Mediterranean Marine Science

Vol 15, No 2 (2014)

Applying a two-stage Bayesian dynamic model to a short lived species, the anchovy in the Aegean Sea (Eastern Mediterranean). Comparison with an Integrated Catch at Age stock assessment model.

M. GIANNOULAKI, L. IBAIBARRIAGA, K. ANTONAKAKIS, A. URIARTE, A. MACHIAS, S. SOMARAKIS, S. SANCHEZ, B. A. ROEL

doi: 10.12681/mms.509

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.509

Applying a two-stage Bayesian dynamic model to a short-lived species, the anchovy, in the Aegean Sea (Eastern Mediterranean). Comparison with an Integrated Catch at Age stock assessment model

M. GIANNOULAKI[1], L. IBAIBARRIAGA[2], K. ANTONAKAKIS[3], A. URIARTE[4], A. MACHIAS[1], S. SOMARAKIS[1], S. SANCHEZ[4] and B.A. ROEL[5]

[1] Hellenic Centre for Marine Research, Institute of Marine Biological Resources, PO Box 2214, GR 71003, Iraklion, Greece
[2] AZTI-Tecnalia, Txatxarramendiugartea z/g, 48395 Sukarrieta, Spain
[3] Department of Biology, University of Crete, Vassilika Vouton, P.O. Box 2208, 71409 Heraklion Crete, Greece
[4] AZTI-Tecnalia, Herrera Kaia, Portualdea z/g, 20110 Pasaia, Spain
[5] Cefas, Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk NR33 0HT, UK

Corresponding author: marianna@hcmr.gr

Handling Editor: Argyro Zenetos

Received: 20 June 2013; Accepted: 7 May 2014; Published on line: 19 June 2014

Abstract

Two different stock assessment models were applied to the North Aegean Sea anchovy stock (Eastern Mediterranean Sea): an Integrated Catch at age Analysis and a Bayesian two-stage biomass based model. Commercial catch data over the period 2000-2008 as well as acoustics and Daily Egg Production Method estimates over the period 2003-2008 were used. The results of the two models were consistent, indicating that the anchovy stock is exploited sustainably in relation to an exploitation rate reference point. Furthermore, the stock biomass appears to be stable or increasing. However, the limitations in age-composition data, potential problems related to misinterpretation of age readings along with the existence of missing values in the survey data seem to favour the two-stage biomass method, which is based on a simplified age structure.

Keywords: Anchovy, Integrated Catch at Age Analysis, Bayesian, stock assessment, two-stage biomass-based model.

Introduction

The European anchovy (*Engraulis encrasicolus*) along with the European sardine (*Sardina pilchardus*) are the two most important small-sized pelagic fish species in the Mediterranean basin both in terms of economic and ecosystem parameters (Lleonart & Maynou, 2003). Anchovies are mainly fished by purse seiners although midwater pelagic trawls also operate in the Adriatic Sea, the Sicily Channel and French coastal waters (Lleonart & Maynou, 2003; Basilone *et al.,* 2006; Machias *et al.,* 2008). Gear operation and fishing practice are based on the spatial detection of major anchovy aggregations by means of echosounders. At the moment, no quotas apply to small pelagic stocks in the Mediterranean Sea and fisheries management is based on technical measures such as spatio-temporal closures, gear and mesh size, engine, Gross Tonnage restrictions and a minimum landing size at 9 cm.

Small pelagic fish like anchovy are known to exhibit high fluctuations regarding their abundance and distribution, largely depending on environmental conditions (Freon & Misund, 1999; Freon *et al.,* 2005). Most anchovy stocks suffer a high exploitation rate (ICES, 2009a; Cardinale *et al.,* 2009, 2010) that renders in-year monitoring, assessment and management of the stocks increasingly necessary. Due to the highly aggregative behaviour of small pelagic species, Catch per Unit Effort (CPUE) indices are considered unreliable (Csirke, 1988). The most effective monitoring programs are based on fishery-independent surveys such as egg or hydro-acoustic surveys (Barange *et al.,* 2009). Population size estimates can be integrated either directly into management plans (Barange *et al.,* 2009) or as input for stock assessment models (Daskalov & Mamedov, 2007; Chen *et al.*, 2008; Kirchner *et al.,* 2010; Antonakakis *et al.,* 2011).

One of the most important population features of anchovies is their short life span, which strengthens the dependence of these stocks on the in-year successful recruitment, causing fluctuations of population size. Specifically, the European anchovy in the Atlantic is known to live up to 3-4 years old (Uriarte *et al.,* 1996; ICES, 2009b). In the Mediterranean, the bulk of anchovy individuals lives up to 4 years in the western basin, with only a few reaching the age of 5 (e.g. Spanish Mediterranean waters, see Morales-Nin & Pertiera, 1990; Cardinale *et al.,* 2009). In the Adriatic Sea, the life span can reach 6 years (Santojanni *et al.,* 2003) whereas in the Strait of Sicily and the Aegean Sea anchovy individuals rarely exceed the age of 3 years (Cardinale *et al.,* 2009). This is also the case in the Gulf of Cadiz (Ruiz *et al.,* 2009). Therefore, the effective application of fully age-structured stock assessment models can be questionable, especially in cases where the age of individuals does not exceed 3 years.

A simpler and less data demanding approach is a two-stage model (Collie & Sissenwine, 1983; Roel & Butterworth, 2000; Mesnil *et al.*, 2009; Roel *et al.,* 2009) that separates the recruits from the rest of the population. This type of models have been implemented to the Bay of Biscay anchovy stock (Ibaibarriaga *et al.,* 2008*,* 2011; Trenkel, 2008) and shown to track sufficiently the main dynamics of the population. The two-stage biomass-based model (BBM) in Ibaibarriaga *et al.* (2008, 2011) was implemented within a Bayesian context (Punt & Hilborn, 1997; Gelman *et al.,* 2004) accounting for the level of catches occurring throughout the year. The two-stage biomass random-effect model applied to the same stock by Trenkel (2008), is based on survey abundance indices and no catches were used. In both cases, the population is separated into two distinct age groups, the recruits (1-year old fish) and the fish being 2 or more years old, and the dynamics is described in terms of biomass.

The Aegean Sea anchovy stock is the most important pelagic resource in the Greek Seas and together with sardine comprise about one third of the total fisheries catch. It belongs to the eastern Mediterranean anchovy stock that presents reduced gene exchange with the respective stocks of the NW Mediterranean and the Adriatic Sea (Magoulas *et al.,* 1996), presenting also differences in terms of population characteristics (Somarakis *et al.,* 2004). The main anchovy distribution grounds in the Aegean Sea (Figure 1) are located within the continental shelf of the North Aegean Sea and the semi-closed areas along the western coast (see more details in Giannoulaki *et al.,* 2004, 2008; Somarakis *et al.,* 2007). Anchovy spawning in the North Aegean Sea occurs from May till September with a peak during June – July. Anchovies mature after completing their first year of life (Somarakis *et al.,* 2004). However, differences can be observed between the eastern part (Thracian Sea and Strymonikos Gulf) and the western part (Thermaikos and North Evoikos gulfs) as shown in Somarakis *et al.* (2012). The stock is harvested, almost exclusively, by the purse seine fleet since pelagic trawls are banned and benthic trawls are allowed to fish small pelagics in percentages less than 5% of their total catch, according to Greek legislation. Commercial catch is sampled regularly since 2003. Fishery independent monitoring with the Daily Egg Production Method and hydro-acoustic survey also takes place once a year since 2003, during early summer at the peak of the spawning season.

In the present study, the North Aegean Sea (N. Aegean Sea) anchovy stock was assessed using two different models: The Integrated Catch-at-age Analysis (ICA) by Patterson & Melvin (1996), which is a fully age-structured model that assumes a period in which fishing mortality is separable into age- and year- effects. The earlier years are modelled backwards by Virtual Population Analysis (VPA). In addition, a Bayesian two-stage biomass-based model, similar to the one used in ICES for the Bay of Biscay anchovy (Ibaibarriaga *et al.,* 2008; ICES, 2009a) was applied. This application takes into account data on maturity to estimate spawning stock biomass, and the parameter accounting for growth and natural mortality is allowed to differ by age group. Our work aims to compare how both stock assessment models describe the exploitation status of this stock.

Materials and Methods

Data

Representative anchovy landings data were obtained on a seasonal basis from 2000 to 2002 and on a monthly basis since 2003 to 2008 for the estimation of the length frequency distribution, the age structure and the biological parameters of landed anchovy. Anchovy landings data were obtained within the framework of the Hellenic Centre for Marine Research (HCMR) data collection system that supports the European Data Collection Framework requirements for the entire Greek part of the N. Aegean Sea (Fig. 1). Length frequency distribution was obtained on a semester basis and on average 20 to 25 otoliths (*sagittae*) from each sample and per each length class were removed and used for age determination. Age groups range from 0 to 4, with age 0 being less than 1% of the total catch (as it is practically bycatch) and age 4 being around 0.5% of the total catch due to the limited presence of this age group in the anchovy population. Prior to 2003, length frequency distribution was obtained on a semester basis and no Age – Length Key (ALK) was available. Thus, age determination was done based on the Von Bertalanffy Growth Function, using the ALK R library (Loff *et al.,* 2013). For years after 2003 the ALK was obtained based on otolith readings and applied on a semester basis, and subsequently the age structure of the landings was pooled on an annual basis. The Length-Weight relationships were estimated annually for the period 2003-2008. Landings in terms of biomass and numbers, catch at age, mean length and mean weight at age in the catch were also available.

