Chapter 5

The White Disaster in the Seas Affecting the Sustainable Environment: Mucilage

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Abstract

Urbanization and industrialization, which come with population growth in the world and in Turkey, bring along various environmental problems. The liquid wastes of all cities, whether coastal or not, eventually reach the seas, and this pollution accumulates and becomes a big problem that cannot be cleaned naturally. These issues lead to the formation of mucilage, which is a natural phenomenon seen in oceans and seas, commonly referred to as sea snot or marine mucus. Mucilage, which threatens the ecosystem, causes serious damage to sea creatures and biodiversity. Through a bibliometric analysis, this study examines the formation process, causes, and environmental influences of mucilage events in the seas of the world and Turkey, and explores solutions for reducing mucilage. Findings present the significance of mucilage formation and discuss the necessary measures that should be taken to mitigate this issue.

1. Introduction

Global warming, seasonal differences, and human impact significantly affect the chemical and biological composition of seawater (Karadurmus & Sari, 2022). These changes disrupt the temperature balance of the seas, alter the structure of ecosystems, and threaten the habitats of marine life. Additionally, increased pollution from human activities negatively impacts the chemical composition of seawater, further deteriorating the health of ecosystems. This situation leads to serious problems which directly

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influence both marine life and human societies. As a consequence of these environmental changes, mucilage sea slime formation in the seas has become increasingly common in recent years (Isin & Efe, 2024).

Mucilage is formed as a result of the combination of various biochemical conditions. Comprising living organisms, dead cell debris, inorganic substances, and other components, mucilage is known as sea slime or marine mucilage and is a naturally occurring formation rich in organic matter. Mucilage forms in nutrient-enriched waters, where, under specific temperature conditions, the warming of the water surface leads to the excessive proliferation of single-celled organisms, which rapidly consume the available nutrients and then undergo mass die-offs, resulting in the formation of deposits (Koncagul et al., 2022). The occurrence of mucilage is affected by environmental situations such as seawater temperature, nutrient load (particularly nitrogen and phosphorus), and water stagnation (Arca, 2023). Mucilage is a mucus-like substance found in the seas, which largely covers the surface of the sea and underlying layers, exhibiting a gelatinous and colloidal structure (Kayhan & Ertug, 2022). This organic matter accumulates in the higher layers of the water column in different shapes. Those that reach the surface of the sea form layers with a gelatinous and spongy consistency can be up to 10 cm thick (Haciefendioglu et al., 2023). Mucilage begins to accumulate and spread through the water, covering the surface, and then dissolves and sinks to the seabed (Aslan et al., 2021). Mucilage can grow to massive sizes, covering hundreds of kilometers of coastline, and its spread can extend over vast areas, forming thick layers that can span hundreds of kilometers (Uflaz et al., 2021).

The study aims to emphasize the environmental impacts of mucilage and the harm it inflicts on sustainable marine ecosystems for the last four years through a bibliometric analysis. The adverse effects of mucilage pose an essential threat to the health of marine environments and negatively impact marine biodiversity. This study will explore the significance of mucilage formation and discuss the necessary measures that should be taken to mitigate this issue.

2. Literature Review

2.1. Mucilage incidents around the world

The first documented mucilage situation occurred in 1729 in the Adriatic Sea. Although it could not be fully identified at the time, it was classified as marine pollution due to its tendency to cover fishing nets. A similar phenomenon was observed in New Zealand during the 1860s. Since then,

multiple mucilage events have been intermittently reported in these regions (Koncagul et al., 2022). Subsequently, due to population growth, the expansion of agricultural land, increased use of fertilizers, and domestic and industrial wastewater discharges, there has been an accumulation of nutrients such as phosphorus and nitrogen in aquatic environments, while global warming has further exacerbated this by increasing water temperatures. The combination of these factors has led to the occurrence of mucilage events worldwide. Since 1973, numerous mucilage incidents have been observed in destinations such as the North Sea, the Adriatic Sea, the coasts of Italy, and the Gulf of Mexico (Yilmaz & Saler, 2023). In Figure 1, the spread area and duration of mucilage events in the Mediterranean and surrounding regions from the 1800s to 2007 are presented chronologically, as visualized by Danovaro and his colleagues.

