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Research Article

Assessment of the sardine (*Sardina pilchardus* Walbaum, 1792) fishery in the eastern Mediterranean basin (North Aegean Sea)

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Abstract

The aim of this study is to describe the biometric characteristics of European sardine *(Sardina pilchardus)* catches and assess the current status of sardine stock in the North Aegean Sea based on population characteristics and abundance trends. The stock was dominated by age groups 1 and 2, not exceeding age group 4. The sardine stock in this area was assessed through an Integrated Catch-at-Age model which implements a separable Virtual Population Analysis on catch-at-age data with weighted tuning indices. Sardine landings data derived from the commercial purse seine fishery over the period 2000-2008 were combined with the age structure of the stock as resulting from fisheries' independent acoustic surveys. Sensitivity analysis of the impact of natural mortality values on stock assessment results was applied. Additionally forecast of the sardine population parameters and catches under different exploitation scenarios was implemented on a medium term basis. Results indicated that the North Aegean Sea sardine stock is considered fully exploited, with the fishery operating close to, but over the empirical exploitation level for sustainability. Finally, the status of the sardine stock in the North Aegean Sea is discussed in relation to the sardine stocks from the western and the central Mediterranean basin.

Keywords: European sardine; Eastern Mediterranean Sea; North Aegean Sea; Stock assessment; Integrated-Catch-at-Age Analysis; Natural mortality sensitivity.

Introduction

The European sardine, *Sardina pilchardus* (Walbaum, 1792), is one of the most abundant and commercially important fish species in the Mediterranean Sea (CARRERA & PORTEIRO, 2003; SANTOJANNI *et al*., 2005; PALOMERA *et al*., 2007), comprising about 20% of the Mediterranean annual landings (LLEONARD & MAYNOU, 2003). Additionally, Mediterranean sardine landings comprise almost 25% of the whole European sardine production (FREON & MISUND, 1999).

Sardine landings in the Greek Aegean Sea, based on FAO (2000) statistical production data for the period 1970-1999, comprised 4% to 7% on average of the total sardine landings of the entire Mediterranean Sea, presenting an increase during the 90's (Fig. 1). Moreover, sardine landings in the Greek Aegean Sea compared to the total sardine landings of the Eastern Mediterranean basin, based on FAO statistical production data represented almost 90% of the total landings during the 70's and 40-50% on average of the total landings over the period 1980-1999 (Fig. 1).

In Greek waters, sardine constitutes almost 15% of the mean total annual landings according to FAO statistics (FAO 2000, based on FAO official reported statistical data 1970-2006) and is almost exclusively exploited by the purse seine fleet (STERGIOU *et al*., 1997a). Pelagic trawl is banned and benthic trawls are allowed to fish small pelagics in percentages less than 5% of their total catch, according to Greek legislation. Regarding other regulations enforced, there is a closed period for the fishery from mid-December to the end of February and technical measures such as minimum distance from the shore (300 m), minimum bottom depth (30 m) and a minimum landing size of 11

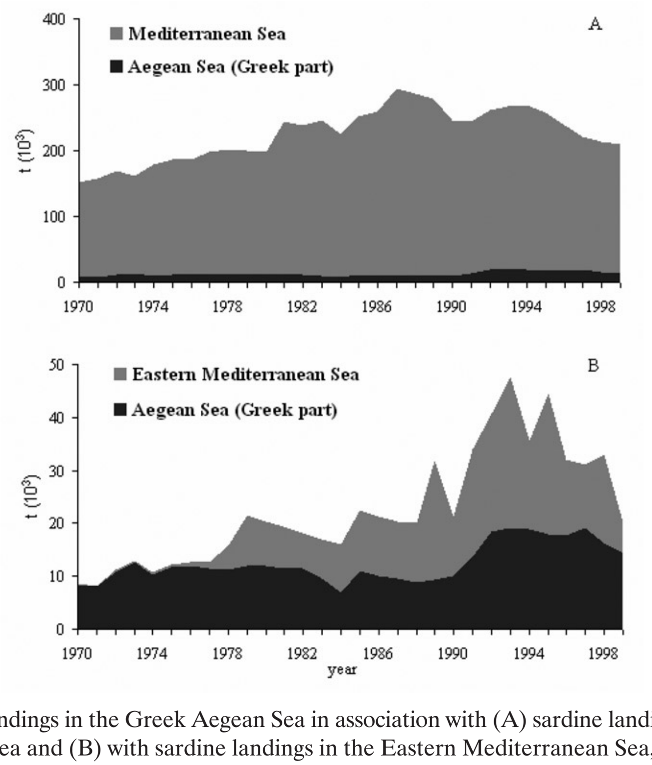

Fig. 1: Sardine landings in the Greek Aegean Sea in association with (A) sardine landings in the entire Mediterranean Sea and (B) with sardine landings in the Eastern Mediterranean Sea, over the period 1970-1999 based on FAO official reported statistical data.

cm. Discards represent less than 1% of the total catch, reaching approximately 0.3% of the landings in the Greek part of the Aegean Sea (SOHELFI, 2007). Small vessels (purse seiners 12-24 m) are those mainly responsible for sardine catches, comprising more than 88% of the species' catches in the entire Aegean Sea (based on Official Greek Reported Data to the EU Data Collection Regulation). The evolution of the Aegean Sea sardine landings shows that they fluctuated around the level of 10000 t on average over the period 1970-1990, presenting a sharp increase after 1992 and remaining at around 18500 t until 1997 (Fig. 1).

Genetic studies concerning sardine stock in the Greek Seas have shown no differences in the stocks between the Aegean and the adjacent Ionian Sea (SPANAKIS *et al*., 1989). The main distribution area of the sardine stock in the Aegean Sea is located on the continental shelf of the North Aegean Sea (Fig. 2A, GIANNOULAKI *et al*., 2005, 2006, 2007; TSAGARAKIS *et al*., 2008) constituting the most important fishing ground for sardine in the Eastern Mediterranean basin

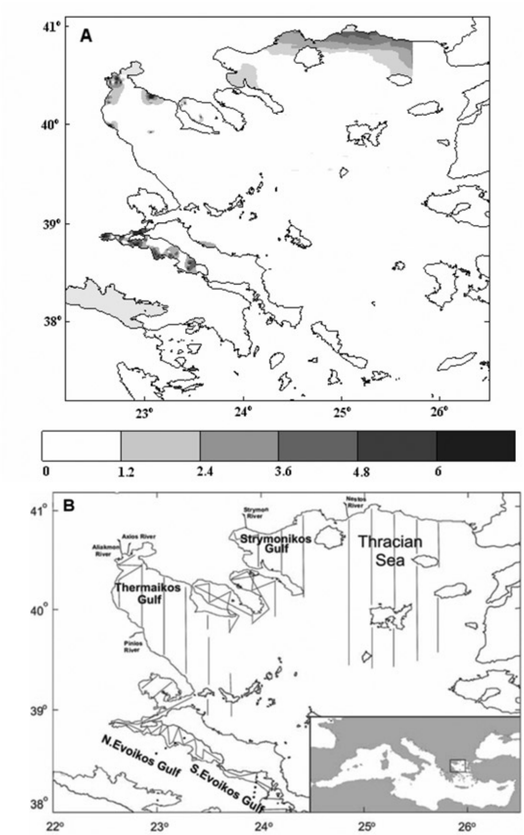

Fig. 2: (A) Sardine distribution grounds in the North Aegean Sea in June 2008 based on acoustic surveys (in NASC: Nautical Area Scattering Coefficient m^2/nm^2). (B) Map of the study area showing transects along which the acoustic survey was carried out in June 2003-2006 and 2008 (redrawn from GIANNOULAKI *et al*., 2006).

