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Spatial distribution of tuna larvae in the Gulf of Gabes (Eastern Mediterranean) in relation with environmental parameters

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Abstract

Spatial distribution and ecology of the larvae of three tuna species (*Thunnus thynnus, Auxis rochei* and *Euthynnus alletteratus*) were studied during an ichthyoplankton survey carried out in the Gulf of Gabes (Tunisia) in June and July 2009. A total of 80 stations, distributed on a regular sampling grid, were sampled. The main objectives of this survey were to provide information on tuna larvae distribution in the Gulf of Gabes in relation to the environmental parameters. Regarding small tunas, larvae of *A. rochei* (bullet tuna) showed the more widespread distribution, being found at both inshore and offshore stations. *E. alletteratus* (Atlantic black skipjack) larvae were mainly found at the inshore stations covering the wide continental shelf of this region. On the other hand, larvae of the large migratory tuna *T. Thynnus* (Atlantic bluefin tuna), were mainly recorded at offshore stations, suggesting that spawning possibly takes place mainly near the shelf break. Regarding the biological and physical parameters examined, our results indicate that tuna larvae were mainly collected in oligotrophic and mixed waters resulting from the confluence of surface water of recent Atlantic origin and resident surface Mediterranean waters, as shown by their preference for lower chlorophyll *a* concentrations (from 1.4 to 2.5 mg m^{-3}) and moderate salinity values (between 37.35 and 37.75). Significantly, tuna larvae seemed to avoid the more eutrophic and saltier waters of the gulf situated very close to the coast and around Kerkennah and Djerba islands.

Keywords: tuna larvae, spatial distribution, ichthyoplankton, Gulf of Gabes, environmental parameters.

Introduction

Tuna species inhabit tropical, subtropical and temperate seas around the world, undertaking major feeding and spawning migrations (Nakamura, 1969; McKeown, 1984; Fromentin & Powers, 2005). Five of these species, belonging to the tribe Thunnini, have been recorded in the Mediterranean (Collete, 1986), i.e., the albacore *Thunnus alalunga* (Bonnaterre, 1788), the skipjack *Katsuwonus pelamis* (Linnaeus, 1758), the Atlantic bluefin tuna *Thunnus thynnus* (Linnaeus, 1758), the bullet tuna *Auxis rochei* (Risso, 1810) and the Atlantic black skipjack *Euthynnus alletteratus* (Rafinesque, 1810).

Among these, Atlantic bluefin tuna (*T. thynnus*) has the widest geographical distribution inhabiting the pelagic ecosystem of the entire north Atlantic and its adjacent seas such as the Mediterranean Sea, and is the only large pelagic fish living permanently in temperate Atlantic waters (Bard *et al.* 1998; Fromentin & Fonteneau, 2001). The migrations of *T. thynnus* have been described by several authors (Sibert *et al.* 2006; Teo *et al.* 2007a). Specifically, the eastern stock of this species carries out extensive migrations from feeding areas located in the Atlantic Ocean to the spawning grounds in the Mediterranean Sea through the Strait of Gibraltar (Fromentin & Powers, 2005; Fromentin, 2009).

With respect to the albacore (*T. alalunga*), an Atlanto-Mediterranean species, knowledge on its migration pattern is relatively poor due to the paucity of tagging studies carried out on this species. As in *T. thynnus*, it is assumed that adults undertake reproductive migrations when summertime approaches. Nevertheless, there are some reports on the albacore migration from the North Atlantic to the Mediterranean and vice versa, as well as information on the occurrence of transatlantic migrations (Alonso *et al.* 2005). Finally, information on the migration pattern of small tunas such as bullet tuna (*A. rochei*), Atlantic black skipjack (*E. alletteratus*) and skipjack (*K. pelamis*) is much scarcer and more fragmented (Di Natale *et al.* 2009).

The principal spawning grounds of tuna species in the Mediterranean Sea are located in the Balearic Sea (Alemany, 1997; Garcia *et al.* 2002, 2003, 2005b; Alemany *et al.* 2010), around the island of Sicily, in the Tyrrhenian coastal waters (Cavallaro *et al.* 1997; Piccinetti *et al.* 1997), in the Ionian (Santamaria *et al.* 1996, 2000; Somarakis *et al*. 2011a) and Levantine (Oray & Karakulak, 2005; Kahraman & Alicli, 2007) Seas and in the Aegean Sea (Somarakis *et al.* 2002; Isari *et al.* 2008).

The Gulf of Gabes is considered to be a nursery area for many fish species (Hattour *et al.* 1995). Its immense continental shelf and its strong tides (with an amplitude that reaches and often crosses, 2 metres) are the main characteristics of this region. The existence of salinity minima in the region, between 37.3 and 37.5, is attributed to the inflow of surface Atlantic water (AW), which was first described by Brandhost (1977) and subsequently confirmed by Béranger *et al.* (2004).

