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ECOLOGICAL CHANGES IN THE SEA OF MARMARA

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FISHERIES, ECOSYSTEM & GOVERNANCE

CHAPTER 23

INDICATOR-BASED ASSESSMENT OF FISHING IMPACT ON THE SEA OF MARMARA ECOSYSTEM

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Abstract

Coastal and shelf regions play an extraordinary role with their rich marine resources and ecosystem services for human use. As an important transition zone, the Sea of Marmara (SoM) and its two narrow straits connect Mediterranean and Black Seas, and also support a diverse and rich ecosystem for many fish species. This chapter aims to examine the impact of fishing and climate change on the status of SoM ecosystem in the last two decades using landed catch and related common indicators. Results showed that the total catch dropped from a maximum amount of approximately 55,000 tonnes during the 2000s to 35,000 t in 2010s, and to 20,000 tonnes in 2020s. If the total catch in the 2000s is 100%, it was about 60% in 2010 and 35% in 2020s. Results of mean trophic level of landed catch confirm that there is a remarkable change in the catch composition during the last two decades. The values significantly decreased from 3.6 to 3.2 meaning withdrawal of predatory species such as European hake, turbot, and Atlantic bonito during 2000s, which led to the dominance of prey species such as anchovy, Mediterranean horse mackerel and deep-water pink shrimp in 2010s. The mean preferred temperature of the landed catch gradually decreased during 2000s and reached its minimum in 2011, followed by a slight increase and remained less fluctuated thereafter. Sea surface temperature gradually increased in the last 23 years and the average values were 15.8 °C in 2000s, 16.6 °C in 2010s, and 17.5 °C in 2020s. Results prove that the SoM is strongly influenced by external factors other than climate change alone, primarily overfishing. The continuous decline and overall negative values in fishing in balance index is related to declines in both the catch and the mean trophic level which indicates that fisheries are no longer efficient in the SoM. Although total vessel number decreased by its 1/4, landing-per-unit values did not show any increase, but gradually decreased after 2010, indicating stocks are declining and fishing effort are no longer sustainable as it is. Overall, ecological groups contributing to fisheries are mainly small pelagic fishes, followed by benthic invertebrates, and with a small number of medium pelagic and demersal fishes, and the SoM fishery depends on small pelagic fishes, mainly anchovy catch. It is concluded that the capacity of the SoM ecosystem has decreased significantly in the last decades and its ecosystem has become constantly vulnerable to human-induced pressures. Urgently, an ecosystem approach to fisheries management is required for understanding the ecosystem as a whole. Hence, specific recommendations for good environmental and fisheries management are provided at the end of this chapter. By implementing recommended measures, it is possible to enhance the resilience of the SoM ecosystem, safeguard its biodiversity, and ensure the sustainability of fisheries for future generations.

Keywords: Overfishing, Sea Surface Temperature, Predator Fish, Ecosystem Approach, Fisheries Management

1. Introduction

Coastal and shelf regions of oceans play an extraordinary role with their rich marine resources and ecosystem services for human use. These ecosystems are the most heavily exposed to all the effects of human impacts, such as overfishing, climate change, pollution and habitat degradation (UNEP, 2006). Overfishing and climate change are two interconnected and compounding threats to marine ecosystems. While sustainable fishing practices can contribute to ecosystem health, overfishing and poorly managed fisheries may undermine the resilience of marine ecosystems (Kenny et al., 2018). Ecosystem components are influenced in different levels by rising sea temperatures, ocean acidification, sea-level rise, altered precipitation patterns, and changes in storm intensity. These changes may directly affect the health and functioning of marine ecosystems, including the distribution and abundance of species, the availability of resources, and the overall balance of ecological processes (IPCC, 2022). Overfishing exacerbates these vulnerabilities, as depleted fish populations have limited capacity to adapt to changing environmental conditions, and to the impacts of climate change. Therefore, ecosystems can be more susceptible to other stressors and disturbances, such as pollution, invasive species, and extreme weather events (Kenny et al., 2018).

