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Inter and intra annual variation in body condition of the Black Sea anchovy, *Engraulis encrasicolus ponticus*—Potential causes and consequences

Ali Cemal Gücü[a,*], Yaşar Genç[b], Nimet Selda Başçınar[b], Murat Dağtekin[b], Elvan Atılgan[b], Murat Erbay[b], İlkay Özcan Akpınar[b], Sebahattin Kutlu[b]

[a] *Institute of Marine Sciences, Middle East Technical University, Erdemli, 33731, Mersin, Turkey*
[b] *Trabzon Central Fisheries Research Institute, Vali Adil Yazar Ave. No:14 Kasustu, Yomra, 61250, Trabzon, Turkey*

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ABSTRACT

Variations in the relative condition (Kn) of the Black Sea anchovy (*Engraulis encrasicolus ponticus*) have been evaluated over eleven overwintering seasons (2005–2016). During the study period, a linear decrease was observed in the condition each year. Difference in condition from the onset to end of winter varied between 10% and 20%. Overall however, condition displayed an increasing trend within the time frame studied. Considering the worsening state of the stock during the same period, this increasing trend indicates that condition may be dependent on the fish density. The negative relationship observed between body condition of anchovies and the spawning stock biomass supports the same view and points out that particularly in winter when food supply is limited, interspecies competition could be a considerable factor determining condition. The strong correlation between condition and eddy kinetic energy underlines that velocity of water movement might be an effective factor conserving energy use and consequently supporting maintenance of body condition. Finally, the positive correlation observed between condition loss during winter and number of recruits the following year indicates that how fish overwinter plays an important role in recruitment success rates.

1. Introduction

Measuring fish length and weight is low cost, fast and requires very little expertise compared to ageing which, in the majority of cases is considered fundamental to assess the state of a stock. This is also apparent from fisheries related studies conducted in regions where stock assessment studies are lacking. In such regions a noticeable percentage of studies performed provide an estimate of length-weight relationship, or fish condition derived from morphometric measurements (weight and length). The latter have significant impact on the control of some biological mechanisms, such as maturation and probability of maturity (Morgan, 2004), reproductive potential (Lloret et al., 2008; Brosset et al., 2016), well-being of the propagule (Adams, 1999), growth (Rätz and Lloret, 2003) and recruitment success of the stock (Marshall and Frank, 1999). Good conditioned fish have been reported to display better survival (Lloret et al., 2008). Consequently, all these factors are either directly or indirectly linked to the key aspects governing the dynamics of fish stocks, such as natural mortality, recruitment and eventually fisheries (Shulman and Love, 1999; Lloret et al., 2012). It is also believed that fish condition is closely linked to the ecological environment of the fish. For instance, European anchovy (*Engraulis encrasicolus*) in the Strait of Sicily (Basilone et al., 2006), in the Gulf of Lions (Brosset et al., 2015a,b) and in the Adriatic (Zorica et al., 2013) are better conditioned when the food availability in the surrounding waters is high. Likewise, there is strong evidence for the control of temperature on the condition of anchovy larvae (RNA/DNA ratio; García et al., 1998). Therefore fish condition is considered a useful tool, bridging stock and its environment (Brosset et al., 2017).

The morphometric indices of fish body condition are the simplest indicators of the physiological state of the fish (Lloret et al., 2014). However, they are quite sophisticated as one single index is an indicator to all the factors listed above (and possibly more). This inflicts uncertainty to the solicited answers addressed through the index as has already been underlined by various authors such as, Froese (2006) and McPherson et al. (2011).

The Black Sea is characterized by strong stratification and extreme variation in the hydrographical conditions as well as very high productivity. The fishes inhabiting the sea are, therefore forced to adopt strategies to utilize the high summer productivity while avoiding the lethal winter conditions. One such strategy is migration of the Black Sea anchovy (*Engraulis encrasicolus ponticus*). The scattered anchovies feed and spawn over the rich northwestern shelf migrating southeastward

* Corresponding author.
E-mail address: gucu@ims.metu.edu.tr (A.C. Gücü).

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when temperatures drop below the tolerable level to aggregate in the warmer but less productive waters (Chashchin et al., 2015). The body condition of the fish is affected significantly from this pattern of behaviour; they feed and store fat during summer when body condition attains a peak before commencing wintering migration at the end of summer (Shulman et al., 2009). Since feeding rates slow down during winter (Chashchin, 1996), the anchovy progressively lose condition throughout the winter season (Gücü, 1997) so that the condition of fish displays a cyclic annual pattern (Shulman et al., 2009).

Because the Black Sea anchovy fishery targets the large, dense overwintering schools, the fishery for the migratory anchovy begins when the anchovies gather in overwintering aggregations and ends when the schools again disintegrate into small clusters departing the overwintering grounds (Gücü et al., 2017). The landings are therefore composed of anchovies at the resting stage with a small by-catch of undersized immature individuals. As the reproductive activities are completed before the overwintering migration (Lisovenko and Andrianov, 1996), the energy allocated for reproductive processes during the fishing season is negligibly low, if any.

Due to the high level of landings exceeding half a million tonnes, the species is among the few stocks regularly assessed by the regional fisheries management organisation in the Black Sea. Assessments however indicate that the stock fluctuates drastically with recruitment being independent of spawning stock biomass. This situation is often explained by the extreme fecundity of the Black Sea anchovy associated with very high productivity of the basin (Lisovenko and Andrianov, 1996) and underlines the importance of external mechanisms controlling the state of the stock.

In this study, we aim to minimize the variance resulting from cyclic changes associated with the biology of the species by targeting only wintering anchovies and examine the changes in condition of the anchovy in the winter period over 11 consecutive years. Results were evaluated from two different perspectives: factors that may affect condition (food, temperature, migration and fishery) and events affected by condition (recruitment and spawning stock biomass).

2. Materials and methods

2.1. Approach and data used

The study focuses on the changes in the weight of overwintering Black Sea anchovies. To standardize the weight of an individual (W) with respect to its size (TL) the relative condition index Kn (observed weight, W/predicted weight, aTL^b) proposed by Le Cren (1951) was adopted. With this approach, the weight of each individual is normalized to the weight of a reference fish representing the entire statistical population. Therefore "a" and "b" in the Kn index were estimated from the entire data set (2005–2016).

The fisheries data used in this study was collected within the framework of the National Anchovy Fisheries Monitoring Program. The program was initiated in 2005 to collect data required for the assessment of the Black Sea anchovy stock, namely length distribution of the anchovies landed along with biological parameters namely weight-length relation, sex ratio, and growth parameters. Within the framework of the program, the landing site surveys are conducted essentially on a monthly basis throughout the year. However since the anchovy fishing season lasts a short time, the sampling during this time of the year is carried out twice or three times a week, depending on the movement of the fishing fleet and the intensity of the fishery. The data are accumulated in conjunction with the following protocol; for each site visited, one box of fish (12–15 kg) was sampled indiscriminately from a randomly selected fishing vessel. A total of 425 days of surveys were conducted throughout the study. Total lengths (TL) of individuals were measured to the nearest 0.5 cm on site. The first ten intact fish belonging to each 0.5 cm length class were selected and transported either fresh or iced (but not frozen) to the lab for precise measurement. At the lab individuals were weighed (to the nearest 0.01 g) and total lengths measured (to the nearest mm) no later than 36 h after sampling.

2.2. Data treatment before the analysis

Data collected within the framework of the abovementioned National Anchovy Fisheries Monitoring Program was subjected to two level filtering. Given that no significant reproductive activity in the Black Sea anchovy has ever been reported during the overwintering season (1st September–28/29th February; Lisovenko and Andrianov, 1996) data collected outside the overwintering period was eliminated to minimize variance associated with the physiological state of the fish and gender related differences. Considering that fishing fleets target mainly large and dense migrating schools, some non-migrating resident anchovy populations occasionally caught outside the overwintering period (Gücü et al., 2017) were also eliminated by the filtering.