(STERGIOU *et al*., 1997a; SOMARAKIS *et al*., 2006b). Sardine stock in the Aegean Sea is a shared stock between the Greek and the Turkish fishing fleets. Enclosed areas like gulfs in the southwest Aegean Sea define the boundaries of sardine stock in the Greek Aegean Sea whereas in the area where the Turkish fleet operates, known fishing grounds for sardine are located in the shallow waters of the northeast Aegean Sea as well as in the gulfs that dominate the eastern coastal waters (LLEONART & MAYNOU, 2003; TURAN *et al*., 2004). Despite the fact that the Aegean Sea is generally characterized by oligotrophic waters, like the rest of the eastern Mediterranean, its northern sector presents high levels of productivity due to the outflow of the Black Sea Waters (BSW, salinity<30), which enter the Aegean Sea through the Dardanelles Strait as a surface current (ZERVAKIS & GEORGOPOULOS, 2002). This increases local productivity and induces high hydrological and biological complexity, generating two anticyclonic systems that are plankton retention areas, characterized by high concentrations of mesozooplankton (SOMARAKIS *et al*., 2002), i.e. high food availability for small pelagic fish (GIANNOULAKI *et al*., 2005). This is further enhanced by the peculiar topography of the area and the presence of a series of rivers that outflow in semi-closed areas (STERGIOU *et al*., 1997a; GIANNOULAKI *et al*., 2006).

The aim of this study is to describe the biometric characteristics of sardine catches, such as length frequency distributions, age distribution and annual growth, along with an assessment of the current status of the sardine stock in the North Aegean Sea. Several studies regarding sardine landings in Greek waters have been made in the past (e.g. STERGIOU *et al*., 1997b; VOULGARIDOU & STERGIOU, 2003) whereas studies concerning the population characteristics focus on the estimation of biological parameters such as growth and reproduction, as well as the spatial distribution of the species (TSERPES & TSIMENIDES, 1991; MACHIAS *et al*., 2001; GIANNOULAKI *et al*., 2005, 2006; SOMARAKIS *et al*., 2006a; GANIAS *et al*., 2007). Landings have been evaluated in terms of their temporal variability and periodicity (PETRAKIS & STERGIOU, 1995; STERGIOU *et al*., 1997b; KOUTRAKIS *et al*., 2005). However, there is a lack of knowledge concerning the age structure of the landings and the population. Additionally, no stock assessment model has been implemented utilizing the age structure of the stock.

Small pelagic species present specific characteristics that should be taken into account for their assessment and management. They are short-lived species and unlike the Atlantic population of *Sardina pilchardus* (SILVA *et al*., 2008), sardine in the Mediterranean generally live up to 6 years (SANTOJANNI *et al*., 2005) and up to 5 years in the Greek Seas (TSERPES & TSIMENIDES, 1991; current work). Their population level depends strongly on the incoming year-class strength, which is highly variable and largely dependent on environmental factors. Thus, the state of these stocks can change sharply on an interannual basis. These features raise several questions and demand transformations, regarding the application of a standard stock assessment technique such as Virtual Population Analysis (VPA, POPE & SHEPHERD, 1985), and the current trend in the stock assessment of the small pelagic stocks suggests the integration of stock assessment techniques that incorporate information from fishery-independent surveys (ICES

2006; IBAIBARIAGA *et al.*, 2008; BARANGE *et al.*, 2009).

Within the framework of the present study the North Aegean Sea sardine stock has been assessed through an Integrated Catch-at-Age model (ICA, PATTERSON & MELVIN, 1996). For this purpose sardine landings data derived from the commercial purse seine fishery over the period 2000-2008 were combined with information from fisheries' independent surveys. The ICA model implements separable VPA (DERISO *et al.*, 1985) on catch data with weighted tuning indices. In the present work, as tuning index we used the stock age structure as resulting from research acoustic surveys. ICA has been successfully applied to other small pelagic fish stocks; it is considered more appropriate for short-lived species such as sardine rather than a conventional VPA (ICES, 2006; DASKALOV & MAMEDOV, 2007).

Moreover, the effect of natural mortality on the stock assessment results was examined. The uncertainty of natural mortality estimation may strongly affect the assessment of the stocks and especially the assessment of a short-lived species like sardine (QUINN & DERISO, 1999). Natural mortality is a biological parameter that plays a key role in the procedure of understanding the dynamics of a fish population. A usual assumption adopted by most age based stock assessment models is the use of constant natural mortality values for all age groups or size classes (CADDY, 1991, 2009). However, the appropriateness of a variable with age and size natural mortality has been suggested by several authors (ABELLA *et al.*, 1997; ANDERSEN & BEYER, 2006; POPE *et al.*, 2006; GISLASON *et al.*, 2008). Therefore, within the present study we examined the sensitivity of the sardine stock assessment estimates to different natural mortalities, including both constant and variable with age values. Finally, based on the ICA stock assessment results, forecast of the sardine population parameters and catches under different exploitation scenarios was made on a medium term basis.

Materials and Methods

Biological data collection

Sardine landings data were obtained on a monthly basis from 2000 to 2008 derived from the purse seine fishery in the North Aegean Sea within the framework of the Hellenic Centre for Marine Research data collection system that covers the entire Greek Aegean Sea. The North Aegean Sea comprises the main fishing ground for the sardine stock in Greek waters. Representative landings samples were obtained on a seasonal basis for the estimation of length frequency distribution, age structure and biological parameter determination of the sardine stock.

Length frequency distribution was obtained on a semester basis; for age determination, on average 20 to 25 otoliths (*sagittae*) from each sample and per each length class were removed and used for age determination (i.e. age groups ranging 0 up to 4). The main conventions for age reading were the periodicity of the otolith ring formation (one year is equivalent to a consecutive opaque and translucent ring) and the date of birth (considered to be the 1st of January) (MORALES-NIN, 1992).

In total, 8205 otoliths were used for age reading. The ALK was obtained and applied on a semester basis and subsequently the age structure of the landings was pooled on an annual basis. A pooled ALK from all years was applied for the years 2000-2002 for which no ALK was available. The length-weight relationships ($W=aTL^b$) were estimated annually concerning the period 2003-2008. Landings in terms of biomass and numbers as well as the catch numbers at age were estimated based on the aforementioned biological information. Moreover, the mean length at age in the catch and the mean weight at age in the catch were also estimated. Finally, the von Bertalanffy (1938) growth parameters were calculated based on the respective growth equation (VBGF):

$$Lt = LA\,(1- e^{-k\,(t-to)}) \qquad (1)$$

where *Lt* is the length at time *t*, *LA* is the asymptotic length or the mean length a fish would reach if it was to grow indefinitely, *K* is the rate at which *LA* is approached and t_0 the age of the fish at zero length if it had always grown according to the equation.

