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RESEARCH ARTICLE

The current state of the turbot, *Scophthalmus maximus* (Linnaeus, 1758), population in the northwestern part of the Black Sea

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Abstract. Turbot is one of the most valuable fish species in the Black Sea commercial fishery. The serious, dramatic depletion of the turbot stock and catches that began in the 1980s was caused by overfishing and poor ecological conditions. The state of the turbot stock began to improve in the northwestern part of the Black Sea in 2016. Landings were at their 30-year maximum in this part of the sea. Catches per unit effort (CPUEs) have been at a stable, high level there for the last few years. Average turbot weight and length have also been increasing. The Stock Synthesis (SS3) framework was used in the stock assessment. According to SS3 analysis, fishing mortality (*F*) reached the minimum level of 0.29 in 2018. The cumulative SPR (Spawner Potential Rate) index was 0.27, which approximately equaled SPR_{MSY} = 0.25. Thus, currently the turbot stock is mostly moderately exploited at a level close to the management target in the northwestern part of the Black Sea. However, the entire Black Sea population has not fully recovered yet.

Keywords: stock assessment, Black Sea, turbot, Stock Synthesis, overfishing

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Introduction

The Black Sea turbot, *Scophthalmus maximus* L., is a bottom-dwelling predator. It prefers sandy and silty-sandy bottoms. It does not make long migrations along the marine shelf zone and is characterized by local movement associated only with feeding and reproduction. Long-term observations during trawl surveys showed that the distribution of turbot along the offshore area is uneven and depends largely on the width of the shelf zone (Nadolinskiy et al. 2018). Its maximum abundance and distribution density are confined to areas with a broad shelf. According to tagging and morphometric data, Black Sea turbot forms several local populations, or subpopulations (Popova 1954, Karapetkova 1964, 1980, Nadolinskiy et al. 2018). The geographical features of the broadest shelf zone in the northwestern part of the Black Sea and minimal turbot migration

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activity contribute to the isolation of this fish population. Based on the morphological features of the shelf and the continental slope, oceanographers determined the western border of the northwestern Black Sea region as Cape Kaliakra and the eastern one as Cape Khersones (Dubinets et al. 1988). Obviously, narrowings of the shelf near Cape Kaliakra and on the section of Cape Khersones – Cape Sarych create natural barriers that prevent turbot from resettling. In addition, migrations of demersal fishes are hindered by an area filled with hydrogen sulfide at depths of more than 120 meters throughout the Black Sea. Accordingly, the turbot population of the northwestern part could be considered as a separate stock unit isolated in the largest shelf area (Shlyakhov 2014). Turbot tagging and trawl surveys carried out by YugNIRO in the northwestern part of the Black Sea in the 1980s confirmed the locality of a so-called western stock unit of this fish (Efimov et al. 1989). The presence of this isolated substock in the Black Sea turbot population is also supported by results of the most recent genetic studies. The fish inhabiting the northern part of the Sea have significant genetic differences from those inhabiting the southeastern and southwestern parts of the marine shelf (Firidin et al. 2020). Thus, it makes sense to assess the turbot stock in the northwestern part separately from the entire Black Sea population.

As turbot is one of the most important species in the Black Sea commercial fishery, the assessment of its stock and fishery management has traditionally attracted particular attention at national and regional levels. In 2008-2017, assessments of the Black Sea turbot stock were conducted by the Working Group of Experts of the Scientific Technical and Economic Committee on Fisheries (EWG STECF) of the European Commission and in 2017–2018 by the Subregional Group for Black Sea Stock Assessment (SGSABS) under the auspice of the General Fisheries Commission for the Mediterranean (GFCM). These two groups consist mainly of experts from research institutes and universities of Black Sea countries. The authors of this article also participated in the work of these research groups. The input data for the whole stock assessment were formed by combining production and biological data from various regions of the Black Sea. According to these estimations, the entire Black Sea turbot stock was overfished and severely depleted for a long period. In 2014, fishing mortality of turbot exceeded F_{MSY} (reference point for fishing mortality when the stock is exploited at a Maximum Sustainable Yield level) by five times. The spawning stock was reduced to an extremely low level of 1,010 tons in the same year, which was much lower than the minimum allowed level (B_{lim}) of 3,535 tons (STECF 2015).

However, there were differences in the assessments of the stock status by sea areas. An LCA assessment of the western stock in Ukrainian waters in 1997-2013 found $F/F_{MSY} = 0.96 \rightarrow 1.77$ and designated the stock status as transitional from fully exploited to overexploited in that period (Shlyakhov 2014). SAM (Nielsen and Berg 2014) assessments of the STECF and GFCM working groups for the entire Black Sea stock were much more pessimistic for this period (Table 1). Marine regions inhabited by turbot, which are located on the shelf of the southern part of the Black Sea, did not show positive signals at all.