The second filter was applied to very small (TL 7 cm or less) and very large fish (TL 13 cm or over), these groups which were under-represented in the samples were removed from the dataset as suggested by Froese (2006). The remaining anchovies were split into two groups and analysed separately; individuals above the minimum landing size (9 cm) were used as the main group of interest (hereafter termed "combined data"); while specimens less than 9 cm were also analysed to evaluate whether these two groups displayed a similar pattern of variation. As minimum landing size also delineates adults and juveniles (Bilgin et al., 2016) the second group is considered as the young-of-the-year, YoY.

Because macroscopic sex determination is difficult in immature/resting stage individuals, figures for gender are available only for some of the samples (Table 1). This data subset was labelled "sexed data" and used to evaluate variations in the fish condition associated with gender.

The first appearance of the migrating anchovies at the fishing/overwintering grounds was assumed to indicate the onset of the overwintering season with the disappearance of large aggregations which usually occurs in February to mark the end of the season. To estimate condition lost throughout the overwintering season, the mean Kn of anchovies in the last week of the overwintering season ("departing anchovies") was compared with the mean Kn of the anchovies sampled in the first week of the season ("arriving anchovies"). Mean Kn values for the last week of the season were subtracted from mean Kn figures for the first week of the following season to estimate condition gained during summer. The lower Kn threshold reached at the end of the overwintering season was estimated by averaging the Kn of the anchovies sampled after January each year. September is assumed to reflect the environmental conditions at the end of summer.

The time series of stock parameters, namely Spawning Stock Biomass (SSB) and Recruitment (REC) estimates of the Black Sea anchovy stock (Table 2) were obtained from assessment results of STECF (2015). The assessment was carried out using eXtended Survival Analysis (XSA), official catch at age tuned with commercial CPUEs and

Table 1
Sex distribution in the dataset used in the analysis.

Year	Undefined	Female	Male	Total
2005/2006	279	112	44	435
2006/2007	541	640	481	1662
2007/2008	479	555	289	1323
2008/2009	456	510	185	1151
2009/2010	5170	1572	287	7029
2010/2011	4187	935	181	5303
2011/2012	7151	796	730	8677
2012/2013	5722	1201	931	7854
2013/2014	5117	1242	874	7233
2014/2015	6725	27	23	6775
2015/2016	5586	38	52	5676
Total	41413	7628	4077	53118

Table 2

Parameters used in the analysis. "**b**" is the slope of the linear model (Kn ~ Time); KnMean is the mean Kn of the combined data; "Arr" and "Dep" are the average Kn of the first and the last anchovies caught at the overwintering grounds; REC and SSB are the numbers of recruits and spawning stock biomass (thousand tonnes) estimates taken from STECF (2015). In the remaining column headings the first three letters represent parameters (Ch = Chlorophyll; SST = Sea Surface Temp; Eke = Eddy Kinetic Energy), the next two letters indicate the season (Sm = Summer; Wn = Winter; Au = Autumn) with the last letters representing region (S = South, NW = Northwest; see Fig. 1 for the definition of the areas).

Year	b	KnMean	Arr	Dep	REC	SSB	ChSmS	ChWnS	ChSmNW	SSTSmS	SSTWnS	SSTSmNW	EkeAuS	EkeWnN	EkeWimS
2005	−8.79E − 04	0.99	0.99	0.98	1.08E + 08	552	0.9	1.16	3.7	16.88	15.26	22.14	8.01E − 03	1.06E − 02	1.32E − 02
2006	−1.43E − 03	0.98	1.00	0.09	1.94E + 08	293	1.04	1.08	3.62	16.51	15.06	21.67	6.15E − 03	7.55E − 03	6.25E − 03
2007	−5.21E − 04	0.95	0.98	0.90	2.77E + 08	480	0.9	1.12	2.41	17.15	15.79	24.38	6.63E − 03	6.62E − 03	6.91E − 03
2008	−2.08E − 04	1.01	1.04	0.90	2.07E + 08	620	1.16	1.32	2.77	16.91	15.39	23.56	8.97E − 03	5.84E − 03	6.55E − 03
2009	−2.42E − 04	0.96	1.00	0.91	1.99E + 08	504	1.04	1.48	3.85	17.2	15.48	22.51	8.67E − 03	6.07E − 03	9.37E − 03
2010	−9.20E − 04	1.03	1.05	0.91	1.56E + 08	490	1.23	1.51	4.09	17.57	16.1	22.96	8.45E − 03	9.92E − 03	6.22E − 03
2011	−7.58E − 04	1.05	1.05	0.95	1.28E + 08	513	1.17	1.07	2.11	17.36	15.26	22.04	5.74E − 03	6.95E − 03	8.27E − 03
2012	−1.50E − 03	0.96	1.00	0.88	1.58E + 08	385	0.94	1.02	2.48	16.94	16.24	23.25	5.44E − 03	4.72E − 03	6.04E − 03
2013	−9.88E − 04	1.04	1.04	1.00	2.49E + 08	384	0.89	0.92	3.03	18	15.53	21.29	6.68E − 03	6.03E − 03	3.95E − 03
2014	−9.59E − 04	1.01	1.01	0.96	1.72E + 08	508	0.91	1.49	2.76	17.6	16.19	22.97	1.21E − 02	1.19E − 02	1.17E − 02
2015	−7.72E − 04	1.07	1.09	0.90	1.24E + 08	387	1.37	1.13	2.28	17.39	16.21	23.07	8.13E − 03	1.30E − 02	2.15E − 02

biomass estimates of hydro-acoustic surveys. This assessment was reported as failing to set a significant stock-recruitment relationship. Therefore, given the very high fecundity of the species (a female producing up to 200 K eggs/season) and considering that a noticeable percentage of YoY attains maturity in the very same spawning season (Lisovenko and Andrianov, 1996), the effect of spawning stock biomass on recruitment was disregarded for this study with recruitment assumed to be independent of biomass the previous year. It should be noted that the uncertainties in the stock assessment (Brooks and Deroba, 2014) were not taken into consideration.

2.3. Environmental data

The monthly sea surface temperature (SST), satellite derived Chlorophyll (CHL) and geostrophic velocities were downloaded from Copernicus Marine Service (CCMS) and analysed in R using the "NCDF" library. Two – dimensional satellite data, which represents only a thin layer at the surface and therefore may seem to be a constraint is not critical in the case of Black Sea anchovy since the species in question exclusively occupies the upper mixed layer (Niermann et al., 1994) in which vertical variability is negligibly low.

Satellite data was filtered for extreme values and/or bad quality flags and then averaged for two geographic subsections. The first represents the main spawning and feeding grounds over the NW shelf zone (43.5°N–47.0°N and 28.0°E–32.5°E), the second is the South coast (40.9°N–42.5°N and 30.0°E–42.0°E) where the Black Sea anchovy inhabit during winter (Fig. 1). In addition, data was averaged over two separate time frames; the overwintering period corresponding to September–February with the period from April – August assumed to represent the active feeding period. The relationship between anchovy condition (Kn) and environmental parameters (Chl and SST) of samples were compared with the mean SST in the South at the time of sampling. The velocity, which is characterized by several mesoscale features along the study area, is incorporated in the analysis by Eddy Kinetic Energy (EKE). The EKE was calculated using the equation $((u^2 + v^2)/2$, "u" and "v" being Geostrophic velocities (Gent, 2011).

2.4. Statistical analyses

Coherence of data with the statistical models employed was checked by a normality test performed using the R programme 'LambertW' with deviation from normality corrected by log transformation. The dependence of Kn on length, sex, week and year were tested using factorial ANOVA applied to "sexed data". Dependency was then tested individually for each sex and for the combined data using linear models. The models and their slopes in particular were compared by means of ANCOVA testing for the interaction between the covariate and the factor. If the interaction between the covariate and the factor is not significantly different from zero, then the slopes are assumed to be similar. The rates of condition loss within overwintering seasons were determined from the slope of the model derived for the period between September to December each year. All trends stated refer to the slope of the linear model between the parameter in question (Kn) and time (Day).

