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RESEARCH ARTICLE

Sea snot and its impacts on the fisheries in the Sea of Marmara and its adjacent waters

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Abstract

This study aims to reveal how the fishing sector was affected by the sea snot seen in the Sea of Marmara in 2021. For this purpose, an online survey was conducted in the Sea of Marmara and the surrounding provinces. In total 211 commercial or recreational fishers participated in the questionnaire and answered the questions between 30 May and 22 June 2021. All components of the fishing industry were affected by the sea snot at varying levels and suffered monetary loss. However, it is important for fishers to keep their catch records by official means on a regular basis, so that they can fully recover their loss. In the coming years, it is necessary to include the fishing sector in the monitoring of sea snot.

Keywords: Sea snot, fisheries, Sea of Marmara, mucilage

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Introduction

The Sea of Marmara shows variable biotic and abiotic characteristics under the influence of two different water systems, that is, the Mediterranean and the Black Sea. Its surface area is 11,500 km^2 and its coastline is 1,189 km. The northern shore is more indented and protruding than the eastern and southern shores. There are no bays and gulfs in the northern part. The southern side continues to the east as narrow and deep bays (Erdek, Bandırma, Gemlik, and Izmit Bays). The furthest distance between east and west is about 250 km, and the distance between south and north is about 70 km. The continental shelf in the south is wider than in the north (Beşiktepe *et al.* 1994; Polat 1995; Özsoy *et al.* 2000).

The Sea of Marmara forms the transitional environment between the Black Sea and the Mediterranean Sea. This unique marine environment exchanges waters with the Black Sea through the Istanbul Strait and with the Mediterranean Sea through the Çanakkale Strait (Gül and Demirel 2016). The Sea of Marmara is one of the smallest areas of occurrence of demersal and small pelagic stocks in the Mediterranean Basin. This is also known habitat for cetaceans and seabirds (Güçlüsoy *et al.* 2014; Tonay *et al*. 2017). The number of provinces bordering the Sea of Marmara is seven and this region constitutes approximately half of Turkey's population. Dense population creates intense pressure and the seafood can be sold at very high prices due to its high demand. Moreover, the fact that the Sea of Marmara constitutes the most important migration routes of highly commercial fish such as bonito and bluefish increases the importance of the region in terms of fish trade (Zengin 2012). It provides a living and spawning opportunity for many fish species in terms of temperature and salinity under the influence of the Black Sea-origin waters on the surface and the Mediterranean-origin waters in the lower layers (Ardel 1975). It is one of the richest regions of the Turkish seas in terms of fishing, with the straits system that directs pelagic fish migrating between the Aegean and the Black Sea in spring and autumn (Öztürk and Öztürk 1996).

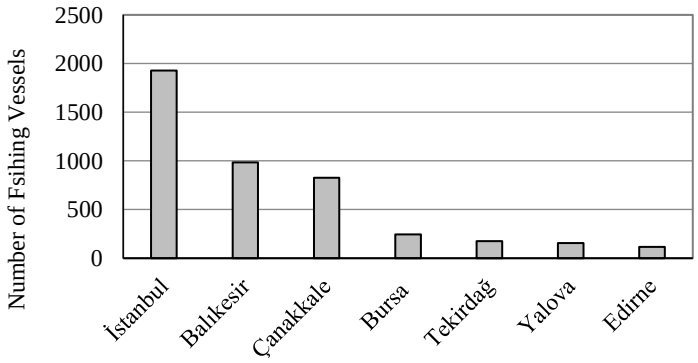

Figure 1. Number of fishing vessels registered in the provinces around the Sea of Marmara (BSGM 2021)

The general feature of coastal fishing is that there are fishing vessels that fish by following migratory fish. More than 90% of the fishing fleet is made up of small fishing boats engaged in daily fishing (Zengin and Mutlu 2000). Fishing vessels use the straits system as a natural fishing trap (Oral and Öztürk 2006). In the Sea of Marmara, fishing is carried out intensively on the coastline of Istanbul, Tekirdağ, Çanakkale, Bursa, Balıkesir, Kocaeli, and Yalova (Benli 2009). Approximately 4000 fishing vessels are registered to the provinces that have coasts to the Sea of Marmara (Figure 1). The majority of these vessels are small-scale fishing boats that are less than 12 m in length and coded as D license plate

(Figure 2). The Sea of Marmara accounts for 8.2% of the total fisheries fishing in terms of catch volume, 17.6% of the total fishing boats, 21.8% of the total fishers, 30.2% of the total fisheries cooperatives, 14.6% of the total fishing income (Doğan 2013). However, when the catch statistics of the last 20 years are examined, it is seen that the number of fishing vessels and the landed total catch tend to decrease (Figure 3).

