Levantine Intermediate Water (LIW) flowing westward in the lower layer. Typically, there are two mainstreams of the Atlantic Water: the most important and less studied one [7] enters the Strait close to the Tunisian coasts; the second stream, defined by Robinson *et al.* [8]

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as the Atlantic Ionian Stream (AIS), flows meandering from the Adventure bank, the largest part of the continental shelf along the south-western Sicilian coast, to the Malta Plateau and the Ionian sea. The LIW enters the Strait mainly through the sill south of Malta and flows towards the western basin of the Mediterranean sea through the two passages in the western sill [1].

The meanders of the AIS have links with five oceanographic features and their variations [4]: the Adventure Bank Vortex (ABV), Maltese Channel Crest (MCC), Ionian Shelfbreak Vortex (ISV), Messina Rise Vortex (MRV), and temperature and salinity fronts of the Ionian slope (ISFs). In this study, the attention is focused on the sea area around Cape Passero (see figure 1) where two of the above features are present.

This area is recognized to be a retention area where larvae of different species, transported by the surface current, can find environmental conditions favourable for their growth [9].

In recent years, increasing effort has been dedicated to the study of the relationships between biology of some species and oceanographic processes in the Strait of Sicily [9–12]. From multidisciplinary surveys conducted by the authors of this paper, it was possible to recognize along the southern coast of Sicily several spawning and nursery areas for anchovy (*Engraulis encrasicolus*) and also to schematize a transport model to explain the distribution patterns of anchovy larvae [9, 13] in relation to the surface circulation.

In the same area, a regular programme of acoustic surveys for the estimation of biomass abundance and distribution of small pelagic fishes has been active since 1998 [14]. The acoustic method for the biomass estimation of juvenile and adult fish of pelagic species has been well

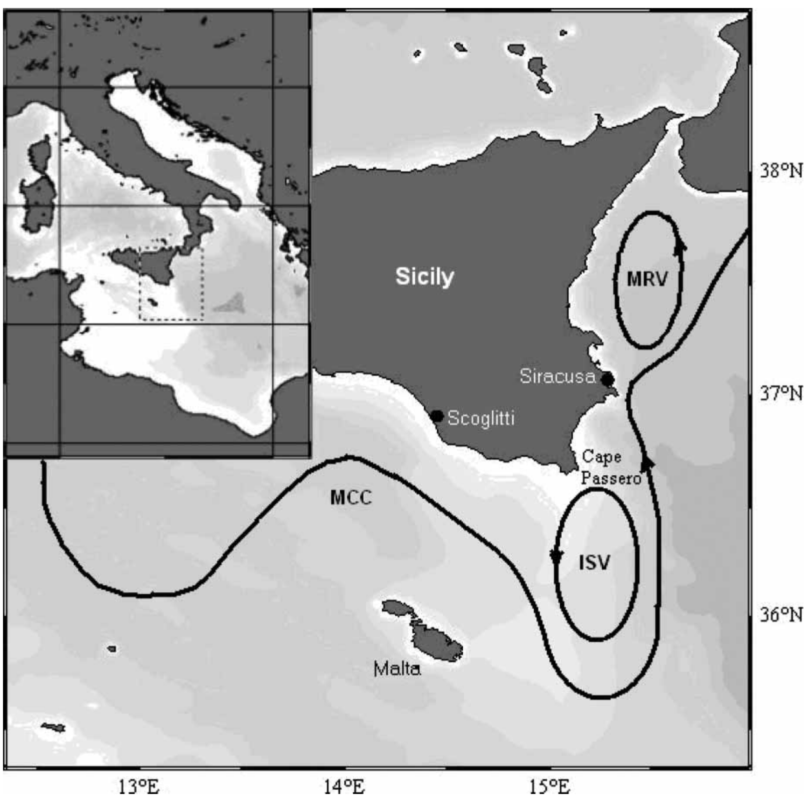

Figure 1. Map of the study area. The black curve shows the typical pattern of the AIS. The positions of Maltese Channel Crest (MCC), Ionian Shelfbreak Vortex (ISV), and Messina Rise Vortex (MRV) are also shown.

studied and widely diffused [15]. On the contrary, a method for the biomass estimation of larvae and zooplankton biomass by acoustic technique still has not been well established. In the present paper, the estimation of the anchovy larvae biomass was performed by applying a technique similar to that used for juvenile and adult fishes. Finally, anchovy distribution pattern are discussed in relation to the evaluated temperature and salinity fields in the study area.