Fishery independent information regarding the state of the anchovy stock was obtained from acoustic surveys (Giannoulaki *et al.,* 2008) and the Daily Egg Production Method (DEPM; Somarakis *et al.,* 2012) that were concurrently implemented during June 2003-2006 and 2008 in the N. Aegean Sea. A pelagic trawl was used

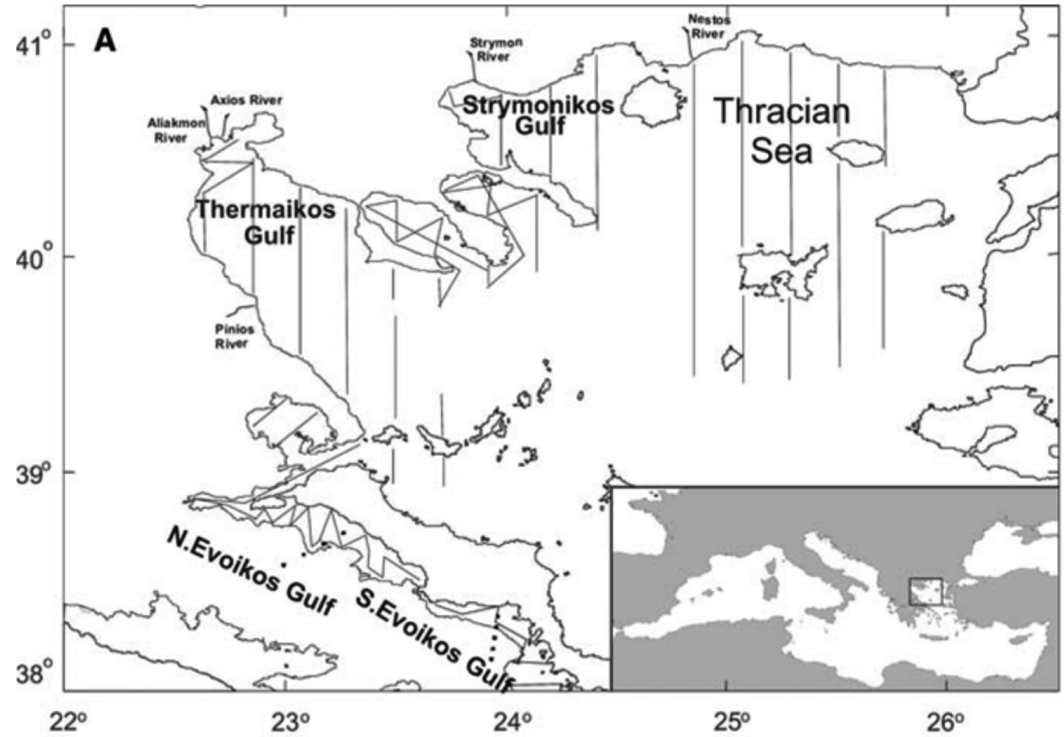

Fig. 1: Map of N. Aegean Sea, the main distribution area of anchovy in Aegean Sea, showing transects along which the acoustic and DEPM surveys were carried out in June 2003-2006 and 2008 (redrawn from Giannoulaki et al., 2008).

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 anchovy stock locally weighted by the acoustic abundance of the species (Simmonds & MacLennan, 2005). The weight at age in the stock was also estimated. Moreover, the maturity at age, based on biological sampling, was estimated from histological and macroscopic determination of the gonads (Somarakis *et al.,* 2004, 2007). The N. Aegean Sea was post stratified into two strata and the acoustic biomass estimation and the DEPM biomass estimation were applied separately in each stratum (Somarakis *et al.,* 2012). Details on survey characteristics, the acoustic methodology followed and the application of the DEPM are described extensively in in Somarakis (2005) and Somarakis *et al.* (2004, 2012).

Stock assessment

Integrated Catch at Age Analysis (ICA) for stock assessment (Patterson & Melvin, 1996; Patterson, 1998) as well as a two-stage biomass-based model (BBM), similar to the one used for the Bay of Biscay anchovy (Ibaibarriaga *et al.,* 2008), were applied to the N. Aegean Sea anchovy stock. ICA was was implemented within the FLR framework (the Fisheries Library in R, Kell *et al.,* 2007), whereas the BBM was implemented in WinBUGS (http://www.mrc-bsu.cam.ac.uk/bugs/; Lunn *et al.*, 2000) using the R2WinBUGS package (Sturtz *et al.*, 2005). The analysis of the results was conducted in R (http://www.r-project.org; R Development Core Team, 2012).

Integrated Catch at Age Analysis (ICA)

ICA is a fully age-structured model that considers, for a specific dataset, a period of 8 years (2000-2008) in which the catch-at-age data are measured with error and on which the fishing mortality is separable into age- and year- effects. Age-structured and spawning stock biomass indices are included as tuning indices.

Details about the equations used by ICA for the estimation of the numbers at age, the catch, the SSB and the fishing mortality are presented in Needle (2003). The optimal parameter values are obtained by minimization of the objective function, which is the sum of squared differences (SSQ) between the observed and the modelled values for the catch at age and the spawning stock biomass and age-structured tuning indices:

$$\Sigma_{a,y}\lambda_{a,y}\,(\ln C_{a,y} - \ln C'_{a,y})^2 + \Sigma_{y,B}\lambda_B\,(\ln I_{y,B} - \ln I'_{y,B})^2 + \Sigma_{a,y,A}\lambda_{a,y,A}\,(\ln I_{a,y,A} - \ln I'_{a,y,A})^2,$$

Where *C, C', I* and *I'* are the observed and the estimated values for the catches by age and the indices (total and age-structured) respectively. The subscripts *a, y* refer to age and year, A and B denote the survey's age-structured and SSB indices respectively. The weighting factor of each term in the objective function is denoted by *λ* with the corresponding subscripts.

For the N. Aegean Sea anchovy stock, the tuning indices were an age-structured index based on acoustic surveys and a non-age structured measure of the spawning-stock biomass (SSB) based on DEPM surveys over the period 2003-2006 and 2008. Since acoustics and DEPM

Table 1. ICA input: Natural mortality (M) of the anchovy stock in the N. Aegean Sea (Greek part) based on three different approaches; maturity at age, average biomass growth rates, age-structure indices from acoustics (age 3 is a plus group) and spawning biomass indices (SSB) from DEPM for the anchovy stock in the N. Aegean Sea (Greek part) over the period 2003-2008, NA: Non available.

Natural Mortality Equation	Age 0	Age 1	Age 2	Age 3	Age 4
Abella *et al.* (1997)	1.50	1.00	0.74	0.66	0.62
Gislason *et al.* (2010)	1.55	0.89	0.66	0.55	0.49
Chen and Watanabe (1989)	0.85	0.61	0.52	0.49	0.51

Average biomass growth rates

Age 1	Age 2+
0.1	0.25

Maturity at age

Year	Age 0	Age 1	Age 2	Age 3	Age 4
2003	0	0.62	0.99	1	1
2004	0	0.67	0.99	1	1
2005	0	0.46	0.98	1	1
2006	0	0.4	0.98	1	1
2007	0	0.4	0.98	1	1
2008	0	0.4	0.98	1	1

	Numbers at age (10^3)			SSB (t)
Year	Age 1	Age 2	Age 3+	
2003	850404	2177712	83246	40042
2004	1888498	1362566	10562	22799
2005	2003094	1029206	11681	20533
2006	5206168	1428316	132910	48700
2007	NA	NA	NA	NA
2008	4469332	2495923	95920	37404

have been applied concurrently during June-July using the same research vessel in the N. Aegean Sea, the assumed relationship between the age-structured indices was selected to have a linear formulation whereas the non-age structure measure was selected to have an absolute formulation (catchability fixed at 1). This selection was made due to the higher uncertainty in the acoustic estimates (age structure index) compared to the SSB estimates by DEPM (non-age structure measure). Using acoustic estimates as a relative index of abundance (thus linear formulation) is a common choice for the assessment of small pelagics stocks (e.g. ICES, 2006). ICA estimates take into account that the survey indices correspond to the middle of the year. The rest of the necessary data to fit the model comprised annual landings, annual catch at age data (numbers at age), and mean weight at age both in the catch and in the stock for the period 2000-2008. Information on age group 5 was added ad hoc because a minimum number of 5 age groups are required for ICA to run. Input (i.e. mean weight at age, natural mortality, etc) for this “fake” age group was based on the available information for age group 4, whereas the catch number at age was set to a minimum number of 100 individuals in all years. The maturity at age estimates and the results of acoustic and DEPM surveys that were used as tuning indices are presented in Table 1. Discards were estimated at less than 1% of the purse seine fishery total catch (Tsagarakis *et al.,* 2012), added to the total reported landings. Reference age for the fishery was age group 2, as fully exploited and fully recruited, for which the selectivity at age is fixed at 1. An eight-year separability period was selected. The age groups 0, 4 and 5 were down weighted in the analysis (i.e. 0.01, 0.01 and 0.001, respectively) given that ages 0 and 4 are considered undersampled in the catch and their numbers are associated with high uncertainty (Fig. 2). The small weight assigned to age group 5 reduces the effect of this “fake” age class in the analysis. Moreover, age 1 in the acoustic surveys was down weighted by 50% because it was assumed that only a part of the juvenile fraction of the population was available to the surveys, due to the coastal distribution of young anchovies and the loss from the analysis of a non-negligible part of age 1 anchovies that is distributed in the eastern part of the Thracian Sea, within Turkish terri-

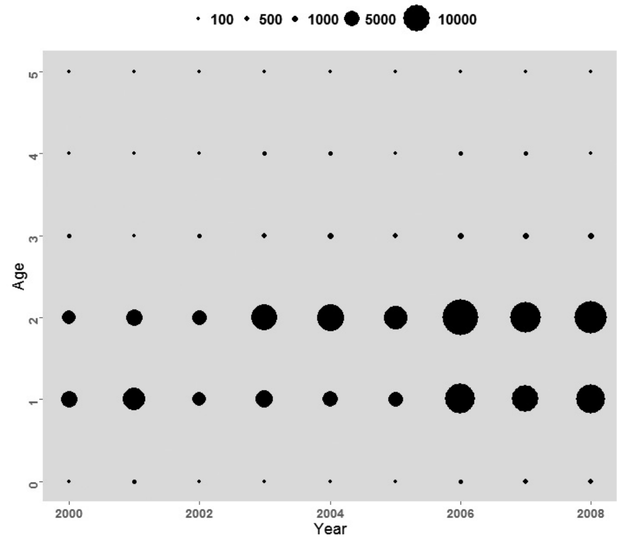

Fig. 2: Catch biomass per age group for Aegean Sea anchovy.

torial coastal waters. Within the framework of sensitivity analysis, three ICA runs were applied based on different natural mortality estimates. Specifically, natural mortality (M) values were estimated based on a) the ProBiom empirical equation (Abella *et al.,* 1997), b) the one proposed by Gislason *et al.* (2010) and c) the one proposed by Chen & Watanabe, (1989). In order to estimate the parameters for the above equations, the Von Bertalanffy Growth Function parameters (i.e. L_{inf}=19.1, t_o=-1.559, K=0.385 according to Cardinale *et al.,* 2009) and the L-W relationship parameters were used. The resulting vector of M varied per age group and was assumed to be constant across years (Table 1). Concerning the lack of acoustic and DEPM information for 2007, average values were used for the maturity ogive and the weight at age in the stock. The data series of catch and survey data are presented in Table 1.

