The spatial distribution of anchovy and sardine in the northern Aegean Sea in relation to hydrographic regimes

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ABSTRACT. Acoustic survey data were combined with hydrological parameters with the aim of understanding the relationships between the spatial distribution of anchovy and sardine and environmental regimes. Acoustic and concurrent hydrological sampling was carried out in the Northern Aegean Sea (eastern Mediterranean) during June 1995 and June 1996. In order to examine hydrological parameter selection by anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*), cumulative distribution functions were estimated. Both species were significantly associated with areas of deeper surface and upper mixed layers, which implied an association of anchovy and sardine with anticyclones. Within the range of available temperatures and bottom depths, sardine further showed a significant affinity to warm as well as to shallow waters. These results are discussed in relation to species' life histories and existing knowledge of oceanographic features in the surveyed area.

KEY WORDS : anchovy, sardine, Northern Aegean Sea, spatial distribution, environmental variable selection.

INTRODUCTION

Small pelagic species comprise a very important part of the total world fisheries catch. About 25% of the total catch of the European pilchard (*Sardina pilchardus* (Walbaum*,* 1792)) and almost 90% of the total catch of the European anchovy (*Engraulis encrasicolus* (Linnaeus, 1758)) is taken in the Mediterranean Sea (FREON & MISUND, 1999). To improve the understanding of the mechanisms that are responsible for the availability of these resources, there is a need to integrate environmental information with biological and fishery knowledge. Habitat selection affects the spatial distribution of the species and is often the outcome of trade-offs between different agents such as heredity, predation and availability of food (FREON & MISUND, 1999).

Although the Northern Aegean Sea is the most important fishing ground for anchovy and sardine in the Eastern Mediterranean (STERGIOU et al., 1997), published studies on their spatial distribution in the area are generally lacking and the linkage to hydrological regimes has never been studied. Previous investigations in the Northern Aegean Sea mainly focused on the ichthyoplankton distribution and abundance in relation to oceanographic conditions (SOMARAKIS et al., 2002), the estimation of the size of the stocks using fisheries independent techniques (MACHIAS & SOMARAKIS 1997), and the analysis of fisheries landings data (STERGIOU et al., 1997 and references therein). The present study attempts to relate the spatial distribution of anchovy and sardine to environmental conditions, combining data from concurrent hydroacoustic and hydrographic surveys carried out in June 1995 and June 1996 over the continental shelf.

MATERIAL AND METHODS

Acoustic data were collected during two surveys carried out on board the "R/V PHILIA" in June 1995 and June 1996. The study area covered the continental shelf and slope waters of the Thracian Sea, Strymonikos Gulf and Thermaikos Gulf (Fig. 1). The sampling scheme was based on 30 predetermined transects and the surveyed area was stratified into : Thracian Sea (Stratum I), Strymonikos Gulf (Stratum II) and Thermaikos Gulf (Stratum III). Stratum I covered 29%, stratum II 27% and stratum III 44% of the study area. (for details see TSIMENIDES et al., 1992).

The acoustic equipment used was a Biosonic Dual Beam 120 kHz V-Fin Echosounder (Model 120, 3º + 3º). The system was regularly calibrated using the standard sphere method (FOOTE, 1987). The echoes were processed using the software ESP v3 of Biosonics Inc. The speed of the vessel was 8 nautical miles (nm) per hour. Acoustic echoes were registered continuously along transects and were integrated over one nm, which served as the Elementary Distance Sampling Unit (EDSU). The sardine and anchovy echoes were discriminated from those of other fishes by the characteristic echogram shape and back-scattered energy of the schools (GIANNOULAKI et al., 1999). Information on fish schools was obtained by means of identification hauls made with a pelagic trawl (vertical opening : 10 m, codend : 10 mm) (GIANNOULAKI et al., 1999).