North of the Italian island of Lampedusa, the surface current of Atlantic water splits into two branches: the first one goes to the southeast, while the second turns southward and contributes to the circulation of water masses in the Gulf of Gabes (Manzella *et al*. 1988). The physical forcing resulting from the AW advection could confront distinct water masses and generate potential mixing of water from coastal and/or open-ocean origin (Bel Hassen *et al.* 2009). This physical factor and other environmental variables, such as temperature, bottom depth and prey availability are also involved in ichthyoplankton distribution (Alemany *et al*. 2006; Auth & Brodeur, 2006; Muhling *et al.* 2008)

Among the tuna species occurring in the Mediterranean Sea, *T. thynnus, A. rochei, E. alletteratus* and accidentally *K. pelamis* have been recorded in Tunisian waters (Hattour, 2000). The most valued species is undoubtedly the bluefin tuna, which is considered as one of the most valuable fish species in the world (Hattour, 2000). In this region, tunas have been mainly exploited by purse seiners, although many other kinds of fishing gears are also used, such as surface longline, light fishing, gill nets and pelagic trawl. Tuna traps, which once constituted the major gear for catching tuna, have been abandoned since 2003 (Hattour, 2007). The total landed catch of tuna in Tunisian waters in 2008 was 5638 tons (Hattour, 2009; ICCAT, 2012), with Atlantic bluefin tuna accounting for the highest proportion (46.5% of the total catch).

Tuna spawning has been reported to occur in the southern coasts of Sicily off the Sicilian channel (Tsuji *et al.* 1995), so it seems likely that the spawning of tuna species occurs along the nearby Tunisian coast as well. This hypothesis, though unconfirmed so far, is supported by the remnants of tuna traps dating back to historical times, set during the spawning season, and also by the analysis of gonadal development of individuals captured in the area (Hattour, 2000). On the basis of gonadal development analysis, Hattour (2000) defined the bluefin spawning season off Tunisian waters as lasting from late June to early July, overlapping the spawning period of bullet tuna and Atlantic black skipjack that lasts from June to August and from late June to September, respectively (Hattour, 2000).

As regards the scope of this preface, it aims at providing an overview of our principal objective, was to determine the spatial distribution of tuna species larvae and their relationship with environmental factors off Tunisian coasts, in the Gulf of Gabes. Such studies are of utmost importance for the management of commercially exploited species, since they set the bases for the development of fishery independent methods for estimating the spawning stock biomass (Scott & Turner, 2001), suggest elaborate models to estimate recruitment success (Hester, 1997), and identify the probable locations of spawning areas (Mariani *et al.* 2010).

Material and Methods

A multidisciplinary tuna larval survey was carried out during the period from June 25 to July 3, 2009 in the Gulf of Gabes, covering waters from Ras Kapudia to the Tunisian-Libyan border during the bluefin tuna spawning season. A total of 80 stations, distributed over a regular grid of 10 nautical miles, were sampled (Fig. 1).

Temperature, salinity and oxygen content were measured at every station by means of a CTD Seabird 911*plus* towed vertically at 1 m s^{-1}. In addition, water samples were taken from the surface for the determination of chlorophyll *a*. For the latter purpose, half a litre of seawater was filtered through Whatman GF / C filter and kept frozen at -20° C until analysis. In the laboratory, 12 ml of acetone (90%) was added on each filter prepared, which was later sonicated and centrifuged. After centrifuging, optical density was measured before and after acidification by means of a spectrophotometer. Chlorophyll *a* concentration was measured by applying the method of Lorenzen (1967).

Zooplankton samples were taken by means of oblique tows with a 60 cm Bongo net fitted with 335µm and 505µm mesh netting. 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.

A flowmeter was fitted to each net's mouth to estimate the volume of water filtered. The zooplankton samples were initially preserved in 4% sea water formaldehyde solution buffered with borax. In the laboratory, the fish larvae were sorted and identified under a dissecting microscope, then preserved in ethanol. Tuna larvae were identified according to the taxonomic descriptions by Yabe *et al.* (1966); Dicenta (1975) and Alemany (1997). Larval abundance was standardized and expressed as numbers relative to 10 m^2 of sea surface. The zooplankton dry weight was obtained following Lovergove (1966) methodology and standardized to mg/m^3.

To establish the resemblance among the prospected stations, a Hierarchical Ascendant Classification (HAC)

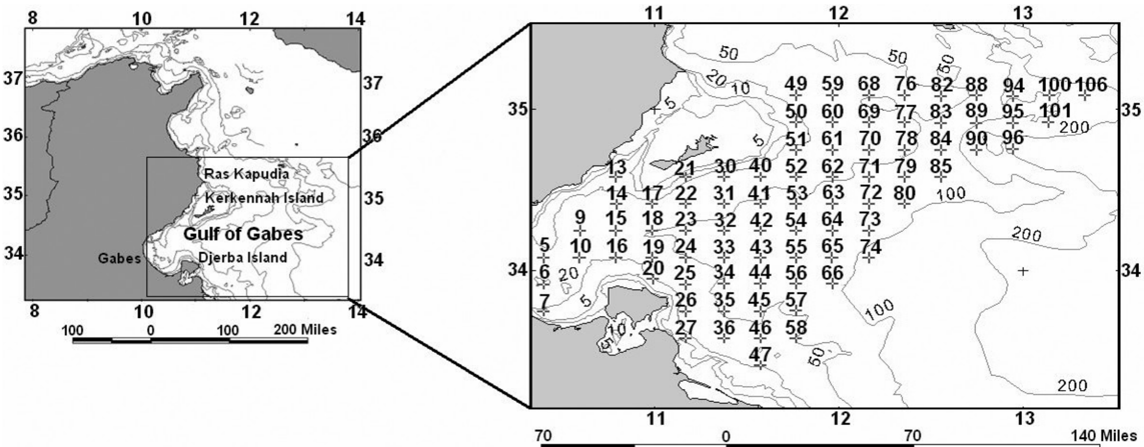

Fig. 1: Map of the study area focusing on the larval sampling stations in the Gulf of Gabes.

