The Black Sea anchovy – new perspectives regarding their spawning, nursery and overwintering behavior

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The anchovy family (Engraulidae), according to FAO, alone contributes more than 10% of the global fisheries landings. The stocks of the members of this family display unpredictable but not so surprising variations as they are fast growing short-lived fishes very sensitive to their surroundings. What is surprising though, is that some of the variations observed on opposite sides of the globe are thought to be tele-connected via large scale climatologic forcing, such NAO, AO (Alheit and Bakun, 2010). Understanding the causes behind their variability, even in a regional sea, would be highly valuable.

The Black Sea anchovy, *Engraulis encrasicolus*, is the third (after *E. ringens* and *E. japonicus*) most important anchovy species harvested, accounting for 1/3 of the global anchovy landing in the early 1980s. However the catches soared to 566,000 tons in 1984; remained at high levels until 1988 (526,000 tons) and abruptly dropped to only 86,000 tons in 1989. From 1995 to 2013 catches ranged with wide oscillations from year to year within the range of 135,000-400,000 tons even though the fishing effort basically remained the same (STECF, 2013). These fluctuations in the fishery as opposed to a *status quo* indicate that environmental drivers are no less important than fisheries in influencing the biomass of a species.

Niermann *et al.* (1999) linked these variabilities in the Black Sea with NAO-induced large scale atmospheric variability, demonstrating the similarities in the long-term climate-plankton-anchovy connection in different regions of the world ocean. Fluctuations in the landings were sometimes very dramatic, adversely affecting the local communities by causing significant economic losses. According to Campbell (1993) and Caddy (1992), the economic loss due to the decline in anchovy catches in late 1980s to early 1990s ranged between US$240e6 and US$309e6, if not more (Knowler, 2005).

Various factors adversely affecting the survival and in turn, recruitment success have emerged in the Black Sea during the last few decades. A decrease in the trophic state to dystrophy at the spawning grounds (Zaitsev, 1993) and intensified predation and competition pressure incurred by an exotic ctenophore (Vinogradov *et al.,* 1989; Vinogradov *et al.,* 1995; Vinogradov *et al.,* 2005) are among the most crucial reasons listed. If such non-fishery impacts on recruitment success are disregarded in stock assessment and fisheries management decisions, the ecological and economic consequences would undoubtedly be misleading (STECF, 2013).

The Black Sea is a huge catchment basin receiving freshwater (hence nutrients) via river drainage from a considerable area of Eastern Europe (Lancelot *et al.,* 2000). Rivers played a crucial role in the biological evolution of the Black Sea; initially by nourishing very rich biological resources; later by overloading the sea mainly with phosphorus and nitrogen due to intensified agricultural activities, and finally by altering the trophic state of the sea. As a characteristic response of an ecosystem to advanced eutrophication, hypoxia occurred in the zone where the rivers enter the Black Sea. The hypoxic conditions were first recognized on the broad NW continental shelf in the mid-1970s and developed very rapidly. In the 1990s the size of hypoxic areas measured 40 000 km^{-2} causing 60 million tons of benthic life to perish (Mee, 2006). The most devastating effect was that these hypoxic areas were essentially the major spawning and nursery grounds for a diverse range of fish species, including the Black Sea anchovy.

Towards the end of the 1980s, when the Black Sea ecosystem was still lingering with the effects of this catastrophic event, an exotic ctenophore appeared in the Black Sea with a massive outbreak following shortly afterwards. Its biomass was estimated as 4.7 kg m-2 throughout the anchovy spawning grounds during the summer of 1989 (Shushkina and Vinogradov, 1991). This ctenophore species was claimed to predate the early life stages of the anchovy (Tzikhon-Lukanina *et al.,* 1993; Shiganova and Bulgakova, 2000) and was even listed amongst the suspects responsible for the collapse of anchovy stocks observed in the late 1980s (Vinogradov *et al.,* 1989; Shiganova *et al.,* 2001).