Indicators of the entire stock state began to improve slightly in 2016. According to the latest results, a stable, positive tendency for the turbot stock was noted throughout the Black Sea (GFCM 2019). The total spawning stock in 2018 increased compared to previous years. Its level remained quite low but was almost 1.5 times higher than the reference point B_{pa} = 2295 tons. However, the fishing mortality rate was 0.44 in 2018, which was three times more than F_{MSY} = 0.14. This stock assessment was also conducted

Table 1

State of the turbot stock and commercial population parameters in 2015-2017

Indexes	Years 2015	2016	2017
F/F_{MSY}	5.38	4.40	3.10
B_{cur}/B_{lim}	0.29	0.44	0.57
B_{cur}/B_{pa}	0.20	0.33	0.41

B_{cur} – current spawning stock biomass,
B_{pa} – spawning stock biomass at the level where fishing does not affect reproduction.

with SAM analysis. Illegal, unreported, and unregulated (IUU) fishing was recorded in these studies. Therefore, it should be assumed that the entire turbot population was overfished in spite of the recent positive tendency in its abundance.

Obviously, the issue of differences in turbot abundance trends in various areas of the Black Sea is of great importance and requires special studies. Currently, we have the material that allows us to identify distinctive features of the abundance dynamics of this species in the most important area of its habitat and fishing, which is the northwestern part of the Black Sea.

Materials and methods

Fish samples were collected from gillnet and trawl catches. Gillnets with mesh sizes of 180–200 mm (knot to knot) are the traditional gears for this species in commercial fishery. All trawl hauls were conducted during special trawl surveys. The total number of fish examined during the period of 2002-2018 was 5,500 individuals. Each individual was measured from the beginning of the snout to the end of the rays of the caudal fin and weighed. Otoliths were collected from 2,800 individuals for age reading. The sexual maturity of fish was also evaluated.

During 2008-2018, a Romanian demersal fish survey was conducted regularly for the turbot stock and other demersal fish assessments using the holistic trawl survey method (surface method) that can be applied to restricted areas. Vessel speed and horizontal opening of the trawl were taken in consideration as survey parameters. The characteristics of the bottom trawl were 2/27-34 m; the horizontal trawl opening was 13 m; the vertical trawl opening was 2 m. Trawling was conducted in spring and fall. The total number of trawlings done in one year was approximately 80 (40 in spring and 40 in fall). The distribution of the hauls is presented in figure 1. Stations were positioned in order to cover the entire Romanian Black Sea shelf habitats and depths. The total time of each haul was 60 min and the trawling speed was between 1.7-2.2 knots. Catches ranged from 10 to 580 kg.

Individual average fish parameters (length, weight, maturity) along with catch at age data were used for population dynamics and fishing impact

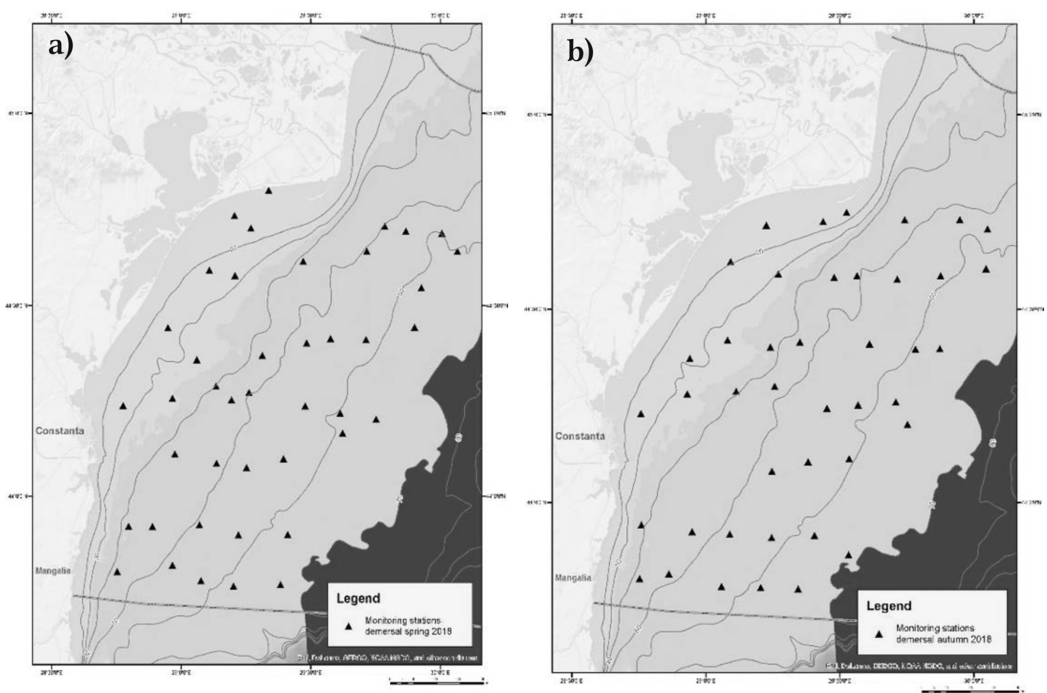

Figure 1. Distribution of trawling stations in the spring (a) and fall (b) seasons in the Romanian area.

modeling. The results of the trawl surveys and CPUE data were used for model tuning. The share of IUU fishing by countries was estimated and included in the catches according to the STECF method (STECF 2014).