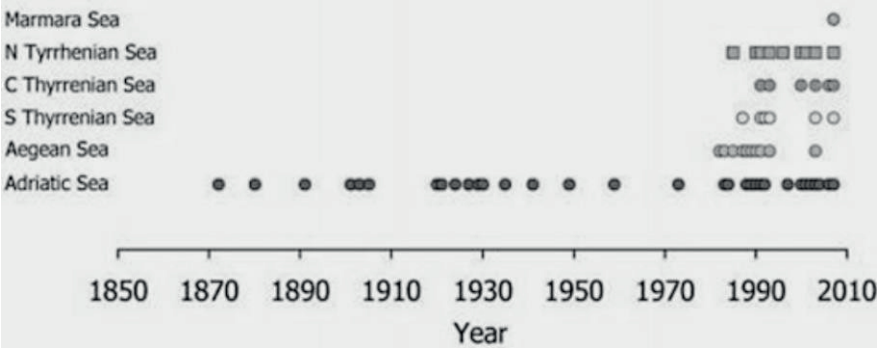

Figure 1: Mucilage occurrences documented in and around the Mediterranean until 2007 (Danovaro et al., 2009)

Mucilage events have been seen in different geographical destinations around the globe, besides the Adriatic and Tyrrhenian Seas. Examples of locations where mucilage occurrences have been documented include the Eastern Mediterranean, the North Sea, New Zealand, and the East China Sea (Kavzoglu et al., 2023).

2.2. Mucilage incidents in Turkey and their effects in industries

The Marmara Sea holds significant scientific importance due to its geological structure and strategic location. Formed approximately 5-20 million years ago, this inland sea allows the mixing of the waters from the Black Sea and the Mediterranean, which have distinct hydrological and physical properties, through the Bosporus. The Marmara Region, with 7 provinces and a population of 25 million, accounts for a large portion of

Turkey's industrial production, is characterized by intensive agricultural activities, and experiences high urban transit usage daily, as well as heavy maritime traffic (Once & Yilmaz, 2024). The provinces in the Marmara Region contribute to the increasing pollution by discharging industrial and urban wastewater into the Marmara Sea. The first mucilage situation in Turkey was seen in 2007 in the northeastern part of the Marmara Sea. While mucilage naturally occurs in the Marmara Sea and worldwide, it was for the first time in 2007 that such large-scale accumulation of this substance was noticed in specific spots of the Marmara Sea (Kavzoglu et al., 2023). Years later, mucilage reoccurred in the Marmara Sea in late 2020 and started accumulating on the surface in April 2021. The mucilage event negatively affected marine operations and fishing activities in the Marmara Sea. Within approximately two months, the phenomenon reached alarming proportions (Figure 2 and Figure 3). Mass mortality of several invertebrate species was observed in both coastal and deep waters. These effects were particularly fatal for fish and shellfish species (Karadurmuş & Sari, 2022).

Figure 2 and Figure 3: Mucilage samples on water surface in the Marmara Sea (Karadurmuş & Sari, 2022)

During periods of calm weather, mucilage spread from the Gulf of Izmit to the Dardanelles Strait; it was observed to be thicker and longer-lasting in the Gulf of Izmit that is affected by heavy sector and has low water circulation compared to the rest of the Marmara Sea. In 2021, the regions where mucilage was seen within the Turkish Straits System, particularly in the Marmara Sea, are presented in Figure 4 (Uflaz et al., 2021).

Figure 4: The spots where mucilage was seen in 2021 in the Turkish Straits System (Uflaz et al., 2021)

The mucilage problem is expanding to larger areas and increasing in intensity each day. As a result, the influences of mucilage are also spreading, leading to more significant negative consequences. Based on the report of Istanbul Technical University (Ozturk et al., 2021), the influences of mucilage are: 1. Aquatic life extinction; 2. Tourism activities; 3. Fishery; 4. Maritime transports and ships, and; 5. Emission of hazardous gases into the atmosphere.

In a broader perspective, mucilage influences the environment and the industries in several ways, such as the destruction of mucilage to fish populations and aquatic life (Sari & Karadurmus, 2024), reducing water quality, perishing of many marine organisms, the fishing industry and adverse effects on tourism (Sefercik et al., 2024; Soydan et al., 2024; Yilmaz & Saler, 2023), and mucilage arising from marine pollution in addition to intensified industrial activities, inadequate wastewater treatment, and environmental pressures, microplastics causing mucilage, oil spills and waste from vessels (Kilinc et al., 2025; Alam, 2023). Especially where mucilage is visible, swimming and other water activities in coastal areas and tourism facilities covering sports preference is decreasing, in this sense sustainable tourism is negatively affected (Palteki, 2021) while considering Turkey as a key global tourism region, with marine tourism conducing to the total tourism income (Baltaoglu, 2025).

