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ETSOURI Mohamed
National Center for Research and Development of Fisheries and Aquaculture (CNRDPA),
etsouri.mohamed@gmail.com

KHAMES Ghollame Ellah Yacine
University Yahia Fares of Medea (UYFM)

SERIDJI Rabea
University of Science and Technology Houari Boumediene (USTHB)

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RESEARCH ARTICLE

Abundance and Distribution of Fish Larvae in the Central Coast of the Algerian Sea

Etsouri Mohamed [a,*], Khames G.E. Yacine [b], Seridji Rabea [a]

[a] University of Sciences and Technology Houari Boumediene, Ecology and Environment, Algeria
[b] University of Medea Yahia Fares, Sciences, Medea, Algeria

Abstract

This study was conducted on a seasonal basis in five (5) stations along the central Algerian coast between April 2013 and April 2014 aboard professional fishing boats. Horizontal plankton tows with a WP2-type net were used to collect ichthyoplankton samples. At each station, temperature, salinity, and chlorophyll-a levels were measured. We identified the larvae of 18 species from 11 different families by sorting ichthyoplankton (Clupeidae, Engraulidae, Gobidae, Gonostomatidae, Mugilidae, Myctophidae, Scombridae, Sparidae, Carangidae, Labridae, Blennidae). Redundancy analysis (RDA) was used to determine the relationship between the abundance of harvested larvae and environmental variables. The results show a clear dominance of small pelagic larvae in the samples, particularly sardine larvae, horse mackerel, sardinella, and anchovy. For harvesting larvae, the main factors for seasonal changes were sea surface temperature and chlorophyll-a. To our knowledge, this is the first study to identify the ichthyoplankton species found in the central Algerian zone.

Keywords: Ichthyoplankton, Seasonal changes, Environmental variables

1. Introduction

Fish live in an unstable environment and are not subjected to constant environmental conditions. Variations between years occur due to the population's response to short-term environmental changes. Ecological factors interact during the embryonic and larval stages to influence the size and composition of the future exploitable stock. To manage fishery resources rationally, it is necessary to understand the entire life cycle of the fish (egg, larva, juvenile, and adult). For most fish species in Algerian waters, the last two stages (juvenile and adult) are more studied, particularly small pelagic. Studies on the embryonic and larval stages, on the other hand, are rare, limited in time and space, and remain descriptive (species inventories). Marinaro [38] conducted a morphological and ecological study of teleost fish eggs in Algiers Bay; Etsouri [25] updated [38] description and updated an inventory of teleost fish eggs from the same area.

Many studies on ichthyoplankton have been conducted in the Mediterranean Sea. Cuttita et al. [18] investigated the composition and distribution of mesopelagic fish larvae in the Strait of Sicily and their relationship with oceanographic events. Basilone et al. [9] investigated anchovy (*Engraulis encrasicolus* - Linnaeus, 1758) spawning site selection concerning oceanographic conditions in the same zone. Zarrad et al. [61] determined a spawning habitat in the Gulf of Gabès for two small pelagic species (*Engraulis encrasicolus* and *Sardinella aurita* - Valenciennes, 1847). Mavruk et al. [64] reported on the diversity and abundance of ichthyoplankton during the winter and spring seasons along the northwestern Levant coast of the eastern Mediterranean Sea. Uygun and Hoşsucu [58] investigated the abundance and distribution of Sardine (*Sardina pilchardus* - Walbaum, 1792) larvae in the Central Aegean Sea as their relationship with environmental factors. Ciannelli et al. [65] were the first to describe summer ichthyoplankton assemblages in the Tyrrhenian Sea.

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* Corresponding author.
E-mail address: etsouri.mohamed@gmail.com (E. Mohamed).

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However, additional ichthyoplankton studies throughout the year are necessary to update our understanding of teleost fish larvae's spatial and temporal distribution. This work is part of a multidisciplinary study on ichthyoplankton that covered the central Algerian region from Mount Chenoua in the West (2° 24′ East and 36° 38′ North) to Zemmouri Bay in the East (3° 43′ East and 36° 52′ North). Thus, a year-long study of the seasonal distribution of the larvae of the major small pelagic species is critical. Over four seasons, this research examines larvae composition, abundance, and spatial and temporal distributions in response to environmental parameters in the central Algerian zone. It is worth noting that this is Algeria's first study to determine the composition of ichthyoplankton.