It is believed that there are at least two distinct anchovy spawning grounds (Ivanov and Beverton, 1985). The Azov anchovy spawns in the Azov Sea and migrates southward through the Kerch strait to overwinter (Figure 2). This group is fished by the Ukrainian, Russian, Georgian and, to a lesser extent, by the Turkish fishing fleets. The Black Sea anchovy (BS) spawns in the north-western shelf and migrates south in winter (Ivanov and Beverton, 1985). The fishing season of BS anchovy usually begins in late autumn and lasts throughout the winter. They are fished almost exclusively in the Turkish and Georgian waters. However in the past, until the late 1980s, Romanian and Bulgarian fishermen used to catch anchovy when they formed schools and migrated towards the south. During the pristine state of the Black Sea before the mid-1970s, the ecological features driving the life cycles of the anchovy were quite clear; the main spawning and feeding areas of the species were located in the most productive regions of the Black Sea (Ivanov and Beverton, 1985; Shulman, 2002). Cooling at the feeding grounds in late autumn was herding the species towards the warmest region of the basin during winter. The Black Sea anchovy were reported to follow the west coast while Azov anchovy pursued the east coast during the winter migration towards the overwintering grounds (Ivanov and Beverton, 1985). It may also be worth noting that in a basin wide ichthyoplankton survey conducted in the 1950s, a noticeable quantity of anchovy eggs and larvae were observed in the south and open sea (Einarsson and Gürtürk, 1960). This indicates that the anchovy's spawning areas were not solely limited to the NW Shelf and Azov Sea even during the pristine state of the Black Sea.

In the 1990s, a series of international ichthyoplankton surveys covering the whole basin were conducted. In these surveys, anchovy egg numbers found in the southern and particularly in the south-eastern Black Sea were significantly higher than those found in the north-western shelf which was essentially the main spawning area of anchovy (Niermann *et al.,* 1994). In 1993 and 1996, two additional ichthyoplankton surveys were conducted covering only the southern half of the Black Sea and it was found that the number of eggs spawned in the south was higher than those previously reported (Kideys *et al.,* 1999). The authors explained this situation with the outburst of the recently introduced ctenophore *Mnemiopsis leidyi* and supported the hypothesis that this invader had played a major role in diminishing the Black Sea anchovy fisheries, by noting that the drastic changes in the Black Sea ecosystem (due to eutrophication, heavy fishing, etc.) might also have had an effect (Niermann *et al.,* 1994; Kideys *et al.,* 1999).

Later, international efforts and particularly the Danube River Protection Convention seemed to work particularly in the NW shelf area, where the major spawning activities of BS anchovy used to take place. Several key littoral ecosystem components such as Zernov's *Phyllophora* fields (Tkachenko *et al.,* 2009), associated benthic communities (Mee, 2006) and mussel beds (Mee *et al.,* 2005) were reported as having revived in the 2000s. Also, the anchovy stocks seemingly recovered to pre-collapse levels. The signs of revival in the Black Sea ecosystem have also been attributed to various other factors; such as the sudden appearance of a new ctenophore *Beroe sp*. predating the former invader *Mnemiopsis leidyi* (Shiganova *et al.,* 2000; Vinogradov *et al.,* 2000) and the relocation of the fishing fleet towards new fishing grounds beyond the Black Sea (Gucu, 2002). Despite evidence reporting recovery in essential habitats and in key species of the NW shelf area mentioned above, it is not known whether or not the change in the spawning grounds of anchovy first reported by Niermann *et al.* (1994) was merely a temporary response and following revival of the ecological state they returned to their former spawning grounds. In this study, we present the current situation two decades later and discuss possible reasons behind the changes addressing similarities and dissimilarities observed in populations of the same species in other seas.

More recently three ichthyoplankton surveys were carried out in July 2013, July 2014 and July 2015 on the Turkish EEZ, which essentially covers the southern Black Sea. The surveys followed exactly the methodology previously applied in the same area (Niermann *et al.,* 1994; Kideys *et al.,* 1999).

Two main points emerged from this study; first, the number of anchovy eggs laid in the southern region of the Black Sea has increased compared to the 1990s. This is due in part to import from adjacent areas, such as the NW shelf area, which is one of the two most important spawning areas of the species. Another proportion of the eggs found in the southern Black Sea had been transported from the Sea of Marmara. However neither of these sources seems to play a significant role on the recruitment success since egg/larvae and live/dead egg ratios are low within the respective area. Another source, with a better chance of survival, lies somewhere in the north, possibly near the Crimean coast (Gucu *et al.,* 2016a).

