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Environmental conditions influencing the larval fish assemblage during summer in the Gulf of Gabes (Tunisia: South central Mediterranean)

W. KOCHED[1], F. ALEMANY[3], S. BEN ISMAIL[2], R. BENMESSAOUD[1], A. HATTOUR[2] and A. GARCIA[4]

[1]Institut National des Sciences et Technologies de la Mer (INSTM), BP 2060, Port de pêche la Goulette, Tunisia
[2]Institut National des Sciences et Technologies de la Mer (INSTM), Salammbô, Tunisia
[3]Instituto Español de Oceanografía, Muelle Pelaires SIN, 07015 Palma de Mallorca, Spain
[4]Instituto Español de Oceanografía, s/n Apdo 285, CP 29640 Fuengirola, Málaga, Spain

Corresponding author: kouched_wael@yahoo.fr

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Abstract

An oceanographic survey was carried out during the summer of 2009, from June 25 to July 3 in the Gulf of Gabes. The study area was characterised by a wide continental shelf.

A plankton sampling scheme was carried out to study the structure of the larval fish assemblages that characterised the surface mixed layer, and to assess the influence of the environmental parameters on their spatial distribution.

A total of 36 taxa were identified, three classified to the level of genus, five to the family and 28 to the species. The majority of identified fish larvae belonged to the demersal species, mainly picarel *Spicara smaris* (23.76% of the total larval fish abundance), followed by red mullet *Mullus barbatus* (14.92%) and several species of the Sparidae family (9.15%). Small pelagic species such as Sardinella *Sardinella aurita* and European anchovy *Engraulis encrasicolus* were also abundant (27.75%) and dominated the fish larvae community in offshore stations. Five large pelagic species were found among the larvae, including bullet tuna *Auxis rochei,* Atlantic black skipjack *Euthynnus alletteratus,* albacore *Thunnus alalunga,* swordfish *Xiphias gladius* and the highly migratory Atlantic bluefin tuna *Thunnus thynnus*. All these apex predator species appear in 38.5% of the sampling stations and contributed to about 7.9% of the total larval catches.

The larval fish assemblage of the Gulf of Gabes is predominantly composed of the neritic species in correspondence with the shallow depths of the study area. Canonical Correspondence Analysis (CCA) showed that larval distributions were mainly conditioned by depth. However, other factors, such as, hydrographic processes, also play a very significant role in shaping the spatial pattern of larval fish distribution.

Keywords: Gulf of Gabes, larval fish assemblage, abiotic factors, mixed layer, geographical distribution.

Introduction

The Gulf of Gabes, located in the central Mediterranean Sea, south of the Ionian Sea, occupies the widest continental shelf in the Mediterranean, with approximately 250 km (DGEQV, 2008). Its extensive shelf is characterised by a shallow depth profile, which has become extremely sensitive to atmospheric warming. Furthermore, the Gulf has the largest tides in the Mediterranean. These tides are semidiurnal, with ranges of up to 2.3m (Sammari *et al.,* 2006).

In depths less than 20 m, the bottom is mainly sandy supporting a high density of *Posidonia oceanica* shoots. Beyond these depths, there is a succession of sand and muddy bottoms (Brahim *et al.,* 2003).

The hydrodynamics around the Gulf of Gabes area are characterised by a high mesoscale activity, related to its location as the transitional region between the two main eastern Mediterranean sub-basins: the Central Mediterranean and the Ionian. During summer, the dynamics of the surface water masses are mainly conditioned by the interaction between the Atlantic Waters (AW), moving southward from the northern part of the Tunisia-Sicily Channel and the Ionian Water (IW) and Levantine Intermediate Water (LIW) flowing northwards from Ionian basin, leading to a complex hydrographic situation. Surface currents are relatively strong and several mesoscale oceanographic features such as fronts and eddies are present in the area (Ciappa, 2009; Sorgente *et al.,* 2011; Ben Ismail *et al.,* 2015).

The surface circulation pattern is subject to different hydrodynamic processes, such as, local coastal currents induced by tide and wind and currents associated with the regional general circulation of the surface Modified Atlantic Water (MAW) and the Mediterranean Mixed Water (MMW) (Bel Hassen *et al.,* 2008, 2009a).This MAW enters into the Tunisia-Sicily channel and produces a surface circulation consisting of two main branches (Herbaut *et al.,* 1998; Ben Ismail *et al.,* 2014). One branch is the MAW jet current called the Atlantic Ionian Stream (AIS), which flows along the southern Sicilian coast (Robinson *et al.,* 1999). The second branch is the

Atlantic Tunisian Current (ATC) (Sammari *et al.,* 1999), which splits into two branches, in the north of Lampedusa Island. The first one, the more important one, flows southwest leaving the island to the west, and the second flows southward, invading the Tunisian coast, including the Gulf of Gabes, over the 200 m isobaths, with salinities between 37 and 37.2 (Sammari *et al.,* 1999, Lacombe & Tchernia, 1972, Ben Ismail *et al.,* 2015).

During the summer period, the Gulf of Gabes is marked by a strong thermal stratification, leading to two distinct water layers, with different thermohaline properties (Ben Ismail *et al.,*2010, 2015) and by an oligotrophic status (Drira *et al.,* 2008).

Despite its oligotrophy, the Gulf of Gabes is the most important fish producing area of Tunisia, where 18 fishing ports land 47.9% of the national marine resource production. On the other hand, this Gulf is considered an important nursery for many fish species (Hattour *et al.,* 1995), as well as, a shelter for marine turtles (Maffucci *et al.,* 2006; Jribi *et al.,* 2008). Nonetheless, the ecosystem is actually under stress due to industrial activities that have brought about studies related to heavy metal bioaccumulation in the fish species (Barhoumi *et al.,* 2009), as well as, concern on the proliferation of toxic dinoflagellates (Drira *et al.,* 2008) as the shellfish industry is central in its coasts.

However, research studies on the early life stage of teleost fish are almost absent. A recent study by Koched *et al.*(2013) has demonstrated that the area is an important spawning habitat for several tuna species such as the Atlantic bluefin tuna *Thunnus thynnus* (Linnaeus, 1758), and for other small tuna species (bullet tuna *Auxis rochei* (Risso, 1810)*,* Atlantic black skipjack *Euthynnus alletteratus* (Rafinesque, 1810).

Ichthyoplankton studies in Tunisian waters have been rather scarce. The main focus of ichthyoplankton research has been centered on small pelagic fish larvae: European anchovy *Engraulis encrasicolus* (Linnaeus, 1758), Sardinella *Sardinella aurita* (Valenciennes, 1847) (Ktari-Chakroun, 1979; Zarrad *et al.,* 2012a*,* 2012b) and on the tuna larvae (Koched *et al.,* 2012, 2013). However, only two of these studies have actually addressed the whole larval fish assemblage in the eastern coast of Tunisia (Koched *et al.,* 2011; Zarrad *et al.,* 2013).

Nonetheless, the icthyoplankton assemblages that occupy the surface layers, where tuna larvae are distributed (Morote *et al.,* 2008; Satoh, 2010) is still not very well known, both from the quantitative and qualitative points of view. In fact, only a few studies provide information on the entire ichthyoplankton community in which tuna larvae are present in the Mediterranean (Somarakis *et al.,* 2002; Alemany *et al.,* 2006; Koched *et al.,* 2011; Torres *et al.,* 2011; Rodriguez *et al*., 2013).

The present study is the first one carried out in the Gulf of Gabes analysing the whole larval fish community distributed over the surface layers. Its immediate objective is to describe the faunal composition of the summer larval fish assemblages in the surface mixed layers and to assess the influence of the parameters on their spatial distribution, aiming at setting the basis for future research on larval ecology.

Material and Methods

Sampling procedure

An oceanographic survey was carried out, on board the R/V Hannibal, from 25 June to 3 July 2009, in the Gulf of Gabes, covering waters from Ras Kapudia to the Tunisian-Libyan border. A total of 78 stations, distributed over a regular grid of 10 nautical miles, were sampled (Fig. 1).

Temperature, salinity and dissolved oxygen were measured at every station by means of a SBE 911 *plus sensor,* towed vertically at 1 m s^{-1}.