2. Material and methods

2.1. Study areas and periods

The study samples were collected from the central Algerian region between Cape Dellys in the East (36° 55′ North, 3° 54′ East) and Mount Chenoua in the west (36° 38′ North, 2° 22' East) (Fig. 1). Tipaza, Algiers, and Boumerdes are its three coastal wilayas; from West to East, it has three bays (Bay of Bou Ismail, Bay of Algiers, and Bay of Zemmouri). Seasonal samples were collected from commercial fishing boats between April 2013 and April 2014. Seasonal sampling lasted two days in each sampling area. In addition, five ichthyoplankton tows were performed per season. The prospecting was done entirely at night. We used specific WTW-type probes to measure the temperature and salinity at each station. Following extraction with 90% acetone, the chlorophyll concentration was determined using a fluorimeter [30]. Ichthyoplankton was sampled for 15 minutes using horizontal tows and a Working Party II (WP2) net with a mesh size of 335 μm and a mouth opening of 0.255 m^2 [57].

A WP2 net was used for horizontally towed sampling at depths ranging from 0 to 5 m. Additional weights attached to the ring and collector of the net allowed for horizontal sampling of ichthyoplankton at a maximum speed of 2 knots. A Hydrobios-type flowmeter was placed at the net's opening to estimate the volume of filtered water. 4% formaldehyde was used to fix the samples. Fish larvae were identified to the lowest taxonomic level possible in the laboratory. The methods described by Refs. [5,19−23]; and [44] were used to identify fish larvae. We used the Smith and Richardson [48] equation to calculate the horizontal distribution of larvae, which is as follows:

$$C = 10\left(a^{-1} b^{-1} c\, d\right) \quad (1)$$

where, C is the number of larvae below 10 square meters of marine surface area, a is the net's opening in square meters, b is the towing path length in meters, c is the number of larvae in the sample and d the tow's maximum depth in meters. b is derived from the flowmeter calibration as follows:

$$b = f\, r \quad (2)$$

where, f is the calibration factor in meters per revolution, and r is the number of revolutions of the flowmeter during the tow.

2.2. Data analysis

The spatial and temporal distribution and abundance of ichthyoplankton were mapped using non-parametric multivariate methods. Using the Bray-Curtis similarity coefficient, data on the abundance of fish larvae were used to generate a similarity matrix. Non-parametric multidimensional scaling (nMDS) was used to display a two-dimensional ordination graphic with assemblage differences [17]. The data was analyzed using two criteria: season and stations. The seasons of spring (April 2013 and May 2014), summer (July 2013), autumn (October 2013), and winter (February 2014) were designated as the season factor. According to Clarke et al. [17]; a stress value of less than 0.1 indicates good ordination with no chance of misinterpretation.

Borcard et al. [12] used multivariate methods to determine how the population of fish larvae has changed over time in relation to environmental variables. To determine whether linear restricted ordination techniques, such as redundancy analysis (RDA), could be used, an initial detrended correspondence analysis (DCA) was performed. Ter Braak and Smilauer [51] were appropriate (R version 4.0.0 was used for this statistical study). According to Kuhn et al. [35]; linear approaches should be used because the data set is homogeneous and the length gradient is less than 3 units of standard deviation. Data on chlorophyll-a, salinity, and water temperature were used as explanatory variables in an alternative statistical model to investigate variations in fish larvae abundance.

3. Results

3.1. Environmental conditions

3.1.1. Temperature

From spring 2013 to spring 2014, the average surface temperature was 21.8 °C, typically ranging