(Lebart et *al.* 1982) was used on the basis of Euclidian distance. This classification was carried out with the environmental parameters (temperature, salinity, oxygen content, chlorophyll *a*, and depth) as the factor rank.

Student t-test was applied to explore statistical significance of the environmental differences between negative stations – those where we had not caught tuna larvae – and positive stations where we had, in fact, captured tuna larvae, named Group I and Group II respectively. These analyses, as well correlation between parameters, were performed using the STATISTICA Software.

Results

Environmental parameters

Horizontal variation

Sea surface temperature (SST) throughout the studied area ranged from 24.1 to 26.7° C, with an average of 24.8 ± 0.54° C (SD). The highest temperature was recorded near the islands of Kerkennah and Djerba. SST displayed a tendency to decrease from coastal waters, located less than 20 miles from the shoreline, to offshore waters situated beyond 60 miles of the coast, as shown by the difference between the mean surface temperature of coastal (25.3° C) and offshore (24.7° C) waters (Fig. 2a).

Sea surface salinity (SSS) showed a similar distribution to that of the SST, thus demonstrating a significant positive spatial correlation with temperature ($r = 0.63$; $p < 0.001$) (Table 1). In fact, the coastal stations were dominated by saltier Mediterranean waters (>38), while lower salinity waters ranging between 37 and 37.4 values of recent Atlantic origin (Astraldi *et al.* 2002; Ben Ismail, 2007; Bel Hassen *et al.* 2008), predominated in the open sea. The horizontal variation detected over the study area was low, with differences between maximum and minimum values of 1.9, with the surface salinity averaging 37.6 ± 0.33 (SD) (Fig. 2b).

The spatial surface concentration of dissolved oxygen ranged from 6.5 to 6.9 mg l^{-1} with mean value of 6.7 ± 0.066 mg l^{-1} (SD) (Fig. 2c). The horizontal distribution of this parameter showed an increasing gradient from coast to the offshore area, in contrast to surface temperature and salinity. These negative spatial correlations between oxygen and temperature on one hand, and between oxygen and salinity on the other were statistically significant; $r_1 = -0.44$; $p < 0.001$ and $r_2 = -0.49$; $p < 0.001$, respectively (Table 1).

The spatial distribution of zooplankton biomass, measured as dry weight, showed a decreasing gradient from the coast to offshore waters (Fig. 2d), ranging from 0.25 to 50.8 mg m^{-3}(mean = 16 ± 15.5 mg m-3 (SD)). Surface chlorophyll *a* concentration ranged from 1.1 to 3.9 mg m^{-3} (mean = 2.2 ± 0.61 mg m-3 (SD)). The highest concentrations were recorded in neritic stations very close to the coast and around the islands of Djerba and Kerkennah, whereas the least productive areas were mainly located in the open sea (Fig. 2e). This preference association to shallow waters, was confirmed by significant negative spatial correlation between these two factors and depth, (Table 1),

$r_{\text{zooplankton/depth}} = -0.55$; $p<0.001$ and $r_{\text{ch } a\text{/depth}} = -0.42$; $p<0.001$

HAC analysis showed 3 main groups of stations, named A, B and C (Fig. 3). Group A was the dominant one, with 38 stations distributed over a wide area (Fig. 4). Stations belonging to this group were mostly coastal, with depths less than 51 m. These stations were characterized by higher temperatures and salinities, and greater zooplankton biomass on average. Group B included stations located in the middle part of the study area (Fig. 4). These stations were characterized by moderate depths, around a mean depth of 57 m, with moderate temperatures and salinities. Finally, stations of group C were located farthest from the coast (Fig. 4) with a mean depth of 108 m and lower temperature and salinity values. Stations of this group were also characterized by low chlorophyll *a* concentration and zooplankton biomass.

