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Postmucilage status of teleost fish assemblages in the Sea of Marmara

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Abstract: A frightening mucilage event occurred in the Sea of Marmara (SoM) from November 2020 to July 2021, leaving devastating effects on maritime industries, fishing activities, and the benthic ecosystem. The mucilage led to intense fish mortalities, particularly affecting species like smelt, anchovy, and picarel, with severe consequences for benthic ecosystems and various marine species. This study aims to analyze the possible long-term effects of the recent mucilage disaster on species diversity and biomass by assessing the current status of teleost fish assemblages in the SoM. The data set is based on bottom trawl surveys carried out at 52 points at ten stations in the SoM throughout 2023. Data presented through biomass and various ecological indices enabled comparative analyses of changes in fish assemblages pre and postmucilage events. During the study, a total of 5066 kg of retained catch in the 4867 km^2 scanned area revealed a biomass of 1040.9 $kg \cdot km^{-2}$, represented by 45 species in the SoM. Commercial species such as *Trachurus trachurus*, *Merlangius merlangus*, *Merluccius merluccius* stood out with the highest biomass in the teleost fish assemblage. Species richness and total teleost biomass tended to decrease by over 20% in the postmucilage period, reflecting the possible destruction of mucilage to fish populations in the SoM. The decreasing trend in biomass was limited to pelagic species. The extent of the impact on pelagic species may be the cumulative effect of ongoing overexploitation and reduced landing size, as well as intense mortality recorded during the mucilage period. The findings underscore the need for sustainable fishing practices and marine protected areas, including compliance with the Marmara Sea Action Plan, for the restoration and conservation of fish assemblages.

Key words: Biodiversity, conservation biology, fisheries management, marine ecology, Türkiye

1. Introduction

The Sea of Marmara (SoM), linking to the Mediterranean through the Dardanelles and the Black Sea via the Bosphorus, constitutes the Turkish Straits System and covers a surface area of 11,500 km^2. The hydrographic configuration is characterized by a dual-layer structure featuring distinct densities delineated by a well-defined interface approximately 25 m deep (Beşiktepe et al., 1994). In the upper layer, waters of Black Sea origin with low salinity (18‰) traverse the Bosphorus, while the lower layer comprises highly saline waters of Mediterranean Sea origin (37‰) entering from the Dardanelles. Photosynthetic processes and primary production are confined to the illuminated layer, extending to a depth of 15–20 m, exclusively sustained by Black Sea water (Özsoy et al., 2001). This dual-current arrangement renders the SoM notably vulnerable to climate change and anthropogenic pressures. Reflecting the global climate change, sea surface temperature within the entire Mediterranean Sea has risen, with the SoM experiencing an elevation averaging 2.2 °C above historical temperatures[1]. The marine ecosystem confronts substantial pressures arising from inputs originating in the Black Sea, terrestrial discharges of domestic and industrial nature, and increased human activities. Deficiencies in treatment and discharge protocols contribute to an escalating eutrophication trend in the SoM (Balcı et al., 2014). In recent years, due to increasing pollution sources, nitrate, and phosphorus concentrations in the bottom layer waters of the SoM increased while oxygen levels reached critical levels. The SoM, which was rich in nutrients, exhibited high chlorophyll-a values due to its extreme productivity (Ediger et al., 2016). Algal blooms occurred as a result of nutrient inputs capable of inducing changes in nutrient levels, affecting the temporal reproduction periods of phytoplankton. As a result of the accumulation of organic substances produced under special trophic and seasonal conditions, mucilage formation has begun to be observed periodically in the SoM (Taş et al., 2016).

[1]National Centers for Environmental Information (2023). Analysis of Mediterranean SST trends. [online]. Website https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/mediterranean-sea-surface-temperature-cumulative-trend-map [accessed 30 Sep 2023].

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The last mucilage disaster in the SoM, observed in November 2020, escalated to alarming proportions, extending across hundreds of kilometers of coastline. This phenomenon detrimentally impacted various sectors, including maritime (Uflaz et al., 2021) and fishing activities (Yıldız and Gönülal, 2021; Karakulak et al., 2023), as well as benthos communities (Özalp, 2021; Topçu and Öztürk, 2021) in the SoM. In April 2021, mucilage accumulation was particularly notable in gulf areas characterized by insufficient current. This disaster resulted in intense fish mortalities attributed to suffocation caused by hypoxia or gill obstruction due to dense mucilage. Pelagic and forage species, such as smelt, anchovy, and picarel suffered significant mortality from mucilage (Karadurmuş and Sarı, 2022). Mucilage also affects benthic ecosystems, including macroalgae, sea urchins, gorgonians, molluscs, crustaceans (Rinaldi et al., 1995; Aktan et al., 2008; Özalp, 2021) and fish assemblages (Taylor et al., 1985; Kent et al., 1995; Karadurmuş and Sarı, 2022). Understanding mucilage dynamics and monitoring its long-term consequences are crucial for mitigating these effects. This study aims to determine the current status of teleost fish assemblages in the SoM and to reveal potential changes in species richness and biomass within these assemblages following the destructive mucilage disaster. The study findings serve to inform decision-making and sustainable practices, including fisheries management in the SoM.