2. Materials and methods

The study area is located on the continental shelf off the southern Sicilian coast from Scoglitti to Siracusa (see figure 1).

Biological samples and acoustical and hydrological data, analysed in the present paper, were collected during the oceanographic surveys 'Ansic 02' and 'Ansic 03' on board the RV *Urania* of the Italian National Research Council, in July 2002 and 2003. Such surveys were carried out in the framework of the ASTAMAR project (Application and Development of Advanced Hydro-Acoustic Technologies for the Study of the Dynamics of Marine Organisms) funded by the Italian 'Ministero dell'Istruzione, dell'Università e della Ricerca'.

Ichthyoplanktonic samples, collected from stations (red dots and labels in figure 2) based on a 4–6-nautical-mile step grid, were obtained using Bongo 40 plankton net equipped with two flow meters, with oblique tows carried out at a speed of 2 knots, using a 200 μm mesh size net for both sides of the frame. Hauls were towed from the bottom to the surface or from 100 m to the surface where the depth was more than 100 m. On board the vessel, ichthyoplanktonic samples were kept in buffered formalin at 4% with Borax. Using laboratory-based sorting different targets were recognized and separated, and the percentages in weight of zooplankton and each larval species in the samples were estimated. Moreover, for each anchovy larva, standard length (SL_{AL}, cm) and weight (w_{AL}, gr) were evaluated. An estimate of mean weight and length for anchovy larvae was calculated for each station.

Acoustical data were acquired by the BioSonics DT 6000 scientific echosounder, equipped with a split beam transducer pulsing at 200 kHz (pulse duration 0.6 ms). The standard sphere method was adopted for calibrating the echosounder, with a tungsten sphere with 36 mm diameter and target strength (TS) of −40 dB. Acoustical data were recorded along transects between the biological stations with a speed of 5–6 knots. The transducer was installed on the BioSonics tow body which, depending on the weather conditions, allows one to work

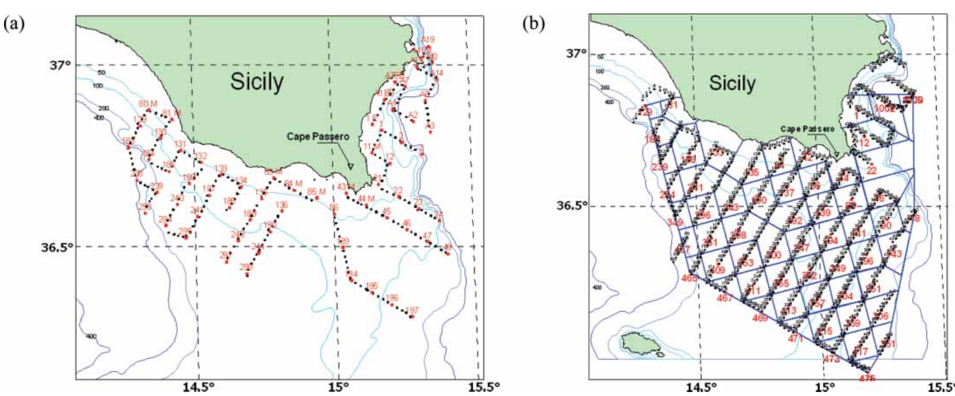

Figure 2. Maps of acoustic transects and biological stations (red dots with red labels) in the study area for the surveys 'Ansic 02' (a) and 'Ansic 03' (b). Black dots indicate the positions of the echointegration points, while blue lines on the right map (b) correspond to the estimated Voronoi polygons.

with a maximum speed of about 6 knots and to maintain a quite constant depth (2.5 m) of transducer; it was positioned 4 m distant from the right-hand side of the vessel. The acoustic signals were analysed and integrated by the post-processing system Echoview v. 2.25. The integration interval of the acoustic data was 1 nautical mile.