Fishery independent information regarding the state of the sardine stock was derived from acoustic surveys that were held during June 2003-2006 and 2008 in the North Aegean Sea. Specifically, acoustic data were collected on a continuous basis on board the R/V Philia along 70 predefined transects (Fig. 2B) by means of a Biosonic Split Beam DT-X echosounder at 38 kHz. Survey characteristics and the acoustic methodology followed are extensively described in GIANNOULAKI *et al*. (2006). Acoustic echoes were registered continuously along transects and were integrated over 1 nm, which served as the Elementary Distance Sampling Unit (EDSU). A pelagic trawl with a vertical opening of 10m and 8mm codend was used to qualify the acoustic targets and to obtain biological samples. The trawl catches were used to determine the length and the age distribution of the sardine stock weighted by the acoustic abundance of the species locally (MACLENNAN & SIMMONDS, 1992). The weight at age in the stock was also estimated. The maturity at age estimations were based on biological samples collected within previous targeted surveys in the Aegean Sea (winter 1999-2001) during the spawning period for sardine (described in GANIAS *et al*., 2007).

Stock assessment - ICA

Integrated Catch at Age (ICA) analysis for stock assessment (Patterson and Melvin, 1996) was applied to sardine commercial catch data from the North Aegean Sea. ICA is a statistical catch-at-age model for stock assessment that uses separable virtual population analysis (VPA) (POPE & SHEPHERD, 1985) with weighted tuning indices. Moreover, in the case of ICA the existence of error in each measurement of the catches at age is determined. In accordance with separability, the fishing mortality is the product of an age selection pattern (age effect) and a year effect (PATTERSON & MELVIN, 1996; NEEDLE, 2003).

In our case, ICA was based on sardine commercial catch data from 2000 to 2008. The population abundance per age group in the stock estimated from the acoustic surveys over the period 2003-2008 was used as a tuning index (no survey in 2007). Specifically, the input parameters for the ICA model used were the annual sardine landings, the annual sardine catch at age data (2000-2008), the mean weight at age in the catch and in the stock, the maturity at age and natural mortality (Table 1).

Discards, although considered negligible as comprising less than 1% of the total catch, were taken into account for the assessment. The numbers at age of the population (i.e. age 1 to age 3+ groups) as estimated from the acoustic surveys were used as a relative index of abundance (Table 2). Concerning the lack of survey information for 2007, average values were used regard-

Table 1
Numbers at age, weight at age in the catch and in the stock for sardine in the North Aegean Sea over the period 2000-2008.

Catch-at-age (10^6)					
Year	**Age 0**	**Age 1**	**Age 2**	**Age 3**	**Age 4**
2000	11.7	551.4	207.8	36.6	1.6
2001	37.5	713.2	199.8	28.8	0.9
2002	51.7	443.2	105.7	13.7	0.4
2003	21.5	295.9	90.3	12.9	0.5
2004	20.2	286.6	84.2	12.0	0.4
2005	6.2	418.9	159.7	28.9	1.2
2006	15.3	421.4	126.7	18.2	0.7
2007	11.7	294.8	88.3	12.6	0.4
2008	22.6	372.3	106.6	14.2	0.4
Catch weight-at-age in the catch (kg)					
2000	0.0146	0.0218	0.0235	0.0261	0.0332
2001	0.0136	0.0189	0.0217	0.0256	0.0328
2002	0.0116	0.0185	0.0217	0.0259	0.0333
2003	0.0105	0.0218	0.0245	0.0287	0.0385
2004	0.0108	0.0213	0.0243	0.0291	0.0384
2005	0.0162	0.0241	0.027	0.0316	0.0393
2006	0.0146	0.022	0.0246	0.0285	0.0366
2007	0.0141	0.0219	0.0246	0.0285	0.0364
2008	0.0104	0.0187	0.0213	0.0245	0.0312
Stock weight-at-age in the stock (kg)					
2000	0.0036	0.0152	0.0201	0.0237	0.0383
2001	0.0036	0.0152	0.0201	0.0237	0.0383
2002	0.0036	0.0152	0.0201	0.0237	0.0383
2003	0.0049	0.0111	0.0128	0.0160	0.0229
2004	0.0049	0.0117	0.0243	0.0276	0.0516
2005	0.0076	0.0196	0.0214	0.0227	0.0487
2006	0.0089	0.0210	0.0248	0.0265	0.0312
2007	0.0036	0.0171	0.0198	0.0235	0.0339
2008	0.0039	0.0149	0.0185	0.0314	0.0379

ing the maturity at age and the weight at age in the stock.

Reference age for the catches at age was age group 1, since it was fully exploited. The age groups 0, 3 and 4 were underweighted in the analysis as they were considered marginal ages in terms of their percentage in the catch. Age group 1 concerning the tuning index was underweighted (by 0.5) as sardine juveniles present a strong coastal behavior resulting in a reduced catchability of the acoustic surveys for this age group (TSAGARAKIS *et al*., 2008). The ICA model was implemented, assuming 6 years of

Table 2
Tuning index: numbers-at-age (10^6) of the stock as estimated by acoustics. Age 3 is a plus group. NA=Non Available.

Year	Age 1	Age 2	Age 3+
2003	742.1	364.9	37.5
2004	472.7	83.5	21.4
2005	779.8	183.7	42.1
2006	1496.6	408	28.2
2007	NA	NA	NA
2008	1844.2	170.4	10.3

separable constraint for fishing mortality, using a constant selection pattern for all years. The complete model description and the index weighting for the age groups are given in Table 3.

The fitting of the parameters was achieved by direct minimization of the objective function. The sums of squared differences (SSQs) between the observed and the modelled values for the catches and the relative index of abundance (tuning index) under the assumption of lognormally-distributed errors were:

$$\min [\Sigma_{a,y}(\ln C_{a,y} - \ln C'_{a,y})^2 + \lambda\Sigma_{a,y}(\ln I_{a,y} - \ln I'_{a,y})^2 \quad (4)$$

where *C, C', I* and *I'* are the observed and the estimated values for the catches by age and the age-structured abundance index respectively. The subscripts *a, y* refer to age and year and finally *λ* is a weighting factor related to the tuning index, defined by the user. The model fit was also examined based on the possible detection of a pattern in the log residuals graph of the catches as well as on the graph of the fitted selection pattern.

ICA model was implemented in R (www.r-project.org) using the FLICA version 1.4-11 in the FLR framework (the Fisheries Library in R, KELL *et al*., 2007).

Natural mortality (M)

The natural mortality (M) estimation was based on the following empirical equation:

$$M = [B / (t_2 - t_1)] * \ln (t_2 / t_1) + A , t>0$$
[Probiom (ABELLA *et al*., 1997)] (5)

which results from the integration of Caddy's (1991) formula

$$M_t = A + B/t, M_t>0, t>0 \quad (6)$$

where *t* is age, *A* is asymptotic natural mortality and *B* is the slope of natural mortality curve with age. In order to estimate *A* and *B* the L-W relationship parameters (*a,b*) and the VBGF parameters (*K, L∞*) were used as well as Probiom Excel spreadsheet. The resulting vector of M varied at age is kept constant for all years.

