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FISHING UNDER CLIMATE CHANGE: DYNAMICS OF COMPOSITION AND STRUCTURE OF CATCHES IN THE RUSSIAN BLACK SEA IN THE XXI CENTURY

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Currently, the Black Sea ecosystem is undergoing significant changes, and that affects the dynamics of the species composition of catches. The main reasons for the change in the Black Sea ichthyofauna are considered to be: fishing, anthropogenic water pollution, invasion of new species, and the effect of large-scale climatic and related oceanological and hydrological processes on the productivity characteristics of commercial Black Sea fish. With no understanding the patterns of the effect of these factors on ichthyofauna, it is impossible to rationally use bioresources and protect nature. The aim of the work was to study the effect of climate warming on the species composition and structure of catches in the Russian Black Sea in the XXI century. The authors had used: the results of own ichthyological observations; data published on the composition of the Black Sea catches; and the information available on the official websites of the Ministry of Agriculture of the Russian Federation, the Federal Agency for Fishery, and its Sea of Azov – Black Sea Territorial Administration. The analysis of the possible effect of global warming on the results of fishing in the Russian Black Sea was carried out. It is shown that in the XXI century, the ratio of thermophilic fish, which spawn in the summer, increased; those species are European anchovy *Engraulis encrasicolus* (Linnaeus, 1758), red mullet *Mullus barbatus* Linnaeus, 1758, and horse mackerel *Trachurus mediterraneus* (Steindachner, 1868). As established, the dynamics of the ichthyofauna in the area is determined by at least four processes related to water warming: improvement of reproduction conditions and increased survival of eggs and juveniles of thermophilic species; change in the intraspecific structure; invasion and naturalization of Mediterranean species with the subsequent change in the food relationships within the ecosystem; and concentration of psychrophilic species at greater depths. The need for a thorough study of this issue is concluded, aimed at long-term forecasting of the raw material base state of the fishing industry in the Russian Black Sea.

Keywords: global warming, fishery, Black Sea, European anchovy, *Engraulis encrasicolus*, European sprat, *Sprattus sprattus*, red mullet, *Mullus barbatus*, horse mackerel, *Trachurus mediterraneus*

The territory of the Russian Federation is washed by 13 seas; out of them, the Arctic ones only, except for the Barents and White seas, are not fishing areas. The Black Sea is not highly productive: benthic organisms inhabit only 20 % of its bottom area due to the hydrogen sulfide zone. The Black Sea

biological productivity is low: about 300 kg·km^{-2} (Kuranova & Moiseev, 1973). However, fishing in the Black Sea area has been known since ancient times (Zaika, 2008) and has experienced ups and downs in its history. In the second half of the XX century, the total catch of all the Black Sea countries reached 600 thousand tons; out of that, the USSR accounted for 200–250 thousand tons (State of Biological Resources of the Black and Azov Seas, 1995).

In the Black Sea, the catch of aquatic biological resources peaked in the 1980s: during that period, the total annual catch exceeded 850 thousand tons (Fig. 1). Then, there was a steady decline in catches: by 1996, those amounted to 396 thousand tons. Thus, over a decade, the catch in the Black Sea decreased by more than 2 times.

Fig. 1. Total catch of aquatic biological resources in the Black Sea in 1970–2010 (Shlyakhov et al., 2018)

The species composition of the catches changed as well. Until the 1950s–1960s, catches mostly consisted of nutritionally valuable species: Atlantic mackerel *Scomber scombrus* Linnaeus, 1758, Atlantic bonito *Sarda sarda* (Bloch, 1793), mullets of the family Mugilidae, horse mackerel *Trachurus mediterraneus* (Steindachner, 1868), Black Sea turbot *Scophthalmus maeoticus* (Pallas, 1814), herrings *Alosa* spp., and sturgeons of the family Acipenseridae. Later (until the 1990s and up to the present), catches consisted mostly of European anchovy *Engraulis encrasicolus* (Linnaeus, 1758) and European sprat *Sprattus sprattus* (Linnaeus, 1758). The catch of the Black Sea fish in the USSR was maximum in the 1970s–1980s, averaging 57 thousand tons; it included mostly European anchovy and European sprat, with their ratios in the total catch reaching 81 and 12 %, respectively (Balykin, 2014).