The analysis of acoustic signals, with the aim of distinguishing different kind of sea organisms like adult fish, fish larvae, and zooplankton, is very complex and still more difficult if we consider that in the investigated area, many species coexist. The visual analysis of echograms enabled acoustic signal belonging to fish schools to be extracted during the day. But during the night, fishes disperse in the water column, and it was not possible to adopt the same procedure for detecting fish, zooplankton, and larvae. In order to use an automatic procedure for separating fish from ichthyoplankton, a threshold for volume backscattering Sv (dB) was installed [16] by using the relationship

$$Sv = 10 \log \rho(\text{larvae/m}^3) + \text{TS}, \tag{1}$$

where ρ is the larvae density obtained by the analysis of Bongo biological samples, and TS is the target strength of the longest larva in the samples.

The output of the post-processing procedure was the estimates of Nautical Area Scattering Coefficient (NASC, $\text{m}^2\ \text{nmile}^{-2}$) [17] for each interval of integration in two different layers: 0–40 m and 0–80 m. The choice of these layers was due to the fact that most of clupeid larvae, in particular anchovy and sardine, are mainly found in the 0–40 m layer, while the total zooplankton biomass is present in the first 80 m of the water column [18, 19].

The estimated NASC values for each nautical mile were then divided into NASC_{Zoo}, NASC_{AL}, and NASC_{OSL}, according to the percentages of zooplankton, anchovy larvae, and other species of larvae found in the biological samples. To this aim, the Voronoi polygons or Dirichlet cells [20, 25] were computed by the GeoStatOffice Ver. 7.1 software [21]. Such a procedure allows us to divide the surveyed area into small areas where the biological samples were considered uniform and equal to those obtained in the biological stations. The blue lines in figure 2b represent the above-mentioned Voronoi polygons for the survey 'Ansic 03'.

The surface density of anchovy larvae ρ_{sAL} (ton nmiles^{-1}) was calculated for each integration point and for both layers by the following equation:

$$\rho_{\text{sAL}} = \frac{\text{NASC}_{\text{AL}}\, w_{\text{AL}}\, 10^{-6}}{4\pi\sigma_{\text{bsAL}}}, \tag{2}$$

where the backscattering cross-sections of anchovy larvae (σ_{bsAL}) were computed by the formula [17]:

$$\sigma_{\text{bsAL}} = 10^{\text{TS}_{\text{SL}}/10}. \tag{3}$$

The equation target strength (*TS*) vs. standard length for the anchovy larvae is unknown, but this species, like sardine, belongs to clupeids, and for this reason, the equation of herring (*Clupea harengus*) larvae was used [22]:

$$TS_{\text{AL}} = 20 \log SL_{\text{AL}}(\text{cm}) - 76.54. \tag{4}$$

The data interpolation on the study area and the presentation of larvae biomass distribution were carried out using the 'Surfer' software (Golden Software, Inc.). Furthermore, the Kriging geostatistic method [23, 24], with exponential models for variograms, was used.

Hydrological data were acquired by means of a CTD probe model SEABIRD 9/11plus. In each biological station (red dots and labels in figure 2), the CTD probe acquired profiles of temperature, salinity, dissolved oxygen, fluorescence, and light transmission. Raw CTD data were then submitted to the suggested post-processing procedure (SEASOFT-Win32, 2002) and analysed using the Ocean Data View software [26].

3. Results and discussion

Figures 2a and 2b show the location of the hydrological and biological stations and the transects for the surveys carried out in 2002 and 2003.

The acquired acoustical data refer to several kinds of signals backscattered by adult fish, fish larvae, and zooplankton. Therefore the procedure for separating signals belonging to different organisms is very complex. An accurate analysis of the echograms acquired during the daytime allowed us to separate the acoustical signals belonging to fish schools from those due to the presence of ichthyoplankton. For night-time echograms, since character of records appreciably differed from daytime echograms, an Sv threshold was opportunely evaluated taking into account the results of the analysis performed on biological samples collected by the Bongo 40 plankton net. In fact, laboratory work allowed us to separate zooplankton from larvae, recognize different larval species, and evaluate length and weight of each larva. The maximum standard length for larvae caught by Bongo 40 net was 4 cm, corresponding to a maximum *TS* value of −64.5 dB, estimated from equation (4). The highest density found in the biological samples was 7 larvae m^{-3}, which gives, using the relationship (1), a maximum Sv level of −56.05 dB.

