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Research article

Recovery potential and management options for European hake, *Merluccius merluccius* (Linnaeus, 1758), stocks in Turkish waters

Nazli DEMIREL*, Güzin GÜL, Ahsen YÜKSEK

Istanbul University, Institute of Marine Sciences and Management, Istanbul, Turkey

*Corresponding author e-mail: ndemirel@istanbul.edu.tr

Abstract: Overfishing has been a topic of fierce discussion over the past several decades. However, a lack of information regarding fish stocks makes proper stock assessment through good fisheries management difficult. This study addresses a problematic question for declining European hake, *Merluccius merluccius* (Linnaeus, 1758), stocks in the Turkish Aegean, Mediterranean, and Marmara seas. The present stock status and fisheries reference points were estimated using novel, data-limited assessment methods with recovery potential and management options for European hake stocks under different exploitation scenarios for each sea. Assessment results show that the ratio of the biomass (B) corresponding to the maximum sustainable yield (MSY) (B/B_{MSY}) was under the threshold, and the ratio of fishing mortality (F) corresponding to the MSY (F/F_{MSY}) was over the threshold, indicating that hake stocks were under ongoing overfishing since 2002 in each sea. After that, the biomass values gradually decreased from outside the safe biological limits, under the critical limits of 0.5 B_{MSY}, while fishing mortality continued over the threshold. Reducing the fishing mortality to half of the estimated F_{MSY} could lead to Marmara Sea hake stocks gradually increase in biomass and close to reaching its B_{MSY}. Reducing fishing mortality to its 0.8 F_{MSY} for Aegean Sea stock, and 0.5 F_{MSY} for Mediterranean stock may help rebuild stocks until 2025. However, even the current estimated F_{MSY} (0.95 F_{MSY} is presented as F_{MSY}), cannot assist in rebuilding any European hake stocks in 15 years projection. It is obvious to say that fisheries regulations must be carefully considered and rearranged, especially for depleted stocks such as those of European hake in Turkish waters.

Keywords: Stock assessment, recovery, data-poor stocks, Mediterranean, fisheries management.

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Introduction

Fisheries are of huge economic importance for Mediterranean countries (FAO, 2018). Thus, stock assessment is a key element for the management of natural resources and is closely related to economic efficiency; economic concerns are the main drivers of fishing activity (Lleonart et al., 2003). Mediterranean fisheries are diverse because of the heterogeneity of the sea in terms of its hydrography, bathymetry, and productivity, as well as its changing cultural, social, and economic conditions (Stergiou et al., 2016). According to official statistics (FAO, 2018), over 1 million t of catches of approximately 400 species of fish and invertebrates are being exploited by numerous fishing gear types and methods in the Mediterranean Sea. Recent studies emphasized that most commercially exploited demersal stocks in the area were subject to high fishing mortality, and their biomass were close to depletion (Abella et al., 2010; Froese et al., 2018). Fisheries management needs biological information and stock assessment studies to be able to assess stock status. However, those studies are not an easy task, and most fisheries are not known for their detailed stock analysis (Cope and Punt, 2009). The only information normally recorded is the decline in fish stocks and weak biological information, which consequently prevents effective management. Therefore, approximately 80% of the total fish stocks are defined as "data poor" in the Mediterranean Sea (Le Quesne et al., 2013).

The surplus production model (SPM) is based on a logistic growth function and the prediction of biomass, which is considered to be a function of the previous year. Catch should be the surplus production of biomass, but ignores age and/or size (Wang, 2004). Among all the other stock assessment models, the SPM requires very few data to estimate the MSY. Although the SPM is criticized for its several limitations, it is considered to be a useful tool for data-limited stock assessments (Wang, 2004). In this study, a data-limited stock assessment model, CMSY (Froese et al. 2017) was used, which is based on the SPM, and uses catch data and resilience/productivity knowledge as inputs.