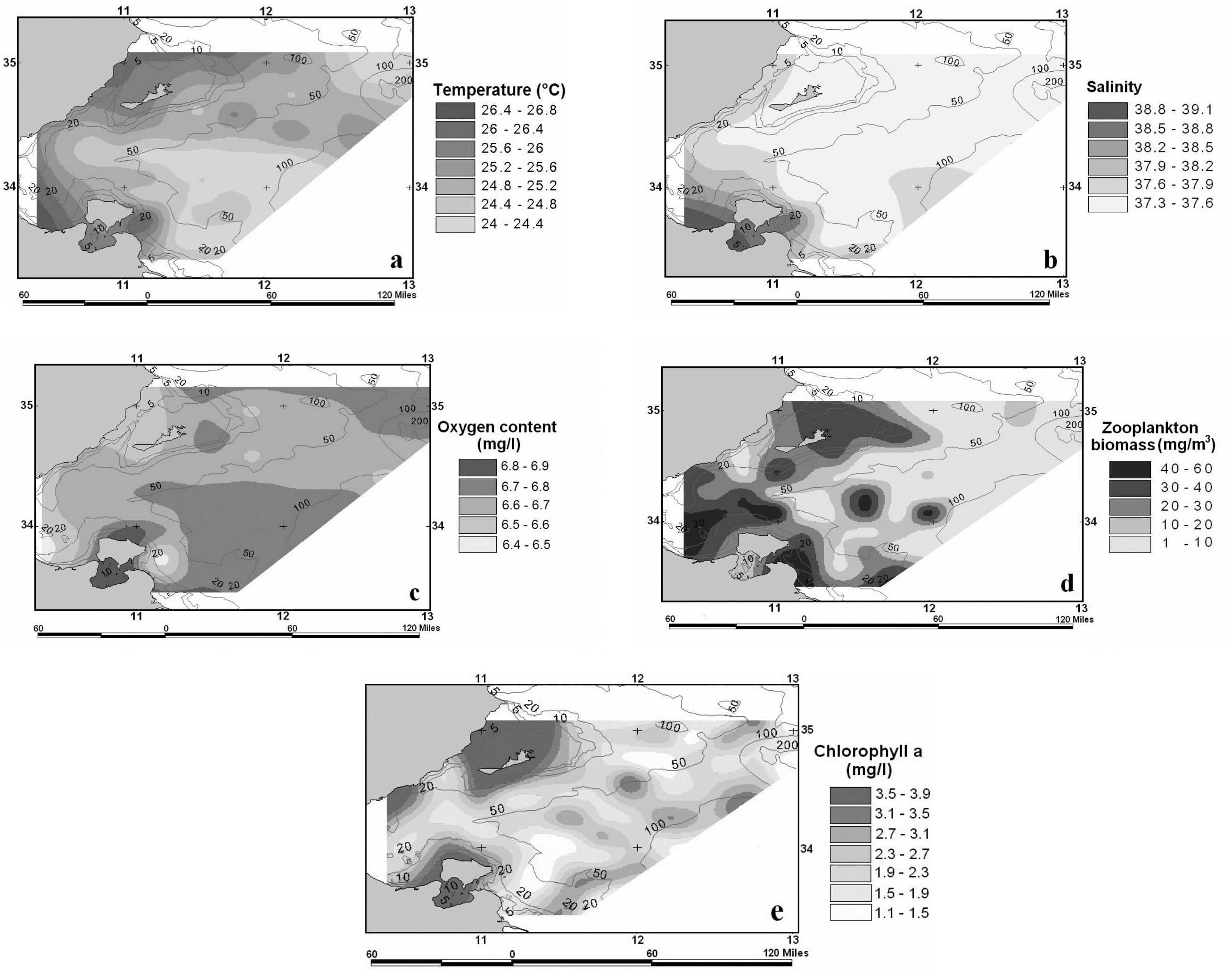

Fig. 2: Spatial distribution of environmental parameters: Temperature (a), Salinity (b), Oxygen content (c), Zooplankton biomass (d) and Chlorophyll *a* (e).

Table 1. Spearman correlation matrix for biotic and abiotic parameters (ns p>0.05, * p<0.05, ** p<0.01, *** p<0.001, number of parameters = 9, number of analyzed sample: n = 76).

	Temperature	**Salinity**	**Oxygen content**	**Ch *a***	**Zooplankton**	**Depth**	***A. rochei***	***T. thynnus***	***E. alletteratus***
Temperature	1								
Salinity	0.63 ***	1							
Oxygen content	-0.44 ***	-0.49 ***	1						
Chl *a*	0,25 *	0.3 *	-0.01 ns	1					
Zooplankton	0.21 ns	0.58 ***	-0.22 ns	0.23 ns	1				
Depth	-0.64 ***	-0.34 **	0.56 ***	-0.42 ***	-0.55 ***	1			
A. rochei	-0.47 ***	-0.08 ns	0.49 ***	-0.07 ns	-0.33 **	0.77 ***	1		
T. thynnus	-0.21 ns	-0.04 ns	0.14 ns	-0.07 ns	-0.22 ns	0.44 ***	0.5 ***	1	
E. alletteratus	-0.14 ns	-0.03 ns	0.35 **	-0.1 ns	-0.13 ns	0.37 **	0.51 ***	0.02 ns	1

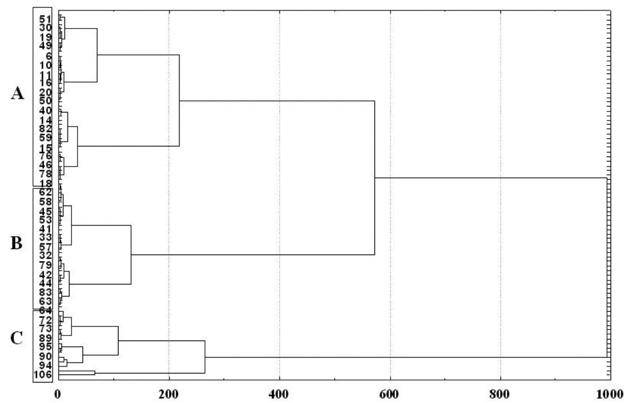

Fig. 3: Dendrogram of the Euclidean distance between the sampling stations based on the environmental factor (temperature, salinity, oxygen content, chlorophyll *a* and depth).