The Correlation coefficient R (covariance of the variables divided by the product of their individual standard deviations) was used to evaluate how variables are linearly related and coefficient of determination (R squared) was used to observe the variance explained by the predictor.

The data manipulations and statistical analyses described above were carried out in R 3.1.2. In the presentation of significance level the R notation was used ("." = $P > 0.05$; "*" = $P \le 0.05$; "**" = $P \le 0.01$; "***" = $P \le 0.001$).

3. Results

The weight- length relationship used to estimate Kn was calculated as $W = 0.0046\,L^{3.122}$ and is presented in Fig. 2 along with standardized residuals. The deviations in the left tail of the QQ plot largely correspond to small sized individuals of 7 cm or less TL (0.85 on the log scale) which were filtered off as mentioned above.

The distribution of Kn estimated for the filtered data set is given in Fig. 3. The figure shows that the skewed distribution observed in the Kn estimates (skewness = 0.41) was removed remarkably (skewness = 0.05) by log transformation.

The results of the factorial ANOVA applied using the sexed dataset to evaluate the associations between Kn and sex, length, week (intra-annual) and year (inter-annual) suggested that all the factors tested do have significant impact on the body condition of anchovy (Table 3). The sex effect is positive with respect to males, indicating the Kn values of males to be higher than the females (Fig. 4). On average the difference found was 0.03 units (1.028–0.998).

The length effect was negative and Kn significantly decreased with length. Fig. 5 displays the relationship between Kn and length in males, females and in the combined data. All groups displayed the same pattern; larger anchovies showed lower condition than small individuals.

The effect of sampling week was also negative with, Kn decreasing significantly (Table 3) with time and displaying a very similar pattern in males and females (Fig. 6). Anchovies sampled early in the fishing season (September) displayed the highest Kn followed by a steady loss in condition until the end of December (week 18). In Fig. 7 only the first 18 weeks were presented for males and females together with linear models fitted to each dataset. The slopes are significantly different (Table 4); however as analysis to compare the two linear models

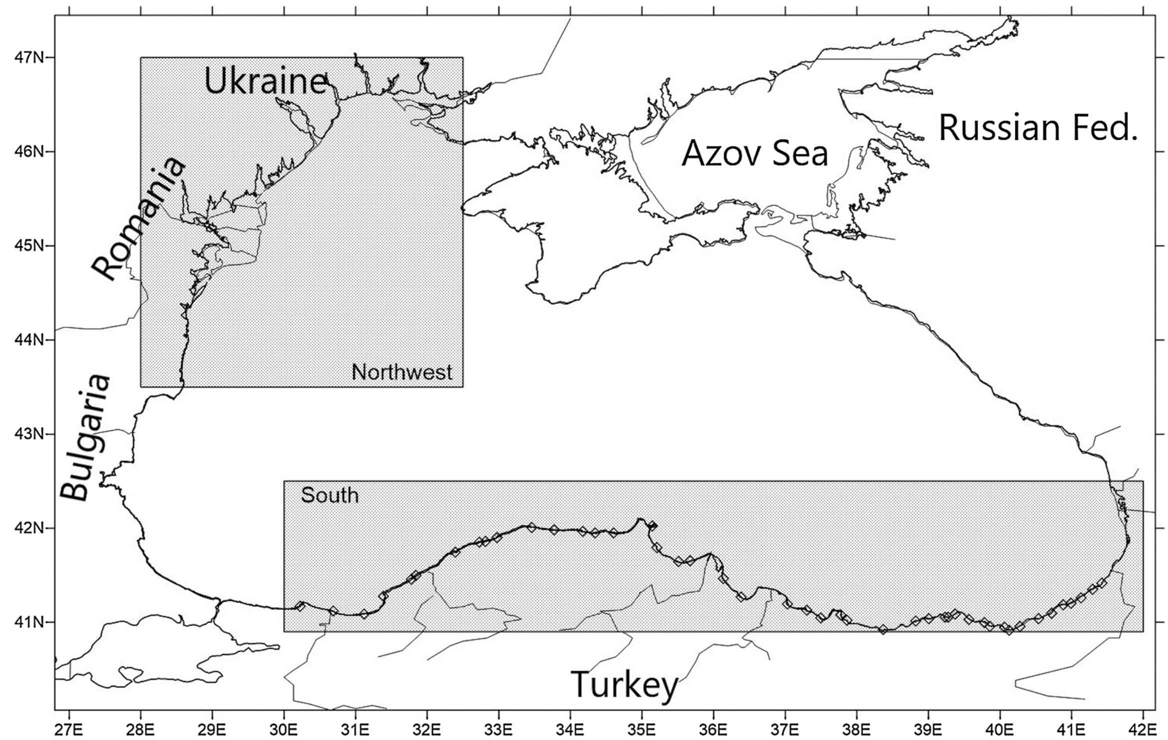

Fig. 1. Areas defined for spawning (northwest) and overwintering (south) grounds and the landing sites visited throughout the study (diamonds).

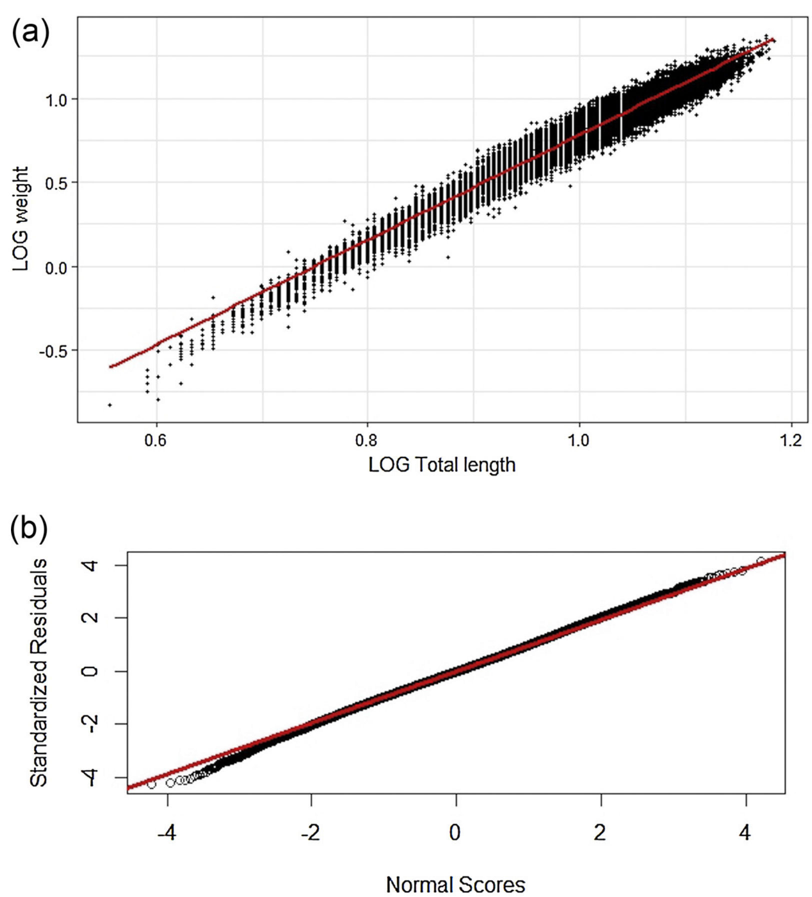

Fig. 2. Linearized weight vs length relation within the samples (a) and the standardized residuals (b).