Therefore, mucilage has both direct and indirect influences on the environment, human health and several industries (Ocak & Saysel, 2025). It causes significant harm to marine ecosystems by reducing oxygen levels, which threatens marine life, leads to fish deaths, and reduces the habitat areas of other marine species. Additionally, mucilage accumulation exacerbates water pollution, negatively impacting sectors such as tourism

and fisheries. The intensification of mucilage also affects maritime transport by complicating ship movements and obstructing sea traffic at certain ports. Furthermore, the decomposition of mucilage releases harmful gases into the atmosphere, contributing to air pollution, which can lead to environmental and health issues (Palteki, 2021).

3. Methodology

The method in this review consists of a comprehensive literature search and synthesis aimed at determining the significance of mucilage events, how and where they occur, and what potential solutions could be proposed. A systematic approach was primarily used to select studies that met predefined criteria (author names, short titles of research studies, publication dates, techniques that are used in the research, and important research findings), through a bibliometric analysis.

The data collection was held between 20 November 2024 and 05 January 2025. A thorough electronic database search on Google Scholar was conducted using the identified keywords: "mucilage", "sea snot", "marine mucilage", "clean water", "climate change", and "sustainability" along with most-cited research studies in the literature. Moreover, manual searching was performed by reviewing the reference lists of key studies and current reports. The search was conducted in both English and Turkish, and only studies published in 2021 and subsequent years (January, 2025) were considered. Finally, a total of 20 fundamental studies have been examined. The steps for the bibliometric analysis in the study are as follows:

1. Determining the key words concerning mucilage
2. Data base search
3. Data collection from fundamental studies
4. Data analysis with MS Excel
5. Description of data from study findings

4. Findings and Discussion

Table 1 below presents 20 key research articles containing author names, short study titles, publication dates and study's methodology and study findings, published between 2021 and 2025 on the subject of mucilage, analyzing the changes in proposed solutions to prevent mucilage over the years.

Table 1: Bibliometric analysis

AUTHOR NAME	*TITLE*	*PUBLICATION DATE, METHOD*	*KEY FINDINGS*
1. Uflaz et. al.	Impacts of mucilage on maritime operation	2021, Risk analysis approach	To prevent mucilage, it is necessary to improve wastewater treatment quality, strengthen legal measures, increase inspections, and expand training programs. Additionally, to prevent pollution from ships and marine vessels, remote monitoring systems, national and international regulations, and effective pollution control tools should be used.
2. Palteki	The visible face of marine symptoms: Mucilage	2021, Qualitative assessment	To reduce pollution and nutrient load in the seas, untreated discharge of nitrogen and phosphorus should be prevented, and buffer zones should be created. Measures to prevent ship discharges should be implemented, monitoring points should be increased, and 24/7 online monitoring and early warning systems should be activated.
3. Akturk & Hauser	Sea snot as a sign of climate change	2021, Observation and expert opinion assessment	Water management relies on stakeholder cooperation and requires transboundary policies to address pollution and climate change. UNESCO-IHP International Water Quality Initiative emphasizes the global importance of water and wastewater management and stresses the need to extend cooperation beyond local pollution. This initiative encourages local stakeholders to monitor the seas and prevent the recurrence of mucilage beyond its removal.
4. Yildiz & Gonulal	Sea snot and its effects on fisheries	2021, Survey	Fishermen should be included as part of a citizen science-based early warning system to detect mucilage formations early. Coastal fishermen and spearfishermen who observe the underwater environment can detect mucilage at an early stage.