In addition to the imports, a new spawning ground was found on the southeast coast. Hydrographic properties, characterised by anti-cyclonic eddies located between the coast and the rim current, seem to play a role in the development of the new site. Also when the counts of gelatinous organisms in recent years were compared with previous surveys carried out in the same area, the maximum *Mnemiopsis leidyi* density observed in 2013 was quasi identical to the value found in 1992; however the average density is double (Mutlu *et al.,* 1994; Gucu *et al.,* 2016a). The opposite situation was found for *Aurelia aurita*; the basin average density was almost the same as in the 1990's; but the maximum density had now doubled. In this respect, distribution of *M. leidyi* appears to have expanded lately, while *A.aurita* is localized. Yet, the remoteness of the anchovy spawning sites from the surface gelatinous predator accumulation sites, such as those of Mnemiopsis leidyi and *Aurelia aurita*, is considered as an opportune loophole for the species (Gucu *et al.,* 2016a).

Whether the eggs and larvae observed in the south are prone to starvation death or whether they survive and recruit to the exploited stock remains an open question. Yet, the second most important point of the study is the significantly higher reproductive activity observed offshore today. It signifies the existence of a growing, and possibly non-migrating stock (Gucu *et al.*, 2016a).

The entrainment of the young population by the elders towards the spawning area, and the transfer of knowledge from repeat spawners to inexperienced recruits may help answer the question as to why the anchovy are spawning offshore and why those who refuse to migrate have increased in the last few decades. The collapse experienced towards the end of the 1980s and the continual removal of aged individuals from the stock through fisheries might possibly reduce the knowledgeable proportion of the population and weaken the continuity of the social transfer of knowledge (Gucu *et al.,* 2016a).

On the other hand all the "collapse" hypotheses summarized above relied on one single, somewhat bold assumption that the landings reflect the quantity of fish at sea and that the drastic drop displayed in the landing statistics points to an equally drastic drop in the size of the anchovy stock. Yet, none of the hypotheses proposed satisfactorily explain the very rapid and sharp increase in the anchovy landings seemingly exceeding the pre-collapse levels when all the factors listed were in effect.

The trends in landings and the "recovery" itself represent quite important information which may present some important hints towards understanding the situation experienced in the Black Sea. According to the FAO statistics (FishStatJ), the anchovy stock in the Black Sea had been exploited by four countries until the dissolution of USSR, namely Turkey, Romania, Bulgaria and the USSR. Following the drastic 1989 collapse, the anchovy fishery recovered in part in Turkey, Georgia and Ukraine, while remaining quasi inexistent in the other Black Sea countries (Figure 1). Gucu *et al.* (2016a) emphasized the opposite patterns in the landings of the north western (Bulgaria and Romania) and south eastern countries (Turkey), questioning possible changes in the spawning grounds and/or alternative migration routes (Figure 2). It must be noted that during the disintegration of USSR drastic changes were experienced in the structure of the fishing fleet (Khavtasi, 2010). The USSR fleet abandoned Georgia where they used to fish the largest part of their BS anchovy catch. Further, following their membership to the EU, some of the old anchovy fishing techniques were abandoned in Bulgaria and Romania. For instance, the number of pond nets, which was used to catch migrating anchovies declined from 140 units in 1965 to 21 units in 2014 (Totoiu *et al.,* 2015). These events might have, to a certain degree, played a role in the low level of catch in the post-collapse period; however the very fast recovery in the Turkish anchovy fishery after 1980s is evidently a sign of a drastic change in the behaviour of BS anchovy.