The model fit was examined based on the possible detection of a pattern in the separable model residuals, the spawning biomass residuals, the age structured index residuals, the fitted selection pattern, the total sum of squared differences between the observed and the modelled values for the catches and the tuning indexes (SSQ plot) and the statistical diagnostics, such as the skewness and kurtosis values.

Moreover, the exploitation rate for each age group *a* in year *y* ($E_{y,a}$) was calculated as the ratio of fishing to total mortality ($E_{y,a} = F_{y,a} / (F_{y,a}+M_{y,a})$). The mean exploitation rate in year y, $E_{y,1\text{-}3}$ was computed as the arithmetic average across ages 1-3.

Bayesian two-stage biomass-based model

A Bayesian two-stage biomass-based model based on the one used for the Bay of Biscay anchovy (Ibaibarriaga *et al.,* 2008) was developed for the N. Aegean Sea anchovy stock for the period 2003 - 2008. The population dynamics are described in terms of biomass with two distinct age groups, fish aged 1 year and fish that are 2 or more years old (i.e. age group 2+). Biomass of each age group *a* decreases continuously in time according to an instantaneous rate of biomass decrease g_a accounting for intrinsic rates of growth G_a and natural mortality M_a, where $g_a = M_a - G_a$ for ages a = 1, 2+. Two periods are considered within each year. The first period goes from the beginning of the year to the date when the monitoring research survey takes place (approximately July 1st). The second period covers the rest of the year. The fraction of the year that corresponds to the first period is denoted by *f*. The time fractions from the beginning of the year to the time point within each period when commercial catch is assumed to take place are denoted by h_1(y) and h_2(y) respectively. Since age 0 fish are usually smaller than the legal minimum landing size (9 cm), this age group is not targeted by the fishery (representing less than 1% of the catch). Thus, this age group was not included in the Bayesian two-stage biomass and opposed to ICA where recruitment corresponds to age 0; here it is assumed that recruitment R_y in year y, corresponds to age 1 biomass and occurs as a pulse at the beginning of the year (Ibaibarriaga *et al.,* 2008).

$B(s_y, a)$ and $C(s_y, a)$ denote respectively biomass and catch (in tons) at age *a* at time instant *s* of year *y*. Then, the age 1 biomass at survey time is:

$$B(f_y,1)=R_y \exp\{-g_1 f\}-C(h_{1y},1)\exp\{-g_1(f-h_{1y})\},$$

and total biomass at survey time is given by:

$$\begin{aligned}
&B(f_y,1+) = B(f_y,1) + B(f_y,2+) = \\
&R_y \exp\{-g_1 f\} \\
&+B(f_{y-1},1)\exp\{-g_1(1-f)-g_2 f\} \\
&+B(f_{y-1},2+)\exp\{-g_2\} \\
&-C(h_{1y},1)\exp\{-g_1(f-h_{1y})\} \\
&-C(h_{2(y-1)},1)\exp\{-g_1(1-h_{2(y-1)})-g_2 f\} \\
&-C(h_{2(y-1)},2+)\exp\{-g_2(1-h_{2(y-1)}+f)\} \\
&-C(h_{1y},2+)\exp\{-g_2(f-h_{1y})\}.
\end{aligned}$$

Applying these equations recursively, total biomass at survey time in any year *y* can be expressed as a function of the initial biomass (B_0), defined as the total biomass at the beginning of the second period of year 0, i.e.

$$B_0 = B(f_{(0)}, 1+),$$

and all previous recruitment $R_1, R_2, \ldots, R_y$ and catch values.

Age 1 proportion in the population at survey time is calculated as the ratio between the biomass at age 1 and the biomass at age 1 and older:

$$P(f_y)= B(f_y,1) / B(f_y,1+).$$

In the Aegean Sea anchovy stock, not all individuals at age 1 are considered fully mature (Somarakis *et al.,* 2012), that resulted in the addition of maturity parameters for age 1. Thus, assuming that individuals at age 0 are fully immature and individuals aged 2 and older are fully mature, the spawning stock biomass at survey time

$$iSSB(f_y) = B(f_y,1)\, O_{y,1} + B(f_y,2+),$$

Where $O_{y,1}$ is the proportion of individuals that are mature at age 1 in year y (in terms of biomass).

Annual harvest rate (H) is defined as the ratio of the total catch at age 1 and older (ages targeted by the fishery) over the biomass (B) at age 1 and older:

$$H_y = (C(h_{1y}, 1+) + C(h_{2y}, 1+))/B(f_y,1+)$$

The estimates of spawning stock biomass from the DEPM and total biomass from the acoustic surveys are assumed to be log-normally distributed as follows:

$$\log(B_{ac}(f_y,1+)) \sim \text{Normal}(\log(q_{ac}) + \log(B(f_y,1+)), 1/\Psi_{ac})$$

and

$$\log(SSB_{depm}(f_y)) \sim \text{Normal}(\log(q_{depm}) + \log(SSB(f_y)), 1/\Psi_{depm}).$$

The parameters q_{depm} and q_{ac} denote the catchability of DEPM and acoustic surveys, whereas the parameters Ψ_{depm} and Ψ_{ac} represent the precision of the respective normal distributions.

In addition, the acoustic survey is assumed to provide estimates of the age structure of the population. The age 1 biomass proportions are taken as beta distributed with the mean given by the age 1 biomass proportion in the population and variance proportional to the product of age 1 and age 2+ biomass proportions, which is parameterized as follows:

$$P_{ac}(f_y) \sim Beta(\exp(\xi_{ac})\, P(f_y), \exp(\xi_{ac})(1 - P(f_y))).$$

For each year and each survey, it is assumed that the observation equations are independent of each other.

The unknown parameters are q_{depm}, q_{ac}, ψ_{depm}, ψ_{ac}, ξ_{ac}, g_1, g_2, B_0, R_y, for y = 1,...,Y (2003-2008) and the corresponding prior distributions considered are:

$$\log(q_{depm}) \sim \text{Normal}(\mu_{qdepm}, 1/\psi_{qdepm})$$
$$\log(q_{ac}) \sim \text{Normal}(\mu_{qac}, 1/\psi_{qac})$$
$$\psi_{depm} \sim \text{Gamma}(\alpha_{\psi depm}, b_{\psi depm})$$
$$\psi_{ac} \sim \text{Gamma}(\alpha_{\psi ac}, b_{\psi ac})$$
$$\xi_{ac} \sim \text{Normal}(\mu_{\xi ac}, 1/\psi_{\xi ac})$$
$$\log(B_0) \sim \text{Normal}(\mu_{B0}, 1/\psi_{B0})$$
$$\log(R_y) \sim \text{Normal}(\mu_R, 1/\psi_R) \text{ for } y=1,...,Y$$
$$\log(g_a) \sim \text{Normal}(\mu_g, 1/\psi_g) \text{ for } a=1,2.$$

Table 2 shows the data series of survey data and Table 3 specifies the hyper-parameters for the prior distributions and the corresponding 90% probability intervals.

From Bayes' theorem, the joint posterior probability density function of the unknowns is proportional to the product of the probability density functions of priors and observations. Inference is conducted by sampling from the posterior probability density function using Markov Chain Monte Carlo (MCMC) techniques (Gilks *et al.*, 1996). All posterior results are based on MCMC runs with a burn in period of $5E^6$ iterations, followed by $5E^6$ iterations, of which one out of 500 are kept. Inspection of the MCMC draws and analysis of the convergence was carried out using the CODA package (Convergence Diagnostics and Output Analysis; Plummer *et al.*, 2006).

Four different cases were explored depending on whether the DEPM spawning stock biomass is considered as absolute (i.e. q_{depm} fixed to 1) or relative (i.e. q_{depm} estimated) and the biomass decrease parameters by age g_1 and g_2 were considered estimated or fixed. Fixed biomass decrease parameters were set similar to ICA where natural mortality M at ages 1 and 2+ was fixed at the values estimated by ProBiom (Abella *et al.,* 1997) and Gislason *et al.* (2010) (Table 1), and the average biomass growth rates (Ga) were fixed at 0.1 for age 1 and 0.25 for ages 2+, as estimated from weight-at-age data.

- Run1: g_1 and g_2 are fixed to 0.9 and 0.4 respectively and q_{depm} estimated. The g_1 and g_2 were estimated

Table 2. BBM input: Historical data series of catch data by period with the corresponding timing and observations from the DEPM and acoustic surveys. $h_{1(y)}$, $h_{2(y)}$: time fractions from the beginning of the year to the time point within each period when commercial catch is assumed to take place; $C(h_{1(y)},1)$, $C(h_{1(y)},1+)$: catch at age 1 and age 1+ in tons at time instant $h_{1(y)}$ of year y; $C(h_{2(y)},1)$, $C(h_{2(y)},1+)$: catch at age 1 and age 1+ in tons at time instant $h_{2(y)}$ of year y; B_{ac}: total biomass from the acoustic survey at age 1 (or 1+) at year y; SSB_{depm}: spawning stock biomass from the DEPM at year y; f : the fraction of the year that corresponds to the first period.

Year	$h_{1(y)}$	$h_{2(y)}$	$C(h_{1(y)},1)$	$C(h_{1(y)},1+)$	$C(h_{2(y)},1)$	$C(h_{2(y)},1+)$	$B_{ac}(f_{(y)},1)$	$B_{ac}(f_{(y)},1+)$	$SSB_{depm}(f_{(y)},1+)$
2003	0.35	0.68	1351	6070	1852	8450	12117	47199	40042
2004	0.36	0.66	2610	9479	2569	7234	24156	46323	22799
2005	0.37	0.68	1013	7643	1961	9665	19520	31825	20533
2006	0.31	0.67	3532	12641	2521	11806	41807	61369	48700
2007	0.37	0.68	1596	3120	3440	8998	NA	NA	NA
2008	0.39	0.67	2756	8746	4238	14545	34499	59772	37404

Table 3. Hyper-parameters specifying the prior distribution and corresponding median (P50) and 90% probability intervals (P5 and P95) for the model parameters. q_{surv}: catchability of the survey; the parameters defining and intervening in the precision of the observation equations y_{surv} and x_{surv} for surv: depm, acoustic; B_0: initial biomass; R_y: recruitment at year y; g_a: instantaneous rate of biomass decrease; μ: the average of the respective distribution; y: the precision of the normal process error for the respective distribution.