Ecological indices serve as indicators of ecosystem health, capturing the complex interactions between species and their environment. These indices quantify various ecological aspects, such as trophic structure, species composition, and habitat quality, enabling a comprehensive assessment of ecosystem integrity (Coll et al., 2016). Monitoring variation of those indices in time, enable to detect changes in the structure and functioning of marine food webs, providing early warnings of ecological imbalances or degradation. Most widely used ecological indices, such as the mean trophic level of landed catch (*mTLc*) and the fishing-in-balance index (*FiB*), provides insights into the effects of fishing activities on the structure and composition of fish populations. The changes in *mTLc* provide information about the health of fish stocks in the seas (Pauly et al., 1998). For example, the decrease in this value indicates that the organisms with high trophic levels in the food web decrease compared to those with low trophic levels and there is a negative trend in terms of the health of the food web. On the other hand, the *FiB* compares the catch composition to the expected ecological composition, indicating whether the fishery is aligned with the ecosystem's natural dynamics or facing imbalances (Pauly et al., 2000). The mean temperature of catch (*mTc*) index tracks the average temperature of the catch over time, providing a measure of the impact of variations in sea water temperature on fish populations and distribution pattern such as any shifts in species ranges (Cheung et al., 2013).

The Sea of Marmara (SoM) is a partially enclosed inland sea located in northwestern Mediterranean. It is an important waterway connecting the Aegean Sea to the south and the Black Sea to the north through the Bosporus Strait and the Dardanelles. The SoM has a complex circulation pattern due to its connections, resulting in water exchange and mixing which bring different water masses and influence the temperature, salinity, and nutrient distribution (Beşiktepe et al., 1994). The surface waters are typically warmer and less saline, while the deeper layers are colder and more saline. The SoM supports a diverse and rich ecosystem, while coastal areas and shallow bays provide various habitats including sea meadows, reefs, and rocky formations that support biodiversity and serve as nurseries for many fish species. Fish diversity of the SoM is reported 235 unique Atlanto-Mediterranean species (Bilecenoğlu et al., 2014) showing similar characteristics to the neighbouring seas with distinct oceanographic and ecological features.

This chapter aims to examine the impact of fishing and climate change on the status of SoM ecosystem in the last two decades using catch trends and common ecological indices. Catch trends help to better understand changes in the composition of commercial marine fishes and invertebrates, while ecological indices provide insight for disruption of ecosystem functioning via marine trophic structure. Variation of the sea surface temperature (SST) of the SoM and its potential impact on composition of landed catch were also examined through the mean temperature of preferred catch approach.

2. Approach

Landings data for all capture marine fish and invertebrates for the SoM were obtained from national fishery statistics from 2000 to 2022 (TURKSTAT, 2023). Although fisheries statistics date back to 1967, there are many concerns about the realibility of catch statistics and species identification. Therefore, catch statistics of commercial species after 2000 which there are at least 5 years of consecutive catches and for which the catch is at least 1000 tonnes were used for analyses. Finally, of the 94 officially listed capture species (66 fish and 28 invertebrates, Figure 1a), 23 of them (22 fish and one invertebrate) were used for analysis (Table 1). Prior to analyses, respresentativeness of the final list were checked and found that the catch of the species in the final list corresponded 84-98% of the overall catch of the SoM (Figure 1b).

Total vessel number including all fishing gear used in the SoM was obtained annually from 2000 to 2022 (TURKSTAT, 2023). Landing-per-unit-effort (LPUE) was calculated as total landed catch divided by total vessel numbers. Sea surface temperature (SST, °C) was obtained from Turkish State Meteorological Service from 2000 to 2022 (MGM, 2023).

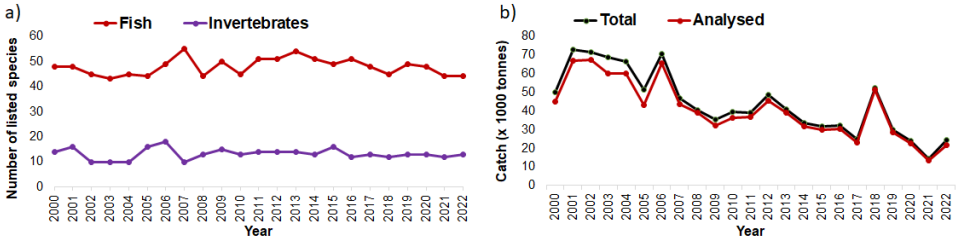


Figure 1. a) Changes in the a) number of officially listed fish and invertebrate species by TURKSTAT. b) Comparison of the overall landed catch of the SoM and catch of 23 species used in the analyses.