2. Materials and methods

Field studies were carried out throughout 2023, encompassing a total of ten distinct stations in the SoM (Figure 1). A total of 52 samples were carried out using a single bottom trawl net at randomly selected points in the study area. A bottom trawl net with a vertical opening of 3.5 m, a horizontal opening of 16 m, and a total length of 32.4 m was employed for the sampling process. Trawl surveys were conducted using two commercial trawlers, namely ZAPRANLAR (overall length: 17 m, engine power: 450 HP) and T.TATLI (overall length: 14 m, engine power: 360 HP). Trawling operations were carried out with hauling speeds ranging from 2.8 to 3.2 knots. Although the haul duration per operation varies depending on the bottom structure, weather conditions, and catch amount, a total of 64.9 h of haul was carried out during the study. A total of 4867 km^2 area ranging from 15.2 to 146.4 m depth was surveyed throughout the study. The trawl survey adhered to the protocol outlined in MEDITS[2] at every stage, encompassing the conception of the survey, characteristics of the sampling gear, sampling methodology, and the subsequent processing of collected samples.

Captured species were identified at the species level utilizing standard taxonomic keys (Fischer, 1973; Nelson, 2006). Taxonomic classifications were subsequently validated in accordance with the criteria established by Fishbase[3]. Upon capture, the retained catch was systematically classified on deck following the guidelines by Carpentieri (2019). Teleost fish assemblages were both weighed and counted at the species level, forming the basis for subsequent biomass and ecological index calculations. All details regarding operations and catch were recorded on standardized field forms, ensuring comprehensive documentation of the raw data.

The duration of each haul was defined as the period from reaching the optimal gear opening to the moment when the speed was decreased for warp retrieval. Biomass (expressed in $kg{\cdot}km^{-2}$) was determined by dividing the overall weight by the swept area method. The calculation of the swept area (denoted as a in km^2), also referred to as the 'effective path swept' during each hauling, the formula $a = D \times hr \times X2$ and $D = V \times t$ described by Sparre and Venema (1992) was followed. The length of head rope (hr) of the trawl net was 40 m. For the Mediterranean Sea, Pauly (1980) proposed that the optimal compromise value for $X2$ is 0.5. This study adopts and adheres to this recommended value of 0.5.

Species richness serves as a metric encompassing the taxonomic levels (S) within a specific site. Species diversity, a construct typically characterized by richness and evenness, reflects the variety of species within a community. Species richness indicates the total number of species present, while evenness elucidates the dominance of species within the community or whether these species are represented by approximately equal numbers (Nkoa et al., 2015). This study focused on Margalef diversity, Shannon-Weiner diversity, and Simpson diversity indices, recognized as commonly utilized metrics for estimating within-community diversity (α-diversity). Detailed definitions and formulas for ecological indices are given in Table 1. Analysis of variance (ANOVA) at a 5% significance level was used to determine the "between-stations" differences across biomass. When the ANOVA results were significant, post hoc tests were performed to determine homogeneous groups in the biomass. The descriptive statistics of the data were calculated using the statistics software version 26 SPSS. Data were visualized via MS-Excel software.

3. Results

The assessment of fish assemblages in the SoM following the mucilage disaster revealed a total catch of 5066 kg across 45

[2]MEDITS (2017). International bottom trawl survey in the Mediterranean. Instruction Manual. Version 9. [online]. Website https://archimer.ifremer.fr/doc/00832/94436/ [accessed 11 May 2023].

[3]Froese R, Pauly D (2024). FishBase version (02/2024). [online]. Website www.fishbase.org [accessed 22 Aug 2023].