Parameter	Hyper-parameters	P5	P50	P95
q_{surv}	m = 0 y 2 2	0.250	1.000	3.200
y_{surv}	*a* = 0.8 *b* = 0.05	0.183	10.027	51.903
x_{surv}	m 5 5 y = 0202	0.617	5.000	8.678
B_0	m = 15.5 y =1	5116	36316	188123
R_y	m = 17.7 y = 5.5	2774	44356	454146
g_a	m LNLN60.65) y = 1	0.092	0.650	3.367

based on the M for age 1 and the mean M for ages 2 to 4 as well as the corresponding growth rate, respectively.

- Run2: g_1 and g_2 are fixed to 0.9 and 0.4 respectively and q_{depm} fixed to 1.
- Run3: g_1 and g_2 are estimated and q_{depm} estimated.
- Run4: g_1 and g_2 are estimated and q_{depm} fixed to 1.

Results

Stock assessment

Integrated Catch at Age analysis – ICA

The fitted selection pattern and the catch residuals scatter plot did not indicate any inconsistency in the model. For practical reasons, the statistical and graphical diagnostics of the model fit are only shown for the best fitted ICA run which was based on the M estimates of the ProBiom equation (Fig. 3). This behaviour was similar for all ICA models (see graphical diagnostics of the separable model in Figures 3a to 3b and Table 4). The plot of the catch residuals (Fig. 3A) shows a different pattern between the years before and after 2003, which is probably due to the different splitting procedure used (i.e. growth parameters and von Bertallanffy equation before 2003 and ALK afterwards) and the lack of landings data on a seasonal basis prior to 2003. This pattern most likely drives the first negative and then positive catch residuals resulting from ICA for ages 1 and 2 in particular. This is something to be considered in future assessments and implies the need for monthly landings sampling and age splitting based on ALK instead of growth parameters.

The residuals of the DEPM index (Fig. 3F) and the acoustic surveys index at age 1, 2 and 3 (Figs 3C to 3E) also generally indicate good model fit besides 2006. This might be partly driven by the lack of survey data in 2007. Parameter estimation for the separable model indicated, consistently in all ICA runs, acceptable values of the coefficient of variation (CVs lower than 33%, Table 4A). The estimated catchabilities of the acoustic surveys for age 2 were 70% higher than for age 1 and almost 92% for age 3. The estimated CVs of the catchabilities were also considered acceptable (Table 4B). Pseudo analysis of variance table (ANOVA) for weighted fits (Table 4C) showed that the model variance remained at low levels although most of it derives from the SSB tuning index variance. The kurtosis and skewness values for the catches and the tuning indices were well below 2, showing no apparent overfiitting or underfitting (Table 4D). The total sum of squared differences (SSQs) between the observed and the modelled values for the catches and the tuning indexes (i.e. DEPM, acoustics) generally presented a fairly minimum under the assumption of log-normally-distributed errors (Needle, 2000; 2003). However, the SSQ plot of the ICA run based on the ProBiom equation estimates of M was the one with the best fit.

ICA model results for the three runs are presented in Figures 4A-4C (stock population abundance) whereas recruitment (abundance at age 0 at the beginning of the year), spawning stock biomass (SSB at survey time coinciding with the middle of the year) as well as mean fishing mortality (F) for ages 1 to 3 are presented in Figures 5A to 5D. Abundance of age groups 1 to 3 is rather stable up to 2004. Since then, the abundance of age groups 0, 1 and 2 sharply increases (Figs 4, 5A). SSB also presents an increasing trend, especially since 2005 (Fig. 5B). Mean $F_{1\text{-}3}$ and $E_{1\text{-}3}$ follow a decreasing trend, almost stabilizing at lower levels since 2004, varying between 0.31 (ProBiom run) and 0.37 (Chen and Watanabe run) (Figs 5C, 5D).

In order to determine whether the status of anchovy stock is harvested within safe levels, we compared stock status based on ICA model results and a biological ref-

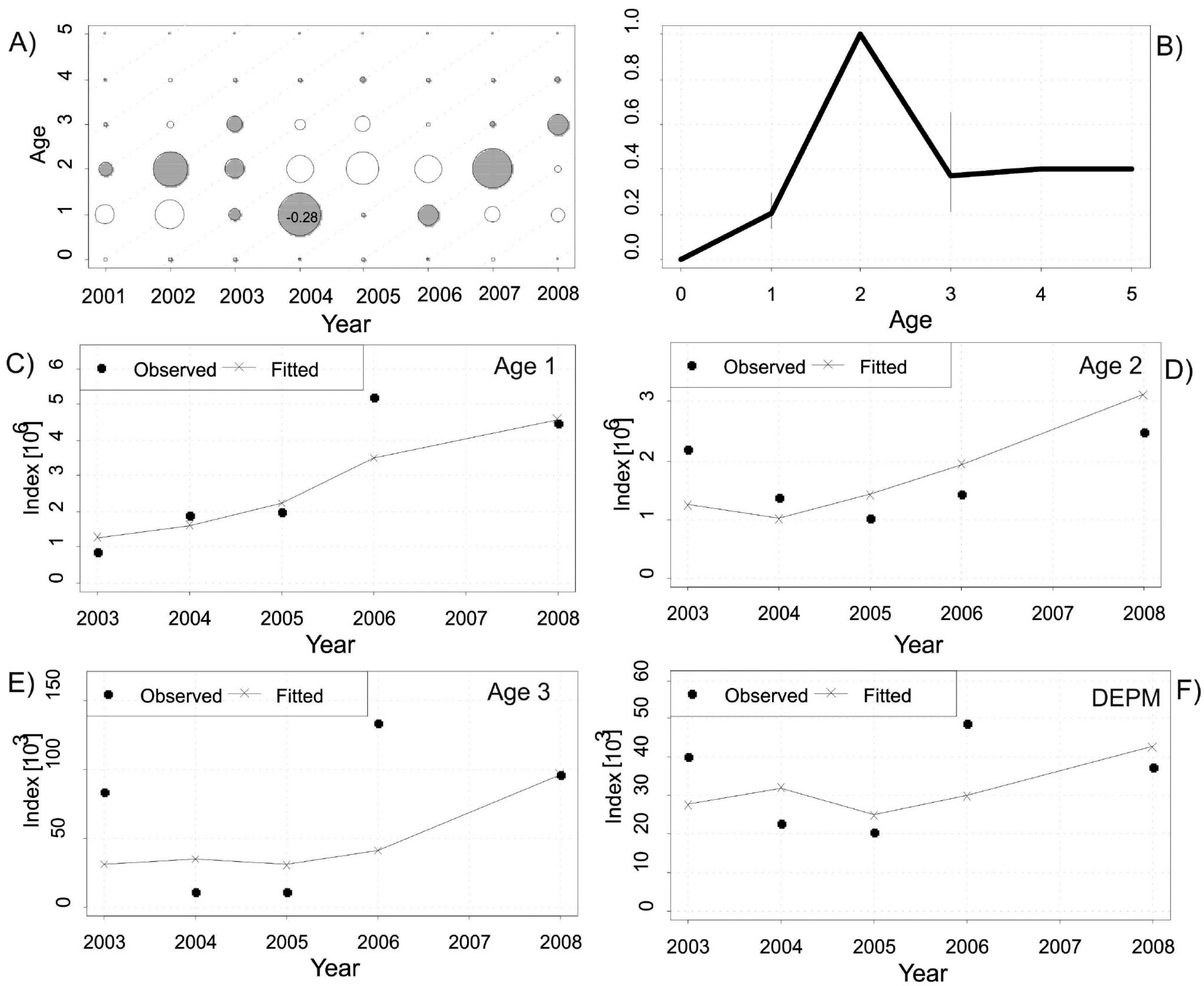

Fig. 3: ICA separable model diagnostics graphs for N. Aegean Sea (Greek part) anchovy: A) catch residuals, B) selection pattern, C) to F) observed vs fitted index for age groups 1 to 3 and SSB respectively. Diagnostics refer to the ICA run based on the ProBiom equation natural mortality estimate.

erence point. Most biological reference points are either minimum acceptable biomass level or maximum fishing mortality rates (Collie & Gislason, 2001). However, in the current stock we were not able to define any reliable spawning stock biomass reference point due to the short time series available (less than 10 years). Available information was insufficient to estimate an explicit stock-recruitment relationship, thus hampering ad hoc estimation of F_{MSY} (F at Maximum Sustainable Yield) and any biological reference point calculated based on this relationship (see Collie & Gislason, 2001 for biological reference points). In addition, the yield-per-recruit analysis applied showed that neither the commonly proposed fishing mortality level at $F_{0.1}$ (Gulland & Boerema, 1973), could be estimated due to the flat-topped shape of the yield-per-recruit estimated curve (not shown). Thus, we evaluated anchovy stock status based on the empirical reference point proposed by Patterson (1992) who concluded that a sustainable exploitation rate for small pelagic fishes (E=F/Z) is around 0.4. We consider this as a precautionary reference point. Recently, Zhou *et al.* (2012) concluded that F_{MSY} for teleosts is around 0.87·M (corresponding to an E of around 0.47). This further supports our choice of the aforementioned precautionary reference point. Specifically, ICA model results show that E_{1-3} (mean for the ages 1 to 3 targeted by the fishery) lies well below the 0.4 value (being around 0.32 to 0.36 depending on the run), denoting that the anchovy stock is likely to be harvested sustainably.

Bayesian two-stage biomass-based model

Chain behaviour was examined by visually inspecting traces, cumulative plots, and autocorrelation functions. Convergence diagnostics implemented in CODA confirmed that chain length, burn-in period, and thinning interval were sufficient to estimate the posterior median and 90% probability intervals with the reported accuracy.