Stock Synthesis (SS3) was applied for the turbot stock assessment in the northwestern part of the Black Sea. This package provides a statistical framework for calibrating population dynamics models using fishery and survey data (Methot and Wetzel 2013). In contrast to virtual population analysis, SS3 uses the forward projection of populations in the statistical catch-at-age (SCAA) approach and allows for errors in catch at age matrices. Stock spawning biomass (SSB), recruitment, and fishing mortality were evaluated with the SS3 model, in which selectivity was cast as age-specific only.

There is no concept of a single annual F in SS3 since this rate varies by age, sex, season, and area. Moreover, it is misleading if there are large differences in fleets or, even worse, if they operate in different areas. In addition, an average F depends on the calculation method chosen. Because of the inferiority and uncertainty of the F criterion within the framework of this model, it was also decided to use the parameter of the reproductive capacity of the population provided by SS3. This parameter, the Spawner Potential Rate (SPR), is a single measure of the equilibrium effect of fishing. SPR is defined as the proportion of the unfished reproductive potential left in the population at any given level of fishing pressure (Goodyear 1993). It can be used for setting the target and limiting reference points in fisheries. SPR_{MSY} is the main reference point instead of F_{MSY}. So, SPR can be calculated as the ratio of the equilibrium reproductive yield per recruit that would occur with the current year's fishing effort and biological parameters of fish to the equilibrium reproductive yield per recruit that would occur with the same biological parameters without fishing activity. It ranges between 0 and 1, with a value of 1 representing an unexploited stock. Therefore, the status of a stock can be classified into three different groups which are under- ($SPR > 0.4$), moderately ($0.2 < SPR < 0.4$) and over- ($SPR < 0.2$) exploited.

Natural mortality at age was fixed at independently obtained values. The Beverton-Holt relationship was taken for recruitment assessment. The high flexibility of SS3 allowed covering various data from commercial and survey catches: landings, abundance indices, catch-at-age, weight-at-age, and maturity proportions. This model contains subcomponents that simulate population dynamics of stocks and fisheries, derive the expected values for various observed data, and quantify the magnitude of differences between observed and expected data. A feature such as a multi-fleet approach provides the spatial and fishing gear differences in this assessment. The integrated abilities of SS3 for obtaining reference points and forecasting allowed evaluating the current status and future prospects of the turbot stock in the northwestern part of the Black Sea. The quality of the assessment was validated through integrated model tools. The surplus production model Combi 4 (Babayan et al. 2018) was also applied in the assessment to compare it with the results of SS3.

Results and discussion

Fishing statistics and catch composition

Very specific turbot population dynamics were observed in the northwestern part of the Black Sea. At first, there was an increase in turbot catches in this region after 2000 (Fig. 2). This was because of improvements in recording catches, which were implemented after Ukrainian enterprises began exporting turbot. After 2012, this positive trend was replaced by a drop in catches similar to the general recession in the Black Sea, and the approach of fish to the coastal zone of the northwestern part of the sea declined significantly. However, the situation in this region, including the largest shelf zone in the Ukrainian waters, started to change since 2016. Catches stabilized significantly at their highest levels in the northwestern part of the Black Sea for the last three decades (Hulak et al. 2019). Simultaneously, there

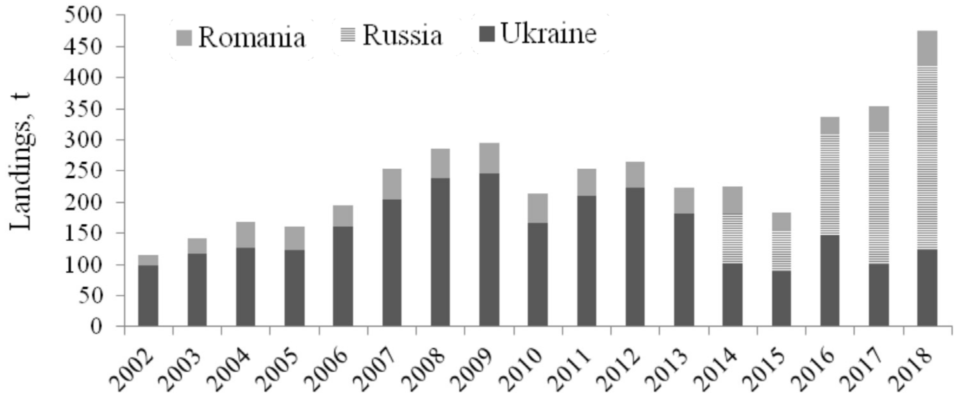

Figure 2. Official landings of turbot in the northwestern part of the Black Sea.

