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On Black Sea Anchovy and Its Fishery

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ABSTRACT
Members of the Engraulidae (anchovies) fuel large fisheries around the globe, helping to fulfil demands for food. On the other hand, unpredictable catches that are a very common occurrence with respect to this family can have drastic consequences on economies of different countries. Like many other fisheries, the Black Sea anchovy fishery is a very good example of a fishery greatly affected by abrupt peaks and troughs in landings. In this work, the existing knowledge on the species' overwintering behavior and exploitation patterns along the south coast of the Black Sea is re-evaluated with respect to recent observations. The strong seasonality and very short fishing season are noted as the main characteristics regulating development of the fishery over time. Climatic variability may sometimes generate favorable overwintering conditions outside areas where anchovy aggregations are usually expected, resulting in a temporal shift in overwintering grounds. As most fishing activity takes place on these grounds, low catches in some years are more likely to have been due to fishing the wrong areas, rather than stock decline. This is particularly the case when geopolitical developments have reshaped the fishery, such as the collapse of the Soviet Union, whose fishing fleet once dominated the anchovy fishery. Such irregularities pose considerable management challenges, in particular stock management. Some significant harvest control strategies applied to various anchovy stocks are reviewed and discussed with respect to peculiarities of the Black Sea anchovy.

KEYWORDS
Anchovy; fishery; migration; seasonality; Black Sea

Introduction

According to the FAO, the anchovy family (Engraulidae) significantly contributes to the total fishery capture worldwide comprising over 10% of landings alone. Stocks of family Engraulidae display unpredictable though not surprising variations in abundance as they are fast-growing short-lived fishes. Therefore, any fluctuation in recruitment success, which itself responds very rapidly to climate and environmental signals, is promptly reflected in population size (Freon and Misund, 1999; Ganias et al., 2014). What is surprising however, is that some of the variations occurring on the opposite sides of the globe are thought to be tele-connected through large-scale climatological forcing, such as the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO; Alheit and Bakun, 2010). Therefore, understanding the mechanisms behind anchovy variability, even in a regional sea, is of significance in understanding global fluctuations of species in this family.

The European anchovy is the third most widely harvested species (after Peruvian and Japanese anchovies) of the anchovy family of which approximately 40% (on average) comes from the Black Sea (FAO, 2016). The taxonomy of the anchovies inhabiting the Black Sea, however, is a long disputed issue. It has long been believed that Black Sea anchovies were represented by two subspecies forming two separate stocks (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), such as the Northwestern shelf (Ivanov and Beverton, 1985). Another form, the Azov anchovy, *E. e. meaticus*, spawns in the nutrient rich shallow waters of the Sea of Azov. A later study on the genetics of the two subspecies claimed that the difference between the two forms was only at population level (Ivanova and Dobrovolov, 2006). From a fisheries management point of view, genetic similarity between the two forms whose overwintering habitats are adjacent and even overlapping contradicts the stock unit definition. Only a few years later, most probably due to the advancement in genetic research techniques, new clues were found to support the initial views concerning the taxonomy of Black Sea anchovies, namely, that the species is represented by two subspecies (Ivanova et al., 2013). Nevertheless, no outright consensus has been

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achieved among the scientists involved in the taxonomy of the Black Sea anchovies (Vodyasova, 2015) and the question as to whether they are two different sub-species forming two different stocks or different populations of the same species is still an ongoing dispute. What is agreed on the other hand is that exploited fishes in the Black Sea are of five different origins displaying numerous adaptations to best utilize the very high productivity of the sea (Zaitsev and Mamaev, 1997; Bat et al., 2011). The oldest of all, autochthonous Ponto-Caspian relics are found in the brackish regions where they had been forced to retreat following the intrusion of saline Mediterranean waters. Thermophobic Boreal-Atlantic relics, also called "cold-water relics," occupy the deep layers below the thermocline. Fresh water fishes are confined mostly to the river mouths and alien species are the newest member of the fauna. The largest group of all is of Mediterranean origin and always prefers warm waters. As a member of the latter group, both forms of anchovy in the Black Sea migrate southward in winter toward the warmest waters on the southeast coast. According to Chashchin (1996), the two forms follow opposite coasts to migrate south; Azov anchovy migrates along the Crimean coast in the east, overwinters in the Caucasian escarpment, and generally does not journey beyond Abkhazia (Figure 1). The Black Sea anchovy travels near the west coast of the Black Sea, crosses Ukrainian, Romanian, and Bulgarian waters, progresses further east, and overwinters in the Turkish and Georgian coasts (Figure 1). Based on this description of movements and definition of overwintering grounds, the Black Sea anchovy stock is assessed assuming that Turkish and Georgian landings are composed exclusively of Black Sea anchovy from the NW shelf and the Azov anchovy is exploited exclusively by the Ukraine and Russian federation (STECF, 2015). This study focuses on the fisheries of true Black Sea anchovy, which occurs exclusively in the Black Sea.

The Black Sea anchovy is no different to others in the Engraulid family with respect to wildly fluctuating annual landings have ranged from 85Kt to 500Kt in the last 50 years (FAO, 2016). Niermann et al. (1999) linking this changeability in the Black Sea with NAO-induced large-scale atmospheric variability demonstrated the similarities in the long-term climate-plankton-anchovy connection in different regions of the world's oceans. Such dramatic fluctuations in landings adversely affected local communities causing significant economic losses. According to Campbell (1993) and Caddy (1992), the economic loss due to the massive decline in the anchovy catches from the late 1980s to the early 1990s possibly ranged between US$240m and US$309m. It was also claimed that the loss might even have been an order of magnitude higher than that when the structural changes