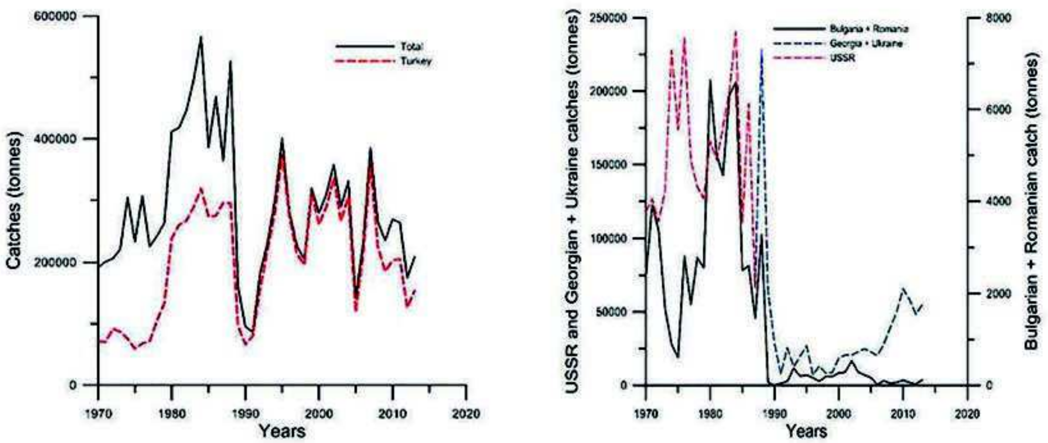

Figure 1.Total Black Sea anchovy landings, signalling dominant catches from Turkey (left) and landings of other Black Sea riparian countries (right). The data are taken from STECF (2015).

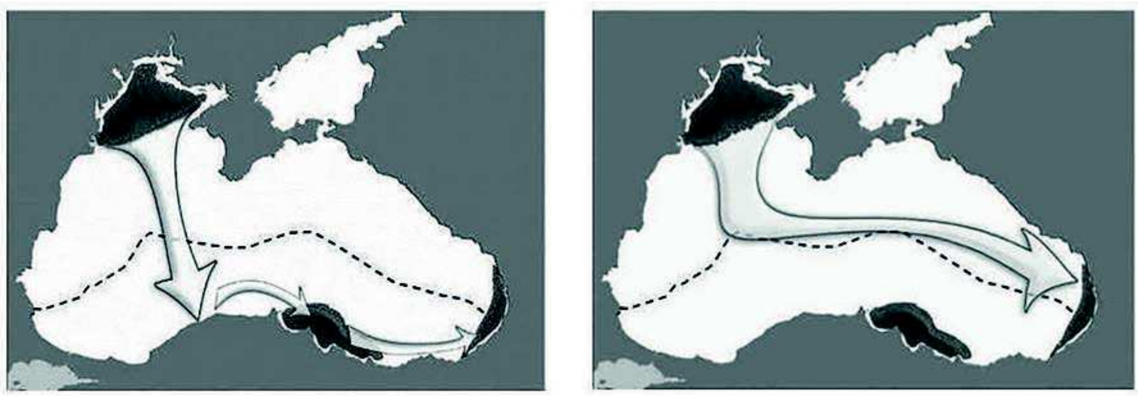

Figure 2.Two schematic alternative overwintering migration routes a) detouring the west coast and heading to central Anatolia; b) the offshore route heading straight to east detouring the Anatolian coast (grey zones are the spawning areas) Taken from Gucu *et al.* (2016b).

Although current fishermen and managers are quite confident that the destination of the migrating anchovies is in the east - within Georgian EEZ - there is contradicting information concerning the overwintering grounds of the BS anchovy. In some ancient reports the overwintering grounds are depicted near to the central part of the Turkish coast (Aasen and Akyüz, 1956). In an acoustical survey conducted towards the end of the overwintering season in the 1970s, Johannesson and Losse (1973) estimated almost a million tonnes of anchovy occupying the central part of the Turkish BS coast. These two reports show that anchovies have been overwintering in the south within Turkish waters. However, other observations such as the very first anchovies in Georgian waters appearing at the Turkish border (Chashchin *et al.,* 2015) support the fisher's thoughts.

The four graphs presented in Figure 4 were drawn based on daily catch registered at the landing port in four successive fishing seasons between 2011 and 2014. The vertical axis is the time scale starting from 1st of September. The quantity of fish landed is represented by the size of the circles. The points where the vertical lines meet the coastline on the background represent the position of the landing sites. These graphs show when and where the main fishery activity took place in a season. The very first landings are reported on the western side. As can be seen from the position of circles the fleet generally moves eastward as the season progresses. As a matter of fact, anchovy is not known as a strong migratory species because it is limited by several constraints, such as size spectrum in food selection, its shape, etc. (Bakun and Broad, 2003; Van der Lingen *et al.,* 2006). The reason why they migrate great distances in the Black Sea is apparently to utilize the nutritious food sources offered by the productive north in summer and but also to avoid lethal temperature of the northern winter. Therefore the rate of cooling, in a sense, determines how fast anchovy migrates during winter.