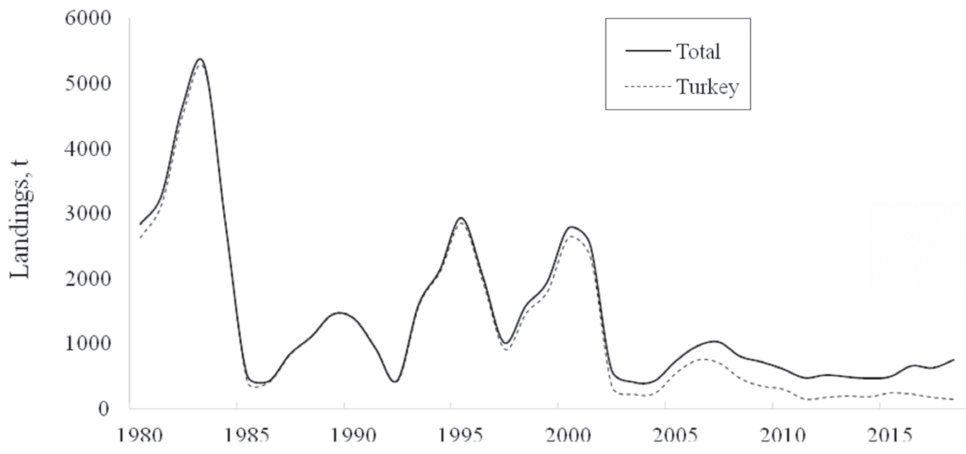

Figure 3. Long-term dynamics of turbot landings in the Black Sea (entire basin), tons (GFCM, 2019).

was a pronounced tendency for an increase in turbot abundance in 2015-2018. This increase indicated directly the ongoing fast recovery of the western stock since the changes were not because of the intensification of fishing activities but to increases in catch per unit effort (CPUE). CPUE was 12 kg/net in 2015, 45 kg/net in 2016, 51.8 kg/net in 2017, and 45.3 kg/net in 2018 in Ukrainian marine zone. This positive trend after 2015 was also confirmed by data from trawl surveys conducted by Romanian scientists (Maximov et al. 2017, 2018). Landing increases mainly occurred at the expense of fishing in Ukraine including the Crimea area. In Romania, landings also increased, but they were not as significant because of EU restrictions.

The assessment of turbot stock in the northwestern part of the Black Sea using the CC3 model was based on Ukrainian, Romanian, and Russian landing data (Fig. 2) and tuning indices since 2002. Prior to 2002, Turkish vessels were known to fish illegally in the territorial waters of Ukraine, Romania, and Bulgaria. Their catches were landed in Turkey and reported in Turkish landing statistics. By 2001, authorities in Ukraine, Romania, and Bulgaria had intensified efforts to stop illegal Turkish fishers. These actions even resulted in a sudden drop in Turkish landings in 2002 (Fig. 3). Fisheries data collection in the northern part of the sea started to improve from 2002.

Biological analyses have shown that, since 2016, the number of individuals has increased in catches

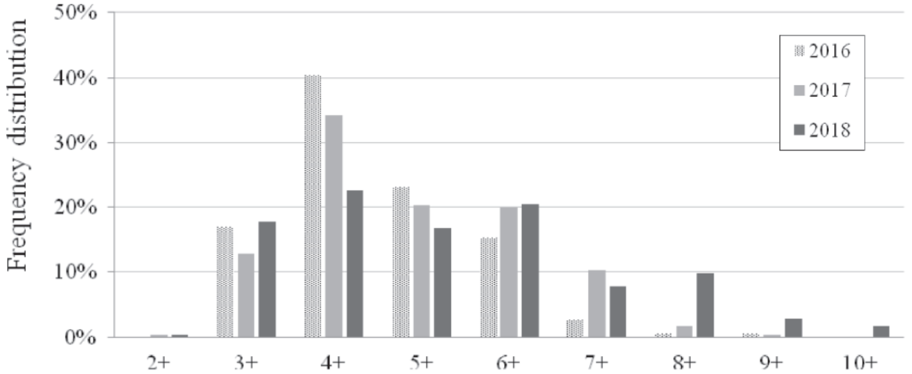

Figure 4. Age frequency distribution of turbot in the northwestern part of the Black Sea.

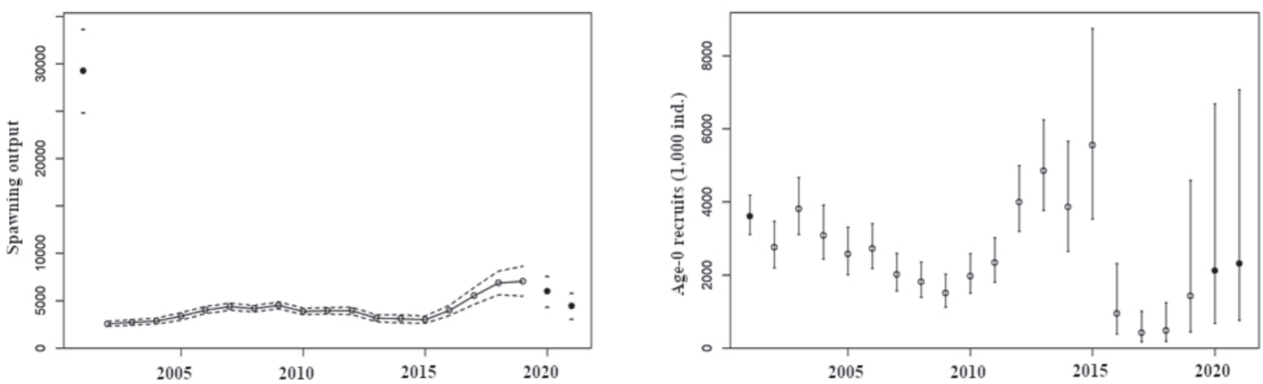

Figure 5. Spawning Stock Biomass, SSB (tons) forecast with 95% asymptotic intervals (left panel) and age-0 recruitment forecast with 95% asymptotic intervals (right panel).

mainly because of older age groups. There was an increase in age groups 6+ and older (Fig. 4). In addition, the same trend was observed for the length groups of turbot. An increase in the number of individuals was noted starting from 55 cm. The average weights at age and corresponding length groups also increased. Obviously, this is a positive trend indicating that, recently, the turbot stock might have been exploited sustainably in the northwestern part of the Black Sea.