In addition, the sensitivity of the ICA assessment to different M values was estimated by repeating the assessment for the following 3 empirical equations (in addition to the Probiom equation of ABELLA *et al*., 1997):

$$\ln M = a + b \ln L + c \ln L_\infty + d \ln K$$
(Gislason *et al*., 2008) (7)

where *L* (cm), *LA* (cm) and *K* are parame-

Table 3
ICA model description and index weighting regarding sardine stock in the North Aegean Sea for the period 2000-2008.

ICA model parameters	Description
Natural mortality	Based on 4 different empirical equations (PAULY 1980, LONGHURST & PAULY 1987, ABELLA *et al.* 1997,1998, GISLASON *et al.* 2008)
Acoustic surveys	Series 2003-2008 (lack of 2007)
Age range in the analysis	0 to 4
Number of years for separable constrain	6
Reference age for separable constraint	1
Selection pattern model	Constant
Selectivity at final age 4	0.4
Plus group	The last age of acoustic surveys (ages 1 to 3+)
Catchability	Linear relationship assumed for the acoustic surveys
Catchability regarding landings	Considered constant with time
Weights for the age structure tuning index	Weight 0.5 for Age 1 Weight 1.0 for Age 2 Weight 1.0 for Age 3+
Weights for the catch at age observations in the separable period contribution	Weight 0.01 for Age 0 catches Weight 1 for Ages 1 and 2 catches Weight 0.3 for Age 3 catches Weight 0.01 for Age 4 catches

ters of the VBGF and *a, b, c, d* are constants and equal with 0.66, -1.69, 1.45, 0.9 respectively,

$$\ln M = -0.22+0.3*\ln T*K \quad \text{(LONGHURST \& PAULY, 1987)} \quad (8)$$

where T (ΓC) is temperature in Celsius scale,

$$\log M = -0.0066 - 0.279 \log LA + 0.6543 \log K + 0.4634 \log T \quad \text{(PAULY, 1980)} \quad (9)$$

Medium term forecast of biological parameters and catches

Medium term forecast of the biological parameters and catches of the North Aegean sardine stock for a 10 year period was implemented in R using the FLR libraries and based on the results of the ICA stock assessment analysis. Maturity at age, natural and fishing mortality, weight at age in the catch and in the stock, catch and stock numbers at age were used as input parameters for the medium term forecast. Maturity at age, weight-at-age in the catch and in the stock was estimated as the mean of the last 3 years.

The scenario used in the medium term forecast assumed a decrease of the F by 2015, towards a value that corresponds to an exploitation rate equal to 0.4. This value is the empirical reference point (E=0.4) suggested by Patterson (1992) for small pelagic species. The stock-recruitment relationship was based on the Ricker's (1954) model for the observed SSB range from 2000 to 2007:

$$R_t = S_t \, e^{\alpha+\beta St} \quad (10)$$

where R_t is recruitment in year t , S_t is stock spawning biomass, α and β are the density-independent and density-dependent parameters of the Ricker model, respectively. The Ricker model is one of the most widely used to describe the fish stock – recruitment relationship, frequently used for small pelagic fish species like the European sardine (CSIRKE, 1980; ZHAO *ET AL*., 2003; MORALES & NEVAREZ 2005; KNOWLER, 2007). Runs were made implementing 500 simulations per run calculating the stochasticity in recruitment. Recruitment was multiplied by log-normally distributed noise with a mean of 1 and a standard deviation of 0.3.

Results

Landings

Sardine landings derived from the commercial purse seine fishery in the North Aegean Sea varied over the period 2000-2008 (Fig. 3) presenting a decreasing trend which was not statistically significant ($P>0.05$). Landings ranged from a minimum value of 8260 t in 2003 to the maximum of 19115 t in 2001 with a mean value around 12420 t.

Biological parameters

Length frequency distribution was estimated on a semester basis for the period 2003-2008 and is presented in Figure 4. In total, the TL of sardine ranged between 75 and 185 mm (mean length = 137.24mm ± 0.31). The dominant length class had mid length 135 mm for all years besides 2005 when the mid-length of the dominant class was 145 mm. The length range of the highest percentage of specimens (>90%) was between 125 and 155 mm mid-length. An increase towards smaller length classes was observed in the second semester due to the recruitment to the fishery of the young of the year sardines.

The mean length at age in the population at survey time and in the fishery for the period 2003-2008 is presented in Figure 5. The range of the mean length at age is wider in the surveys' samples (population),fluctuating from 83 mm (age 0 in 2008) to 179 mm (age 4 in 2003) than in those of the fishery

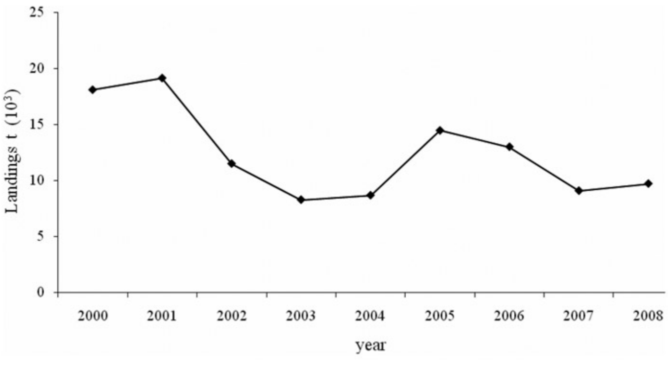

Fig. 3: Sardine annual landings derived from the commercial purse seine fishery in the North Aegean Sea over the period 2000-2008.

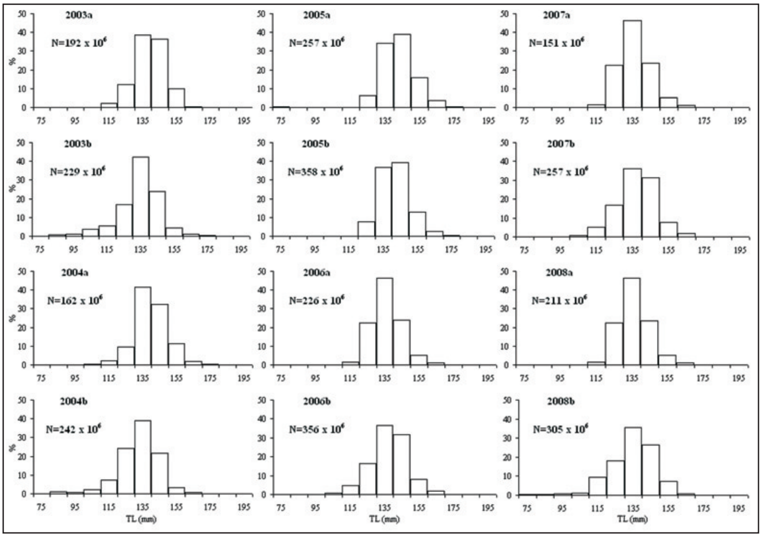

Fig. 4: Length-frequency distribution of sardine in the North Aegean Sea per semester (a=1st and b=2nd semester) for the period 2003-2008. (N = number of specimens per vessel in the sample weighted to the total production of the vessel).