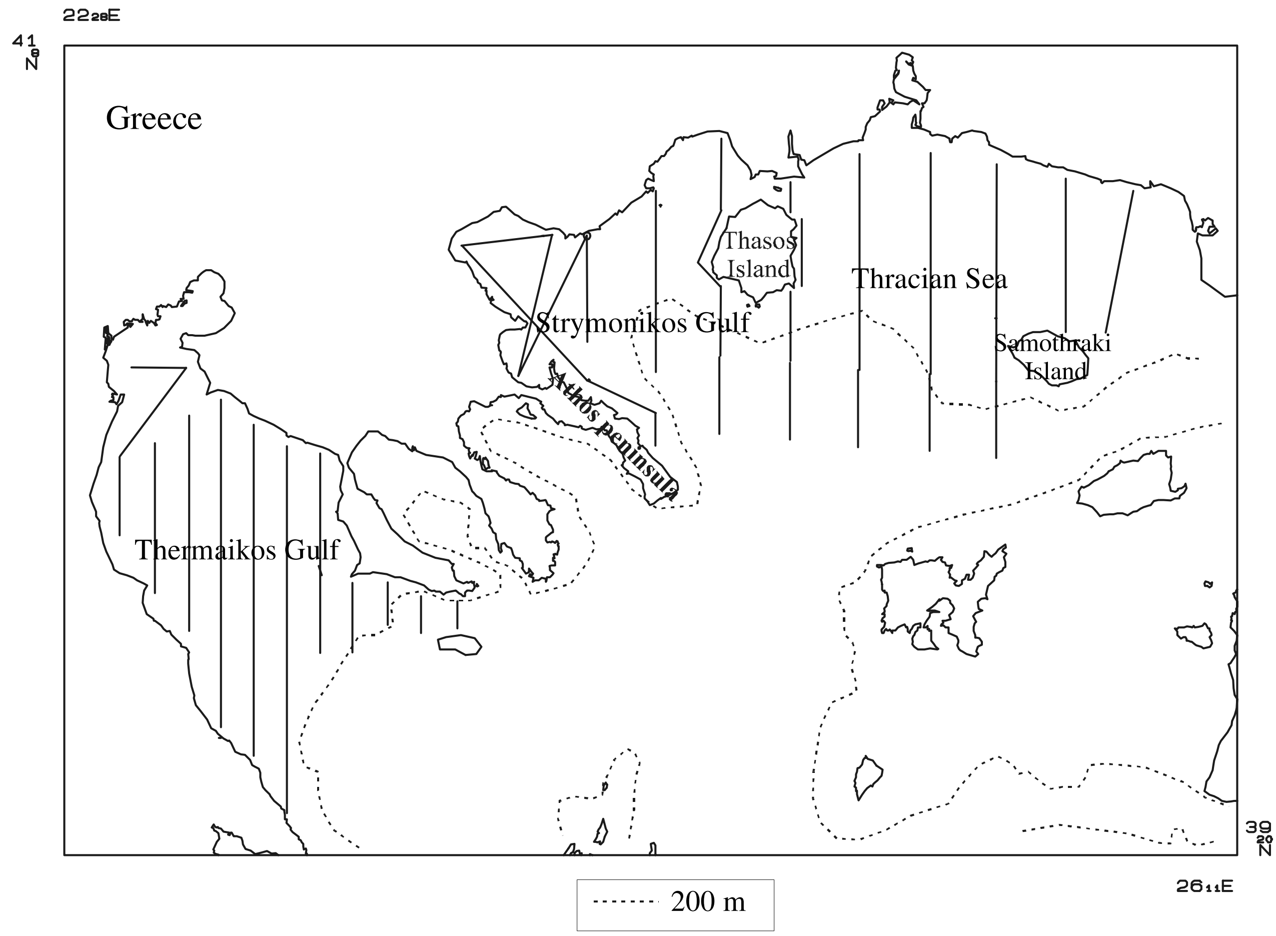

Fig. 1. – Map of the study area (Northern Aegean Sea) showing transects (lines) and toponyms mentioned in the text.