Over the entire history of observations in the Black Sea, 180 fish species have been recorded; out of them, 110 are of Atlantic origin, 2 are of Indo-Pacific origin, 2 are of Pacific origin, 33 are the Black Sea endemics, 21 are endemics of the Mediterranean basin, 11 are cosmopolitans, and 1 species (sterlet *Acipenser ruthenus* Linnaeus, 1758) is common in European freshwater and brackish water (Black Sea Fish Check List, 2020). Among the invaders currently actively spreading in the Black Sea area, *Lithognathus mormyrus* (Linnaeus, 1758), *Sarpa salpa* (Linnaeus, 1758), and *Gobius xanthocephalus* Heymer & Zander, 1992 are to be noted (Yankova et al., 2013). Out of the total

number of species, about 20 % are fishing objects (State of Biological Resources of the Black and Azov Seas, 1995). At present, the fishing species are as follows: European sprat, European anchovy, whiting *Merlangius merlangus* (Linnaeus, 1758), Black Sea turbot, flathead grey mullet *Mugil cephalus* Linnaeus, 1758, golden grey mullet *Chelon auratus* (Risso, 1810), red mullet, horse mackerel, spiny dogfish *Squalus acanthias* Linnaeus, 1758, thornback ray *Raja clavata* Linnaeus, 1758, common stingray *Dasyatis pastinaca* (Linnaeus, 1758), garfish *Belone belone* (Linnaeus, 1758), bluefish *Pomatomus saltatrix* (Linnaeus, 1758), Atlantic bonito, blotched picarel *Spicara maena* (Linnaeus, 1758), Atlantic mackerel, and *Atherina* spp. In recent decades, the commercial part of the Black Sea ichthyocene was replenished by the Far Eastern so-iuy mullet *Planiliza haematocheila* (Temminck & Schlegel, 1845), which successfully acclimatized in the Sea of Azov – Black Sea basin (Balykin & Startsev, 2017).

The Mediterranean and Black seas are the areas where, according to the United Nations Convention on the Law of the Sea (Konventsiya OON, 2020), coastal countries are to cooperate on aquatic biological resources management and scientific research. In the Mediterranean basin, regional fishery management is carried out by the General Fisheries Commission for the Mediterranean (GFCM). Its activities extend to the Black Sea. However, in this water area, there is no regional fishery regulation, since only three coastal countries – Bulgaria, Romania, and Turkey – have GFCM membership, and there is no agreement on fishery between all the Black Sea countries. The leading position in terms of the annual catch volume of aquatic biological resources is held by Turkey: it accounts for more than 75 % of the catch. The second and third places are occupied by Russia (Shlyakhov et al., 2018) and Ukraine, respectively. Ratio of each of the other countries in the area is about 1 % (Drozdov, 2011).

The main reasons for the change in the Black Sea ichthyofauna are considered to be as follows: fishing, invasion of new species, anthropogenic pollution, and the effect of large-scale climatic and related oceanological and hydrological processes on the productivity characteristics of commercial Black Sea fish (Drozdov, 2011 ; Tsikliras et al., 2015 ; Zaitsev et al., 2002). One of the best known and most widely discussed global climatic processes is warming; according to instrumental observations, it is most pronounced in the last 35 years (Toropov et al., 2018 ; Sakalli & Sakalli, 2018). Global warming is evident in the Black Sea area as well (Rybak & Rybak, 2013). As established, warming of the Black Sea surface in 1982–2009 averaged 0.06 °C·year^{-1} (Ginsburg et al., 2011). Climate change in the Black Sea area is manifested mainly in the summer season, during which a statistically significant positive temperature trend is recorded throughout its territory, reaching 1 °C in 10 years (Toropov et al., 2018). Thus, in the Sukhumi area, the mean temperature of the Black Sea water in July increased by 2.2 °C in the period 1994 to 2016 (Dbar et al., 2018).

The work was aimed on studying possible effect of climate warming on the species composition and structure of catches in the Russian Black Sea in the XXI century.

MATERIAL AND METHODS

The data published on the composition of the Black Sea catches (Kozhurin et al., 2018 ; Kumantsov et al., 2012 ; Luts et al., 2004 ; Cardinale et al., 2017) was used, as well as the information available on the official websites of the Ministry of Agriculture of the Russian Federation (2020), the Federal Agency for Fishery (2020), and its Sea of Azov – Black Sea Territorial Administration (2020).

The obtained results of studying possible changes in the ichthyofauna components based on the example of catches do not claim to be completely reliable, primarily due to the inaccuracy of fishing reports (Balykin & Boltnev, 2014). Therefore, the authors additionally used for the analysis the results

of ichthyological observations carried out by IBSS researchers. Fish were caught April to October in 2012 and 2018, with BS-3 trap nets with a 12-mm mesh; the trap nets were installed on sand sediments both in the Karantinnaya Bay mouth at a depth of 10–12 m and in the Sevastopol Bay water area.