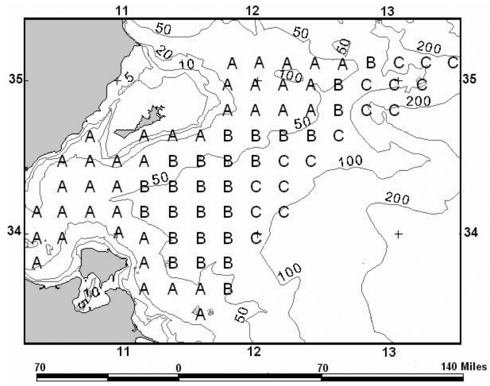

Fig. 4: Distribution of stations with classes obtained by the HAC analysis.

Vertical variation

The vertical distribution of temperature ranged from 14.3 to 26.7° C, and had a tendency to decrease vertically, from the surface to the bottom. The thermocline, characterized by a rapid decrease of temperature, starts at about 20 - 25 metres and continues until 50 metres of depth. Because of that, the lowest temperature in the coastal stations, recorded near 50 metres depth, was relatively high (17° C). In the deeper stations, the temperature continues to decrease progressively after the thermocline, reaching 14.4ºC at 200 metres (Fig. 5a).

As regards salinity, the vertical profile recorded at coastal stations shows a decreasing trend from the surface to deeper layers. In the open sea, where depths exceed 100 metres, the salinity profile was characterized by relatively low values (37.4 - 37.6) at the surface layer, and lower values (37.1 - 37.4) between 10 and 50 metres which correspond to the thermocline. Below 50 m depth the salinity starts to increase progressively until it reaches 38.8 at 216 metres (Fig. 5b).

With regard to the dissolved oxygen, the values increase from surface to bottom. At the surface layer, a progressive increase was registered down to 15 metres, and below this depth the rate of variation increases, till a depth of 50 metres. In the deeper layers (>100 metres), the distribution appears to be uniform, with values ranging between 8 to 8.1 mg l^{-1} (Fig. 5c). The vertical distribution of chlorophyll *a* measured at different depths (surface, 25 m, 50 m and 75 m) shows that the deep chlorophyll maxima (DCM) is observed at 25 metres for the coastal stations and at 50 metres for the oceanic stations (Fig. 5d). However, since tuna larvae are mainly distributed in the mixed surface layer, above the thermocline, surface values are those that can more directly influence the distribution of tuna larvae.

Larval abundance and distribution

Larvae of three tuna species *(Thunnus thynnus, Auxis rochei* and *Euthynnus alletteratus)* were found in our plankton samples. Tuna larvae were present in 36.25% of the stations. These positive stations for tuna larvae were mainly located in the intermediate part of the study area, between the islands of Kerkennah and Djerba and in offshore stations off Kerkennah.

The most abundant species among tuna larvae was bullet tuna, with a total of 341 larvae in all samples, which represented 84.4% of total tuna larvae found in our samples. They were present in 35% of the sampled stations. Atlantic bluefin tuna and Atlantic black skipjack larvae appeared in 7.5% and 16.25% of the stations, respectively.

Bullet tuna larval densities varied between 1 to 101 larvae 10 m^{-2}, with averaged density in the positive stations of 21 ± 24 larvae 10 m^{-2} (SD). This species showed a more widespread distribution over the survey area, being present in the intermediate and offshore stations over the continental shelf and near the shelf break. The highest concentrations were recorded at the offshore stations of Kerkennah Island.

Bluefin tuna larvae were mostly captured in the most distant stations from the coast up to the meridian 12.5° E, at depths > 100 m, whereas Atlantic black skipjack larvae were only collected in the intermediate stations located in the southern part of Kerkennah Island. The mean densities of bluefin tuna and Atlantic black skipjack larvae, in the positive stations, were 5 and 7 larvae 10 m^{-2} respectively much lower than the average density of bullet tuna.

Tuna larvae were absent in those coastal stations, and near Kerkennah Island, that are characterized by depths less than 50 metres. The distribution of *T. thynnus, A. rochei* and *E. alletteratus* larvae is shown in Figure 6.

The standard length (SL) of bluefin tuna larvae varied between 3.9 and 8.6 mm, with a mean of 5.8 ± 1.04 mm (SD); the majority of which were between 4.6 and 6.5 mm representing 78.6% of the larvae. A noticeable absence of small larvae (<3.5 mm) was recorded in bluefin tuna samples.