Stock assessment results

The vectors of natural mortality and the proportion of mature individuals were taken from the EWG GFCM for the entire Black Sea turbot stock assessment (GFCM 2019) (Table 2). The assessment results were interpreted as providing information on stock development up to January 1, 2019, i.e., not for 2019. The SSB in the northwestern part of the sea showed a generally increasing trend after a drop in 2002 with a peak of $6.4*10^3$ tons in 2019 and the virgin SSB was estimated at $29.3*10^3$tons (Fig. 5, left panel).

Table 2
Natural mortality and mature proportion vectors

	Age groups										
Vectors	0+	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+
Natural mortality	0.47	0.34	0.28	0.24	0.22	0.20	0.19	0.18	0.17	0.16	0.16
Maturity	0.0	0.0	0.0	0.43	0.69	1.0	1.0	1.0	1.0	1.0	1.0

However, SSB will go down after 2019 according to this forecast. Here, and throughout the forecast, this was done with the assumption that $F = F_{2016\text{-}2018} = 0.366$. Recruitment was estimated as the number of age-0 fish related to the spawning biomass in accordance with Beverton-Holt stock-recruitment relationship. It reached a maximum of $5.6*10^6$ ind. in 2015 and decreased to $0.4*10^6$ ind. in 2017 (Fig. 5, right panel). The SS3 estimated a significant drop in recruitment in 2016–2018. However, the situation was forecast to improve from 2019.

Fishing mortality F was calculated considering ages 4 to 8 (Fig. 6, left panel). Fishing mortality showed a fluctuating trend with local peaks observed in 2008, 2013, and 2016 with the minimum value of 0.293 in 2018. According to SS3 estimations for the turbot stock in the northwestern Black Sea, $SPR_{MSY} = 0.25$. The SPR index showed a drop to 0.17 in 2016 and reached a maximum of 0.27 in 2018. In the other years of the observed period, this value was close to the SPR_{MSY} level (Fig. 6, right panel). Thus, recently, the turbot stock was mostly moderately exploited.

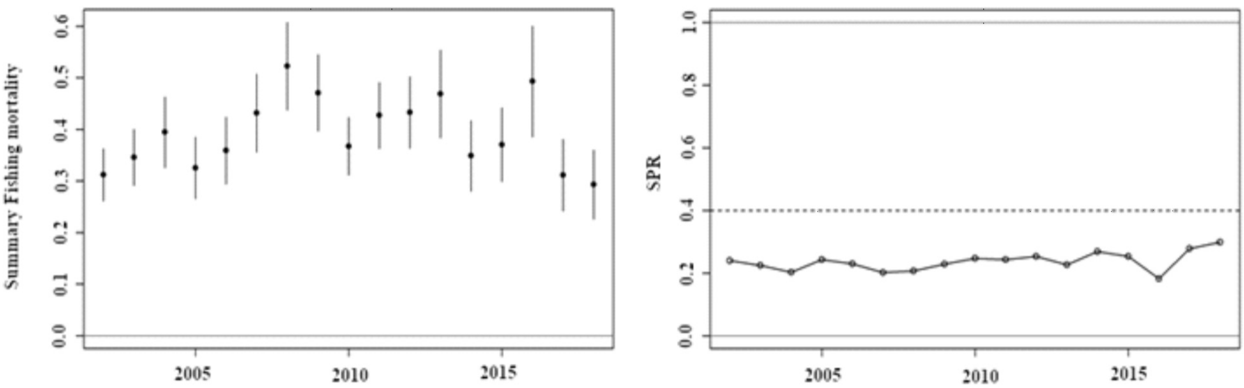

Figure 6. Total fishing mortality F with 95% asymptotic intervals (left panel) and Spawner Potential Rate with 95% confidence intervals (right panel).

According to SPRMSY, the target turbot catch in the northwestern part of the Black Sea is 836 tons with an upper limit of 935 tons as the MSY value. Although the actual total landings of turbot (Fig. 2) were below these recommended values in recent years, the commercial exploitation of this stock should not be increased because of IUU catches. These IUU catches of Black Sea turbot were comparable with official ones in recent years and were previously substantially higher (GFCM 2019). In addition, it should take into account that the total turbot stock is overexploited throughout the Black Sea. So, fishing at a level below F_{MSY} would facilitate the recovery of the Black Sea turbot population.