RESULTS

The state authorities of Russia – the Ministry of Agriculture and the Federal Agency for Fishery – summarize the data on the catch of aquatic biological resources for the fishery basins (Makoedov, 2014). In 2001–2018, the catch in the Sea of Azov – Black Sea basin was of 25–103.4 thousand tons (Fig. 2). In 2018, the total Russian catch exceeded 5 million tons; so, this area does not play a significant role in domestic fishery. Nevertheless, fishing in the Sea of Azov – Black Sea basin significantly contributes to the development of the regional economy.

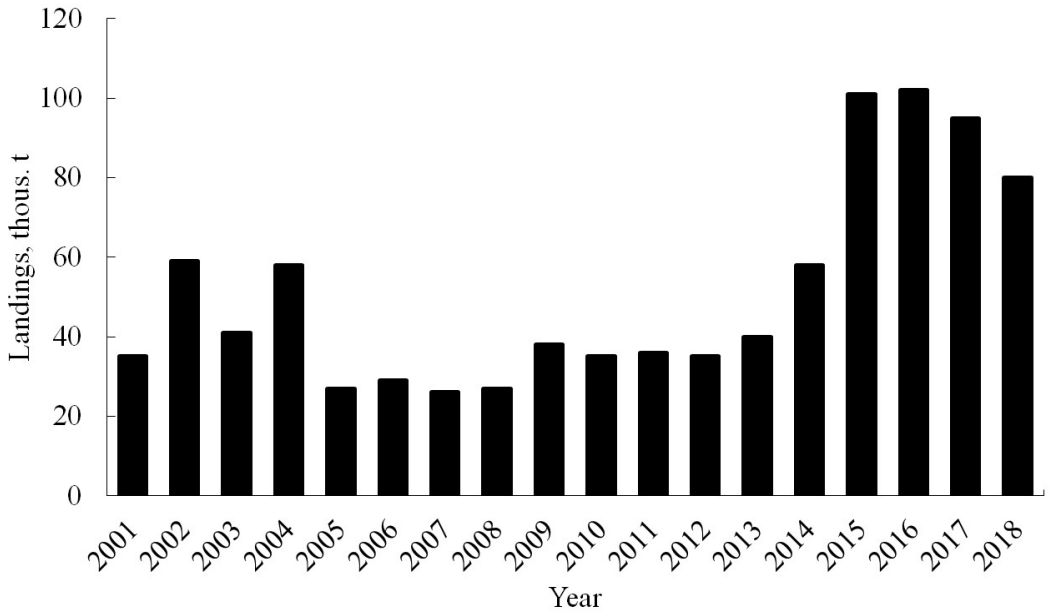

Fig. 2. Russian catches in the Sea of Azov – Black Sea basin

The water area studied can be divided into two parts: the waters of the Caucasian coast (northeastern area) and the waters of the Crimean Peninsula.

In the **northeastern Black Sea**, 102 fish species were recorded in the catches of commercial fishing gear in 1993–2002 (Nadolinskii, 2004). The state of commercial fish stocks is characterized as unstable. In this area, fishing with all fishing gear is multi-species; however, statistics takes into account the main species alone, whereas by-catch goes under the main species name at best or, at worst, is thrown overboard. The use of blocked and balanced quotas can contribute to a more complete development of marine biological resources and a balance in fishing efforts (Kumantsov et al., 2012 ; Nadolinskii, 2004).

In the northeastern Black Sea, the main fishing objects are two species accounting for about 90 % in the total catch: European anchovy (> 60 %) and European sprat (> 30 %). Other species account for less than 10 % (Balykin, 2014). In the total stock of explored biological resources (about 300 thousand tons), a significant part (about 42 % of all stock and more than 53 % of the volume of possible catch) consists of the objects, which are not currently used due to the lack of the technological base required for processing: small crustaceans, molluscs, algae, and seagrass (Dudkin et al., 2011).

Significant variations in the catch can result from the dynamics of its composition. To confirm this assumption, the authors used the data published on the composition of the Black Sea catches in 2001–2003 (Luts et al., 2004) and 2009–2011 (Kumantsov et al., 2012), as well as the material for recent years, 2016–2018, available on the official websites of the Federal Agency for Fishery and its Sea of Azov – Black Sea Territorial Administration. The species composition of catches, averaged over the periods indicated, is shown in Fig. 3.