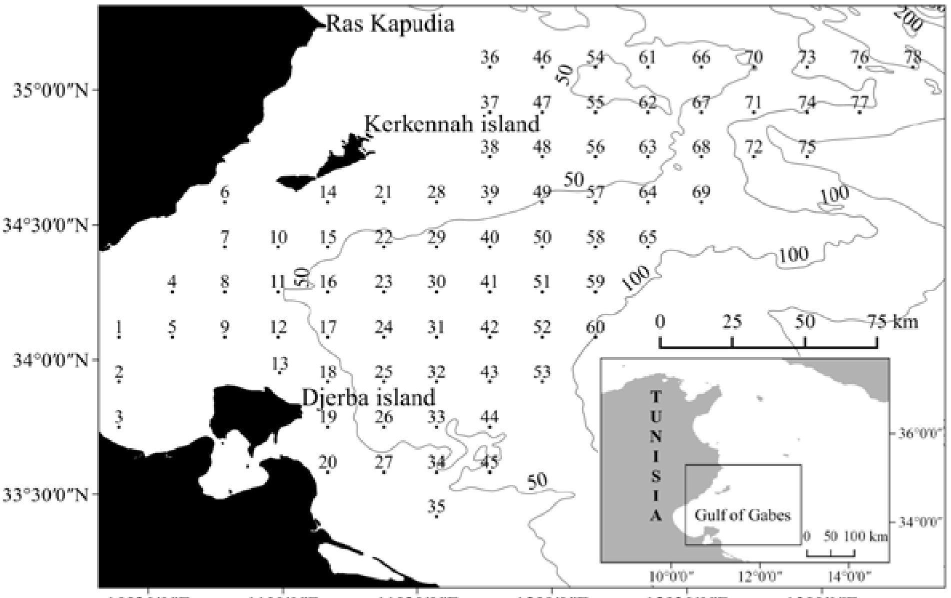


Fig. 1:Sampling stations.

For determining chlorophyll *a,* water samples were taken from different level depths (surface, 25 m, 50 m, 75 m and 100 m) with Niskin bottles mounted in a rosette. Half-a-liter of this sample was filtered through a Whatman GF/C glass fibre filter, with a pore size of 1.2 µm, and kept frozen at -20°C until analysis.

Ichthyoplankton samples were collected, during the day, by means of oblique tows with a 60 cm Bongo, fitted with 335μm and 505μm mesh nets. The average speed of the vessel was 2 knots, and the maximum depth sampled was 30 metres. The average duration of each haul was 15 minutes, with an average filtered volume of 174 ± 118 m^3 (S.D). These samples were preserved in 4% sea water, formaldehyde solution, buffered with borax.

Different size fractions of the zooplankton were sampled by means of a small- sized Bongo-type plankton net with a 25 cm mouth opening, fitted above the Bongo 60 frame. The mesh of this plankton net was 150 μm and 250 μm. The zooplankton samples were preserved by freezing to -20°C.

Hydro-Bios flowmeters were fitted to each net's mouth to estimate the volume of water filtered.

Laboratory analysis

The concentration of chlorophyll *a* was measured by applying the conventional technique proposed by Lorenzen (1967). Thus, 12 ml of acetone (90%) was added on each filter prepared, which was later sonicated and centrifuged. After centrifuging, the optical density was measured before and after acidification by means of a Jenway model 6405UV/Visible spectrophotometer.

Fish larvae were sorted, counted, and identified, under a binocular microscope, to the lowest possible taxonomic level, and then preserved in ethanol.

Larvae identification was determined according to the taxonomic descriptions by Yabe *et al.* (1966), Dicenta (1975), Alemany (1997) and Fahay (2007).

Larval abundance was standardised and expressed as numbers relative to 10 m^2 of sea surface (Smith & Richardson, 1977).

The zooplankton dry weight was obtained following the method described by Lovegrove (1966), which consisted of drying zooplankton samples in an electric oven, at a temperature of 60°C, for 72 hours and dry weighed. The unit was standardized to mg/m^3.

Ecological indices

The abundance and frequency of occurrence of each species were calculated. The Shannon-Weaver index H′ was expressed as:

$$H' = - \sum_{i=1}^{S} p\mathrm{im}p\mathrm{i}$$

where *S* is the total number of species and *pi* is the proportion of *S,* which represents the i^{th} species. The Pielou's evenness index was expressed as: $J' = H'/H'_{max}$, where $H' = ln\ S$ was equally calculated for each sampling station.

The fish larvae dominance index δ was calculated using the formula $\delta = (n_1+n_2)/N$, which expressed the relative contribution of the two most abundant species (n_1+n_2) and the number of individuals *(N*).

Data analysis

Resemblance among the stations was established through hierarchical analysis clustering (HAC) (Lebart *et al.,* 1982), using the Euclidean distance. This classification was carried out with the environmental parameters (temperature, salinity, dissolved oxygen, chlorophyll *a* and depth) as factor ranks. To better visualize the resemblance among stations, a principal component analysis (PCA) was carried out. Data were log (x+1) transformed in order to stabilize the variance (Frontier, 1973).

A canonical correspondence analysis (CCA) (Legendre & Legendre, 1998) was used to address the relationship between species comprising of the larval fish assemblage and physical environmental variables.

The variables considered were depth, sea surface temperature (SST), sea surface salinity (SSS), zooplankton biomass (ZB) and surface chlorophyll *a* concentration (Chl *a*).

Cluster analysis was carried out using the PRIMER 6.1.6 package (Clarke & Gorley, 2006). The CCA analysis was performed with the XLSTAT package (Ter Braak, 1986).

Results

Environmental parameters

Sea surface temperature (SST) and Sea surface salinity (SSS) displayed the same horizontal variation, showing a significant positive spatial correlation ($r_{temp\text{-}sal} = 0.63$; $p < 0.001$), with a tendency to decrease from the coastal to the offshore waters (Fig. 2A, B).

Throughout the studied area, the SST ranged from 24.1 to 26.7°C, with an average of 24.8 ± 0.54°C (S.D). The highest temperature was recorded near the islands of Kerkennah and Djerba (Fig. 2A).

The horizontal variation of SSS detected over the study area showed differences between the maximum and minimum values of 1.9 and mean of 37.6 ± 0.33 (S.D) (Fig. 2B). The saltier resident surface of the Mediterranean mixed waters (>38) dominated in the coastal stations, while lower salinity waters, with values ranging between 37 and 37.4 values, of recent Atlantic origin (Astraldi *et al.,* 2002; Bel Hassen *et al.,* 2009a), predominated in the open sea.

Vertical distribution of temperature showed highly stratified waters, with tendency to decrease from the surface (26.7°C) to the bottom (14.3°C). The thermocline starts at about 20 - 25 m and continues until 50 m of depth (Fig. 3A).

Regarding salinity, the vertical profile recorded at the coastal stations shows a decreasing trend from the surface to the deeper layers. In the open sea, where depths exceeded 100 m, the salinity profile was characterised by relatively low values (37.4 - 37.6) at the surface layer, and lower values (37.1 - 37.4) between 10 and 50 m, which correspond to the thermocline. Below a 50 m depth the salinity starts to increase progressively until it reaches 38.8 at 216 m (Fig. 3B).

