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Summer distribution of fish larvae in northern Aegean Sea

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Larval fish and hydrographic data were collected in Kavala Gulf (northern Aegean Sea) across a fine scale grid of 17 stations in two surveys, carried out in the beginning of July 2002 and 2003. Despite the different taxonomic resolution and excluding the unidentified larvae, 22 taxa were caught in 2002 and 27 in 2003. Seventeen taxa were present in both years' collections. A total of 833 larvae were collected during the two samplings. The adults of several larvae caught, although sometimes at very low concentrations, are species with high commercial value or represent a major proportion of the captured production of the northern Aegean Sea. The larvae of European anchovy (Engraulis encrasicolus) *were most abundant in both years followed by the brown comber (*Serranus hepatus*), the gobies* (Gobius *sp.*) *and, only for 2003, round sardinella* (Sardinella aurita). *Maximum anchovy larval densities reached 4145/10 m² and 13852/10 m² in the 2002 and 2003 surveys, respectively. The spatial extent of anchovy larvae was also high as they were collected at 12 stations in 2002 and at 15 in 2003. Besides water circulation, the spatial distribution of fish larvae was largely influenced by temperature, salinity and dissolved oxygen.*

Keywords: summer, larval distribution, fish, northern Aegean Sea

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INTRODUCTION

Early life stages of fish that constitute the most important period of fish growth are directly influenced by biotic and abiotic parameters (Claramunt & Wahl, 2000). Fish larval stages are particularly sensitive and suffer high mortalities resulting from starvation (Bailey & Houde, 1989), predation (Bailey & Houde, 1989; Cowan *et al*., 1996), and competition (Cowan *et al*., 2000). Additionally, the survival and growth of early life stages depend on certain oceanographical conditions (e.g. currents, frontal structures and water upwelling), which may cause the advection of eggs and larvae towards or away from suitable nursery areas (Iles & Sinclair, 1982; Agostini & Bakun, 2002; Bakun, 2006). The survival of early life stages of fish has direct relevance to their recruitment and to adult biomass (Blaxter, 1974), and hence to the regulation of local populations and the potential fishery yield of an area. Thus, information on fish larval stages is important for understanding the recruitment processes and for designing fisheries management. Indeed, ecosystem-based management plans, such as marine protected areas that incorporate temporal and spatial fishing restrictions (e.g. Tsikliras & Stergiou, 2007a), are based on fish species composition and abundance data, including the effect of small-scale oceanographical processes on the survival of early life stages (Gell & Roberts, 2003).

Knowledge of the larval distributions and associations and the oceanographical features and biotic components involved is particularly useful in understanding the factors influencing the distribution of adults. Early summer surveys are particularly important in the Mediterranean Sea because most fish spawn in spring and summer months (Tsikliras *et al*., 2005) including the most commercially exploited species of the continental shelf and slope of Greek waters. Indeed, the small- and medium-sized pelagic fish (anchovy, sardines and small scombroids) constitute the majority of marine landings in the northern Aegean Sea, while several other commercially important demersal species are also landed (Tsikliras & Stergiou, 2007b).

The majority of ichthyoplankton studies in the Mediterranean Sea have been undertaken in the coastal waters of the north-western and central parts of the Sea (Sabatés, 1990; Palomera & Sabatés, 1990; Garcia & Palomera, 1996; Palomera & Olivar, 1996; Sabatés & Olivar, 1996; Olivar & Sabatés, 1997; Cuttitta *et al*., 2003; Sabatés, 2004). In the eastern part of the Mediterranean Sea, large-scale ichthyoplankton surveys are concentrated in the central Aegean (Caragitsou *et al*., 2001) and eastern Ionian waters (Sorra *et al*., 2000), whilst the summer distribution and abundance of larval fish in the northern Aegean Sea have been surveyed by Somarakis *et al*. (2002). Recently, Koutrakis *et al*. (2004) studied the seasonal larval distribution and abundance in two gulfs of the northern Aegean Sea, that are closely situated to the one studied in the present study but exhibit different hydrographical characteristics (Sylaios *et al*., 2006).

The objectives for this work were to assess the summer ichthyoplankton abundance, distribution and community structure of Kavala Gulf; examine their interannual variations between 2002 and 2003; relate these factors to water

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circulation, temperature, salinity and dissolved oxygen; and compare species composition and diversity of the Gulf with other Mediterranean areas.

MATERIALS AND METHODS

Study area

The Kavala Gulf (24°25′00″E 40°52′50″N) is located on the continental shelf of the northern Aegean Sea (Figure 1) and is a shallow gulf (maximum depth: 50 m, mean depth: 34 m) covering an area of 264 km^2. Kavala Gulf is connected to the Aegean Sea through its main mouth in the south, which is wide (20 km) and deep, and through the smaller (7.3 km wide), shallower mouth, the Strait of Thassos, in the east (Figure 1). The topographical variations inside the Gulf are minimal because of the flat seabed. The primary bathymetric feature of the area is a trough about 56 m deep, at its southern part, which creates a steep slope and a narrow transition between the 50 and 100 m depth contours (Figure 1). Hydrology of the gulf is influenced by the, seasonally oscillating in terms of occurrence, intensity and direction, fresher and cooler Black Sea water (Sylaios *et al.*, 2005a). Black Sea water forms a surface current flowing to the northern coastline of Greece (Poulos *et al.*, 1997). Kavala Gulf is among the most important, in terms of landed biomass, fishing grounds of Greek waters (Greek fishing subarea 14: Stergiou *et al.*, 1997).

