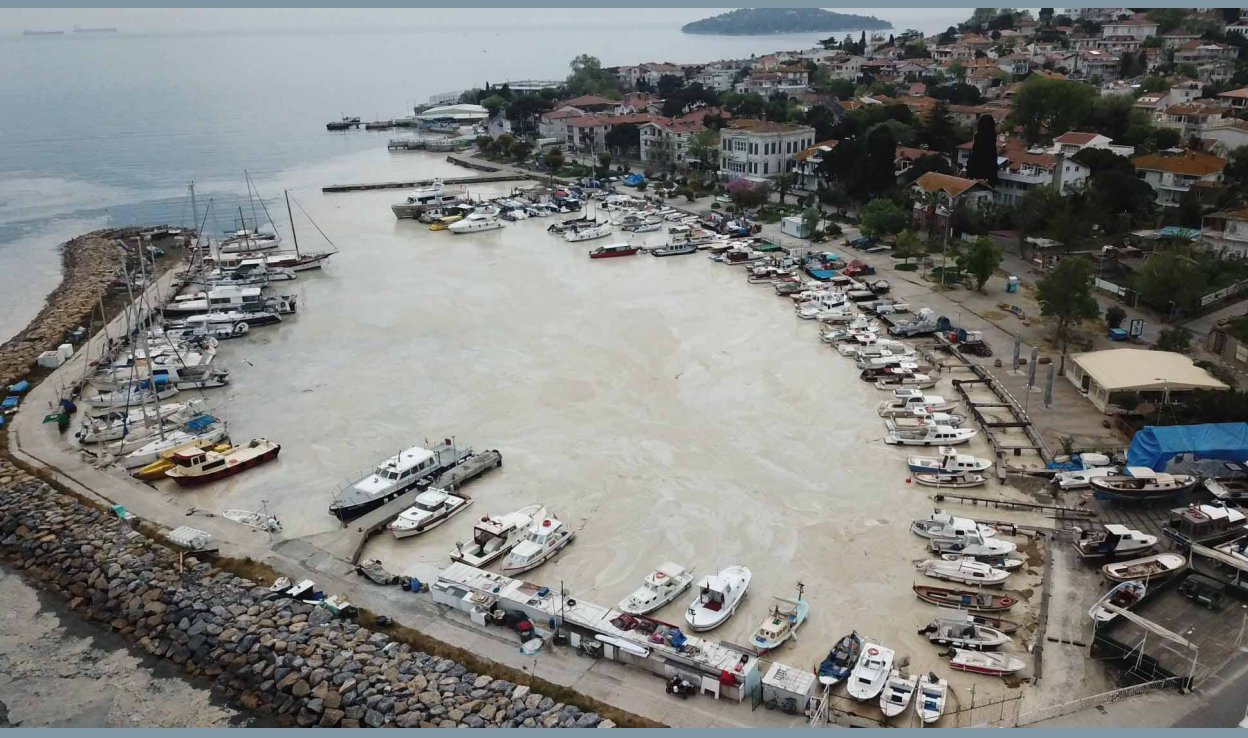
100th ANNIVERSARY OF THE REPUBLIC BOOKS

MUCILAGE PROBLEM
IN THE SEA OF MARMARA

EDITOR

Meriç ALBAY



İSTANBUL UNIVERSITY PRESS

Published by
Istanbul University Press
Istanbul University Central Campus
IUPress Office, 34452 Beyazıt/Fatih
Istanbul - Turkey

https://iupress.istanbul.edu.tr

Book Title: Mucilage Problem in the Sea of Marmara

Editor: Meriç Albay

E-ISBN: 978-605-07-1304-6

DOI: 10.26650/B/LS32.2023.003

Istanbul University Publication No: 5316

Published Online in March, 2023

It is recommended that a reference to the DOI is included when citing this work.

This work is published online under the terms of Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0)
https://creativecommons.org/licenses/by-nc/4.0/

This work is copyrighted. Except for the Creative Commons version published online, the legal exceptions and the terms of the applicable license agreements shall be taken into account.

This book was published as part of the Istanbul University Press' 100th Anniversary of the Republic book project.

CHAPTER 10

STATUS OF THE SEA OF MARMARA ECOSYSTEM AND ITS FISHERY RESOURCES: MUCILAGE EPISODES AND RECOMMENDATIONS FOR SUSTAINABLE FISHERIES

Nazli DEMIREL[1], Taner YILDIZ[2], Aylin ULMAN[3], Mustafa ZENGİN[4], Ekin AKOGLU[5], İsmet SAYGU[6], Pınar ERTOR-AKYAZI[7], Güzin GÜL[1], Dalida BEDİKOĞLU[1], I. Noyan YILMAZ[8]

[1]Istanbul University, Institute of Marine Sciences and Management, Istanbul, Turkiye
E-mail: ndemirel@istanbul.edu.tr
[2]Istanbul University, Faculty of Aquatic Sciences, Istanbul, Turkiye
E-mail: yldztnr@istanbul.edu.tr
[3]Mersea Marine Conservation Consulting
E-mail: uaylin@hotmail.com
[4]Central Fisheries Research Institute, T.C. Ministry of Agriculture and Forestry, Trabzon, Turkiye
E-mail: muze5961@gmail.com
[5]Middle East Technical University, Institute of Marine Sciences, Erdemli, Turkiye
E-mail: eakoglu@metu.edu.tr
[6]Çukurova University, Faculty of Fisheries, Adana, Turkiye
E-mail: isaygu@cu.edu.tr
[7]Boğaziçi University, Institute of Environmental Sciences, Istanbul, Turkiye
E-mail: pinar.ertor@boun.edu.tr
[8]Deakin University, School of Life and Environmental Sciences, Melbourne, Australia
E-mail: noyan.yilmaz@deakin.edu.au