The T-S diagram (Fig. 4) identified three water masses: the surface layer (< 60 m depth) dominated by the Atlantic Water (AW), designated as A, and characterised by high temperature (>16.5 °C) and low salinity (<37.7). The second group, designated as B, dominated by Mixed Transitional Water (MTW) integrated the stations with depth between 60 and 150 m with low records in temperature (<16) and salinity between (37.7 and 38). The third group, designated as C, represents the Levantine Intermediate Water (LIW), which is dense water characterised by a maximum salinity of >38.78 and a temperature of <14.5. The density profile helps to distinguish between the three water masses identified with the in situ measurements. The three density ranges are presented in a T–S diagram. The

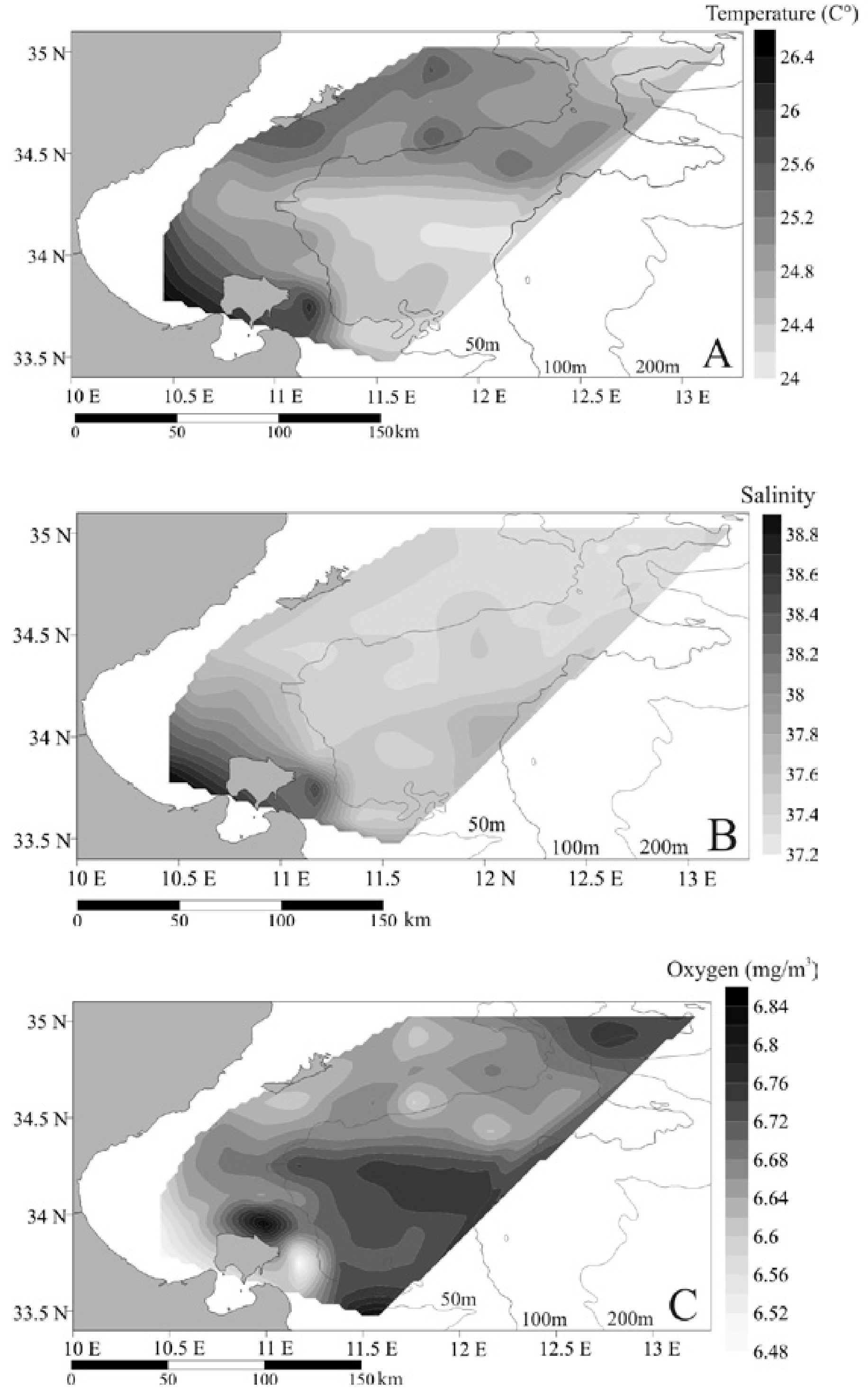


Fig. 2: Spatial distribution of surface temperature (A), salinity (B) and dissolved oxygen concentration (C).

first density range (from 25 to 27.5) corresponds to the AW characterised by high mesoscale and seasonal variability. The second range (from 27.5-28.3) represents the transitional layer between AW and LIW comprising of MTW, with the water mass being indicated by a relatively lowest temperature and a large range of salinity. The water mass contained in the third range is mainly the LIW with the density range between 29 and 29.1.

The horizontal distribution of dissolved oxygen showed an increasing gradient from the coast to the offshore area, in contrast to the surface temperature and salinity. The surface concentration ranged from 6.5 to 6.9 mg l^{-1} with a mean value of 6.7 ± 0.066 mg l^{-1} (S.D.) (Fig. 2C). With regard to its vertical variation, the dissolved oxygen values increased from the surface to the bottom, in contrast to the temperature.

At the surface layer, a progressive increase was registered down to 15 m and below this depth the rate of variation increased, until a depth of 50 m. In the deeper layers (>100 m), the distribution appeared to be uniform, with values ranging between 8 to 8.1 mg l^{-1}(Fig. 3C).

Surface chlorophyll *a* concentration ranged from 1.1 to 3.9 mg $m^{-3\ (\text{mean} \pm \text{S.D.} = 2.2 \pm 0.61\ \text{mg m-3})}$. High concentrations were recorded in neritic stations very close to the coast and around the island of Djerba, whereas, the least productive areas were mainly located in the open sea (Fig. 5A).

The highest zooplankton biomass patches (> 40 mg m^{-3}), were found near the coast and around the island of Djerba. Nevertheless, the majority of the study area was dominated by lower values (< 10 mg m^{-3}) (Fig. 5B).

The PCA and HAC analysis showed three main groups of stations, namely A, B and C (Fig. 6, 7). Sta-

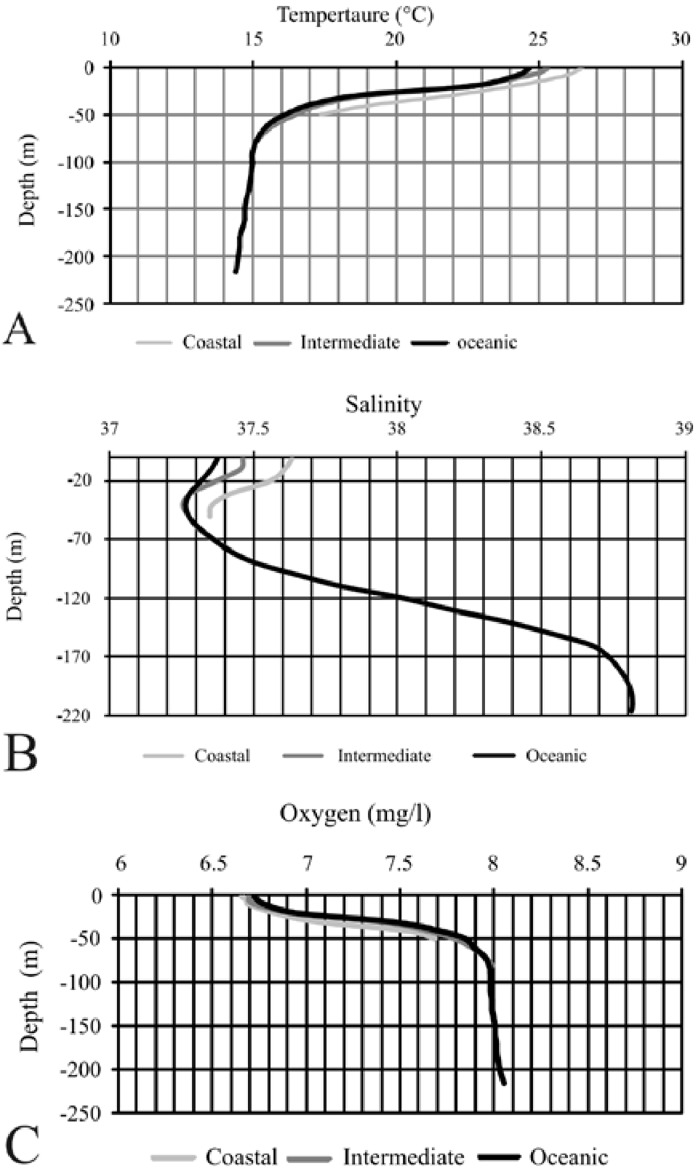


Fig. 3: Vertical profiles of temperature (A), salinity (B) and dissolved oxygen concentration (C) for coastal intermediate and oceanic stations.