Sampling procedure

Larval fish and hydrographical data (depth, temperature and salinity) were collected in Kavala Gulf across a fine scale grid of 17 stations (Figure 1) in two surveys, carried out on 2 and 3 July 2002 and 2003. A paired bongo net sampler was used for the collection of planktonic larvae. This sampler design has two 60 cm diameter frames (0.28 m^2 mouth area each) fitted with 250 μm mesh conical nets. The open/filtering area ratio was 9.46. The cod-end consisted of a plastic container incorporating a window of 250 μm mesh net that allowed water to escape. A flowmeter was centrally mounted at the opening of each frame to estimate the volume of water (m^3) flowing through the net. The sampler was deployed in a double oblique tow from the surface to within 1–2 m of the bottom, and returned at the surface, thus forming a 'V' shaped dive profile. Lowering (45 m/minute) and retrieval (20 m/minute) speed was kept at the same rate at all samplings, which were all carried out in daylight (between 09:00 and 18:00). Upon recovery of the sampler, the net was gently washed down from the outside with seawater. The container was removed and the plankton was washed into a jar and fixed at a final concentration of 4% formaldehyde solution buffered with seawater. Fish larvae were removed from plankton samples (the whole sample was used), identified to the lowest possible taxonomic level, i.e. for some groups, individuals were not identified at the species level, and enumerated. Temperature (°C), salinity, dissolved oxygen (mg/l) and depth (m) profiles were obtained at each sampling station from CTD sensors (Ocean 301, Idronaut) deployed simultaneously with the net sampler. The surface circulation pattern was generated using a three-dimensional shelf numerical model (ELCOM, Estuary, Lake and Coastal Ocean Computer Model), solving the unsteady Reynolds-averaged, hydrostatic, Boussinesq, Navier–Stokes and scalar transport equations, including external environmental forcing, such as tidal forcing, wind stresses, rotational effects and inflows and outflows (Hodges & Dallimore, 2001). The shelf model was nested on a northern Aegean Sea coarse grid ELCOM model (G. Sylaios, unpublished data).

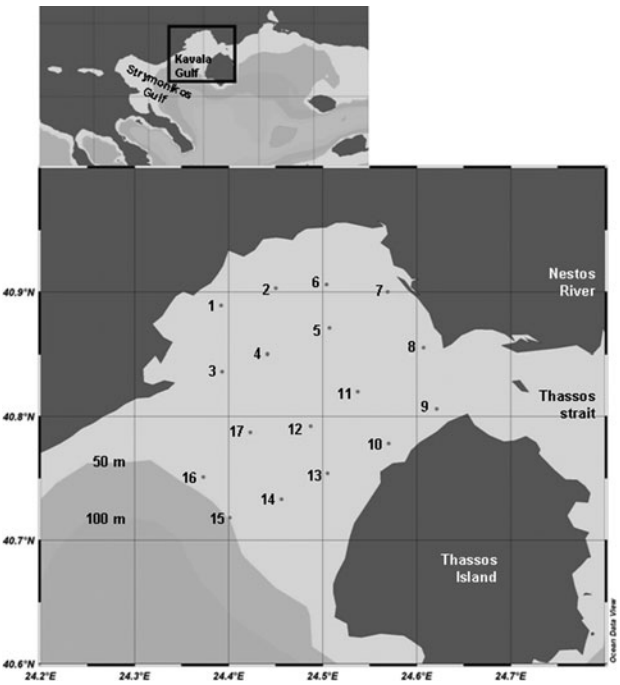

Fig. 1. Map of the study area (Kavala Gulf, northern Aegean Sea, Greece) showing the grid of 17 sampling stations. The depth contours of 50 and 100 m are also indicated.

Data analyses

Fish larval data were expressed as number of larvae/m^3 by dividing the numbers per sample by the volume of water filtered. The larvae distributions were standardized as number of larvae beneath a unit sea-surface area (10 m^2), obtained by multiplying the larvae/m^3 by 10 and by the sampling depth (in m) during deployment. The standardized numbers were used to calculate the percentage contribution of each taxon to the total catch. Larvae/10 m^2 and hydrographical data of sea-surface were plotted as contour lines using the Ocean Data View Software (Version 3.0.1-2006, http://odv.awi.de). The Shannon–Wiener (H′) and Simpson (D′) indices of diversity were used (Krebs, 1994) to assess the diversity of the larval community at each station, while the species richness was calculated as the Margalef index (d), which also incorporates the total number of individuals (Clarke & Warwick, 1994). Larval abundance data from each tow were transformed to $\log_{10}$ (number + 1) to approach to normality and homogeneity of variances and to ensure comparability with previously published literature.

The relationship between fish larval densities and environmental variables (temperature, salinity and dissolved oxygen) was investigated with canonical correspondence analysis (CCA), a multivariate method of direct gradient analysis (ter Braak, 1986). The software CANOCO (version 4.5-2002) was used. A forward selection procedure was performed to test the statistical significance of environmental variables that contributed most to the model. Taxa that were present in fewer than three stations were excluded from the analysis.

RESULTS

Hydrography

Overall, sea-surface temperature varied between 23.7 and 25.5°C in 2002 and between 24.2 and 25.4°C in 2003 (Figure 2). Lowest temperatures were recorded at inshore stations, namely at Station 3 for the 2002 survey and at Station 6 for 2003. The warmest water, over 25°C, occurred in the offshore stations located at the south-western part of the Gulf. The vertical temperature profile and the temperature gradient of the warmer surface compared to the cooler bottom water patterns, which differed by 8–9°C, indicated stratified waters in both surveys. This is consistent with the expected pattern of thermal stratification in the area after May. Thermocline ranged between 11 and 18 m in 2002 and from 6 to 17 m in 2003 (Figure 3).

The patterns of surface salinity distribution showed little variation in 2002 and a tongue of less saline water along the latitudinal axis in 2003 (Figure 2). Especially for 2003, surface salinities were higher at the deeper south-western part of the Gulf and lower towards the shore (Figure 2). Surface salinity varied between 32.9 and 34.4 in 2002 and between 30.5 and 32.9 in 2003, and along with the vertical salinity profiles (Figure 3) indicated that the water column was less saline in 2003 compared to 2002.

Dissolved oxygen ranged from 7.56 (Station 3) to 8.66 (Station 6) mg/l in 2002 with mean value (±SD) of 8.28 (±0.293). In 2003, the dissolved oxygen levels were lower (mean ± SD = 8.09 ± 0.246) ranging from 7.66 (Station 10) to 8.47 (Station 5).

