

An Acoustic Study on the Overwintering Black Sea Anchovy in 2020

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Abstract

The Black Sea anchovy (*Engraulis encrasicolus ponticus*) is not only the top commercial species with around 250 thousand tonnes of annual catch but a key species of the Black Sea ecosystem facilitating the flow of energy within the food chain. The General Fisheries Commission for the Mediterranean has assessed the status of its stock for the Mediterranean since 2013. Underlining the shortcomings in the assessments, the commission has recommended diversifying and strengthening the data used and promote methods that provide biomass and abundance indices, such as hydro-acoustics. This study aims to help fulfill the underlined deficiency by pursuing the implementation of the hydro-acoustic research surveys in the Turkish Black Sea EEZ. The survey was carried in November/December 2020, when the anchovies were accumulated within the Turkish EEZ, and cruise tracks were designed to cover the distribution areas of juvenile (0-year-old) and adult (Age 1 and over) anchovies displaying different distribution patterns within the Turkish EEZ in winter. The results show that the stock size is noticeably smaller than in previous years. Pelagic trawl sampling conducted alongside the acoustic data collection to estimate the size composition of anchovies indicated that the juvenile fish constitute an alarmingly large part of the overwintering stock.

Introduction

In September 2015, all member states of the United Nations have agreed to adopt a universal action plan for global cooperation on sustainable development for the period 2015 to 2030 in an attempt to correct the off-course deviations in the world economy (UN-SDGs, 2021). The "Transforming the World: the 2030 Agenda for Sustainable Development" agreement has defined 17 Sustainable Development Goals (UN-SDGs, 2021). Among them, SDG-14 aims to "Conserve and sustainably use the oceans, seas and marine resources for

sustainable development". This goal is addressed in the ten targets, and these targets, directly (T4: Sustainable fishing; T7: Increase the economic benefits from the sustainable use of marine resources; T8: Increase scientific knowledge, research, and technology for ocean health) or indirectly (T2: Protect and restore ecosystems; T5: Conserve coastal and marine areas; T6: End subsidies contributing to overfishing; T9: Support small scale fishers) necessitates the marine living resources being well- managed. Without a doubt, those targets require a better understanding of the status of the fish stocks. To facilitate the member countries to

fulfill their mandates, the Regional Fisheries Management Organizations (RFMOs) were delegated by the agenda to implement the SDG14 (Haas et al., 2020).

The Black Sea anchovy (*Engraulis encrasicolus ponticus*; anchovy here after) is among the significant fish stocks in the world's oceans, with its catch that exceeded half a million tonne in the past (Figure 1). For over ten years, this important stock's status has been assessed by the subsidiary bodies of the General Fisheries Commission of the Mediterranean (GFCM), the RFMO responsible for the Black Sea. The annual assessment reports prepared in this context repeatedly underline the importance of reliable fisheries independent data that provides scientifically sound insight into the anchovy biomass at sea. Such data is deemed fundamentally important for most advanced analytical stock assessments and is generally used to tune the model (Lassen & Medley, 2001).

One of the most commonly applied techniques to collect fisheries independent data for small pelagic fish stocks is the hydro-acoustic method (Fréon & Misund, 1999). This method has been used in the Black Sea for many years to estimate the biomass of anchovy. The first hydro-acoustic survey was conducted in 1956 by a Turkish Research vessel, *RV ARAR* and the overwintering ground of the Black Sea anchovy was surveyed (Aasen & Artüz, 1956). The second survey was expanded to cover the entire Black Sea and was carried out in the summer of the following year with the same research vessel (Acara, 1960). The next survey that covered the same area was conducted in 1979 (Johannesson & Loose, 1977). After a long period, the acoustic surveys were initiated again in the winter of 1989 (Stepnowski et al., 1993) and continued in the following four years (Bingel et al., 1995). Since 2011, the southern coast of Turkey is being surveyed using Hydro-acoustic method to monitor the overwintering and spawning aggregations of Black Sea anchovy within the Turkish Exclusive Economic Zone.

In the former USSR, the anchovy biomass overwintering in the Georgian coast was regularly monitored using hydro-acoustics between 1981 and 2003 (Chashchin et al., 2015). Following the integration of Bulgaria and Romania to the European Union, the monitoring of small pelagic stocks within the respected waters of these countries was mandated, and a series of hydro-acoustic surveys were conducted within this context in the Northern Bulgarian Black Sea area (Panayotova et al., 2014).

The current study reports the findings of the 2020 winter hydro-acoustic survey, which is a part of the anchovy monitoring program initiated in 2011. With this study, we aimed to provide fisheries independent data, which GFCM has identified as a critical deficiency that weaken the reliability of the stock status assessments. In addition, emphasis was given to the distribution of different life stages and the unusually low spawning stock biomass.

Material and Methods

The study was based on the data collected on-board *RV Akdeniz Araştırma -1* during the anchovy monitoring survey conducted in winter 2020.

Temporal Coverage

The Black Sea anchovy is a highly migratory species. The cooling in the surface waters in winter drives the adult anchovies from the northwest to the south-eastern corner of the Black Sea, and they occupy the Turkish EEZ where they overwinter between November and December. As the overwintering adult anchovy aggregations are subjected to heavy pressure on the Turkish coast, a significant part of the stock is removed by the fishery in a short period of time, and more than 80% of the annual catch is harvested within 30 days following their arrival at Turkish EEZ (Gücü et al., 2017). Taking this time constraint into consideration, the survey strategy targeting the Black Sea anchovy's winter distribution has been designed to be finalized as quickly as possible before a remarkable part of the fish is removed by the fishery.

Spatial Coverage

The Black Sea anchovy's migration route is determined mainly by the seawater's cooling pattern and, connectively, by the hydrographic features like eddies and fronts. Accordingly, they either migrate close to the shore and so that the aggregations of adult anchovies are observed on the continental shelf, or else they follow a route off-shore (Gücü et al., 2018). Contrary to the adults' migration patterns, the young of the year (YoY), which are distributed all over the basin in summer, begins to aggregate later than the adult fish (Chashchin et al., 2015; Gücü et al., 2018). In November and partly in December, the aggregations of YoY are usually patchy, less dense compared to the adults, and almost always away from the continental shelf.

Taking the total survey area to be covered, the distribution of different life stages, and the time limitations explained above into consideration, the survey was carried out in two phases. The first phase was carried out before the adult anchovy aggregations migrating to the Turkish coasts for wintering started to appear. In this phase, the anchovy aggregations consisting of 0 age groups outside the continental shelf (200m<) were targeted. For this purpose, data were collected on the off-shore transects covering the region between the Turkish-Bulgarian border in the west and the Turkish-Georgian border in the east (Figure 2). This part of the study was completed in 20 days between 13 November and 3 December 2020.

Immediately after the first phase, the survey was continued in the reverse direction, and the acoustical transects were limited to the continental shelf (200 m>).

The second phase of the study was carried out between 4 and 13 December 2020 and was completed in 10 days.