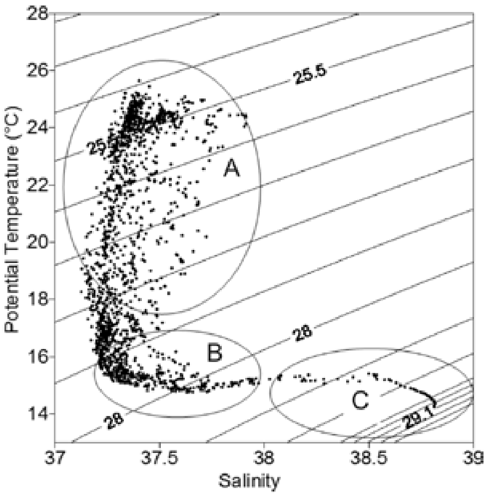


Fig. 4:T-S data from the CTD profiles measured in June 2009 in the Gulf of Gabes. Group (A) data represent AW, group (B) data represent the MTW and the group (C) represent the deep water mass (LIW).

tions belonging to group A were almost always coastal, with depths less than 30 m. These stations were characterised by higher temperatures and salinities and greater zooplankton biomass on average. Group B was the dominant one, with 37 stations distributed over a wide area that included stations located on the coast and the middle part of the study area.

These stations were characterised by moderate depths, around a mean depth of 47 m, with moderate temperatures and salinities. Finally, stations of group C were located farthest from the coast with a mean depth of 96 m and lower temperature and salinity values. The stations of this group were also characterised by low chlorophyll *a* concentration and zooplankton biomass.

Larval fish composition, abundance and ecological indices

A total of 5215 fish larvae, belonging to 36 different taxa were identified. 28 were classified to species level, three to genus and five to the family level, whereas, 18 larvae remained unidentified (Table 1).

The Scombridae family was the most represented, which grouped four species. It was followed by the Labridae and Myctophidae families that comprised of three species. On the other hand, 16 families were represented by only one species.

The majority of the identified fish larvae taxa (58.3%) belonged to the demersal species, which mainly belonged to the families of Centracanthidae, Mullidae, Sparidae, Blenniidae, Gobiidae.

Larval abundance per station ranged between 3.8 to 1367 larvae/10m² (mean ± S.D. = 159.8 ± 223.59 larvae/10m²). Mean abundance values by taxa, in the positive stations, are detailed in Table 1.

The most abundant species was the picarel *Spicara smaris* (Linnaeus, 1758), which accounted for 23.75% of the total larval fish catches (mean ± S.D. = 51.15 ± 84.5 larvae/10m²), followed by larvae of the small pelagic species *S. aurita* (22.3%) and that of the demersal species red mullet *Mullus barbatus* (Linnaeus, 1758) (14.9%).

However, the majority of taxa (24) were very poorly presented in the sample, with percentages not exceeding 1% of the total amount.

Larvae of the mesopelagic species (*Lampanyctus pusillus* (Johnson, 1890), *Lampanyctus crocodilus* (Risso, 1810), *Ceratoscopelus maderensis* (Lowe, 1839), *Cyclothone pygmaea* (Jespersen & Taning, 1926) and *Cyclothone braueri* (Jespersen & Taning, 1926) were rarely collected (24 larvae comprised of 0.46% of the total larval catches). The most abundant mesopelagic species was *C. maderensis* (54.2% of the mesopelagic larvae).

On the contrary, larvae of the Sparidae species were relatively abundant, representing 11.7% of the total catch, which showed an average abundance of 38.14 ± 74.9 larvae/10m². Among this group, the larvae of red porgy *Pagrus pagrus* (Linnaeus, 1758) were the most frequent, which accounted for 71.8% of the sparid larvae.

Five scombriform species were identified among these larvae, namely *A. rochei, E. alletteratus, T. alalunga, T. thynnus* and swordfish *Xiphias gladius* (Linnaeus, 1758). All these species were caught in 38.5% of the sampling stations and contributed to about 7.9% of the total larval catches.

The most abundant tuna species was *A. rochei,* a middle-sized scombroid, with a total of 341 larvae (mean density ± S.D. = 20.9 ± 24 larvae/10m²), which represented 82.8% of the total tuna larval found in our samples.

Shannon's diversity index ranged between 0 and 2.1 (Table 2), with a mean value of 1.19. The lowest value was found at stations characterised by the dominance of one species. The highest value was recorded in station 59 located in the offshore area; 85 miles to the east of the Djerba Island coast.

Pielou's evenness index showed values between 0 and 1, with a mean of 0.68 (Table 2). In the neritic stations the mean value was higher than the ones calculated in the offshore stations, reflecting a relatively higher biodiversity stability of the coastal ecosystem compared to the oceanic one.

Spatial distribution pattern

The spatial distribution of the larval fish assemblage showed lower abundances in the neritic stations with depths less than 50 m. Higher abundances of the larval fish were mainly found in the intermediate and offshore stations located in the southeast of the Kerkennah Island (Fig. 8).

The horizontal distribution of fish larvae differed among species (Fig. 9). Some species showed a wide geographical distribution, such as *S. smaris,* which was collected in 85% of the stations, and preferentially in the intermediate stations.

The Sparidae, Gobidae and Mullidae larvae ranked high in the number of stations, which showed respective

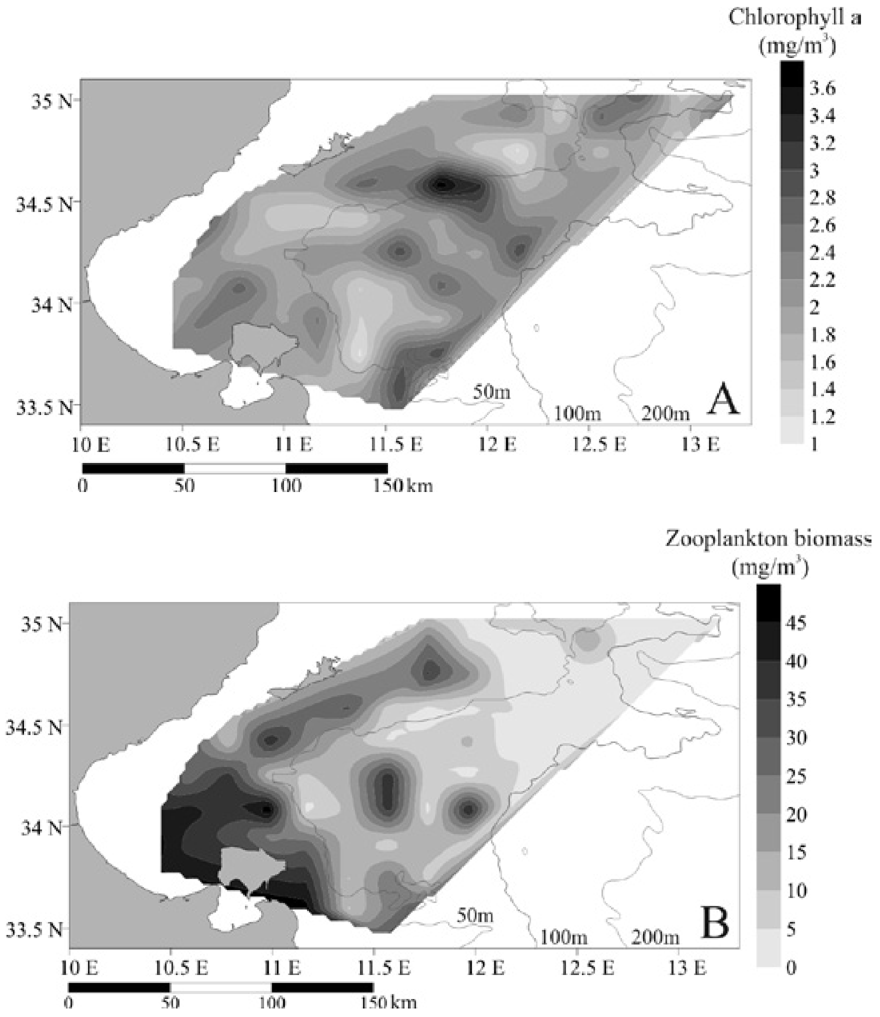


*Fig. 5:*Superficial distribution of chlorophyll *a*: (A) and dry weight zooplankton biomass (B).

occurrence frequencies of 69, 60 and 59%. The Gobidae larvae were more coastal, whereas, the two other taxa (Sparidae and Mullidae) were mainly found in the intermediate stations.