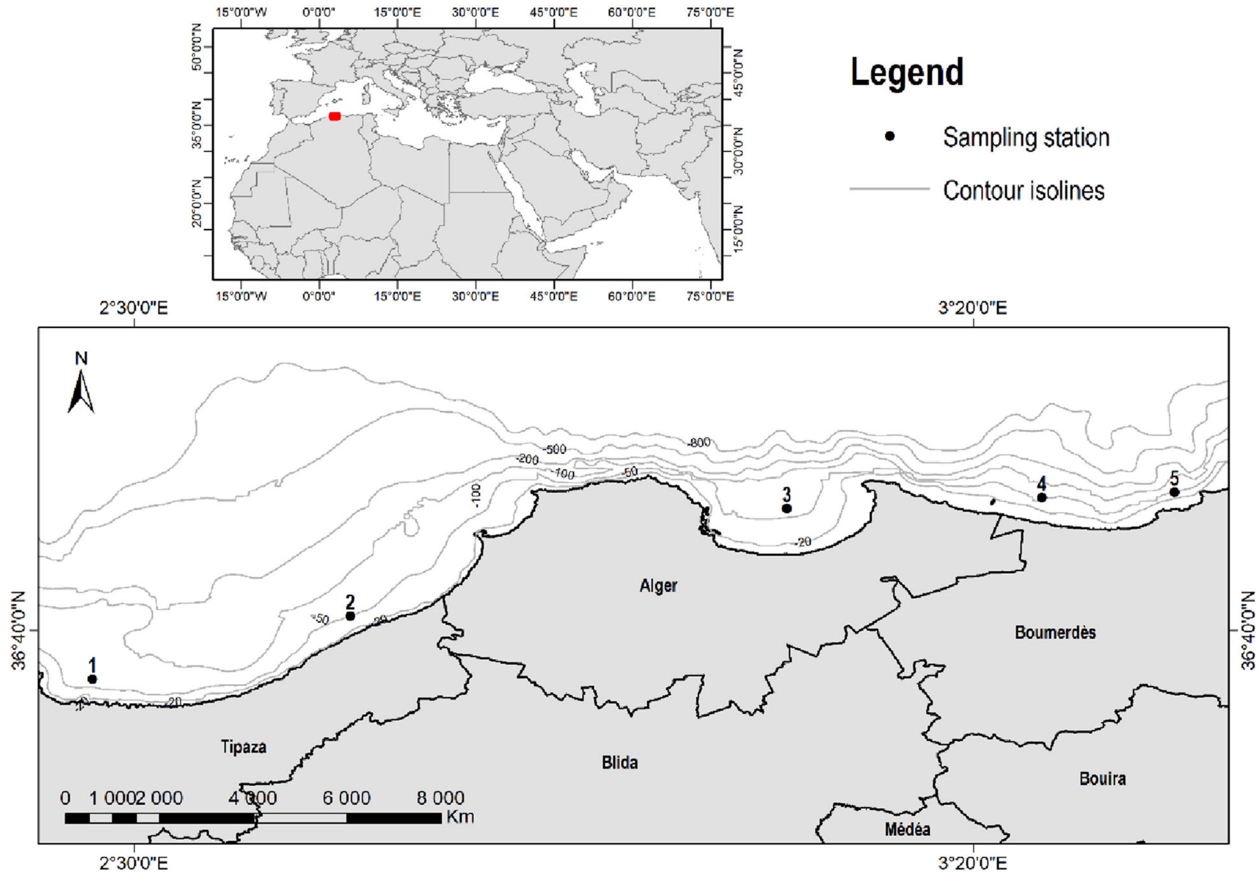

Fig. 1. Map of the study area.

between 17.8 and 25.4 °C. The measured values are associated across all study regions and reflect significant seasonal weather periods during the measurement period (Fig. 2). The observed surface temperature peaked in 2013 (summer and autumn), with values ranging from 24.6 °C to 25.4 °C, indicating a 0.8 °C spatial variation. The lowest temperatures were recorded in 2013, with only a 0.6 °C variation and an average of 17.9 °C. In spring 2013 and 2014, the horizontal distribution of surface temperature appeared homogeneous across all study areas, with a more significant variation in spring 2013.

3.1.2. Salinity

Fig. 3 shows that the salinity ranges from 37.7 to 36.7, with a mean of 37.1 and a standard deviation of 0.242. The salinity fluctuation in all of the study area's marine waters remains very homogeneous, except for the Fouka area to the East of Bou Ismail Bay, where we observed a maximum value of 37.7, which could be attributed to the proximity of the Fouka seawater desalination plant.

3.1.3. Chlorophyll-a

The average chlorophyll-a concentration indicates that phytoplankton biomass ranges between 0.135 and 0.372 μg/l, with a mean value of 0.243 ± 0.069 μg/l (Fig. 4). The analysis of the chlorophyll-a concentration diagram by seasons and stations reveals that the highest concentrations for all stations are observed during spring 2013 and 2014. During summer, the peak is observed at the Algiers station, with a value of 0.33 μg/l. In Zemmouri, the autumn peak is observed. However, two peaks with values close to 0.29 μg/l are observed in the Algiers and Boumerdes stations during winter. The chlorophyll-a value observed at the six stations is less than 1 μg/l.

3.1.4. Ichthyoplankton composition and abundance

Eleven taxa were found in the central Algerian zone between spring 2013 and spring 2014. Nine species were identified, one genus and two families were identified (Table 1). *Sardina pilchardus* (31.1%) and *Trachurus trachurus* (Linnaeus, 1758) (21.7%) had the most fish larvae. The abundance of ichthyoplankton was recorded at Zemmouri station at 39.1%. The abundance decreased but remained stable between 17% and 19% towards the east stations, namely Boumerdes, Algiers, and Tipaza, to arrive at 6.2% towards the station of Fouka (Table 1).