Figure 5 displays the dates of the highest fishing activity in the ports (longitudes). The positive linear relation (dotted line; $P>0.05$) confirms that the fish moves from lower longitudes to higher, or in another words migrates from west to east. The linear relation also shows that the distance covered in a day is almost constant but displays variation from season to season. The speed of the move estimated ranges between 7 and 25 n.mils/day. Moreover the speed of migration in a season seems to have linear relation with the cooling rate in the southwest; the faster it cools in the feeding grounds the faster they migrate to overwintering sites. Hence, the higher the speed of migration, the shorter the fishing season anchovy is fished.

The currents along the south coast are characterized by an alongshore peripheral current (Rim Current, RC; Figure 3). The current is located over the continental slope flowing in the same direction as the migrating anchovy. Its velocity accelerates and slows down ranging between 50–100 cm/s in the upper layer (Oguz and Besiktepe, 1999) depending on the strength of the heat loss from the sea to atmosphere (Korotaev *et al.,* 2001). The migration speed - being considerably slower than the velocity of RC (~25-50 n.miles/day) - shows that the anchovy do not use the RC, but to the contrary avoids it as a typical response of the pelagic fishes against strong currents (Freon and Misund, 1999). In association with the RC, several anticyclonic eddies (CAEs) are observed over the continental shelf, between the RC and the coast (Steneva *et al.,* 2001) and it seems that overwintering anchovy occupies these coastal eddies in order not to be drifted away by the RC. This also explains the difference presented in Figure 3a and Figure 3b, in which anchovy aggregations nestle up to the coastal at the sites under the influence of RC in the west while within the large CAEs on the east they form offshore aggregations. It may also worth to note that Gucu *et al.* (2016a) draws attention to the very same coastal anticyclonic structures selected as spawning areas by the southern anchovy population.

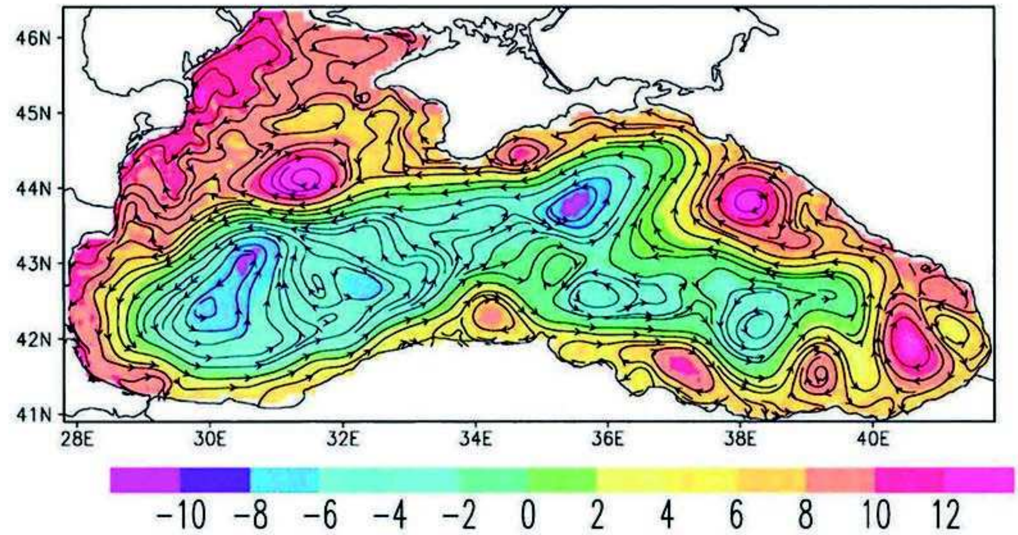

Figure 3.Schematic presentation of the main currents of the Black Sea and mean sea level height (taken from Staneva *et al.,* 2001).