At the same time, another approach was adopted to estimate the maxima Sv values both for fishes and for zooplankton and larvae. The method consisted in evaluating frequency distributions of acoustic signals in opportunely selected echograms, since it is well known that the Sv distribution allows different acoustic signals to be associated with different size organisms. According to this approach, an $Sv_{\max}$ of about −35 dB was estimated for fish schools. For larvae and zooplankton, some parts of the echograms, where no fish was present, were selected.

Figures 3 and 4 show some examples of echograms with some fish schools, larvae, and zooplankton aggregations. This methodology allowed us to estimate an $Sv_{\max}$ of −56 dB for the above-mentioned aggregations, which is a value very close to that estimated by equations (3) and (4). The same procedures were applied to the data collected in the survey of 2003, but here the $Sv_{\max}$ for zooplankton and larvae aggregations was estimated to be −54 dB.

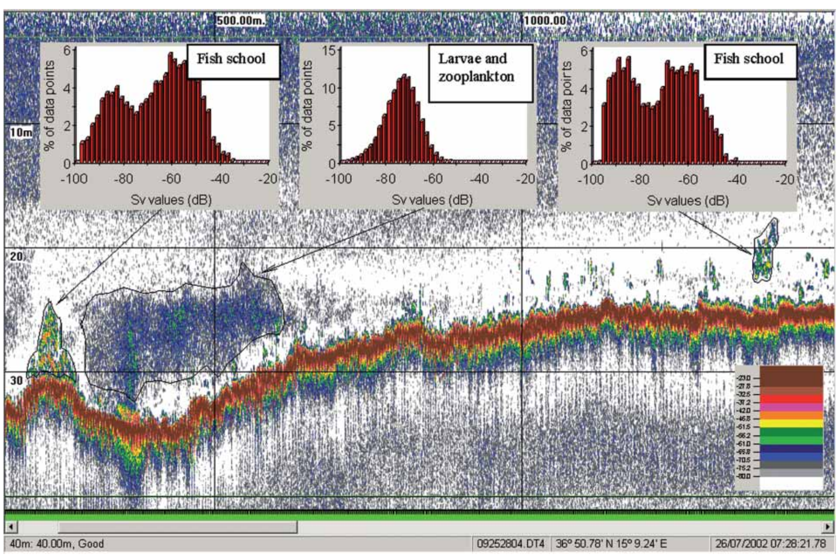

Figure 3. Echogram showing fish schools, larvae, and zooplankton aggregations. Histograms in the upper part show the Sv distribution in relation to different organism aggregations.