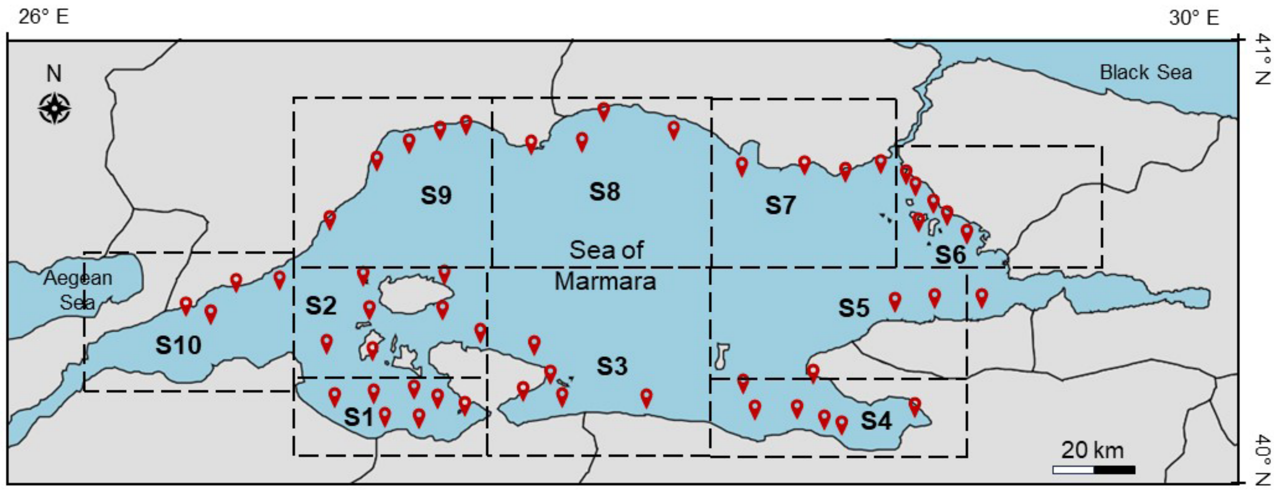

Figure 1. Map of the study area with stations and sampling points (red marks) in the Sea of Marmara, Türkiye. Dashed black lines represent the limit of the stations (S1: Erdek Gulf, S2: Marmara Islands, S3: Bandırma Gulf, S4: Gemlik Gulf, S5: İzmit Gulf, S6: Prens Islands, S7: Avcılar, S8: Silivri, S9: Tekirdağ, S10: Şarköy).

Table 1. Detailed definitions and formulas for ecological indices.

Ecological indices (Reference)	Definitions	Formulas
Margalef diversity index (D_{Mg}) (Margalef, 1958)	*S*: number of species. *N*: total number of individuals in the sample.	$D_{Mg} = \frac{S-1}{\ln N}$
Shannon-Weiner diversity index (*H'*) (Shannon and Weaver, 1963)	p_i: proportion of individuals belonging to the i_{th} species. *S*: total number of species.	$H' = -\sum_{i=1}^{S} p_i (\ln p_i)$
Simpson's diversity index (λ) (Simpson, 1949)	p_i: proportion of individuals belonging to the i_{th} species. *S*: total number of species. $E_{1/D}$: the equivalent measure of evenness	$\lambda = \sum_{i=1}^{S} p_i^2$ $E_{1/D} = \frac{(1/D)}{S}$
Pielou's evenness index (*J'*) (Pielou, 1969)	*S*: total number of species. *H'*: Shannon-Weiner diversity index	$J' = \frac{H'}{H'_{max}}$

teleost fish species, representing 30 families. Among these species, ten were considered the commercial catch, while 16 were considered entirely discarded catch (Figure 2). Notably, 69.2% (3507 kg) of the retained catch consisted of target catch above the minimum landing size and marketable catch from bycatch. Including the discarded part of the target species, 30.8% (1559 kg) of the total prey was discarded (Figure 3). *Trachurus trachurus* emerges as the most prominent, representing 26.8% of the total catch, followed closely by *Merlangius merlangus* (18.2%) and *Merluccius merluccius* (14.3%). *T. mediterraneus* (6.6%) and *Mullus surmuletus* (6.5%) exhibiting lower biomass values in comparison with dense species. The combined contribution of the other 40 species, accounted for 27.6% of the total catch, with a cumulative catch of 1399 kg (Figure 4).

The distribution patterns of species varied according to the stations in the SoM (Table 2). Nineteen species were observed across all stations, indicating a widespread presence, while 11 species were found at fewer than five stations, suggesting a more restricted distribution. *Microchirus ocellatus* (in Erdek Gulf), *Syngnathus acus* (in İzmit Gulf) and *Umbrina cirrosa* (in Tekirdağ) were rare species recorded at a single station. *T. trachurus* displayed notable variation between stations. Erdek Gulf had a significant biomass of 675.7 kg·km^{-2}, accounting for 44.6% of the total catch (606 kg). Similarly, *M. merlangus* predominantly clustered at Erdek Gulf, representing 67.1% of the total catch (620 kg), with a biomass of 283.8 kg·km^{-2}. Marmara Islands and Erdek Gulf stood out as hot spots for *M. merluccius*, with biomass of 281.5 kg·km^{-2} and 232.7 kg·km^{-2}, respectively.

Differences in species richness were observed between sampled stations, reflecting differences in the number of species present (Table 3). Stations S1, S4, S6, S8, S9, and S10 exhibited higher species richness, ranging from 34 to 36 species. Meanwhile, other stations showed slightly lower species richness but still maintained considerable

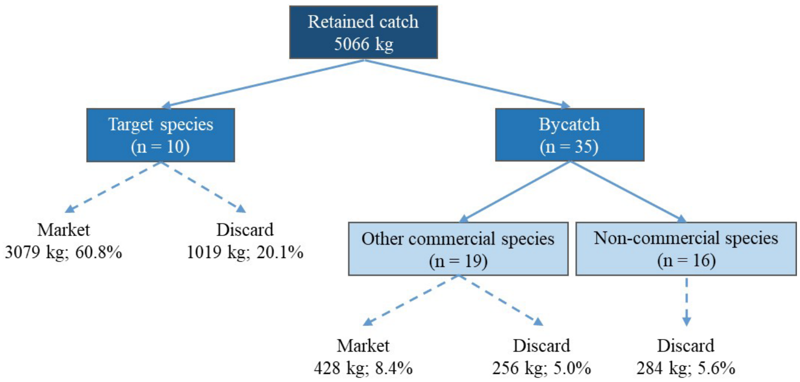

Figure 2. Evaluation of retained catch.