European hake, *Merluccius merluccius* (Linnaeus, 1758), has an important role in the food web with a trophic level of 4.4, it is considered a large predator in the demersal zone (Sinopoli et al., 2012). It is distributed in the northeastern Atlantic, including the Mediterranean Sea (Froese and Pauly, 2020). Several studies were performed from the western and central part of Mediterranean on its biology and ecology (Murua, 2010; Aranciaba, 2015; Martínez-Baños et al., 2018), on spatial distribution patterns, habitat preferences and recruitments (Abella et al., 2010; Caddy, 2015; Khoukh and Maynou, 2018), and for stock assessment and its management (Aldebert and Recasens, 1996; Ratz et al., 2013; Osio et al., 2019; Piroddi et al., 2020). On the other hand, very limited knowledge available of hake stocks in the eastern part of the Mediterranean (Gücü and Bingel, 2011; Tserpes et al., 2016; Demirel et al., 2020). In the Mediterranean, European hake is targeted in shrimp fisheries and multispecies fisheries via bottom trawling, as well as it is an important fish for small scale fisheries (SSF) which uses gillnets and longlines (Bensch et al., 2009). Notably important demersal resources, shrimp and hake share the same habitats in deep waters, and Turkey exports them to many EU countries as frozen or semi-finished products that provide an important economic input (Zengin et al., 2004).

Since there are no previous assessments and reference points with respect to the fishing mortality and biomass levels that ensure MSY, the aim of the present work is to assess the stock state and exploitation of three different European hake stocks in Turkish seas. We used CMSY stock assessment model which is suitable for data-limited stocks (Froese et al., 2017), to estimate fisheries reference points. Our results provide management advice with future scenarios for improving sustainability and management of three different hake stocks in Turkish waters.

Material and Methods

Catch data

The Turkish Statistical Institute (TUIK) collects catch data for commercial fish species from all regions of the Black Sea, Marmara Sea, Aegean Sea, and Mediterranean Sea. Catch data according to region (such as the regular national catch statistics), can be found up until the 1970s, and the TUIK has published them since then. However, until the end of the 1980s, some species were misidentified or combined with other species of the same genus; the catch data for hake was reported to be mixed with whiting until the year 2000 (Tıraşın and Ünlüoğlu, 2012). Thus, only the catch data between 2000 and 2019 was considered. Hake is the main demersal fish family in all Turkish seas except the Black Sea. Even though there are records for its presence only in the western part (Bilecenoğlu et al., 2014), no hake fishery has been mentioned in the Black Sea.

Stock analysis

Stock analysis were performed for three different stocks in Turkish waters (Marmara Sea, Aegean Sea and Mediterranean Sea). In CMSY model, probable ranges for the maximum intrinsic rate of population increase (*r*), and for unexploited population size (or carrying capacity, *k*) are filtered using a Monte Carlo approach to detect "viable" *r*-*k* pairs. Prior estimates of (*r*) are obtained from the life-history traits of hake from FishBase (Table 1) (Froese et al., 2017).

Prior information is used for estimating fisheries reference points in CMSY. If only catches are known, a prior *r* is derived from life-history traits records from FishBase (Froese and Pauly, 2022), and a prior range for *k* is derived from the maximum catch. The Schaefer function for biomass dynamics (SPM) estimated by CMSY (Eq. 1).

$$B_{t+1} = B_t + r\left(1 - \frac{B_t}{k}\right) B_t - C_t, \qquad \text{(Eq. 1)}$$

where *B* is biomass (metric tonnes), *C* is catch (metric tonnes), *r* is the intrinsic rate of population growth, *k* is the carrying capacity, and *t* is time (years).

CMSY estimates the biomass, exploitation rate, MSY, and related fisheries reference points from the catch data and resilience of the species. The parameters estimated by the CMSY method relates to standard fisheries reference points, such as MSY = *rk*/4, the fishing mortality corresponding to the MSY is $F_{MSY} = 0.5r$, the biomass corresponding to MSY is $B_{MSY} = 0.5k$, and the biomass below which recruitment may be compromised is half of the B_{MSY} (Froese et al., 2017).

Future scenarios

To determine the future situation of hake stocks, scenarios with different fishing mortality of F_{MSY} estimated by CMSY were created with the aim of providing a perspective for fisheries management. The model was used to create these scenarios using estimated F_{MSY} values and set F_{MSY}: i) 5%, ii) 20%, iii) 40%, and iv) 50%. Four different, reduced-fishing mortality scenarios were applied to determine the biomass level required to produce the MSY in 15-year projection. The recovery time of the stock to reach B_{MSY} is a function of fishing mortality (F) and is calculated by the formula (Eq. 2) given by Froese et al. (2018):

$$\Delta t = \frac{\log(\frac{2B_{MSY}}{B}-1)}{2(F_{MSY}-F)}. \qquad \text{(Eq. 2)}$$