DOI: 10.26650/B/LS32.2023.003.10

ABSTRACT

Various studies have recently been carried out to assess the condition of the Sea of Marmara's ecosystem and fish stocks. In this section, i) The results obtained from these studies are synthesized to reveal the ecosystem change and fisheries status; ii) The relationship between the mucilage event and the fisheries, and the status of the important fish stocks before and after mucilage events are evaluated; and lastly iii) Recommendations are developed for better fisheries management and stock sustainability. The Sea of Marmara has undergone a significant regime transition in terms of ecosystem status and human-induced pressures between 1994 and 2012. In this period, human-induced

pressures increased notably due to overfishing, increasing seawater temperatures due to climate change, and pollution in the marine environment, especially via the main city of Istanbul and the Gulf of Izmit. Furthermore, some commercial fish and invertebrate species which were extirpated in the Sea of Marmara fisheries or decreased by their catches more than 80% were observed during this period. Especially, the majority of large pelagic predator species have disappeared, which is a strong indication of a failing marine ecosystem. The withdrawal of predatory species during this transition period increased the stocks of small pelagic fish and deep-water pink shrimp for benthic species. In addition to the effects of other anthropogenic pressures (e.g., eutrophication via nutrient and organic matter load) mentioned in the formation of mucilage in 2007, fisheries, which alter the relative composition of species in the food web and thus their interactions with each other, by targeting only certain species (selective exploitation), appears to have a significant effect. Subsequently, after the 2007 mucilage formation, the SoM fisheries suffered the most economic damage.

Keywords: Ecosystem Shift, Climate Change, Overfishing, Fisheries Management, Good Environmental Status

1. Introduction

The Sea of Marmara (SoM) is a semi-enclosed sea that comprises the Turkish Straits System along with the Çanakkale and Istanbul Strait and a transition zone between the Black Sea and the Mediterranean Sea. It is a migration route of economically important pelagic fishes of Atlantic-Mediterranean origin from the Mediterranean and the Aegean Sea to the Black Sea (Kocataş et al., 1993) and is defined as an ecological corridor (Oral and Öztürk, 2006). Although it has a much smaller catchment area than other Turkish seas, its contribution to Turkish fisheries is considerable which varies between 10-15%. Considering the pressures brought on by humans, the SoM is impacted by several general pressure types specified on the marine ecosystem in various ways and at various levels, particularly in the Gulf of Izmit region in the east and the 15 million-person Istanbul metropolitan area in the northeast. Generally, those human-induced pressures can be defined as biological degradation, pollution of hazardous substances, nutrient and organic matter enrichment, solid waste pollution, and physical habitat loss (TDÇSO, 2021). The SoM is important in understanding the human-induced pressures on other marine ecosystems, as it is a natural laboratory where the effects of anthropogenic pressures on marine ecosystems can be evaluated separately and cumulatively.

Since the previous 30 years, there have been significant decreases and oscillations in fish stocks due to the absence of management, regulation, and control mechanisms in marine fisheries, which cannot keep up with the rate of technological advancements (Ulman et al., 2013; 2020). This process, which started with uncontrolled fishing, combined with other human-induced effects, namely climate change and pollution, causes the resilience of marine ecosystems to weaken, their health to deteriorate and their changes irreversible (Demirel et al., 2023). The resilience and health of an ecosystem are related to the balanced relationships of its components with each other and their environment, namely the food web and habitat structure. Any changes resulting from human activity harm social, economic, and governmental issues because they interfere with ecosystem services, specifically the advantages that people get from the sea (Demirel et al., 2023). The mucilage event, which was first observed in the SoM in 2007, aside from the visual pollution, directly affected the upper pelagic system and caused serious economic damage to the SoM fisheries (Yıldız and Gönüal, 2021). Unfortunately, at the beginning of 2021, the intense mucilage event was observed once again but more intensely and existing in almost every part of the SoM, leading to the blocking of all ecosystem services in addition to negative impacts on fisheries. Although there is still no definite answer for the cause of the mucilage formation, its intense aggregation certainly directly affects both pelagic and benthic ecosystems (Pusceddu et al., 2009).

Evaluating the impacts of mucilage events on fish stocks is not an easy task. Many countries lack detailed long-term data sets for fish stocks which are needed for the evaluation of proper stock assessment practice, and SoM stocks are defined in the "data poor stocks" category (FAO, 2020). However, the information that has been gathered thus far is still highly valuable and serves as the foundation for the development of new stock models and the evaluation of ecosystem health. SoM ecosystem and its fish stocks have recently been the subject of significant research that reveal their condition. In this section, i) The results obtained from these studies are synthesized to reveal the ecosystem change and fisheries status; ii) The relationship between the mucilage event and the fisheries, and the status of the important fish stocks before and after mucilage events are evaluated; and lastly iii) Recommendations are developed for better fisheries management and stock sustainability. The details of the studies used herein which their results are compiled can be accessed here:

1) Demirel et al. (2020) provided the first stock assessment study of the 17 commercial fish stock of the SoM between the years 1967-2020 through the model implementation of the catch-based data-limited CMSY algorithm (Froese et al., 2017).

2) Ulman et al. (2020) examined commercial species which were disappeared and which became commercially extinct by decrease in catch more than 80% in the SoM official catch statistics from 1967 to 2016.