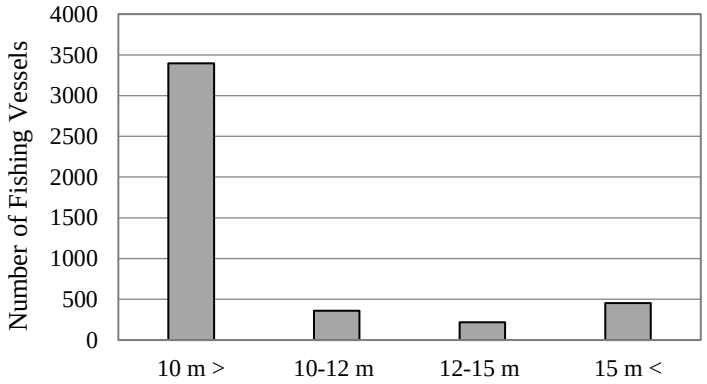

Figure 2. Number of fishing vessels by the size around the Sea of Marmara (BSGM 2021)

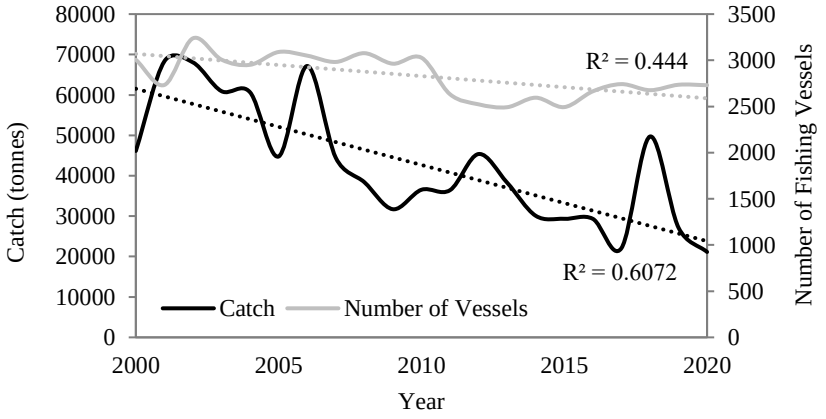

Figure 3. Number of fishing vessels and catch landed in the Sea of Marmara for the last 20 years (TÜİK 2021)

The Sea of Marmara is subjected to tremendous anthropogenic pressure through multiple uses and climate change (Yücel *et al.* 2021a). From the point of pollution, it is known that the Marmara coasts contain the densest residential and industrial areas of Turkey. The Sea of Marmara is highly exposed to pollution from domestic and industrial wastewater discharges, agricultural activities, ship

wastewater and atmospheric precipitation (Taşdemir 2002). Moreover, an adequate self-cleaning mechanism of the Marmara does not occur, especially due to the stratified structure and the amount of outflow limited by the straits (Özgür 2006). The Sea of Marmara has already had jellyfish blooms (Isinibilir 2014), algal blooms (Taş *et al.* 2016), decrease in oxygen (ÇŞB 2017), loss of its biodiversity (Ulman *et al*. 2020), and sea snot (Aktan *et al*. 2008) problems due to anthropogenic pressures and different sources of pollution. Among them, the sea snot formations can cause short-term economic loss in fishing, tourism, and aquaculture sectors as well as pollution in many coastal areas. Sea snot can be defined as the accumulation of white-brown colored and gelatinous matter that appears in a short time on the sea surface. Although the sea snot phenomenon and the reasons for its emergence are a complex subject, it can be said that sea snot is predominantly composed of organic structures consisting of carbohydrate-protein mixture (Yücel *et al.* 2021b).

The observation of sea snot events in the Mediterranean dates back to the beginning of the 1700s (Danovaro *et al.* 2009). In Turkey, sea snot was reported for the first time in the Sea of Marmara in September-October 2007 (Aktan *et al*. 2008). Recently in December 2020, the sea snot formation was scientifically recorded in the Çanakkale Strait over the colonial hard corals, gorgonians, coralligenous and sponge assemblages (Özalp 2021). Thereafter, Balkis-Özdelice *et al.* (2021) found that *Phaeocystis pouchetii* generates the mucilaginous foam in the Sea of Marmara. These foamy and filamentous formations affect the fishing operations quite negatively (Keleş *et al*. 2020).