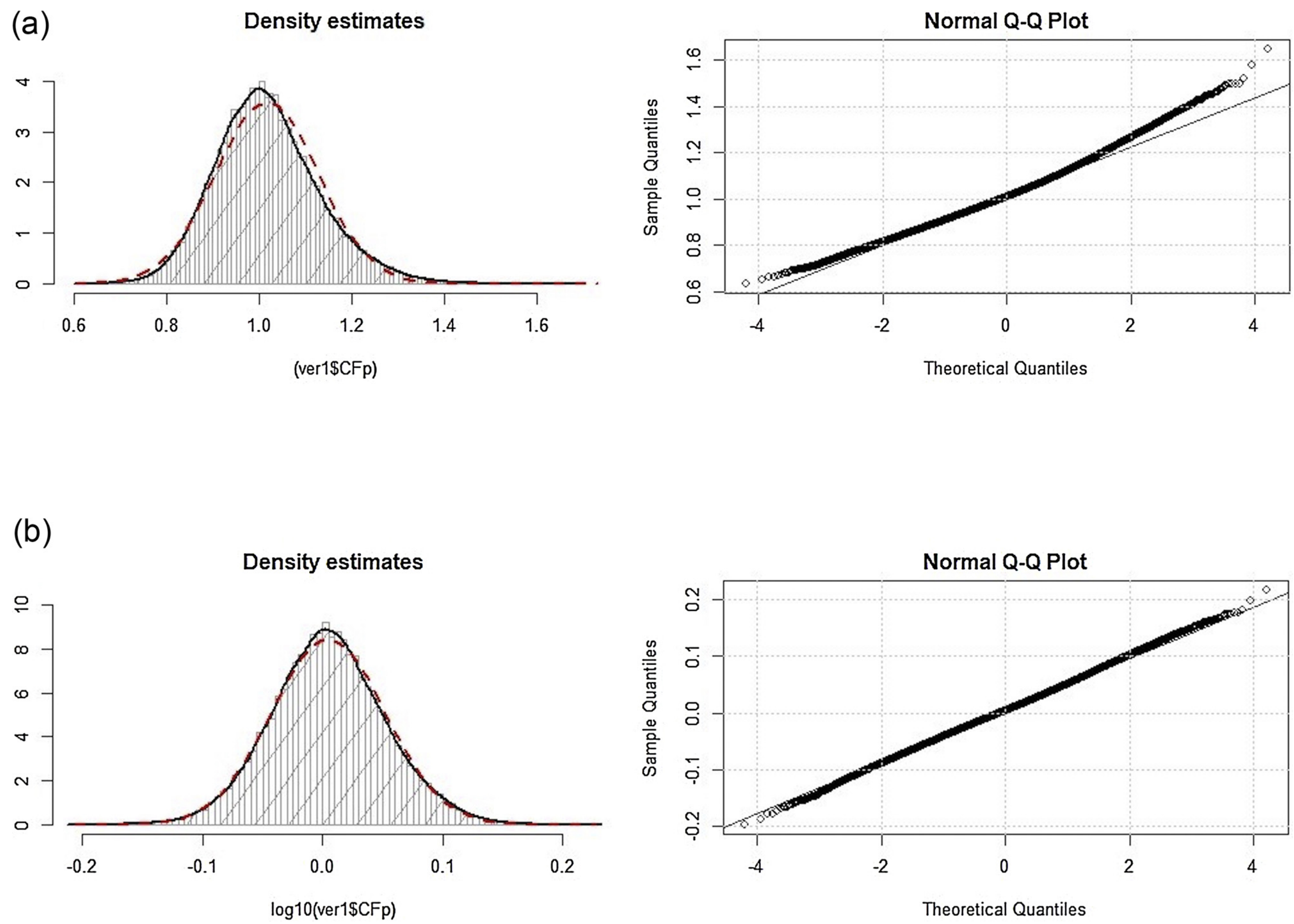

Fig. 3. Distributions of Kn before (a) and after (b) log transformation and the corresponding Q-Q plots.

suggested, the trend (slope) is not particularly strong (Table 5). At the end of the calendar year (week 18) the values levelled off and the Kn index fluctuated slightly above 0.9 throughout the remainder of the fishing season. The linear models applied to each gender indicated that the trends in this second half of the season were not significantly different (Table 4). ANOVA analysis applied to determine inter-annual variation on the average Kn within the second period (threshold) was statistically significant ($F = 72.9$; $p < 2.2e\text{-}16$).

In the combined data a similar pattern was observed with the exception that Kn values continued to decrease after December; however the slope for the second period ($b = -0.0012 \pm 0.00035$) was significantly less than the slope for the first ($b = -0.0054 \pm 0.00012$).

The factorial ANOVA (Table 3) showed a positive yearly effect (inter annual), indicating that Kn displayed a significant increasing trend over the eleven year period examined. The linear models fitted to males and females showed that although the models and their slopes were significantly different (Table 6); the difference between the slopes of males and females were not significant. This indicates that despite differences in the absolute values of Kn, the trends displayed by gender over the eleven years were similar (Fig. 7)

When the inter-annual data was analysed individually, the progressively decreasing linear trend occurred every year (Fig. 9). The slopes, however varied significantly ($F = 627$, $p < 2.2e\text{-}16$) with Kn loss highest for the 2008 and 2009 overwintering seasons (Table 2).

Values for YoY also displayed a pattern very similar to that exhibited by the adult anchovies. Kn decreased in winter (Fig. 10) with yearly patterns fairly similar to those of the adults (Fig. 11) with the exception of 2008 when the trend was positive.

Table 3
Results of factorial ANOVA analysis representing the effects of gender, length, week and year on Kn.

	Estimate	Std. Error	t value	Pr(> |t|)	
Intercept	−3.01E + 00	3.49E − 01	−8.626	< 2.00E − 16	***
Length effect	−1.07E − 02	4.05E − 04	−26.393	< 2.00E − 16	***
Sex (M) effect	6.52E − 03	8.77E − 04	7.437	< 1.20E − 13	***
Week effect	−4.35E − 03	7.16E − 05	−60.797	< 2.00E − 16	***
Year effect	1.58E − 03	1.73E − 04	9.153	< 2.00E − 16	***

	Df	Sum Sq	Mean Sq	F value	Pr(> F)	
Length	1	0.9615	0.9615	630.702	< 2.20E − 16	***
Sex	1	0.3171	0.3171	208.010	< 2.20E − 16	***
Week	1	6.0504	6.0504	3968.917	< 2.20E − 16	***
Year	1	0.1277	0.1277	83.783	< 2.20E − 16	***
Residuals	8727	13.3037	0.0015			

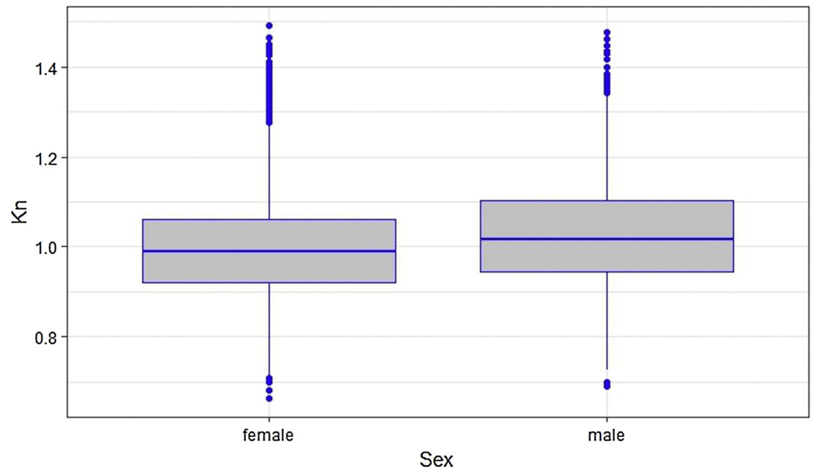

Fig. 4. Kn of males and females.