3) Demirel et al. (2023) identified the marine regime shifts and their drivers including anthropogenic impacts through overfishing and eutrophication, as well as climate change on the SoM pelagic ecosystem between the years 1986 and 2020.

4) Demirel et al. (2022a) analyzed the inter- and intra- annual landing dynamics of pelagic species concerning potential impact of climate change between 2000 and 2020.

5) Saygu et al. (2023) established the first ecosystem model combining fisheries and food-web interactions among pelagic and demersal species in the SoM between 1990 and 2020.

6) Yıldız et al. (2020) evaluated the effectiveness of the fishing ban, which took place between April 15 and September 1 in the SoM, under changing environmental conditions over the years, and developed suggestions for better management practices.

The SoM fisheries are characterized by their diversity in terms of target species, fishing gear, and therefore fishing vessel characteristics. Fishing boats use the Turkish Straits System as a natural trap (Oral and Öztürk, 2006). Despite having a relatively small catchment area in

contrast to other Turkish seas, the SoM supports a variety of ecosystem features and benefits as a migration corridor, which enables about 3500 fishing boats to operate there annually. This fleet includes 2500 small-scale (≤12 m) and 110 semi-industrial boats (purse seine) distributed amongst 60 cooperatives along the coastline and some of its islands. Additionally, there are an unknown number of sports fishing boats.

In terms of targeted species, the fishing fleet is highly opportunistic in structure, where more than one species is targeted (multi-species) and more than one fishing gear is used (multi-gear). Since the national fisheries management authority does not precisely define the sector by each group of fishing operations (métier) for the entire fleet, it is not able to identify in each group's catch contribution. It also has an open-access policy with no catch caps. This creates a barrier to defining the fishing effort of each species following fishing gear, which is a crucial component to understanding stock dynamics and improving stock management. For this reason, tuna fishing managed by an international committee (ICCAT) and its quota regime application, which is not practiced in the Black Sea (GFCM) except for turbot fishing, is among the management applications dependent on the production of such information. Also, the SoM is a region where illegal, illegal, and unregistered fishing (IUU) is understood to be very common (Zengin et al., 2004).

2. Status of fish stocks and ecosystem of the Sea of Marmara

According to the annual catch statistics provided by Turkish Statistical Institute (TURKSTAT), likewise Black Sea, SoM fisheries are dominated by pelagic species (Figure 1a). Small pelagic fish, especially anchovy, horse mackerel, and sardine catch constitute 80% of the total catch in the SoM (TURKSTAT, 2022; Figure 1b). Within the past ten years, there have been significant declines in both the pelagic and demersal fisheries, particularly in the medium-sized predatory pelagic fish stocks like bluefish and bonito as well as the predatory demersal species hake (Figure 1c,d). On the other hand, small pelagic fisheries have had relatively stable catches, especially mainly for anchovy (Figure 1c).

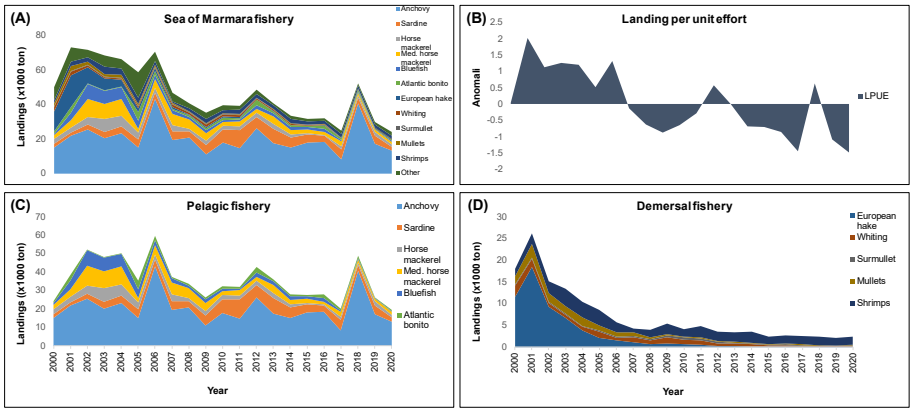


Figure 1: SoM fishery between the years 2000-2020. A) 11 commercial species constituting 90% of the SoM total catch, B) Anomaly of landings per unit effort (LPUE), C) Pelagic fisheries, D) Demersal fisheries.

According to the EU's Marine Strategy Framework Directive, Good Environmental Status (GES) related to healthy fish stocks is based on two important criteria (EU MSFD, 2008): i) Available biomass (B) and the biomass that can produce maximum sustainable yield (Bmsy) should be equal (B/Bmsy = 1), and; ii) The current fishing mortality rate (F) and the fishing mortality rate that can provide MSY (Fmsy) should be equal (F/Fmsy = 1).

The stock assessment model developed for data-limited stocks (CMSY, Froese et al. 2017; Demirel et al., 2020; 2021) was used to analyze the stock status of 11 species constituting 90% of the catch in the SoM (Figure 2). Three species were small pelagic fish: anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*), and Mediterranean horse mackerel (*Trachurus mediterraneus*); three species were medium pelagic fish: horse mackerel (*Trachurus trachurus*), Atlantic bonito (*Sarda sarda*) and bluefish (*Pomatomus saltatrix*); four taxa are demersal fish: hake (*Merluccius merluccius*), whiting (*Merlangius merlangus*), surmullet (*Mullus surmuletus*) and mullet (Mugilidae spp.), and one benthic invertebrate, deep water rose shrimp (*Parapenaeus longirostris*). The stock model covered the years 1967-2020, and the results from 2000-2020 are presented here.