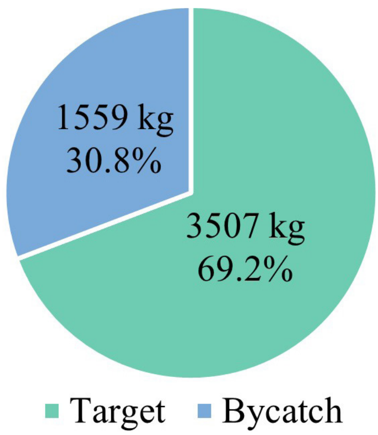

Figure 3. Target and bycatch with amounts (kg) and proportions (%).

diversity. Although the highest species richness was recorded in S9 and S10 with 36 species, S1 was the station where the highest number of individuals (N = 68498) was calculated with 35 species. The Margalef diversity index (D_{Mg}), Shannon-Weiner diversity index (H'), and Simpson's diversity index (λ) collectively shed light on the evenness and distribution of species within these stations. Higher values of D_{Mg} and H' observed in stations S6, S8, S9, and S10 suggest increased diversity and a more even distribution of species, highlighting a more balanced ecosystem within these locations. Conversely, stations like S2, S3, and S7, despite having a moderate species richness, demonstrated comparatively lower values in diverse indices. Stations S6, S8, S9, and S10 exhibited a notably high level of evenness, as indicated by Pielou's evenness index (J'). These areas harbor more diverse, evenly distributed, and less dominant fish assemblages compared to other sampled sites (Table 3).

The average biomass of teleost fish assemblages in the entire SoM was recorded as 1040.9 kg·km^{-2}. To examine variations in the distribution of biomass across different stations, we utilized analysis of variance (ANOVA) as a statistical method, given the observed unequal variances among groups. The results of the ANOVA indicated a statistically significant difference in biomass levels among stations (df = 9; F = 3.34; $p < 0.05$), suggesting significant spatial differences in the biomass of teleost fishes within the SoM. Tukey's test revealed that Gulf of Erdek and Gulf of İzmit differed significantly from other stations (Table 3). According to the species diversity similarity dendrogram, the stations are clustered in two groups and a 49% similarity was found between the stations. These findings underscore the importance of recognizing and considering spatial heterogeneity when evaluating the ecological dynamics of teleosts in the SoM. Erdek Gulf stood out prominently with the highest biomass of 1745.4 kg·km^{-2}, represented by 36 species. İzmit Gulf and Gemlik Gulf presented higher biomass than average (1040.9 kg·km^{-2}) with 1471.8 kg·km^{-2} and 1135.7 kg·km^{-2}, respectively. Conversely, the Marmara Islands and Bandırma Gulf exhibited notably lower biomass values of 702.4 kg·km^{-2} and 754.9 kg·km^{-2}, respectively. Despite Avcılar and İzmit Gulf exhibiting high biomass within the teleost fish assemblages, they