In the summer, the northern Aegean water enters Kavala Gulf from the Strait of Thassos, flows westwards along the northern coast of Thassos Island, and then is incorporated into the (generally) cyclonic surface-water circulation of the Gulf (Figure 4). An anticyclonic eddy is formed outside the south-western boundary of the Gulf. A frontal structure associated with these patterns was formed at the

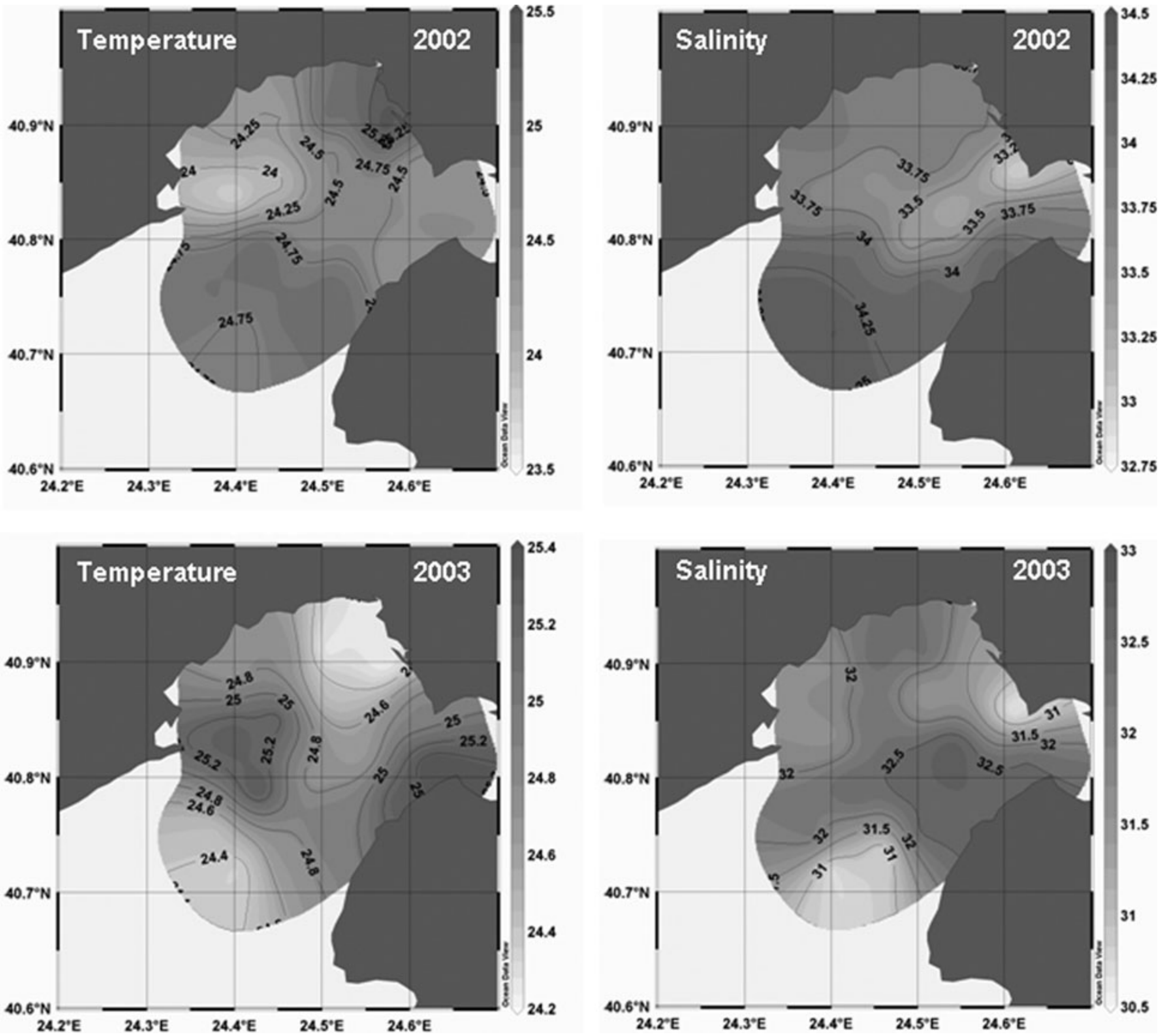

Fig. 2. Surface horizontal distribution of temperature (°C) and salinity in Kavala Gulf, northern Aegean Sea in July 2002 and 2003.

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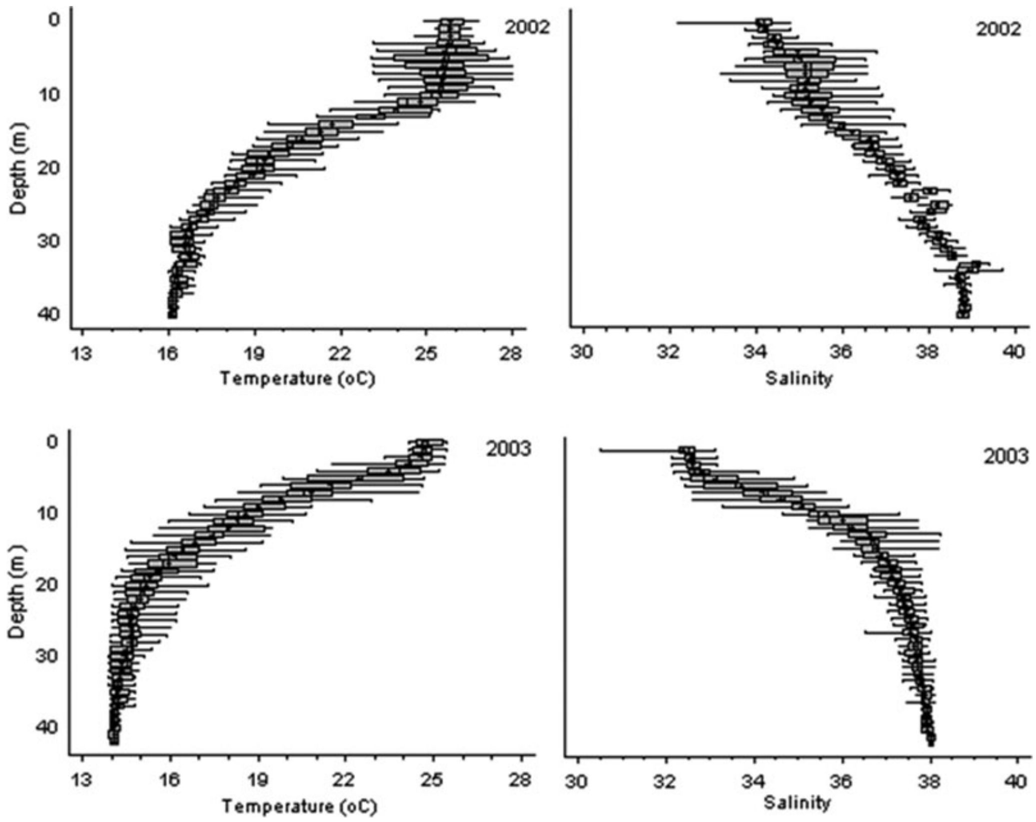