Table 4. ICA fitting results: (A) Parameter estimates of the separable model, (B) age-structured index catchabilities (linear model fitted) - acoustic surveys (ages 1 to 3+) and **(C)** ICA model analysis of Variance (weighted statistics). (D) Distribution statistics for catches at age, DEPM and acoustic surveys (ages 1 to 3+) CL: Confidence level, CV: Coefficient of Variation, s.e.: standard error, d.f.: degrees of freedom, WSSQ: weighted sums of squared differences; F: fishing mortality; Q: catchability of the survey.

(A) Parm No.		**Maximum Likelihood Estimate**	**CV (%)**	**Lower 95% CL**	**Upper 95% CL**	**- s.e.**	**+ s.e.**	**Mean of Param. Distrib.**
Separable model: F by year								
1	2001	1.2346	32	0.659	2.313	0.896	1.701	1.299
2	2002	0.6703	30	0.371	1.212	0.495	0.907	0.702
3	2003	0.9729	25	0.587	1.612	0.752	1.259	1.006
4	2004	0.9501	26	0.564	1.601	0.728	1.239	0.984
5	2005	0.7440	27	0.438	1.2648	0.568	0.975	0.772
6	2006	0.8540	27	0.495	1.472	0.647	1.127	0.887
7	2007	0.7139	28	0.406	1.255	0.535	0.952	0.744
8	2008	0.6113	31	0.327	1.144	0.444	0.842	0.643

(B) Linear model fitted. Slopes at age:				**CV (%)**	**-s.e.**	**+s.e.**	**Mean of Param. Distrib.**
24	1	Q	0.701	34	0.503	1.945	0.701
25	2	Q	2.313	28	1.765	5.324	2.313
26	3	Q	0.188	38	0.129	0.591	0.188

(C)	**WSSQ**	**Data**	**Parameters**	**d.f.**	**Variance**
Total for model	1.730	60	26	34	0.051
Catches at age	0.554	40	23	17	0.033
SSB Indices - DEPM	0.555	5	0	5	0.111
Aged Indices Acoustic surveys (ages 1 to 3+)	0.620	15	3	12	0.052

(D)				
Catches	Skewness test	-1.288		
	Kurtosis test	-0.720		
SSB Indices - DEPM	Skewness test	0.664		
	Kurtosis test	-0.608		
		Age 1	**Age 2**	**Age 3**
Aged Indices Acoustic surveys (ages 1 to 3+)	Skewness test	0.039	0.585	-0.044
	Kurtosis test	-0.452	-0.579	-0.784

Summary statistics (posterior median and 90% probability intervals) of the model parameters for the four different cases (runs) are presented in Table 5. The recruitment (age 1 biomass at the beginning of the year) series for the respective cases are shown in Figure 6. When DEPM spawning stock biomass is relative (runs 1 and 3) the catchabilities of the two surveys (DEPM and acoustics) are below 1 (Table 5) and the recruitment estimates present the same trend but with larger values and wider posterior probability intervals compared to the results from the runs with absolute DEPM biomass estimates (Figure 6). When the biomass decrease rates by age, g_1 and g_2, are estimated, their posterior medians are around 0.39 when both DEPM and acoustics spawning

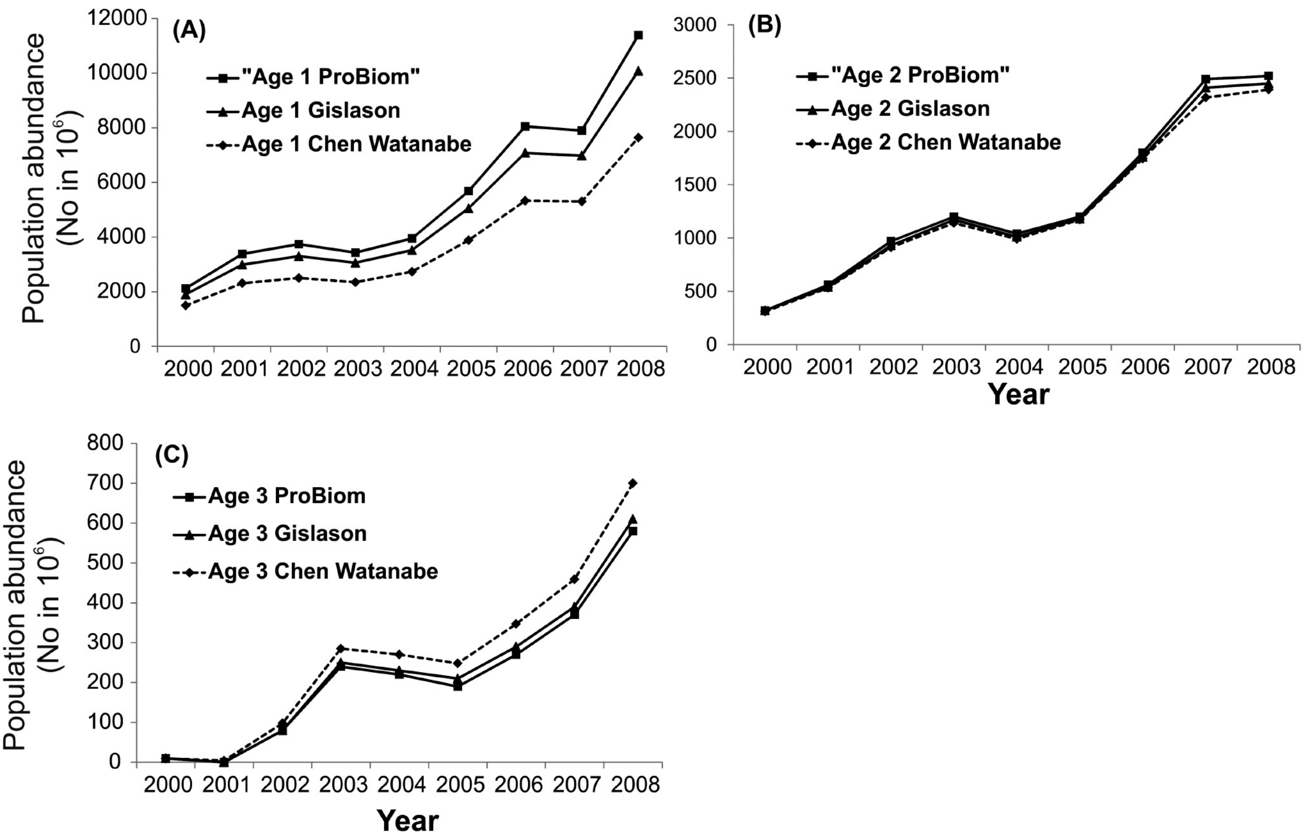

Fig. 4: ICA model results for the anchovy stock assessment in N. Aegean Sea (Greek part) over the period 2000-2008. Based on three different runs for natural mortality estimates the estimated population abundance in the beginning of the year (A) for Age 1, (B) for Age 2 and (C) for Age 3 is shown.

stock biomass are considered relative and around 0.34 for age 1 and 0.28 for age 2+ when DEPM spawning stock biomass is taken as absolute (Table 5). This leads to lower recruitment levels compared to when the biomass decrease rates are fixed at 0.9 and 0.4 for ages 1 and 2+, respectively. For comparison with the ICA assessment of this stock, the case in which g_1, g_2 and q_{depm} are fixed is studied in detail (Table 6).

Table 5. BBM results: Posterior median (P50) and 90% probability intervals (P5 and P95) depending on the assumptions on biomass decrease parameters (g1 and g2) and the catchability of the DEPM survey. Fixed & estimated explanations, NA: Not available estimates, qdepm: catchability of the DEPM survey, qac: catchability of the acoustic survey, the parameters defining and intervening in the precision of the observation equations y_{depm}, y_{ac},x_{ac}, for the DEPM and the acoustic survey respectively, B_0: initial biomass, g_1: instantaneous rate of biomass decrease at age 1, g_2: instantaneous rate of biomass decrease at age 2+.

	g1 AND g2 FIXED						g1 AND g2 ESTIMATED					
	DEPM RELATIVE			DEPM ABSOLUTE			DEPM RELATIVE			DEPM ABSOLUTE		
	P5	P50	P95	P5	P50	P95	P5	P50	P95	P5	P50	P95
qdepm	0.34	0.54	0.86	NA	NA	NA	0.386	0.64	1.040	NA	NA	NA
qac	0.37	0.57	0.86	0.56	0.80	1.11	0.42	0.68	1.08	0.69	0.95	1.27
y_{depm}	2.50	9.23	25.40	1.38	5.00	20.65	2.82	10.40	28.30	2.46	8.86	24.20
y_{ac}	4.21	15.70	43.70	3.66	15.00	47.66	4.13	15.10	41.70	4.11	15.70	43.00
x_{ac}	2.56	5.01	8.20	1.73	4.03	7.96	2.60	5.44	8.73	2.36	5.28	8.60
B_0	55530	73300	98000	39279	59360	73890	37600	59800	108000	32400	42900	65300
g_1	NA	NA	NA	NA	NA	NA	0.10	0.39	1.09	0.	0.34	0.88
g_2	NA	NA	NA	NA	NA	NA	0.14	0.39	0.72	0.09	0.28	0.57