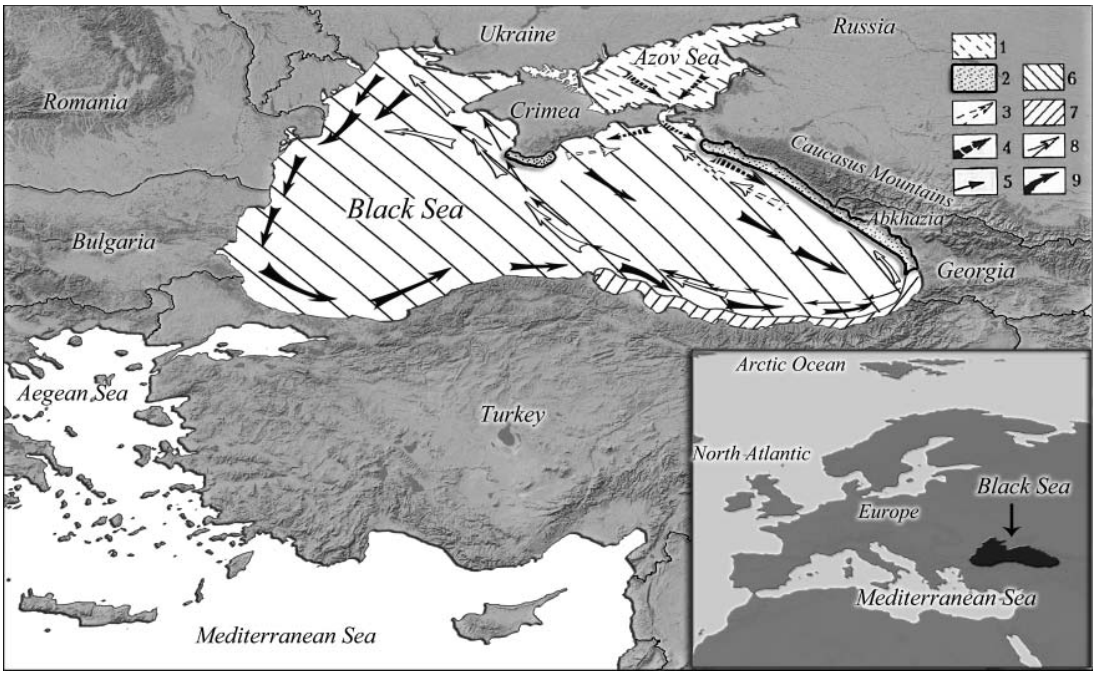

Figure 1. Spawning and overwintering grounds and migration routes of anchovies in the Black Sea (Azov anchovy: 1 = spawning and foraging region; 2 = wintering region; 3 = Spring migrations; 4 = Autumn migrations; 5 = periodic migrations of a mixed population. Black Sea anchovy: 6 = spawning and foraging region; 7 = wintering region; 8 = spring migrations; 9 = Autumnal migrations, redrawn using Chashchin, 1996).

in the food webs, i.e., exotic gelatinous organisms occupying the niche of the anchovy in the Black Sea ecosystem were considered (Knowler, 2005).

The reasons behind the very sharp drop in Black Sea anchovy landings experienced in the 1980s have been studied from different perspectives and various hypotheses set forth. One such hypothesis draws attention to the rapid development of the Turkish purse seine fishery in the 1980s and blames overfishing (Gucu, 2002). Within the same time period, the nutrient composition of the rivers flowing into the sensitive spawning and nursery grounds in the north-western shelf of the Black Sea changed drastically (Cociasu and Popa, 2005). These changes reduced the trophic state of the spawning grounds to dystrophy (Zaitsev, 1993). Deteriorating state was followed by equally drastic change in the composition of the primary producers (Moncheva and Krastev, 1997) and zooplankton (Kovalev et al., 1998; Ostrovkskaya et al., 1998) and finally followed by the disappearance of small sized copepods preferred by the juvenile anchovies in particular (Tkach et al., 1998). The combined effect of these pressures on the small pelagic fish dominated Black Sea ecosystem was believed to spark a shift of the system to a gelatinous plankton dominated regime (Oguz and Gilbert, 2007), which was eventually followed by the population outburst of a gelatinous invader, *Mnemiopsis leidyi* attaining gigantic volumes (4.7 kg m^{-2}) throughout the anchovy spawning grounds (Shushkina and Vinogradov, 1991). A counter argument that disregards the conditions altering the environment links the sudden disappearance of anchovy in the Black Sea with the almost synchronous appearance of the gelatinous invaders and focuses on the intensified predation and competition pressure incurred by this new species (Vinogradov et al., 1989; Vinogradov et al., 1995; Vinogradov et al., 2005).

Parallel to this series of ecological changes impacting the main anchovy spawning grounds in the north western shelf of the Black Sea, a series of international ichthyoplankton surveys were conducted between 1991 and 1996 covering the entire basin, which drew attention to a shift in the anchovy spawning grounds (Niermann et al., 1994; Kideys et al., 1999). The number of eggs spawned in the south during the peak spawning season was far greater than in the historical spawning grounds of the north. The shift was seen as a response by the anchovy against worsening ecological conditions associated with river-induced pollution and competitive pressure incurred by the exotic invasive ctenophore over the major spawning ground (Kideys et al., 1999). Two decades later, a similar survey conducted over the southern half of the Black Sea showed that the situation first recognized in the early 1990s has further modified as, the egg density was far greater than for any of the surveys conducted previously (Gucu et al., 2016). Such findings signify the existence of a growing, non-migrating southern Black Sea anchovy stock.

A stock collapse or fisheries failure?

All the above summarized hypotheses rely on one single, and to an extent, bold assumption: that the landings reflect the quantity of fish at sea and that the drastic drop displayed in the landing statistics revealed an equally drastic drop in the size of the anchovy stock. Yet, the landings in 1995 and in the following years seemingly leveled and even exceeded the pre-collapse levels when all the factors listed were still in effect. This surprising recovery, in a sense, challenged the explanations given for the anchovy stock at the end of the 1980s. An alternative theory that has never been addressed is whether the anchovy stock really did collapse during the period in question or by some unknown mechanism had simply moved away from the regular fishing grounds. There are various cases reported in other regions of the world where fish stocks, particularly migratory pelagic species, may temporarily change their usual habitat due to some environmental forcing (Checkley et al., 2000; Coetzee et al., 2008).

The "recovery"

The trends in landings and the "recovery" itself present some important hints toward understanding the situation experienced in the Black Sea. According to the FAO statistics (FAO, 2016) anchovy stocks in the Black Sea until dissolution of the USSR were exploited by four countries, namely, the USSR, Turkey, Romania, and Bulgaria. Following the breakdown of the Soviet Union, the number increased to six with the newly emerged countries, the Ukraine and Georgia. Following the so-called collapse period, the only country where the anchovy fishery recovered is Turkey (Figures 2 and 3). Gucu et al. (2016) emphasizing the opposite trends in the landings of the north western (Bulgaria and Romania) and south eastern countries (mainly Turkey), suggested possible changes in the spawning grounds and/or alternative migration routes. When landings of the former USSR are evaluated, the situation is no different; landings decline at the end of the 1980s and the total landings of former-USSR countries (Russian Federation-RF+ Ukraine + Georgia) have remained low since (Figure 3). It should be noted that during the breakdown of the USSR, drastic changes occurred in the structure of the fishing fleet (Khavtasi et al., 2010). The RF fleet abandoned Georgia where they previously caught the largest proportion of

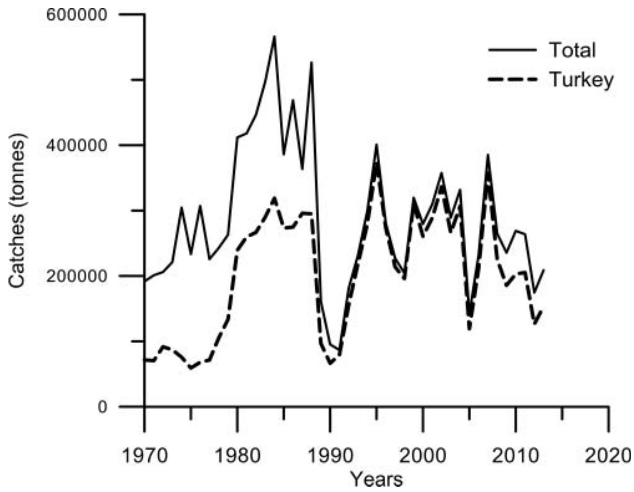

Figure 2. Turkish and overall Black Sea anchovy landings (STECF, 2015).