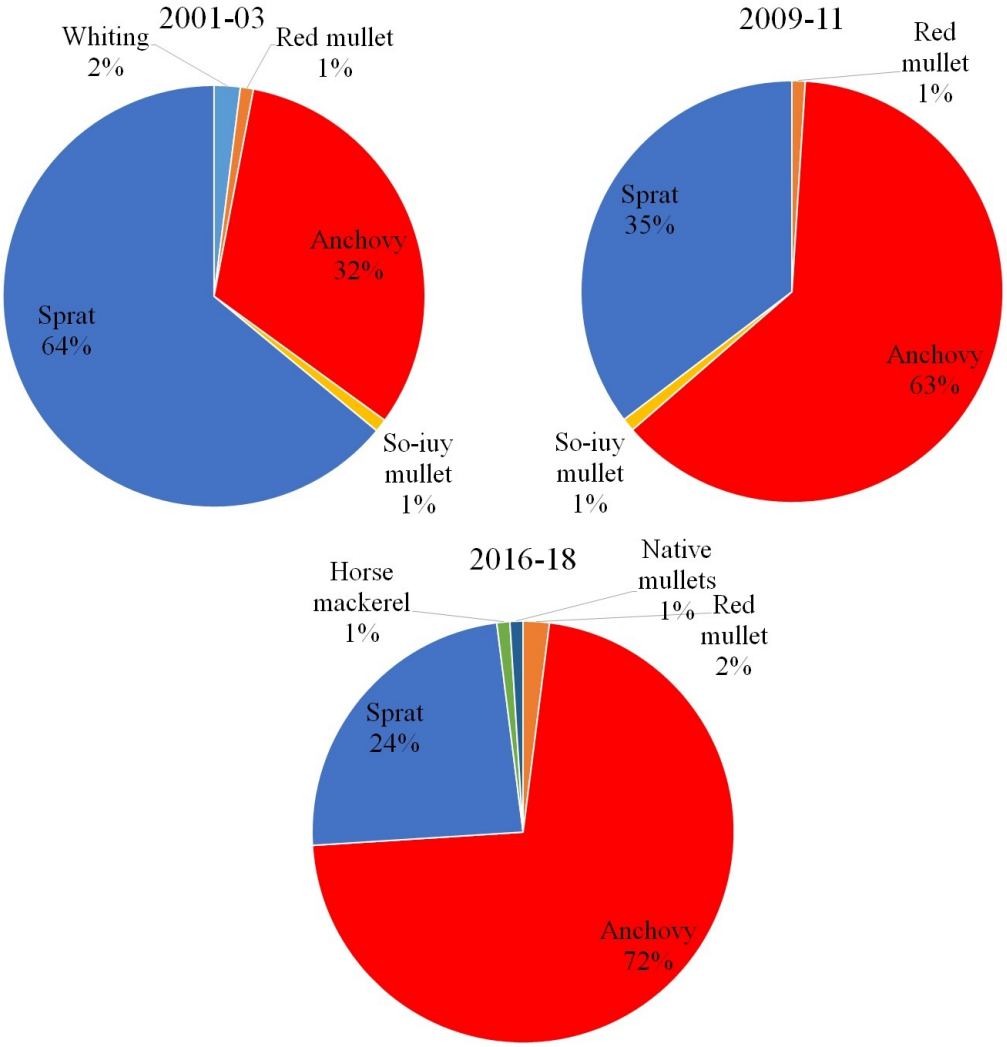

Fig. 3. Contribution of the most common fish species to the structure of Russian catches in the northeastern Black Sea in different periods of the XXI century

The main phenomenon to focus on is the change of dominant species in the composition of catches (Fig. 3). During the study period, the ratio of European sprat decreased by more than 2.5 times, and the contribution of European anchovy increased by the same value. Among other important processes, it is worth noting a twofold increase in red mullet catches (up to 300–560 tons *per* year), an almost complete disappearance of whiting and so-iuy mullet (less than 1 ton), and a significant increase in horse mackerel catches (130–330 tons *per* year) and Black Sea mullet catches (90–270 tons) in 2016–2018 (Fig. 3).

The dynamics of catches in **the waters of Crimea** (Crimean – Black Sea fishing area) is given according to data published (Kozhurin et al., 2018) and is supplemented by the information for 2018 from the website of the Federal Agency for Fishery. In this water area in 2001–2018, from 18.9 thousand tons (2007) to 72.9 thousand tons of fish (2016) were caught. To study possible variations in the species composition, the authors chose the same time intervals as for the northeastern Black Sea: 2001–2003, 2009–2011, and 2016–2018 (Fig. 4).