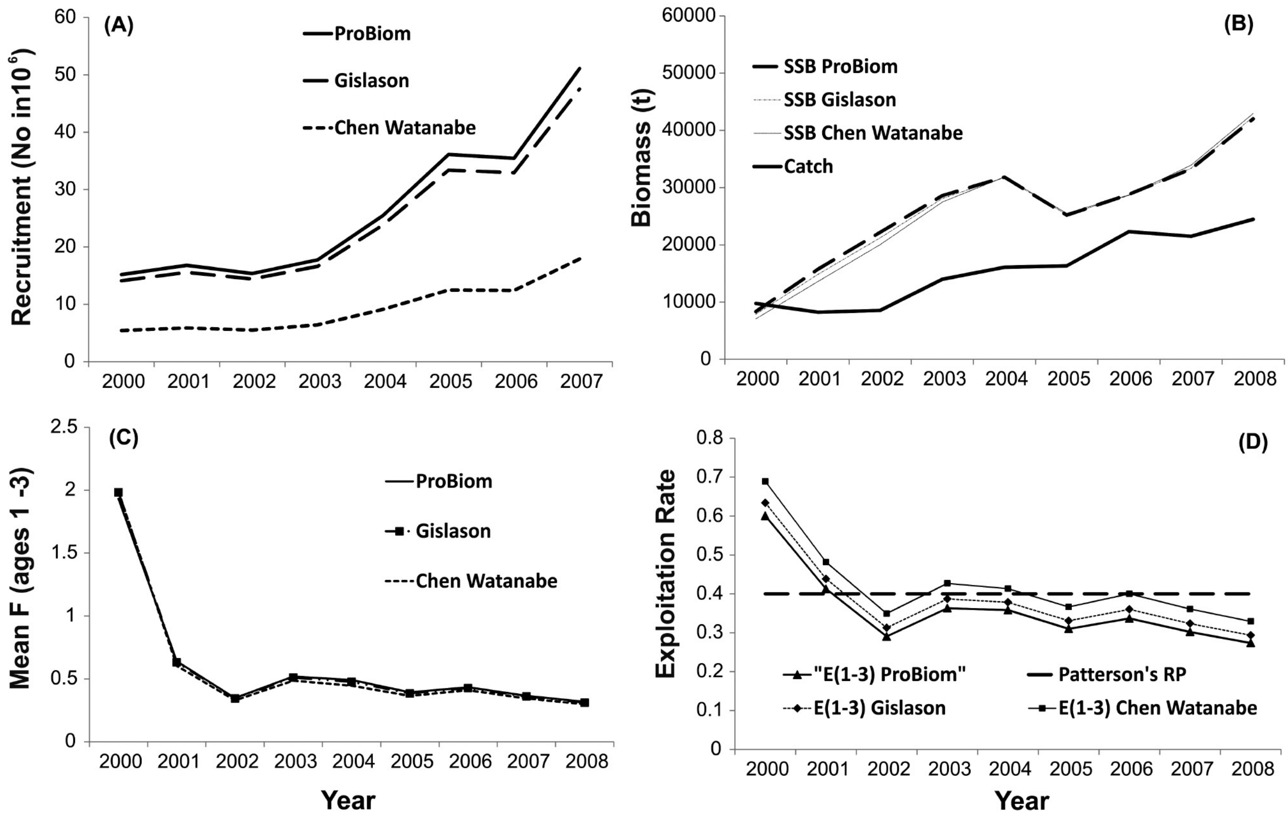

Fig. 5: ICA model results for the anchovy stock assessment in N. Aegean Sea (Greek part) over the period 2000-2008. (A): Recruitment (abundance in age 0) in numbers in the beginning of the year, (B): SSB in the survey time and Annual catches in t (C): mean F for ages 1-3 (Fbar), and (D): exploitation rate for ages 1 to 3 and Patterson empirical Reference Point (RP). Results are based on three different runs for natural mortality estimates.

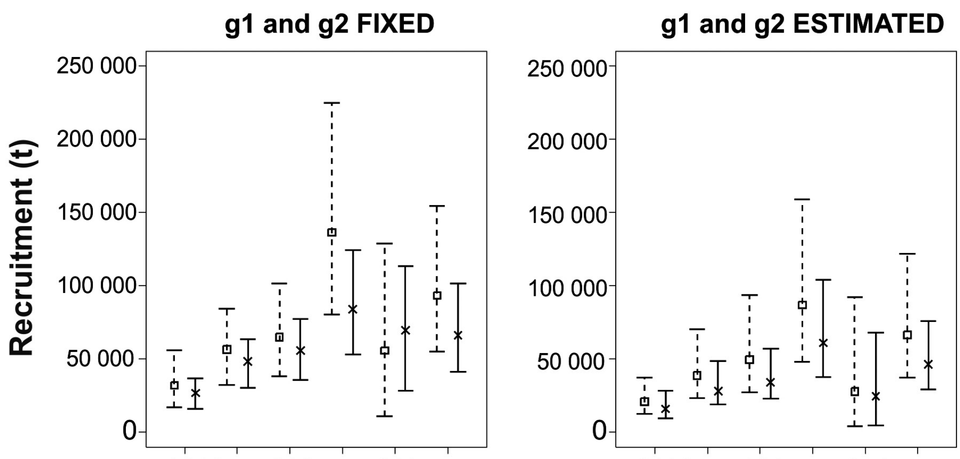

Fig. 6: Median and 90% probability intervals of recruitment, when the biomass decrease rates by age are fixed (left panel) and estimated (right panel). The dashed line corresponds to the case when the DEPM biomass is relative and the solid line when it is absolute.

Biomass at age 1 at the beginning of the year (considered as recruitment in BBM) and at age 1+ (at survey time) (i.e. ages targeted by the fishery), as estimated by the BBM model (run 2), are presented in comparison to the three runs of the ICA model in Figure 7. The specific BBM model allowed comparisons in consistency with ICA due to the underlying assumptions on DEPM and g_1 and g_2 estimates. The trend in both approaches is generally quite similar concerning the biomass at age 1 at the beginning of the year (Fig. 7B), with the exception of the estimates in 2006 when the BBM model predicts higher values and 2008 when ICA has resulted in higher estimates. In any

Table 6. BBM estimates: Posterior median (P50) and 90% probability intervals (P5 and P95) of recruitment, biomass and harvest rates when the biomass decrease rates and the catchability of the DEPM surveys are fixed.

	RECRUITMENT			BIOMASS			HARVEST RATES		
YEAR	P5	P50	P95	P5	P50	P95	P5	P50	P95
2003	15380	27450	42450	44000	60220	75301	0.193	0.241	0.330
2004	28840	48870	65682	35520	54005	71541	0.234	0.309	0.471
2005	34570	55950	79210	36810	54690	78303	0.221	0.316	0.470
2006	52870	89110	144405	44130	71215	107700	0.227	0.343	0.554
2007	15357	61865	114205	45090	67290	102500	0.118	0.180	0.269
2008	39000	67360	107905	43810	68130	108100	0.215	0.342	0.532

case, the ICA estimates are found generally within the 90% posterior probability intervals from the BBM. Differences are slightly larger when it comes to biomass at age 1+, where the Bayesian estimates are higher than the ICA ones. Consequently, ICA estimates indicate higher harvest ratio (i.e. expressed as the ratio of the catch at age 1+ to Biomass at age 1+) at 0.38 to 0.40 (depending on the run) compared to the BBM model estimate at 0.28.

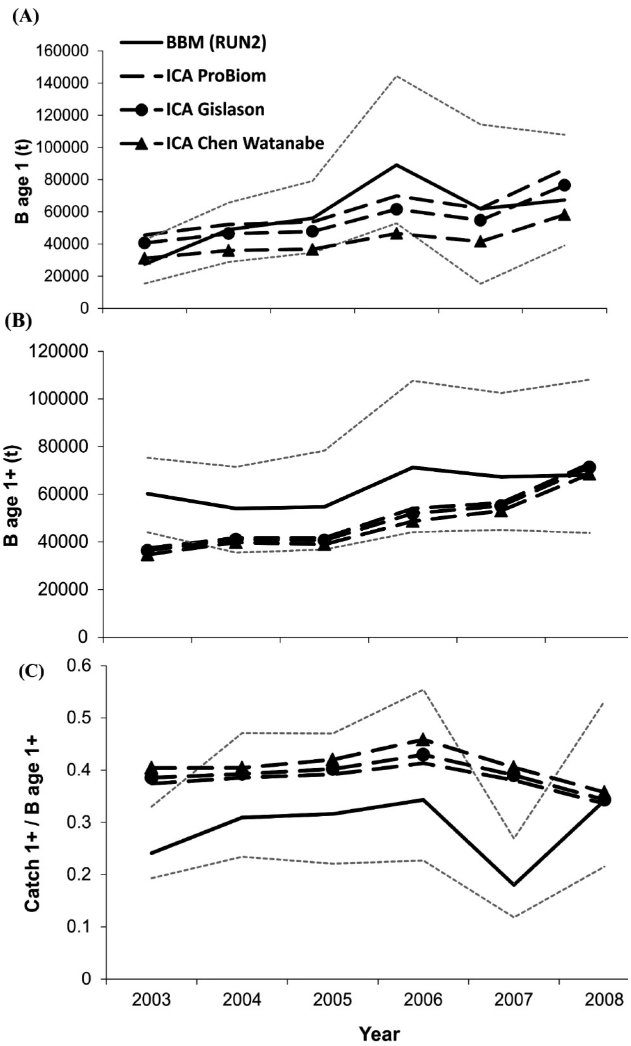

Fig. 2: (A) Biomass at age 1 (B age 1) in t as estimated by ICA and BBM (run 2) in the beginning of the year, (B) Biomass at age 1+ (B age 1+) in t as estimated by ICA and BBM (run 2) in the time of survey and (C) harvest rate expressed as catch at age 1+ / B at age 1+ ratio as estimated by ICA and BBM (run 2).

Discussion

The N. Aegean anchovy stock is characterized by a short life span, with individuals seldom exceeding 3 years of age. This is also one of most pronounced features of anchovy stocks in most areas of the Mediterranean basin (Cardinale *et al.,* 2009) and in the Atlantic (Uriarte *et al.,* 1996; De Oliveira *et al.,* 2005). This feature renders these stocks particularly sensitive since their abundance and composition is highly dependent on the annual successful recruitment and can fluctuate widely with changes in the environmental conditions (Freon *et al.,* 2005).

VPA based approaches such as the ICA model are often used to assess the status of small pelagic fish stocks (e.g. ICES, 2006; Daskalov & Mamedov, 2007; Antonakakis *et al.,* 2011). However, the application of a fully age-structured stock assessment model for a short lived species might be questionable, especially when missing values occur in certain years or for the relatively old age classes (Ibaibarriaga *et al.,* 2008). The short time series of data, as in our case, can cause additional difficulties regarding the model's fit and produce poor convergence properties. The two-stage Bayesian BBM is a simpler and less data demanding stock assessment model based on biomass estimates from surveys. Considering the aforementioned high dependence of the anchovy stock on in-year successful recruitment, the separate modelling of recruits and the "fully recruited" fraction of the population, as in the Bayesian BBM model, can sufficiently illustrate the status and potential changes of the entire population (Ibaibarriaga *et al.,* 2008).