Size distribution of bullet tuna larvae ranged between

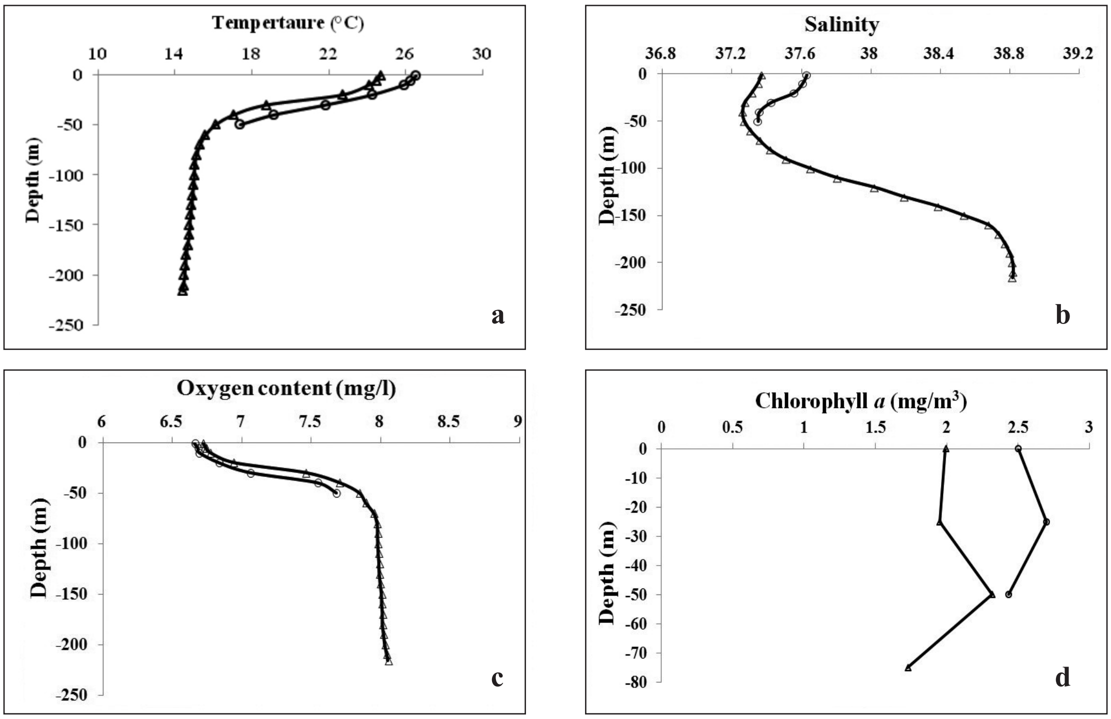

Fig. 5: Vertical profiles of different environmental parameters [Temperature (a), Salinity (b), Oxygen content (c) and Chlorophyll a (d)] for coastal (—⊖—) and oceanic (—△—) stations.

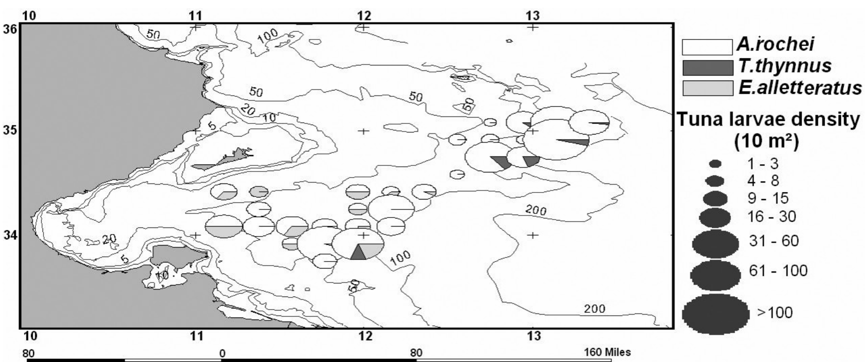

Fig. 6: Spatial distribution and density of tuna larvae.

2 and 6.96 mm, for a mean of 3.7 ± 1.05 mm (SD). Larvae ranging between 2.6 and 4.5 mm represented 69.7% of bullet tuna samples. On the other hand, the percentage of small size Atlantic black skipjack larvae (2 - 3.6 mm) was high (74.4%), which explains the low average size, 3.1 ± 1.1 mm (SD) calculated for this species (Fig. 7).

Larval distribution and environmental parameters

More than 96% of positive stations for tuna larvae belonged to the B and C groups which, as mentioned before, were characterized by higher depths and lower temperature and salinity in comparison to the coastal stations belonging to group A.

Tuna larvae appeared at sea surface temperatures ranging between 24.1 and 25.45° C. The overall mean temperatures of occurrence were similar for the three tuna species. The mean values of Sea Surface Salinity (SSS) were also almost identical for all species: 37.46 for bullet tuna, 37.47 for Atlantic bluefin tuna and slightly higher 37.49 for Atlantic black skipjack.