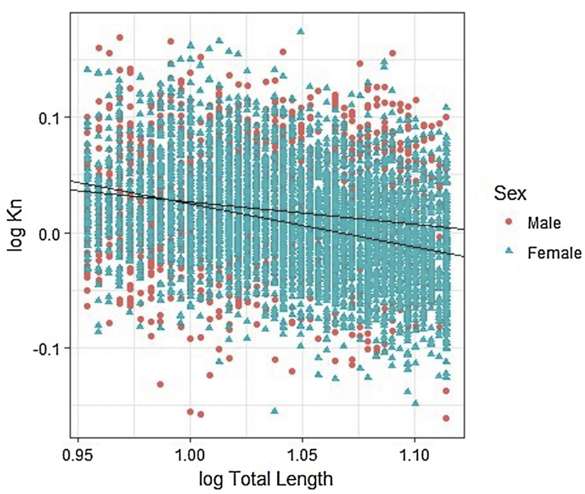

Fig. 5. Effect of length on Kn.

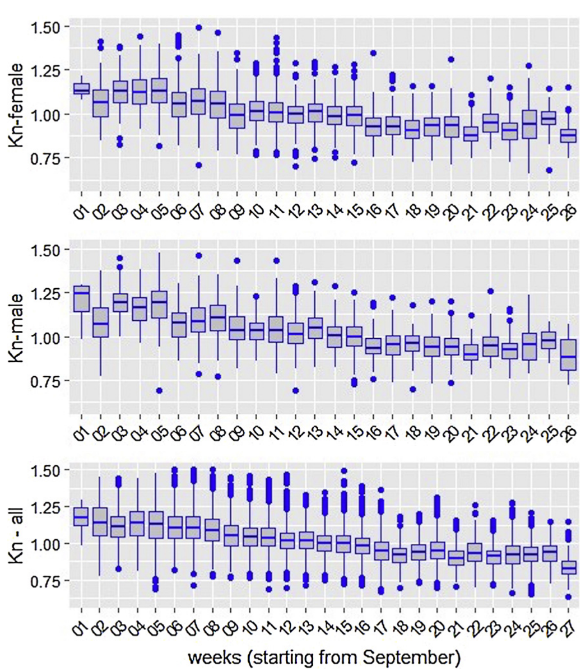

Fig. 6. Weekly changes in the Kn by gender.

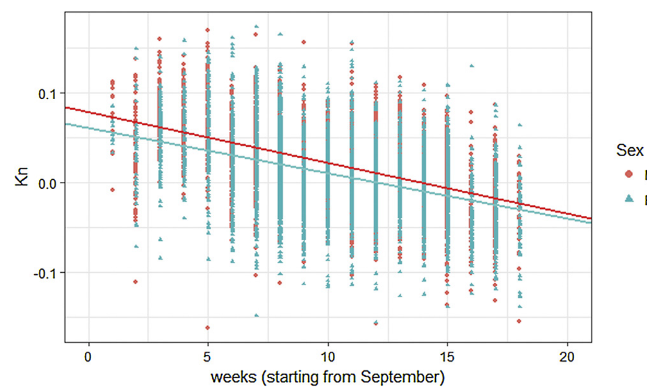

Fig. 7. Changes in the Kn within the overwintering season displayed by genders.

With regards to environmental variables, Kn significantly correlated with the mean SST at the time of sampling; however no correlation was found between Kn and chlorophyll level. A test to assess if summer conditions (SST and CHL) in the NW shelf where anchovies theoretically feed and spawn before returning to the overwintering grounds, displayed any impact on Kn resulted in no statistical significance; Kn of the 'arriving anchovies' on their return to the overwintering grounds, Kn gained during summer or the yearly average Kn correlated with neither of the environmental parameters assessed (Table 2). On the other hand, the same Kn indicators displayed positive correlation with the summer averages of the same environmental factors in the South (Table 7; see also Fig. 1 for the implied areas). Yet when combined, Chlorophyll and SST accounted for a very high percentage of the variance in Kn ($R^2 = 0.87$).

The statistical test applied to determine if the changes in Chlorophyll levels and/or SST within an overwintering season had any effect on Kn of the anchovies showed no statistically significant correlation.

Similarly, the rate of condition lost (both linear trend and absolute differences between the Kn values of arriving and departing anchovies) showed no correlation with winter averages of temperature and chlorophyll.

However, the Eddy Kinetic Energy, EKE seems to exert significant control on the condition of the species. The condition of the arriving anchovies displayed positive significant correlation with the EKE at the end of summer ($R^2 = 0.857$; $p < 0.01$, Fig. 13). Also if the two extreme EKE values observed in 2013 and 2015 are removed, the average Winter EKE values in the south were strongly negatively correlated with the rate of condition loss during winter ($R = -0.907$; $p < 0.01$;

Table 4
Results of linear models analysing the decreasing trend in Kn before and after 18th week (end of December) in males, females and the combined data.

Response: Log Kn (September-December; weeks 1–18 in Fig. 6)					
	Estimate	Std. Error	t value	Pr(> |t|)	
Intercept (male)	0.079118	0.00214	36.98	< 2e − 16	***
Slope (male)	−0.00568	0.000189	−30.05	< 2e − 16	***
Intercept (female)	0.060942	0.001885	32.33	< 2e − 16	***
Slope (female)	−0.00504	0.000165	−30.61	< 2e − 16	***
Intercept (combined)	7.45E − 02	7.52E − 04	99.08	< 2e − 16	***
Slope (combined)	−5.39E − 03	6.32E − 05	−85.37	< 2e − 16	***
Response: Log Kn (January-February; weeks 19–26 in Fig. 6)					
	Estimate	Std. Error	t value	Pr(> |t|)	
Intercept (male)	−1.53E − 01	6.63E − 02	−2.314	0.0209	*
slope (male)	3.08E − 06	1.63E − 06	1.892	0.0589	.
Intercept (female)	−0.02272	0.012214	−1.86	0.0631	.
Slope (female)	−0.00057	0.000556	−1.029	0.3037	
Intercept (combined)	−0.00465	0.003902	−1.191	0.234	
slope(combined)	−0.00125	0.00018	−6.96	3.70E − 12	***

Table 5
ANOVA results comparing the two linear models applied to males and females sampled between September and December.

Response: Log Kn (September-December; weeks 1–18 in Fig. 6)						
	Df	Sum Sq	Mean Sq	F value	Pr(> F)	
Week	1	3.1327	3.1327	1866.93	< 2e − 16	***
Sex	1	0.2042	0.2042	121.67	< 2e − 16	***
Week:Sex	1	0.0109	0.0109	6.50	0.01081	*
Residuals	6721	11.2777	0.0017			

Table 6
ANOVA tables testing the trends in Kn displayed by gender over the eleven years evaluated.

Response: Log Kn						
	Df	Sum Sq	Mean Sq	F value	Pr(> F)	
Date	1	0.6613	0.6613	291.21	< 2e − 16	***
Sex	1	0.2739	0.2739	120.6	< 2e − 16	***
Date:Sex	1	0.0046	0.0046	2.0474	0.1525	
Residuals	8728	19.8206	0.0023			

Fig. 14).

Statistical comparison of Kn and the recruitment and spawning stock biomass of the same year was not significant, however the condition loss in winter was correlated with SSB ($R^2 = 0.536$ p: 0.010). The same parameter, both in adults (R^2: 0.486; F: 9.5; p: 0.015) and YoY (R^2: 0.446; F: 8.3 p: 0.021) also correlated positively with the number of recruits in the following year (Fig. 15).