Black Sea anchovy. Also, after becoming EU member states, some of the old fishing techniques previously used to catch anchovy were abandoned in Bulgaria and Romania. For instance, the number of pond nets, which were used to catch migrating anchovies dropped from 140 units in 1965 to 21 units in 2014 (Totoiu et al., 2015). The decrease in fishing effort in the northern Black Sea countries might, to a certain degree have played a role in the low catch levels during the post-collapse period. Nevertheless, in clear contrast to the drop in the catches of northern countries, the rapid recovery of the Turkish anchovy fishery for the same period supports the above-mentioned hypothesis proposed by Gucu et al. (2016) and indicates a drastic change in the behavior of Black Sea anchovy. Furthermore, recent ichthyoplankton surveys conducted between 2013 and 2015, covering the southern half of the Black Sea (south of 43.2°N latitude)

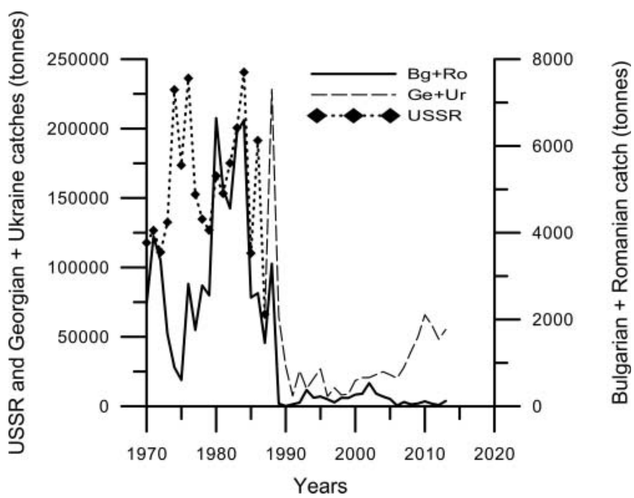

Figure 3. Landings of present and former Black Sea riparian countries, except Turkey (STECF, 2015).

indicate a significant increase in the density of eggs and larvae: 5-fold and 30-fold increases, respectively, compared to the nearest numbers previously recorded (Gucu et al., 2016). This increase, particularly in the number of eggs spawned in the south also means an increase in the number of spawners and hence, at least a 5-fold increase in the spawning stock biomass. That further strengthens the hypothesis and signifies the existence of a growing, non-migrating southern Black Sea anchovy stock.

The issues raised above in relation to collapse and recovery, combined with recent ichthyoplankton studies underline that our knowledge of the present day Black Sea anchovy is insufficient to understand the stock behavior. Despite the considerable literature addressing Black Sea anchovy and its behavior in the past (Chashchin et al., 2015 and the reference cited therein), the post collapse situation concerning the fate of the species in the core spawning area of the northwestern Black Sea is not clearly known. In the south, a series of surveys were completed by Middle East Technical University-Institute of Marine Sciences and Trabzon Central Fisheries Research Institute (CFRI). These include monitoring 55 major landing ports throughout the anchovy fishing season. The data collected, which in essence forms the backbone of this work, are however, limited to the Turkish Exclusive Economic Zone with some supplementary information gathered from Turkish fishing vessels licensed to fish within Georgian waters.

Black sea anchovy fishery: Strong seasonality

Since the 1990s and until recently almost the entire Black Sea anchovy catch was landed in Turkey; however since 2006 the Georgian catch has increased from 10Kt to some 80Kt. Landings for the other countries are either negligibly low, or composed of Azov anchovy, or Illegal, Unreported, Unregulated (IUU) fishing as was the case for Abkhazia (Ulman and Divovich, 2015). Turkey's fishing fleet is mainly made up of purse seine vessels engaged in the anchovy fishery and, to a lesser extent, pelagic trawlers primarily targeting sprat. Examination of daily catch records from vessels revealed that catches, which usually do not exceed more than a few tons at the onset of the anchovy fishing season, gradually increase as the season progresses reaching 600t per vessel per day. Characteristically, peak catches in daily landings are followed by a decline displaying a normal-like distribution over a season. Table 1 shows the date corresponding to the mid-season (mean) and duration of the four fishing seasons (2011–2015) during which 95% of catches (± 1.96 SD) are landed based on the assumption that the fishery is distributed around a mean corresponding to a central day when the daily catch of the fleet reaches its maximum.

Table 1. Some seasonal peculiarities of anchovy fisheries on the Turkish coast, mid-season, length of the season during which 95% of the catch is landed, beginning and the end of season, mean lengths of anchovy landed, total landings and mean, min, and max distances of fishing operations to the nearest coast.

Season	Mid-season	Length of season (95%)	Onset of season	End of season	Mean length (cm)	Total landings (t)	Mean (min–max) distance to coast (n.miles)
2011–12	11 Nov 2011	33	26 Oct 2011	28 Nov 2011	10.77	205,243	3.3 (0.5–10)
2012–13	29 Dec 2012	69	25 Nov 2012	2 Feb 2013	9.43	126,331	3.2 (0.5–12)
2013–14	6 Nov 2013	59	8 Oct 2013	6 Dec 2013	10.01	153,555	10.6 (1–38)
2014–15	26 Nov 2014	60	27 Oct 2014	25 Dec 2014	9.98	70,414	4.6 (1–19)

The fishing season, which varies from year to year, usually lasts between 1 to 2 months (November–December) indicating that the Turkish Black Sea anchovy fishery displays very strong seasonality. This situation is also similar on the Georgian coast, although the season is usually slightly longer (Table 2). These values contradict with the other European anchovy fisheries in the northern hemisphere, where the fishing season may either be in spring–summer (Pertierra and Lleonart, 1996) or continues year round (Andonegi et al., 2011).

As a management control measure, the industrial scale anchovy fishery in Turkey is banned for 4.5 months with the official fishing season beginning on 1st of September, although small quantities of anchovy are caught by artisanal fishers year round. The strong seasonality in landings is not due to the length of the fishing ban. As seen in Table 1, the actual onset of the anchovy fishing season is always later than the official opening. The minimum sizes of the daily anchovy landings examined over four fishing seasons (2011–2015) show that fishermen target only one large anchovy school that can enable a boat to catch at least 300 boxes (approx. 5t) of fish in one operation. The lengths of anchovy fishery vessels vary between 12 and 62 m, vessels between 30 and 50 m being the most common (Dağtekin et al., 2015). Typically, the boats are equipped with powerful engines (1000 kW on average) of capacity up to 2500 kW, disregarding the cost effectiveness of the operation (Dağtekin et al., 2015). Primarily due to the very high fuel consumption, operative costs of the fleet are extremely expensive, therefore the occurrence of dense and compact schools of fish that ensures profitability of the operation is crucial for the commencement of the anchovy fishery. No matter how large the overall biomass, targeting scattered anchovies is not profitable due to the technological and legal constraints (i.e., light fishing is not permitted). The season, therefore does not begin until the large schools appear in the fishing ground and closes with their disappearance later in the season.