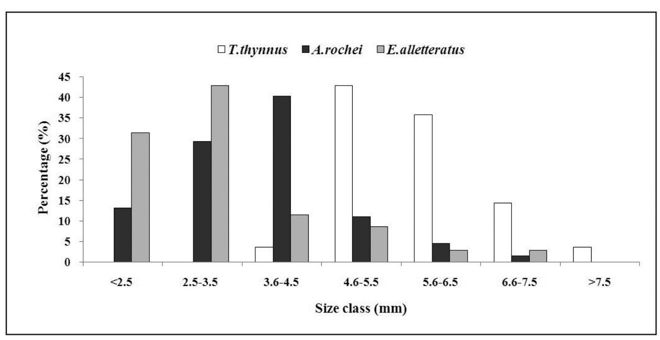

Fig. 7: Histogram showing the different size class of tuna species with their approximate ages.

Table 2. Results of t-test for environmental parameters by group. GI: group the stations where we have not caught tuna larvae, and G II: group the positive stations where we captured tuna larvae, df: degree of freedom, p: probability with ns ($p>0.05$), * ($p<0.05$), ** ($p<0.001$).

Parameters	Mean I	Mean II	t-value	df	p
Temperature (° C)	25	24.5	4.35	78	ns
Salinity	37.6	37.45	2.4	78	ns
Oxygen content (mg l^{-1})	6.66	6.7	-3.2	78	ns
Zooplankton biomass (mg m^{-3})	20.5	8.5	3.6	78	*
Chlorophyll *a* (mg m^{-3})	2.2	2.1	0.83	78	ns
Depth (m)	36.6	85.5	-8.25	78	**

Considering the dissolved oxygen concentration, the higher tuna larvae densities were found in waters between 6.7 and 6.8 mg l^{-1}. Zooplankton biomass in positive stations for Atlantic bluefin tuna indicated that this species occurs in waters with low values, not over 6.9 mg m^{-3} in comparison to the other tuna species which occurred over a wider range of zooplankton biomass, between 0.25 and 43.7 mg m^{-3}. Chlorophyll *a* concentration in stations positive for tuna larvae ranged between 1.4 and 3.3 mg m^{-3}. Tuna larvae, especially those of Atlantic bluefin tuna, were more frequent in waters with low chlorophyll *a* concentrations.

Finally, bullet tuna larvae were found at depths between 46 and 230 m, while the other small tunas, i.e., Atlantic black skipjack were found at over depths between 51 and 129 m, indicating a preference, on their part, for shallower waters rather than the continental shelf or near the shelf break. On the contrary, bluefin tuna larvae where found at slightly deeper stations (136 ± 53 m (SD)) than Atlantic black skipjack in waters nearer the shelf break.

Results of Student's t-test analysis of groups I and II showed significant differences only for the depth and zooplankton biomass (Table 2).

Discussion

Knowledge on the early life stages of tuna species in Tunisian waters was, up to now, very scarce. In 1994, during the bluefin spawning season, two contemporaneous surveys carried out off the southern Tyrrhenian and the Sicilian Channel demonstrated the presence of bluefin tuna and other tuna larvae in areas adjacent to Tunisian waters (Piccinetti *et al.* 1997; Tsuji *et al.* 1995). The present study is the first one reporting on tuna larvae distribution patterns in relation to environmental parameters in the Gulf of Gabes.

Bullet tuna larvae were the most abundant and showed a widespread distribution over the study areas in comparison to the larvae of other tuna species. Similar observations have been made in other studies carried out in different parts of the Mediterranean Sea (Sabatés & Recasens, 2001, Alemany *et al.* 2010).

Regarding the depth range where bullet tuna larvae were found, we observed that this species was distributed in shallower waters over the continental shelf and near the shelf break, which finding is in agreement with earlier works carried out in the Mediterranean (Sabatés & Recasens, 2001; Alemany *et al.* 2010). This fact may explain the broad distribution of bullet tuna larvae over the study area, since most of the bullet tuna positive stations were located over the Gulf of Gabes continental shelf, which is the widest part of the Mediterranean Sea (Burollet, 1979).

Atlantic black skipjack larvae were considerably less abundant than bullet tuna in our samples, as also reported in other ichthyoplankton studies in the Mediterranean Sea (Garcia *et al.* 2005b; Oray & Karakulak, 2005; Alemany *et al.* 2010; Somarakis *et al.* 2002; 2011a). The confinement of Atlantic black skipjack larvae to the stations located between Kerkennah and Djerba Island which are characterized by low depths, may indicate that the spawners of the species tend to avoid open sea waters, showing a preference for stations over the continental shelf. According to our data, the optimum depth range for the occurrence of Atlantic black skipjack larvae was even shallower than that for bullet tuna. The dominance of small larvae between 2 and 3 mm which correspond to yolk-sack preflexion larvae only a few days old, indicates that this region could constitute a potential spawning area for these two species.

Concerning Atlantic bluefin tuna, their larvae were present only at the stations far from the coasts, characterized by greater depths (> 120 m), and located over the continental slope. Previous studies provided the same results, showing that this species mainly spawns offshore (Oray & Karakulak, 2005; Alemany *et al.* 2010). According to their distribution pattern, taking into account the observed hydrodynamic scenario, and larval standard length distribution, which shows that small yolk sac larvae are absent in our samples, it seems that the spawning area of bluefin tuna may be located more towards the open sea. It can thus be concluded that spatial coverage of ichthyoplankton surveys should be expanded offshore to get a more complete view of larval distribution.