Fishing pressure (F) was substantially higher than necessary for almost all populations to produce MSY, with biomass values for most stocks being critically low, as seen by the decreased catch yield (Figure 2a). Only the sardine stock situation was moderate (Figure 2b). The biomass level of deep water rose shrimp was good, but fishing pressure is still very high and is in a state of ongoing overfishing (F > Fmsy). Eight stocks were found to be subject to ongoing overfishing with very high levels of fishing pressure, especially on

bonito, anchovy, and Mediterranean horse mackerel (Fig. 2c,d). Estimated biomass (B) values show that demersal fish have decreased by one-fifth, while the predatory pelagic fishes have decreased by half (Figure 2a,c) in two decades. Fishing mortality (F) is found to be much too high for both demersal and medium pelagic fish (Figure d). Small pelagic fishes are in a slightly different scenario; although their biomasses slightly declined, this absence of a significant reduction was assessed as a result of the reduced biomass of demersal and pelagic stocks owing to overfishing, which are the primary predators of small pelagic fishes. On the other hand, the fishing pressure increased gradually as the fisheries completely restructured themselves in the late 2000s to target the remaining small pelagic fishes (Figure 2c,d).

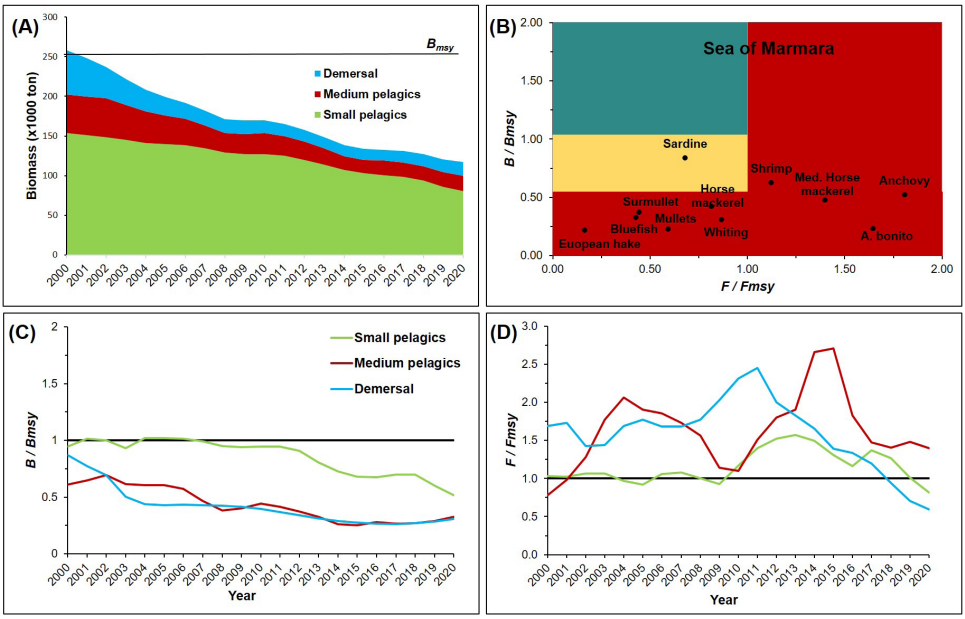


Figure 2: 2000-2020 stock indicators of Sea of Marmara fish stocks (Demirel et al., 2020): (A) Variation of biomass values by functional groups between 2000 and 2020; (B) Stock status of 11 species in 2020 according to CMSY analysis. Color classification is based on EU - Good Environmental Condition criteria. The red area is "very bad", the yellow area is "moderate", and the green area is a "good" status indicator; (C) The change in the ratio of biomass (B) values to sustainable biomass (Bmsy) values by functional groups between 2000 and 2020; and (D) Variation of fisheries mortality (F) by functional groups concerning sustainable fisheries mortality (Fmsu) between 2000 and 2020.

The commercial fisheries of the SoM comprise an average of 66 fish and 28 invertebrate species. Ulman et al. (2020) examined the catch of fish and invertebrate species for 50 years using official catch statistics between 1967 and 2016. According to their results, 19 species were extirpated in the SoM, and 22 species were commercially extinct by decreased catch

of 80-99.9% (Ulman et al., 2020). This noteworthy and original study is the first to examine how fisheries are impacted by biodiversity loss in Turkish seas.

The pelagic ecosystem of the SoM has undergone significant changes and transformations in the last 35 years. Demirel et al. (2023) contributed the first comprehensive assessment of the changes that occurred in the pelagic ecosystem of the SoM between the years 1986 and 2020. The changes in the ecosystem status and the relationship with the human-induced environmental factors that trigger these changes were found that there were significant shifts in all biotic and abiotic datasets of the SoM pelagic ecosystem (Demirel et al., 2023). The SoM ecosystem, according to the study, was divided into three periods: the early regime, which represented the initial state between 1986 and the mid-1990s; the transitional regime, which occurred between the mid-1990s and the mid-2010s; and the late regime, which represented the state in which an alternative ecosystem emerged from the mid-2010s to the end of the period to 2020. The period from the mid-2010s to 2020 was the alternative late regime period in which most of the biotic variables, especially fish biomass, did not return to their initial state, contrary to the trends observed in abiotic variables. The study defined the observed changes in the SoM ecosystem as a discontinuous regime shift.