Fig. 3. Vertical profiles of temperature (°C) and salinity in Kavala Gulf, northern Aegean Sea in July 2002 and 2003 (all stations combined). The rectangular part of the plot extends from the lower to the upper quartile; the centre lines within each box show the location of the median and the cross the location of the mean.

south-western part of the Gulf, off the western coast of Thassos Island (Figure 4).

Fish larvae

Overall, fish larvae from 19 species were identified. A further eleven groups of larvae were identified to the family or genus level only (e.g. Sparidae, Soleidae, *Callionymous* sp. and *Gobius* sp.), while two groups were unidentified. Despite the taxonomic resolution and excluding the unidentified larvae, 22 taxa were caught in 2002 and 27 in 2003 (Table 1). Seventeen taxa were present in both years' collections. A total of 883 larvae were collected during the two sampling periods, of which 807 larvae were identified. All stations of both years were positive, i.e. at least one larva was captured (Table 1).

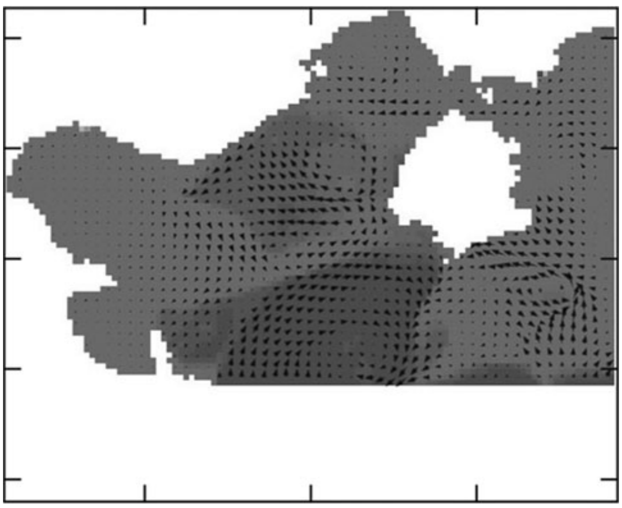

Fig. 4. Surface water circulation in Kavala Gulf and part of the northern Aegean Sea in the summer based on an ELCOM three dimensional model (for explanation see text). Line width indicates the strength of the current.

The adults of several larvae caught, though sometimes at very low concentrations, are species with high and moderate commercial value (such as the common sea-bream, *Pagrus pagrus* and the annular sea-bream, *Diplodus annularis*) or represent a major proportion of the marine fisheries catches of the area (such as European anchovy, *Engraulis encrasicolus*, the chub mackerel, *Scomber japonicus* and the Mediterranean horse mackerel, *Trachurus mediterraneus*). Four pelagic (anchovy, the chub mackerel, the Mediterranean horse mackerel and round sardinella, *Sardinella aurita*) and several demersal commercial species were caught, while the presence of the mesopelagic *Ceratoscopelus* sp. is reported for the first time in the Kavala Gulf.

Overall, the larvae of European anchovy were most abundant in both years followed by the brown comber, *Serranus hepatus*, the gobies, *Gobius* sp. and round sardinella (only for 2003). The spatial extent of anchovy larvae was also high as they were collected at 12 stations in 2002 and at 15 in 2003. Maximum anchovy larval densities reached 4145/10 m^2 and 13852/10 m^2 in the 2002 and 2003 surveys, respectively. Lower anchovy larval densities were recorded in 2002 despite the extended anchovy larval distribution. Peak numbers generally occurred close to the open waters and at

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Table 1. The average abundance (larvae/10 m^2), of the fish taxa collected in Kavala Gulf, northern Aegean Sea in the July surveys of 2002 and 2003, the number of stations in which they were present and the percentage of samples in which taxa occurred. The taxonomic authorities of the species are according to FishBase (Froese & Pauly, 2007; www.fishbase.org).