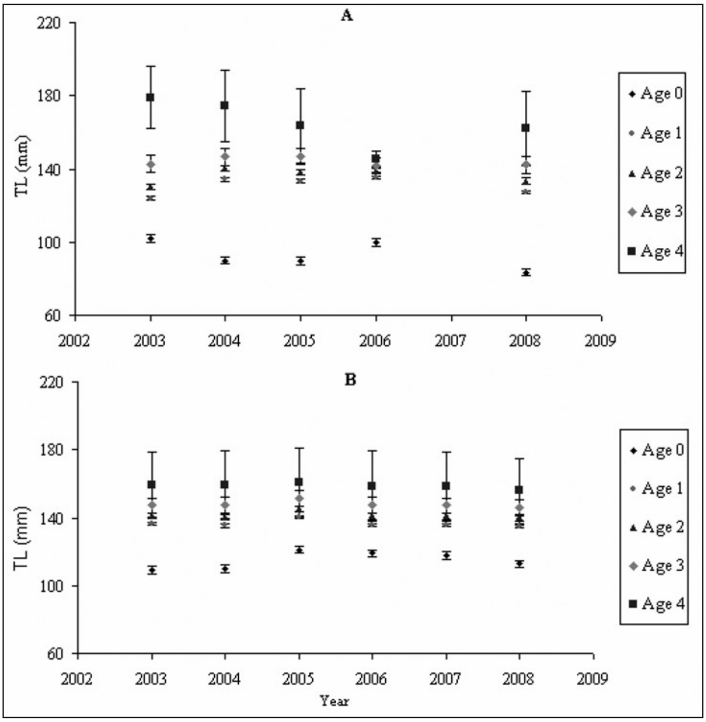

Fig. 5: Mean length at age for sardine population (A) and sardine landings (B) over the period 2003-2008.

(landings), fluctuating from 109 mm (age 0 in 2003) to 161 mm (age 4 in 2005). The mean length at age 0 is higher on average (115 mm) in the fishery than in the population (93 mm). The age structure in the sardine stock for the period 2003-2008 and in the sardine catch for the period 2000-2008 is shown in Figure 6. The dominant age group in the sardine stock and in the catch alike is that of age 1.

Natural mortality

Natural mortality values for sardine stock in the North Aegean Sea are presented in Table 4 as calculated by the implementation of 4 different empirical equations. The empirical equations of PAULY (1980) and LONGHURST & PAULY (1987) estimate constant values for all ages and years. Contrary to this, the empirical equations of PROBIOM & GISLASON *et al*. (2008) calculate different values per age group.

Stock assessment - ICA

The graphical diagnostics of the model are shown in Figure 7, generally indicating good model fit besides the acoustic surveys index at age 2 in 2003 and 2006 and age 3 in 2005. The total sum of squared residuals surface plot (SSQ) presented a fairly minimum indicating moderately good model fit. In addition, the fitted selection pattern and the catch residuals scatter plot (Fig. 7) did not indicate any inconsistency of the model. Parameters' estimation concerning the catches also indicated good model fit as coefficients of variability (CVs) did not exceed 20% in most cases (Table 5). Regarding the estimated catchabilities of the surveys, catch-

Table 4
Natural mortality estimated values for sardine stock in the North Aegean Sea.

Empirical equations	Age 0	Age 1	Age 2	Age 3	Age 4
GISLASON et al., 2008	2.00	1.15	0.76	0.60	0.52
LONGHURST & PAULY, 1987	0.70	0.70	0.70	0.70	0.70
PAULY, 1980	0.80	0.80	0.80	0.80	0.80
Probiom (ABELLA et al. 1997, 1998)	1.50	0.96	0.69	0.61	0.57

Table 5
Parameter estimates of separable model.

Parm. No.	Maximum Likelh. Estimate	CV (%)	Lower 95% CL	Upper 95% CL	-s.e.	+s.e.	Mean of Param. Distrib.
Separable model:	**F by year**						
2003	0.6675	17	0.4724	0.9433	0.5596	0.7963	0.678
2004	0.5245	18	0.3675	0.7484	0.4375	0.6288	0.5332
2005	0.7416	15	0.5451	1.0091	0.6338	0.8678	0.7509
2006	0.8456	15	0.6284	1.1379	0.7267	0.9839	0.8554
2007	0.7445	16	0.5424	1.0219	0.6334	0.8751	0.7543
2008	0.8769	30	0.4831	1.5914	0.6469	1.1885	0.9184

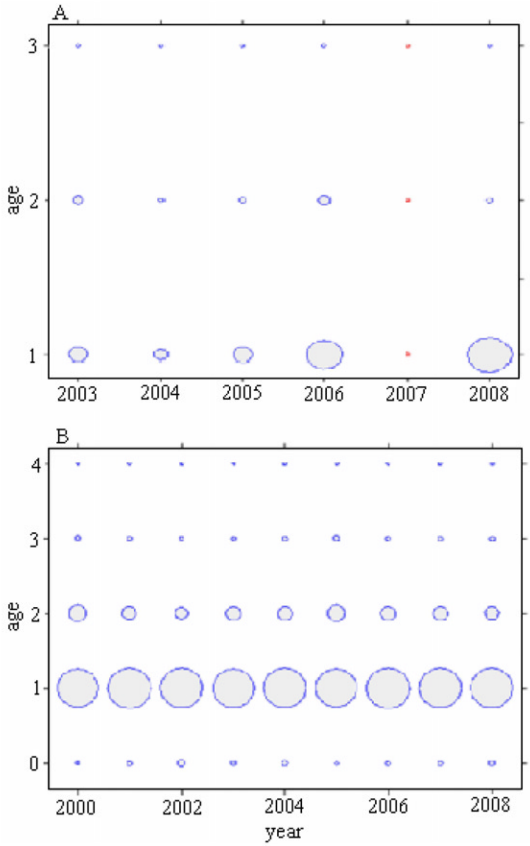

Fig. 6: Numbers at age in A. The North Aegean Sea sardine stock for the period 2003-2008 and B. in sardine landings for the period 2000-2008.

ability for age 2 was higher by 41% compared to age 1, while age 3 was lower by 22%. The estimated CVs of the catchabilities were also considered acceptable (Table 6). The residual variance of the age indices of the surveys was generally low and the absolute values of skewness and kurtosis were much smaller than 2, thus justifying the assumption of lognormally distributed errors (Table 7). The Analysis of Variance for the weighted fits of the results (Table 8) showed that most of the model variance originates from the age tuning indices of the surveys (NEEDLE, 2003).

The ICA model results concerning the estimated population abundance, the recruitment, the total biomass (TB) and the spawning (SSB) biomass and the mean fishing mortality for ages 1 to 3 (F_{bar}) are presented in Figure 8. The Exploitation rate (E) is also shown as the ratio of F to total mortality (E= F/(F+M)) calculated for ages 1-3 (E_{1-3}). The population abundance graph presents the estimated age structure in the stock based on the standard ICA model where Probiom empirical equation values are used concerning the natural mortality estimations. Age groups 0 and 1 are the most abundant age groups in the sardine population. Moreover, sensitivity analysis

Table 6
Age-structured index catchabilities. Acoustic surveys (ages 1 to 3+).