4. Discussion

Fish condition indicators may be grouped under two generic categories. Organosomatic indicators (bioenergetics or morphophysiological) such as mesenteric (adipose/perivisceral) fat index, hepatosomatic (liver index), and digestivosomatic index, which directly utilize body tissues where the energy is stored (Lloret et al. (2014). Morphometric indicators, however approximate the energetic fitness based on body mass (Lloret et al., 2014). There are however contradicting views concerning how well the morphometric indexes represent the condition of a fish. According to Shulman et al. (2009) lipid content is fundamental to understanding fish condition and as lipid accumulation is often accompanied by loss of water and mass reduction (or vice versa), indexes that depends on body mass are therefore deemed

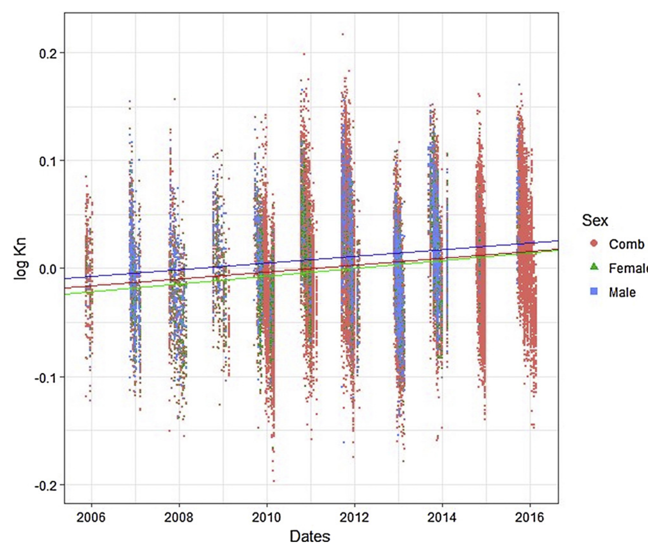

Fig. 8. Composite graph displaying the tends in the Kn of the adult anchovies during the overwintering periods.

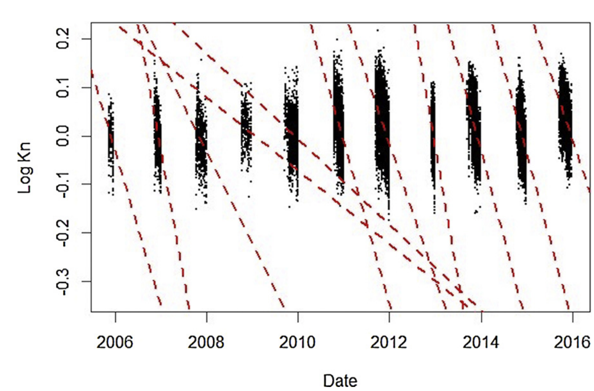

Fig. 9. Overall trend in the relative body condition of Black Sea anchovy between 2005 and 2016.

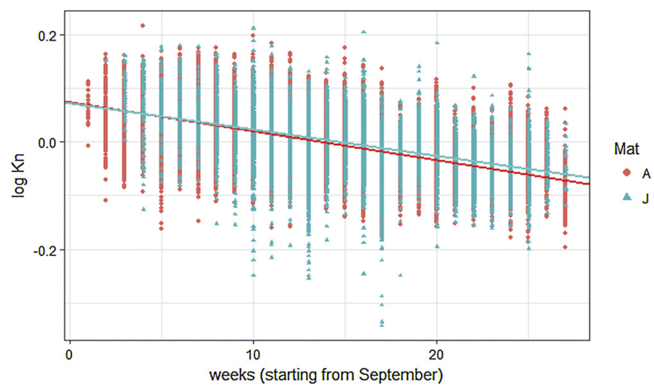

Fig. 10. Kn changes within overwintering season displayed by adults and juveniles.

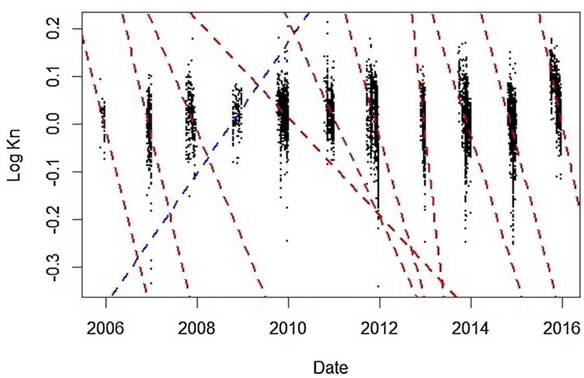

Fig. 11. Composite graph displaying the tends in the YoY during the overwintering periods.

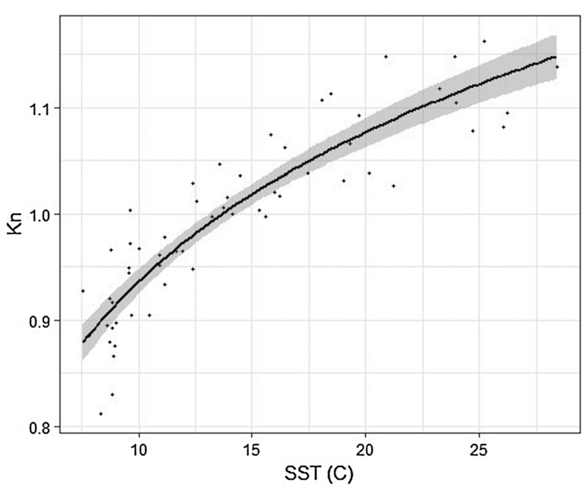

Fig. 12. The mean Kn and SST at the time of sampling.

inappropriate to reflect energy accumulation or expenditure. On the other hand, the annual cyclic dynamics of the anchovy fat content proposed by the same authors which display a peak in October followed by a sharp decline conform to the dynamics of anchovy body condition found in this study using the morphometric index.

Choosing the best morphometric index to represent the fish condition is a debatable issue (Froese, 2006). Given the overall aim of the study, Le Cren's relative condition was considered appropriate, however results indicate that the Kn estimates based on a common set of weight-length related parameters were not totally independent of sex (Table 3) with males displaying slightly higher Kn than females. Also, although the length ranges of the samples were optimized to minimize

Table 7
Output of the linear model testing the link between mean Kn values of the arriving anchovies and the environmental parameters in Summer (sea surface temperature, SST and chlorophyll, Chl).

Response: Kn on arrival at the overwintering area

	Estimate	Std. Error	t value	Pr(> |t|)	
Intercept	0.20565	0.15813	1.301	0.22962	
ChlSmS	0.17092	0.02362	7.236	8.93E − 05	***
SSTSmS	0.03705	0.00912	4.064	0.00361	**

Multiple R-squared: 0.899, Adjusted R-squared: 0.8738.
F-statistic: 35.61 on 2 and 8 DF, p-value: 0.000104.

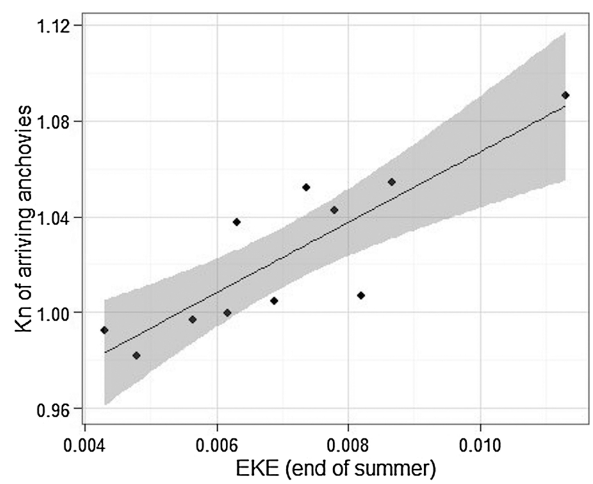

Fig. 13. EKE and the mean Kn or the "arriving" anchovies.