2.1. Mean Trophic Level of Landed Catch (*mTLc*)

Trophic levels (TL) of all examined species (Table 1) were obtained from FishBase (fishbase.org) and SealifeBase (sealifebase.org). The *mTLc* is calculated for each year by weighting the trophic level of all species by their catches (Pauly et al., 1998).

$$\mathrm{mTL_c} = \Sigma(TL_i * Y_{ik}) / \Sigma Y_{ik}$$

where, Y*iy* represents the amount of fish caught for that year, k is the amount of catch of *i* species and TL*i* is the trophic level of species.

A cut-off of trophic level below 3.25 for prey fish and invertebrate and above 4.00 for apex predators are considered to examine changes within prey-predator relationship.

2.2. Fishing in Balance Index (FiB)

FiB index (Pauly et al., 2000) was calculated in order to assess if changes in the mean trophic level were compensated by changes in catches using following formula:

$$\mathrm{FiB} = \log10[\mathrm{Y_k} * (1/\mathrm{TE})^{\mathrm{TL_k}}] - \log10[\mathrm{Y_0} * (1/\mathrm{TE})^{\mathrm{TL_0}}]$$

where Y*k* is the catch, TL*k* is the mean trophic level of the catch in the year *k*, the subscript 0 refers to the first year in a time series that is used as a baseline and TE is the mean energy-transfer efficiency between trophic levels that is assumed to be 0.1.

2.3. Mean Temperature of Landed Catch (mTc)

mTc was calculated annually based on the median temperature preference of each fish species (Table 1; Cheung et al., 2013) weighed by its landings, according to the following formula:

$$\mathrm{mT_{cy}} = \Sigma \mathrm{T_i c_{i,y}} / \Sigma \mathrm{c_{i,y}}$$

where C*i*,*y* are the landings of species *i* in each sub-region for year *y*, T*i* is the median temperature preference of species *i*.

Table 1. Information for analysed fish and invertebrate species between 2000 and 2022 in the SoM.

Turkish name	English name	Scientific name	Trophic Level	Group	Preferred Temperature °C
Çaça	European sprat	*Sprattus sprattus*	3	Small Pelagic	12.0
Hamsi	European anchovy	*Engraulis encrasicolus*	3.1		19.0
Sardalya	European pilchard	*Sardina pilchardus*	3.1		16.0
İstavrit Kraça	Med. horse mackerel	*Trachurus mediterraneus*	3.2		19.0
Uskumru	Atlantic mackerel	*Scomber scombrus*	3.6	Pelagic	12.0
Karagöz istavrit	Atlantic horse mackerel	*Trachurus trachurus*	3.7		18.0
Kolyoz	Atlantic chub mackerel	*Scomber colias*	3.9		22.5
Tirsi	Pontic shad	*Alosa immaculata*	4		13.0
İzmarit	Blotched picarel	*Spicara maena*	4.2		16.0
Zargana	Garfish	*Belone belone*	4.2		15.0
Lüfer	Bluefish	*Pomatomus saltatrix*	4.5		27.0
Palamut-Torik	Atlantic bonito	*Sarda sarda*	4.5		23.0
Kefal	Flathead grey mullet	*Mugil cephalus*	2.6	Demersal	27.0
Kupez	Bogue	*Boops boops*	2.8		20.0
Dil	Common sole	*Solea solea*	3.2		16.0
Kalkan	Turbot	*Scophthalmus maximus*	3.5		11.0
Levrek	European seabass	*Dicentrarchus labrax*	3.5		14.0
Tekir	Surmullet	*Mullus surmuletus*	3.5		19.0
Barbunya	Red mullet	*Mullus barbatus*	3.6		17.0
Berlam	European hake	*Merluccius merluccius*	4.4		18.0
Karagöz	Two-banded seabream	*Diplodus vulgaris*	4.4		21.0
Mezgit	Whiting	*Merlangius merlangius*	4.4		11.0
Pembe karides	Deep-water rose shrimp	*Parapenaeus longirostris*	2.5		14.0