Observations from sea and literature (Chashchin et al. 2015) show that the adult Black Sea anchovies form dense aggregations when the ambient temperature drops to 16–18°C. Figure 4 displays both changes in the mean SST between September 1st and March 31st of the preceding year (http://www.myocean.eu.org) along the south coast where the first anchovy schools are detected and temperature data for the opening and closing of the fishing seasons for four successive years (2011–15). As the anchovy fishery exclusively targets dense aggregations, the dates indicate the timing of formation of the first dense overwintering schools targeted by the fishery. The young of the year (YoY) anchovy, however, remained scattered until the SST had further decreased to 11–12°C, which occurred later in the season, usually around December. The different temperature thresholds that trigger the schooling of adults and YoY were also reflected in the monthly length distribution of the catch (Figure 5). The percentage of YoY lower than larger fish (age class 1 and older), i.e., never exceeding 30% at the beginning of the season. Schooling YoY appeared only toward the second half of the season when the SST had dropped below 13°C.

After the withdrawal of ex-USSR vessels, there has since never been a strong Georgian fishing fleet. The existing Georgian fleet is neither comparable with its Turkish counterpart in size nor in capacity (Castilla-

Table 2. Some seasonal peculiarities of anchovy fisheries on the Georgian coast.

Season	Duration	Onset of season***	End of season***	Mean length (cm)*	Total landings (t)**	TAC**
2011–12	38	23 Dec 2011	30 Jan 2012	10.50	11,006	70,000
2012–13	90	2 Jan 2013	2 Apr 2013	8.20	56,777	60,000
2013–14	99	14 Dec 2013	23 Mar 2014	10.17	70,795	80,000
2014–15	88	16 Dec 2014	14 Mar 2015	9.94	61,000	85,000

*sampled from fish exported to Turkey.
**Guchmanidze (2015).
***one of the five licensed fisheries companies did not use its quota in 2014–15 (Information provided by the Ministry of Environment and Natural Resources Protection of Georgia, The Conventional Division of The Black Sea Protection of Environmental Supervision Department, Batumi-Georgia, 2016).

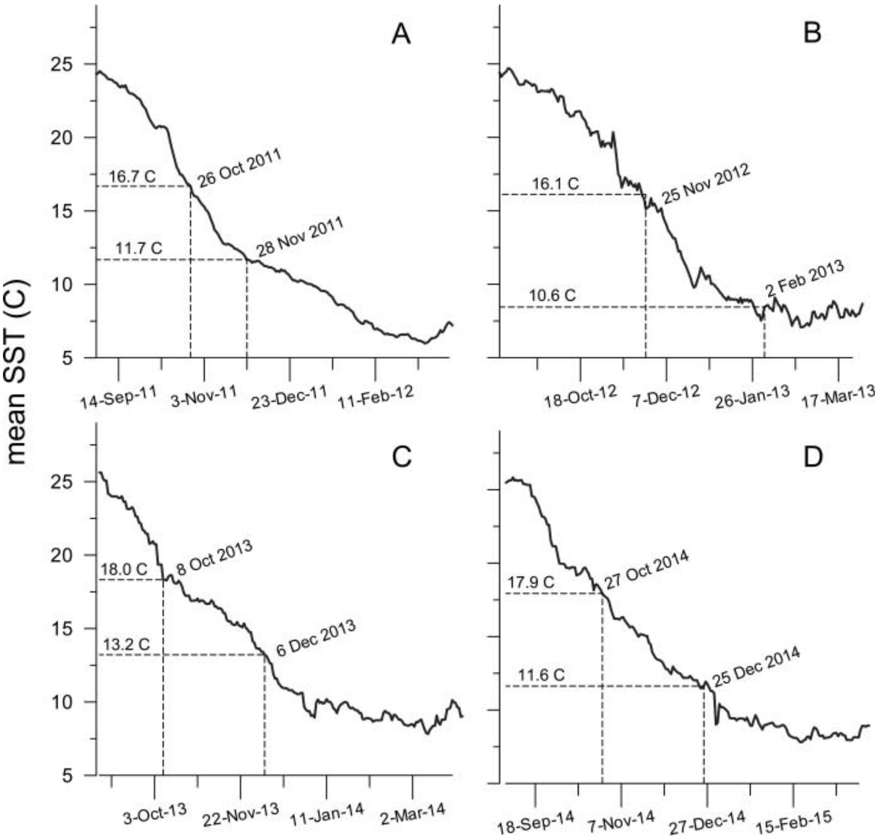

Figure 4. Mean SST for the southwestern Black Sea coast during four successive winters, dates and corresponding onset, and end of anchovy fishing season (A = 2011–12; B = 2012–13; C = 2013–14; D = 2014–15 fishing season).

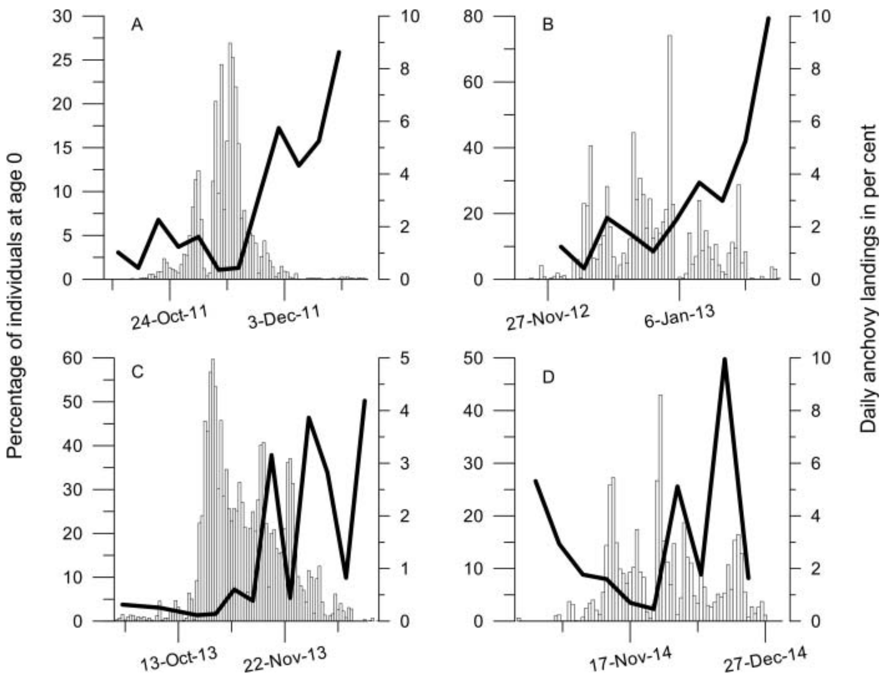

Figure 5. Percentage of 0 year class (<9 cm) in the weekly landings (solid line) and daily anchovy landings (bars). A = 2011–12; B = 2012–13; C = 2013–14; D = 2014–15 fishing season.