Changes in seawater temperature due to climate change and prey-predator interactions among species affect their fisheries. Demirel et al. (2022a) examined intra- and inter-annual landing dynamics of pelagic fisheries in the SoM. According to the study landing dynamics of small and medium pelagic fish showed high seasonality and annual variation in the SoM. The anchovy, sardine, and horse mackerel fishing seasons have decreased and moved by an average of one month over the past 20 years. The concentration of fishing pressure on small pelagic fishes and the effects of climate change on their life cycles are both demonstrated clearly by this seasonal shift. In addition, Akoğlu (2021) revealed that the catch amounts of all small pelagic fish, except sardines, showed decreasing trends between 2000 and 2019, and these decreasing trends, in addition to fishing pressure, were also related to biotic and abiotic factors such as primary production and sea surface temperature. Overall, such changes caused a decrease in landings but increased the effort spent by the fishing fleet continuously.

Saygu et al. (2023) established the first food-web model for the SoM that showed the interactions between functional groups, energy flows between the benthic and pelagic systems, and the changes in the ecosystem structure and function from 1990 to 2020. According to reports, the comparison of the three different SoM trophodynamic models revealed that over three decades, the ecosystem's energetic capacity significantly decreased, and the declining cycling indices indicated that the SoM ecosystem was continuously becoming

more vulnerable to anthropogenic disturbances. The ecosystem theory indices indicated that the SoM is an immature ecosystem at a stage of autotrophic succession, with a very high total primary production, much more above unity that greatly exceeds total respiration. Study results highlighted that the SoM ecosystem was under bottom-up control exerted by mesozooplankton; however, anchovy was a bottleneck in energy transfers to higher trophic levels creating a wasp-waist control in the trophic network. While the diet matrix of SoM food web was established, recent studies on the trophic ecology on some mesopredator fish species which were identified solely for the SoM were used (Gül et al., 2021; 2022).

3. Fisheries and mucilage events

In this section, a synthesis is provided based on the research summarized above on the relationship between fish stocks and mucilage formation in the SoM. First, by analyzing the fishing data, a decrease in the catch efficiency of the SoM following the first mucilage event in 2007 is noticed. The number of fishing boats remained the same, but the dramatic decline in catch per unit effort starting in 2007 indicates a substantial trend through 2020. According to stock assessment findings (Demirel et al., 2020, 2021), all stocks in the SoM, except for sardine, are currently being overfished as of 2020. Hake and bonito stocks are at critical biomass levels and on the verge of collapse, and surmullet, whiting, and bluefish stocks are also in danger. According to the results of the ecosystem model established for the SoM, small pelagic fish such as anchovy, horse mackerel, and sardine constitute the main prey species of the medium predatory fish such as hake, bluefish, bonito, and whiting (Saygu et al., 2023). The decrease in the stocks of these medium predatory fish from overfishing has led to a decrease in predation pressure on small pelagic fish and an increase in their fishing pressure. Additionally, Demirel et al. (2022a) reported that the surface water temperature of the SoM increased by 0.05 °C annually from 2000 to 2020 because of climate change for the entire basin, and this situation has reduced the fishing seasons, especially for the small pelagic fish by one month. According to the results of the study examining the regime shifts in the SoM (Demirel et al., 2023), the increase observed in the small pelagic fish stocks, namely anchovy, horse mackerel, and sardine from the mid-1990s to the end of the 2000s, followed by a relatively stable catch yield without sharp catch declines was due to reduced predation pressure on them. On the other hand, the excessive fishing pressure on anchovy and horse mackerel stocks will cause these stocks, which are currently decreasing (Figure 2), to collapse in coming years (Demirel et al., 2020). Between the mid-1990s and mid-2010s, the SoM has undergone a significant regime transition in terms of ecosystem status and human-induced pressures (Demirel et al., 2023). Due to overfishing, rising sea temperatures brought on by climate

change, and pollution in the maritime environment, particularly through the main metropolis of Istanbul and the Gulf of Izmit, human-induced pressures increased significantly during this era. Additionally, the commercial fish and invertebrate species extirpated in the SoM fisheries and those that are considered commercially extinct with catches decreasing by over 80% have also further suffered in this period. Most large pelagic predator species became extirpated, which serves as a prime indication of deteriorating marine ecosystem health (Ulman et al., 2020). The withdrawal of predatory species during this transition period increased the stocks of small pelagic fish and deep-water pink shrimp for benthic species (Demirel et al., 2020; 2023). In addition to the effects of other anthropogenic pressures (e.g., pollution, nutrient and organic matter load, etc.) mentioned in the formation of mucilage in 2007, fisheries, which alter the relative composition of species in the food web and thus their interactions with each other, by targeting only certain species (selective exploitation), appears to have a significant effect (Demirel et al., 2023, Saygu et al., 2023). Subsequently, after the 2007 mucilage formation, the SoM fisheries suffered the most economic damage. The pressure on zooplankton caused by the excessive increase of *Liriope tetraphylla*, a small hydrozoa species in the SoM between 2006 and 2008 (Yılmaz, 2015), may have triggered the intense mucilage formation that was prevalent over the entire basin. Due to the SoM ecosystem's susceptibility and incapacity to deal with the cumulative stressors and changes during this period, which effectively reduced its ability to recover, this situation should be understood. Although it is not known exactly what dynamics *L. tetraphylla* can cause from their excessive increase, anchovy fishing pressure two times more than normal (40 thousand tons) in 2006 led to an increase in food availability in the marine ecosystem, especially for zooplankton abundance (Cladocera group, Bedikoğlu et al., 2022) and jellyfish which may have caused the species to have an advantage. The sharp decrease observed in zooplankton abundance just before the mucilage formation and after the excessive increase of *L. tetraphylla* (Yılmaz, 2015; Bedikoğlu et al., 2022) led to a decrease in predation pressure on the phytoplankton group and excessive increases in phytoplankton (Taş et al., 2022). On the other hand, because their research has a limited time series and is locally centered, there are very few basin-wide studies on the status of jellyfish species in the SoM. It is known that the species from the jellyfish group, *Aurelia aurita* and *Pleurobranchia pileus* that feeds on zooplankton are the dominant species of the SoM (Bedikoğlu et al., 2019). However, the lack of studies on biomass and zooplankton consumption of these species creates a deficiency in the ability to conduct a thorough SoM ecosystem assessment. Since mucilage formation is known to be the extracellular fluid in polysaccharide structure produced by some phytoplankton species (Tüfekçi et al., 2010), it is understood that disruption of the balance between lower food web levels triggered the