Hydrographic sampling was performed over a grid of 144 and 147 stations in 1995 and 1996, respectively. At each station vertical profiles of temperature and salinity were obtained with a SBE-19 Seacat internally recording CTD unit (Sea Bird Electronics). To study the association of fish with environmental factors, we calculated the depth and mean values for temperature and salinity of the following water column layers : (a) the surface mixed layer (SML) ; (b) the upper mixed layer (UML) and (c) the bottom layer (BL) (LAPRISE & PEPIN 1995). In addition, (d) the mean temperature stratification ($^oC\ m^{-1}$) and (e) mean salinity stratification (psu m^{-1}) for the UML were calculated. The SML was defined as the homogeneous layer immediately below the sea surface where temperature was 1^{o}C less than that of surface waters (LAPRISE & PEPIN 1995). The UML was the layer from the surface down to the depth where temperature was 1 ^{o}C higher than that of bottom waters. The BL was the layer from the end of the upper mixed layer down to the bottom or until 200m, wherever bottom depth was greater than 200 m. The breakdown of the water column into SML, UML and BL described better the well-stratified conditions at sea and provided a rough indication of the water circulation (e.g. UML depth was deeper in anticyclonic than in cyclonic areas).

We used the local regression model, LOESS (CLEVELAND 1979), in a predictive mode, to interpolate as a function of latitude and longitude, all the above-mentioned variables onto the anchovy and sardine locations (multiple R-squared >0.94). A neighbourhood of 40% of the data (span =0.4) was used here. The number of nearest-neighbours (i.e. size of the neighbourhood) usually expressed as percentage or span of the data points, is a smoothing parameter. LOESS models provide much flexibility because the model is fitted as a single smooth function of all the predictors.

The habitat selection of the two species was simplified by analysis of cumulative distribution functions (CDFs) following PERRY & SMITH (1994). We examined relationships between each species density (integrated echo per nautical mile) and each one of the hydrological variables, as well as bottom depth. The CDF (in %) for all variables f(t), were calculated as follows :

$$f(t)=100\frac{\sum_{h=1}^{L}\sum_{i=1}^{n_h}\frac{A_h}{n_h}I}{\sum_{h=1}^{L}\sum_{i=1}^{n_h}\frac{A_h}{n_h}} \quad \text{where } I=\begin{cases}1, & if\ \ x_{hi}<t\\ 0 & otherwise\end{cases}$$

and t is a level of each variable ; A_h is the area of stratum h ; n_h is the number of EDSU in stratum h ; x_{hi} is the value of the variable at the EDSU i in stratum h ; L is the number of strata. The CDF for anchovy or sardine integrated echo per mile, g(t), was calculated similarly :

$$g(t)=100\frac{\sum_{h=1}^{L}\sum_{i=1}^{n_h}\frac{A_h}{n_h}y_{hi}I}{\sum_{h=1}^{L}\sum_{i=1}^{n_h}\frac{A_h}{n_h}y_{hi}} \quad \text{where } I=\begin{cases}1, & \text{if } x_{hi}<t\\ 0 & \text{otherwise}\end{cases}$$

and y_{hi} is anchovy or sardine integrated echo in EDSU *i* in stratum *h*.

To examine variation in the parameters selection by anchovy or sardine, we compared CDFs of each variable, f(t), and anchovy or sardine echo in relation to the corresponding variable g(t). We calculated parameter

$$S=\sum_{t=1}^{t}\left[f(t)-g(t)\right]$$

for each variable. S compares average available variable to the average variable selected by anchovy or sardine. Positive values of S indicated that anchovy or sardine select high values within the ranges studied (SWAIN & KRAMER, 1995). We used a Kolmogorov-Smirnov type of statistic to test the significance of variable selection. The test statistic D was defined

$$D=\max\left|f(t)-g(t)\right|$$

(maximum absolute vertical distance) when f(t) and g(t) were the two functions compared. Significance was assessed using randomisation tests (PERRY & SMITH, 1994). All statistical inferences were based on a 0.05 significance level.