Linear model fitted. Slopes at age:				CV (%)	-s.e.	+s.e.	Mean of Param. Distrib.
20	1	Q	2093	27	2093	3642	2869
21	2	Q	2957	26	2957	5039	4000
22	3	Q	1632	56	1632	5057	3371

Table 7
Distribution statistics for acoustic surveys (ages 1 to 3+).

	Age 1	Age 2	Age 3+
Variance	0.0646	0.1451	0.0476
Skewness test stat.	-0.0458	-0.4529	-0.1984
Kurtosis test statistic	-0.6621	-0.5172	-0.6729
Partial chi-square	0.0125	0.0302	0.0113
Significance in fit	0	0.0001	0
Number of observations	5	5	5
Degrees of freedom	4	4	4
Weight in the analysis	0.1667	0.3333	0.3333

results in terms of the effect of different natural mortality values on the ICA model are also shown (Fig. 7).

Recruitment presents an increasing trend since 2006 with a maximum value in 2008. Both TB and SSB decreased up to 2003 but presented an increasing trend since then. F_{bar} and E vary over time, presenting similar trends showing the lowest values in 2002, 2004 and 2008 (around 0.85 and 0.5 respectively). Exploitation rate is well above the empirical reference point (E=0.4) suggested by Patterson (1992) for the sustainable exploitation of the small pelagic species, being on average 0.6.

Similar trends were observed in all cases regarding the sensitivity analysis results of the different estimations of M. However, the effect of the variability in M on the assessment results is more pronounced in terms of the absolute values of recruitment and TB. Generally, empirical equations that estimate M values that vary with age (i.e. equations 5 and 7) produced higher values in recruitment and TB compared to empirical equations (i.e. equations 8 and 9) that produced constant M values with age. Regarding SSB, the different M values resulted in less than 11% change in all cases, independently of the equation used. In the cases of F_{bar} and E_{1-3} the difference in the absolute values was less than 14% in both cases.

Medium term forecast of biological parameters and catches

The graphs in Figure 9 show the 5th, 25th, 50th, 75th and 95th percentiles for SSB, recruitment and catches from 2000 to 2020, considering a decrease of the F_{bar} by 48%

(F=0.49) for 2015 in order to catch the F (E0.4) and remain at this level for the rest of the forecasted period. The model predicts recruitment values that fluctuate around the level of 5300000 recruits on average for the whole predicted period ranging from 3960489 to 6716726 recruits. SSB exhibits a continuous increase since 2007, starting at the level of 5935 t and reaching the maximum level of 13892 t in 2020. Catches present a slight decreasing trend till 2015 and remain almost stable till 2020 at around 8000 t.

Discussion

The present work aims to describe the fishery and the status of the sardine stock in the North Aegean Sea over the last decade. This stock is one of the most important sardine stocks in the Eastern Mediterranean basin in terms of landings. Sardine landings as derived from the commercial purse seine fishery in the North Aegean Sea over the period 2000-2008 indicated a sharp decrease in 2002, oscillating since then around a mean value of 12420 t, although for the last two

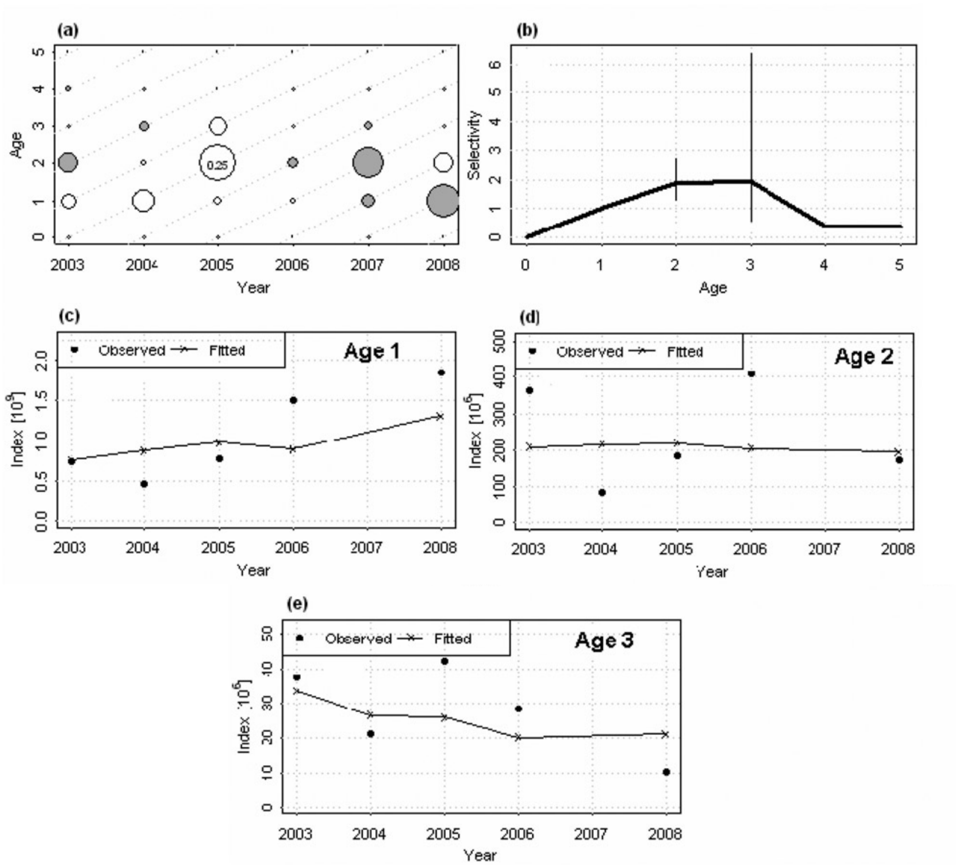

Fig. 7: Separable model (2003-2008) diagnostics graphs: (a) catch residuals, (b) selection pattern, (c) to (e) observed vs fitted index for age groups 1 to 3, respectively.

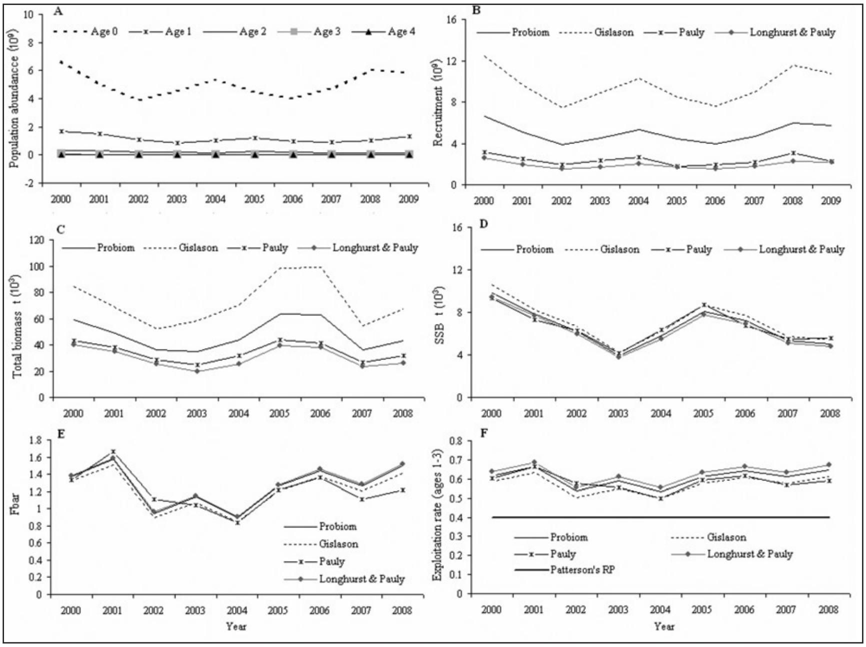

Fig. 8: ICA model results for the sardine stock assessment in the North Aegean Sea over the period 2000-2008. A. Estimated population abundance, B. recruitment in numbers, C. total biomass, D. stock spawning biomass, E. F_{bar} and F. exploitation rate for ages 1 to 3.