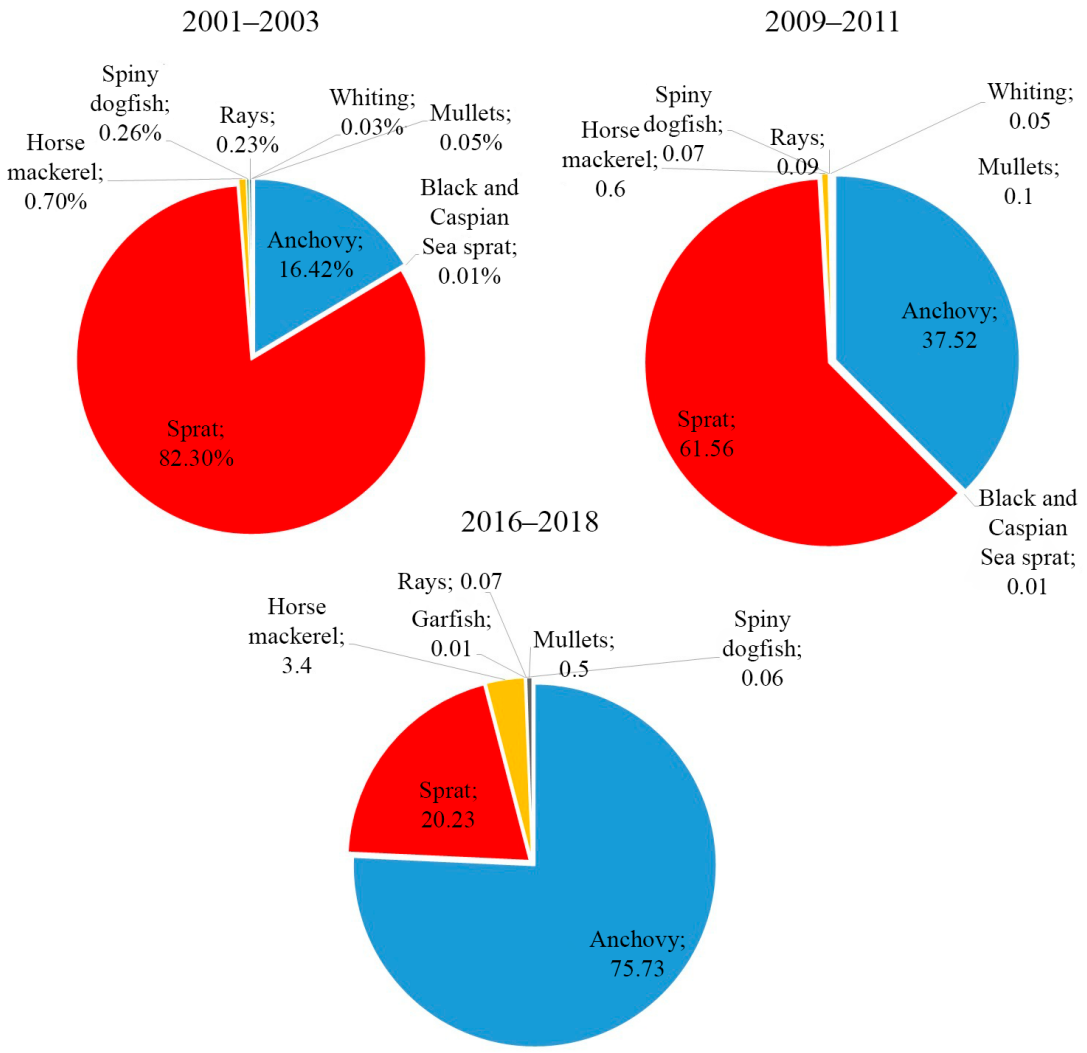

Fig. 4. Contribution of the most common fish species to the structure of Russian catches in Crimean – Black Sea area in different periods of the XXI century

The species composition of catches in the waters of Crimea changed similar to that in the waters of the Caucasian coast. During the study period, the ratio of European sprat decreased by 4 times (80 to 20 %), while the ratio of European anchovy increased approximately in the same proportion (16.5 to 75 %). Other changes include the complete disappearance of so-iuy mullet (< 0.3 tons), more than 10-fold increase of red mullet catches (7 to 300–571 tons *per* year), 10-fold increase of Black Sea mullet catches (270–275 tons in 2016–2018), 4-fold increase in herring catches (20–34 tons in 2016–2018), and almost 4-fold increase in horse mackerel catches (about 2 thousand tons in 2016–2018) (Fig. 4).

The data published, which are presented above, are in good agreement with the results of our own ichthyological observations carried out in the coastal water of the southwestern Crimea using trap nets. In 2012, 1,258 specimens of different fish species were examined; in 2018, 861 specimens were examined. The ratio of thermophilic species in the catches increased. Thus, during the study period, the ratio of greater weever increased more than 3 times, and horse mackerel – almost twice; at the same time, whiting almost disappeared from coastal catches (Fig. 5).