Quality of the assessment

A retrospective analysis of the results showed that the applied model is quite stable even though IUU catches were estimated. The values of Mohn's rho-index (the average relative bias of retrospective estimates) (Mohn 1999) were -0.060 for SSB and 0.083 for F over the last three years. The age frequency distributions (AFDs) aggregated across time were reconstructed quite well by the model for both fishing fleets and surveys. The double normal distribution with defined initial and final levels (type selex24 in SS3) was applied to fit all AFDs. The Pearson residuals for the fishing fleets and surveys were quite low (mostly between -2 and 2) and were without patterns (Fig. 7 and 8); although, it is often difficult to pinpoint the cause of residuals that have substantial patterns. Usually, the two potential reasons for these residuals are unrealistic starting values and poor model specification. We managed to avoid these problems in this study. However, the fitting presented some inconsistency for surveys provided by Romania, where some drops could not be described well by the model (Fig. 8). The fitting also

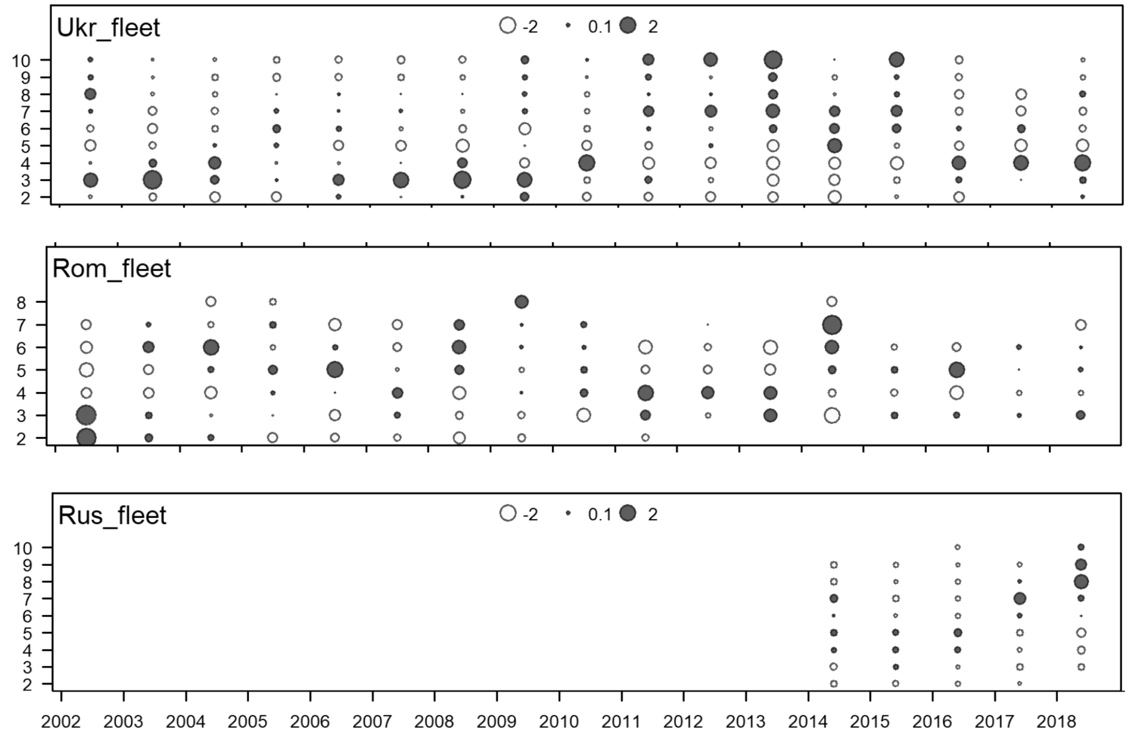

Figure 7. Pearson's residuals for commercial fishery data.