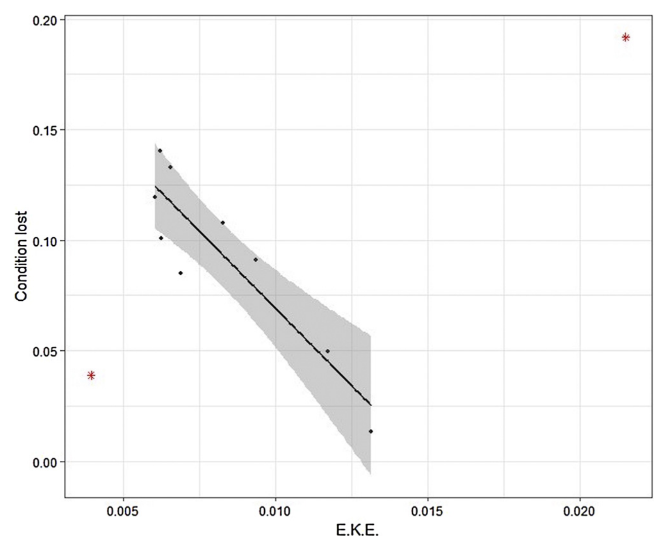

Fig. 14. EKE and the condition lost during winter (two outliers marked in red (larger) asterix were not considered). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the association between body condition and length as underlined by Lloret et al. (2002), estimates were evidently still dependent on length (Table 3). This may partly be the indication of variation in allometry displayed by different genders not accounted for by this approach. However, this may also be a reflection of age dependent energy deposition strategy. Observations reported by Nikolsky et al. (2012) support the latter view as, according to the authors, mid-sized anchovies in the Black Sea accumulated more fat than the older and larger

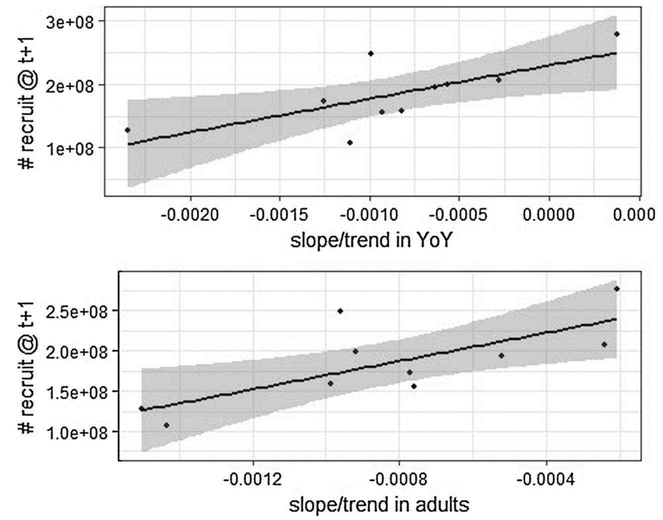

Fig. 15. Relation between rate of condition loss of adults and YoY (slopes of the dashed lines in Figs. 8 and 11) and number of recruits in the following year (Recruitment is taken from STECF, 2015).

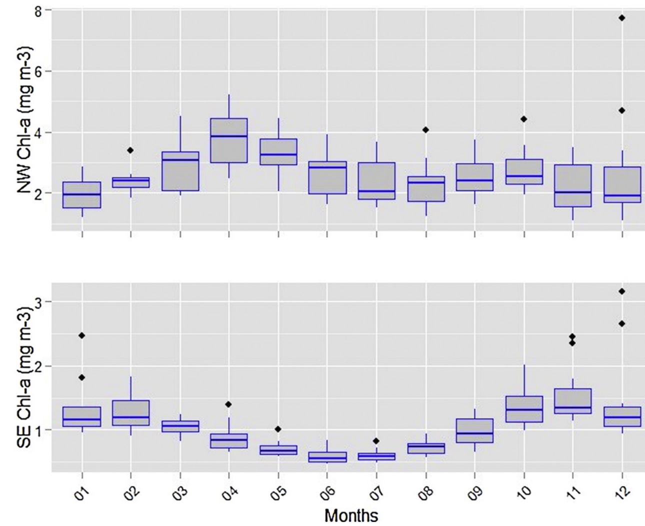

Fig. 16. Satellite derived Chlorophyll-a (mg m^{-3}) in NW and S Black Sea (see Figure 1 to areas implied).

individuals during the period between 2005 and 2007. On the other hand, despite the significant gender effect perceived by the index, it is also seen that the changes exhibited throughout the time series were not different from each other when the sex groups were handled separately (Fig. 7; Table 6). It has therefore been recognized that using combined data to elucidate the Kn associations provides a practical solution as this approach adequately compromise the differences arising from gender and length effects within the population.

Throughout the eleven years of observation, the condition of the fish declined gradually with individuals losing condition at rates between 1.4–9.5% per month during winter. However, fish restored this loss and returned with higher Kn values prior to the overwintering season, apparently gaining condition during summer when the overall productivity of the Black Sea is at maximum (Bologa et al., 1999). This is not surprising as the European anchovy is usually classified as an income breeder, feeding and spawning concurrently (Bulgakova, 1996). The intense summer feeding and consequent energy deposition before winter is of crucial importance for the stock since anchovies that cannot build up sufficient energy reserves during summer in the north (i.e. fat accounting for at least 14% of body weight) are unable to migrate south in winter and consequently die (Shulman, 2002).

The YoY behave differently when compared with the adult population, forming winter aggregations almost a month later than the parent stock (Chashchin et al., 2015; Gücü et al., 2017). Such a behavioural difference is expected to be reflected in the body condition of both groups. However what was actually observed is the opposite; the Kn indices of both adults and YoY displayed very similar patterns of fluctuation (Fig. 6). Such similarity in the patterns exhibited by the small and large groups shows that the impact of external predictors are common, have similar influence on both groups and control the condition of the entire stock.

One very likely explanation of variability in condition is food availability. As illustrated by the satellite derived CHL data, productivity of the overwintering grounds in the south in winter (1.1 mg m^{-3}; Fig. 16) is almost three times lower than that of the northwest during summer (3.0 mg m^{-3}). Therefore the nutritious capacity of the overwintering grounds in the south, which is also constrained by the very narrow continental shelf is insufficient for the overwintering schools which tend to aggregate in gigantic, very dense schools sometimes exceeding 1000 ind m^{-3} (Gücü et al., 2017). Consequently, the anchovies do not feed (Chashchin, 1996), but use their reserved energy and gradually lose condition throughout the winter as displayed in Fig. 6. However it may be worth noting that the entire data set does not fit this picture. In contrast to the general pattern, productivity in the south rises at the end of summer and reaches a maximum in December (Fig. 16). The loss of condition that continues from September to December seems to stop at a threshold level even though the environment is still unsuitable in terms of temperature and other regional constraints. The significant year to year differences between the threshold level observed at the end of the season indicates that the threshold is not a physiologically tolerable minimum limit but there may be some other mechanisms, such as fishing pressure, temperature and migration, alleviating the living conditions of the anchovies towards the end of winter.

As stated in Gücü et al. (2017), the Black Sea anchovy fishery is short and strongly seasonal with 95% of the total catch being landed within two months. The sizes and densities of the anchovy aggregations are drastically reduced at the end of this very intense fishing season and eventually the stock is thinned out. The core fishing activity usually ends between the last week of December and the first week of February coinciding with the above mentioned period when the negative trend in the condition loss is levelled off. This, if not a coincidence, points to density dependence in Kn that has already been proposed by Casini et al. (2014). In other words, the rapid removal of fish decreases the competition for food so that the scarce winter food supply can be utilized by the survivors.