The off-shore transects were placed in the NS direction and 0.5 degrees (~23 nmi) apart. The samplings transect on the continental shelf were positioned in the same manner; however, the transects' interval was reduced to 0.1 degrees, which corresponds to ~4 nautical miles (Figure 2).

Data Collection

The hydro-acoustic data were collected at three different frequencies, 38, 120, and 200 kHz, the former being the target frequency, using an echo sounder (EK80, Simrad-Kongsberg, Norway) with split-beam transducers mounted on the hull, ~2.5 m below the water surface. The three transducers (38, 120 and 200

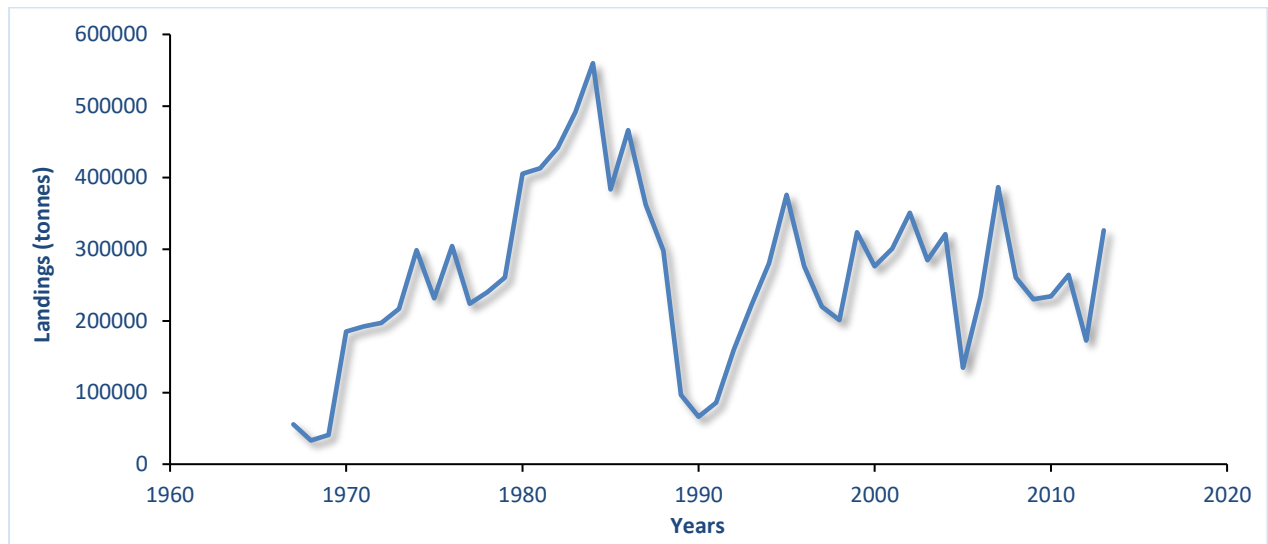


Figure 1. Total Black Sea anchovy landings by all riparian countries (GFCM-SAF, 2018).

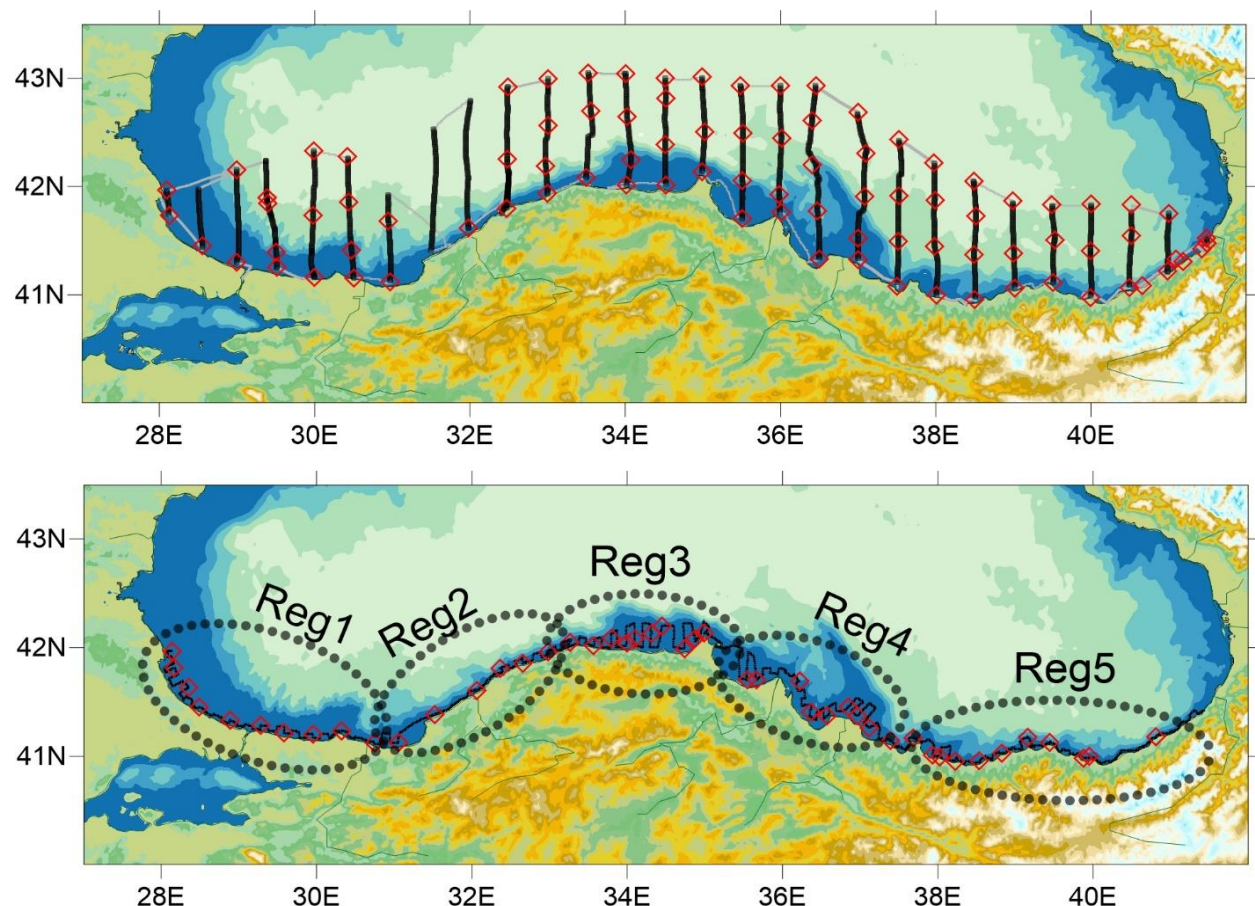


Figure 2. The cruise tracks and the position of the CTD stations: the upper is off-shore transects (bold lines are used for echo integration; the lower is the tracks studied on the continental shelf (200m >), ellipses indicate the sub-regions used for stratification.