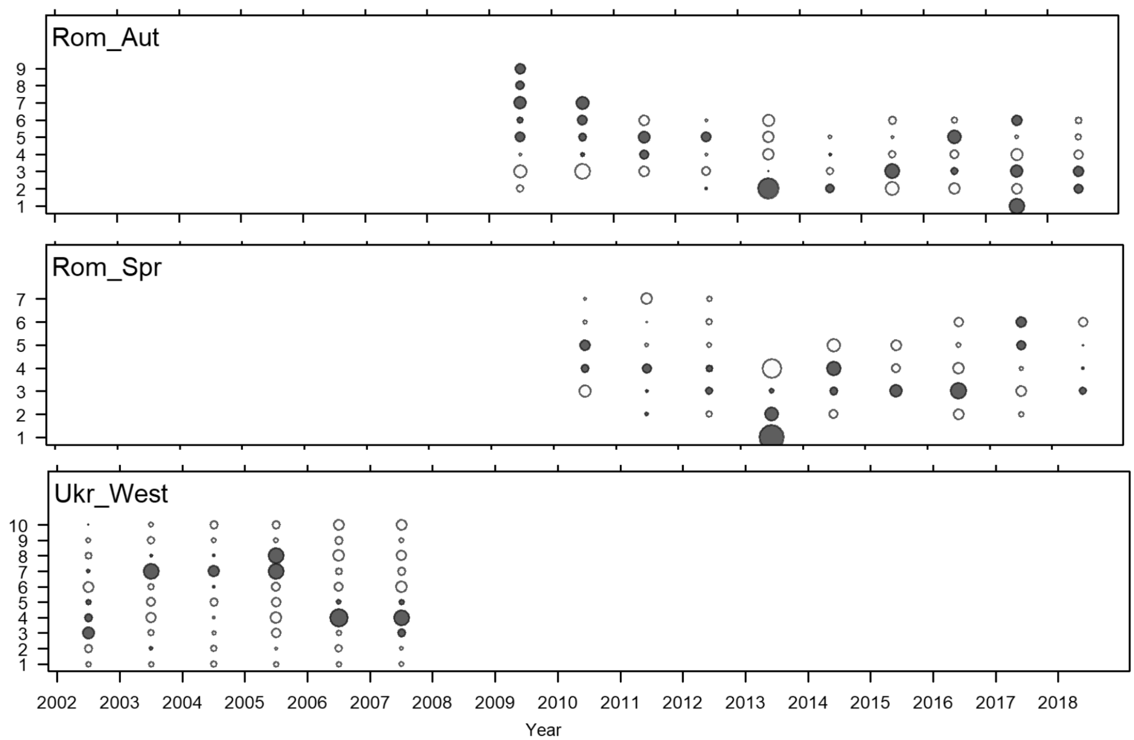

Figure 8. Pearson's residuals for trawl surveys.

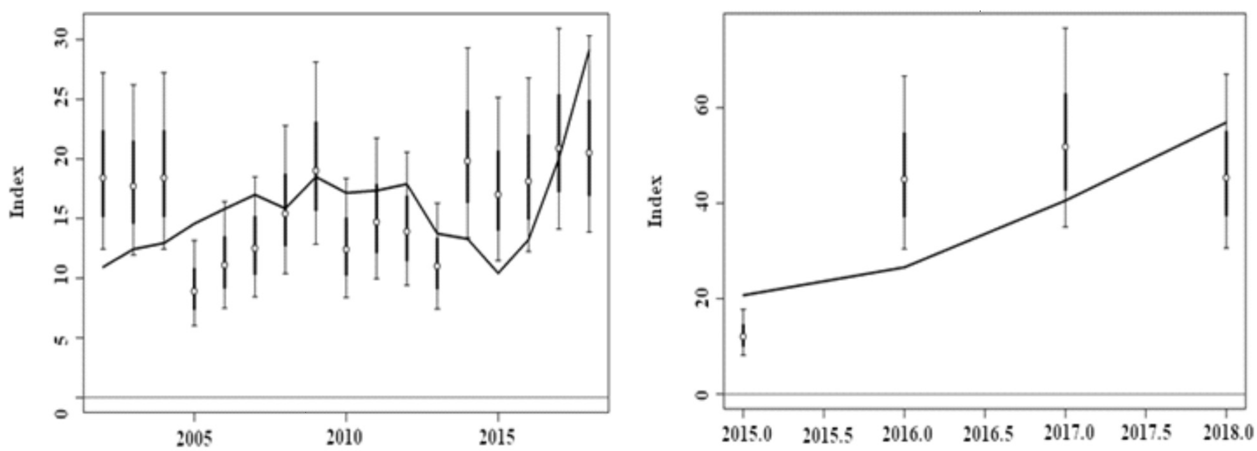

Figure 9. Fitting for Ukrainian CPUE series – Crimea (left panel) and mainland (right panel).

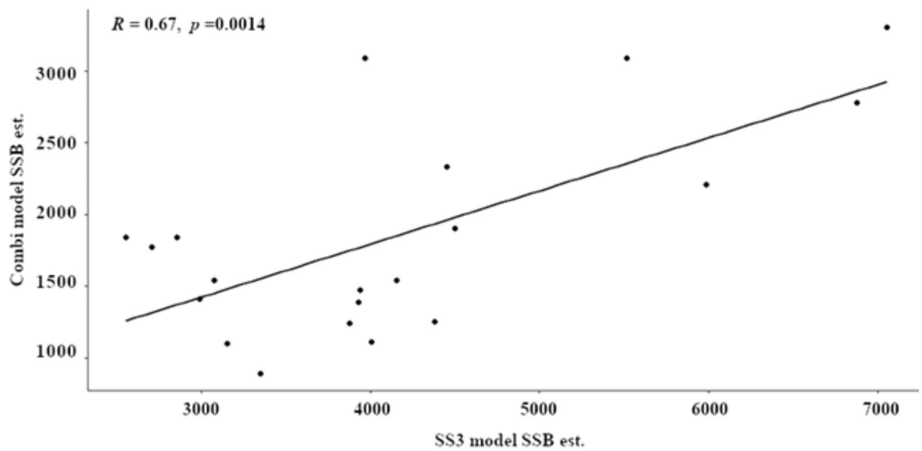

Figure 10. Pearson's correlation test for Spawning Stock Biomass, SSB, estimated with Stock Synthesis, SS3, and Combi.

presented some inconsistency for the observed and expected CPUE indices. Most peaks and drops on the chart were poorly described by the model (Fig. 9). The biomass estimation obtained by the surplus production model Combi 4 was consistent with SS3 results (Fig. 10). This model also indicated that turbot biomass has been increasing in the northwestern part of the sea since 2016.