TABLE 1

Northern Aegean Sea. The hydrological characteristics of the water column in June 1995 and June 1996. Avg.: Average values, s.d.: standard deviation, Max: maximum value, Min: minimum value, SML: surface mixed layer, UML: upper mixed layer, BL: bottom layer (see text for layer definition).

		June 1995				June 1996			
	Layer	Avg.	s.d.	Max	Min	Avg	s.d.	Max	Min
Depth (m)	SML	9.15	1.86	12.51	5.08	8.23	2.05	11.63	4.61
	Uml	35.51	7.45	48.17	16.93	25.55	4.70	35.83	19.59
Mean Temperature (^{0}C)	Sml	24.30	0.58	25.06	23.01	21.93	0.86	24.47	20.00
	Uml	19.57	0.64	21.38	18.13	19.04	0.44	19.89	18.04
	Bl	14.38	0.41	15.47	13.74	12.86	0.24	13.58	12.31
Mean Salinity (psu)	Sml	34.66	1.11	36.07	32.46	33.89	1.19	35.33	31.05
	Uml	36.55	0.88	37.97	34.65	35.43	0.93	37.07	33.86
	Bl	38.52	0.22	39.01	37.75	38.24	0.22	38.64	37.67
Temperature stratification (^{o}Cm^{-1})	Uml	-0.31	0.07	-0.20	-0.62	-0.35	0.09	-0.22	-0.58
Salinity stratification (psu m^{-1})	UML	0.13	0.06	0.38	0.07	0.18	0.06	0.33	0.08

RESULTS

The water column in the North Aegean Sea presented typical spring-to-early summer conditions. It was generally well stratified during both surveys (SOMARAKIS et al., 2002). The upper water column as well as the bottom layer was generally warmer and more saline in 1995 than in 1996 (Table 1). Acoustic data were used to estimate the anchovy and sardine biomass in the area, which was similar for the two years (EPET, 1996[1] ; MACHIAS & SOMARAKIS, 1997).

Distribution and abundance maps of anchovy and sardine (Fig. 2) showed that, in the Thracian Sea, the main concentrations of both species generally occurred between the islands of Thasos and Samothraki. High numbers for both species were also recorded between the island of Thasos and the Athos peninsula (Strymonikos Gulf), however anchovy abundance was lower and fish distributed more inshore in Strymonikos Gulf during June 1996 when compared to June 1995 (Fig. 2d). In the Thermaikos Gulf, anchovy distribution consisted of two major groups, one in the inner and another one in the outer part of the Gulf, whereas the distribution of sardine comprised many small clusters (Fig. 2).

Analysis of the CDFs revealed positive associations of anchovy with SML depth, UML depth and BL temperature at a significant level (Table 2, Fig. 3). These results were indicative of a higher probability of occurrence for anchovy in water columns characterized by deeper surface and upper mixed layers. Anchovy affinity to warmer waters below the thermocline (BL) was marginally significant (p=0.049, Table 2). Sardine showed a strong positive relationship ($p << 0.01$) with SML depth, UML depth, SML temperature, UML temperature and BL temperature (Table 2, Fig. 3). Hence, in contrast to anchovy, sardine was clearly associated with warmer waters. Moreover sardine showed a negative relationship with bottom depth (Table 2, Fig. 3) indicating a selection for shallow waters. Salinity and stratification parameters did not exhibit statistically significant effects (Table 2).

[1] EPET (1996). Development of Greek Fisheries. EPET 125, II/94, Final Report.

TABLE 2

Indices of parameter selection by species. S: index of parameter selection; D: test statistic; p-value: probability of statistical significance of parameter selection based on the randomization test described in the text. SML: surface mixed layer; UML: upper mixed layer; BL: bottom layer.