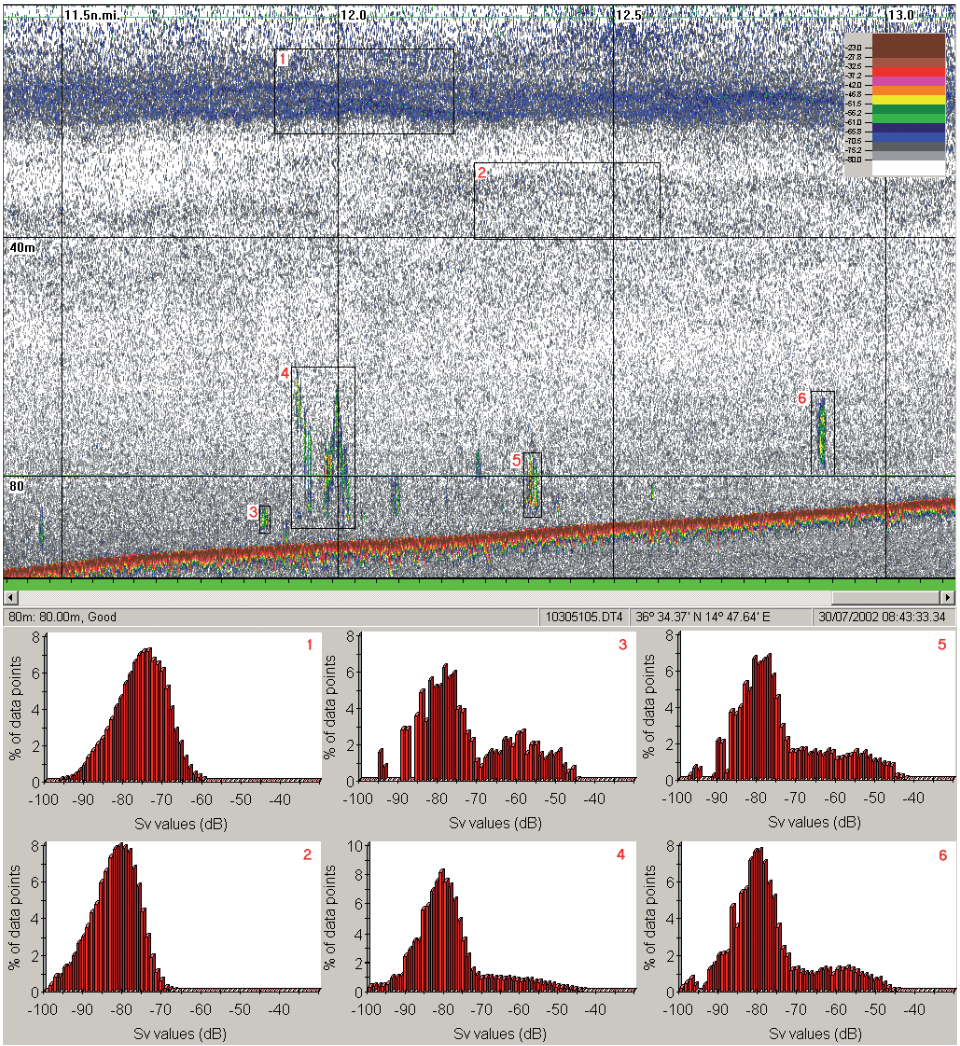

Figure 4. Example of echogram acquired during the 2002 survey, showing fish schools, larvae, and zooplankton aggregations. Histograms in the lower part show the Sv distribution of different parts of the echogram.

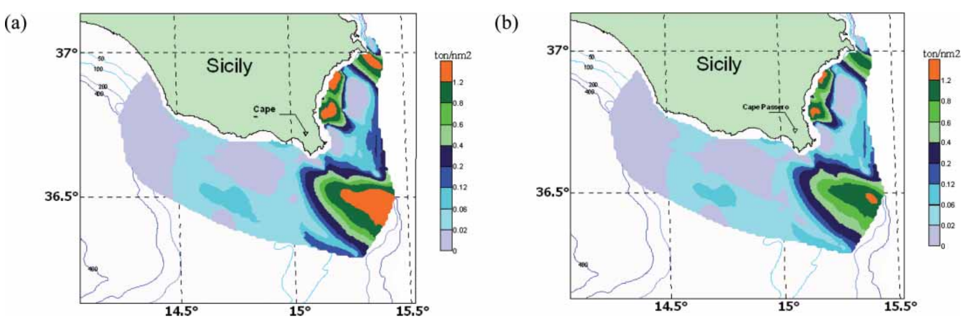

Figure 5. Distribution maps of anchovy larvae density (tons per square nautical mile) estimated for the survey 'Ansic 02': (a) echointegration performed in the layer 0–80 m and (b) in the layer 0–40 m. Total area: 1303 square nautical miles.