Although the effects of sea snot on fisheries are less known but discussed by fishers and other stakeholders on different platforms, scientific studies on this subject are not sufficient. A detailed analysis of the effect of sea snot on the fishing industry is needed for planning future operations. Hence, in this study, an online survey was conducted with fishers in the region to understand the effect of sea snot seen in and around the Sea of Marmara on fisheries quantitatively for the 2020-2021 period.

Materials and Methods

Data on the effects of sea snot was collected from fishers by using an online questionnaire survey. The online questionnaire form can be easily visited through the following link (https://forms.gle/bqL4zSw4q2An1MuEA) without any user limitation. The fisher survey consists of 11 questions and the fishers were asked to mark the appropriate option(s) for them. Through questionnaires, fishers were asked when they noticed the sea snot, when they were affected, their monetary loss, what kind of damage they had on the fishing gear and the fishing vessel. Between 30 May and 22 June 2021, 211 online surveys were completed by 77 gillnet fishers, 61 hand-line fishers, 31 purse seine fishers, 30 beam-trawl fishers, 10 bottom and pelagic trawl fishers, and two stationary uncovered pound net

fishers . The Global Fishing Watch data provider system which combines tracking data from the publicly available automatic identification system (AIS) and integrate that with information acquired through vessel monitoring systems was used to determine the fishing areas in the Sea of Marmara (Global Fishing Watch 2021). In Global Fishing Watch online system, "Turkey" was used as a filter item and then fishing effort map was created by selecting a time interval.

The areas where sea snot spreads were obtained from the Sentinel-3 OLCI satellite which has a multi-device mission such as sea-surface topography, ocean color, sea and land surface temperature, and land color to detect in line with the operational needs of the Copernicus program (Sentinelhub 2021). Another task of this satellite is to provide ocean weather systems, environmental and climatic monitoring (OVL 2021). To figure out the sea surface areas occupied by sea snot online maps were used by selecting specific time interval.

A retrospective analysis was conducted to find some digital records which can be taken by any amateur or sport fisher before the sea snot appeared in the sea surface. For this analysis, the most popular social media applications (YouTube, Instagram, Facebook etc.) were checked backwards from June 2021 to September 2020. Besides, a google trend analysis, which is an online tool used to discover what topics are being searched all over the world, was performed to see the public awareness about sea snot.

Results

When did sea snot start and how did it expand?

Although it has been mentioned among fishers since November 2020, it was about the end of March 2021 that sea snot came to the fore, when it was seen in large masses on the surface of the Sea of Marmara (Table 1). In addition, a retrospective analysis reavealed that a spear fisher near Heybeliada in March 2021 filmed the sea snot underwater and posted it on the YouTube (Figure 4). When the google trend analysis was examined, it was seen that the terms "mucilage" and "sea snot" started to be searched on 14-20 March 2021 and peaked (around 100 search) on 6-12 June 2021. Then, at the end of May 2021, the sea snot was seen in the northern Aegean and western Black Sea, even around Samsun (Hurriyet Daily News 2021) and Ordu (Sözcü 2021) provinces in the central Black Sea as quite local events. Fishers in Kavala, Greece, noticed a thick, slimy layer of the mucus-like matter, floating off the coast of the town since April 2021 (Greekreporter 2021). In the last week of June 2021, sea snot was seen on the shores of the Greek island of Lemnos. A local manager, however, said "the slimy layers were phytoplankton that tend to appear every year due to the stillness of sea waters and high temperatures and appears every year and we can't connect it to (the sea snot in) the Sea of Marmara" (Reuters 2021).