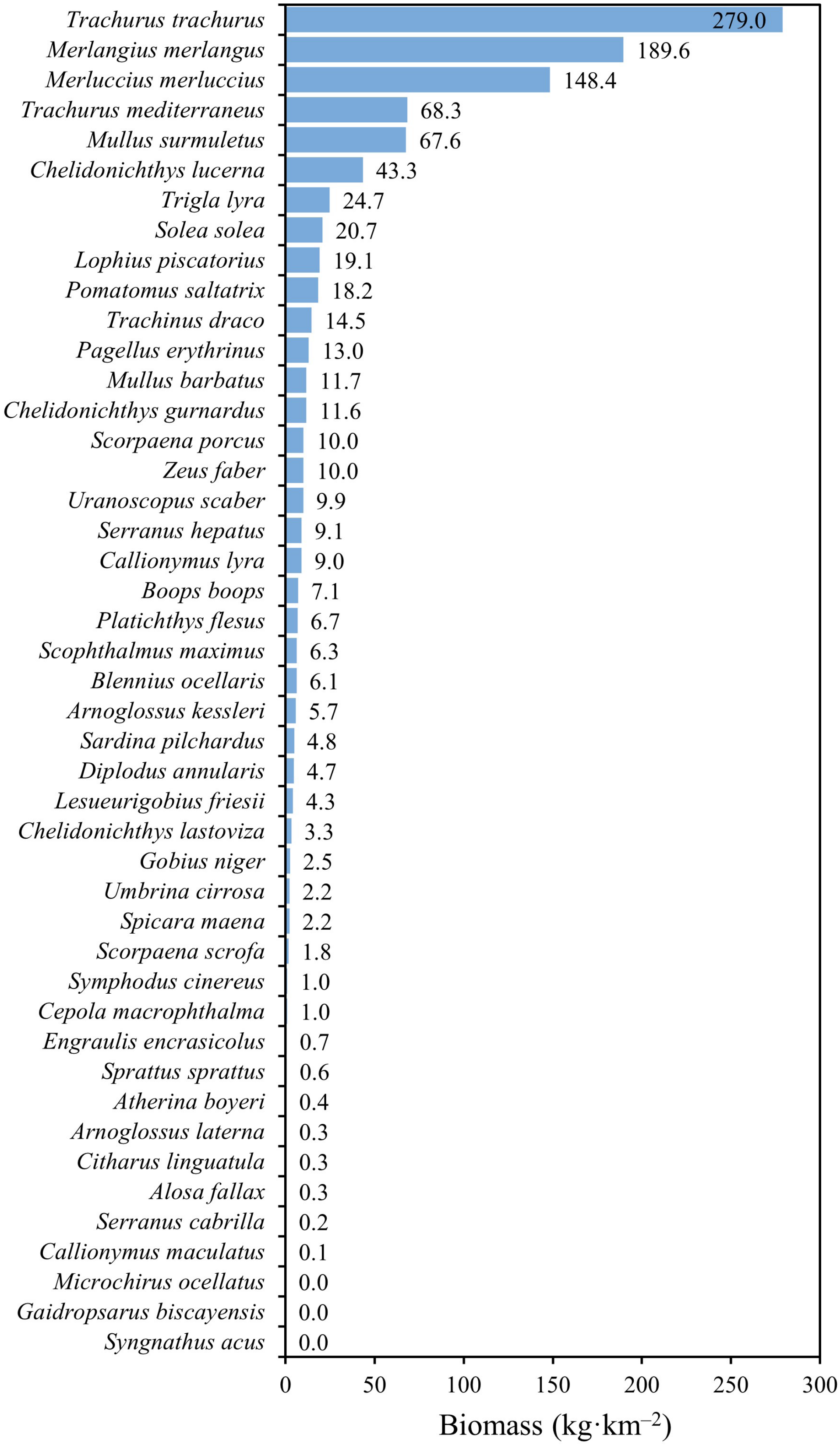

Figure 4. Average biomass (kg·km^{-2}) of teleost fish assemblages in the Sea of Marmara, Türkiye.

Table 2. Variation of average biomass (kg·km^{-2}) of teleost fish assemblages in the Sea of Marmara according to stations (S1: Erdek Gulf, S2: Marmara Islands, S3: Bandırma Gulf, S4: Gemlik Gulf, S5: İzmit Gulf, S6: İstanbul Islands, S7: Avcılar, S8: Silivri, S9: Tekirdağ, S10: Şarköy).