	Taxon	Average abundance (larvae/10 m^2)		Number of stations present		Percentage of samples in which species occurred	
		2002	2003	2002	2003	2002	2003
1	*Ammodytes cicerellus* (Rafinesque, 1810)	265	–	1	0	5.9	0
2	*Arnoglossus laterna* (Walbaum, 1792)	–	247	0	3	0	17.6
3	*Arnoglossus thori* Kyle, 1913	–	654	0	2	0	11.8
4	*Arnoglossus* sp.	396	223	4	8	23.5	47.1
5	*Buglossidium luteum* (Risso, 1810)	249	114	2	1	11.8	5.9
6	*Callionymus* sp.	432	268	10	11	58.8	64.7
7	*Cepola macrophthalma* (Linnaeus, 1758)	244	520	8	3	47.1	17.6
8	*Ceratoscopelus* sp.	215	798	1	4	5.9	23.5
9	*Chromis chromis* (Linnaeus, 1758)	675	265	5	4	29.4	23.5
10	*Coris julis* (Linnaeus, 1758)	364	290	4	1	23.5	5.9
11	*Crenilabrus* sp.	–	257	0	8	0	47.1
12	*Crystallogobius linearis* (Dóben, 1845)	396	194	3	3	17.6	17.6
13	*Diplodus annularis* (Linnaeus, 1758)	559	–	1	0	5.9	0
14	*Engraulis encrasicolus* (Linnaeus, 1758)	1293	3710	12	14	70.6	82.4
15	*Hygophum benoiti* (Cocco, 1838)	–	276	0	3	0	17.6
16	*Gobius* sp.	800	665	13	9	76.5	52.9
17	Labridae	455	274	4	1	23.5	5.9
18	*Lesueuerigobius friesii* (Malm, 1874)	518	–	2	0	11.8	0
19	Myctophidae	–	454	0	1	0	5.9
20	*Pagrus pagrus* (Linnaeus, 1758)	–	179	0	2	0	11.8
21	*Sardinella aurita* Valenciennes, 1847	248	2450	6	5	35.3	29.4
22	*Scomber japonicus* Houttuyn, 1780	284	554	1	2	5.9	11.8
23	*Scorpaena* sp.	–	173	0	1	0	5.9
24	*Serranus cabrilla* (Linnaeus, 1758)	215	1060	1	4	5.9	23.5
25	*Serranus hepatus* (Linnaeus, 1766)	1425	1183	9	8	52.9	47.1
26	Soleidae	–	343	0	2	0	11.8
27	Sparidae	242	675	10	6	58.8	35.3
28	Centracanthidae	235	–	3	0	17.6	0
29	*Trachinus draco* Linnaeus, 1758	230	–	2	0	11.8	0
30	*Trachurus mediterraneus* (Steindachner, 1863)	361	303	5	3	29.4	17.6
31	Unidentified 1	–	486	0	6	0	35.3
32	Unidentified 2	–	1499	0	9	0	52.9

isolated stations and declined towards the shore (Figure 5). Likewise, round sardinella larval densities were higher in the 2003 survey (Figure 5). In 2002, round sardinella larvae were scattered throughout the Gulf, while in 2003 they were concentrated offshore, near the trough. Round sardinella's larval densities reached 4617/10 m^2 in 2003. The overall density of Mediterranean horse mackerel larvae and the spread of their horizontal distribution also differed between the two surveys. Larval densities were higher (reaching 796/10 m^2) and more scattered in 2002 compared to 2003 (Figure 5).

The horizontal distributions of the most abundant demersal taxa for both surveys are shown in Figure 6. The larvae of Sparidae were recorded in low concentrations in 2002 and were distributed in the centre of the Gulf with their abundance declining from north to south (Figure 6). In 2003, the Sparidae larval densities were higher (1496/10 m^2) and larvae were primarily concentrated at the southern part of the area. The larvae of the two identified sparids (common and annular sea-breams) were found in very low concentrations off the northern coast of Thassos Island. The distribution of the brown comber larvae was similar between the two surveys (Figure 6). Their densities reached 3981 and 2777/10 m^2 in the 2002 and 2003 surveys, respectively. Finally, the larval densities of *Gobius* sp. were different, in terms of both abundance and horizontal distribution, between the two surveys. In 2002, *Gobius* sp. larvae were scattered reaching their peak densities (3352/10 m^2) off the northern coast of Thassos Island, while in 2003 survey maximum densities (2136/10 m^2) were recorded further offshore.

The number of taxa was highest in both surveys at station 13, off the Thassos coast, which together with the other offshore stations (12, 14, 15, 16 and 17) displayed the highest total number of larvae/10 m^2. In contrast, the lowest number of taxa and total larvae/10 m^2 was recorded at the shallow, inshore Stations 6 and 7. The number of taxa was also low in the mid-Gulf Stations 4, 5 and 11. The variation of species richness was identical with that of the number of taxa for both years. The diversity indices also showed a rather similar pattern with the highest values of D′ and H′ measured in Stations 1 and 13 for 2002 and in Stations 2, 13, 14 and 15 for 2003.

Temperature, salinity and dissolved oxygen influenced the spatial distribution of fish larvae in Kavala Gulf as revealed from the CCA (Figure 7). In 2002, the first CCA axis (Axis 1: eigenvalue = 17.1%) modelled 59.8% of the total explained

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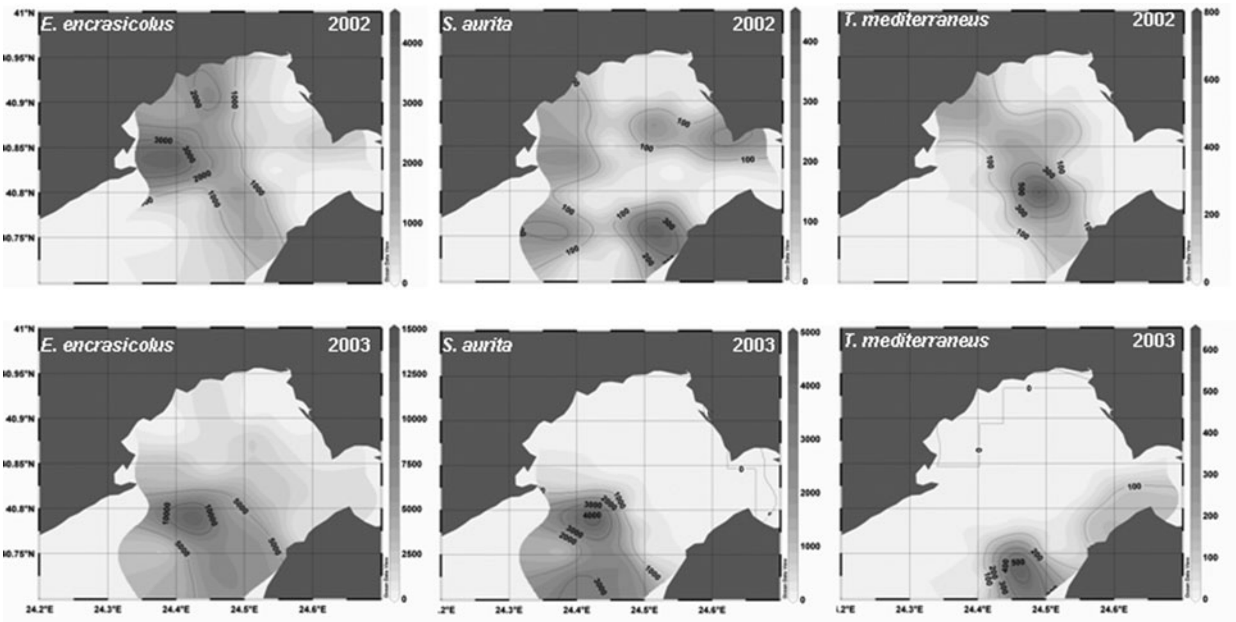