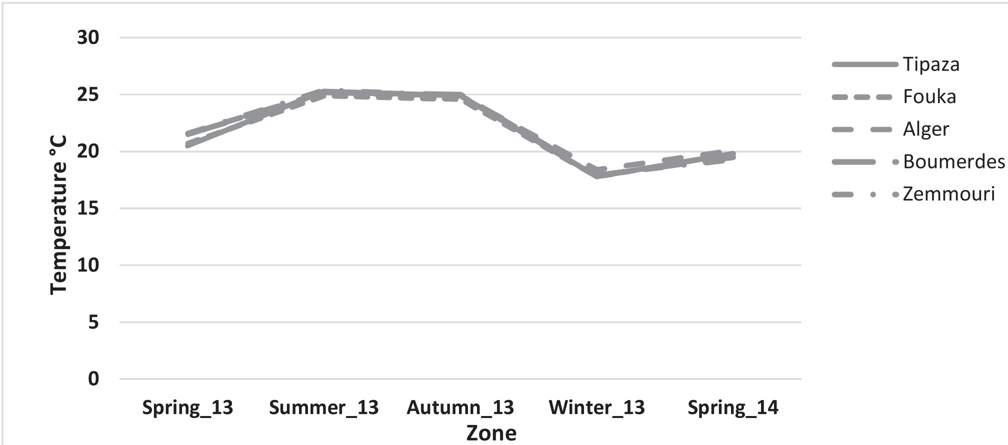

Fig. 2. Horizontal surface temperature distribution (in °C).

The highest abundances were found in the Tipaza and Zemmouri areas, where the target species abundance ranged between 2000 and 2500 larvae/10m^2. In contrast, the Algiers and Fouka areas had the lowest abundance, with approximately 1200 larvae/10m^2. Notably, *S. Pilchardus* is the most abundant species in the five study stations, followed by *T. Trachurus*. The multivariate analyses on the matrix of fish larvae abundances allow for the differentiation of season groupings independent of the prospected zones (Fig. 5). The hierarchical ascending classification highlights four station groupings with stress of 0.2 that agree with the non-metric multidimensional framing (nMDS). The nMDS ordination of the fish larvae samples revealed four major seasonal groups (Fig. 5). Each group contains five zones for a single season, except for Group 2, which contains all of the zones for two seasons, namely Spring 2013 and Spring 2014. Except for spring 2013 and 2014, the abundances of fish larvae observed show a significant difference between sampling seasons. However, there is no distinction between the zones.

3.1.5. Horizontal distribution of fish larvae

During spring (Fig. 6a), chlorophyll-a, temperature, and the larvae species *Coris julis, Pagrus pagrus, Cyclothone braueri, Ceratoscopelus maderensis, Boops boops, T. trachurus,* and *S. pilchardus* are found to be associated. Another link between salinity and Gobidae and *Benthosema glaciale* larvae can be noted; *E. encrasicolus and Myctophidae larvae* appear inversely related to temperature. During summer (Fig. 6b), a correlation exists between chlorophyll-a and temperature on the one hand and a group of species represented by *Sardinella aurita, S. pilchardus,* and *B. glaciale* on the other. Some species, such as *T. trachurus* and *C. braueri*, show other relationships between chlorophyll-a and salinity. On the other hand, the species of the Gobidae grouping, *C.*

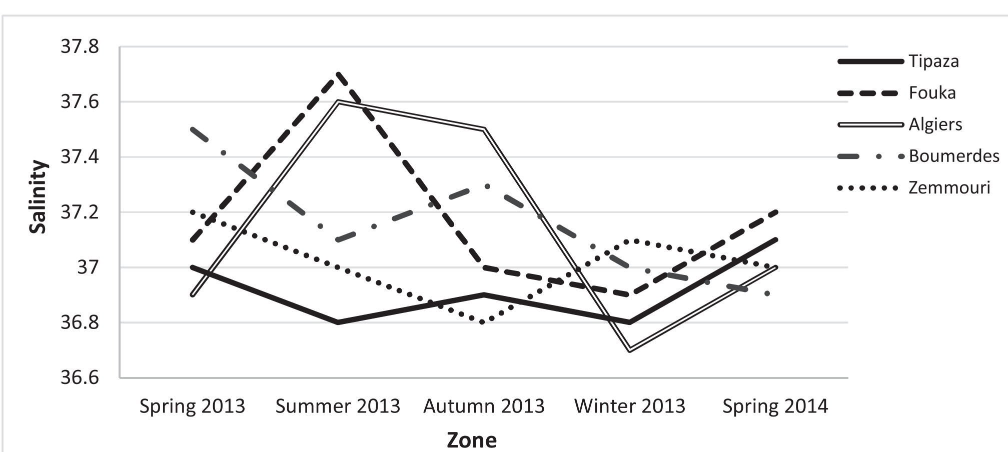

Fig. 3. Horizontal distribution of surface salinity.