kHz) of the acoustic system were calibrated with 60.0, 23.0 and 13.7 mm copper spheres, respectively (Foote et al., 1987) on the second day of the surveys due to unfavorable conditions prevailed before the survey. The calibrated parameters were applied to the data collected during the first day of the surveys while analyzing the data in EchoView software following the procedure described in the software's manual. The transmission power was set according to Korneliussen et al., (2008) to avoid nonlinear effects and cavitation. The pulses transmitted at 0.512 ms, nominally one to four times in a second (intermittently adjusted to avoid aliased seabed echoes within the range of interest). The vertical resolution was nominally 1/2 of the pulse length, ~38 cm. The data to 300 m depth (raw format) were recorded continuously throughout the survey, day and night, along the transects run at an average speed of 8 kts to avoid cavitation problem

In general, data collection was in line with the "Common Protocol for the Mediterranean International Acoustic Survey, MEDIAS (Anon. 2019)", namely target frequency (38 kHz), noise threshold (-70 dB), TS estimation procedure. However, due to the Black Sea's specific peculiarities, such as the permanent anoxic layer below 100-200 m, and because of the behavioral differences of the species explained above some modifications were made on the protocol. In the following, all the modification made on the protocol and their reasoning was explained.

In order to keep the noise level at a reasonably low level, the pulse duration was set to 512 ms which is shorter than that recommended in the MEDIAS protocol. As shortening the pulse length increases the vertical resolution of the acoustic data, shorter pulse duration was also helped to distinguish better the plankton (mainly gelatinous macro-plankton), which is very abundant in the survey area. As the anchovy occupy only the narrow upper mixed layer during the time of sampling, using a shorter pulse duration did not affect the noise level.

Another significant diversion from the MEDIAS protocol was in the daily survey duration. Hydro-acoustic surveys should ideally be conducted either during the day or at night to avoid the diel behavioral differences displayed by the fish and by the other targets in the water column, such as plankton. The MEDIAS protocol recommends collecting echo-integration data only during the day (from sunrise to sunset). However, there are two significant limitations with regard to the duration of the surveys; i) the broadness of the Turkish marine area that accommodates the Black Sea anchovy, and ii) the fact that the anchovy is transboundary species occurring in the Turkish waters only for a limited time in winter. Given that the length of the diurnal period was short (only 9:30h), adopting the MEDIAS recommendation would reduce the area surveyed within the time limits by 2/3. Therefore, data collection continued day and night without interruption. The possible differences in

the results that would emerge due to behavioral changes in the planktonic groups were mitigated during post-processing.

Post Processing

The acoustic data were post-processed using commercial software (Echoview V9.0, Sonardata, Australia): Background noise was removed using the technique of De Robertis & Higginbottom, (2007), with a maximum noise threshold of -70 dB re $1 \text{ m}^{-2} \text{ m}^{-3}$ and a signal-to-noise ratio greater than 10 dB. Noise spikes, the seabed, surface reverberation, bubble clouds, and false bottom echoes were removed using line tools.

Distinguishing the Fish from the Other Targets - Plankton Removal

The plankton is usually removed from the acoustical data by setting a threshold value. The MEDIAS protocol recommends using -70 dB to eliminate plankton in the day data surveys. At night, plankters aggregate near the surface layer, where the main accumulation of fish is. Some countries use -65 dB if data is collected at night (Anon., 2017).

In the Black Sea, plankton biomass is dominated by gelatinous macro-zooplankton, such as *Aurelia aurita*, *Mnemiopsis leidyi*, and *Rhizostoma pulmo*, as well as large sizes copepods like *Calanus euxinus*, which form a dense scattering layer (Sakinan & Gücü, 2017). The plankton was distinguished and removed from fish echoes based on their response to different frequencies (38, 120, and 200 kHz). Basically, instead of using the -70 dB threshold for only 38 kHz frequency, the sv values were considered fish if the sum of sv measured at 38, 120, and 200 kHz did not exceed a maximum noise threshold of -200 dB re $1 \text{ m}^{-2} \text{ m}^{-3}$ (de Robertis et al., 2010; Sakinan & Gücü, 2017).

Distinguishing the Anchovies from the Other Fishes

The small pelagic fish in the Black Sea has a relatively low species diversity represented by only three species, namely Anchovy, Horse Mackerel, and Sprat (Slastenenko, 1956). The former two are warm affiliated species (Gücü et al., 2017). The latter is found in the cold waters below the seasonal thermocline before the winter convection when the surface layer is thoroughly mixed. This feature of the Black Sea small pelagic fish assemblage offers a possibility of delineating the two groups of fish acoustically. When it exists, the thermocline sets a sharp boundary between the warm affiliated anchovy and horse mackerel, which inhabit the warm upper side, and the sprat, which remains in the lower part of it. Therefore, the first step in identifying the anchovy aggregations was determining the depth of the thermocline.

For this purpose, a series of CTD cast was conducted along the acoustic transects (Figure 2) using

a CTD (SBE 25 plus, SeaBird Electronics, USA), and the data were processed to remove spikes. The collected data were then analyzed in ODV 5.3.0 (Schlitzer, 2020) to deliver a vertical temperature profile. The thermocline positioning on the echograms was achieved using the vertical temperature profiles that were synchronized with hydro-acoustic data. Synchronization was done by EchoView Line Import utility. The imported thermocline line was visually checked, particularly for the regions where CTD stations were missing. Finally, the line was used to delineate the areas occupied by anchovy and horse mackerel from sprat.

As stated above, the species diversity of the small pelagic fishes in the Black Sea is not very diverse, and the existing species are relatively easy to distinguish acoustically or hydrographically. Nevertheless, the lack of dense and large aggregations, which are a typical case for the distribution of YoY in November, was an important obstacle in determining species composition.

In such cases, two supplementary methods were used. The first is the ground-truthing hauls (Figure 3). A pelagic trawl net equipped with two depth sensors attached to the footrope and to the headline, was used to sample the fish aggregations. At least three random hauls were made in a day. If no aggregation was detected the random hauls were made at randomly selected locations after sunset, before sun rise and in the midday. The trawl operations lasted 30 min. The catch was sorted out into species. Each species was weighed to estimate the species composition of the catch. The species composition of the catches in the hauls was then used to estimate the species

composition for the transect on which the haul was made.

The catch was also used to generate the length-frequency distribution of the fishes in the survey area as well as the size distribution of the fishes. For that, the total length of the fishes was measured to the nearest 0.5 cm length class.

Discrimination of Anchovy and Horse Mackerel

Usually, horse mackerel schools display peculiar morphologic, energetic, vertical positional features, while anchovy forms more variable patterns depending on the life stages within the aggregation and the ambient temperature. Also, when compared with horse mackerel, the school parameters of the anchovy aggregations display a more pronounced day and night variability. Therefore, the post-processing analysis was based on identification of horse mackerel schools. In the areas where anchovy and horse mackerel form distinguished school forms, they are identified through an automated procedure. This procedure is composed of the following steps;

The parts of the acoustic recordings where the fish formed separable aggregations (mostly in aggregations of adult fish observed on the continental shelf) were analyzed using the "school detection" module of the EchoView software. By this module, the group of echoes that match the criteria given in Table 1, were classified as fish schools, and so that echoes reflected by the fish aggregations were distinguished from the rest.