Results

The main hake fisheries in Turkish waters were based on the Marmara Sea; however, the catch statistics indicated a sharp decline since 2001 and its catch in 2019 was notably lower than Aegean Sea. In the Mediterranean Sea, catch was very low after 2008 (Figure 1a). According to the stock assessment results of the CMSY analysis, hake catch from Turkish waters were well below the estimated MSY values for each sea (Table 2). Estimated relative biomass values showed sharp decrease in each seas until 2008, and since then biomass was found stable (Figure 1b). The ratio of estimated fishing mortality (*F*) to F_{MSY}, was over 1.5 (with a threshold of 1) in most years for all seas, which implies overfishing. Relative biomass estimations have been as low as half of the B_{MSY} since 2008 (Figure 1d). After 2016, fishing mortality was below its F_{MSY} in Mediterranean, however, it should be considered that the stock was severely depleted (Figure 1c), by virtue of the very low catch, and decreasing biomass (Table 2). Reducing fishing mortality to half of the estimated F_{MSY} could lead to hake stocks recover until 2025 in Aegean Sea, but until 2029 in Mediterranean Sea. As a depleted stock in Marmara Sea, reducing fishing mortality cannot help hake stock to rebuild in 15-year projection but only reach half of its sustainable biomass. In 5% reduced- fishing mortality that corresponds current estimated F_{MSY} cannot help to rebuild hake stocks in Turkish water (Figure 2a, b, c).

Discussion

The European hake stocks were found below healthy conditions in northeastern Mediterranean waters (Marmara Sea, Turkish Aegean Sea and Eastern Mediterranean). Catches below the MSY should inherently support the increase of European hake stocks. However, the estimated biomass values were never able to reach the estimated maximum sustainable biomass values that could produce an MSY over 10-year period. The stock status of hake within the estimated current biomass and MSY values can be classified as “Bad” according to healthy stock description that is an indication of “Good Environmental Status” as acknowledged in the European Union’s Marine Strategy Framework Directive (MSFD 2008/56/EC; EU, 2008). Stock assessment results showed that the hake stock were depleted in the Marmara Sea, and were severely declined in the Aegean and Mediterranean seas. Those results are similar to the overexploitation reports in previous studies in the eastern Mediterranean stocks (Gücü and Bingel, 2011; Tserpes et al., 2016; Demirel et al., 2020; Piroddi et al., 2020) and western Mediterranean (Ratz et al., 2013; Osio et al., 2018).

Fall and rise of hake stocks in the Turkish seas

Hake, together with deep-water rose shrimp, constitutes one of the most dominant species of the benthic ecosystem in the Marmara Sea. However, national catch statistics clearly show the serious collapse of hake stocks from 20,000 tonnes at the beginning of the 2000s, to only 79 tonnes in 2017 (TUIK, 2020). Hake was severely reported as a dominant species in the catch composition, according to the results of several survey-at-sea studies during 1990s and 2000s (JICA, 1993; Kocataş et al., 1993; Gözenç et al., 1997; Okuş et al., 1997). However, recent studies were emphasized notable decrease in mid-2010s (Torcu-Koç et al., 2012; Demirel and Gül, 2016). Discard ratio related to size limits namely allowed minimum landing size (MLS) reported around 20% of total hake composition (Bayhan et al., 2006; Yazıcı et al., 2006; Deniz-Bök et al., 2011; Demirel and Gül, 2016). In our results for future scenarios by different fishing mortality level, hake stock in the Marmara Sea cannot reach its sustainable level in 15 years projection. Therefore, it is difficult to predict a timeframe in which to rebuild its severely depleted stock in this projection. Because the sustainability of fish populations from low biomass levels, aside from reducing fishing mortality, is also dependent on their life history traits, food availability and trophic interactions amongst species (Hutchings and Reynolds 2004, Audzijonyte and Kuparinen 2016). Although drastic reductions in fishing mortality would contribute to fish biomass recoveries (Hutchings 2000, Neubauer et al. 2013), the historically high overexploitation levels may result in slower recovery rates than predicted by stock assessment models (Neubauer et al. 2013).

Table 1. CMSY input parameters of *Merluccius merluccius* for prior distribution of r, based on classification of resilience on FishBase records and B/k according to depletion status.

Region	Resilience	Prior ranges for r	Based on FishBase	Relative Biomass Category	Prior ranges for B/k
Marmara Sea Aegean Sea Mediterranean Sea	Medium	0.35 – 0.80	K=0.07-0.3 tmax=20 Fecundity=7 M	Low depletion	0.4 – 0.8

Table 2. CMSY outputs of estimated fisheries reference points and stock status indicators of *Merluccius merluccius* in Turkish waters.