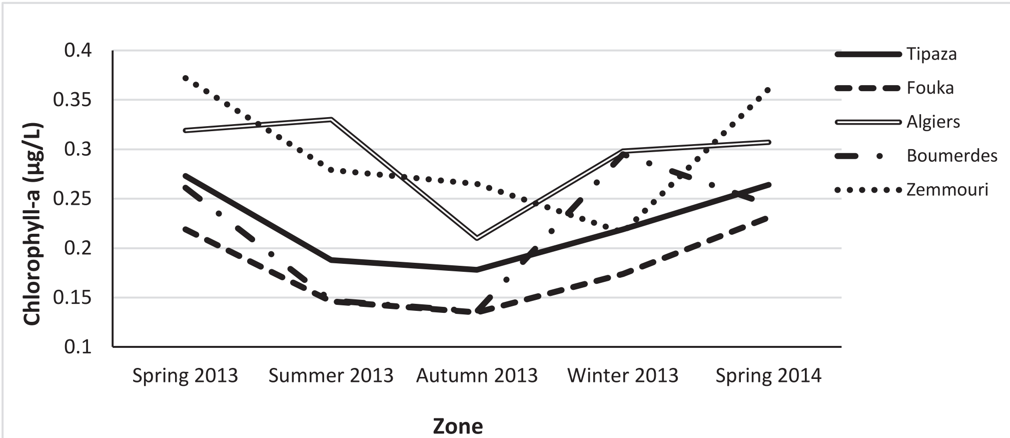

Fig. 4. Horizontal distribution of surface chlorophyll-a (µg/l).

maderensis and *Parablennius pilicornis*, are inversely correlated with Chlorophyll-a.

The variation of environmental parameters affects species distribution in autumn (Fig. 6c). Indeed, chlorophyll-a is associated with the distribution of *S. pilchardus*, *E. encrasicolus*, and *C. maderensis*. There is a temperature correlation between the species *S. aurita* and *P. pagrus*. The species groups *Pagellus bogaraveo*, *Mugil cephalus*, *Lampanyctus pusillus*, and *T. trachurus* are inversely related to temperature and chlorophyll-a. During winter (Fig. 6d), redundancy analysis reveals a significant relationship between *S. pilchardus* larvae and chlorophyll-a, on the one hand, and *L. pusillus* larvae and salinity, on the other. *P. bogaraveo* and *T. trachurus* larvae are inversely related to Chlorophyll-a, while *M. cephalus* and *Scomber colias* larvae are inversely related to temperature. *Pagellus bogaraveo* and *Trachurus trachurus* larvae are inversely related to Chlorophyll-a, while *Mugil cephalus* and *Scomber colias* larvae are inversely related to temperature.

4. Discussion and conclusion

Pelagic fish larvae are the most abundant in larval samples collected in the central Algerian zone throughout the four seasons. The importance of pelagic fish stocks in this zone can explain this

Table 1. Species composition, percentage and abundance Ai (No. of larvae per 10 m^2 of the fish larvae on the Tipaza, Fouka, Algiers, Boumerdes and Zemmouri zone) during 2013–2014.

Family	Larvae	Tipaza		Fouka		Algiers		Boumerdes		Zemmouri		Total
	Species	Ai	%	Ai	%	Ai	%	Ai	%	Ai	%	
Clupeidae	*Sardina pilchardus* (Walbaum, 1792)	493.90	5.9	126.16	1.5	629.45	7.5	326.77	3.9	1023.86	12.3	**31.1**
	Sardinella aurita (Valenciennes, 1847)	194.23	2.3	45.79	0.5	172.15	2.1	133.26	1.6	187.68	2.2	**8.8**
Engraulidae	*Engraulis encrasicolus* (Linnaeus, 1758)	131.58	1.6	57.88	0.7	11.53	0.1	61.45	0.7	156.80	1.9	**5**
Gobidae	Gobidae	23.38	0.3	1.64	0	0.00	0	8.21	0.1	9.93	0.1	**0.5**
Gonostomatidae	*Cyclothone braueri* (Jespersen & Tåning, 1926)	48.59	0.6	8.21	0.1	47.95	0.6	27.77	0.3	56.51	0.7	**2.3**
Mugilidae	*Mugil cephalus* (Linnaeus, 1758)	17.97	0.2	20.01	0.2	7.00	0.1	1.34	0	0.72	0	**0.6**
Myctophidae	*Lampanyctus pusillus* (Johnson, 1890)	16.47	0.2	8.66	0.1	6.02	0.1	27.33	0.3	43.10	0.5	**1.2**
	Ceratoscopelus maderensis (Lowe, 1839)	15.84	0.2	5.04	0.1	23.68	0.3	33.22	0.4	83.85	1	**1.9**
	Benthosema glaciale (Reinhardt, 1837)	42.15	0.5	21.94	0.3	91.26	1.1	120.34	1.4	213.08	2.6	**5.9**
	Myctophidae	26.44	0.3	11.35	0.1	8.35	0.1	46.63	0.6	53.73	0.6	**1.8**
Scombridae	*Scomber colias* (Gmelin, 1789)	46.19	0.6	34.86	0.4	18.93	0.2	58.81	0.7	65.56	0.8	**2.7**
Sparidae	*Pagellus bogaraveo* (Brünnich, 1768)	55.43	0.7	52.70	0.6	56.81	0.7	55.02	0.7	171.02	2	**4.7**
	Boops boops (Linnaeus, 1758)	91.43	1.1	17.49	0.2	106.90	1.3	180.32	2.2	387.52	4.6	**9.4**
	Pagrus pagrus (Linnaeus, 1758)	4.59	0.1	1.73	0	14.96	0.2	25.26	0.3	59.43	0.7	**1.3**
	Pagellus Sp	1.50	0	0.00	0	0.00	0	0.00	0	0.00	0	**0**
Carangidae	*Trachurus trachurus* (Linnaeus, 1758)	370.82	4.4	105.19	1.3	349.66	4.2	290.42	3.5	698.22	8.4	**21.7**
Labridae	*Coris julis* (Linnaeus, 1758)	3.91	0	0.00	0	12.26	0.1	15.34	0.2	50.50	0.6	**1**
Blennidae	*Parablennius pilicornis* (Cuvier, 1829)	5,26	0,1	1,64	0	0,00	0	7,38	0,1	0,70	0	**0,2**
	Total	**2494,**	**0,19**	**1165,06**	**0,062**	**1000,07**	**0,187**	**1574,06**	**0,17**	**2114,3**	**0,391**	**1**