Figure 4. Sea snot formations recorded by a spear fisher around Heybeliada in March 2021 (Şahintürk 2021)

Table 1. Proportions (%) of fishers based on the time when the sea snot was noticed and when it started affecting them

	Region		**Fishing gear**			
	East (N=118)	West (N=93)	Purse seine (N=31)	Beam trawl (N=30)	Gillnet (N=77)	Hand-line (N=61)
When did you notice sea snot?						
September 2020	18.56	15.22	7.69	10.34	16.22	15.56
October 2020	12.37	2.17	34.62	10.34	8.11	2.22
November 2020	13.40	19.57	11.54	37.93	9.46	11.11
December 2020	17.53	0.00	11.54	13.79	16.22	2.22
January 2021	25.77	15.22	30.77	10.34	21.62	11.11
February 2021	12.37	23.91	3.85	6.90	16.22	13.33
March 2021	-	6.52	-	3.45	5.41	13.33
April 2021	-	13.04	-	6.90	2.70	26.67
May 2021	-	4.35	-	-	4.05	4.44
When did you start to be affected by sea snot?						
September 2020	9.40	6.67	3.57	-	16.00	-
October 2020	7.69	2.22	10.71	7.14	6.67	9.09
November 2020	12.82	8.89	21.43	25.00	12.00	4.55
December 2020	8.55	4.44	14.29	10.71	6.67	4.55
January 2021	18.80	13.33	25.00	17.86	12.00	13.64
February 2021	11.11	22.22	14.29	21.43	18.67	4.55
March 2021	12.82	20.00	7.14	3.57	14.67	15.91
April 2021	11.97	11.11	3.57	14.29	4.00	29.55
May 2021	6.84	11.11	-	-	9.33	18.18

Fishing grounds and fishing effort in the Sea of Marmara

Since the Marmara Sea is an inland sea and is on the migration route of migratory species such as bonito and bluefish, fishers fish in this small sea, which functions as a natural big fish trap, wherever there is fishing opportunity. The Istanbul and Çanakkale Straits, the Marmara entrance of the Istanbul Strait, Gemlik Bay, Tekirdağ Bay, and the Marmara Archipelago are the most important fishing areas around the Sea of Marmara. In addition, it can be mentioned that fishing activities are more intense in the east of the system and the fishing effort is higher (Figure 5). According to the record of Global Fishing Watch, the total fishing effort performed in the Sea of Marmara was 10,022 and 10,413 hours for 2019-2020 and 2020-2021 fishing seasons, respectively (Figure 6).

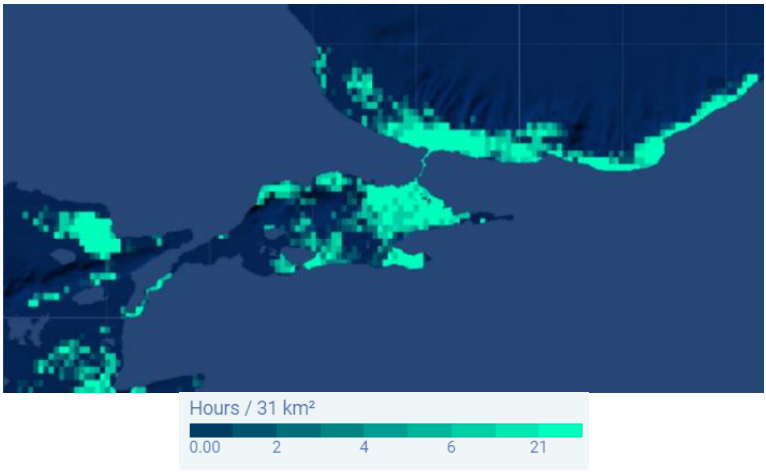

Figure 5. Fishing effort in the Sea of Marmara during 2020-2021 fishing season (Global Fishing Watch 2021)

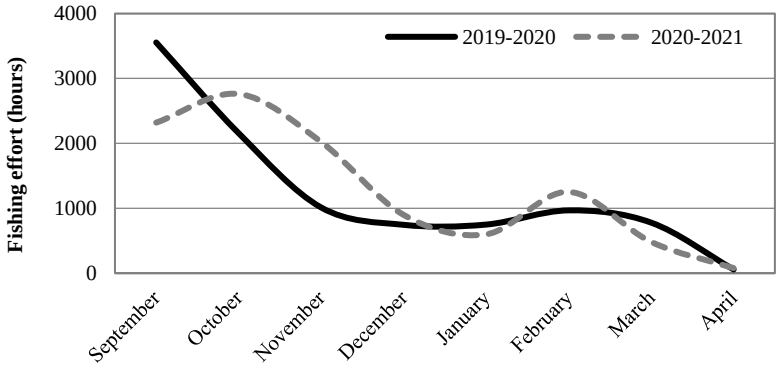

Figure 6. Total fishing effort as fishing hours in the Sea of Marmara (Global Fishing Watch 2021)

Dispersion area of sea snot

As shown in Figure 7, particularly in the Sea of Marmara, the sea snot can be seen with satellite images in almost all important fishing areas, starting from the shores to open waters of the Marmara Sea, İzmit Bay, Gemlik Bay, Erdek Bay, Marmara Archipelago, and Istanbul Princes islands. Among them, Izmit bay was most affected area (Figure 8). In the satellite images of 9 May 2021, it is understood that the sea snot on the surface spread towards Gökçeada, Bozcaada, and Limnos islands to the northern Aegean with the surface current of the Çanakkale Strait.