Region	Year	MSY (t)	C_{2017} (t)	C / MSY	F_{MSY}	F_{2019}	F / F_{MSY}	B_{MSY} (t)	B_{2019} (t)	B / B_{MSY}
Marmara S.		8,779	88	0.01	0.05	0.04	0.13	27,000	2,160	0.08
Aegean S.	2019	1,105	1,143	1.03	0.33	0.61	1.87	3,400	1,870	0.55
Mediterranean S.		90	38	0.42	0.16	0.55	1.70	275	68	0.25

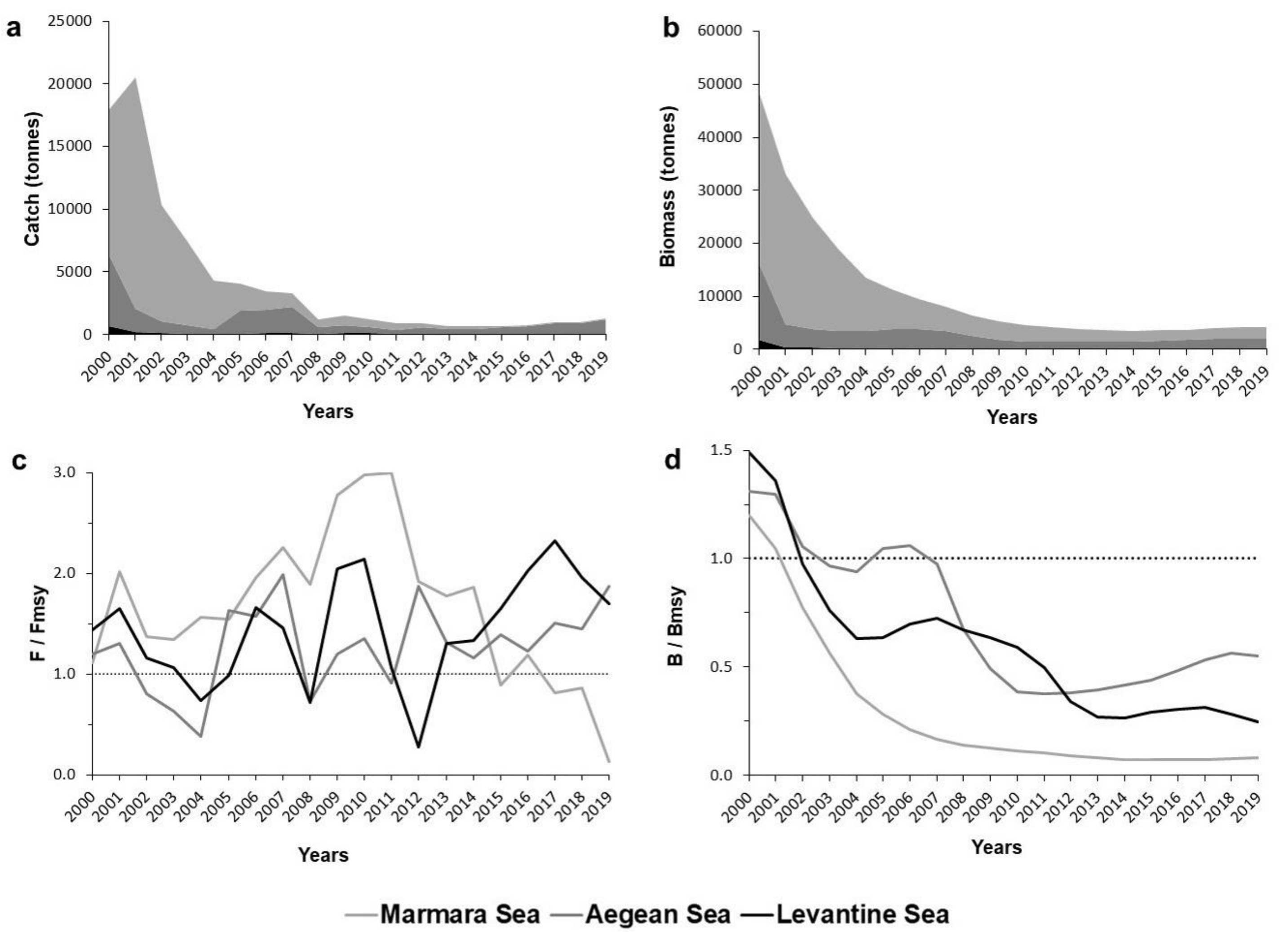

Figure 1. The graph with four different panels showing European hake catch (TUIK, 2022) and stock assessment outputs according to seas between 2000 and 2017; a) National catch statistics, (b) Estimated total biomass, (c) Fishing mortality (*F*) relative to F_{MSY}, (d) Biomass relative to B_{MSY}. Solid black lines present threshold value as 1.