5.	Ozkul & Sivrikaya	Sustainable Development Goals 6: Clean Water and Sanitation	2022, Interview	For the first time in Turkey, a system implemented in Kocaeli has made it mandatory for all operating septic trucks (vacuum trucks) to be integrated into the system. This system ensures the proper transportation of liquid waste, prevents illegal dumping, determines the amount of waste, prevents the mixing of different liquid wastes, and ensures that any adverse situations are reported to the monitoring authorities for immediate intervention. The transfer of liquid waste is monitored online.
6.	Tuzcu et al.	Detection of mucilage in the Marmara Sea	2022, Satellite images, field photos and survey	The sea surface temperature increase illustrates a likely relation with mucilage formation and recommend a repeating mucilage event soon.
7.	Koncagul et al.	Formation and the influence of mucilage in Marmara Sea	2022, Case study	A directive on the restriction of discharge standards has been published in the scope of the Marmara Sea Action Plan. In this context, in all of the provinces of Istanbul, Bursa, and Kocaeli, a restriction of 20% has been applied to the Chemical Oxygen Demand parameter for municipal wastewater, and approximately 50% restriction has been applied for industrial wastewater in wastewater treatment facilities.
8.	Karakulak et al.	Impacts of mucilage on the fisheries	2023, Survey	Effective monitoring of fishing activities plays an important role in preventing mucilage. To prevent overfishing, protect fish stocks, and manage marine ecosystems sustainably, fishing activities must be kept under strict control.
9.	Yilmaz & Saler	The silent cry for help of our sea: mucilage	2023, Case study	A risk analysis should be conducted for ship-generated wastewater pollution, a three-dimensional dispersion model should be created, and a remote monitoring system should be developed to control illegal discharges. Remote sensing tools can effectively detect this, and redirecting current investments towards these technologies will be beneficial for developing sustainable water management strategies.

10.	Yumun et al.	Causes of mucilage formation and solution suggestions	2023, Quantitative analysis	To prevent mucilage, increasing water flow is important to reduce water pollution in the seas. For this purpose, natural or artificial water channels should be created to supply clean water, helping to dilute pollution and improve seawater quality.
11.	Haciefendiog-lu et al.	Deep learning-automatic detection of mucilage event	2023, Quantitative analysis	The detection of mucilage formation is important due to the increase in bacterial activity and the possibility of early intervention. Deep learning methods were used to detect mucilage spots. However, the exact size of the mucilage spot was not determined, only its presence and location were identified. In the future, if the extent of the mucilage-covered area can be detected remotely, intervention plans can be made without the need to visit the site.
12.	Alam	Land-based marine pollution	2023, Case study	The study identifies sources and impacts of land-based pollutants and discovers obstacles of the current regime for land-based marine pollution control in Bangladesh.
13.	Yilmaz et al.	Marine mucilage	2024, Quantitative analysis	The findings revealed the effectiveness of water related indices in mucilage mapping and formations, using deep learning model. The applied CNN model enabled automatic detection and monitoring of mucilage formation in marine environments. The model predicted marine surface mucilage formations with 96% accuracy.
14.	Kahraman	Multi-Stakeholder sustainable environmental management	2024, Case study	The Marmara Sea Action Plan (MSAP) is emphasized, highlighting the importance of public-private partnerships and legal regulations in wastewater treatment plants. Urban infrastructure should be strengthened, and appropriate facilities for industrial wastewater should be built. Wastewater reduction and reuse play a critical role in environmental improvement. Pre-treatment systems should be installed in industrial areas with insufficient facilities.

15.	Gundogdu et al.	Comparing microbial communities in mucilage and seawater samples	2024, Quantitative analysis	The relation between the microbiome and mucilage formation is being investigated. Unidentified readings in water samples before and during mucilage outbreaks highlight the role of unknown microbial taxa. As a result, a deeper investigation of microbial composition and ecological roles is required. In this study, the marine microbiome remains insufficiently explored. Early detection of microbial community changes could help in combating mucilage outbreaks.
16.	Karadurmus & Sari	Marine mucilage	2024, Observation	Lots of deaths in the Marmara Sea are likely to have negative impacts soon, specifically on the food web due to mucilage.
17.	Sefercik et al.	Evaluating physical and chemical features of marine mucilage	2024, Quantitative analysis, new method developed	A methodology has been developed for the detection of mucilage with the aid of remote sensing methods by considering the current mucilage occurrence in the Marmara Sea.
18.	Soydan et al.	Marine mucilage bio-composite films	2024, Collection of mucilage, experiment	A robust and biodegradable film having UV protection and antibacterial activity was created from marine mucilage bio-waste.
19.	Kilinc et al.	Biological and chemical characterization of marine mucilage	2025, Quantitative analysis	Findings state that electricity can be generated using marine mucilage in single-chamber microbial fuel cells.
20.	Ocak & Saysel	Deep-Sea discharge project and failure of environmental protection	2025, Case study	The shift in from local to central authorities obstructed comprehensive participation in planning and had a key role in the failure of environmental protection in Ergene Basin.