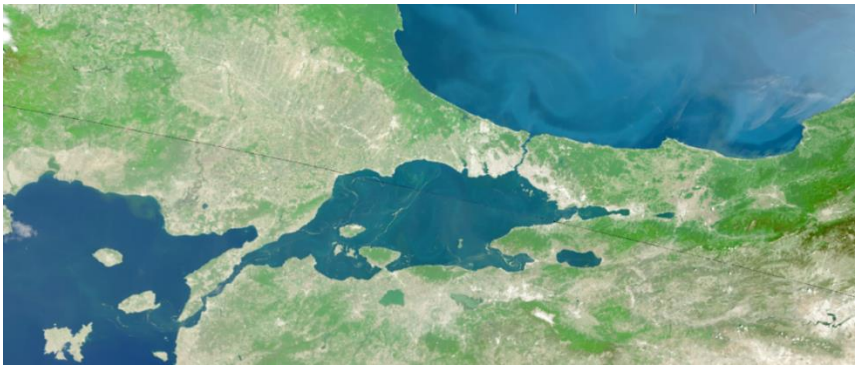

Figure 7. Satellite image of the Marmara Sea and adjacent areas on 9 May 2021 (Sentinelhub 2021)

Figure 8. Satellite image of Izmit Bay on 13 June 2021 (OVL 2021)

When did you notice sea snot and when did you start to be affected by sea snot?

As seen in Table 1, sea snot was noticed by the fishers in the east of the Marmara Sea one month before in the west. Sea snot was seen by the most fishers in the east in January 2021 and in the west in February 2021. Considering the fishing types, purse seine fishers were the first to notice and be affected by sea snot. It was the anglers who were the last to notice the sea snot and were the last to be affected. Purse seine fishers noticed sea snot in October 2020 and were mostaffected in January 2021.

Do you think that sea snot will affect the migration of bonito and bluefish?
It was found that 89.1% (188) of the fishers participating in the survey thought that sea snot would affect the spawning migration of bluefish and bonito to the Black Sea. Only two fishers stated that they had no idea about this issue. It is noteworthy that eight fishers were purse seine fishers among the 17 fishers who said no.

How was your fishing gear damaged by sea snot?
Purse seiners and gillnet fishers stated that the meshes of nets were mostly clogged (Table 2). However, more than half of the beam trawl and boat-seine fishers indicated that their nets became completely unusable. Anglers say that the hooks were mostly covered with sea snot and the fish were not caught by the hook.

Table 2. Proportion (%) of damage type based on fishing gears

	Purse seine	**Beam trawl and boat seine**	**Gillnet**	**Bottom and pelagic trawl**	**Stationary uncovered pound nets**	**Handline**
Meshes are clogged	70.83	36.67	59.42	20.00	50.00	-
Completely unusable	12.50	53.33	31.88	80.00	50.00	-
Lost in the sea	8.33	3.33	1.45	-	-	-
Head and lead line are covered	8.33	6.67	2.90	-	-	-
All of above	-	-	4.35	-	-	-
Hooks are covered	-	-	-	-	-	85.71
Line is covered	-	-	-	-	-	14.29

How was your fishing vessel effected by sea snot?
About 65% of the fishers pointed out that it was difficult to find fish with radar system, the cooling systems of the fishing boats were broken and the water circulation system was blocked (Table 3).

Table 3. Proportion (%) of type of damage to fishing vessels by sea snot

Type of damage	**%**
Harder to find fish with radar	9.65
Harder to find fish with radar + Water circuit is clogged	9.09
Cooling systems are affected	9.09
Cooling systems are affected + Harder to find fish with radar	1.70
Cooling systems are affected + Harder to find fish with radar + Water circulation is blocked	38.06
Cooling systems are affected + Water circulation is blocked	11.36
Water circulation is blocked	19.32
Propeller does not turn	1.70

Monetary loss caused by sea snot by fishing sectors?
Monetary losses for more than 70% of purse-seine fishers were over 100 K TL, for about 50% of the beam trawl and boat seine fishers were between 15 K and 35 K TL, for about 50% of the gillnet fishers were between 10 K and 25 K TL, and for 50% of the anglers were between 5 K and 10 K TL. These monetary losses cover low catch, gear damage, and cost for cleaning in fishing operations (Table 4).