Fig. 5. Horizontal distribution map of standardized number of larvae (N/10 m^2) for three abundant pelagic species (European anchovy, *Engraulis encrasicolus*; round sardinella, *Sardinella aurita*; and Mediterranean horse mackerel *Trachurus mediterraneus*) in Kavala Gulf, northern Aegean Sea (July 2002 and 2003).

variance demonstrating a high species–environment correlation (0.863). The second axis (Axis 2: eigenvalue = 8.9%) that represented 31% of the explained variance, also demonstrated a high species–environment correlation (0.547). Axes 3 and 4 accounted for less than 10% of the total explained variance and were not interpreted further. Axis 1 was negatively correlated with temperature (r = −0.93) and salinity (r = −0.42), while axis 2 was negatively correlated with salinity (r = −0.58), and dissolved oxygen (r = −0.55). Species, such as European anchovy, associated with low temperature (r = −0.56) and low salinity (r = −0.31) had high axis 1 scores, while Mediterranean horse mackerel, associated with low dissolved oxygen levels (r = −0.23), had high axis 2 scores (Figure 7). In 2003, the first CCA axis (Axis 1: eigenvalue = 10.5%) modelled 59.8% of the total explained variance demonstrating a high species–environment correlation (0.861). The second axis (Axis 2: eigenvalue = 5.6%) that represented 31.9% of the explained variance, also demonstrated a high species–environment correlation (0.547). Axes 3 and 4 accounted for less than 9% of the total explained variance and were not interpreted further. Axis 1 was positively correlated with temperature (r = 0.63) and salinity (r = 0.99), and negatively correlated with dissolved oxygen (r = −0.77), while axis 2 was negatively correlated with temperature (r = −0.56),

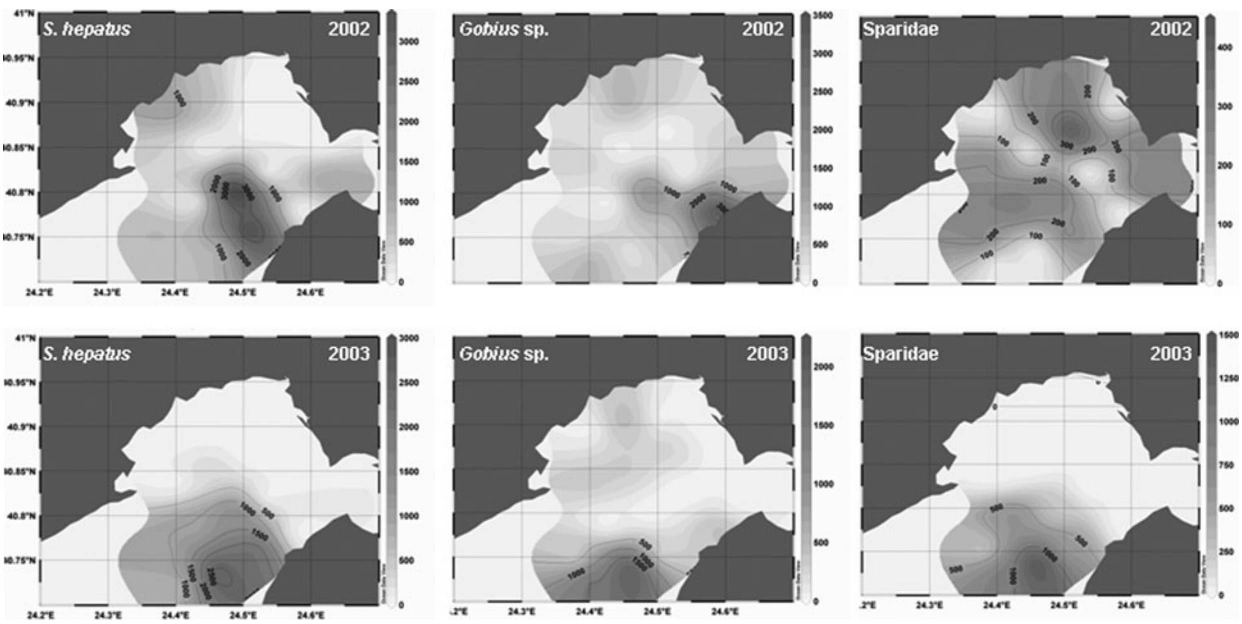

Fig. 6. Horizontal distribution map of standardized number of larvae (N/10 m^2) for three abundant demersal taxa (brown comber, *Serranus hepatus*; gobies, *Gobius* sp.; and sparids, Sparidae) in Kavala Gulf, northern Aegean Sea (July 2002 and 2003).