3. Results

The total catch dropped from an average of approximately 55,000 tonnes during the 2000s to 35,000 t in 2010s, and to 20,000 tonnes in 2020s. Specifically, the medium pelagic and large demersal fish catches have dramatically decreased in recent years. The demersal fish catch dropped from an average of approximately 10,000 t in the 2000s to 2,000 t in 2010s and to 700 t in 2020s. The pelagic fish catch dropped from an average of approximately 10,000 t in the 2000s to 5,000 t in 2010s and to 3,500 t in 2020s. The small pelagic fishes, on the other hand, showed no sharp collapse during 2000s and 2010s and remained around 30,000 t (Figure 2a). Over 90 commercial fish and invertebrate species are officially listed in fisheries statistics between 2000 and 2022 (TURKSTAT, 2023), up to 90% of the total catch consists of only 11 species such as anchovy (43%), sardine (10%), Mediterranean horse mackerel (8.6%), horse mackerel (5.9%), bluefish (5.6%), European hake (6%), shrimps (4%), Atlantic bonito (3%), whiting (1.8%), and mullets (1.7%). Total number of fishing vessels decreased its 1/4 after 2010 and it has been stable since 2016. LPUE values showed continuous and gradual decline in the entire period (Figure 2b).

The *mTLc* decreased from 3.6 to 3.2 from 2000 to a minimum in the 2022 with a significant decreasing trend ($R^2 = 0.67$, $p < 0.05$; Figure 2c). Prey-predator ratio was gradually increased in years, showing the decrease in large predators (TL > 4.00), and increase in preys (TL < 3.25). A very rapid increase to its maximum has been observed in the last five years (Figure 2d). The *FiB* index in the SoM gradually declined to the negative values after 2003 and reached its lowest in 2021 (Figure 2e). The *mTc* gradually decreased during 2000s and reached its minimum in 2011, followed by a slight increase and remained less fluctuated thereafter. The average *mTc* was 18.9 °C in 2000s, 18.5 °C in 2010s, and 18.5 °C in 2020s. SST showed gradual increase in the last 23 years and the average SST was 15.8 °C in 2000s, 16.6 °C in 2010s, and 17.5 °C in 2020s (Figure 2f).

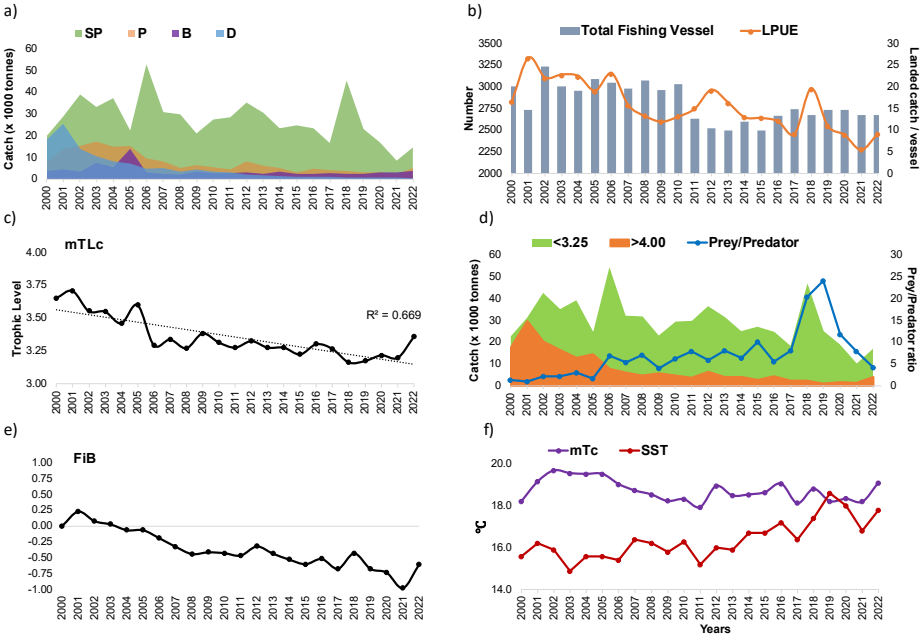


Figure 2. Changes in a) the landed catch for group of small pelagic (SP), pelagic (P), demersal (D), and invertebrate (B) species; b) total number of fishing vessel and landing-per-unit-effort (LPUE); the common indicators of c) mean trophic level of the catch (*mTLc*); d) landed catch of species by their trophic level (TL<3.25 and TL>4.0) and prey-predator ratio, e) fishing in balance index (*FiB*); i) mean preferred temperature of the landed catch (*mTc*), and sea surface temperature (SST) of the SoM from 2000 to 2022.