Factors determining stock dynamics

To understand the current situation of the turbot stock, we refer to the long-term landing dynamics of this species. In the 1980s, catches of all Black Sea countries dropped significantly for the first time. According to statistics, this was preceded by a sharp increase in turbot landings. Almost all of these catches were generated by the Turkish fleet (Fig. 3). Turkish landing reached a maximum of 5216 tons in 1983. Moreover, small Turkish vessels equipped with multi-kilometer nets began to deploy their gears on the wide northern shelf of the Black Sea, where this fish was much more abundant than in Turkish waters (Acara 1985). Even the introduction of economic zones in the Black Sea did not immediately stop the Turkish fleet, which frequently fished the economic zones and even the territorial waters of neighboring counties (Öztürk 2013). This could not but have affected the turbot population. Considering the critical state of the fish stock, the USSR introduced a 10-year ban on turbot fishing in 1981. However, the main fishery country of the Black Sea, Turkey, did not support these restrictions. Cases of poaching continued in Ukrainian waters. Catches began to fall again. For this reason, EU countries and Ukraine strengthened the protection of their waters from penetration by Turkish poachers. Since 2002, after strengthening control of Ukrainian, Romanian, and Bulgarian waters, Turkish fishermen were forced to harvest turbot only in their country's zone, and this is when the downward trend in turbot catches in Turkey started (Fig. 3).

Whereas previously Turkish landing data included catches in waters of other countries, the previous low values of landings in Ukraine and Russia were largely because of the discrepancy between real catches and official statistics. The share of IUU catches in northern part of the Black Sea exceeded official data by more than five times for a long time. Only since 2000 has there been an increase in Ukrainian landings associated with an improvement in catch recording along with the development of the fish export business. Currently, the number of unregistered catches in the northwestern part of the Black Sea has diminished, and official data reflect the state of the population much better.

Obviously, the poor state of the turbot population in the southern part of the Black Sea is because of its over-exploitation in the absence of any catch regulations in Turkish waters. The legislation of this country does not provide for the any catch limit or quota allocation among fishers. The bottom trawls used for fishing in countries located in the southern part of the Black Sea also affect the turbot stock negatively. The greatest impact on the turbot population is exerted by the active beam trawl fishing of rapa whelk. Experiments with these fishing gears in Ukraine showed that the by-catch of turbot juveniles was always large and could lead to decreases in the fish population (Hulak et al. 2019). It is known that this method of fishing has been used in Turkey and Bulgaria for over twenty years, and the number of vessels deploying this gear exceeds 500 units. Beam trawls have never been deployed in northern part of the Black Sea, and the use of bait hooks and nets with mesh sizes of 70-170 mm is prohibited in Ukraine to reduce the by-catch of juvenile fish.

It is obvious that differences in the states of turbot stocks across these marine areas is explained by the fact that the most intensive methods are used and fishing regulations are insufficient in the southern part of the sea on the small shelf zone off the coast of Turkey. At the same time, on the much larger northern shelf of the Black Sea, where restrictions on the use of bottom fishing gears are in force, turbot has had the ability to restore its abundance quickly. The current differences observed in the dynamics of catch trends in Turkey and other countries also lead to this conclusion. In Turkey, catches have continued to decline amid recent increases in total catches in the Black Sea (Fig. 3).

Conclusions

Black Sea turbot was subjected to high overfishing, resulting in the collapse of this fishery in the 1980s. The most serious and excessive fishing pressure, in terms of volume, has been observed for many years in the southern part of the sea. Fisheries regulations were insufficient to preserve the turbot stock and protect juveniles in this region. This negatively affected the general state of the turbot stock in the Black Sea. At the same time, a notable increase in turbot abundance has been observed in the northwestern part of the Black Sea over the past several years. This separate population, or subpopulation, is characterized by a different abundance dynamic, which was formed in this marine area because of the low migration activity of these fish and certain geographical conditions such as the presence of a deep-water zone with a significant volume of water saturated with hydrogen sulfide in the central part of the sea.

As mathematical modeling in the SS3 framework showed, turbot is currently mostly moderately exploited at a level close to the SPR management target in the northwestern part of the Black Sea. In spite of the highest landings for the past 30 years, recently CPUEs have been at a stable, high level in the northwestern marine area. Moreover, fishing mortality decreased in 2017 and 2018 and reached its minimum level. The spawning biomass has been increasing since 2016. Average turbot weight and length have also been increasing since 2016. Thus, the status of the turbot population is improving here, and this is positively affecting stock estimates throughout the Black Sea.

The improved state of the turbot population, or subpopulation, in the northwestern part of the Black Sea is ensured by the presence of the largest shallow water shelf where turbot can breed and feed on various small fishes and invertebrates. Measures aimed at protecting juveniles from by-catch are also better implemented here. This supports the large difference between the abundance of this fish in the northern and southern parts of the Black Sea.

However, in general, the entire Black Sea turbot stock has not yet fully recovered. Therefore, fishing mortality should not be increased; all by-catches of small size specimens with beam trawls and IUU catches must be minimized to maintain the viability of this species in the Black Sea.

Author contributions. B.H., Y.L., V.M., G.T., V.S. and M. P. provided and processed fishery data, run SS3 model; V.M. and G.T. provided and processed fishery data, scientific trawl survey data; V.S. and M.P. provided and processed fishery data, run Combi model. All authors have read and agreed to the published version of the manuscript.

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