Herein, the exploitation status of the N. Aegean anchovy stock was assessed using the ICA model (Needle, 2000) with 3 runs based on different natural mortality (M) values and a Bayesian two-stage BBM similar to the one used for the Bay of Biscay anchovy stock (Ibaibarriaga *et al.,* 2008). Different ICA runs showed similar estimates of abundance at age 2, SSB, and F_{1-3} independently of the M applied. Deviations were observed in terms of abundance estimates at age 1 and 0 (recruitment) where the ICA run based on the Chen & Watanabe (1989) M estimates provided the lowest values. Results of both the ICA and the BBM models indicated reasonable agreement in terms of trends besides the differences in the absolute values.

For the given time series 2000-2008, ICA indicated a slightly increasing trend for biomass at age 1+ (i.e. the age group targeted by the fishery) and a more apparent increasing trend regarding the biomass of age 1. With the same assumptions regarding g values (as known) and DEPM catchability (as 1), the BBM model estimated higher biomass values and a more moderate increasing trend compared to ICA. According to the BBM model, biomass at age 1+ seems to stabilize around a mean value of 62000 tons in the period 2006-2008. Harvest rates expressed as the catch of age 1+ to biomass of age 1+ ratio seem to stabilize around 0.28 in the case of the Bayesian model and at the higher level of 0.38 to 0.40 in the case of ICA.

The Bayesian two-stage biomass-based model for anchovy in the N. Aegean Sea provides an extension of the model in Ibaibarriaga *et al.* (2008). The model allows the biomass decrease parameters to differ by age classe (g_1 and g_2) and, using the maturity at age 1 (as known input parameter), it converts total biomass into spawning stock biomass. Model output corresponds to the biomass indices provided by the DEPM. Results of this model largely depend on the assumptions regarding the catchability of the DEPM survey and the biomass decrease rates. When DEPM biomass is considered relative, recruitment presents higher values with increased uncertainty. In addition, when the biomass decrease rates (g_1 and g_2) are considered fixed, recruitment values are at higher levels compared to when g_1 and g_2 are estimated, regardless of the DEPM survey's catchability assumptions. The indeterminacy of the assessment as revealed by the high correlation between the parameters (such as survey catchability and recruitment) was also observed in Ibaibarriaga *et al.* (2008). Thus, similarly to ICA, when the DEPM survey catchability is considered fixed at 1, the assessment is scaled to the survey's catchability assumption. When the biomass decrease rates are estimated, the results suggest that they might be rather similar between ages and smaller than the ones assumed when fixed. As a result, the annual recruitments and the biomass estimates are also lower when g_1 and g_2 are estimated. Contrary to the BBM, where the acoustic survey catchabilities are assumed equal across age groups, in ICA the catchability at ages 1 and 3 are estimated to be less than 1/3 of the one estimated for age 2.

The similarity of the g_1 and g_2 estimates (with g_1 at a lower value than believed) and the differences in the acoustic catchability at ages 1 and 2, could be related to undersampling of age 1 during the survey. The survey loses a percentage of age 1 that presents a very coastal distribution over non-sampled shallow waters as well as because a part of age 1 although contributing to the anchovy population in the next year, is distributed in the Turkish territorial waters of the Thracian Sea. This could explain the large differences in the catchability, for the assumed pattern of natural mortality in ICA as well as the similar values of g_1 and g_2 as estimated by the BBM. Nevertheless, this cannot explain the very low catchability at age 3 compared to age 2, which might be due to several phenomena, either particular catchability anomalies associated with the survey, or incorrect age determination or higher natural mortalities than the ones estimated. Therefore, the former results could also be indicative of inconsistencies between the pattern of natural mortality and the observation of population at age from the acoustic survey.

According to both the ICA and Bayesian two-stage models, the N. Aegean anchovy stock is considered to be harvested sustainably, with the fishery operating below but close to an optimal yield level with respect to Patterson's (1992) empirical reference point (E=0.4) and well below the sustainable exploitation rate recently suggested by Zhou *et al.* (2012) (E= 0.47). Mean exploitation rate of the anchovy stock was below 0.35 whilst both recruitment and catch to biomass ratio appeared rather stable for the whole time series. Nevertheless, in terms of management, the mixed nature of the anchovy and sardine fishery as well as the fact that the anchovy stock in the Aegean Sea is shared between Greek and Turkish fishing fleets should be considered. In a future perspective, it would be interesting to see the outcome of the application of two-stage BBMs to different stocks presenting different age range and subject to a different degree of exploitation.

It is worth discussing the suitability of Bayesian two-stage stock assessment models compared to VPA based ones. A fully age-structured model in terms of numbers-at-age, such as ICA, has been argued as inappropriate by several authors (e.g. Roel & Butterworth, 2000; Ibaibarriaga *et al.,* 2008; Trenkel, 2008), favouring the application of a Bayesian two-stage model. Estimating "quantities of interest for management" like biomass can be more reliable than using a more reality reflective method on the one hand but a more complex one on the other hand (Roel & Butterworth, 2000; Ibaibarriaga *et al.,* 2008; Trenkel, 2008). Moreover, the short life span of a species renders the application of ICA rather questionable as rnoted by Ibaibarriaga *et al.* (2008). Additionally, quite often the paucity of age, the lack of reliable age-size data and/or the total absence of age-size data due to methodological difficulties or high costs, are reasons that favour the use of the two-stage biomass method, which is based on a simplified age structure (e.g. Roel & Butterworth 2000; Beare *et al.,* 2005; Trenkel, 2008; Roel *et al.,* 2009, Cook, 2013).

Misreporting of landings and un- or misreported discarded fish result in erroneous stock abundance estimates (Quinn & Deriso, 1999; Cook, 2013). Additionally, Catch per Unit Effort (CPUE) indices for small pelagics present low reliability due to highly aggregative behaviour. This rather inevitable uncertainty within commercial catch information has also raised concern and queries regarding the use of VPA based approaches. In our Bayesian approach, the way catches are used only serves setting minimum biomass levels that explain the level of catches, thus avoiding unrealistic low biomass level estimates. Cotter *et al.* (2009) and Mesnil *et al.* (2009) have recently presented some ideas and considerations on the advantages and drawbacks of using fishery-independent stock assessment methods. Survey-based methods avoid the introduction of catch data uncertainty and the temporal delay of the assessment as they provide direct information on the status of the stock while they do not require an estimation of questionable assessment parameters such as natural mortality values. Nevertheless, the strongest drawback of these methods is that they mainly use one source of information thus rendering the planning of surveys and the quality of the data obtained the most determining factor for the assessment (Mesnil *et al.,* 2009).

Acknowledgements

The study was partially supported and financed by the Greek National Fisheries Data Collection Program, the European Commission (''SARDONE: Improving assessment and management of small pelagic species in the Mediterranean'', FP6 – 44294). We wish to thank the captain and the crew of RV ''Philia'' as well as all the scientists on board for their assistance during the surveys. Moreover, we feel the need to thank Mark Payne for his help with the FLICA code in FLR.

References

Abella, J.A., Caddy, F.J., Serena, F., 1997. Do natural mortality and availability decline with age? An alternative yield paradigm for juvenile fisheries, illustrated by the hake *Merluccius nerluccius* fishery in the Mediterranean. *Aquatic Living Resources,* 10, 257-269.

Antonakakis, K., Giannoulaki, M., Machias, A., Somarakis, S., Sanchez, S., Ibaibarriaga L., Uriarte A., 2011. Assessment of the sardine (*Sardina pilchardus* Walbaum, 1792) fishery in the eastern Mediterranean basin (North Aegean Sea). *Mediterranean Marine Science,* 12, 333-357.

Barange, M., Bernal, M., Cercole, M.C., Cubillos, L., Cunningham, C.L. *et al.*, 2009. Current trends in the assessment and management of stocks. p. 191–255. In: *Climate Change and Small Pelagic Fish Stocks.* Checkley, D., Roy, C., Oozeki, Y., Alheit, J. (Eds). Cambridge University Press, New York, 372 pp.

Basilone, G., Guisande, C., Patti, B., Mazzola, S., Cuttitta, A. *et al.*, 2006. Effect of habitat conditions on reproduction of the European anchovy (*Engraulis encrasicolus*) in the Strait of Sicily. *Fisheries Oceanography,* 15, 271-280.

Beare, D.J., Needle, C.L., Burns, F., Reid, D.G., 2005. Using survey data independently from commercial data in stock assessment: an example using haddock in ICES Division VIa. *ICES Journal of Marine Science*, 62, 996-1005.

Cardinale, M., Cheilari, A., Raetz, H.J. (Eds), 2010. *Assessment of Mediterranean stocks—Part 1*. Report of the Scientific, Technical and Economic Committee for Fisheries (STECF). JCR Publications Repository. Publications Office of the European Union., 31 May – 4 June 2010, Iraklion, Greece, 1080 pp.

Cardinale, M., Ratz, H.J., Cheilari, A. (Eds), 2009. *Report of the SGMED-09-02 Working Group on the Mediterranean Part I*. Scientific, Technical and Economic Committee for Fisheries (STECF), 8-10 June 2009, Villasimius, Sardinia, Italy, 846 pp.

Chen, Y., Jiao, Y., Sun, C.-L., Chen, X., 2008. Calibrating virtual population analysis for fisheries stock assessment. *Aquatic Living Resources*, 21, 89-97.

Chen, S., Watanabe, S., 1989. Age dependence of natural mortality coefficient in fish population dynamics. *Nippon Suisan Gakkaishi*, 55(2), 205-208.

Collie J.S., Gislason, H., 2001. Biological reference points for fish stocks in a multispecies context. *Canadian Journal of Fisheries and Aquatic Sciences,* 58, 2167-2176.

Collie, J.S., Sissenwine, M.P., 1983. Estimating population size from relative abundance data measured with error. *Canadian Journal of Fisheries and Aquatic Sciences*, 40, 1871-1879.

Cotter, A.J.R., Petitgas, P., Abella A., Apostolaki, P., Mesnil, B. *et al.*, 2009. Towards an ecosystem approach to fisheries management (EAFM) when trawl surveys provide the main source of information. *Aquatic Living Resources*, 22, 243-254.