Catch	Family	Species	Stations									
			S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Target	Carangidae	*Trachurus mediterraneus*	192.3	41.9	48.4	41.9	38.5	10.0	6.1	13.5	54.2	88.0
		Trachurus trachurus	675.7	174.4	201.2	283.6	522.6	51.6	69.7	58.4	181.4	192.7
	Gadidae	*Merlangius merlangus*	283.8	75.4	298.6	270.4	32.8	198.1	402.0	47.9	74.9	76.1
	Merlucciidae	*Merluccius merluccius*	232.7	281.5	48.2	76.9	135.9	49.6	11.1	34.1	197.2	126.2
	Mullidae	*Mullus barbatus*	10.8	2.1	2.0	8.4	5.6	16.7	5.6	73.4	20.1	8.3
		Mullus surmuletus	107.0	9.4	14.5	80.3	47.2	61.3	42.9	341.6	55.4	30.9
	Pleuronectidae	*Platichthys flesus*	2.1	0.0	5.4	3.9	0.0	21.2	23.7	28.5	2.3	8.6
	Scopthalmidae	*Scophthalmus maximus*	0.0	0.0	3.1	4.7	6.2	43.0	0.0	10.5	9.9	0.0
	Soleidae	*Solea solea*	16.2	2.2	54.7	11.3	19.5	28.2	17.2	34.8	13.8	27.9
	Triglidae	*Chelidonichthys lucerna*	32.4	21.7	12.8	44.7	175.9	128.2	41.9	30.0	40.7	19.3
Bycatch (commercial)	Alosidae	*Alosa fallax*	0.0	0.0	0.3	0.0	3.1	0.0	0.0	0.0	1.7	0.0
		Sardina pilchardus	12.2	1.7	1.4	2.2	0.0	14.3	4.5	1.1	0.8	3.7
	Atherinidae	*Atherina boyeri*	0.0	0.0	0.2	0.8	0.0	0.2	0.5	0.4	2.3	0.3
	Bothidae	*Arnoglossus kessleri*	9.0	2.2	4.7	2.5	4.1	1.9	0.3	9.7	10.2	16.9
	Clupeidae	*Sprattus sprattus*	0.2	0.0	0.6	1.9	6.7	0.0	0.0	0.0	0.0	0.0
	Engraulidae	*Engraulis encrasicolus*	1.3	0.0	0.6	1.6	0.0	0.7	0.0	0.0	0.3	0.7
	Lophiidae	*Lophius piscatorius*	1.2	14.2	1.6	34.6	177.4	25.1	6.6	12.0	7.3	10.3
	Pomatomidae	*Pomatomus saltatrix*	0.0	0.0	0.0	53.2	11.8	3.3	220.2	10.1	0.0	15.0
	Sciaenidae	*Umbrina cirrosa*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.5	0.0
	Scorpaenidae	*Scorpaena porcus*	16.1	5.8	2.0	15.0	0.0	16.5	1.5	16.9	10.7	8.3
		Scorpaena scrofa	2.5	0.0	0.5	2.0	3.1	1.0	1.5	7.1	3.1	2.0
Bycatch (commercial)	Sparidae	*Boops boops*	10.2	0.0	1.6	11.0	8.7	2.9	22.7	19.9	4.2	10.3
		Diplodus annularis	5.0	3.2	1.9	6.4	4.1	5.3	13.1	8.6	2.0	4.3
		Pagellus erythrinus	23.4	4.2	0.0	34.0	22.1	3.1	2.5	11.6	13.8	7.3
		Spicara maena	0.7	0.0	3.3	0.0	7.2	0.0	4.0	7.9	4.0	7.1
	Triglidae	*Chelidonichthys gurnardus*	6.3	4.7	6.8	16.3	49.2	25.1	12.1	5.6	12.7	9.6
		Chelidonichthys lastoviza	4.0	0.7	2.2	1.4	8.2	10.7	2.0	3.7	2.3	3.7
		Trigla lyra	21.3	11.3	5.4	35.0	70.3	57.3	18.2	52.4	11.0	17.3
	Zeidae	*Zeus faber*	17.1	16.6	0.9	16.3	0.0	3.1	0.0	0.0	0.0	16.9
Bycatch (noncommercial))	Blenniidae	*Blennius ocellaris*	8.4	8.4	0.6	4.0	15.4	0.5	2.0	6.7	4.8	14.3
	Bothidae	*Arnoglossus laterna*	0.0	0.0	0.9	0.0	0.0	1.0	3.0	0.4	0.0	0.0
	Callionymidae	*Callionymus lyra*	2.3	2.2	9.2	13.3	24.6	12.2	6.6	1.1	23.2	17.6
		Callionymus maculatus	0.0	0.3	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
	Cepolidae	*Cepola macrophthalma*	1.1	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.0
	Citharidae	*Citharus linguatula*	0.8	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.8	0.0
	Gaidropsaridae	*Gaidropsarus biscayensis*	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Gobiidae	*Gobius niger*	6.9	0.0	0.0	0.2	0.5	0.5	1.0	2.2	2.3	13.0
		Lesueurigobius friesii	4.4	2.2	6.8	2.8	0.0	2.1	0.5	6.0	6.2	12.3
	Labridae	*Symphodus cinereus*	0.2	0.5	0.0	1.4	0.0	1.4	0.0	5.2	2.3	1.3
	Serranidae	*Serranus cabrilla*	0.0	0.4	0.0	0.0	0.0	0.0	1.5	0.0	0.3	0.3
		Serranus hepatus	12.9	1.3	2.0	13.5	22.1	2.4	14.6	12.7	15.8	13.6
	Soleidae	*Microchirus ocellatus*	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Syngnathidae	*Syngnathus acus*	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
	Trachinidae	*Trachinus draco*	11.7	3.6	5.9	26.5	25.6	17.4	15.7	35.6	10.5	23.3
	Uranoscopidae	*Uranoscopus scaber*	12.9	6.5	6.2	14.1	23.1	1.4	5.6	12.4	7.6	16.9
Statistical analysis			Kruskal-Wallis H = 11.194; df = 9; Sig = 0.263									

Table 3. Spatial variations of the ecological indices of teleost fish assemblages in the Sea of Marmara, Türkiye.

Sites	*Haul point*	*Mean biomass ($kg{\cdot}km^{-2}$)*[*]	*S*	*N*	D_{Mg}	*H'*	*λ*	*J'*
S1	7	1745.4[a]	35	68498	3.054	1.460	0.362	0.411
S2	7	702.4[ab]	30	19446	2.937	1.557	0.335	0.458
S3	5	754.9[ab]	33	19413	3.241	1.518	0.312	0.434
S4	7	1135.7[ab]	35	25004	3.357	1.836	0.281	0.516
S5	3	1471.8[b]	29	9240	3.066	1.451	0.484	0.431
S6	6	817.2[ab]	35	7321	3.821	2.179	0.211	0.613
S7	4	982.6[ab]	33	5097	3.749	1.684	0.344	0.482
S8	4	922.8[ab]	34	6594	3.753	2.245	0.185	0.637
S9	5	841.0[ab]	36	9490	3.822	2.072	0.225	0.578
S10	4	825.3[ab]	36	9151	3.837	2.038	0.226	0.569
Total	52	df = 9; F = 3.34; $p < 0.05$	45	179254	3.637	1.814	0.282	0.477

[*]Superscripts denote comparisons between stations. S: Number of species at taxonomic level, N: Total number of individuals

were the stations characterized by the highest bycatch rates, with 37% and 33%, respectively (Figure 5).