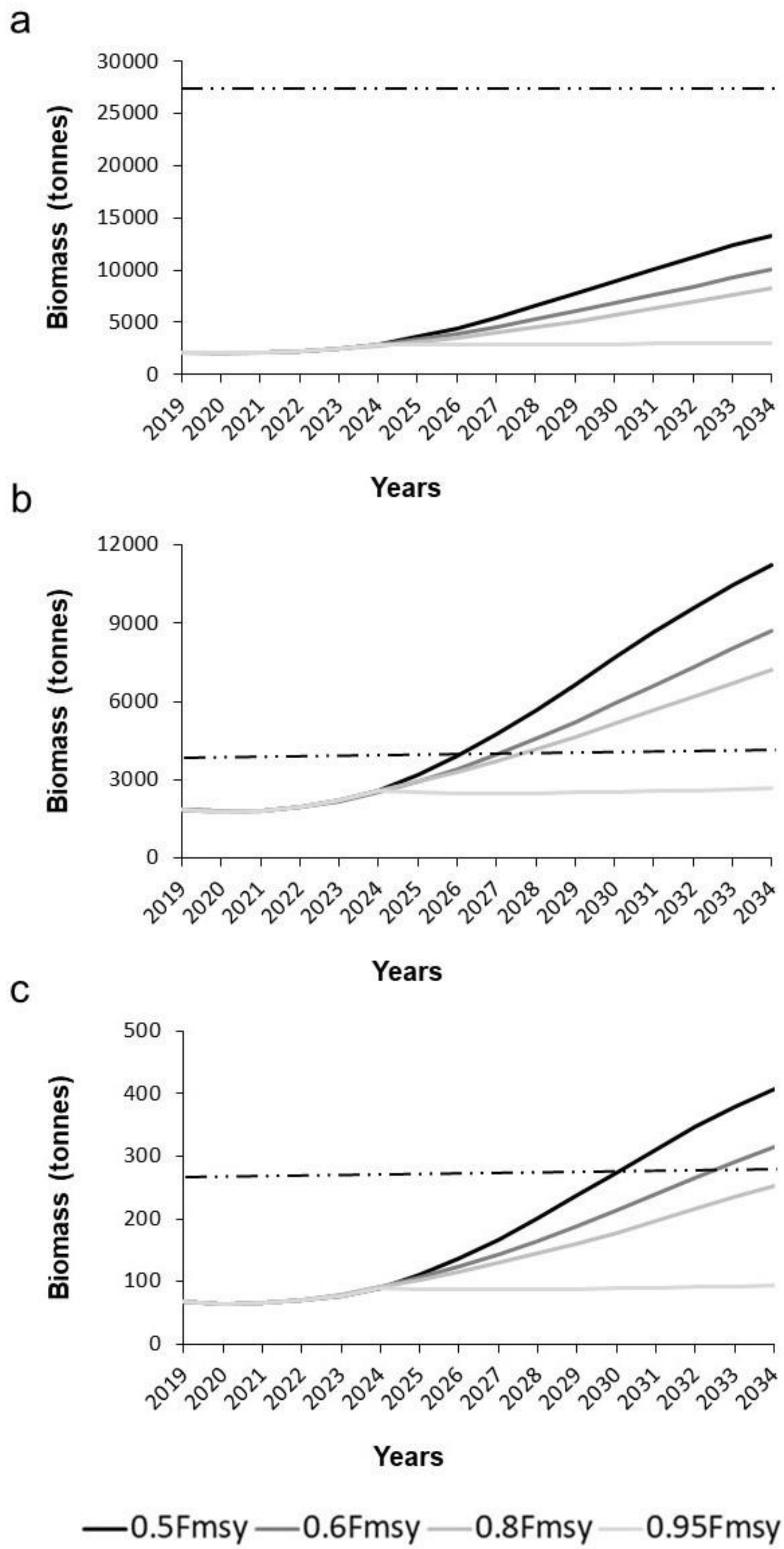

Figure 2. Future projection of biomass changes in depleted hake stock in (a) Marmara Sea, (b) Aegean Sea, and (c) Mediterranean Sea under four different fishing mortality scenarios as 0.5 F_{MSY}, 0.6 F_{MSY}, 0.8 F_{MSY} and 0.95 F_{MSY} values.