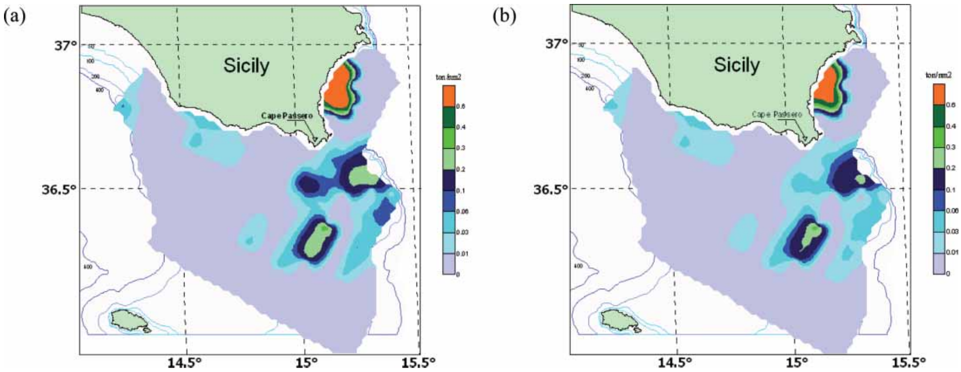

Figure 6. Distribution maps of anchovy larvae density (tons per square nautical mile) estimated for the survey 'Ansic 03': (a) echointegration performed in the layer 0–80 m and (b) in the layer 0–40 m. Total area: 2070 square nautical miles.

In figures 5a and 5b, the density maps of anchovy larvae estimated in the layers 0–40 m and 0–80 m, respectively, for the 'Ansic 02' survey are shown. Figures 6a and 6b present the density maps of anchovy larvae for the survey 'Ansic 03'. From these figures, high density values are found in the area between Cape Passero and Siracusa. Moreover, the sea area south of Cape Passero presents several zones with a high larval density.

The analysis of CTD data allowed us to estimate temperature and salinity fields in the study area. Figures 7 and 8 show such fields at 10 m depth for 2002 and 2003, respectively. The strong salinity front of the Ionian slope can be observed in both periods, which is shown more clearly in figures 9 and 10, where two sections parallel to the southern coast of Sicily are presented. The relative minima in salinity profiles, in figures 9 and 10, reveal the presence of the Modified Atlantic Water (MAW) associated with the AIS pattern.

The temperature maps (see figures 7a and 8a) single out lower surface values in the Strait of Sicily compared with those of the Ionian sea, due to the persistent upwelling governed by the south-eastward winds and by the inertia of the isopycnale domes of the AIS meanders [5]. Unfortunately, from our data, it was not possible to describe completely the Ionian Shelfbreak Vortex (ISV).

From the comparisons between the salinity maps (see figures 7 and 8) and the anchovy larvae biomass distribution (see figures 5 and 6), it is possible to note a high density of larvae in the Ionian side of the temperature-salinity front in 2002 but not in 2003. In the latter, the

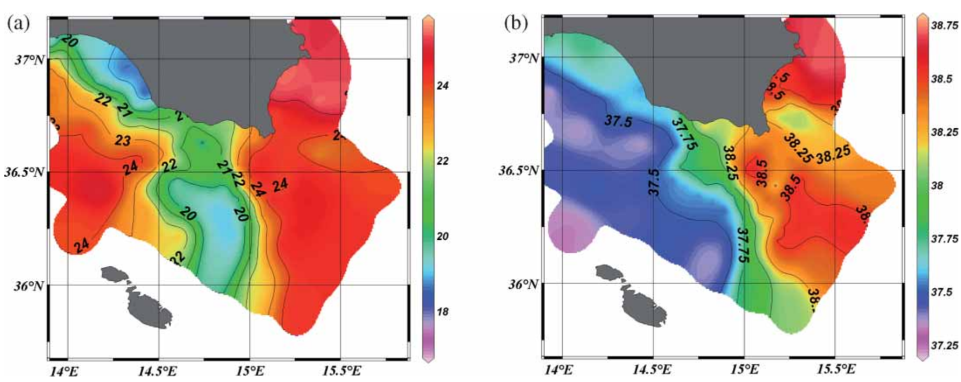

Figure 7. Maps of (a) temperature and (b) salinity at 10 m depth, estimated from CTD data acquired during the survey 'Ansic 02'.