Table 4. Proportion (%) of type of monetary loss caused by sea snot

Monetary loss (TL)	Purse seine	Beam trawl and boat seine	Gillnet	Handline	Bottom and Pelagic trawl	Stationary uncovered pound nets
5000 >	-	-	-	7.32	-	-
5000-10000	-	-	10.96	51.22	-	-
10000-15000	7.69	8.33	21.92	19.51	-	-
15000-25000	-	20.83	28.77	14.63	-	-
25000-35000	7.69	25.00	12.33	4.88	-	50
35000-50000	-	8.33	12.33	-	-	50
50000-75000	11.54	25.00	9.59	2.44	-	-
100000 ≤	73.08	12.50	4.11	-	100	-

Can you formally document your monetary loss?
Among the fishers who participated in our survey, 57 (27.01%) stated that they could officially document their monetary loss. They were nine purse seine fishers (Sea of Marmara), 15 beam trawl fishers (Sea of Marmara), 20 gillnet fishers (Sea of Marmara), seven bottom trawl fishers (western Black Sea), two big fish trap fishers (Saros Bay) and four others.

Do you expect financial support from relevant institutions?
Twenty-eight fishers (13.3%) did not expect any support from the relevant official institutions and all of them were those who cannot officially document their monetary loss. There was no any trend for this question in terms of fishing gear or regional category.

Discussion

Sea snot problem is clearly not a new phenomenon in the Sea of Marmara as it has been seen in the past (2007-2008) and no one can guarantee that it will not be seen in the future if adequate precautions are not taken. This study showed that the fishing industry in the Sea of Marmara has been negatively affected by sea snot at different levels for almost all its components.

During our online survey, some fishers claimed that the sea snot had been seen every year with increasing density since 1994. Some fishers also stated that it existed for 10 years but it was not intense and permanent until this year. Historically, in the past, the first sign of sea snot was recorded in 1958 as long

and continuous foam piles around Arnavutköy, Kandilli, and Küçüksu in the Istanbul Strait (Artüz 1958). Even earlier, in 1945, meshes of the boat seine nets were clogged by a substance like yogurt that is dark in color and sticks even to fishing hooks in the Istanbul Strait (Güler 1945). The author of the paper defined this material as "coagulum". Ecological events in the Sea of Marmara have been came across more frequently in the daily news these days. For example, in 2015, the satellite images of red algae growth (red algae bloom) in the Sea of Marmara took place in the world press. Fish deaths in 2017, stranding of red algae in the Sea of Marmara since 2019, the increase in *Salpa* colonies, and the latest increase in jellyfish invading the entire Sea of Marmara have been caused due to the fact that the Sea of Marmara starts to respond more quickly and sharply to sudden changes in the food web (Yücel 2021b).

Fishing was described by respondents as the weakest sector among tourism, transportation, urbanization, agriculture, industry and commerce according to a survey conducted throughout the Sea of Marmara. The main reason for this was emphasized as the pollution in the Sea of Marmara seriously reducing fish diversity (Türk 2008). Another important issue that makes fisheries weak is the situation of living resources in the Sea of Marmara. Concretely, in a recently published scientific study (Demirel *et al.* 2020), only sardine and horse mackerel stocks in the Sea of Marmara have not been overfished. In addition, according to Ulman *et al.* (2020) using catch data between 1967 and 2016, there are 19 extinct taxa and 22 commercially extinct taxa (56% of commercial species) in this small sea. Here, we should also indicate that the main reason of poor condition of stocks is clearly overfishing and Illegal, Unreported and Unregulated (IUU) fishing in this sea.