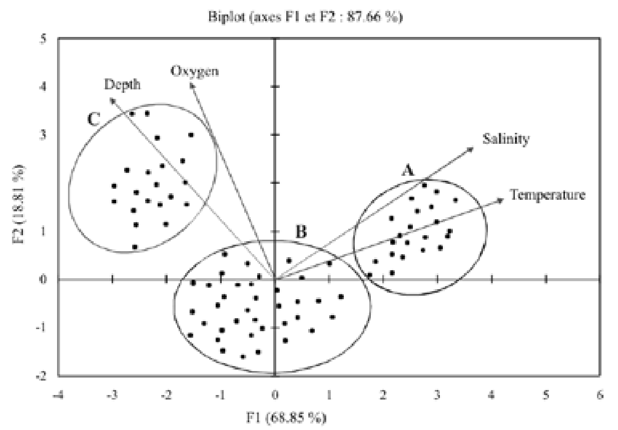


Fig. 6: Principal Component Analysis (PCA) showing the resemblance among stations based on different environmental parameters (temperature, salinity, oxygen and depth).

Small pelagic larvae *(S. aurita* and *E. encrasicolus)* were present over the continental shelf, but they were absent in the southern and northern parts of the study area, near Kerkennah Island. Most of the Sardinella larvae

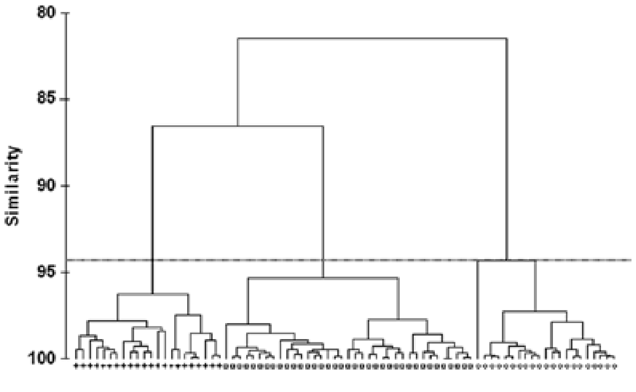


*Fig. 7:*Dendrogram based on the Euclidean distance between the sampling stations based on the environmental factors (temperature, salinity, oxygen content, chlorophyll *a,* zooplankton biomass and depth). Station groups were plotted in plus (A) squares (B) and circles (C).

Table 1. Number, Mean abundance (individuals 10 m^{-2}), *F* (frequency of occurrence) and % (relative abundance of fish larval).

Family	**Species**	**Category**	**Code**	**Number**	**Mean abundance (10m^2)**	***F***	**%**
Apogonidae	*Apogon imberbis*	Demersal shelf/slope	-	2	1.43	1.3	0.04
Blenniidae	Blenniidae sp.	Demersal shelf/slope	Blenn_*spp*	149	16.23	38.5	2.86
Bothidae	*Arnoglossus* sp.	Demersal shelf/slope	-	5	4.22	6.4	0.1
Callionymidae	*Callionymus* sp.	Demersal shelf/slope	*Callio_spp*	23	7.4	12.8	0.44
Carangidae	*Trachurus mediterraneus*	Small pelagics	*Trach_med*	60	19.7	19.2	1.15
	Trachurus trachurus	Small pelagics	*Trach_trac*	7	0.95	4	0.13
Centracanthidae	*Spicara smaris*	Demersal shelf/slope	*Spic_sma*	1218	51.15	81	23.3
	Spicara sp.	Demersal shelf/slope	-	21	4.6	14.1	0.4
Clupeidae	*Sardinella aurita*	Small pelagics	*Sard_aur*	1162	52	38.5	22.3
Coryphaenidae	*Coryphaena hippurus*	Medium pelagics	-	2	1.61	2.6	0.04
Engraulidae	*Engraulis encrasicolus*	Small pelagics	*Engr_enc*	285	22.1	33.3	5.47
Gobiidae	*Lebetus guilleti*	Demersal shelf/slope	-	1	4.3	1.3	0.02
	Gobiidae sp.	Demersal shelf/slope	Gobi_*spp*	197	11.3	60.2	3.78
Gonostomatidae	*Cyclothone braueri*	Meso- and bathypelagics	*Cycl_bra*	7	1.89	7.7	0.13
	Cyclothone pygmaea	Meso- and bathypelagics	*Cycl_pyg*	2	1.6	2.6	0.04
Labridae	*Coris julis*	Demersal shelf/slope	*Cor_jul*	3	2.4	4	0.06
	Xyrichthys novacula	Demersal shelf/slope	-	4	5.28	4	0.08
	Symphodus sp.	Demersal shelf/slope	*Sym_spp*	17	3.9	9	0.33
Mugilidae	*Mugil cephalus*	Demersal shelf/slope	-	6	2.73	7.7	0.12
Mullidae	*Mullus barbatus*	Demersal shelf/slope	*Mull_bar*	778	41.2	59	14.9
Myctophidae	*Ceratoscopelus maderensis*	Meso- and bathypelagics	*Cera_mad*	13	4.1	6.4	0.25
	Lampanyctus pusillus	Meso- and bathypelagics	*Lamp_pus*	1	2.25	1.3	0.02
	Lampanyctus crocodilus	Meso- and bathypelagics	*Lamp_cro*	1	2.24	1.3	0.02
Pomacentridae	*Chromis chromis*	Demersal shelf/slope	*Chro_chr*	44	6.3	15.4	0.84
Serranidae	*Serranus hepatus*	Demersal shelf/slope	*Serr_hep*	117	20.4	33.3	2.24
	Serranus cabrilla	Demersal shelf/slope	*Serr_cab*	31	9.9	18	0.6
Sparidae	*Pagrus pagrus*	Demersal shelf/slope	*Pagr_pag*	438	50.8	44	8.4
	Diplodus sp.	Demersal shelf/slope	-	8	4.45	7.7	0.15
	Sparidae sp.	Demersal shelf/slope	Spar_*spp*	164	9.3	62	3.14
Scombridae	*Thunnus thynnus*	Large pelagics	*Thun_thy*	27	5	8	0.52
	Auxis rochei	Medium pelagics	*Aux_roc*	341	20.9	36	6.54
	Euthynnus alletteratus	Medium pelagics	*Euth_all*	36	7	13	0.69
	Thunnus alalunga	Large pelagics	*Thun_ala*	8	3.75	5	0.15
Scorpaenidae	*Scorpaena* sp.	Demersal shelf/slope	-	1	2.46	1.3	0.02
Synodontidae	*Synodus saurus*	Demersal shelf/slope	-	2	1.1	1.3	0.04
Trachinidae	*Trachinus draco*	Demersal shelf/slope	-	15	7.12	11.5	0.29
Xiphiidae	*Xiphias gladius*	Large pelagics		1	1.1	1.3	0.02
Unidentified				18	5.5	11	0.35

were caught in offshore waters, while the Anchovy larvae did not show any clear preference; being collected in high densities in the neritic and offshore stations.

A. rochei larvae also showed a widespread distribution from neritic to offshore stations of the survey area. The highest concentrations were recorded at the offshore stations of Kerkennah Island, whereas, *E. alletteratus* larvae were only collected in the intermediate stations located in the southern part of Kerkennah Island.

Other larvae were not so widely distributed. Their presence was confined to specific areas, such as the mesopelagic larvae (*C. maderensis, C. pygmaea* and *C. braueri*) and *T. thynnus* larvae, which were mostly captured in the most distant stations at the limits of the shelf

Table 2. Total larval density (individuals 10 m^2), Shannon-Weaver's diversity index (*H'*) and Pielou's evenness index (*J'*).

