Mar. Sci. Tech. Bull. (2024) 13(2): 124-134
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1466847

Marine Science and Technology Bulletin

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RESEARCH ARTICLE

The presentation of the risks that oil pollution poses to aquaculture

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ARTICLE INFO

Article History:
Received: 08.04.2024
Received in revised form: 31.05.2024
Accepted: 14.06.2024
Available online: 24.06.2024

Keywords:
Fish farm
Food security
Risk management
Marine pollution

ABSTRACT

Aquaculture has emerged as the most rapidly growing technology for food production on a global scale. The current growth trajectory of aquaculture production surpasses that of all other meat production types and is anticipated to persist in its ascent with the continuous expansion of the agriscience industry. The contribution of aquaculture to food security varies based on species and country, either directly through domestic consumption or indirectly through the stimulation of economic growth via exports. In Türkiye, the share of aquaculture in overall production has increased over the years and has become a significant contributor to the country's economic development through exports. Fish farms concentrated in the Eastern Black Sea and Southern Aegean regions also draw attention due to their proximity to sea areas with intense maritime activities. Potential marine pollution in these regions poses a serious risk to these economically important resources, making it crucial to predict the extent of this risk in advance and take preventive measures. This study aims to simulate, through a scenario, how a possible oil spill in the Southern Aegean region would spread in the sea, how quickly it would reach the fish farms in this region, and how long it would take to impact the fish population to a certain extent. The values derived from this simulation will shed light on intervention plans to be implemented by both local and central authorities, serving as exemplary models for formulating similar plans for all aquaculture resources.

Please cite this paper as follows:

Aşan, C. (2024). The presentation of the risks that oil pollution poses to aquaculture. *Marine Science and Technology Bulletin*, *13*(2), 124-134. https://doi.org/10.33714/masteb.1466847

Introduction

The escalating global population, advancements in technology, and the globalization of fisheries marketing have recently resulted in a significant increase in fishing capacity, which in turn has triggered overfishing pressures on natural resources by expanding fishing fleets in various regions worldwide (Watson et al., 2013). Consequently, since the late 1980s, this has led to the attainment of limits on aquatic product

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reserves, culminating in a decrease in the quantity of catch in the seas. In 2019, the proportion of fish stocks maintained at biologically sustainable levels diminished to 64.6%, marking a decline of 1.2% from 2017. The total output of global capture fisheries in 2020 amounted to 90.3 million tonnes, valued at an estimated USD 141 billion. This total includes 78.8 million tonnes harvested from marine environments and 11.5 million tonnes from freshwater sources, representing a decrease of 4.0% compared to the average yield of the preceding three years. Conversely, global aquaculture production reached an unprecedented level of 122.6 million tons in 2020, encompassing 87.5 million tons of aquatic organisms, which were valued at USD 264.8 billion (FAO, 2022).

According to scientific research, it is anticipated that investment in aquatic products will continue to expand in the coming years. This trend underscores the increasing significance of the world's oceans and inland waters with each passing day. While aquaculture is projected to become a sector with high potential in the future, the sustainability of this growth necessitates implementing environmental measures to protect water resources and ensure their planned utilization.

In Türkiye, as is the case globally, aquaculture is increasingly gaining importance and is experiencing an average annual growth rate of 8%. Over the last decade, total production from aquaculture has surged by 99%, while production through fishing has witnessed an average annual contraction of 2.3%. In 2012, aquatic product production through fishing amounted to 433,000 tons, and aquaculture accounted for 213,000 tons. By 2022, these figures had reversed, with fishing production at 335,000 tons trailing behind aquaculture's output of 515,000 tons (AEPDI, 2023). As of 2022, aquaculture production in Türkiye, accounting for 60.5% of total fisheries production, has predominantly occurred at sea (72%) with the remaining 28% taking place in inland waters. The most significant species cultivated include trout in inland waters, with a production volume of 145,649 tons, and at sea, sea bass and sea bream with productions of 156,602 tons and 152,469 tons, respectively (TUIK, 2023). The key provinces involved in marine aquaculture around Türkiye's coasts are illustrated in Figure 1.