The fishing industry in the Sea of Marmara is vulnerable to environmental disasters. The industry has to save up in its own resources against such disasters. In addition, licensed fishers should be supported with interest-free loans and debts should be deferred during such disasters as sea snot. In the "Action Plan for the Protection of the Marmara Sea" announced by the Ministry of Environment and Urbanization, three items directly concern fishing; (i) all ghost nets in the Sea of Marmara will be cleared within one year, (ii) it will be ensured that fishing activities are carried out on an ecosystem basis, and protected areas will be developed, and (iii) financial support will be provided to fishers who are harmed by sea snot. In this respect, with the decision of the Presidency, within the scope of the program for the registration and support of traditional coastal fisheries, the amount of monetary support for fishing vessels in the provinces bordering the Sea of Marmara (Istanbul, Balıkesir, Bursa Kocaeli, Çanakkale, Tekirdağ and Yalova) was twice as much compared to other areas. During the present sea snot period, approximately 950 pieces of fishing nets were lost due to the sea snot problem (pers. comm. Erdoğan Kartal-Manager of Istanbul Region Fishery Union), these were mostly gillnets of small-scale fishers. These lost nets, so-called "ghost gear", must be retrieved from the habitat to prevent ghost fishing by these gears.

As sea snot affects the fishing industry in different ways, an important issue among them is increased workload. According to Murat Kul, a purse seine fisher and the head of the professional fishing committee of the chamber of commerce, purse seine fishers draw nets in 1 hour and 45 minutes under normal conditions, but this can go up to 4-5 hours with sea snot (Twitter 2021). On the other hand, gillnet fishers indicated that their workloads were at least doubled due to sea snot (pers. comm. Berke Yalçıntepe, a gillnet and beam trawl fisher). The clogging of the nets sometimes causes the net reels to be unable to lift the heavy fishing net. In addition to the increasing labor, the amount of fuel increases as the time spent at sea increases.

When considered within the scope of citizen science, fishers must be involved to develop as an early warning system in the coming years. At this point, according to the findings of this study, purse seine fishers in the Sea of Marmara were the group that could detect sea snot formation at the earliest. Since they are quite mobile, they fish in many areas and therefore their observation capabilities are much higher than other types of fishing. Spear fishers who have the opportunity to observe underwater due to the nature of their fishing can also be considered as a tool to record sea snot formations as early as possible. An online platform should be established to quickly collect and evaluate the data and images obtained individually by the "citizens" in an environmental disaster that is effective in such a large area.

It was also found that, traditionally, fishers do not record the catch amount, so they cannot officially prove their loss due to sea snot. However, Ministry of Agriculture established two digital systems, Fisheries Information System (SUBIS-2008) and Fishing Vessels Monitoring System (BAGIS-2016), to control and record the landed catch. These systems do not seem to work properly yet because most fishers indicated that they cannot show their catch officially. In relation to this, under the "landing obligation" implementation launched by European Commission with collaboration and exchanges between EU countries, fishers, NGOs, scientists, the European Parliament, and the European Fisheries Control Agency, all catches have to be kept on board, landed and counted against quotas (EU 2019). Fishers should declare their catch formally and more importantly landing system must be rearranged to make sure that all catches are formally recorded by management authorities. Inherently, fishers should request such a system in order to be able to prove their economic loss in any adverse environmental situation.

Another important issue affecting the fishing industry due to sea snot is the decrease in fish consumption. General public avoided seafood consumption due to the false media coverage that it might be risky to consume seafood produced in the Sea of Marmara (DoğruHaber 2021). It is necessary to investigate and to enlighten the public in detail whether the consumption of fish is harmful to human

health during sea snot events. As conclusion, it is hereafter necessary to include fisheries sector in monitoring of sea snot problem.

Deniz salyasının Marmara Denizi ve çevresindeki balıkçılığa etkileri

Öz

Bu çalışmada, 2021 yılında Marmara Denizi'nde görülen deniz salyasından (müsilaj) balıkçılık sektörünün nasıl etkilendiği ortaya çıkarılmaya çalışılmıştır. 30 Mayıs ve 22 Haziran 2021 tarihleri arasında anketler sonucunda 211 ticari ve amatör balıkçı anketlere katılmış ve sorulara cevap vermiştir. Yapılan analizlere göre balıkçılık sektörünün tüm bileşenleri değişik seviyelerde deniz salyasından etkilenmiş ve parasal kayıplara uğramıştır. Ancak, balıkçıların kayıplarını tam olarak karşılayabilmeleri için av kayıtlarının düzenli olarak resmi yollarla tutulması önem arz etmektedir. Önümüzdeki yıllarda deniz salyasının izlenmesi çalışmalarına balıkçılık sektörünün de dahil edilmesi gerekmektedir.

Anahtar kelimeler: Deniz salyası, balıkçılık, Marmara Denizi, müsilaj

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