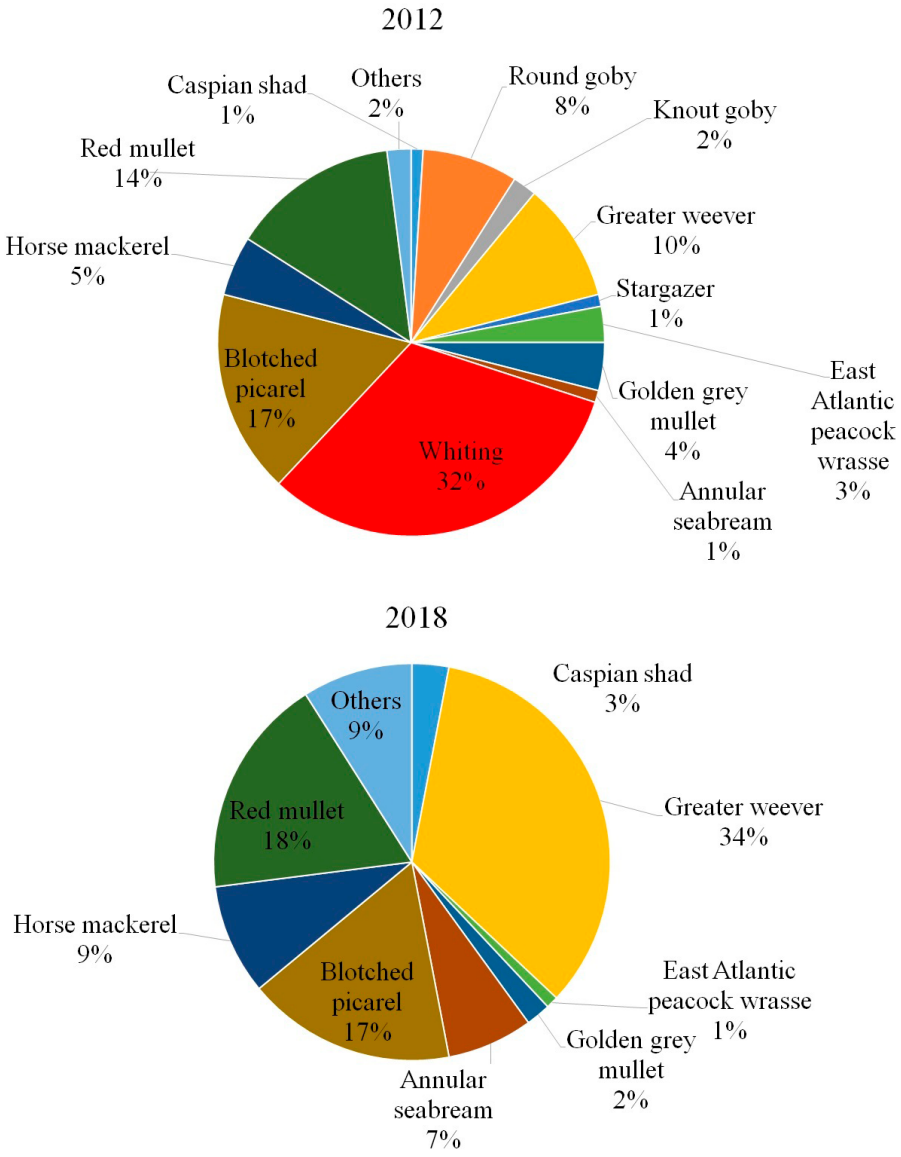

Fig. 5. Fish species composition in Sevastopol coastal waters in April – October 2012 and 2018

DISCUSSION

To date, it has been established that climate warming has a profound effect on the dynamics of ichthyofauna and fishing on a global scale (Cheung et al., 2013).

The most noticeable trend is the increase in the thermophilic species catch, which is clearly seen on the example of Crimean – Black Sea fishing area. For catches of European anchovy (Fig. 6a), horse mackerel (Fig. 6b), and red mullet (Fig. 6c), a pronounced correlation was revealed between

the logarithm of catch values and the sea surface temperature shifted by two years (approximate age at maturity). Thus, European anchovy had a linear correlation coefficient $r = 0.52$ at $p = 0.027$; horse mackerel had $r = 0.46$ at $p = 0.057$; and red mullet had $r = 0.57$ at $p = 0.013$. An increase in the ratio of thermophilic species in catches *amid* global climate warming may be related to the improvement of reproduction conditions and an increase in the duration of spawning and feeding periods. Thus, at present, a change is recorded in the species composition and abundance of ichthyoplankton, which is characterized by an increase in the ratio of early stages of summer-spawning thermophilic fish: red mullet, horse mackerel, and European anchovy (Nadolinskii & Nadolinskii, 2018). An increase in the European anchovy productivity in the Russian Black Sea is registered by other researchers as well (Dudkin et al., 2011 ; Zuyev, 2019).