These results support the interpretation advanced by Alemany *et al.* (2010), who indicates that the association of bullet tuna larvae with the shallower waters and of Atlantic bluefin tuna with the deeper stations may be a direct consequence of adult distribution, since bullet tuna is a small tuna that inhabits inshore waters whereas Atlantic bluefin tuna is a large tuna whose spawning migration in the Mediterranean Sea is influenced by the path of entering surface Atlantic waters, which flows mainly offshore of the shelf break (Millot, 1987), hence bluefin tuna larvae are located preferentially at stations over the slope or in deeper areas.

It is worth noting the absence of tuna larvae at productive stations very close to the coast and in the vicinity of Karkennah and Djerba Islands. This study, as well as those undertaken in the Gulf of Mexico (Teo *et al.* 2007b), shows that Atlantic bluefin tuna tend to avoid the productive coastal waters for spawning. It has been hypothesized that larval survival of this species, as in other scombriforms, would be favoured by the scarcity of predators and competitors in open seawaters (Bakun & Broad, 2003; Alemany *et al.* 2010).

Regarding temperature, Alemany *et al.* (2010) indicated that bullet tuna initiates spawning earlier in the season, when the mean temperature at the surface mixed layer reaches 19.5° C, whereas Atlantic bluefin tuna spawning starts at 20.5° C, peaking around 23ºC. Another study in the Levantine Sea has shown that this species spawns from late May to early June, at sea surface temperatures (SST) ranging between 21.1 and 24.9° C, about a month earlier than in the western Mediterranean (Oray & Karakulak, 2005). These authors suggest that the earlier spawning of Atlantic bluefin tuna in the Levantine Sea is due to differences in the timing of summer heating of surface waters between the Levantine Sea and the western Mediterranean. Such observations confirm the key role of temperature, which acts as a trigger for the spawning process of tuna species.

In the present work, tuna larvae were collected within the temperature ranges cited in the literature. Atlantic bluefin tuna larvae appeared within SST varying from 24.28 to 24.69° C, whereas bullet tuna and Atlantic black skipjack were found in waters between 24.1 and 25.44° C, coinciding with those reported by previous studies. For instance, Garcia *et al.* (2005 a, b) reported that in the Balearic Sea, Atlantic bluefin tuna spawning takes place preferentially in the mixing zones between Atlantic and Mediterranean waters, from late June to July, in sea surface temperatures ranging between 23.5 and 25° C. Moreover, in the Catalan Sea, Sabatés & Recasens (2001) captured a high number of bullet tuna larvae when the sea surface temperature ranged between 23.7 and 25.4° C. In the northeast Aegean Sea, Somarakis *et al.* (2011b) concluded that bullet tuna larvae were more abundant during the warm season.

Dicenta & Piccinetti (1978) reported that in the western Mediterranean, *T. thynnus* and *A. rochei* larvae were found when SST ranged from 20.88 to 26.32° C and between 19.11 and 26.32° C respectively.

The differences in the temperature ranges where tuna larvae have been captured may indicate that tuna larvae – predominantly bullet tuna larvae – exhibit a relatively high tolerance for temperature variations. The broad tolerance of *A. rochei* larvae to temperature variations could explain their long spawning season.

Surface salinity values indicate that the three tuna species spawn preferentially in the areas influenced by the current of Atlantic waters that flow into the study area. Alemany *et al.* (2010) observed an association of bluefin tuna larvae with salinity levels corresponding to mixed surface waters and an avoidance of the highest and lowest salinities values which correspond to the Mediterranean and Atlantic waters, whereas bullet tuna larvae were frequently found in typical surface resident Mediterranean waters.

Based on salinities values, *T. thynnus*, *A. rochei* and *E. alletteratus* larvae were found in both Mediterranean and Atlantic waters (Oray *et al.* 2005). However, it must be taken into account that bluefin spawners inhabiting the eastern Mediterranean probably constitute a non-migrating population that stay in this area the year round (De Metrio *et al.* 2004), and hence their reproductive strategies would not be so directly associated with the dynamics of inflowing surface Atlantic waters.

Summing up, this study represents a first contribution to the understanding of tuna larval ecology in the central Mediterranean; but further investigations are necessary to define the spawning grounds of tunas in this area, besides enabling a better understanding of the influence of environmental parameters on spawning strategies and larval survival and, therefore, of the factors controlling tuna recruitment success.

Conclusion

As for many other areas of the Mediterranean Sea, the Gulf of Gabes constitutes a potential spawning area for several tuna species. Its wide continental shelf seems to offer a suitable spawning habitat for small tuna species. Bullet tuna and Atlantic black skipjack larvae were more abundant in shallower waters, over the continental shelf and close to the shelf break, whereas larvae of Atlantic bluefin tuna showed a preference for offshore waters. Larvae of all tuna species seemed to avoid the neritic areas of the study area, characterized by shallow depths and high primary productivity.

In conclusion, this study underlines the critical importance of information regarding environmental parameters to support larval ecology research and demonstrates potential suitable spawning conditions for a number of tuna species in the Gulf of Gabes.

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