Although the time frame of this study was not sufficient to analyse the cyclic patterns in Kn occurring over longer periods, the trend lines suggest that concealed behind the fluctuating pattern within the studied period is a slight increase (Fig. 8). A similar increasing trend for the Black Sea anchovy reported by Shulman et al. (2009) indicates that the origin of the increase goes back even further in the area. This however contradicts with the opposite situation reported for the Mediterranean anchovy stocks where a decrease in body condition is linked to fishery and phenotypical changes in the stocks associated with overfishing such as earlier maturation (Brosset et al., 2017). Such an effect does not seem evident for the Black Sea anchovy, where body condition displays an upward trend even though the anchovy stock is considered overfished, i.e. exploitation rate is above the precautionary value of 0.4 for more than a decade (GFCM 2016). Under the light of the present study it is more likely that condition of anchovy in the Black Sea is density dependent and the impact of fishing on the body condition of anchovy is positive. Density dependence of Kn is in fact inevitable when the tremendous food demand of anchovy, amounting to 146 Cal per gram daily (25% of body wet weight) and accounting for about 20% of the daily fodder plankton production in the Black Sea (Bulgakova, 1996;

Lisovenko and Andrianov, 1996) is considered. A similar density effect was already reported for the Black Sea sprat by Shulman et al. (2009).

As displayed by the strong positive correlation between Kn and SST (Fig. 12) it appears that temperature in winter has a strong impact on the condition of Black Sea anchovies. Temperature alone has a significant impact on the physiology and biology of fish by affecting the rate and direction of metabolic processes (Lloret et al., 2014). Temperature is also associated with oxygen saturation which may be crucially important in a basin like the Black Sea where over 90% of the water volume is anoxic and the vertical depth of the anchovy friendly oxygenated warm layer seldom exceeds 80 m. On the other hand, despite the very high correlation with temperature, the rate of condition loss was not affected by the cooling rate in this study. This contradiction is probably associated with the fact that temperature itself is not the only factor, but may also have some indirect consequences or may substitute some other factors, such as circulation patterns and hydrographic dynamism. Shulman et al. (2009) pointed out the relationship between the anchovy landings and the temperature difference between the north and the south of the Black Sea during the winter reporting that the poorly fattened anchovies continued to feed in the north without migrating to the south during the years when the longitudinal temperature gradient was not high.

Migrating fish generally do not feed (Lloret et al., 2014) and therefore to supply the energy required to fuel increased swimming activity, reserves are utilized throughout the journey. During the seasons covered by the surveys, Black Sea anchovy need energy, firstly to migrate to the overwintering grounds and secondly, to sustain the fish once they have reached the grounds best suited to their overwintering requirements. Apart from scarcity of food supply at the overwintering grounds, the additional cost of migration is another reason for the sharp decline observed in the Kn. The inter-annual differences in the rate of decline during this period however, may be linked to certain physical conditions which assist or distress the individuals during migration by facilitating or hindering transport such as currents. It is quite common that pelagic fish species (Fréon and Misund, 1999) including anchovy at various stages in their life cycles (Nelson and Hutchings, 1987) use currents to facilitate migration. The oceanography of the BS is known to be influenced by heat loss to the atmosphere; the higher heat flux resulting in more intense circulation in the sea (Korotaev et al., 2003) which would eventually be reflected as higher EKE. The migration path of the Black Sea anchovy, despite variation in some years (Shulman et al., 2009; Chashchin et al., 2015), follows the direction of the main cyclonic Rim current characterizing the oceanography of the Black Sea (Korotaev et al., 2003). The positive relationship between condition of the anchovies arriving at the overwintering grounds and the hydro dynamism (average Autumn EKE) during the migration indicates that the currents are positive mechanisms helping anchovy to reduce their energetic cost of swimming. The negative correlation observed between EKE in winter and the rate of condition loss throughout the winter however, may suggest that the anchovy could also be benefiting from the reduced oceanographic dynamism and thereby reducing the amount of energy needed to maintain their position once they have settled at the overwintering grounds. It is known that the Rim current meanders and gives way to form a series of coastal mesoscale eddies in the Black Sea when it is less energetic (Korotaev et al., 2003). According to Gücü et al. (2017) such formations which occurred between the coast and the rim current match with the spawning and overwintering grounds of the Black Sea anchovies. It is quite likely that such mesoscale features form retention pools enabling the anchovy to expend less energy for swimming at the overwintering grounds. In this context, it is also possible to disclose variations in migratory anomalies associated with anchovy lipid reserves and sea surface temperature reported by Nikolsky et al. (2012).

Interestingly, findings of this study reveal that the condition of the anchovies on arrival at the overwintering grounds and the condition they gained during summer correlated better with the Summer SST and CHL in the south than those in the NW shelf. This observation is consistent with the view that the spawning grounds of the Black Sea anchovy have extended southward in recent years (Niermann et al., 1994; Gücü et al., 2016).

As body condition positively affects various biological processes incorporated in reproduction such as fecundity (Ferrer-Maza et al., 2016), maturity age/probability (Morgan, 2004), egg quality (Brosset et al., 2016), Kn is considered to be related to recruitment success for a variety of fish species (Carbonell et al., 2008) including the European anchovy (Bergeron and Masse, 2012). Given that the Kn index in this case represents the winter condition and that the species feeds and spawns almost synchronously (as an income breeder; Bulgakova, 1996) during summer, the expectation of a direct relationship between recruitment and body condition of the adults might not be realistic due to lags in the timing of events. Similarly, the XSA based estimates used to assess the Black Sea anchovy stock give the recruitment at the onset of the year (Shepherd, 1999). On the contrary, the Kn estimates provided in this study represents the condition of the anchovies at the end of the year. With that respect, one possible explanation of the inverse relationship between condition loss and the SSB of the same year could again be density dependence due to high biomass inducing intra-species competition.

Better condition at the beginning or at the end of the overwintering period, or for the season average does not seem to have much consequences on recruitment. However, in the years followed by a slower rate of condition loss in both the small and large anchovies, the recruitment success was usually higher. This indicates that fish rapidly losing condition (possibly due to harsh winter conditions and unfavourable hydrography) are less successful in reproduction than those experiencing better winter conditions and therefore reserving energy throughout the winter. This pattern is not unique to the Black Sea anchovy. For instance, recruitment in the Georges Bank haddock is known to be affected by the condition of adults in the previous year (Friedland et al., 2008). On the other hand, this relationship which links environmental conditions, fish condition and recruitment success, deserves further attention as it could shed light on the abrupt fluctuations in recruitment and hence in the stocks of species. Also, the rate of loss, in some respects, summarizes the entire season. The average condition however, may or may not reflect the same information depending on how well the factors affecting condition, such as seasonality and length groups are balanced in sampling.

4.1. Implications to fisheries

The Black Sea anchovy is a transboundary species fished by almost all Black Sea countries with the stock in overexploitation (GFCM, 2016). Effective management therefore necessitates a harmonized strategy involving all countries, which is currently lacking. The regulations applied differ from country to country with only a few commonly applied to several countries. One such regulation is the "Minimum temporal restriction" enforced in five out of six Black Sea countries (GFCM, 2016). Due to various constraints associated with the migratory behaviour of the Black Sea anchovy and with the expansive nature of the fishery, any regulation setting a fixed limit on permissible catch is not found applicable and yet, prone to IUU fishing (Gücü et al., 2017). Therefore alternative harvest control measures other than TAC gain importance. In this respect, the drastic drop in the condition Kn observed in winter may be considered as a means to optimize harvesting strategy (timing of fishing) and so maximise the economic benefits already pointed out by Lloret et al. (2014). Considering that a significant part of the anchovy catch is used in fish oil production, setting the fishing season based on the maximum body condition (fatness) period, may be a management strategy to increase the profitably and efficiency of the harvest control measured applied.

5. Conclusion

Observations presented in this work are preliminary as they are based solely on a single index, and need to be supported and verified by direct methods such as lipid analysis. The study, however underlines that the dynamic of body condition in a migrating small pelagic fish, can be very fast. Irrespective of which condition indicator is used, such rapid change will ascertain date of sampling as extremely critical, especially when inter annual comparisons are to be made. On the other hand, continuous monitoring of the body condition and the evaluation of the rate of intra annual changes have the potential to provide information in a variety of contexts from recruitment variability to the relationship of the stock to the environment.

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