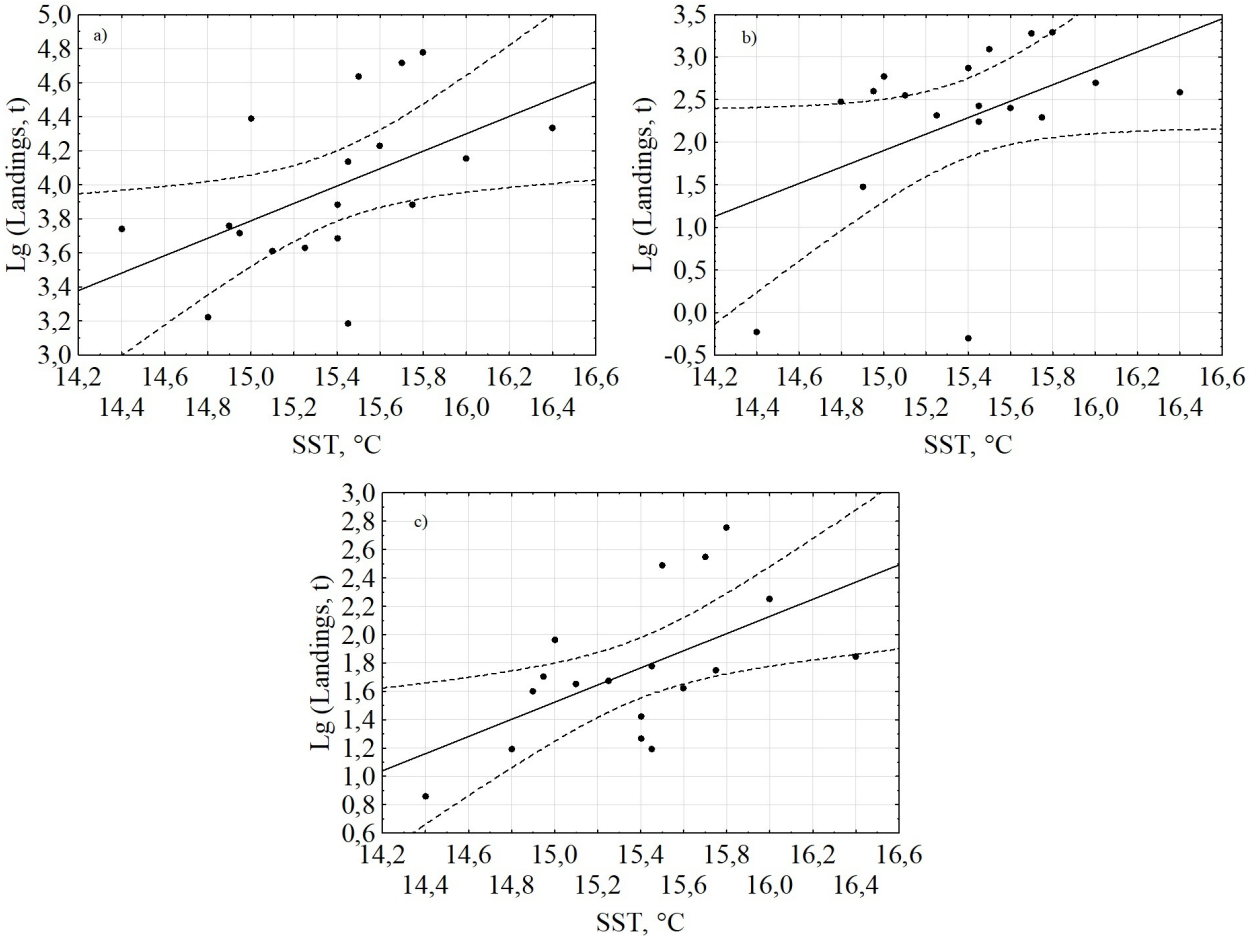

Fig. 6. Correlation between the logarithm of catch values of European anchovy (a), horse mackerel (b), and red mullet (c) and sea surface temperature (SST) (Federal'noe agentstvo po rybolovstvu, 2020) shifted by two years

Along with an increase in the abundance of various fish species, one can observe a change in the intraspecific structure of the ichthyofauna, namely an increase in the ratio of the Azov form of European anchovy (Kozhurin et al., 2018). This may be due to the expansion of its range under increasing salinity of the Sea of Azov, which results from climate changes as well.