Espino et al., 2014). Therefore, Georgian quota holder fishery enterprises hire up to 20 Turkish purse seiners (plus their carriers and auxiliary skiff) each year. Turkish purse seiners hired by the Georgian agencies only travel to Georgia once catches in Turkish waters decline to an unprofitable level, which usually coincides with the end of the calendar year (Tables 1 and 2). The Turkish boats are allowed to remain in Georgian waters until the end of March, however it is known that following the vernal equinox, large schools separate into small clusters commencing the spawning migration (Chashchin et al., 2015). The short and seasonal characteristic of the Georgian anchovy fishery (Table 2) is, again due to the biology of the species.

Race for anchovy

We would expect the longer the fishing season continues, the more fishing operations target the schools, and eventually the more anchovies are caught. Conversely, less fish would result in lower catches leading to a shorter season. Even though the data set is only limited to 4 years, Table 1 displays exactly the opposite; the highest catch was obtained when the season was shortest. This seems to be associated with the schooling pattern of the species. Catchability of the fishery increases remarkably when the anchovy are aggregated in coastal schools. This makes the species particularly vulnerable to exploitation and susceptible to overexploitation (Auckland and Reid, 1998; Petitgas et al., 2001) and evidently shortens the season.

The short fishing season and overcapacity of the Black Sea anchovy fleet, which is capable of harvesting the bulk of available stock within a few weeks (Table 1) is reminiscent of the race in the Peruvian anchovy fishery, where the motive to get a larger share from the Total Allowable Catch (TAC) alone, eventually incurred a significant shortening of the fishing season before the government implemented individual vessel quotas (Aranda, 2009). A TAC does not apply to the Turkish anchovy fleet operating in the southern Black Sea, however, rivalry exists between the Turkish fleet vessels due to the belief that once the schools are sighted the anchovies migrate eastward to Georgian waters. As a result, the motive to catch as much as possible before the schools exit the jurisdictional waters is strong.

Migration and overwintering grounds

Although nowadays fishermen and fisheries management are quite confident that the destination of the migrating anchovies is eastward, within the Georgian EEZ, there is contradicting information concerning the location of overwintering grounds of the Black Sea anchovy. Overwintering grounds were historically depicted as being near the central region of the Turkish coast (Aasen and Akyüz, 1956). In an acoustical survey conducted toward the end of the overwintering season (March–April) in the 1970s, Johannesson and Losse (1973) estimated almost a million tons of anchovy occupying the central zone of the Turkish Black Sea coast. These two reports demonstrate that anchovies were at the time overwintering in the south on the Turkish coast. Nevertheless, observations by Chashchin et al. (2015) of the very first anchovies of the season observed in Georgian waters appearing at the Turkish border support the fishermen's theory.

As a harvest control measure and in an attempt to prolong the fishing season, the anchovy fishery is banned during day time on the Turkish coast. Because the number of purse seining operations practiced in a fishing day (sunset to sun rise) is limited to three or four; each may secure landings as high as several hundred tons. When summarized, the total fish potentially caught in one day, particularly during the height of the season, reaches gigantic volumes that cannot be stored on-board. In competition with others, a boat's catch is immediately transported by carrier boats to the nearest landing site either for market or for the fish meal and/or fish oil industry. After unloading the harvest, the carrier boat must return to accompany the main boat before the next fishing operation is completed thus to save time, transport boats always head to the nearest port. Therefore, the size of landings at a given port essentially reflects the quantity and the location of fish aggregated in the vicinity of the port. Figure 6 displays the daily catches registered at a landing port in four successive fishing seasons between 2011 and 2015 from which we can visualize when and where the main fishery activity took place in a season. Excluding the minor fish landings by mainly local small-scale fisheries, the initial catches (usually around 300 boxes) marking the commencement of the fishing season are reported from the western Black Sea. As can be seen from the position of circles the fleet moves eastward as the season progresses. One exception is when the first schools were sighted at the Turkish/Georgian border in the 2014–15 season; however, it is possible to see another wave of anchovy moving from west to east (Figure 6) later in the same season. In this sense, the graphics also display some interesting peculiarities of the anchovy movements during the fishing season. Incidently, anchovy is not known as a strong migratory species because of several constraints, such as coarse branchial apertures limiting the prey-size selection (Bakun and Broad, 2003; Van der Lingen et al., 2006). The apparent reasons why the anchovy migrate such distances in the Black Sea are to utilize the nutritious food sources offered by the productive north in summer but also to avoid the lethal temperatures

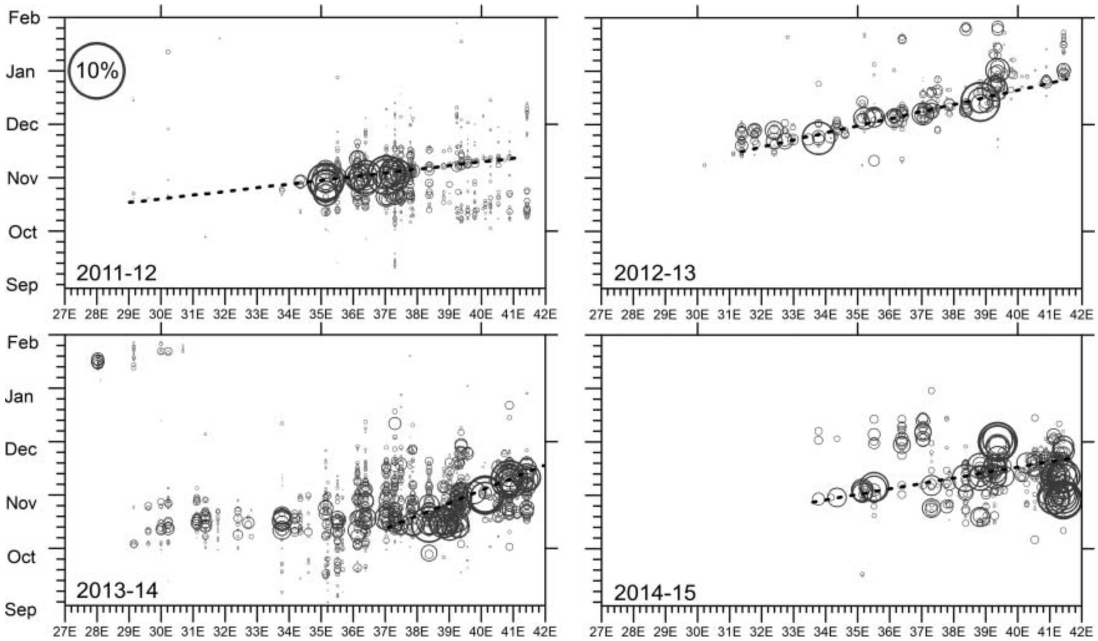

Figure 6. Variation in the landings of the fleet by time and place. Vertical axis denotes time scale from September 1st. The percentage of fish landed is represented by circle area (square root). Horizontal axis represents longitude of the landing port (fish migrates horizontally within the 40th latitude). Dashed straight line represents west to east shift.

of the northern winter. Therefore, the rate of cooling, essentially determines how fast the anchovy migrate during winter.