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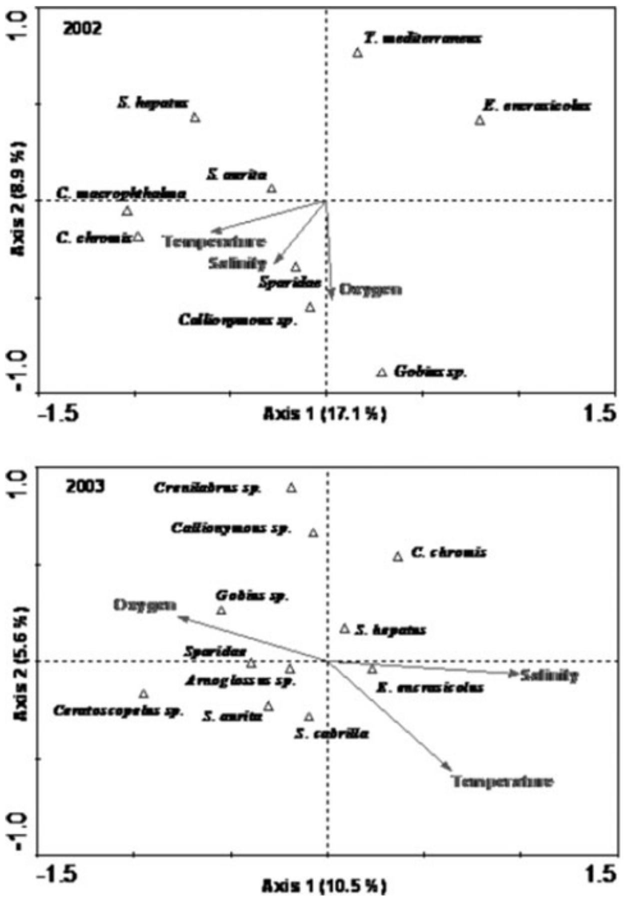

Fig. 7. Biplots of larval fish species scores in the first two canonical correspondence analysis axes for 2002 and 2003 surveys, Kavala Gulf, northern Aegean Sea.

and positively correlated with dissolved oxygen (r = 0.23). *Gobius* sp. that was associated with low temperature (r = −0.41) and low salinity (r = −0.61) had low axis 1 scores, while *Ceratoscopelus* sp., associated with low temperature (r = −0.50), low salinity (r = −0.97) and high dissolved oxygen (r = 0.69) levels, had low axis 1 scores (Figure 7).

DISCUSSION

In the shallow areas of the northern Aegean Sea, a thermocline depth ranging from 10 to 17–18 m is common in early July. Thermal stratification shows interannual variations and the surface distribution of temperature and salinity depends on precipitation, wind force and runoff. Thus, the differences in the sea-surface salinity and temperature between the two survey years are generally attributed to the cooler and rainier days just prior to the 2003 survey. These findings are supported by the data obtained from a meteorological station located nearby (at Fisheries Research Institute, Kavala).

Thirty-three out of the 77 larval taxa that have been reported for the entire northern Aegean Sea were collected during both samplings in Kavala Gulf. The relatively high number of taxa recorded is probably because Kavala Gulf is sheltered and shallow containing a variety of habitats and emphasizes its importance, not only as a fishing ground, but also as a nursery ground. It seems that the entire coastal zone of the northern Aegean Sea serves as a spawning and nursery ground since similar results are reported by other ichthyoplankton surveys conducted in the area (Koutrakis *et al.*, 2004). Despite the different hydrographical characteristics, the size of the area and the resolution of sampling, the number of taxa recorded during this study was similar to that found in the adjacent Strymonikos Gulf in the summer (Koutrakis *et al.*, 2004: 31 taxa) but considerably less than in Pagasitikos Gulf, central Greece (Caragitsou *et al.*, 2001: 90 taxa), a coastal area of the north-western Mediterranean (Sabatés, 1990: 45 taxa) and Bahia de La Paz, Gulf of California (Sanchez-Velasco *et al.*, 2004: 110 species). The taxonomic composition of the larval ichthyofauna in the summer was also similar between Kavala and Strymonikos Gulfs, with more meso- and bathypelagic fish (Myctophidae and Sternoptycidae) inhabiting the deeper Stymonikos Gulf (maximum depth of 80 m). However, these species were collected beyond the 50 m depth contour in Strymonikos (Koutrakis *et al.*, 2004), while the maximum depth of Kavala Gulf is less than 50 m.

With only few exceptions (the European sardine, *Sardina pilchardus* and some gadoids), most Mediterranean fish are spring/summer spawners (Tsikliras *et al.*, 2005). Thus, high taxonomic diversity and larval densities are observed in spring/summer surveys in estuarine and coastal waters of the Mediterranean (Sabatés, 1990; Palomera, 1992; Somarakis *et al.*, 2002). This also holds for other subtropical areas such as the Brazilian waters (Nonaka *et al.*, 2000) and the Gulf of California (Sanchez-Velasco *et al.*, 2004) probably owing to the higher availability of food resources and warmer water temperatures. The temporal coincidence of spawning with the water column stratification and the subsequent phytoplankton bloom offers the early life forms sufficient resources for growing and better chances of survival.

The horizontal distribution and the diversity of larvae among the stations indicate that the main spawning area for most species is located at the southern part of the Gulf. Spawning is often associated with special oceanographical structures (e.g. Page *et al.*, 1999) and the general water circulation widely determines the subsequent larval distribution (e.g. Cuttitta *et al.*, 2003). The formation of an anti-cyclonic eddy outside the southern boundary of Kavala Gulf and the associated front, are common in summer months and have been previously observed (figure 7 in Kourafalou & Tsiaras, 2007). In Kavala Gulf, the highest larval densities and the highest taxa richness were recorded at the stations located close to the front at the southern part of the gulf (Figure 4) and above the trough. Frontal systems (whether temporal or permanent) may result in increased local productivity (Mann & Lazier, 1996) and have been reported to attract spawning adults and to concentrate high numbers of larvae (Le Fevre, 1986). The mechanisms leading to variability in spatial abundance of ichthyoplankton include the water mass circulation (Cuttitta *et al.*, 2003), the different growth rates and mobility among species, and predation pressure (Parsons *et al.*, 1996).

The explanatory power of CCA may be low at small scale processes because of the high spatial variability of larval fish (Garrison *et al.*, 2002). There were, however, some distinct distribution–environment patterns. A common pattern in the two surveys was the general association of the larvae of most demersal taxa (Sparidae, *Callionymous* sp. and *Gobius* sp.)

with high dissolved oxygen values, and the preference of brown comber and of *Chromis chromis* for high temperature, high salinity waters. In contrast, the spatial distribution of the abundant pelagic taxa (anchovy, round sardinella and Mediterranean horse mackerel) seems to have been influenced by the different hydrological conditions between the two surveys. The preference of anchovy for cooler and less saline waters (Allain *et al.*, 2007) was depicted by the CCA in 2002 (Figure 7) but was missed in 2003 when the waters were cooler and less saline compared to 2002.