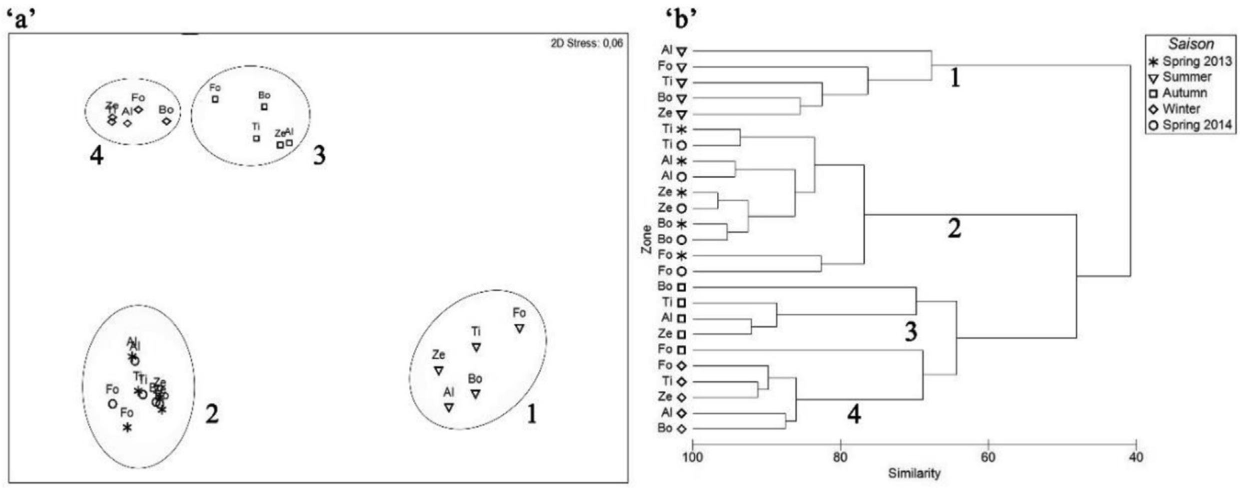

Fig. 5. (a) Non-metric Multidimensional Scaling (nMDS) of sampling stations, (b) projection on an Ascending Hierarchical Classification.

finding. Indeed, pelagic fish landings in the study area are extremely high. Small pelagic species such as sardines, sardinella, horse mackerel, and anchovies account for nearly half of the total fishing landings in the Mediterranean, according to Ref. [39]. In Algeria, studies on bioeconomic models of small pelagic fisheries in the central region by Zeghdoudi and Maouel [37,62] revealed significant biomass of small pelagic landed in the same area. During the study period, the abundance of larvae of