Migration speed

The quantity of anchovy landed daily at a given port throughout a season usually follows a normal-like distribution curve, its mean representing the date corresponding to highest fishing activity in a port. The date when highest fishing activity is recorded, is assumed to signify the arrival of the main migrating group. In Figure 6, mean dates (($\sum$ landing at *i*th day * Julian date) / total landing of the port) are plotted against port longitudes. Latitudinal differences are ignored as the fish migrate within a path not exceeding 41°N. The positive linear relationship also confirms that the fish move from lower longitudes to higher, in other words migrate from west to east. The linear relationship also shows that the distance covered in a day is almost constant but displays seasonal variation (Figure 7). The speed of movement, estimated based on the slope of the linear curve, ranges between 7 and 13 nm d^{-1} (Figure 7), which corresponds to 1.5 to 3 body lengths sec^{-1} (~10 cm TL). These values are in agreement with the swimming speed of Peruvian anchovy during migration (Peraltilla and Bertrand, 2014).

Currents

The currents along the south coast are characterized by a permanent alongshore peripheral current (Rim Current, RC; Figure 8). The current is located over the continental slope flowing in the same direction as the migrating anchovy throughout the year. Its velocity accelerates and slows down ranging between 50 and 100 cm sec^{-1} in the upper layer (Oguz and Besiktepe, 1999) depending on the strength of the heat loss from sea to atmosphere (Korotaev et al., 2001). The migration speed of anchovy being considerably slower than the velocity of the RC shows that the anchovy do not use the RC, but in contrast avoid it as a typical response of pelagic fishes against strong currents (Freon and Misund, 1999). In association with the RC, several coastal anticyclonic eddies (CAEs) are present over the continental shelf, between the RC and the coast (Staneva et al., 2001). It seems that overwintering Black Sea anchovy (Figure 1) occupy these coastal eddies in order not to be swept away by the RC. This can be better observed in the hydro-acoustically inferred distribution of anchovies in the southern Black Sea at the onset of the fishing season 2014–15 when anchovies in the east had already settled in the overwintering grounds (Figure 9). It may also be worth noting that Gucu et al. (2016) draw attention to the very same coastal anticyclonic structures selected as

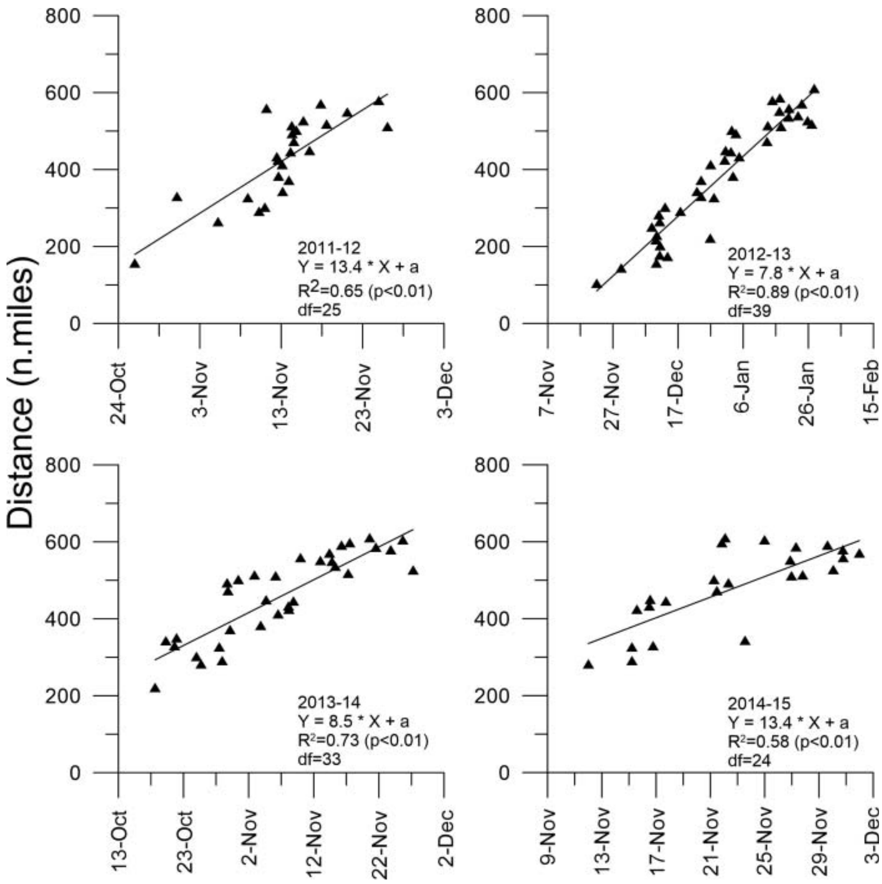

Figure 7. Estimation of anchovy migration speed for four successive fishing seasons.

spawning areas by the southern anchovy population. Interestingly, these mesoscale features, generated to an extent by geographical obstacles, such as capes and submerged ridges, coincide with the anecdotal "anchovy beds" where anchovy were historically believed to settle in winter.

Rapid winter cooling drives the anchovy faster so that migration is sooner. On the contrary, the daily quantity of fish removed by the fishery is lower when cooling is slower; the season prolongs and a larger proportion of the stock migrates to Georgian waters. Lastly, given that the strength of the RC is, in a sense, determined by cooling (heat loss from the sea to atmosphere; Korotaev et al., 2001), fast cooling accelerates the RC and reduces the size of the CAEs that provide retention areas for the anchovy. Therefore, the main implication of cooling rate for management of the

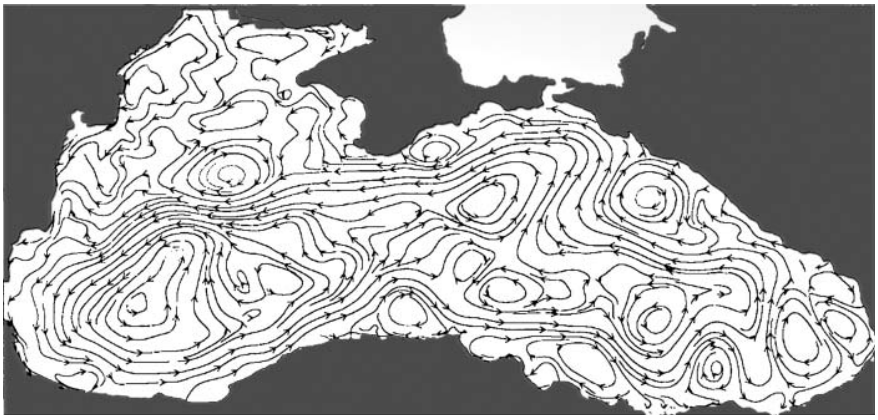

Figure 8. Schematic presentation of the main currents in the Black Sea (taken from Staneva et al., 2001).