Station	Depth	Individuals 10m^2	*H'*(bits)	*J'*	Station	Depth	Individuals 10m^2	*H'*(bits)	*J'*
1	24.1	47.2	1.59	0.89	**40**	51.6	26.6	1.41	0.88
2	18.6	4.2	0	0	**41**	64.3	143	1.35	0.75
3	18.3	177.5	0.78	0.48	**42**	70.2	201.9	1.45	0.81
4	34	44.4	1.22	0.76	**43**	68	472.65	1.77	0.69
5	18.6	8.6	0.69	1	**44**	55	245.6	1.68	0.70
6	15.5	127.85	0.98	0.61	**45**	50.5	78.5	1.44	0.80
7	38	16.75	1.73	0.97	**46**	38.3	22.65	0.85	0.78
8	39.3	91	0.46	0.33	**47**	28	36	1.2	0.86
9	21.2	12	0.64	0.92	**48**	32.5	14.9	0.41	0.59
10	30.2	25.8	1.33	0.96	**49**	50	92.75	1.71	0.78
11	47.5	88.7	1.33	0.74	**50**	66.5	377.55	1.87	0.73
12	29.3	10.45	0.64	0.92	**51**	77.5	316.8	1.93	0.75
13	17	18.9	0	0	**52**	82.1	107.65	1.37	0.71
14	16.7	28.85	1.01	0.92	**53**	84	1366.7	1.98	0.75
15	45.8	262.6	1.48	0.62	**54**	51.6	42	1.21	0.87
16	51.9	90.9	1.78	0.86	**55**	41.5	20.6	1.23	0.77
17	51.8	322.6	1.66	0.67	**56**	43.5	21.95	1.36	0.84
18	38	3,8	0	0	**57**	57.1	150	0.84	0.52
19	28	50	1.2	0.86	**58**	82.8	154.3	0.8	0.41
20	19	59.2	0.69	0.63	**59**	89	654.8	2.1	0.86
21	29.5	18.45	1.01	0.92	**60**	97.6	170	1.38	0.67
22	54.7	135.8	1.84	0.84	**61**	45.1	40.55	0.98	0.55
23	63	513.7	1.22	0.63	**62**	37.8	4.9	0.95	0.86
24	55.6	439.6	1.8	0.75	**63**	42.1	530.25	0.39	0.22
25	49	210.9	0.31	0.28	**64**	65.5	51.6	1.78	0.72
26	50.5	23.85	0.95	0.86	**65**	89.6	49.3	1.35	0.7
27	38.1	18.7	1.39	1	**66**	38	49	1.58	0.76
28	34.5	37.6	1.12	0.81	**67**	69.2	43.5	2	0.87
29	51.2	46.4	1.18	0.85	**68**	65	51	1.52	0.78
30	60.9	560.7	0.86	0.48	**69**	67.1	175.6	1.62	0.7
31	60.7	830.25	1.73	0.72	**70**	55.6	5.7	1.49	0.93
32	61.1	99.9	1.57	0.68	**71**	191.8	32.5	1.69	0.87
33	52.6	28.7	0.41	0.59	**72**	121	178.5	1.4	0.59
34	42	41.5	1.59	0.89	**73**	152	341.8	0.69	0.27
35	19.6	4.75	0	0	**74**	102	107.5	0.88	0.4
36	27	109.75	1.38	0.77	**75**	230	42.45	1.76	0.73
37	17.5	177.65	0.81	0.45	**76**	129	631.7	0.81	0.35
38	24.3	51.4	0.54	0.78	**77**	103	256	1.43	0.6
39	42	188.2	0.42	0.26	**78**	166	125.8	1.87	0.71

break, while contrarily, species such as *Symphodus* sp and *Callionymus* sp larvae were strictly restricted to the coastal stations.

Spatial variation of the dominance index (Fig. 10) showed a decrease from inshore to offshore waters, recording from 85% at five miles to the coast to 51% at 110 miles from the coast. This is demonstrated by the negative correlation between the dominance index and the coast-offshore gradient ($r = -0.54$; $p<0.001$).The highest value of this index (86%) was recorded at 50 miles from the coast, which was the consequence of the clear dominance of *S. smaris* larvae.

The shallower coastal waters (<20 miles from the coast) were dominated by larvae of the Gobidae and

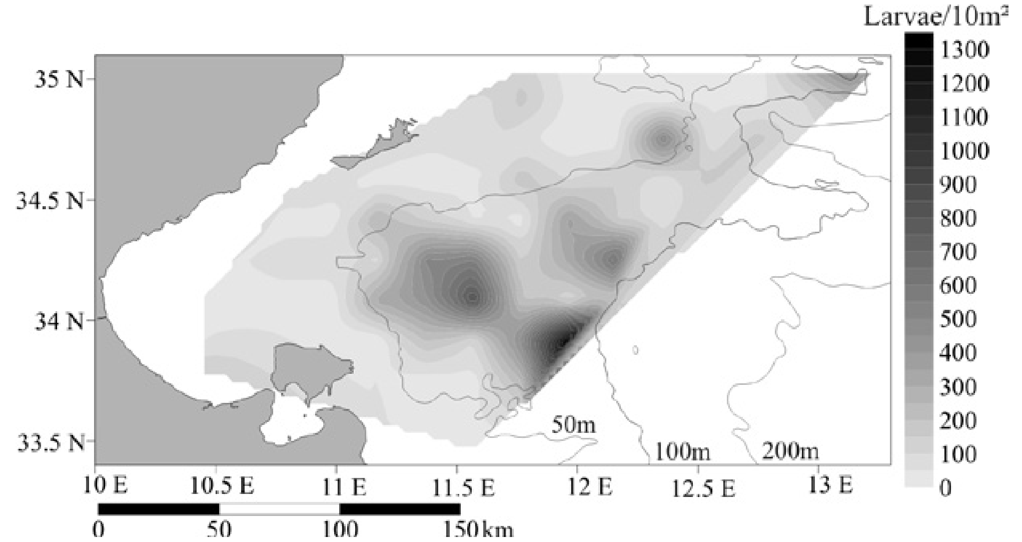


Fig. 8: Spatial distribution of fish larval abundances.

Blennidae family, while the intermediate waters were characterised by the abundance of larval *S. smaris*. The oceanic stations were characterised by the dominance of Sardinella larvae.

Relation between larval fish and environmental parameters

The general patterns of the relationships between summer larval fish assemblage and the five environmental variables (Depth, temperature, salinity, zooplankton biomass and chlorophyll *a*) are shown in Fig. 11.

The first two canonical axes explained 78.2% of the inertia of the species-environmental relation, 51.33% represented by the first axis and 26.86% by the second axis.

Axis II was negatively correlated with depth, SST and SSS and positively correlated with Chlorophyll *a* and ZB, whereas, Axis I was only positively correlated with depth.

The CCA analysis shows that depth is the most significant environmental factor affecting the composition of the larval fish assemblage; but that other hydrographic factors also shape the spatial patterns of fish larval assemblage.

The two tuna species (*T. thynnus* and *T. alalunga*), *S. aurita* and the mesopelagic larvae, including those from the Myctophidae and Gonostomatidae families, were closely associated with the depth, as indicated by a high positive correlation at deeper stations. Inversely, some neritic species belonging to the family of Gobidae, Blennidae and *Callionymus* sp*,* were clustered in the shallower waters with higher SST and SSS values.