Parameters	Layer	Anchovy			Sardine		
		S	D	p-value	S	D	p-value
Bottom Depth (m)		-68.63	11.26	0.629	-123.33	8.75	0.018
Depth of SML (m)		117.23	20.06	0.016	69.52	12.10	0.004
Depth of UML (m)		103.48	18.78	0.035	93.88	11.58	0.006
Temperature (^{o}C)	Sml	169.63	16.82	0.121	211.47	20.13	0.000
	Uml	43.91	8.92	0.853	74.23	12.87	0.000
	Bl	131.81	17.62	0.049	193.93	23.87	0.000
Salinity (psu)	Sml	-2.75	6.70	0.992	-20.37	7.90	0.058
	Uml	6.91	16.84	0.117	6.44	4.75	0.445
	Bl	-11.33	13.21	0.463	15.73	8.13	0.053
Temperature stratification (^{o}C m^{-1})	Uml	-77.65	11.43	0.605	-54.24	6.41	0.170
Salinity stratification (psu m^{-1})	Uml	-80.20	12.69	0.550	-35.59	7.32	0.105

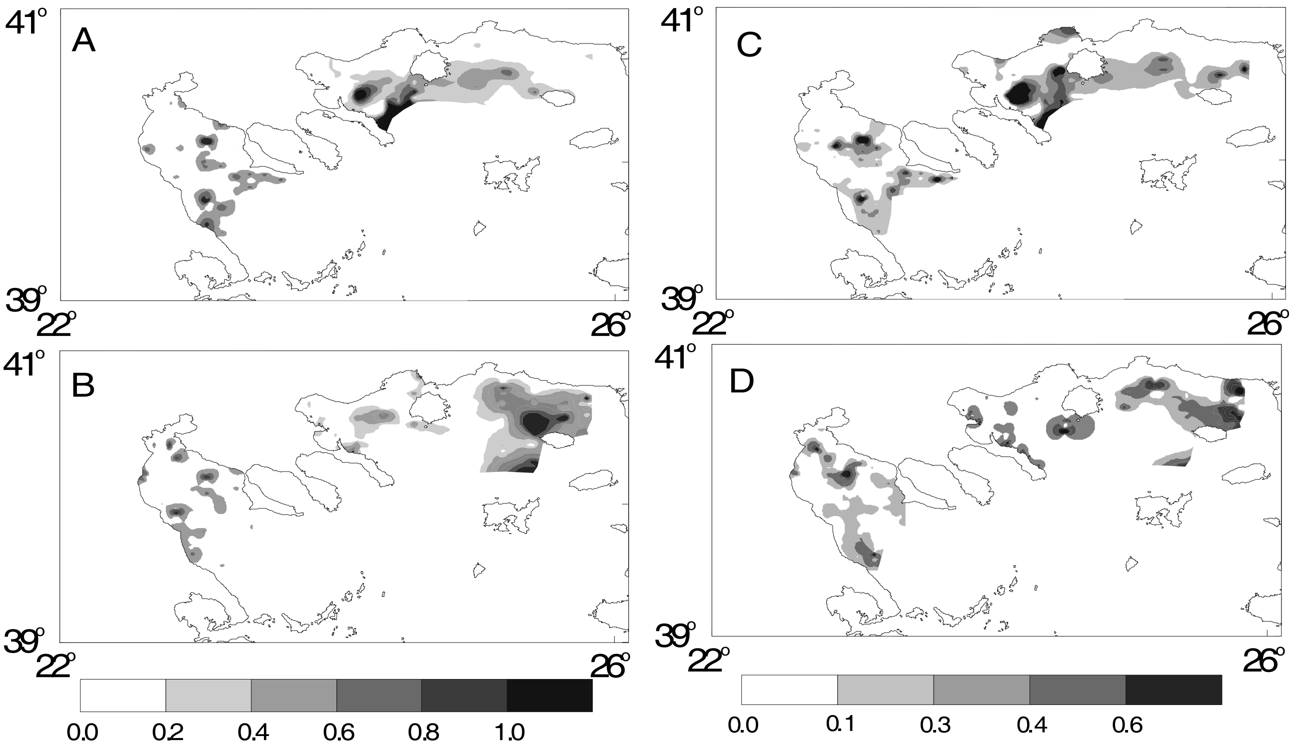

Fig. 2. – Contour maps of fish acoustic cross section (in md) in the Northern Aegean Sea. (A) Sardine distribution in June 1995, (B) Sardine distribution in June 1996, (C) Anchovy distribution in June 1995, and (D) Anchovy distribution in June 1996.