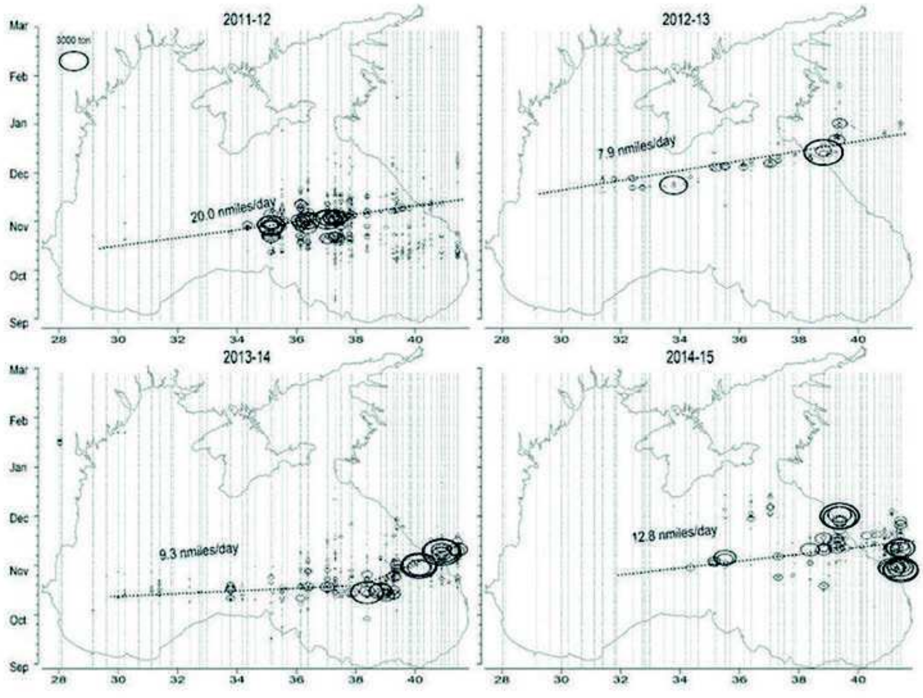

Figure 4.Landings by position of landing ports, by time and by size

As all these observations suggest, fast winter cooling has three effects on the anchovy; first, it drives anchovy faster so that migration is faster and second, it deepens the UML faster so that anchovy can approach to coast, settles on the overwintering grounds and form compact schools faster. In the case of fast cooling in autumn, they turn into easy targets for the fishers; they are fished out faster; the daily catch of the fleet is high; the over-all landing of the season is usually higher and the fishing season lasts less than the other years. In the case of slowly cooling winters, thermocline persists for a longer period and keeps the anchovy away from the coast, so that they migrate off the continental shelf in sparse surface aggregations. Consequently the daily quantity of fish removed by fishery is lower; the season prolongs and a larger part of the stock migrates to Georgian waters. 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, reduces the size of the CAEs which provides retention areas for the anchovy. Therefore the main implication of cooling rate on management of anchovy fishery might be that it determines the final destination of the transboundary migrating schools, and which would evidently influence the total level of landings by countries.

An acoustic survey conducted in autumn 2014 (10 October – 5 November) reveals the distribution of anchovies during the cooling period (Figure 5). Therefore the map also signals the location of anchovies in the southern Black Sea before or at the onset of the fishing season. Three main areas of accumulations draw attention on the map. The first is that one at the eastern most edge of the map. The second is in the central Turkish coast and possibly representing a part southern stock mentioned by Gucu *et al.,* (2016a). Finally, the third is located off the NW shelf, probably from where it was originated. Although they display different patch sizes, their densities are within the same order of magnitude. As the map is evaluated together with the position of the landings (Figure 4), it can be seen that the first group in the east seems to be there at the same spot even before the fishing season. The area in question located in effluent of the Batumi anticyclonic gyre and coincides with the spawning area noted by Gucu *et al.* (2016a). This one and the second accumulation were detected by the fishermen shortly and fished at two different sites.