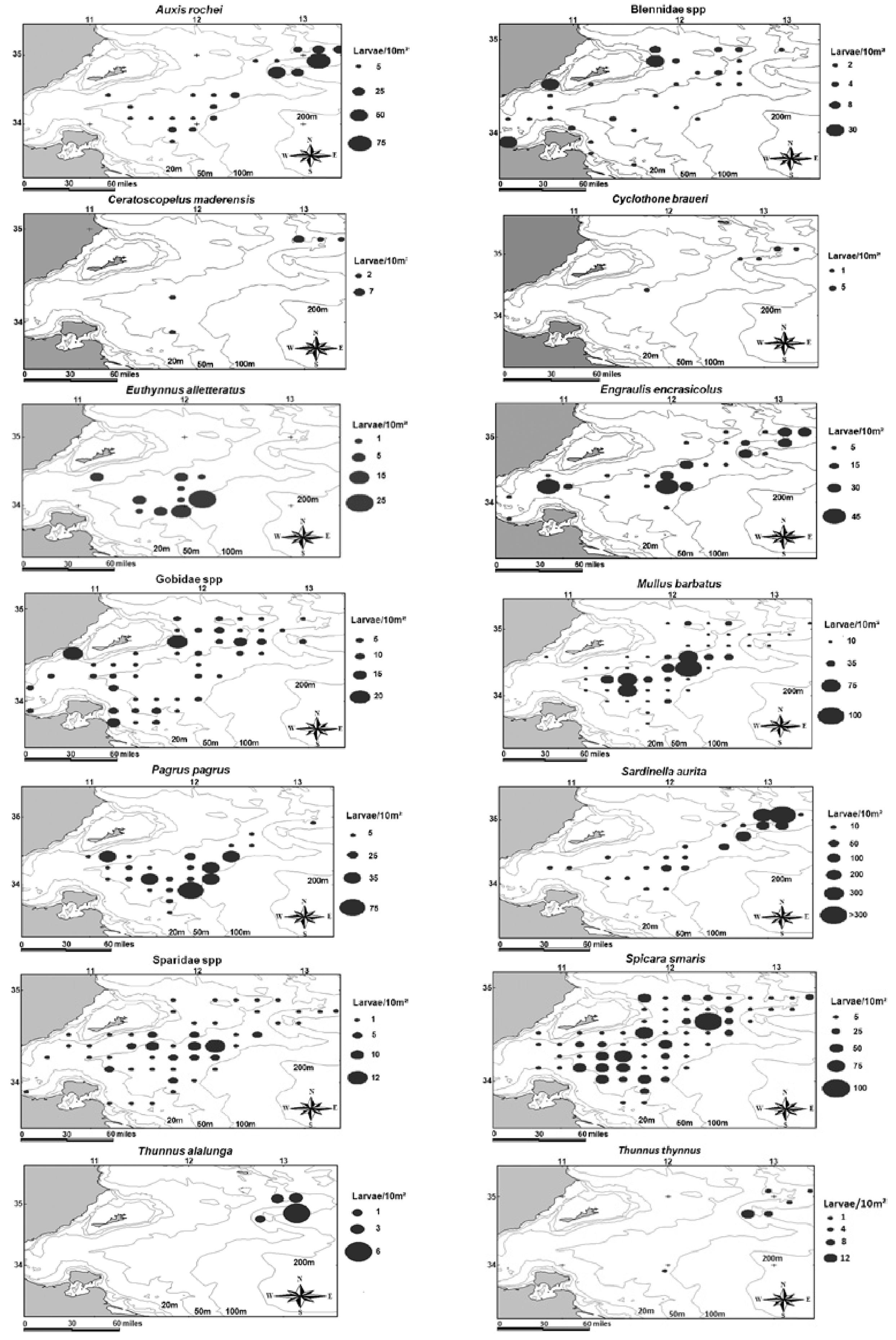
Other taxa, such as *M. barbatus, S. smaris* and Sparidae sp*,* were located near the centre of the ordination diagram, not showing any spatial trend with any variable. Most of them were shelf species and had a broad or random spatial distribution.

Discussion

The Gulf of Gabes is considered a nursery for many fish species of Tunisian waters (Hattour *et al.,* 1995). Its immense continental shelf, which is the widest in this part of the Mediterranean Sea, and it's very flat low slope, are the main characteristic of this Gulf (Burollet *et al.,* 1979), which explains the clear dominance of the low depths (<100 m) in the study area.

Water circulation in the Gulf of Gabes is mainly influenced by the semi-diurnal tides that cause strong and reversing currents (Sammari *et al.,* 2006; Hattour *et al.,* 2010). However, similar to other regions of the Tunisian waters, this area is under the influence of the inflow of surface Atlantic water that directly affects the circulation at the mouth of the Gulf (Sammari *et al.,* 1999; Béranger *et al.,* 2004). This inflow surface water, noticeable by its minimal salinity ranged between 37.3 and 37.5 (Ben Ismail *et al.,* 2012), and was observed in the intermediate (40 to 60 miles from the coast) and offshore stations (> 60 miles) during this survey.

This Gulf, as the whole Mediterranean Sea, displayed a general oligotrophic character (Bel Hassen *et al.,* 2009a), but the high rate of urbanization and industry along its coasts caused an organic mainland input through the potential discharge of sewage and industrial pollutants (Barhoumi *et al.,* 2009). This generates a high nutrient concentration near the coast (Bel Hassen *et al.,* 2009b) which explains the high values of chlorophyll *a* and zooplankton biomass registered at the inshore stations. Nevertheless, the high zooplankton biomass recorded in some offshore stations may be explained by the effect of hydrodynamic processes, such as the ebb tides, being relatively stronger than the flood tides (Ben Ismail *et al.,* 2015), which can promote the export of zooplankton from inshore to offshore, and the Atlantic water circulation, which may contribute to nutrient enrichment



Auxis rochei

Blennidae spp

Ceratoscopelus maderensis

Cyclothone braueri

Euthynnus alletteratus

Engraulis encrasicolus

Gobidae spp

Mullus barbatus

Pagrus pagrus

Sardinella aurita

Sparidae spp

Spicara smaris

Thunnus alalunga

Thunnus thynnus

Fig. 9: Horizontal distribution of some species of fish larvae.

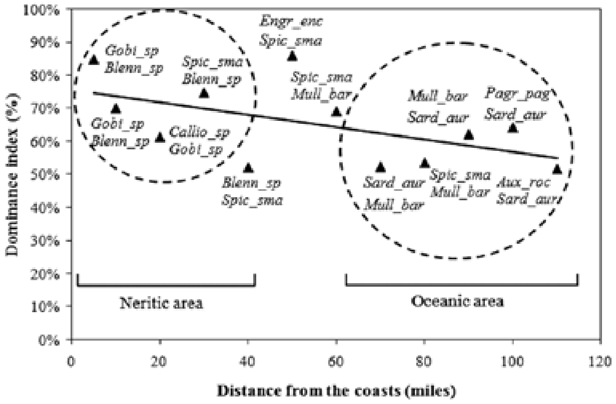


Fig. 10: Relationships between the dominance index and distance from the coast. The two most dominant species are indicated for each interval distance. Relationships between the dominance index and distance from the coast. The two most dominant species are indicated for each interval distance. (*Aux_roc*: *Auxis rochei, Blenn_sp*: Blenniidae sp, *Callio_sp*: *Callionymus* sp, *Engr_enc*: *Engraulis encrasicolus, Gobi_sp*: Gobiidae sp, *Mull_bar*: *Mullus barbatus, Pagr_pag: Pagrus pagrus, Sard_aur*: *Sardinella aurita, Spic_sma: Spicara smaris).*

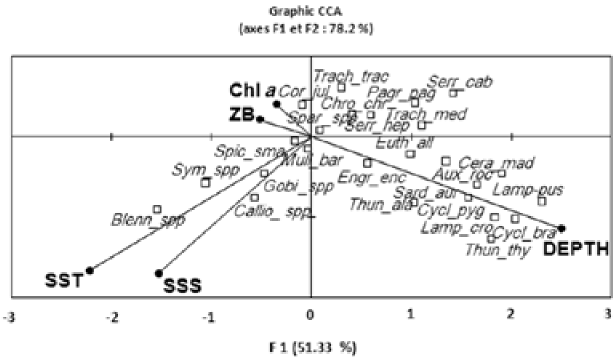


*Fig. 11:*Biplots corresponding to canonical correspondence analysis (CCA) for environmental variables indicated by arrows and larval fish species by squares.(SST: Sea Surface temperature, SSS: Sea Surface Salinity, ZB: Zooplankton biomass, Ch*a*: Chlorophyll *a).*

offshore, thereby inducing phytoplankton production and consequently, enrichment of the zooplankton biomass. This nutrient enrichment offshore can be accomplished directly by simple inflow, or indirectly via the disturbance of sediments with an upward release of nutrients (Bel Hassen *et al.,* 2009a).

Despite sampling was restricted to surface layers, where tuna larvae are distributed (Morote *et al.,* 2008; Satoh, 2010; Alemany *et al.,* 2010), the comparison with other Mediterranean areas show strong similarities in the larval fish taxa composition reported by other studies as to those carried out in the east coast of Tunisia (Zarrad *et al.,* 2013), the north western Mediterranean (Alemany *et al.,* 2006; Olivar *et al.,* 2010; Sabatés, 1990; Rodriguez *et al.,* 2013; Giordano *et al.,* 2015) and the eastern Mediterranean (Somarakis *et al.,* 2002). In fact, from 50 to 76% of the larval fish taxa mentioned in those studies were also present in the study area. These results show that ichthyofaunal assemblages inhabiting different parts of the Mediterranean Sea, in the western and eastern basins, are relatively similar to those of the Gulf of Gabes, where the majority of larval fish taxa can be found in the upper surface layers.