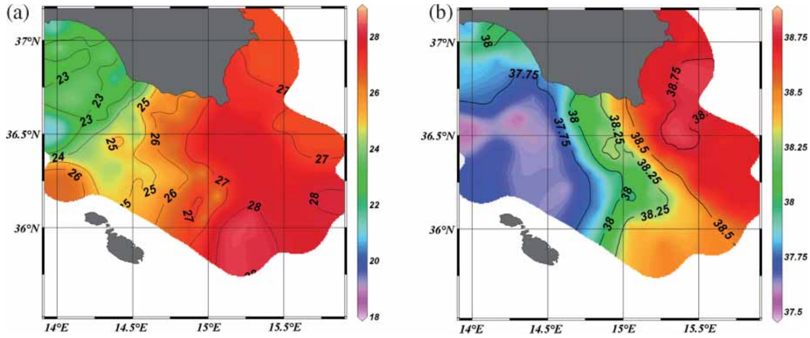

Figure 8. Maps of (a) temperature and (b) salinity at 10 m depth, estimated from CTD data acquired during the survey ‘Ansic 03’.

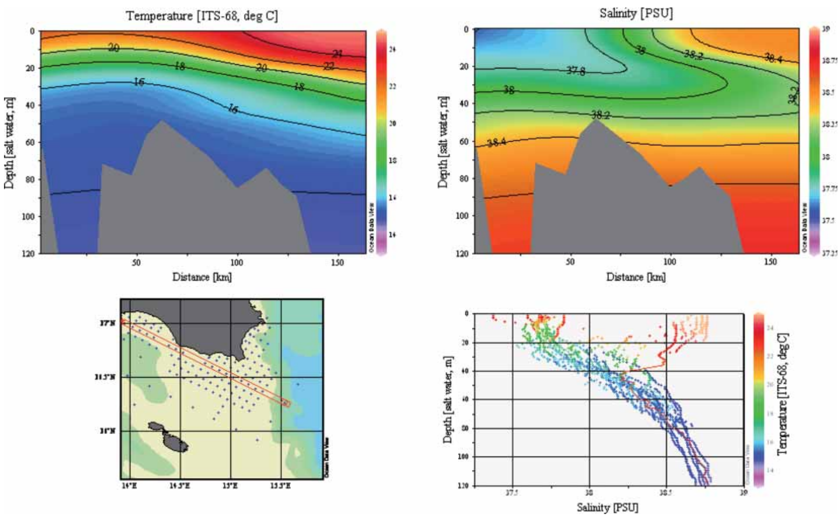

Figure 9. Plots of (a) temperature and (b) salinity along the section shown in the map, from CTD data acquired during the survey ‘Ansic 02’. Salinity profiles in the layer 0–120 m are shown in the lower-right-hand corner.

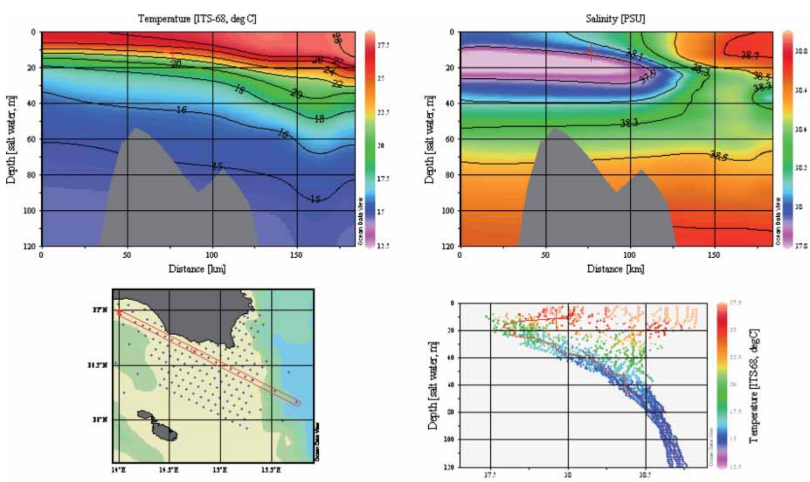

Figure 10. Plots of (a) temperature and (b) salinity along the section shown in the map, from CTD data acquired during the survey ‘Ansic 03’. Salinity profiles in the layer 0–120 m are shown in the lower-right-hand corner.

larvae distribution is patchy, and it seems to be less related to the large-scale pattern of salinity and temperature of the area.

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