Table 1. School detection parameters

Criteria	
Minimum total school length (m)	10.0
Minimum school height (m)	1.0
Minimum candidate length (m)	10.0
Minimum candidate height (m)	1.0
Maximum vertical linking distance (m)	5.0
Maximum horizontal linking distance (m)	10.0

Table 2. Horse mackerel school parameters (taken from Bilir, 2019; definition of the parameters are given in Annex 1)).

School Parameter	Average	Min	Max	Stdev	n	CI
Standard deviation of sv	4.18E-05	3.58E-07	0.000478	5.03E-05	726	3.66E-06
Skewness	3.93	0.19	23.09	1.99	726	0.15
Kurtosis	26.38	-1.47	555.74	38.29	726	2.79
Image compactness	43.62	2.21	1169.76	69.35	726	5.05
Coefficient of variation	186.34	0.00	635.69	63.03	726	4.59
Horizontal roughness coefficient	0.000154	1.46E-07	0.00	0.00	726	1.59E-05
Vertical roughness coefficient	3.03E-05	1.23E-07	0.00	0.00	726	2.91E-06
Rectangularity	0.49	0.08	0.92	0.14	726	0.01
Circularity1	548.18	27.80	14699.62	871.43	726	63.49
Circularity2	11.36	0.26	261.41	17.39	726	1.27
Circularity3	0.13	2.99E-06	11.02	0.55	726	0.04
Elongation	20.90	0.32	407.36	32.10	726	2.34
Altimeter	-2.64	-4.27	12.32	2.24	726	0.16

The fish schools identified and filtered in the previous step were further screened through another set of criteria that describe the horse mackerel aggregations in the Black Sea with respect to their school forms (Table 2, Bilir, 2019) .

The schools identified as horse mackerel and observed within the depth strata occupied by anchovy (above the thermocline) were then subtracted from the total NASC attributing the remaining to anchovy.

In the present survey, the monospecific horse mackerel schools could not be sampled well during the ground-thruting hauls. Therefore, the horse mackerel school parameters were taken from Bilir (2019).

Exporting NASC Data

For the biomass estimation, the part of the resulting data that represents the layer between thermocline (or bottom depth if shallower than the thermocline) and the surface were echo-integrated (MacLennan, 2002) over EDSU of one nautical mile and expressed in nautical area backscattering coefficients (NASC) using EchoView exporting function.

Conversion of NASC into Fish Densities

The integrated acoustical data that were expressed in NASC, were converted into metric units using a common approach, in which the mean NASC in the EDSU in question, is divided by the target strength, TS of the fishes encountered (Simmonds & MacLennan, 2005). The TS is classically expressed in dB as a function of total fish length L_{cm} in cm

$$TS = 20 \log_{10} (L_{mean, cm}) - b_{20} \quad \text{eq (1)}$$

where b_{20} is a species-specific parameter and commonly expected as -71.2 for the anchovy (Anon., 2017). L_{mean} is the mean total length of the fishes sampled either on an off-shore transect, or in a sub-region delineating the continental shelf. The quantity of fish estimated in acoustic units were converted into fish density with the following equation,

$$\text{Fish density (individuals/nmiles)} = \frac{NASC}{4\pi \cdot 10^{\left(\frac{TS}{10}\right)}} \quad \text{eq (2)}$$

Stock Numbers, Stock Weight and the CV Estimation

Two methods were used to estimate the stock numbers/weights, and their statistical confidence, CV. First, the geostatistic approach, which is based on the degree of spatial continuity in the NASC values (Walline, 2007) and recommended by the MEDIAS group (Anon., 2017) was used for the off-shore transects which were positioned systematically. This method involves rasterization of the survey area, calculation of empirical variogram, modeling the variogram (with nugget), and random sampling from all rasterized blocks in the area.

This procedure was repeated 100 times and resulted in 100 equally possible occurrences of the spatial distribution of biomass, by which the abundance of anchovy within the study area was estimated along with its coefficient of variation.

On the part of the survey conducted on the continental shelf, some of the transects could not be positions systematically due to sea state, heavy marine traffic, and fishery activities. Therefore, instead of using the method applied to off-shore stations where the inter-transect distances are relatively large, the coast was divided into 5 bathymetrically and hydrographically distinct sub-regions (Figure 2) and each sub-region was analyzed individually. The stock numbers were estimated by multiplying the fish densities (eq 2) with the surface area of the regions. The CV was estimated from the standard deviation of the NASC within the sub-regions.

Results

The vertical temperature profile used to delineate the thermal border between warm (anchovy and horse mackerel) and cold (sprat) affiliated small pelagic fishes is given in Figure 4. The figure displays a very strong vertical temperature gradient between the surface and deep waters, which facilitated exclusion of sprat.

The percentage distribution of the fishes in the ground-thruting hauls were dominated by sprat and anchovy, and to a lesser extent, by the horse mackerel (Table 3).

The mean total length of the anchovies is represented in the lower panel of Figure 3, and the length-frequency distribution of the anchovies sampled at the pelagic trawl stations are depicted in Figure 5. The cohort composed of young anchovies can be distinguished in the figure, where the size groups ranging between 3 to 8 cm total lengths represent the young anchovies recruited in 2020. The general pattern observed was that the small-sized young anchovies were observed at the off-shore stations, while the adult anchovies larger than 8 cm are aggregated at the coastal areas on the continental shelf (Figure 3 and Figure 5).

The acoustical sizes of the fishes (Target Strength, TS) that were used to convert the NASC into anchovy abundance and biomass are presented in Table 4, along with the mean length, mean weight, back-scattering cross-section (σ_{bs}) of the anchovies observed on the off-shore transects.

NASC Distributions

The distribution of NASC over the Turkish Black Sea EEZ and on the continental shelf are presented in Figure 6 and Figure 7. Three remarkable off-shore aggregations displaying NASC greater than 500 m^2m^{-2} , located at west, central and east can easily be noticed, while dense and large schools observed on the western and central part of the continental shelf.

Abundance and Biomass Estimates

The NASC estimates were converted to abundance (number/n.miles²) using the equation (eq.1), and the results are presented for off-shore (Table 4) and continental shelf (Table 5). The final estimates of abundance and biomass for 2020 are summarized Table 6.

Stock Numbers by Length Groups

The estimated number of anchovies in the stock and their distribution into the length groups, which are the two crucial tuning parameters commonly used in the stock assessment models are presented in Table 7

Discussion

This study was carried out to provide fisheries independent data to assessment studies for determining the status of Black Sea anchovy stock. In a study conducted between southern central (Sinop) towards east (Perşembe) in 1977, the size of the anchovy stock was estimated as 1M tonnes. In the January acoustic surveys conducted between 1981 and 2003 by the former USSR scientists, the estimated anchovy stock biomass wintering on the Georgian coast in January ranged between zero in 1991 and 550K

tonnes in 1983 with an average of 270K tonnes (Chashchin et al., 2015).