DISCUSSION

The present study showed a high concentration for both anchovy and sardine in the waters between the islands of Thasos and Samothraki, as well as the island of Thasos and the Athos peninsula. These areas were characterized by the presence of two anticyclonic systems : one in the Samothraki plateau (the Samothraki gyre) and another one in the Strymonikos Gulf (SOMARAKIS *et al*. 2002). These gyres are an almost permanent feature in the area during early summer and are coupled with a cyclonic system located south of the island of Thasos, the overall circulation being mainly determined by the presence of the Limnos-Imvros stream, which carries waters of Black Sea origin onto the Samothraki plateau (SOMARAKIS et al., 2002). Deeper surface and upper mixed layers characterize the anticyclonic gyres due to the tendency of isopycnals to move downward in down-welling areas in contrast to cyclonic (up-welling) areas where the isopycnals tend to move upwards (POND & PICKARD, 1983). The association of anchovy and sardine with anticyclones was shown by the significant relationships with deeper SMLs and UMLs (Table 2). These anticyclonic gyres are plankton retention areas and characterized by high concentrations of mesozooplankton (SOMARAKIS, 1999), i.e. high food availability for small pelagic fish. Such structures are also known to entrain fish eggs and larvae and restrict their dispersal (HEATH, 1992). Early summer is the spawning period of anchovy in Greek waters (SOMARAKIS, 1999), thus, selection by spawning adults of areas of favourable feeding conditions within gyres, would also be favourable for their spawn, because of retention and the reduced offshore dispersal (BLAXTER & HUNTER, 1982).