An interesting point draws attention when comparing Figure 5 with the landings of the 2014-15 fishing season (Figure 4): fishery seems to target mainly the anchovy accumulations which were already on the south. On the other hand the same landing graphs do not give any indication that the western accumulation originated from the NW shelf was found and fished by the Turkish fleet. This group seems to follow an unusual route, heading straight to east along an offshore path not seen on the Turkish coast before they form dense schools sought by the fishermen and so that not fished on the Turkish coast (Figure 5). As a consequence, Turkish landing (70 000 tonnes) reported for the season is the lowest since the dramatic decline in 1990. In contrary, companies (except one) along the Caucasian coast filled their limits (GFCM, 2015), Georgia alone catching up with Turkish the landing first time in the history. The difference between TAC and the total landing of Georgian is due to some enterprise not being able to operate (GFCM, 2015). Besides as Ukraine lost the sovereignty of the Black Sea anchovy fishing grounds in Crimea, which used to be fished by their fleet, it is not known whether or not a part of the stock is overwintered in the north as they did in 2005.

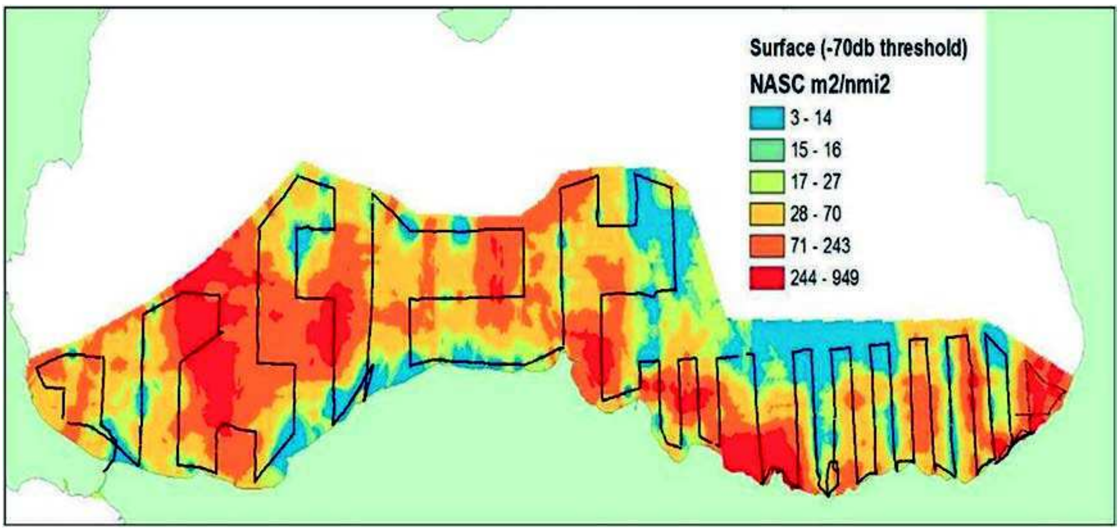

Figure 5.Distribution of anchovy in autumn 2014

There are two more similar significant drops in the Turkish anchovy landings (1989-1991 and 2005) experienced within the last 4 decades (Figure 1). The former is considered as a direct consequence of collapse of the stock which was attributed to various factors. In 2005, the landings decreased to a level lower than 100 thousand tonnes, and the stock unrealistically recovered the very next year. Interestingly, in contrary to regular overwintering pattern, a significant fraction of BS anchovy was reported to accumulate in the southern Crimea during the very same year (Chashchin *et al.,* 2015). Apparently, that year, a part of the BS anchovy stock was overwintered outside its range and the significant drop in the southern landings is, quite likely, a consequence of the temporal shift in the overwintering ground. 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 was not actually collapsed but simply anchovy overwintered outside the areas where they were expected. It may worth to note that the "collapse" in 1989-1991 coincided with the dissolution of USSR and during this period there were either no fishery in some areas like Georgia (Van Anrooy *et al.,* 2006), or fishery was not reported due to the lack of authority (Ulman and Divovich, 2015).

Finally, Figure 2 b is the output of an hypothetical migration model based on the assumption that the cooling in the upper mixed layer is the main driver of the Black Sea anchovy migrating south. The model suggests that the cooling pattern in the Black Sea is in fact facilitates the anchovies occupying the NW shelf area, taking a detour following an offshore route heading straight to the east coast.

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