Before comparing the remarkable difference reported over the years, it needs to be considered that the anchovy feeds, grows, and spawns mainly on the wide continental shelf in the northwest of the Black Sea, where the highest productivity occurs. When the water temperature falls below the level that anchovy can tolerate, they migrate to the warmer sides of the Black Sea located in the south-eastern corner passing through the Turkish waters (Ivanov & Beverton, 1985). During this journey, the dense migrating aggregations are first fished along the coasts of Turkey until the end of the year. Only after December, remaining anchovies move to Georgian waters. According to Chashchin et al., (2015), the first anchovies of the season arriving at the Georgia coast were always observed at the border with Turkey. This observation approves that the exploitation of the stock begins in the Turkish waters first and then continues in the Georgian waters. Therefore, the results of the surveys conducted in the Georgian waters in January address the remaining part of the stock after being fished in Turkey. Considering that some 66K (in 1990) to 374K (in 1995) tonnes of anchovy were fished in Turkey in those years (Figure 1), and this amount should be added to the estimates. Therefore, it will not be wrong to state that the size of the stock was at least two times higher than estimated in January.

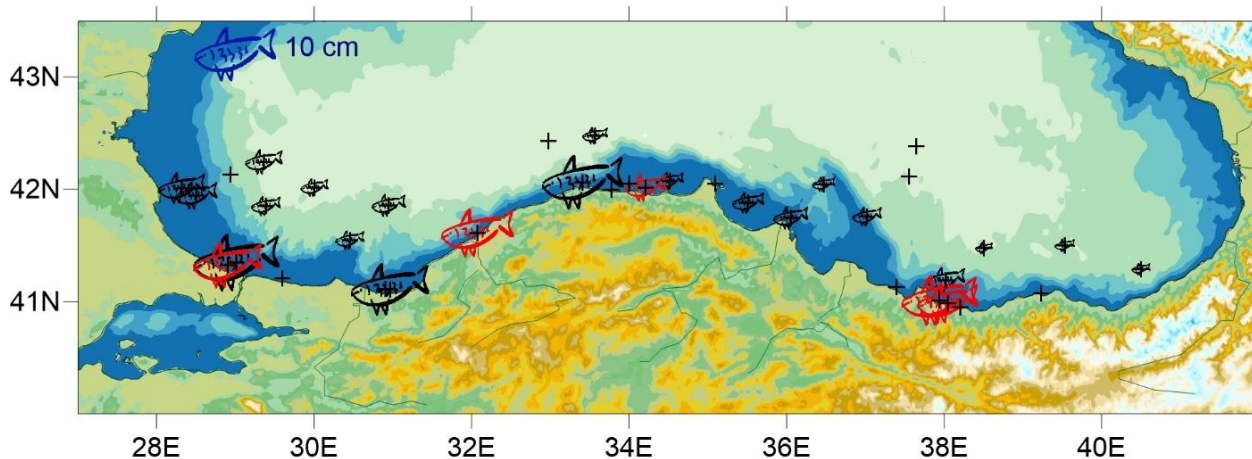


Figure 3. Pelagic trawl stations (plus sign) and the mean length (TL) of the anchovies sampled.

Table 3. The composition of the samples taken at the ground-truthing stations in numbers (per 30 min haul) and in weight, (g) (see the position of the pelagic hauls in Figure 2 upper panel).

Species	% In numbers	% in weights
<i>Sprattus sprattus</i>	55.183	49.452
<i>Engraulis encrasicolus ponticus</i>	44.207	48.091
<i>Trachurus mediterraneus</i>	0.368	1.728
<i>Syngnathus sp.</i>	0.148	0.100
<i>Merlangius merlangius euxinus</i>	0.092	0.340
<i>Pomatomus saltatrix</i>	0.003	0.288

The anchovy biomass and abundance estimates in a more recent survey conducted along the same transects followed in this study and using the same method described above indicate significant changes in stock in 2020 (Bilir, 2019). Although the biomass was almost two times higher in November 2016, when the number of fish in the sea is considered, it is seen that there were 1.6 times more anchovies in 2020. The reason for this discrepancy is seen in the average

weights presented in Table 7. The larger and older fish, which constitute a significant part of the biomass in 2016, decreased in 2020; however, in return, there was a significant increase in the number of juvenile fish.

On the one hand, the significant increase observed in the young of the year could be a sign of the strong year class recruited in 2020. However, of concern is the significant decrease observed in the spawning stock biomass (Table 7), particularly the meager

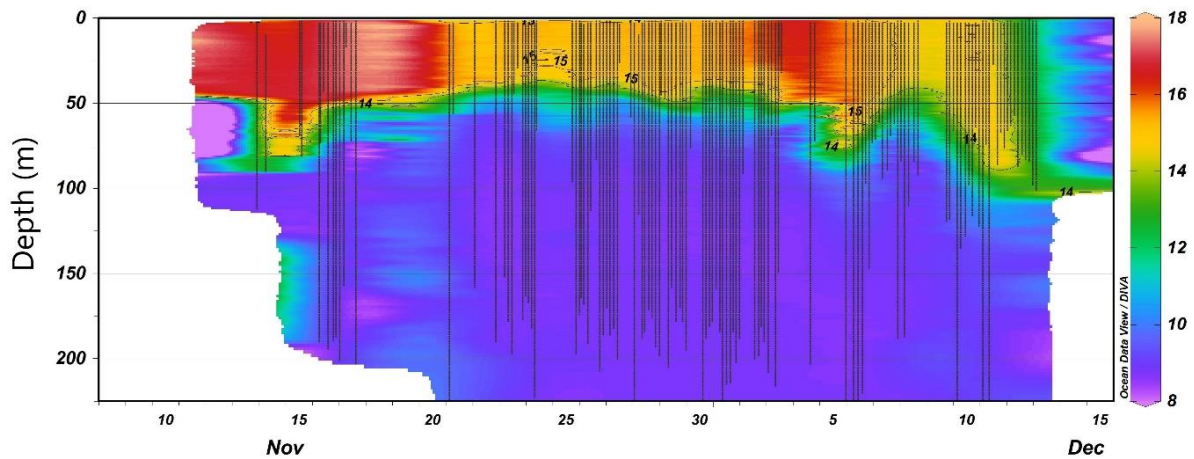


Figure 4. Vertical temperature profiles along the acoustic transects (Vertical lines indicates the position of the CTD casts)