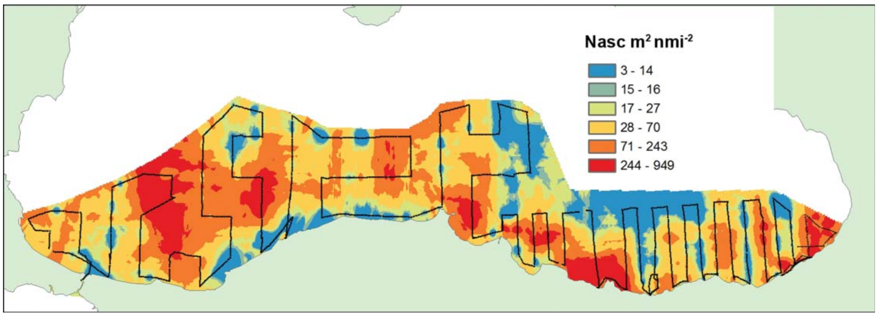

Figure 9. Hydro-acoustically inferred anchovy distribution in Autumn 2014. Colors show the vertically integrated acoustic backscattering intensity in the units of Nautical Acoustic Scattering Coefficient (NASC). This metric relatively represents the abundance distribution.

anchovy fishery might be that it determines the final destination of the transboundary migrating schools, which would evidently influence the total level of landings by countries.

Occasional deviations from the regular migration path and overwintering grounds

Wind direction, the cooling pattern of surface waters, and the Black Sea currents, to a significant extent, dictate the migration routes and overwintering grounds of the Black Sea anchovy (Chashchin et al., 2015). According to authors, the true Black Sea anchovy follows two paths at the onset of overwintering migration. One group follows the west coast, passes through Romania and Bulgaria, reaches the western Turkish coast, and then heads east (Figure 1). The other group, which is usually smaller, moves eastward to arrive at Cape Sarytch located on the southern tip of Crimea. Typically, strong northerly winds result in very sharp drops in the SST, which force anchovies to move immediately south through the center of the Black Sea at the beginning of December. Interestingly, in contrast to the regular pattern reports, an unusual case occurred when some of the stock overwintered in the north in 2005. The very same winter has been noted as exceptionally calm and warm by the elder fishermen. A lack of strong winds and consequently mild conditions in that year possibly held the anchovy in the north.

Another interesting point when comparing anchovy distribution in the southern Black Sea before or at the onset of the 2014–15 fishing season (Figure 9) and the spatial exploitation pattern of the same season (Figure 6) is that the fishery seems to target mainly the anchovy accumulations that were already in the south. This is evidently the southern stock as mentioned by Gucu et al. (2016). On the other hand, the same landing graph gives only very little indication that the western accumulation that originated from the NW shelf was found and fished by the Turkish fleet. This group seems to follow an unusual northern route heading directly eastward, along an offshore path not seen on the Turkish coast before they form dense schools sought by the fishermen and so are not fished on the Turkish coast. As a consequence, Turkish landings (70kt) reported for this season are the lowest since the dramatic decline in 1990. On the contrary, fishing companies (except one) along the Caucasian coast surpassed their limits (GFCM, 2015) with Georgia alone equaling Turkish landings for the first time in recorded fishing history. The difference between TAC and the total landings of Georgia is due to some enterprises not being able to operate (GFCM, 2015). Since the Ukraine lost the sovereignty of the Black Sea anchovy fishing grounds in Crimea in 2014 which was formerly fished by their fleet, it is not known whether or not a part of the stock overwintered in the north as they did in 2005 (Chashchin et al., 2015).

Two additional similar significant drops in Turkish anchovy landings (1989–1991 and 2005) were experienced during the last four decades (Figure 2). The former is considered as a direct consequence of the purported stock collapse, which was attributed to various factors (see Introduction). In 2005, the landings decreased to less than 100Kt and the stock unrealistically recovered the very next year. Notably, contrary to the regular overwintering pattern, a significant quantity of Black Sea anchovy was reported to accumulate in the central north (south of Crimea) during the very same year (Chashchin et al., 2015). Apparently, in that year, a proportion of the Black Sea anchovy stock overwintered outside its normal range and the significant drop in the southern landings is, quite likely, a consequence of that temporal shift in the overwintering grounds. This exceptional case raises the question as to whether the sharp decrease in the anchovy landings experienced in 1989–1991 might have resulted from a similar shift and the stock had not actually collapsed but that the anchovy had simply overwintered outside the areas where they were expected. It may be worth noting that the "collapse" in 1989–1991 coincided with the dissolution of the USSR when during this period there were either no fisheries in some areas like

Georgia (Van Anrooy et al., 2006), or the fishery was not reported due to the lack of authorities (Ulman and Divovich, 2015).

Evaluation of current fishery regulations and some recommendations for harvest control

Despite their gigantic size, it has been proven that, like many other small pelagic fishes the stocks of the anchovy family are vulnerable to unrestrained fishing (Pitcher, 1995). There are various worldwide examples that even very profitable fisheries have suffered collapses (Schwartzlose et al., 1999). Therefore, sustainable utilization of the stocks to a significant extent rests on proper management. On the other hand, as underlined by Beverton (1983) the stocks of this group of fish are among the most difficult to predict and bear high risks in their exploitation associated with these uncertainties. A very well-known example is the Southern Peru/ Northern Chile fishery targeting anchoveta (*Engraulis ringens*). Once supporting a fishery as high as 13.1Mt, the stock experienced a dramatic collapse after 1972 when landings dropped to 4.4Mt (FAO, 2005) causing remarkable economic as well as ecological consequences (Pitcher and Hart, 1982). Presently the stock is managed separately by Chile and Peru. The Peruvian fishery is managed by maintaining a spawning biomass of 5 Mt at the beginning of the spawning periods in August and February (Barange et al., 2009). Various other restrictions, such as closed season and areas, basically targeting the protection of juveniles are also enforced. The northern stock in the Chilean waters, the fishery targeting the same species is managed through TAC along with closed periods during the spawning and recruitment seasons. The TAC is estimated based on medium term projections with uncertainty and risk analysis of different scenarios for recruitment (Barange et al., 2009). Monitoring the abundance of recruits is not unique to anchoveta, but in fact, a common approach used in the management of some other fisheries targeting anchovy. For instance, in the Pacific stocks of the Japanese anchovy, where a part of the recruits (those larger than minimum size allowed, 8 cm SL) are targeted by the fishery, the abundance of pre-recruits is estimated and included in catch prognosis and quota determination. Yet, due mainly to probable uncertainties in SSB and recruitment predictions, the commercial catch and survey results are monitored within each season to fine tune the TACs (Barange et al., 2009).