mucilage formation. It should be emphasized that the excess of phytoplankton species is largely caused by the rise in nitrogen and phosphate loads from anthropogenic sources, as well as climate change. However, in the marine ecosystem, the deterioration of the intricate food web balance and the declining the resilience of SoM ecosystem led to the formation of the mucilage process.

Beginning in February-March 2021, fishers in the northern regions of the SoM started to report that they could not cast nets due to the intense "sea snot" formation. It is not yet understood to what extent the intense mucilage event observed in almost every part of the SoM beginning in early 2021 affected the stock statuses of both pelagic and demersal fish. Because the 2021 fisheries data, which are issued in August of each year, had not yet been published when this section was written, it was not possible to create a stock assessment that included those data. However, from the 2007 mucilage event, the economic damage to all aspects of the SoM fisheries was calculated to result in 95.7% losses (Zengin et al., 2017). Ultimately, many of the fishers who suffered losses were unable to pay their bank loans and had to sell some of their real estate (Zengin et al., 2017). To estimate the losses on the fishing economy, the level of losses that occurred in the SoM in 2007 was adjusted to 2021, and a decrease in per capita fishing income was calculated to be 27,459 Euros on average, with fishing income reduced by 61% (Keleş et al., 2020). The biggest economic impact of both mucilage events was on the pelagic fisheries of the SoM.

Consequently, the formation of mucilage has a significant impact on the SoM's fishery, and the SoM's overall ecosystem state has weakened a result, which has contributed to the formation of mucilage. These two factors are related because the SoM's fishery is not well managed following stock assessment results and is not regulated following the changing conditions because of the climate and human-induced pressures on this sea. In the Mediterranean basin, which is more heavily affected by climate change than the global seas and human-induced pressures, intensive efforts are made to develop "adaptive" fisheries management measures, and similar efforts are required for the SoM fishery.

4. Recommendations for better fisheries management

Fisheries management is the state of managing fisheries sustainably in a way that ensures long-term and optimal resource use. To effectively manage fish stocks, various control measures exist that directly or indirectly limit catches. An application of catch quotas, which restricts the amount of fish that can be caught, is the main direct control measure. On the other hand, indirect restrictions mainly involve measures that will lower the catch of young fish

and the number of species discarded, via different fishing restrictions (i.e. minimum landing sizes, temporary/seasonal closures). As catch quotas are not implemented (aside from Atlantic bluefin tuna and turbot), the main applications of these indirect controls in the SoM are as follows: i) Restriction of fishing vessels, trawling is prohibited in the TSS; ii) Minimum landing size (MLS) – catch below the legal length is prohibited for many commercial species, iii) Species-specific fishing bans, some endangered species mostly sharks are subjected to this ban in the SoM, iv) Temporary/seasonal closures, the SoM is closed to industrial fishing between April 15 and September 1, and this prohibition period is the longest closure period in the Mediterranean Sea (Yıldız and Ulman, 2020; Yıldız et al., 2020).

Numerous aspects of SoM fisheries are under decline, including capture rates, net fishery income, the number of target species, and average fish size. Fisheries both affect and are affected by ecological conditions. Concrete suggestions are developed for fisheries management, considering its effects on ecosystem functioning:

Fishing pressure on all stocks of the Sea of Marmara needs to be reduced. According to the future fisheries scenarios, a 60% reduction in fishing pressure shows that the fish stocks in the SoM may ultimately increase from the current "poor" stock status to "medium" stock status within 10 years (Figure 3; Demirel et al., 2020; Demirel et al., 2022b).

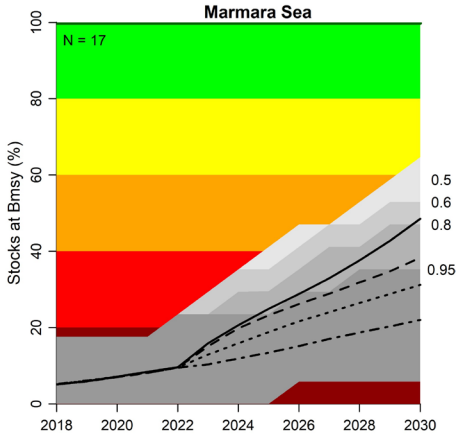


Figure 3: Estimated cumulative biomass change under four different fishing mortality scenarios ranging from 0.5 to 0.95 Fmsy in the Sea of Marmara (Demirel et al., 2020).