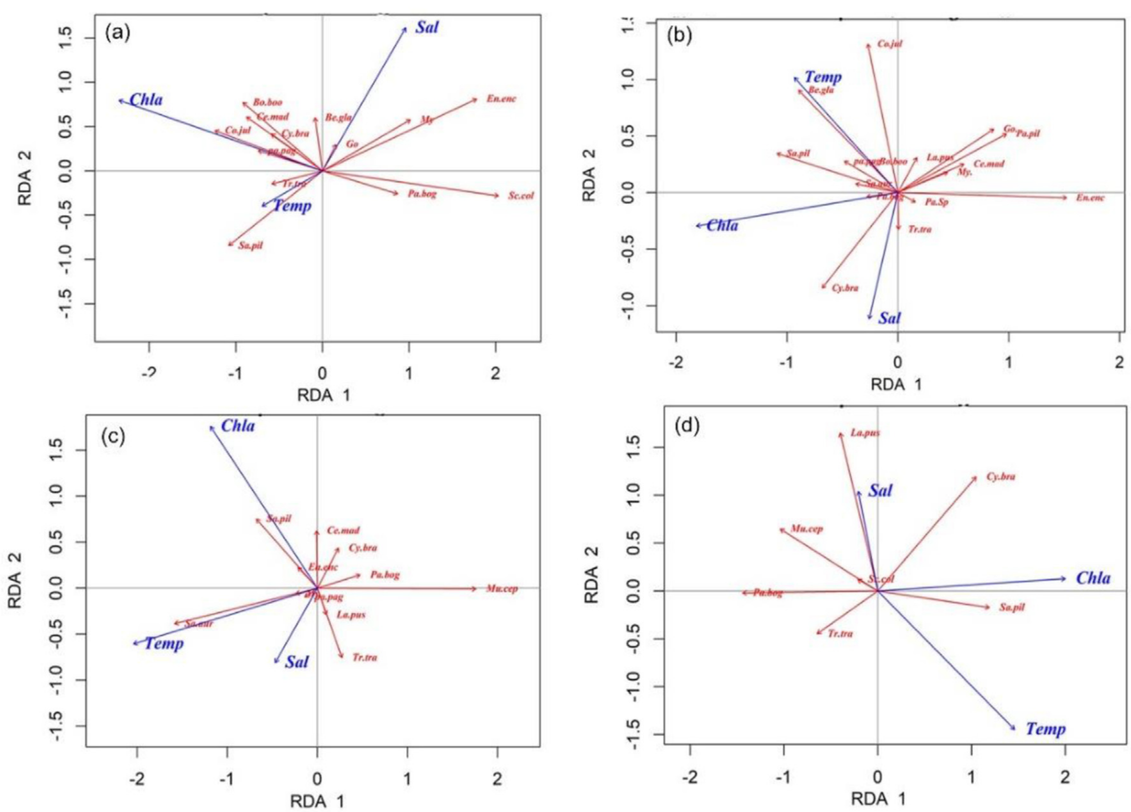

Fig. 6. RDA of the Hellinger-transformed fish abundance data constrained by all environmental variables, (a) Spring 2013–2014, (b) Summer 2013, (c) Autumn 2013 and (d) Winter 2013. Arrows in red represent fish larvae taxa, while arrows in blue represent measured environmental variables. Be.gla: Benthosema glaciale, Bo.boo = Boops boops, Ce.mad = Ceratoscopelus maderensis, Co.jul = Coris julis, Cy.bra = Cyclothone braueri, En.enc = Engraulis encrasicolus, Go = Gobidae, La.pus = Lampanyctus pusillus, Mu.cep = Mugil cephalus, My = Myctophidae, Pa.bog = Pagellus bogaraveo, Pa.Sp = Pagellus Sp, pa.pag = Pagrus pagrus, Pa.pil = Parablennius pilicornis, Sa.pil = Sardina pilchardus, Sa.aur = Sardinella aurita, Sc.col = Scomber colias, Tr.tra = Trachurus trachurus. Temp = Temperature, Sal = Salinity, Chla = Chlorophyll-a.

five small pelagic species, namely S*. pilchardus, T. trachurus, S. aurita, B. boops,* and *E. encrasicolus*, was observed, which can be explained by the sampling period intersecting with the spawning period of these main species. Several studies carried out in the Mediterranean on the reproduction periods of some fish have reported that reproduction can occur over a short or long period depending on the area and year [14,24,55].

The larvae of *S. pilchardus* were most abundant in winter 2013, autumn 2013, and spring (2013 and 2014). This abundance (2013 and 2014) is explained by the subsequent egg-laying in 2013 (winter, autumn, and spring). Mouhoub and Tomasini et al. [41,52] indicated a sardine spawning period in Algeria from autumn to winter in their studies on sardine stocks. In contrast, Garcia-Garcia, Abad and Giraldez [1,26]; and Khemiri [33] observed a first spawning period from January to April and a second spawning period from September to winter the following year in Spain (Sea of Alboran and Malaga) and Tunisia (Golf of Tunis). According to Bouhali et al. [15], the spawning period of sardine stocks in Algeria's northeastern region (Annaba) occurs between October and March, with spawning observed in January.

The species *T. trachurus* had the most larvae abundance in winter 2013 and spring 2014. Korichi [34] discovered a reproduction period in horse mackerel stocks in the central region that lasts from spring to the end of summer. According to Karlou-Riga [32]; the spawning season for this species in Greece begins in January and usually lasts until late summer in September. Zeghloul [63] reported a shorter spawning period from February to April. Sardinella *S. aurita* larvae were most abundant in summer 2013, with around a hundred larvae also recorded in 2013 (autumn). The winter and spring samples contained no larvae. This species breeds on the Algerian coasts during summer, which begins in June and ends in September, according to Talet et al. [11], Tsikliras and Antonopoulou [54]; and Bouaziz [13]. The studies carried out by Refs. Pawson and Giama, and Wassef et al. [43,60] in some Mediterranean countries, such as Egypt and Libya, revealed a longer period that begins in spring and ends at the end of summer.