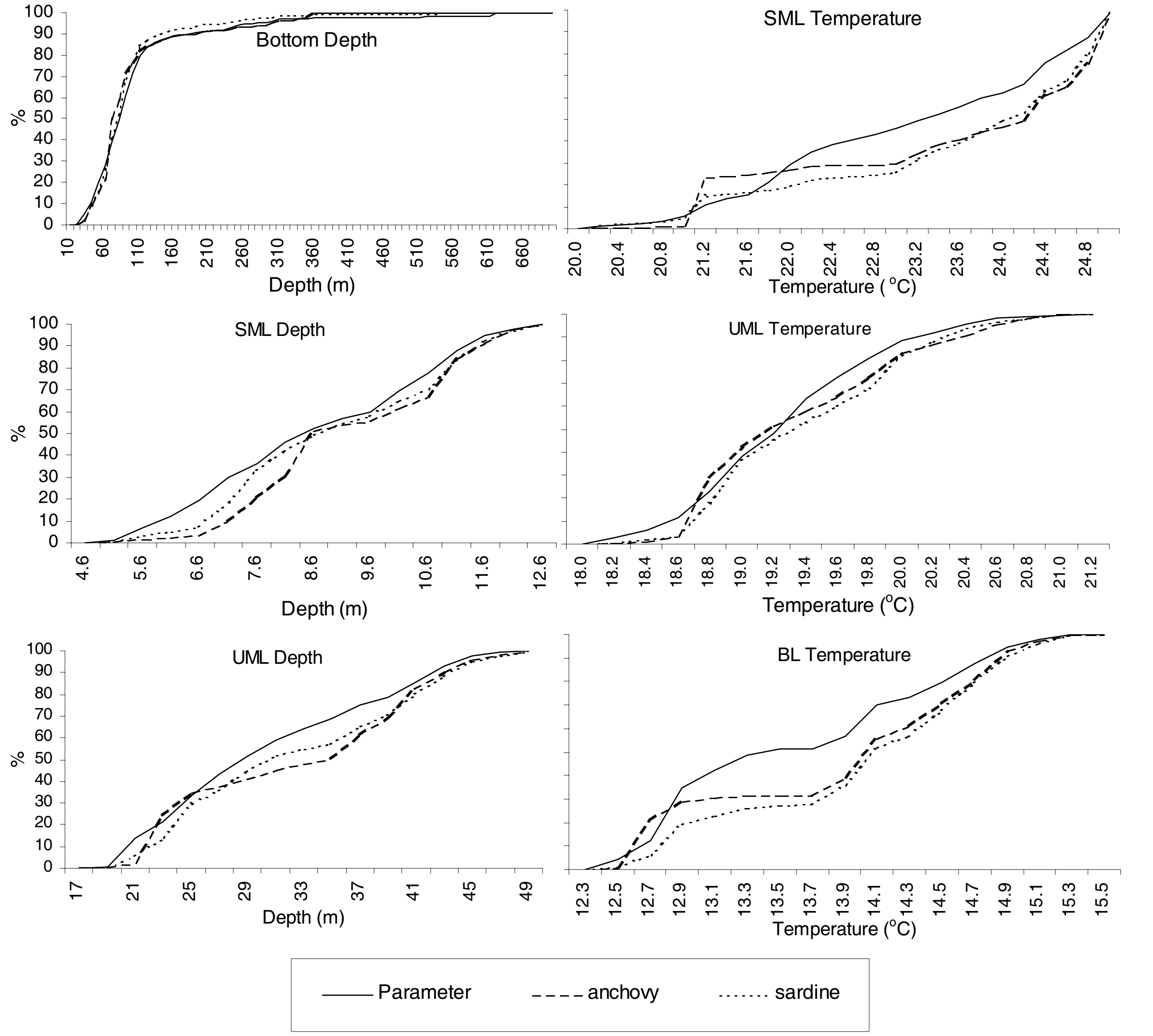

Fig. 3. – Cumulative distribution functions of bottom depth, significant hydrological parameters and anchovy/ sardine backscattering cross-section in relation to the available values of the parameters. SML : surface mixed layer ; UML : upper mixed layer ; BL : bottom layer.

In the Thermaikos Gulf, which is a semi-enclosed gulf, fish were generally distributed in many small clusters covering most parts of the gulf. The degree of enclosure of an area is significantly related to higher spatial patchiness for pelagic resources in the Greek seas, as has been shown by a recent study using geostatistical techniques (GIANNOULAKI et al., 2002).

Within the range of available temperatures, sardine was further selective for warm waters, which was not the case for anchovy. Sardine spawns during winter, whereas during summer it is characterised by fast somatic growth and fat deposition (SARDINE, 2001[2]). Temperature accelerates growth, within the natural thermal range experienced by the species in its habitat (URSIN, 1979). Hence sardine`s selection for warm waters is probably related to growth optimisation.

Another significant relationship for sardine was its affinity to shallow waters. Inshore waters are the preferred habitat for age-0 fish, which dominate the sardine population during early summer (SARDINE, 2001). Close association of sardine to shallow waters has also been reported for *Sardinops sagax* in the Southern Ben-

[2] SARDINE 2001: Evaluation of the Southern Greek Sardine Stocks, No 98/039. Final Report.

guela up-welling region (Barange & Hampton, 1997) and *Sardina pilchardus pilchardus* in the Bay of Biscay (Scalabrin & Masse, 1993).

The present study is the first attempt to relate the spatial distribution of anchovy and sardine to hydrology in the Northern Aegean Sea. It highlights the significance of environmental regimes in determining population patterns in space. Further investigations on the spatial patterns of these planktivorous fish should address the effect of food availability, which controls both their growth and reproduction (Freon & Misund, 1999).

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