An individual non-shared and non-transferable quota or Total Allowed Catch (TAC) system should be introduced to fishing vessels for the main species of the SoM. The quota or TAC system aims to establish a sustainable fishing regime. For an effective quota/TAC system, both the stocks should be constantly monitored and the catch amount should be

regulated according to species each year. The involvement of stakeholders, particularly scientists and small-scale and industrial fishers, should be promoted in the design of the system because there may be various challenges in the implementation of the quota or TAC system. It should not be forgotten that participatory processes increase the legitimacy of the policies implemented and have a high potential to lead to fairer processes and results, and are therefore more embraced by the stakeholders who use the resources.

The fishing effort of large-scale industrial fisheries should be limited. Fishing effort is a measure of a fleet's capacity to catch a certain proportion of its fish stock each year. The fishing effort should be controlled to lessen the strain on stocks because it is typically expected that if fishing effort increases, the number of fish that are caught would also increase. One method to accomplish this is by limiting the days those boats can fish. These restrictions should be applied to all fishers (or at least 90%) registered in the fleet, otherwise, this practice will not be effective, because any gap left in the partial controls may leave room for the expansion of the uncontrolled portion of the fishery which should be avoided.

Minimum landing size (MLS) controls and sanctions should be continually enforced at the landing sites. Yildiz and Ulman. (2020), revealed that the MLS regulation applied in fisheries management did not show the expected effect. MLS regulations should be regulated in the direction of selectivity of fishing gear and fishing areas for both control and deter catching of fish under the legal size (Yıldız and Ulman., 2020).

A biological monitoring system should be established for fishery resources. Most commercial fish species in the SoM are protected during their breeding season, which corresponded with the temporary ban on industrial fishing, especially small and medium pelagic fish and some demersal fish (15 April-1 September). According to the study conducted by Yıldız et al. (2020), species with winter spawning seasons such as sardine, whiting, Joh dory, brown meagre, big-scale sand smelt, and bogue do not benefit from the summer ban (>50% of catch totals) of commercial fishing. In addition, heavy fishing of some species (more than 35% of their total catches) during the closure period indicates that they are targeted by small-scale fisheries. Yıldız et al. (2020) proposed the establishment of a Real-Time Monitoring system to protect the spawning stocks. It is stated that this proposed system can be combined using live video feedback, onboard observers, and Vessel Monitoring System (VMS).

One of the most important effects of climate change is the increasing seawater temperature which also affects the SoM. According to Demirel et al. (2022b), the fishing seasons of

anchovy, horse mackerel, and sardine shifted to one month earlier. The shift in fishing season may have an impact on the recruitment process by catching juveniles frequently because temperature change will alter all biological activities of marine species, including reproduction, migration, feeding, and distribution characteristics. Thus, adjusting the fishing season ahead by one month from September 1 to October 1 will provide more protection and is a necessary regulation (Demirel et al., 2022a).

Although recreational fishing is common in the SoM, its dynamics are not well known. Eryaşar and Saygu (2022) emphasized in their citizen science-based study that the effect of recreational fishing on stocks needs to be monitored and the necessity of considering it in stock management studies. They demonstrated the efficiency of an innovative method that can be used to monitor this fishery and generate regular data by scanning certain social media networks using certain keywords and evaluating this as a data source. A notable example showed that bluefish smaller than 25 cm were caught in the SoM during the spring and autumn months, which are migration periods for bluefish (Eryaşar and Saygu, 2022). With the assistance of machine learning and its various components, this kind of innovative work has the potential to advance significantly. To include this underutilized sector in stock management studies, citizen science research should be considered along with traditional sampling methods and satellite-based environmental parameters.

Finally, scientific studies should be further supported for bringing ecosystem approach to fisheries management via characterizing the ecological roles and functions of species, better understanding their reactions to shifting anthropogenic pressures and climate change, and establishing a holistic approach to the SoM ecosystem.

References

Akoğlu, E. (2021). Exploring the dynamics of small pelagic fish catches in the Marmara Sea in relation to changing environmental and bio-optical parameters. Turkish Journal of Zoology, 45(3), 257-265.

Bedikoğlu, D., Yılmaz, İ.N., Demirel, N. (2022). Reproductive strategies and population characteristics of key Cladocera species in the Sea of Marmara. Regional Studies in Marine Science, 54: 102450. https://doi.org/10.1016/j.rsma.2022.102450

Bedikoğlu, D., Yılmaz, İ.N., Demirel, N. (2019). Seasonal zooplankton distribution of the year 2019 in the Sea of Marmara. 2nd National Marine Monitoring and Evaluation Symposium, 11 – 13 December 2019, Ankara, Türkiye.

Demirel, N., Zengin, M., Ulman, A. (2020). First large-scale Eastern Mediterranean and Black Sea stock assessment reveals a dramatic decline. Frontiers in Marine Sciences, 7: 103. https://doi.org/10.3389/fmars.2020.00103

Demirel, N., Akoglu, E., Ulman, A., Ertör-Akyazı, P., Gül, G., Bedikoğlu, D., Yıldız, T., Yılmaz, İ.N. (2023). Uncovering ecological regime shifts in the Sea of Marmara and reconsidering management strategies. Marine Environmental Research, 183: 105794. https://doi.org/10.1016/j.marenvres.2022.105794.

Demirel, N., Akoglu, E., Yıldız, T. (2022a). Inter- and intra-annual landing dynamics of small and medium pelagic fish potentially affected by climate change in Turkish fisheries. (under review)

Demirel, N., Gül, G., Yüksek, A. (2022b). Recovery potential and management options for European hake, *Merluccius merluccius* (Linnaeus, 1758), stocks in Turkish waters. Acta Biologica Turcica, 35(2), A3: 1-9.