However, some significant differences can be remarked, such as the low number of identified taxa in comparison to other areas. In fact only 36 taxa were identified compared to 46 different taxa collected from the eastern coast of Tunisia (Koched *et al.,* 2011), 52 taxa from the Balearic Island (Alemany *et al.,* 2006), 48 taxa from the Greek waters (Koutrakis *et al.,* 2004) and 45 taxa from the Catalan coast (Sabatés, 1990). This can be the result of the sampling strategy that mainly targeted the upper mixed layer on the oceanographic regime, which may induce changes in fish reproductive behavior and in adult composition, as also the result of the shallowness of the study area and the homogeneity at the bottom (muddy and sandy) of the Gulf of Gabes (Burollet *et al.*, 1979). The low abundance of mesopelagic and rockfish species, seems to corroborate this hypothesis.

In the present study, the results of the CCA analysis showed that the depth is the main factor conditioning larval fish assemblage, which is in agreement with the previous studies carried out in the Tunisian waters (Koched *et al.,* 2011; Zarrad *et al.,* 2013) and in the other regions of the Mediterranean (Sabatés, 1990; Alemany *et al.,* 2006; Olivar *et al.,* 2010). Nevertheless, other factors, such as the width of the continental shelf (Sabatés, 1990) and mesoscale circulation patterns (Sabatés & Masó, 1992; Torres *et al.,* 2011; Rodriguez *et al.,* 2013) can also control this horizontal distribution.

The sampling grid encompassed the wide continental shelf of the study area which did not go beyond the 200 m depth. This could explain the broad distribution of the neritic species, which are usually restricted to coastal stations, such as *M. barbatus, P. pagrus, S. smaris,* and larvae of the Sparidae, Gobiidae, and Blenniidae families. For this reason, the defined community structure responds to a typical coastal assemblage, similar to the ones reported in the Aegean Sea (Somarakis *et al.,* 2002; Koutrakis *et al.,* 2004).

In contrast, other studies conducted previously in nearby areas off the east coast of Tunisia (Koched *et al.,* 2011; Zarrad *et al.,* 2013) and in the western Mediterranean (Sabatés, 1990; Alemany *et al.,* 2006), have identified two main larval assemblages, that is one coastal, mainly composed of neritic taxa, and the other one over the shelf break and slope, mainly composed of oceanic taxa.

These results put into evidence that depth and the shelf break are determinant factors of taxonomic composition and abundance of fish larvae assemblages, by limiting the habitat of the adults, mainly in the case of the demersal species (Sparidae sp, *M. barbatus, S. smaris* etc.).

Thus, the presence of mesopelagic fish larvae in our samples was sporadic; in fact, only 24 larvae belonging to the mesopelagic species (*C. maderensis, C. braueri, C. pygmaea, L. pusillus* and *L. crocodilus)* were caught, in contrast to the aforementioned studies (Somarakis *et al.,* 2002; Alemany *et al.,* 2006; Torres *et al.,* 2011; Giordano *et al.,* 2015), which included stations well away from the shelf break, and where larvae of the mesopelagic species dominated the summer larval assemblage. The presence of the mesopelagic larvae in the upper layer was also reported by other previous studies in the northwestern Mediterranean (Olivar *et al.,* 2010; Granata *et al.,* 2011; Torres *et al.,* 2011).

However, in spite of their low concentration, the appearance of some larvae of mesopelagic species in the shallow stations, around a 50 m depth may be considered an intrusion of offshore waters. As some mesopelagic larvae mainly occupy the surface layers, they are at the mercy of entrainment to other areas by the circulation pattern (Sabatés, 2004; Cuttitta *et al.,* 2004).

These findings show that the mesoscale hydrographic features also play an important role in shaping the spatial distribution of the larval fish community in the Gulf of Gabes, by facilitating the transport of eggs and/or larvae far from their natal area to adulthood habitats.

On the other hand, the larvae of four tuna species (*T. thynnus, A. rochei, E. alletteratus* and *T. alaunga*) were found in our plankton samples, which confirmed that the Gulf of Gabes was a spawning area for these tuna species, as previously stated in Koched *et al.* (2013).

Bullet tuna larvae were the most abundant and frequent tuna species in our sample, showing a widespread distribution over the study areas, mainly over the outer continental shelf. Similar results were reported in other studies carried out in the waters of the east coast of Tunisia (Koched *et al.,* 2012) and in different parts of the Mediterranean Sea (Garcia *et al.,* 2005; Oray & Karakulak, 2005; Alemany *et al.,* 2006; 2010).

Considering the depth range of the stations in which small tuna (bullet and Atlantic black skipjack) larvae were found, it can be deduced that the spawning of these species takes place mainly over the continental shelf, with more coastal preference for the Atlantic black skipjack.

Although, Atlantic bluefin tuna and albacore larvae, as a large tuna species, were present only at the most distant station from the coast near the shelf break, characterised by greater depths (> 120 m), it could be inferred that the spawning area of these two species (bluefin and albacore tuna), could be located more towards the open sea.

The horizontal pattern of the Atlantic bluefin tuna larvae distribution is probably because of their spawning migration in the Mediterranean Sea, influenced by the path of entering surface Atlantic waters that usually flows outside the shelf break (Millot, 1987). Our result would support the interpretation given by Koched *et al.* (2012) about the Eastern coasts of Tunisia, Garcia *et al.* (2005); Alemany *et al.* (2010); Torres *et al.* (2011) and Reglero *et al.* (2012) about the Balearic Sea and Oray & Karakulak (2005) about the Levantine Sea.

The observed high variation of horizontal distribution between the tuna larvae species, some found preferentially in neritic stations (bullet and Atlantic black skipjack) and others in the oceanic offshore stations (Atlantic bluefin and albacore) have been reported in other Mediterranean areas (Oray & Karakulak, 2005; Alemany *et al.,* 2006, 2010; Reglero *et al.,* 2012; Koched *et al.,* 2012, 2013).

On the other hand, the presence of larvae of other medium–large pelagic fishes such as Common dolphinfish *Coryphaena hippurus* (Linnaeus, 1758) and *X. gladius*, even with very low concentration, could suggest that the study area is also a spawning ground for these species, such as the Balearic Sea (Alemany *et al.,* 2006; Torres *et al.,* 2011) or waters around Cyprus (Oray & Karakulak, 2005).

However, the larval fish assemblage was clearly dominated by two neritic species *S. smaris* and *M. barbatus,* which represented 38.7% of the total sampled larvae. The high concentration of these two species may reflect the local high abundance of adults, considering their preference for shallow and muddy bottoms (Lloris & Rucabado, 1998), such as those occupying most of the studied area, confirming that the Gulf of Gabes constitutes a favourable spawning ground for these species.

The small pelagic species *S. aurita* and *E. encrasicolus* were also abundant and dominated the larval fish community in the offshore stations. The high concentration of small pelagic larvae during the summer period in the region has been also reported by previous studies carried out in the North east of Tunisia (Koched *et al.,* 2011; Zarrad *et al.,* 2013) and other sectors of the Mediterranean Sea (Koutrakis *et al.,* 2004; Isari *et al.,* 2008). Furthermore, their preference to spawn in the deeper waters near the shelf break (Olivar *et al.,* 2001; Cuttitta *et al.,* 2006; Zarrad *et al.,* 2012b) should explain the higher abundance of their larvae in the offshore stations.

Conclusion

This study has described, for the first time, the summer fish larvae assemblage in the upper mixed layer in the Gulf of Gabes. It can be concluded that the horizontal spatial distribution pattern of fish larvae in this area is significantly linked to the combined effect of two factors; the first being the depth gradient, which determined the habitat of spawners and the second being the mesoscale hydrodynamic features (currents and tides), which modify the initial fish larvae assemblage distribution.

Further investigations are necessary to cover their cycle over the successive seasons along the year and in the entire Tunisian waters, to better understand the dynamics that influence larval fish assemblages in this region, to get a wider knowledge of their inter- and intraspecific interactions, either through predation and/or competition processes, and furthermore, to achieve a deeper understanding of the influence of the environmental parameters on the spawning strategies and larval survival.

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