years landings have been low, around 9000 t. Based on the catch-at-age information derived from otolith reading, sardine in the North Aegean Sea presented an age range from 0 to 4 years. This age range is very narrow compared to that found in the Atlantic (SILVA *et al*., 2008), and also compared with other Mediterranean Sea sardine stocks (CINGOLANI *et al*., 2005; SANTOJANNI *et al*., 2005; Silva *et al*., 2008). Age group-1 and age group-2 were dominant, ranging from 68 to 73% and from 17 to 26% of the total catch respectively. The lack of previous studies on the age structure of sardine landings in the North Aegean Sea does not allow any comparison with the past status of this fishery. Sardine landings in the Adriatic Sea present an age range which exceeds the age group-6 having as dominant age the age group 3 (CINGOLANI *et al*., 2005; SANTOJANNI *et al*., 2005) whereas in the Western Mediterranean, the age range

Table 8
ICA model analysis of Variance (weighted statistics).

	SSQ	Data	Parameters	d.f.	Variance
Total for model	0.4815	45	22	23	0.0209
Catches at age	0.1815	30	19	11	0.0165
Aged Indices of acoustic surveys	0.3	15	3	12	0.025

in sardine landings exceeds age group-5 having as dominant the age group-0 and the group-1 (BELLIDO *et al*., 2008a,b).

Moreover, the length distribution in sardine landings in the North Aegean Sea presented on average smaller mean length (137mm) compared to the Adriatic Sea (approximately 160-170mm, SGMED, 2009a) and the Western Mediterranean (183 mm in Alboran Sea and 168mm in the northern Spanish waters, BELLIDO *et al*., 2008a,b). The examination of the catch length-frequency distributions on a semester basis indicated an increased representation of the

Table 9
Von Bertalanffy growth parameters for sardine in Greek waters and in other areas of the Western and Central Mediterranean Sea.

Area	Year	K (1/year)	L;∞ (mm)	t_o	Sampling	Method	Reference
Northern Alboran Sea	2000-2007	0.25	241	-2.663	Purse seine landings	Otoliths	BELLIDO *et al.* (2008a)
Southern Alboran Sea	2007	0.56	213	-0.670	Purse seine landings		IDRISSI (2008)
Northern Spain	2000-2007	0.25	241	-2.663	Purse seine landings	Otoliths	BELLIDO *et al.* (2008b)
South of Sicily	1997-2009	0.21	205	-4.260	Purse seine and pelagic trawl landings	Otoliths	PATTI *et al.* (2009)
Northern Adriatic	1975-2008	0.38	188	-2.302	Purse seine and pelagic trawl landings	Otoliths	SANTOJANNI & CINGOLANI (2009)
North Western Aegean Sea	1996-2003	0.80	219		Purse seine landings	Length-frequency analysis	TSIANIS (2003)
North Western Aegean Sea	1996-1999	0.86	208		Purse seine landings	Length-frequency analysis	VOULGARIDOU & STERGIOU (2003)
Aegean and Ionian Seas	1983-1984	0.30	181	-3.210	Purse seine landings	Scales	TSERPES & TSIMENIDES (1991)
Central Aegean and Ionian Seas	1999-2001	0.31	191	-1.839	Research surveys and purse seine landings	Otoliths	MACHIAS *et al.* (2001)
N. Aegean Sea	2000-2008	0.39	195	-0.480	Purse seine landings and research surveys	Otoliths	Present study

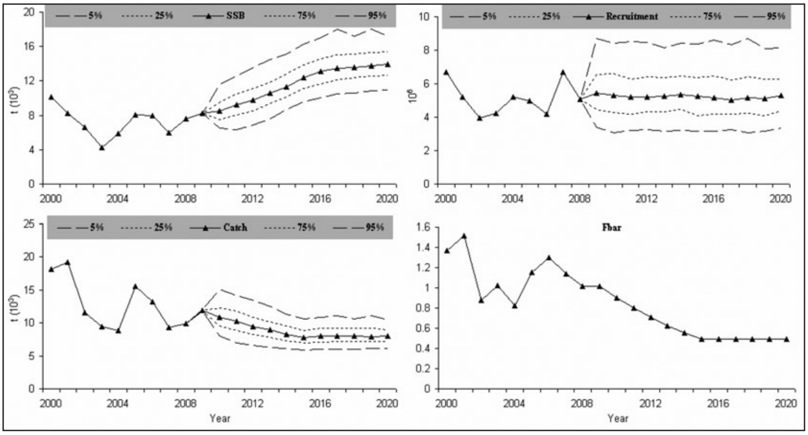

Fig. 9: Medium term forecast for sardine stock in the North Aegean Sea based on ICA model results. SSB, recruitment, catches with 5th, 25th, 50th, 75th and 95th percentiles and F_{bar}.

smaller length classes in the catch (<115mm) regularly during the second semester, a period when the young of the year join the adult population so being accessible to the fishery.

Age and growth studies for sardine in Greek waters are limited and otolith interpretation was not validated in general (SOMARAKIS *et al*., 2006b). Growth parameters (K, LA) for sardine within the current work have been estimated based on otolith reading and are presented in Table 10 in comparison to the respective values that have been found in literature concerning the past status of this fishery in Greek waters. Moreover, growth parameters from other areas of the Western and Central Mediterranean Sea, estimated during the same period, are presented comparatively. Similar K values are found when estimations are derived from the same estimation method used independently of the area, the period or the sampling procedure. Lower K values are estimated when age is determined based on skeletal structure readings (otoliths or scales) compared to the K values estimated when the assignment to age is done based on length data only. Moreover, in the study area, sardine is characterized by intermediate LA and relatively low K values when compared with the respective estimates of previous studies in the Western Mediterranean and Eastern Adriatic Sea (PERTIERRA & MORALES-NIN, 1989; ALEMANY & ALVAREZ, 1993). The estimated L-W relationship parameters approximately coincide with the values estimated from past studies concerning sardine in Greek waters (VOULGARIDOU & STERGIOU, 2003).