Cook, R.M., 2013. A fish stock assessment model using survey data when estimates of catch are unreliable. *Fisheries Research*, 143, 1-11.

Csirke, J., 1988. Small shoaling pelagic fish stocks. p. 271–302. In: *Fish population dynamics*, 2nd ed. Gulland, J.A. (ed.). John Wiley & Sons, New York.

Daskalov, G.M., Mamedov, E.V., 2007. Integrated fisheries assessment and possible causes for the collapse of anchovy kilka in the Caspian Sea. *ICES Journal of Marine Science,* 64, 503-511.

De Oliveira J.A.A., Uriarte A., Roel B.A., 2005. Potential improvements in the management of Bay of Biscay anchovy by incorporating environmental indices as recruitment predictors. *Fisheries Research,* 75, 2-14.

Freon, P., Misund, O.A., 1999. *Dynamics of Pelagic Fish Distribution and Behaviour: Effects on Fisheries and Stock Assessment*. Fishing New Books, Oxford, 348 pp.

Freon, P., Cury, P., Shannon, L., Roy, C., 2005. Sustainable exploitation of small pelagic fish stocks challenged by environmental and ecosystem changes. *Bulletin of Marine Science*,76, 385-462.

Gelman, A., Carlin, J. B., Stern, H. S., Rubin, D.B., 2004. *Bayesian Data Analysis*, 2nd edn. Chapman and Hall, London, 668 pp.

Giannoulaki, M., Machias, A., Somarakis, S., Tsimenides, N.,

2004. The spatial distribution of anchovy and sardine in the northern Aegean Sea in relation to hydrographic regimes. *Belgian Journal of Zoology*, 134, 43-48.

Giannoulaki, M., Valavanis, V.D., Palialexis, A., Tsagarakis, K., Machias, A. *et al*., 2008. Modelling the presence of anchovy *Engraulis encrasicolus* in the Aegean Sea during early summer, based on satellite environmental data. *Hydrobiologia*, 612, 225-240.

Gilks, W.R., Sylvia Richardson, S., Spiegelhalter, D.J., 1996. *Markov Chain Monte Carlo in Practice*. Chapman & Hall, London, 486 pp.

Gislason, H., Daan, N., Rice, J., Pope, J., 2010. Does natural mortality depend on individual size. *Fish and Fisheries*, 11(2), 149-158.

Gulland, J.A., Boerema, L.K., 1973. Scientific advice on catch levels. *Fishery Bulletin,* 71(2), 325-335.

Ibaibarriaga, L., Fernández, C., Uriarte, A., 2011. Gaining information from commercial catch for a Bayesian two-stage biomass dynamic model: application to Bay of Biscay anchovy. *ICES Journal of Marine Science,* 68 (7), 1435-1446.

Ibaibarriaga, L., Fernández, C., Uriarte, A., Roel, B.A., 2008. A two-stage biomass dynamic model for Bay of Biscay anchovy: a Bayesian approach. *ICES Journal of Marine Science,* 65, 191-205.

ICES, 2006. *Report of the Working Group on Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy*. ICES Document CM 2006/ACFM, 36, 601 pp.

ICES, 2009a. *Report of the Working Group on Anchovy and Sardine*. ICES Document CM 2009/ACOM: 13, 354 pp.

ICES, 2009b. *Report of the Workshop on Age reading of European anchovy (WKARA)*. ICES Document CM 2009/ ACOM: 43, 122 pp.

Kell, L.T., Mosqueira, I., Grosjean, P., Fromentin, J-M., Garcia, D. *et al*., 2007. FLR: an open-source framework for the evaluation and development of management strategies. *ICES Journal of Marine Science,* 64, 640-646.

Kirchner, C., Bauleth-D'Almeida, G., Wilhelm, M.R., 2010. Assessment and management of cape horse mackerel *Trachurus capensis* off Namibia based on a fleet-disaggregated age-structured production model. *African Journal of Marine Science*, 32, 525-541.

Lleonard, J., Maynou, F., 2003. Fish stock assessments in the Mediterranean: state of the art. *Scientia Marina,* 67, 37–49.

Loff, J. F., Murta, A., Kell, L., 2013. *ALKr: Generate Age-Length Keys for fish populations*. URL http://CRAN.R-project.org/package=ALKr.R package version 0.5.3.

Lunn, D.J., Thomas, A., Best, N., Spiegelhalter, D., 2000. WinBUGS -- a Bayesian modelling framework: concepts, structure, and extensibility. *Statistics and Computing*, 10, 325-337.

Machias, A., Stergiou, K.I., Somarakis, S., Karpouzi, V.S., Kapantagakis, A., 2008. Trends in trawl and purse seine catch rates in the north-eastern Mediterranean. *Mediterranean Marine Science*, 9, 49-65.

Magoulas A., Tsimenides N., Zouros, E., 1996. Mitochondrial DNA phylogeny and the reconstruction of the population history of a species: The case of the European anchovy (*Engraulis encrasicolus*). *Molecular Biology and Evolution*, 13 (1), 178-190.

Mesnil, B., Cotter, J., Fryer, R.J., Needle, C.L., Trenkel, V.M., 2009. A review of fishery independent assessment models and initial evaluation based on simulation data. *Aquatic Living Resources*, 22, 207-216.

Morales-Nin, B., Pertiera, J.P., 1990. Growth rates of the anchovy *Engraulis encrasicolus* and the sardine *Sardina pilchardus*in the northwestern Mediterranean Sea. *Marine Biology,* 107, 349-356.

Needle, C.L., 2000. *The ins and out of the ICA*. Marine Laboratory. Aberdeen Report No 04/00, 80 pp.

Needle, C.L., 2003. *Workshop Course on Fish Stock Assessment Techniques*. ICES Headquarters, Copenhagen, 182 pp.

Patterson, K.R., 1992. Fisheries for small pelagic species: an empirical approach to management targets. *Reviews in Fish Biology and Fisheries,* 2, 321-338.

Patterson, K., 1998. *Integrated catch at age analysis, version 1.4*. Scottish Fisheries Research Report, FRS Marine Laboratory Aberdeen, 38 pp.

Patterson, K.R., Melvin, G.D., 1996. *Integrated Catch at age Analysis. Version 1.2*. Scottish Fisheries Research Report No. 58. FRS Marine Laboratory, Aberdeen, 42 pp.

Plummer, M., Best, N., Cowles K., Vines, K., 2006. CODA: Convergence diagnosis and Output Analysis for MCMC, *R News*, 6, 7-11.

Punt, A. E., Hilborn, R., 1997. Fisheries stock assessment and decision analysis: a review of the Bayesian approach. *Reviews in Fish Biology and Fisheries*, 7, 35-63.

Quinn, T.J.II, Deriso, R.B., 1999. *Quantitative Fish Dynamics*., Oxford University Press, Oxford, 542 pp.

R Development Core Team, 2012. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Roel, B.A., Butterworth, D.S., 2000. Assessment of the South African chokka squid *Loligo vulgaris reynaudii*: is disturbance of aggregations by the recent jig fisheries having a negative impact on recruitment? *Fisheries Research*, 48, 213-228.

Roel, B.A., De Oliveira, J.A.A., Beggs, S., 2009. A two-stage biomass model for Irish Sea herring allowing for additional variance in the recruitment index caused by mixing of stocks. *ICES Journal of Marine Science,* 66, 1808-1813.

Ruiz, J., Gonzalez Quiros, R., Prieto, L., Navarro, G., 2009. A Bayesian model for anchovy (*Engraulis encrasicolus*): the combined forcing of man and environment. *Fisheries Oceanography,* 18 (1), 62-76.

Santojanni, A., Arneri, E., Barry, C., Belardinelli, A., Cingolani, N. *et al*., 2003. Trends of anchovy (*Engraulis encrasicolus*, L.) biomass in the northern and central Adriatic Sea. *Scientia Marina*, 67, 327-340.

Simmonds, J., MacLennan, D., 2005. *Fisheries acoustics, theory and practice*, 2nd edn. Oxford: Blackwell Publishing, 437 pp.

Somarakis, S., 2005. Marked interannual differences in reproductive parameters and daily egg production of anchovy in the northern Aegean Sea. *Belgian Journal of Zoology,* 134, 123-132.

Somarakis, S., Machias, A., Giannoulaki, M., Schismenou, E., Tsagarakis, K. *et al*., 2007. Ichthyoplankton and acoustic biomass estimates of anchovy in the Aegean Sea (June 2003, June 2004, 2005 and 2006). In *Report of the GFCM Sub-Committee for Stock Assessment, Working Group on Small Pelagic Species, Athens, 11-14 September 2007.* GFCM, Rome.

Somarakis, S., Palomera, I., Garcia, A., Quintanilla, L., Koutsikopoulos, C. *et al*., 2004. Daily egg production of anchovy in European waters. *ICES Journal Marine Science,* 61, 944-958.

Somarakis, S., Schismenou, E., Siapatis, A., Giannoulaki, M., Kallianiotis, A. *et al*., 2012. High variability in the Daily Egg Production Method parameters of an eastern Mediterranean anchovy stock: Influence of environmental factors, fish condition and population density. *Fisheries Research*, 117-118, 12-21.

Sturtz, S., Ligges, U., Gelman, A., 2005. R2WinBUGS: A Package for Running WinBUGS from R. *Journal of Statistical Software*, 12 (3), 1-16.

Trenkel, V.M., 2008. A two-stage biomass random effects model for stock assessment without catches: What can be estimated using only biomass survey indices? *Canadian Journal of Fisheries and Aquatic Sciences*, 65, 1024-1035.

Tsagarakis K., Vassilopoulou, V., Kallianiotis, A., Machias, A., 2012. Discards of the purse seine fishery targeting small pelagic fish in the Eastern Mediterranean Sea. *Scientia Marina*, 76 (3), 561-572.

Uriarte, A., Prouzet, P., Villamor, B., 1996. Bay of Biscay and Ibero Atlantic anchovy populations and their fisheries. *Scientia Marina,* 60, 237-255.

Zhou, S., Yin, S., Thorson, J.T., Smith, A.D.M., Fuller, M., 2012. Linking fishing mortality reference points to life history traits: an empirical study. *Canadian Journal of Fisheries and Aquatic Sciences,* 69, 1292-1301.