In 2021, various measures were emphasized to prevent marine mucilage. It was stated that improving treatment quality, strengthening legal regulations, increasing inspections, and expanding education were necessary. Additionally, remote control systems and the effective implementation of rules were highlighted to prevent ship-based pollution. With early warning systems and online monitoring platforms, marine pollution should be continuously monitored, and fishermen should also be included in the system. This aims to achieve an effective fight against pollution at both local and global levels. In 2022, it was observed that the issues emphasized in 2021 were put into action. The septic tank integration system implemented in Kocaeli helps prevent environmental pollution by ensuring the proper transport and

monitoring of liquid waste. Moreover, the processes have become more transparent with online inspection. Under the scope of the Marmara Sea Action Plan, discharge restrictions in Istanbul, Bursa, and Kocaeli provinces are an essential step for the preservation of water resources. The adoption of such measures by the local population and industry is critical for success.

In 2023, the addition of new solutions to those implemented in 2021 shows significant progress in the fight against mucilage. Measures such as effective monitoring of fishing activities, increasing water flow, and creating clean water channels contribute to improving seawater quality and preventing the formation of mucilage. With advancing technology, the use of deep-learning techniques for mucilage detection accelerates intervention processes and enhances the efficiency of fieldwork. These developments are important steps for achieving a sustainable marine ecosystem.

In 2024 and 2025, it was observed that mucilage could not be completely prevented, and efforts to address this issue are still ongoing. Despite significant progress in early detection and monitoring of mucilage through artificial intelligence and other technological innovations, efforts to protect marine ecosystems continue. More research and collaboration are needed to eliminate marine pollution and prevent mucilage. This process stands out as an area where both technological developments and increased public awareness are crucial along with the support of stakeholders such as local authorities, coastal tourism establishments, and government authorities.

In terms of understanding used techniques in the research studies, nine studies used a quantitative technique and only five studies preferred the case study technique. Interviews with first-hand data providers are not very much preferred by the researchers. In the following years after 2025, more interview techniques and qualitative analysis with the field experts are expected. In sectoral perspectives, more research concerning mucilage and tourism-related activities, and pilot studies in mucilage incidents influencing coastal tourism activities and future tourism potential in specific destinations, especially in Turkey, are also expected.

5. Conclusion

This exploratory study examined the formation process, causes, and environmental influences of mucilage events in the seas of the world and Turkey, and intended to explore solutions for decreasing mucilage by investigating fundamental studies concerning mucilage in the literature through a bibliometric analysis.

As a consequence, the mucilage problem is a complex environmental issue that threatens the health of marine ecosystems and negatively affects water quality and industries like coastal tourism. The excessive load of nutrients, particularly the collection of phosphorus and nitrogen, is among the main causes of mucilage. The uncontrolled discharge of these nutrients into the seas has led to mucilage becoming a persistent problem. To prevent mucilage, it is important to continuously monitor the nutrient load in seawater and analyze its effects with a scientific approach. However, solving this issue should not be limited to technological advancements alone; environmentally friendly policies and sustainable management methods in related industries must also be implemented. As of 2024 and 2025, it has been observed that mucilage has not been completely eradicated, and efforts to address this issue are still ongoing at both the national and international levels. This indicates that mucilage is a complex and multi-dimensional problem, and its solution will take time.

The study has some limitations. This compact study only focuses on the mucilage problem in the seas and its impacts on the ecosystem through a bibliometric analysis for the last four years by using selected and most-cited studies in the field. An effective solution to mucilage requires a multidisciplinary approach. Scientists, academics, public officials, sectoral stakeholders (tourism- resort hotels, coastal establishments, water sports facilities such as surf centers and manufacturing sector, etc.), and all segments of society must collaborate to address this key issue. Moreover, monitoring the impacts of mucilage should be carried out regularly, taking into account seasonal changes, and solution strategies should be developed based on the data collected. Raising environmental responsibility awareness, creating public consciousness, and developing sustainable solutions will reduce the effects of mucilage and ensure the continued health of marine ecosystems. As of 2025, it is clear that the effects of mucilage are still significantly felt, and more research and cooperation are needed for a solution. This holistic approach not only serves to protect existing ecosystems but also guarantees the right of future generations to live in a clean environment.

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