In order to assess the North Aegean Sea sardine stock, a separable VPA stock assessment technique, the Integrated Catch-at-Age model (ICA, PATTERSON & MELVIN, 1996), was implemented on sardine landings data incorporating information from fishery independent surveys for tuning the VPA. The ICA model based on different natural mortality estimates per age group, estimated F_{bar} values (averaged over ages 1 to 3) that vary from 0.85 to 1.46. Mean exploitation rate (F/Z ratio) for ages 1 to 3, fluctuates from 0.5 to 0.6 during the whole time series of data (2000-2008) being above the empirical reference point of E (0.4) suggested by PATTERSON (1992). According to PATTERSON (1992), the possibilities for a stock to increase or to decrease are equal when $0.3 \leq E \leq 0.5$ and just a few stocks have managed to recover with E>0.5. The current value of E for sardine lies on a lower level in comparison with the mean value of E=0.76 as estimated in the work of VOULGARIDOU & STERGIOU (2003) for the period 1996-2000 in the Northwestern Aegean Sea. Based on these aforementioned results the North Aegean Sea sardine stock is considered fully exploited with the fishery operating close but over a sustainable exploitation level. However, results on recruitment indicate a slight increase during recent years, since 2006.

Taking into account recent assessment results concerning the status of sardine stocks in other Mediterranean regions we note different trends concerning the recruitment (R) within the last decade among different areas. In the Northern Alboran Sea and Northern Spain the highest R values were estimated in 2004, whereas in the Adriatic and the North Aegean Sea during recent years (2007-2008) the highest levels of R were observed (SGMED, 2008; BELLIDO *et al*., 2008a,b; SGMED 2009b; ANONYMOUS, 2010). Low R recruitment values have been observed for most areas (i.e. the North Aegean Sea, Northern Alboran Sea and Northern Spain) in 2002 (SGMED, 2008; BELLIDO *et al*., 2008a,b). Low values were also observed in the Adriatic Sea and in the Northern Alboran Sea in 2006 (SGMED, 2008; BELLIDO *et al*., 2008a; SGMED, 2009b). Similarly, concerning the SSB values an increase has been noticed in all four aforementioned areas since 2003 (SGMED, 2008; BELLIDO *et al*., 2008a,b; SGMED, 2009b; current paper) despite the differences in the absolute values among these areas.

Concerning the degree of exploitation besides the North Aegean Sea, most sardine stocks in the Mediterranean seem to suffer a high degree of exploitation, being harvested close to or over sustainability in most areas. In the Western Mediterranean, E for sardine ranges from 0.5 to 0.7 in the Northern Alboran Sea (2000-2007) and Northern Spain (1994-2007), so it is above the Patterson reference point (BELLIDO *et al*., 2008a,b; SGMED, 2008, 2009b) whereas in the Northern Adriatic Sea (SGMED, 2009b) sardine stock generally exhibits, for the period 1975-2008, an exploitation rate (E) which is below the Patterson threshold, besides a short time period (1999-2003) when E exceeds this threshold. Since different fishing regimes have been applied in the different areas resulting into different degrees of exploitation, any similarities in the trends of the SSB and the recruitment in the different sardine stocks could potentially be attributed to a common temporal variability of the favourable environmental conditions for spawning and recruitment over the Mediterranean region. Such a scenario presents special interest and deserves more thorough research.

Moreover, the uncertainty in the estimation of the natural mortality (M) may have a strong impact on the assessment of the stocks and especially in the case of short lived species like sardine (QUINN & DERISO, 1999). Several authors have suggested the use of a constant M value for all age groups or size classes while others have introduced the use of a variable one with age where the estimation of M relies on empirical equations that incorporate growth parameters (CADDY, 1991; ABELLA *et al*., 1997; ANDERSEN & BEYER, 2006; POPE *et al*., 2006; GISLASON *et al*., 2008). Within the present work two constant (PAULY, 1980; LONGHURST & PAULY, 1987) and two varying with fish age and size

M values [ABELLA *et al*., 1997 (Probiom); GISLASON *et al*., 2008] were used for the implementation of the ICA stock assessment model. The differences among the estimated values of TB and recruitment based on these four M equations were higher compared to the variation in the respectively estimated SSB values. More precisely, the GISLASON *et al*. (2008) empirical equation for M produced the highest values of recruitment and TB, followed by the Probiom (ABELLA *et al*., 1997), whilst the constant M values of the equations of PAULY (1980) and LONGHURST & PAULY (1987) gave the lowest values. Parameters M and recruitment (R) are positively correlated. This means that for a given age structure the higher the M values estimated at the young ages (i.e. Gislason and ProBiom equations estimates) the higher the model estimates of R and TB should be in order to adjust to the observed minimum abundance differences between the older fish (ages 2 and 3) indicated by landings, and the young ones detected by the surveys. Regarding the SSB, F_{bar} and exploitation rate, the differences in the estimated values based on the four empirical M equations were minimal, varying less than 15%. These parameters are mainly related to ages 1 to 3. Therefore, the smaller variation of M estimated at the greater age classes is reflected in the lower variation of these population parameters.

Current stock assessment results suggested that in theory, F value (F_{bar}=0.49) has to decrease by 48% in order to meet the sustainable exploitation level of E=0.4 in the North Aegean Sea. A medium term forecast was implemented for a 10 year period using the Ricker's stock-recruitment model (RICKER, 1954) and assuming a progressive decrease of the F by 2015, towards the Patterson sustainable exploitation level (E=0.4). Under this scenario catches present a slight decreasing trend till 2015 (to about 8350 t) and then stabilize around a median of 8500 t until 2020. Such a decrease of F would cause a subsequent increase of SSB reaching the maximum level of 14400 t (median) in 2020.

In conclusion, the sardine stock in the North Aegean Sea over the period 2000-2008 is characterized by age groups 0 to 4 years old, with the age groups 1 and 2 being the dominant ones, based on age data derived from otoliths reading. These age groups are also dominant in the fisheries of other sardine stocks from the western and the central Mediterranean, but make a strong contrast with the Atlantic and the Adriatic (SANTOJANNI *et al*., 2005; BELLIDO *et al*., 2008a, b; SILVA *et al*., 2008).

Based on current stock assessment results the sardine stock was considered as fully exploited with the fishery operating close to but over the empirical level of stock decline suggested by PATTERSON (1992). However, a slight increase in the recruitment and the stock spawning biomass (SSB) in recent years could be associated with a slight recovery of the stock. The remaining noise shown by the fitting of the current model and the short length of the existing time series suggest that the current results should be taken with caution, not allowing yet the estimation of reliable biomass reference points for the sardine population. Moreover, similar to other Mediterranean areas, sardine in the study area are mainly exploited along with anchovy in the context of a multispecies fishery. As such, coherent management practices require also the consideration of the status of anchovy stock. Besides the application of management strategies that control the fishing effort, alternative strategies could also be examined, such as the potential benefit of changing the existing closed period for the purse seine fishery in the North Aegean Sea or the protection of certain areas that constitute sensitive spawning and nursery grounds for the species. According to Greek legislation there is a closed period for purse seine fishery from the middle of December till the end of February. A shift in the current closed period towards the end of the second semester, i.e. October to November when smaller length classes are more abundant in sardine landings should be examined with respect to the subsequent effects on the catches and the status of the stock (i.e. SSB and recruitment).

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