4. Discussion

The SoM has a significant importance for fisheries in Türkiye by supporting a variety of commercially valuable fish species, which are important for local fishing communities, as

well as contribute to the national economy. The fisheries characteristic is mainly coastal for benthic/demersal species by beam trawling, and the rest is seasonal pelagic fishery by purse-seines related to seasonal migrations of pelagic species. Results showed that the annual total catch in the SoM has decreased in recent years. The total landed catch of the SoM have been gradually declining in years, with the lowest catch observed during the last years. If the total catch in the 2000s is 100%, it was about 60% in 2010 and 35% in 2022. Landed catch showed dramatic declines in demersal fishes followed by pelagic fishes while trends were almost stable for small pelagic fish.

Results of *mTLc* confirm that there is a remarkable change in the catch composition of the SoM during the last two decades. The *mTLc* gradually decreased from 2000 to a minimum in the 2022 meaning withdrawal of predatory species such as European hake, turbot, and Atlantic bonito during 2000s, which led to the dominance of prey species such as anchovy, Mediterranean horse mackerel and deep-water pink shrimp in 2010s. In 2019 up to 90% of the total catch consists of only five species including anchovy (57.8%), sardine (15.2%), horse mackerel (8.2%), deep-water rose shrimp (5.2%), and Mediterranean horse mackerel (4.2%). Here, the year 2019 is considered for the latest year in the official catch statistics to better representation, because the fisheries and catch efficiency in the year 2020 and 2021 were influenced Covid-19-related lockdown periods and basin-wide heavy mucilage episodes, respectively.

'Fishing down food webs' (Pauly et al., 1998) has clearly occurred in the SoM with the larger species being the most heavily overfished and have even nearly disappeared from the SoM ecosystem. The increasing trend in SST values were clear, and the impact of climate change on sea water temperatures became evident, especially during the 2010s. Results of the *mTc* is less fluctuated after 2010s and remained around 18.5 °C as close to the preferred temperature of anchovy and Mediterranean horse mackerel. The SoM is east-west oriented transition zone, and it is not easy to predict direct effect of climate change on species distribution. Hence, the *mTc* results also prove that the SoM is strongly influenced by external factors other than climate change alone, primarily overfishing. The continuous decline and overall negative values in *FiB* is related to decrease in both the catch and the *mTLc* which indicates that fisheries are no longer efficient in the SoM. Although total vessel number decreased by its 1/4, LPUE values did not show any increase, instead, gradually decreased after 2010, indicating stocks are declining and fishing effort are no longer sustainable as it is. Overall, in the SoM, ecological groups contributing to fisheries are mainly small pelagic fishes, followed by benthic invertebrates, and with a small number

of medium pelagic and demersal fishes, and the SoM fishery depends on small pelagic fishes, mainly anchovy catch.

The capacity of the SoM ecosystem has decreased significantly in the last decades and its ecosystem has become constantly vulnerable to human-induced pressures (Demirel et al., 2023). Unfortunately, disastrous impact of weakened ecosystem resilience led to basin-wide mucilage formation in which all ecosystem services temporarily blocked during the year 2021 in the SoM. An ecosystem approach to fisheries management (EAFM) is required for understanding the ecosystem as a whole. Ongoing research, conservation initiatives, and effective management strategies should be considered for the long-term sustainability and improvement of the resilience of this unique marine environment.

Firstly, implementing sustainable fishing practices is essential to ensure the long-term health of fish populations and the overall ecosystem. Establishing marine protected areas, implementing coastal zone management strategies, and reducing pollution and habitat degradation is important for maintaining biodiversity and supporting the resilience of the SoM ecosystem. Considering recent mucilage episodes during the year 2021 in the SoM, effective wastewater treatment, controlling chemical and nutrient runoff, and minimizing pollution from shipping and other maritime activities are also necessary steps in preserving the health of the ecosystem. Based on EAFM, involving local communities, fishers, scientists, and other stakeholders in the decision-making process is crucial for effective management. Collaborative approaches that incorporate traditional ecological knowledge and engage local communities in conservation efforts can lead to more sustainable and successful outcomes. Finally, developing strategies to adapt to the impacts of climate change is essential for enhancing ecosystem resilience. This can include monitoring and assessing climate-related changes, identifying vulnerable areas and species, and implementing adaptive management approaches to protect and restore the ecosystem. By implementing recommended environmental and fisheries management measures, it is possible to enhance the resilience of the SoM ecosystem, safeguard its biodiversity, and ensure the sustainability of fisheries for future generations.

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