Another manifestation of water warming effect is the expansion and displacement of the ranges of the tropical species to high latitudes. Within the Black Sea, those processes result in the intensive invasion of species from the Mediterranean Sea. To date, the number of invasive species and subspecies of the ichthyofauna is 21 (Yankova et al., 2013); taking into account climatic trends, we can conclude that the list will expand.

Climate changes are bound to affect all the ecosystem components, which naturally affects the ichthyofauna composition and structure. A good example is the invasion of the predatory ctenophore *Beroe ovata* Bruguière, 1789 in the Black Sea. As a result of its invasion, the abundance of the ctenophore *Mnemiopsis leidyi* A. Agassiz, 1865 decreased significantly, and this led to the restoration of the zooplankton and pelagophilic fish abundance (Shiganova et al., 2003). Other changes, less noticeable ones, in the peculiarities of food relationships are likely as well, *inter alia* among native species.

Climate warming effect on the dynamics of the abundance and distribution of psychrophilic species can also be observed on the example of whiting. With a decrease in catches in coastal water area, its commercial catch with trawls at a depth of 50 m and deeper increases (Kozhurin et al., 2018), which may indicate a vertical redistribution of its population. This is most likely related to global climate changes as well, which is confirmed by hydrological observations. Thus, a long-term increase in the depth of the upper quasi-homogeneous layer in the warm season was established. Until the 2000s, its thickness in the summer period was of 6–8 m; after 2010, the values on average exceeded 10 m (Kubryakov et al., 2019).

Conclusion. The dynamics of ichthyofauna and commercial catch in the Russian Black Sea in the XXI century are determined by at least four processes directly or indirectly related to water warming:

1) an improvement of reproduction conditions and increased survival of eggs and juveniles of thermophilic species, such as European anchovy, horse mackerel, and red mullet;
2) a change in the intraspecific structure observed on the example of European anchovy;
3) an invasion and naturalization of Mediterranean species with the subsequent change in the food relationships within the ecosystem;
4) a concentration of psychrophilic species at greater depths.

In order to assess consequences of climatic processes for the resource base of the Black Sea and ichthyofauna in total, the entire available dataset of scientific observations should be analyzed: hydrological, hydrobiological, and ichthyological ones.

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РЫБОЛОВСТВО В УСЛОВИЯХ КЛИМАТИЧЕСКИХ ИЗМЕНЕНИЙ: ДИНАМИКА СОСТАВА И СТРУКТУРЫ УЛОВОВ В РОССИЙСКОЙ ЧАСТИ ЧЁРНОГО МОРЯ В XXI ВЕКЕ

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В настоящее время экосистема Чёрного моря претерпевает существенные изменения, что закономерно отражается на динамике элементов уловов рыб. Главными причинами изменения ихтиофауны Чёрного моря считаются: рыболовство, антропогенное загрязнение вод, вселение новых видов, влияние крупномасштабных климатических и связанных с ними океанологических и гидрологических процессов на показатели урожайности промысловых рыб. Без понимания закономерностей воздействия этих факторов на ихтиофауну невозможны рациональное использование биоресурсов и охрана природы. Целью работы было изучить влияние потепления климата на состав и структуру уловов в российской части Чёрного моря в XXI веке. Авторы использовали: результаты собственных ихтиологических наблюдений; опубликованные данные о составе черноморских уловов; информацию, доступную на официальных сайтах Минсельхоза РФ, Росрыболовства и его Азово-Черноморского территориального управления. Выполнен анализ влияния процессов глобального потепления на результаты рыболовства в российской части Чёрного моря. Показано, что в XXI веке возросла доля теплолюбивых рыб, нерест которых происходит летом: хамсы *Engraulis encrasicolus* (Linnaeus, 1758), барабули *Mullus barbatus* Linnaeus, 1758 и ставриды *Trachurus mediterraneus* (Steindachner, 1868). Установлено, что динамика ихтиофауны в регионе определяется как минимум четырьмя процессами, сопряжёнными с потеплением вод: улучшением условий воспроизводства и роста выживаемости икры и молоди теплолюбивых видов; изменением внутривидовой структуры; вселением и натурализацией видов из Средиземного моря с последующим изменением характера пищевых взаимоотношений внутри экосисемы; концентрацией холодолюбивых видов на больших глубинах. Сделан вывод о необходимости тщательного изучения влияния потепления вод Чёрного моря в целях долгосрочного прогнозирования состояния сырьевой базы рыбной промышленности черноморского бассейна России.

Ключевые слова: глобальное потепление, рыболовство, Чёрное море, хамса, *Engraulis encrasicolus*, шпрот, *Sprattus sprattus*, барабуля, *Mullus barbatus*, ставрида, *Trachurus mediterraneus*