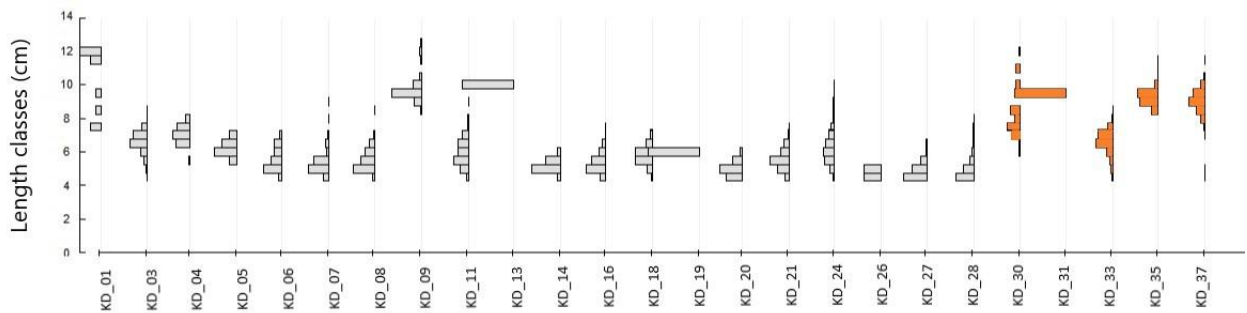


Figure 5. Length Frequency Distributions of the anchovy samples at trawl stations (colored data are the coastal stations).

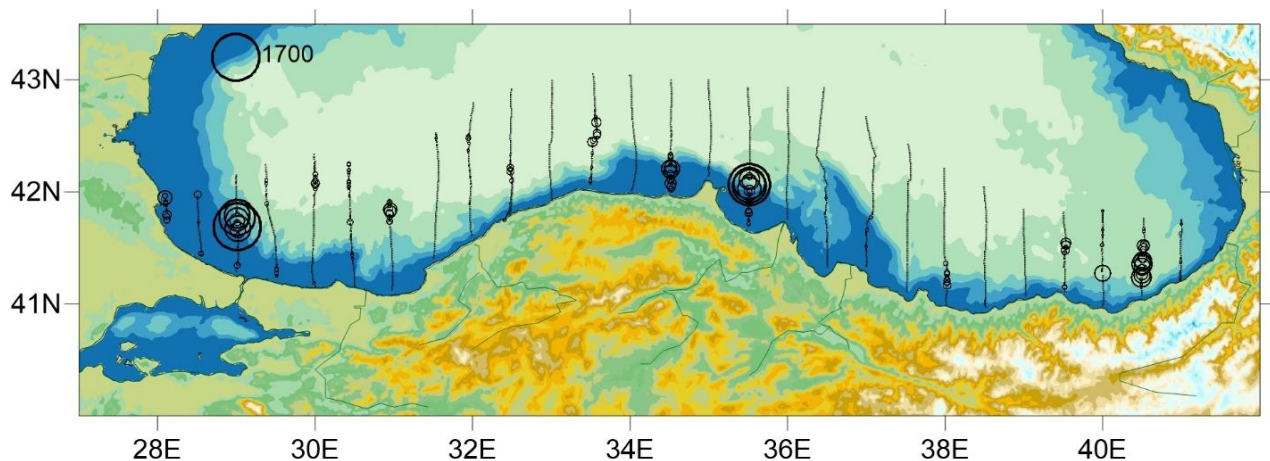


Figure 6. NASC (m^2m^{-2}) distribution observed over the off-shore transects.

representation of old fishes larger than 10.5 cm in the stock. Such signals should be regarded with care by the fisheries managers as they possibly indicate that the anchovy stock is alarming. If the fishery is allowed to catch the young of the year in the absence of large anchovies, the spawning stock will remain low in the following years, too. Eventually, because the fish caught in the 2020-2021 fishing season mainly consisted of

small fish, anchovy fishery on the coast of Turkish coasts has been temporarily banned to protect the stock against overfishing.

(<https://www.tarimorman.gov.tr/Haber/4902/Hamsi-Avciligina-Kismi-Durdurma-7-Subat-2021-Tarihine-Kadar-Uzatildi>).

Similar situations were observed in 2005 and 2012 (Chashchin et al., 2015; Gücü et al., 2017), and they were

Table 4. Mean length, mean weight, back-scattering cross-section (σ_{bs}), Target Strength (TS), abundance and biomass of the anchovies observed on the off-shore transects.

Transect	n	σ_{bs}	TS	NASC	L_{mean} (cm)	W_{mean} (g)	Abun (thou/n.m ²)	Bio (tonnes)
28.0E	32	3.77E-06	-54.23	152.24	7.0	2.106	3211.164	6.8
28.5E	361	3.33E-06	-54.77	28.30	6.6	1.710	675.320	1.2
29.0E	10	8.46E-06	-50.73	165.00	10.4	7.564	1551.709	11.7
29.5E	48	2.44E-06	-56.13	20.71	5.6	1.016	676.177	0.7
30.0E	188	2.21E-06	-56.55	30.37	5.4	0.867	1092.009	0.9
30.5E	260	2.29E-06	-56.41	43.19	5.5	0.921	1502.988	1.4
31.0E	84	7.19E-06	-51.43	54.97	9.7	6.041	608.525	3.7
31.5E	395	2.68E-06	-55.71	6.12	5.9	1.191	181.371	0.2
32.0E				22.86	6.2	1.384	601.715	0.8
32.5E	No fish – the overall average was used			17.80	6.2	1.384	468.580	0.6
33.0E				1.82	6.2	1.384	47.924	0.1
33.5E	58	2.05E-06	-56.89	59.27	5.2	0.777	2305.506	1.8
34.0E	1	7.59E-06	-55.19	2.02	6.2	1.384	53.247	0.1
34.5E	471	2.21E-06	-56.56	87.42	5.4	0.868	3152.654	2.7
35.0E	No fish – the overall average was used			2.02	6.2	1.384	53.212	0.1
35.5E	92	2.55E-06	-55.93	112.20	5.8	1.105	3501.456	3.9
36.0E	No fish – the overall average was used			0.83	6.2	1.384	21.965	0.0
36.5E	67	1.87E-06	-57.28	7.22	4.9	0.668	306.821	0.2
37.0E	467	2.34E-06	-56.31	14.22	5.5	0.953	484.199	0.5
37.5E	No fish – the overall average was used			0.36	6.2	1.384	9.575	0.0
38.0E	1017	3.13E-06	-55.05	28.01	6.3	1.493	712.908	1.1
38.5E				4.01	6.2	1.384	105.526	0.1
39.0E	No fish – the overall average was used			0.74	6.2	1.384	19.388	0.0
39.5E	382	1.69E-06	-57.71	49.36	4.7	0.565	2320.412	1.3
40.0E	No fish – the overall average was used			38.83	6.2	1.384	1021.873	1.4
40.5E	553	1.62E-06	-57.91	191.31	4.6	0.516	9405.253	4.9
41.0E				33.15	6.2	1.384	872.459	1.2
41.5E	No fish – the overall average was used			7.27	6.2	1.384	191.289	0.3
Total	X	X	-55.19	35.93	6.2	1.606	1244.819	1.7

Table 5. Abundance, Biomass, Stock number and stock weight estimates of the anchovies occurring on the Turkish continental shelf.