Given the transient nature of the Black Sea anchovy moving between Riparian countries (Ukraine, Romania, Bulgaria, Turkey, and Georgia) during the fishing season, sustainable utilization of stock necessitates cooperative international management among the countries involved. Various agreements have proven that shared stocks nearing collapse when managed alone, can be recovered by multinational cooperative management plans, with clear objectives. One such example is the Blue Fin Tuna fishery regulated by the International Commission for the Conservation of Atlantic Tunas, ICCAT. The member states involved jointly developed scientifically supported harvest control strategies and regulations to limit landings for all fleets (ICCAT, 2016). The Norwegian Spring Spawning Herring stock exploited originally by Norway, Iceland, Russia, the Faeroe Islands, and later the European Union (EU) and managed by a cooperative resource management arrangement may be listed among the most successful initiatives of its kind (Kvamsdal et al., 2016).

Other than a few attempts toward a regional management plan elaborated by Regional Fisheries Management Organizations addressing the harmonization of harvest control measures, the Black Sea anchovy fishery is regulated at the national level. The sharp seasonality of this species and the significant annual variation in overwintering behavior exert additional complexity regarding regional management of the Black Sea anchovy fishery sometimes even at the national level. For the EU, Black Sea anchovy is not a high priority species as the total catches of Bulgaria and Romania have never recovered since the dramatic decline in the late 1980s. The Ukraine and Russian Federation manage the Azov anchovy stock through annually revised TACs, whereas the Black Sea anchovy fishery is regulated by spatial restriction to decrease fishing effort and to protect spawners and by minimum mesh size to decrease bycatch of undersize individuals (GFCM, 2015). The only country regulating the anchovy fishery by TAC is Georgia, but the scientific rationale behind the estimation of TAC is unclear. The quota had initially been set to a fixed quantity (60Kt) determined during the USSR period (Khavtasi et al., 2010). This was gradually increased with the establishment of fish meal and fish oil plants. As of 2015, the Georgian anchovy TAC is 85Kt (GFCM, 2015).

On the Turkish Black Sea coast, the licensing of new fishing boats was halted in 2005 with the aim of reducing the fishing pressure on stocks and to maintain sustainable fisheries. Another remedy toward achieving a sustainable fishery is the voluntary-based fishing vessel decommissioning program periodically applied since 2012. Fleet landings are monitored via 28 fisheries port offices distributed along the 1700 km coastline where logbook data are collected. As fishing occurs over a very short period and fishers target migrating aggregations of anchovy, the fishing activity is usually concentrated around one of the 28 ports at any one time. When the sizes of these ports are considered, a single landing site is usually insufficient to serve the entire fleet and the associated truck traffic racing to transport their load. Therefore, the boats use other ports in the close vicinity. There are more than 200 such secondary landing sites along the coast traditionally used to land anchovy, hence a significant quantity of the catch is not actually landed at the designated ports hence tracking data can be an extremely drawn out process due to the technical limitations. Until recently, total landings were estimated based on personal communication with professional fishermen in January and February of each year based on the information from the previous year (OECD, 2004).

On the other hand, for such a short-lived fishery, very efficient and fast networking to ensure the timely flow of landing data is essential, for instance to halt the fishery once the TAC is reached. It is apparent that the existing infrastructure is not at a level to fulfil this requirement. Besides, given the dispersed nature of the fishery, upgrading facilities, which would involve the enlargement of harbors and increasing the number of port offices, etc., is very costly. To overcome the time constraints, one alternative could be to establish individual fishing quotas (IFQs) for each fishing vessel. On the other hand, when present conditions, regional infrastructure, and fishery size are considered, this would inevitably increase the IUU (GFCM, 2013) and for this reason is avoided. Under existing conditions, the best method of harvest control is to close the fishery when the critical catch level has been reached.

One possibility could be to utilize the migratory peculiarities: (i) the anchovy arrives at the fishing grounds asynchronously in age-specific cohorts; (ii) the adults dominate the first wave of arrivals, and (iii) the share of the 0 year class in the catch gradually increases as the season progresses (Figure 5). Using the percentage of 0 year class fish in the catch as a proxy to TAC and closing the fishery for the remainder of the fishing period when a specified percentage of 0 year class fish (currently 150 g in 1 kg) is reached or exceeded in the landings seems to be a promising alternative regulation. This would not only control the harvest, but also secure the recruits as the catch would then be dominated by individuals aged 1 year and upward.

Although it does not explicitly control the number of fish that are removed from the stock, the minimum size regulation is listed among the harvest control measures implemented to protect certain life stages (Owen et al., 2016). The aim is usually to allow most fish to spawn at least once by setting the limit above a species' size at maturity. Due to its simplicity and ease of enforcement, it has wide application (Anderson, 1989). The biomass protected by this measure would be comprised of all fish above the size limit. One possible drawback is that the above proposed harvest control measure would disproportionately protect smaller fish and would eventually alter the demographic structure of the stock in favor of young fish not yet having completed the one full life cycle. This, on the other hand, can threaten population resilience particularly if social transmission of certain critical behavioral traits such as migration routes, from older to younger fish is important. Such "social" interactions and more specifically transfer of knowledge from one generation to the next have been reported to be crucial in maintaining meta-population structure such as those of Atlantic herring (McQuinn, 1997). Once the stock is subjected to adverse conditions and experience a collapse, recovery may take several years.

A management plan aiming solely at protection of the recruits would eventually disregard the parent stock and the risk of spawning stock being overfished is considerable. Due to its opportunistic nature, anchovy is characterized by high fecundity, which is an efficient trait to utilize the best use of the ecosystem services and also to explore the opportune loopholes to survive adverse ecological conditions. With an extreme fecundity of 138,000–231,000 eggs laid per female anchovy per season, Black Sea anchovy is an efficient performer of this trait and characterized by high ability to restore its biomass (Lisovenko and Andrianov, 1996). As inevitable results of high fecundity, population competition, and mass mortalities due to overgrowth of the population are quite frequent in the Black Sea (Shulman, 2002; Chashchin et al., 2015). Underlining the deterministic role of recruitment success on the overall biomass, the risk entailed in the strategy targeting the recruits only, may therefore be minimal for the case of Black Sea anchovy.

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