Eryaşar, A. R., Saygu. İ. (2022). Using social media to identify recreational bluefish angling in the Mediterranean and Black Sea. Mariner Policy, 135: 104834. https://doi.org/10.1016/j.marpol.2021.104834

FAO (2020). The State of Mediterranean and Black Sea Fisheries. General Fisheries Commission for the Mediterranean. Rome. 172 pp.

Froese, R., Demirel, N., Coro, G., Kleisner K., Winker, H. (2017). Estimating fisheries reference points from catch and resilience. Fish and Fisheries, 18: 506-526.

Gül, G., Demirel, N. (2021 Evaluation of the comprehensive feeding strategy and trophic role of overexploited mesopredator species in the Sea of Marmara (Northeastern Mediterranean). Estuarine Coastal and Shelf Science, 259: 107448. https://doi.org/10.1016/j.ecss.2021.107448

Gül, G., Demirel, N. (2022). Ontogenetic shift in diet and trophic role of *Raja clavata* inferred by stable isotopes and stomach content analysis in the Sea of Marmara. Journal of Fish Biology, 101: 560-572. https://doi.org/10.1111/jfb.15123

Keleş, G., Yılmaz, S., Zengin, M. (2020). Possible economic effects of mucilage on Sea of Marmara fisheries. International Journal of Agriculture Forestry and Life Sciences, 4(2): 173-177.

Kocataş, A., Koray, T., Kaya, M., Kara, Ö. (1993). Studies and Reviews, No. 64. Fisheries and environment studies in the Black Sea system. Rome, Italy: FAO.

Oral, N., Öztürk, B. (eds.) (2006) The Turkish Straits, Maritime Safety, Legal and Environmental Aspects, Turkish Marine Research Foundation, Publication no: 25, İstanbul, Turkey.

Pusceddu, A., Dell'Anno, A., Fabiano, M., Danovaro, R. (2009). Quantity and bioavailability of sediment organic matter as signatures of benthic trophic status. Marine Ecology Progress Series, 375: 41-52.

Saygu, İ., Akoglu, E., Gül, G., Bedikoğlu, D., Demirel, N. (2023). Fisheries impact on the Sea of Marmara ecosystem structure and functioning during the last three decades. Frontiers in Marine Science, 9: 1076399. https://doi.org/10.3389/fmars.2022.1076399

Tas, S., Kus, D., Yilmaz, I. N. (2020). Temporal variations in phytoplankton composition in the northeastern Sea of Marmara: potentially toxic species and mucilage event. Mediterranean Marine Science, 21(3), 668-683.

Tüfekçi, V., Balkis, N., Beken, C. P., Ediger, D., Mantikci, M. (2010). Phytoplankton composition and environmental conditions of the mucilage event in the Sea of Marmara. Turkish Journal of Biology, 34(2), 199-210.

TURKSTAT (2022). Fishery Statistics. www.tuik.gov.tr (Retrieved on June 2022)

Ulman, A., Bekisoglu, S., Zengin, M., Knudsen, S., Unal, V., Matthews, C., Zeller, D., Pauly, D. (2013). From bonito to anchovy, a reconstruction of Turkey's marine fish catches (1950-2010). Mediterranean Marine Science 14(2): 309-342.

Ulman, A., Zengin, M., Demirel, N., Pauly, D. (2020). The lost fish of Turkey: A recent history of disappeared species and commercial fishery extinctions for the Turkish Marmara and Black Seas. Frontiers in Marine Science, 7: 650. https://doi.org/10.3389/fmars.2020.00650

Yıldız, T., Gönülal, O. (2022) Sea snot and its impacts on the fisheries in the Sea of Marmara and its adjacent waters. Journal of the Black Sea/Mediterranean Environment 27 (2): 167-183.

Yıldız, T., Ulman, A. (2020). Analyzing gaps in policy: Evaluation of the effectiveness of minimum landing sizes (MLS) regulations in Turkey. Marine Policy, 115: 103829. https://doi.org/10.1016/j.marpol.2020.103829

Yıldız, T., Ulman, A., Demirel, N. (2020). A comparison of market landings during fish spawning seasons to better understand the effectiveness of the temporal fishery closure in Turkey. Ocean & Coastal Management, 198: 105353. https://doi.org/10.1016/j.ocecoaman.2020.105353

Yilmaz, I. N. (2015). Collapse of zooplankton stocks during *Liriope tetraphylla* (Hydromedusa) blooms and dense mucilaginous aggregations in a thermohaline stratified basin, Marine Ecology, 36: 595-610. doi.org/10.1111/maec.12166

Zengin, M., Polat, H., Kutlu, S., Dinçer, A. C., Güngör, H. (2004). An Investigation on the Development of Deep Water Rose Shrimp (*Parapenaeus longirostris*, Lucas 1846) Fisheries in the Sea of Marmara. (Central Fisheries Research Institute). Project Acronym: TAGEM/HAYSUD/2001/09/2004. Final report. (in Turkish)

Zengin, M., Güngör, H., Güngör, G., Demirkol, C., İnceoğlu, H., Düz, G., Benli, K., Dağtekin, M., Kocabaş, E. (2017). Socio-economic structure of Marmara Sea fishery and determination of management strategies (MARBAL) (Central Fisheries Research Institute). Project Acronym: TAGEM HAYSÜD/2008/09/04/01. Final report. (in Turkish)