Region	Reg1	Reg2	Reg3	Reg4	Reg5	Total
Longitude from	28.00E	31.00E	33.25E	34.80E	36.06E	
Longitude to	31.00E	33.25E	34.80E	36.06E	41.42E	
L_{mean} (cm)			7.4			
W_{mean} (g)			2.485			
σ_{bs}			4.30E-06			
TS			-53.67			
NASC	272.81	40.88	10.78	290.26	25.77	
Standard dev – NASC	1038.94	70.95	26.20	1832.71	41.40	
N	254	152	199	154	475	
CV % - NASC	12	21	48	15	25	
Surface Area (nmiles ²)	2347	461	762	9324	25047	37941
Abundance (thousands/nmiles ²)	5051.788	757.035	199.551	5374.804	477.181	1961.578
95% conf. interval SN (\pm)	2377.315	210.558	67.832	5402.695	69.116	
Biomass (tonnes/ nmiles ²)	12.552	1.881	0.496	13.354	1.186	4.875
95% conf. interval SW (\pm)	5.907	0.523	0.169	13.424	0.172	

attributed to the possibility that anchovy did not overwinter in the south-west of the Black Sea as expected, but remained in the southern Crimean coast with the help of favorable climatic conditions prevailed there in those years.

Another surprising finding is the bimodal distribution of individuals between 3 and 8 cm representing the young of the year. In addition to the 0-year class anchovies represented between 3-6 cm length classes in 2016, it is seen that the individuals between 6-8 cm, which were previously unobtrusively represented in the past, increased in 2020. This indicates two different forms of juveniles with different growth rates, or cohorts, and the one which is larger with respect to the other increased proportionally in 2020. The occurrence of two subspecies forming two separate

stocks in the Black Sea has long been known. (Ivanov and Beverton, 1985). The true Black Sea anchovy, *Engraulis encrasicolus ponticus* spawns almost everywhere in the basin, however tends to be more abundant in the region of freshwater influence (ROFIs), the Northwestern shelf in particular. Another form, the Azov anchovy, *E. e. meaticus*, spawns in the Sea of Azov. In winter, they migrate to the Black Sea. It is believed that their overwintering area is located in the northeastern Black Sea, where, in some years, two stock mix (Chashchin et al., 2015). It is also known that two forms of anchovy produce hybrids; however, their fate is not clearly known. Considering the results presented in Figures 3 and Figure 5, it is seen that 3-6 cm group were clustered in the east and 6-8 cm group in the west. In this case, the group seen in the east may indicate the presence of Azov

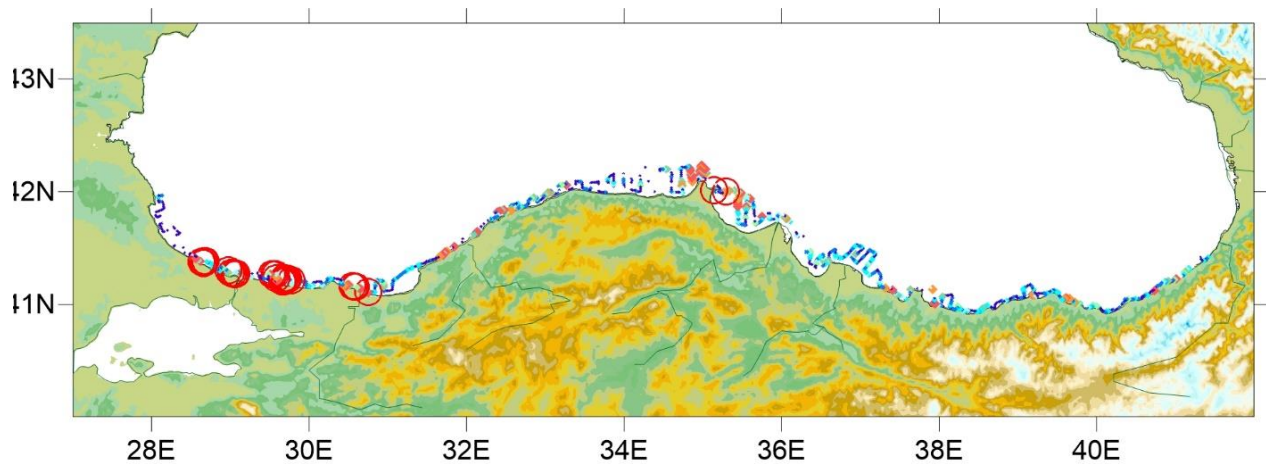


Figure 7. NASC distribution observed on the Turkish Black Sea continental shelf (red circles indicate the position of large anchovy aggregations displaying a NASC greater than 500 m²m⁻²).

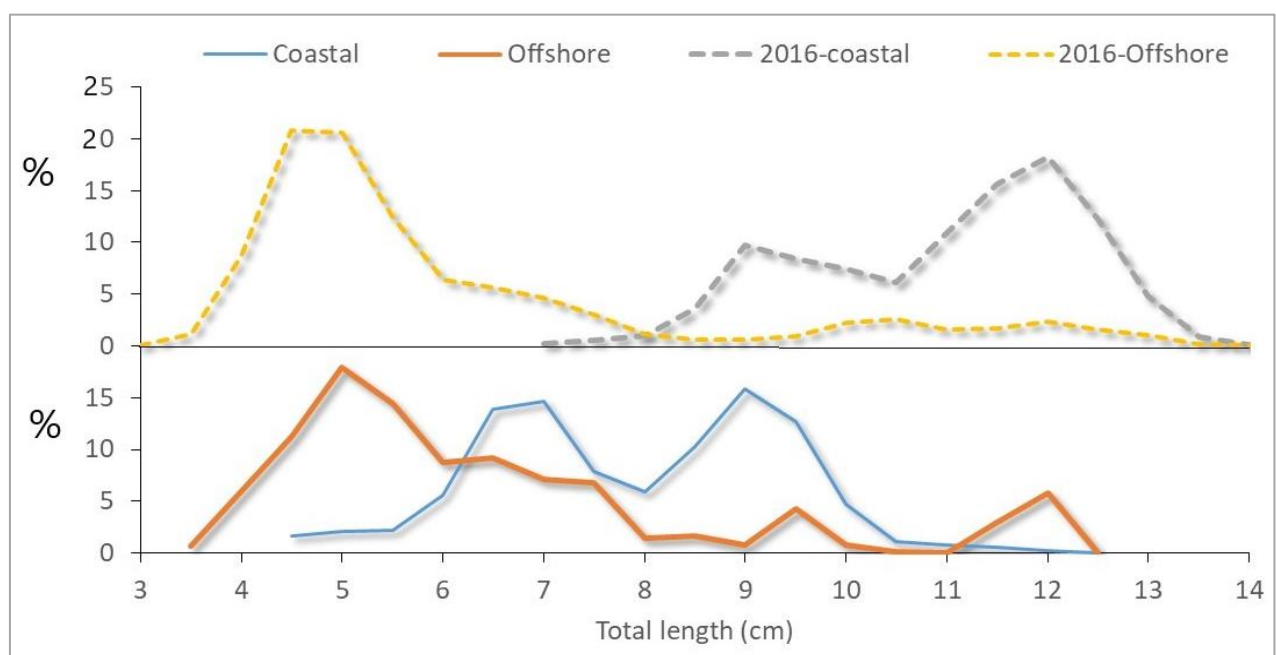


Figure 8. Comparison of length-frequency distribution of the coastal and off-shore anchovies (LFD of 2016 is redrawn from Bilir 2019)

anchovy (or hybrids) that are smaller in size and slower growing than the Black Sea anchovy.