B. boops larvae were only discovered in spring samples taken in 2013 and 2014. In the Bou Ismail region, Chali-Chabane [16] discovered a very short spring egg-laying period that begins in April and ends in June. Bensahla Talet et al. [10] described a longer breeding season that begins in early spring and lasts until the end of summer. Anato and Ktari, and Khemiri [4,33] determined that the spawning season for this species in Tunisia is from winter to early summer. Alegria-Hernandez [3] showed that the bug's breeding season begins in spring and lasts until summer in the Adriatic on the northern shore of the Mediterranean. The European anchovy larvae *E. encrasicolus* were mostly found in spring and summer 2013 samples. According to Refs. [8,29,40]; and [33]; the breeding season of this species begins in the spring and lasts until the end of the summer.

This study's findings show that temperature significantly impacts the horizontal distribution of sardine larvae. Temperature does play an important role in regulating the development speed of eggs, larvae, and juveniles, as well as their survival rate and growth. Similarly, chlorophyll-a concentration, an indirect measure of primary production, directly affects food availability for larvae, including *T. trachurus*. The seasonal distribution of larvae concerning environmental parameters reveals a relationship. In the spring, winter, and autumn, *S. pilchardus* larvae may prefer chlorophyll-a and warmer temperatures. In the spring, *T. trachurus* larvae are more closely related to chlorophyll-a and the milder spring and summer temperatures. In the summer and autumn, *S. aurita* is strongly associated with chlorophyll-a. *B. boop*s larvae bound strongly to chlorophyll-a and were only found in spring samples from 2013 to 2014. The distribution of anchovy larvae in the spring is inversely related to the season's temperature.

Some studies have found a link between larval distribution and environmental variables [6]. Temperature is an important but not major factor in the variation in larval abundance, and it affects the distribution and abundance of commercial species. According to Bachouche[7]; the central Algerian zone is located in a region with relatively strong water mixing, and the passage of weak surface fronts can impact local biology. According to Somarakis et al. [49]; physical composition and biological factors influence fish eggs and larvae distribution, abundance, survival, and growth. According to Lloret et al. and Torri et al. [36,53]; large fluctuations in pelagic fish biomass can occur across years. According to Türker et al. [56], sardine larvae account for more than 8.3% of the larvae sampled in Aegean Sea ichthyoplankton samples. According to this author, the composition of sardines in ichthyoplankton varies yearly, depending on climate, hydrographic conditions, sampling methods, and fluctuations in sardine stocks over time. Uygun and Hoşsucu [58] observed a connection between sardine larvae and environmental factors.

Szu-Chia Kao [31] discovered that zooplankton vertical displacement varies during the night, noting that smaller specimens occupy surface layers, increasing larval predation risk. Zarrad et al. [61] demonstrated that anchovy and sardinella spawn when the waters are warmer (spring and summer) and that anchovy larvae aggregation is greater than sardinella larvae; the same author concludes that temperature is an important factor, but that other biological factors, such as food, also play a role in the process of spawning and larval recruitment. According to Schismenou et al. [47]; sardinella and anchovies are coastal species that spawn in more productive continental shelf areas with higher chlorophyll-a values. The Aegean Sea's anchovy egg-larvae association, characterized by an anticyclonic circulation rich in zooplankton, is likely to be important for retaining ichthyoplankton [50]. According to Palomera and Sabatés [27,42]; anchovy and sardinella larvae can be found in plankton from spring to autumn. According to Refs. [2,28,45,50]; and [46]; sardine and anchovy spawning is generally associated with hydrographic structures that promote egg advection and larvae in suitable habitats.

According to Voss et al. [46], an increase in surface temperature causes an increase in larvae's primary prey (phytoplankton and zooplankton), resulting in a significant aggregation of larvae near the surface. Furthermore, Yi Chen Wang [59] reported that the dynamics of the Kuroshio front strongly influence the distribution of fish larvae in the southeastern part of the South China Sea. Furthermore, Yi Chen Wang [59] concluded that the area's unique hydrodynamics significantly impact the larvae's survival strategy.

In conclusion, the results of this study show that small pelagic larvae, specifically sardine larvae, saurel, sardinella, and anchovy, have a clear dominance in the samples. These larvae have a very different seasonal distribution, which the sampling technique, hydrological conditions in the area, or other biological factors can explain. Improving our understanding of ichthyoplankton requires examining other areas in different seasons and depths and with more environmental factors. Future studies will be initiated in this context to gather more information.

Conflict of interest

I confirm that I have no conflicts of interest to disclose in relation to my involvement in this publication. My research, findings, and recommendations have been conducted with full objectivity and independence.

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