4. Discussion

The results obtained from the assessment of fish assemblages in the SoM postmucilage provide diverse and varying compositions among species and stations, shedding light on the ecological dynamics within the SoM. A substantial portion of the retained catch consisted of target species above the minimum landing size and marketable bycatch, underscoring the importance of these species within the ecosystem. Species like *T. trachurus*, *M. merlangus*, *M. merluccius*, *T. mediterraneus* and *M. surmuletus* emerged as prominent contributors to the fisheries, showcasing crucial roles in the fish assemblages' structure. The presence of target species above the minimum landing size indicates that these species are potentially growing in the ecosystem. This situation is crucial as it signifies a certain level of ecosystem welfare and functionality supporting these species (Stergiou et al., 2009; Alonso-Fernández et al., 2021). Some species often play important roles in trophic dynamics, acting as predators, prey, or keystone species. These species might contribute to various ecosystem services, such as nutrient cycling, maintaining biodiversity, and supporting the overall health of the ecosystem. The presence of marketable bycatch and target species above the minimum landing size also suggests sustainable fishing practices (Yıldız and Ulman, 2020). This situation indicates that fishing activities are not excessively targeting juvenile or undersized fish, allowing populations to reproduce and maintain sustainable stocks. Marketable target species can influence the economic viability of fisheries operations and provide livelihoods for fishing communities.

The recorded heterogeny in biomass values among stations provide crucial insights into the varying biomass of fish assemblages across different regions in the SoM. Erdek Gulf notably stood out with the highest biomass, indicating a significant dominance of fish species in this specific region. Conversely, stations like the Marmara Islands and Bandırma Gulf exhibited notably lower biomass. These findings suggest that certain regions within the SoM might host more diverse and balanced fish assemblages compared to others, indicating potential ecological differences across different locations. Variations in fish biomass and distribution patterns across stations might reflect ecological zonation within the SoM. Certain regions might serve as hotspots for specific species due to specialized habitats or environmental conditions (Akoğlu, 2021). Stations exhibiting higher fish biomass values, such as the Erdek Gulf, might indicate healthier and more productive ecosystems in terms of supporting fish populations. Higher fish biomass often suggests better habitat quality, suitable environmental conditions, and availability of resources necessary for fish survival and reproduction. Differences in fish biomass among stations might be linked to variations in habitat quality, such as water quality, temperature, salinity, and availability of food sources (Barange et al., 2014; Sun et al., 2022).

Daban et al. (2021) during 2017–2018 provided valuable insights into fish assemblages in the SoM, offering a close approximation to the premucilage conditions. This study, adapted in methodology, depth ranges, and study framework, facilitates comparative analysis, shedding light on the potential effects of mucilage on teleost fish assemblages. Earlier studies were excluded from comparison due to their temporal limitations, confined geographical coverage, and limited depth (Eryılmaz, 2001; Altuğ et al., 2011; Torcu Koç et al., 2012). Comparative analysis revealed a sharp decline in species richness (26%; from 61 to 45 species) and a significant reduction in total teleost biomass (22%; from 1338.2 to 1040.9 $kg{\cdot}km^{-2}$) following the mucilage disaster. The comparison of the top ten dominant species by biomass (Table 4) indicated a decrease across pelagic assemblages, excluding

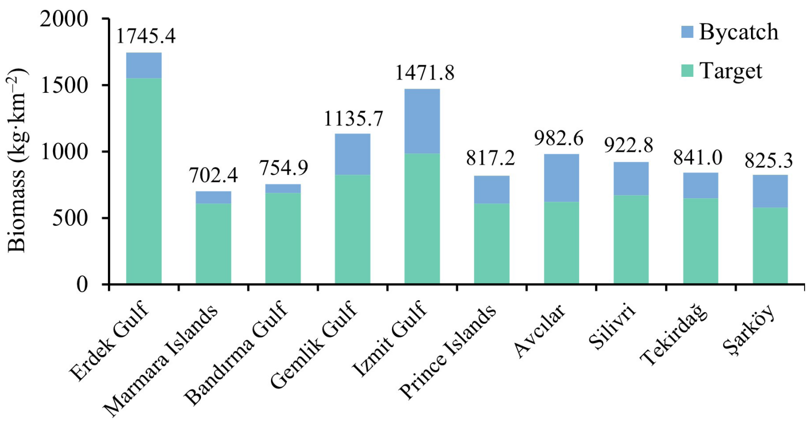

Figure 5. Spatial variation of target (green bar), bycatch (blue bar) and total biomass (numbers above the bars) of teleost fish assemblages in the Sea of Marmara, Türkiye.