Anchovy is a fast-growing fish with high fecundity. It has been reported that a single female can lay up to 200,000 eggs in a single breeding season (Lisovenko & Andrianov, 1996). This feature of the anchovy, when combined with the high productivity of the Black Sea (Zaitsev, 2008), increases the stock's resilience against external pressures such as fishing. As a matter of fact, the fast recovery of the stock in 1994 after the drastic collapse experienced in 1989-1990 is the best example reflecting this situation (Figure 1). On the other hand, the same feature increases the dependency of the stock against environmental variations. Changes in primary production due to eutrophication (Gucu, 2002), changes

in the dynamism of the currents due to the climate (Gucu et al., 2016), and changes in the food chain such as the outbreak of *Mnemiopsis leidyi* (Shiganova, 1998), or changes in the biomass of the predators such as Atlantic bonito (Leonchuk et al., 2018) cause sudden ups and downs in the anchovy stock. Although the anchovy stock is highly resistant to fishing pressure, disregarding such ecosystem-driven changes in fisheries management causes abrupt fluctuations in the stock as experienced in the last 3 decades (Figure 1). This fact emphasizes the importance of continuous monitoring surveys in the management of fishery on short-lived, fast-growing, opportunistic species such as anchovy within the framework of sustainability principles.

Table 6. Estimated stock size of anchovy in the Turkish EEZ.

Region	Stock n (thousands)	Stock W (tonnes)	CV %
Reg1	11854672	29455	12
Reg2	349167	868	21
Reg3	152012	378	48
Reg4	50114817	124517	15
Reg5	11952072	29697	25
Coastal Total	74422742	184913	22
Off-shore total	55328590	88857	12
Over-all total	129751332	273770	22

Table 7. Comparison of 2016 and 2020 survey results (The figures representing 2016 are taken from Bilir, 2019)

Year / Region	Stock weight (SW) tonnes		Stock numbers (SN) thousands		Mean weight (g)		SW difference 2016/2020	SN difference 2016/2020
	2016	2020	2016	2020	2016	2020		
Coastal	435975	184913	4.660E+07	7.442E+07	9.36	2.48	0.63	2.36
Offshore	13353	88857	1.076E+07	5.533E+07	1.24	1.61	0.19	0.15
Total	449329	273770	5.735E+07	1.298E+08	7.83	2.11	0.44	1.64

Table 8. Stock numbers by length classes

Length class (cm)	Stock numbers (thousands)		
	Off-shore	Coastal	Total
3.5	382151	-	382151
4.0	3347656	-	3347656
4.5	6227591	1206002	7433593
5.0	9889647	1590062	11479710
5.5	7970057	1664260	9634318
6.0	4821340	4170512	8991851
6.5	5071983	10315474	15387457
7.0	3945207	10886389	14831596
7.5	3769374	5858852	9628225
8.0	817130	4384488	5201618
8.5	917754	7631258	8549012
9.0	449069	11823590	12272659
9.5	2338547	9444900	11783447
10.0	449332	3495743	3945075
10.5	95750	794475	890225
11.0		598253	598253
11.5	1612000	420603	2032603
12.0	3192084	137881	3329965
12.5	31917	-	31917
Total	55328590	74422742	129751332

Ethical Statement

This research followed all applicable guidelines for the care and use of fish.

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Author Contribution

All authors participated in the hydro-acoustic research survey for the Black Sea anchovy in the Turkish Black Sea exclusive economic zone on-board the research vessel "RV Akdeniz Araştırma 1" and contributed to acoustic data collection and processing, as well as biological and oceanographic sampling. Conceptualization, data analysis, and calculation, writing, review and editing performed by Ali Cemal Gücü. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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Annex 1. Definitions of the school parameters used to identify horse mackerel aggregations (taken from <https://support.echoview.com/WebHelp/Echoview.htm>)

Parameter	Definition
Height_mean	The mean height of the school which was analyzed (m).
Depth_mean	The mean depth of the school which was analyzed (m).
Standard_deviation	Standard deviation of analyzed sample values.
Skewness	A numerical measure for symmetry of the tails of the distribution of a data set. When skewness is equal to zero, the data has a normal distribution. Skewness indicates the direction of deviation from the mean. Positive skewness means the left tail is shorter than the right tail and the distribution is skewed to the right. Negative skewness means that the left tail is longer than the right tail and the distribution is skewed to the left. Small set size adversely affects skewness.
Kurtosis	Kurtosis represents a measure of the combined weight of the tails relative to the rest of a distribution. As the tails of a distribution become heavier, the kurtosis will increase. As the tails become lighter, the kurtosis value will decrease.
Corrected_length	The Uncorrected_length corrected for known beam geometry according to the system of Diner (1998)
Corrected_thickness	The Uncorrected_thickness corrected for known beam geometry according to the system of Diner (1998)
Corrected_perimeter	The Uncorrected_perimeter corrected for known beam geometry according to the system of Diner (1998)
Corrected_area	The Uncorrected_area corrected for known beam geometry according to the system of Diner (1998) (m).
Exclude_below_line_range_mean	The mean range of the analyzed below line over the domain.
Image_compactness	The image compactness is a statistic which measures the ratio between the perimeter (squared) of the observed school to the area of the observed school. A circle has an image compactness of 1.
Coefficient_of_variation	It defines the coefficient of variation of the Sv sample values in a school represented as a region on echogram.
Horizontal_roughness_coefficient	The horizontal roughness coefficient is a statistic used to measure the dispersion of acoustic energy within the school in the horizontal direction.
Vertical_roughness_coefficient	The vertical roughness coefficient is a statistic used to measure the dispersion of acoustic energy within the school in the vertical direction.
Rectangularity	Rectangularity shows how the school shape close to the rectangle. It measured with the formula "Corrected Area / (Corrected Thickness x Corrected Length)"
Circularity1	Circularity shows how the school shape close to the circle. Three parameters were used "Corrected Length/(π x (Corrected Area/2) ²)" "Corrected Area/ π x (Corrected Thickness/2) ² " "Perimeter ² / Corrected Area"
Elongation	Elongation of a school was measured by the formula "Corrected Length/Corrected Thickness"
Altimeter	Elevation of the school from sea bottom. It measured with the formula "Exclude_Below_Line_Range_Mean - ((Height_mean/2)+Depth_Mean) " (m)