In the Aegean Sea, fishing activity is dominated by SSF with various fishing techniques through diverse species and habitats (Tunca et al., 2022). The important demersal fishes are red mullet and hake. Hake was reported to be the most abundant fish species, and contributed to 22% of the total demersal fish landings. Its production increased to the historical maximum of 5,652 tonnes in 2000, and declined to around 500 tons after 2010 (TUIK, 2020). The results of limited fishery survey studies also supported the fact that red mullet, hake, and red water rose shrimp constituted the main portion of catch composition during the 1990s (JICA, 1993; Tıraşın and Ünlüoğlu, 2012); however, gradual decrease were reported during 2010s (İşmen et al., 2015). In addition, the discard ratio was noted high for hake due to catch of small sizes below MLS (Kınacıgil et al., 2008).

The Turkish Mediterranean Sea is the easternmost part of the Mediterranean Sea. Catch composition is greatly influenced by alien species from the Indo-Pacific via the Suez Canal (Gücü and Bingel, 2011). Hake was the dominant demersal species in catches during the 1990s, with 4,000 tonnes of catch in the Mediterranean Sea, followed by a sharp decline in the 2000s (around 500 tonnes). Its catch has been slightly decreasing since the 2010s, and was a reported to be 39 tonnes in 2019 (TUIK, 2020). Gücü and Bingel (2011) reported three reasons for the disappearance of hake in this region: overfishing, competition of alien species (mainly lizardfish), and changes in the hydrographic conditions.

Our estimations for future scenarios show that exploitation levels of 50% and 60% of the maximum may help to rebuild stocks very quickly in Aegean Sea as well as for the Mediterranean Sea stock. This improvement also lead to higher catches than those currently obtained, with substantial profits for the fishers. This is in line with the concept of MEY, which is a reference point on the left of the MSY curve (Narayanakumar, 2017). Controlling multi-species and multi-fleet fisheries in the Mediterranean is always a difficult task for management (Guillen et al. 2013); however, the MSY concept is still a useful tool for data-limited stocks (Ratz et al., 2013) in which only catch is available.

Management options

In the fisheries management, there are direct and indirect control regulations on harvesting fish stocks. Common indirect control regulations are MLS implementation, seasonal and temporal closures, and gear restrictions (Maynou, 2020). In Turkey, as an important indirect control measure seasonal closure in industrial fisheries has been implemented since 1970s and it is the longest one (from 15 April – 1 September) in the entire Mediterranean. This regulation was found effective for summer spawning species such as European hake in the Marmara Sea (Yıldız et al., 2020). Another indirect control measure, MLS implementation is also very effective for protecting juveniles of fish stocks. Until 2016, the MLS for hake was 25 cm TL; however, in 2016, its MLS decreased to 20 mm TL (BSGM, 2016). According to the very few studies performed so far in the Marmara Sea, first maturity is recorded at over 25 cm (Akyüz, 1959; Kahraman et al., 2017), and over 20 cm in the Aegean Sea (Soykan et al., 2015). Therefore, it is important to consider different MLS regulation according to different regions to protect juvenile fish and support recruitment of hake stock in the Marmara Sea.

Catch statistics by small-scale fisheries (SSFs) are missing data, as their catch is landed locally. This is a serious drawback for the monitoring of catches, and the availability of fisheries data. It was recently pointed out that hake catch by SSFs could be much more than recorded in the Marmara Sea (Göktürk et al., 2019). The fisheries statistics are publicly available, but are not detailed enough for SSF contributions; therefore, the fishing effort remains insufficiently known for proper assessments.

Fisheries regulations must be carefully considered and rearranged, especially for depleted stocks. Therefore, it is necessary to monitor fish populations, the status of stocks, and the basic parameters of fish biology in an up-to-date manner. It is crucial that monitoring work is fundamentally addressed in the formulation of fisheries policies for resource efficiency and a sustainable economy.

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Conflicts of Interest

No potential conflict of interest was reported by the authors.

Ethical approval

All applicable national guidelines for the care and use of animals were followed.

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