The time of sampling coincided with the onset of the spawning activity of several commercially important pelagic fish in the Mediterranean Sea, such as the chub mackerel (Bottari *et al.*, 2002) and the Mediterranean horse mackerel (Nannini *et al.*, 1997), as well as the peak of spawning for anchovy and round sardinella. Although the main spawning area for anchovy in the northern Aegean Sea is further offshore and is concentrated at the eastern coast of Thassos Island (Somarakis *et al.*, 2002; Sylaios *et al.*, 2005b), the spread of spawning into shallower waters seems to occur in early summer. The time of anchovy spawning in the northern Aegean Sea extends from April to October and the spawning adults are often concentrated in areas of high productivity such as estuaries (Koutrakis *et al.*, 2004) and frontal systems (Palomera, 1992; Sylaios *et al.*, 2005b). Practically, our results showed that the entire coastal zone is occupied by high concentrations of anchovy larvae, a pattern also observed in Strymonikos Gulf in early summer (Koutrakis *et al.*, 2004). The larval distribution of round sardinella throughout the survey generally reflected the distribution of the mature adults fished during the months just prior to species' spawning (Tsikliras, 2004a). Considering round sardinella's main spawning grounds are concentrated at the southern part of the Gulf (Tsikliras, 2004a), it seems that only a small proportion of larvae were drifted near-shore, while the majority was retained along the spawning area. The distribution of the adult spawning population and their spawning grounds are among the factors that determine the horizontal distribution of larvae (Sabatés, 1990). The interannual variations on the extent and intensity of round sardinella larval concentrations may be due to the time the species spawns (Tsikliras & Antonopoulou, 2006), which strongly depends upon the seawater temperature (Tsikliras, 2004b, 2007) and may influence the temporal occurrence and abundance of its larvae. The Mediterranean horse mackerel spawns over an elongated period (March–October) of time in the central Mediterranean Sea (Nannini *et al.*, 1997) and its larvae are commonly collected in spring/summer surveys in Greek waters (Somarakis *et al.*, 2002; Koutrakis *et al.*, 2004). The differences in the abundance of the Mediterranean horse mackerel larvae in the Kavala Gulf between the two surveys are attributed to the hydrographical conditions prevailing, which may have constrained the spawning area or altered the onset of spawning.

As far as the demersal fish are concerned, most of the 23 sparids occurring in Greek waters inhabit the northern Aegean Sea and some of them occur in high population densities inside the Kavala Gulf. Regardless of species, sparid larvae occur throughout the year in the Mediterranean (northern Aegean Sea: Koutrakis *et al.*, 2004; north-western Mediterranean: Sabatés, 1990). Several of them spawn in the winter (*Diplodus vulgaris*) or early (the bogue *Boops boops*) and late (the white seabream *D. sargus*) spring and are therefore unlikely to appear as larvae in summer surveys. Of the other species, the common sea bream, *Pagrus pagrus*, and the annular sea bream, *D. annularis*, are likely to be present as their larvae have already been collected in the same survey. Moreover, the striped seabream, *Lithognathus mormyrus*, and the common Pandora, *Pagellus erythrinus*, are known to be summer spawners (Papaconstantinou *et al.*, 1986) and abundant in the northern Aegean commercial catches. Five (*Gobius cobitis*, *G. niger*, *G. paganellus*, *G. geniporus* and *G. cruentatus*) out of the ten species of *Gobius*, inhabiting the Mediterranean Sea, occur in the northern Aegean Sea (Bauchot, 1987). The rock goby, *G. paganellus*, spawns in the winter (Azevedo & Simas, 2000), *G. cobitis* (giant goby) spawns from February to March (Grubišić, 1962), *G. geniporus* from February to April (Grubišić, 1962), and *G. cruentatus* (red mouthed goby) is an autumn/winter spawner (Grubišić, 1962; Gil *et al.*, 2002). It is therefore unlikely to feature as larvae in summer surveys. The presence of *G. niger* (black goby) seems more likely as it is common nearshore, spawns from April to August (Mazzoldi & Rasotto, 2002) and it has been recorded as larva in June and July in Strymonikos Gulf (Koutrakis *et al.*, 2004). Finally, the two combers, that are typical species of the coastal waters of the northern Aegean Sea, spawn successively with their spawning overlapping only in June. The comber, *Serranus cabrilla*, spawns between April and June (Bouain, 1981) and the brown comber between June and August (Wague, 1997). These species often occur as by-catch in commercial fishery but have no commercial value.

The presence of the deep trough at the southern part of the Kavala Gulf and the cyclonic circulation of the northern Aegean water masses (Poulos *et al.*, 1997) permits several species that occur typically in the deeper waters to enter and/or reproduce in Kavala Gulf (e.g. the redband fish, *Cepola macrophalma*) or facilitates the transport of the mesopelagic fish larvae (e.g. *Hygophun benoiti* and other Myctophidae species). The occurrence of meso- and bathypelagic species in coastal waters, which as adults inhabit the deeper water layers outside the continental shelf, has been reported in other areas of the Aegean (Koutrakis *et al.*, 2004), of the Mediterranean Sea (Regner, 1981; Palomera & Olivar, 1996; Sabatés & Olivar, 1996) and of the Brazilian coast (e.g. Nonaka *et al.*, 2000).

In conclusion, it seems that Kavala Gulf is an important spawning/nursery ground for several summer-spawning species, some of which are of high commercial interest. The surface water circulation of the Gulf was cyclonic and a frontal structure was observed at the south-western part of the Gulf. The warmest water occurred in the offshore stations located at the south-western part of the Gulf and the water column was less saline in 2003 compared to 2002. The spatial distribution of the Kavala Gulf spawners is largely determined by the environmental conditions and the water circulation patterns. Similarly, the density and spatial distribution of larval fish is influenced by environmental variables such as temperature, salinity and dissolved oxygen, with most larvae being aggregated in areas with higher food availability, i.e. in areas where the potential for survival is increased.

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