Serranus hepatus. Intense fish mortalities attributed to hypoxia and gill clogging have been recorded during the peak period of mucilage (Karadurmuş and Sarı, 2022). Pelagic species such as *Engraulis encrasicolus*, *Sardina pilchardus*, and *T. trachurus* were severely affected by intense mortality, with a rate of 93%. These mortalities may have caused significant disruptions in pelagic populations and consequentially disturbed the food web, contributing to the observed biomass decline. Keleş et al. (2020) reported that the mucilage disaster in 2007 led to a notable decline in commercial landing, primarily impacting income from pelagic species (anchovy, mackerel, and sardine) by over 90%. Long-term official landing data from the SoM revealed a concerning trend: 22 commercial fish species extinct between 1967 and 2016, accompanied by a 90% decrease in catch per unit effort (Ulman and Pauly, 2016; Ulman et al., 2020). These trends resulted widespread reductions in fish size attributed to overexploitation (Ulman et al., 2020). The pressure on overexploited stocks may be further exacerbated by the possible effects of mucilage disaster. Recent study (Daban et al., 2023) also provided promising insights suggesting that the last mucilage disaster did not significantly impede recruitment success of fishes. Success of recruitment will contribute to the postmucilage restoration of shallow water assemblages affected by intense mortality. Contrary to the biomass decline in pelagic species, a noteworthy increase in benthic species biomass was recorded postmucilage. Although the recorded mortality rate among benthic species during the mucilage period remained low at 7%. While the mucilage did not visibly impact benthic species, it might have negatively impacted animal welfare by causing significant changes in zooplankton abundance and community structure, as recorded in the mucilage disaster in 2008 (İşinibilir Okyar et al., 2015). Considering the current state of overexploitation of demersal stocks in the SoM (Karadurmuş, 2022a; Karadurmuş, 2022b; Demirel et al., 2023; Karadurmuş and Sarı, 2024), it is crucial to emphasize the necessity for further studies focusing on postmucilage dynamics (such as growth rates, condition factor, reproduction, and mortality rate). These investigations are indispensable for a comprehensive understanding of the effects of mucilage on the multiple ecosystems and fish assemblages of the SoM.

5. Conclusion

This study, which conducted following the mucilage disaster in the SoM, sheds light on the discernible effects of the mucilage disaster on teleost fish assemblages, specifically pelagic species. In addition to overfishing (Demirel et al., 2023), eutrophication (Ediger et al., 2016), deoxygenation (Akçay and Yücel, 2023) and anthropogenic pressures (Tan, 2021) in the SoM, the effects of mucilage disaster on the ecosystem could cause cumulative damage on fish assemblages. The relative resilience of demersal species presents an opportunity for strategic conservation efforts. Compliance to the Marmara Sea Action Plan, a vital conservation effort spearheaded by the Ministry of Environment, Urbanization and Climate Change[4], stands as an obligatory precaution. Reducing marine pollution, promoting of sustainable fishing practices, and identifying strategic designation of marine protected areas are suggested as vital efforts for the restoration and conservation of fish assemblages in the SoM.

[4]Republic of Türkiye Ministry of Environment, Urbanization and Climate Change (2023). Marmara Sea Action Plan. [online]. Website https://webdosya.csb.gov.tr/db/cygm/icerikler/stratej-k-plan_marmara-20211216082358.pdf. [accessed 22 Sep 2023].

Table 4. Comparative results of teleost fish assemblages in the Sea of Marmara according to species richness (S) and biomass (kg·km^{-2}) pre and postmucilage disaster.

Taxa	**Premucilage 2017–2018 (Daban et al., 2021)**	**Post mucilage 2023 (This study)**	**Rate of change**
Species richness (S)	61	45 ↓	–26%
Biomass (kg·km^{-2})	1338.2	1040.9 ↓	–22%
Dominant species with biomass			
Trachurus trachurus	841.2	279.0 ↓	–67%
Sprattus sprattus	106.4	0.6 ↓	–99%
Merlangius merlangus	72.7	189.6 ↑	161%
Merluccius merluccius	71.7	148.4 ↑	107%
Engraulis encrasicolus	36.7	0.7 ↓	–98%
Trachurus mediterraneus	36.3	68.3 ↑	88%
Sardina pilchardus	35.6	4.8 ↓	–87%
Serranus hepatus	28.7	9.1 ↓	–68%
Pomatomus saltatrix	19.2	18.2 ↓	–5%
Chelidonichthys lucerna	15.7	43.3 ↑	176%
Mullus surmuletus	10.2	67.6 ↑	565%
Trigla lyra	8.5	24.7 ↑	190%
Solea solea	1.4	20.7 ↑	1409%
Lophius piscatorius	12.9	19.1 ↑	48%

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Conflicts of interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics
With the decision of the Official Gazette of the Republic of Türkiye dated 9 March 1997, the entire Sea of Marmara is closed to trawling fisheries. Trawling surveys were carried out with the permission decision dated 06.04.2023 and numbered 23592707-605.01.04.01-E.85711 and dated 18.08.2023 and numbered 23592707-619.03.01-E.99823 of the Ministry of Agriculture and Forestry. Ethical considerations were paramount throughout the research process. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. No shark and ray individuals were landed during the study, so formal consent is not required for this study.

Data availability
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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