In the marine aquaculture sector, 39% of production takes place in Muğla, with the entirety of this output comprised of sea bass and sea bream (TUIK, 2023).

In line with global trends, aquaculture in Türkiye significantly contributes to economic growth, with its proportion of the Gross Domestic Product (GDP) increasing steadily. This has heightened the sensitivity towards marine pollution, underscoring the need to safeguard this sector. The susceptibility of aquaculture farms to potential marine pollution can be mitigated with the aid of previously established contingency plans and preventive measures.

Figure 1. The major aquaculture regions around the Turkish seas (TUIK, 2023)

In the literature, the focus has predominantly been on the marine pollution generated by the aquaculture industry and its effects on ecological balance. However, Kayhan et al. (2009) examined the potential general health issues, stress, and consequent biological responses in aquatic organisms caused by the accumulation of toxic heavy metals. Tacon (2020) who has analyzed trends in global aquaculture and aquafeed production between 2000–2017 emphasized that future efforts in the aquaculture feed industry, supported by governmental initiatives, should prioritize the utilization of locally sourced, nonfood grade feed resources over the reliance on imported, potentially food-grade inputs. This approach is essential to guarantee the long-term economic viability and ecological sustainability of the aquaculture sector. Subasinghe et al. (2009) explored the role of aquaculture, predominantly driven by small-scale farmers, in promoting sustainable development, alleviating poverty, and enhancing global food security. Hu et al. (2020) provide a comprehensive summary of research advancements over the past two decades, focusing on four key areas: the acquisition and pre-processing of water quality factors, the prediction of water quality factors, the analysis of fish morphological characteristics, and the recognition of fish behavioral characteristics, as well as the mechanisms linking fish behavior to water quality factors. Cai et al. (2010) establish a conceptual model that identifies the links between various threats such as human activities, self-pollution, chemical misuse, and climate changes to the marine aquaculture ecosystem, highlighting these as significant risks. Döndü et al. (2024) emphasize the impact of thermal power plants and aquaculture on the mobility of heavy metals affecting marine life and aquaculture. Offering insights into the redox regulation of fish, Wang et al. (2024) addresses how environmental pollution endangers fish populations and the healthy development of marine aquaculture. By focusing on sustainable marine living resources, Ha (2024) discusses the sustainability of capture fisheries, shellfish aquaculture, and marine aquaculture. To investigate the harmful effects of pesticide pollution on aquaculture, Zhao et al. (2024) look into cypermethrin's comprehensive effects on the aquatic system. Carballeira Braña et al. (2021) delineate the primary ecological concerns associated with marine finfish aquaculture, detailing the interactions between aquaculture practices and environmental health, and underscores the adoption of sustainable methodologies in the sector. They emphasize the importance of rigorous environmental monitoring, strategic siting of aquaculture operations, and the minimization and repurposing of waste and chemicals, as fundamental measures to sustain and expand aquaculture production in an environmentally responsible manner. Green (2016) assesses the effects of conventional and biodegradable microplastics at different concentrations on aquatic ecosystems through outdoor mesocosm experiments that mimic semi-natural conditions. It focuses on whether these microplastics would impact the physiological functions and growth of European flat oysters, alter the diversity and density of macrofauna in oyster habitats, and change the biomass of benthic algae. Emenike et al. (2022) examine the sources, impacts, and remediation strategies for heavy metal pollution in aquaculture, based on literature from academic databases. It underscores the risk posed by enduring heavy metals such as mercury, lead, and cadmium, which build up in the food chain, threatening the viability of aquaculture. The paper explores the use of mitigation methods like adsorption, bio-sorption, and phytoremediation to tackle such contamination.

The purpose of this study is to simulate the impact of an oil spill in the Aegean Sea on aquaculture farms located in the southwestern region of Türkiye, with the intent to determine the time it takes for the pollution to reach these farms and to quantify the rates of fish loss over time as a consequence of this pollution. Considering the fish farms established in the seas surrounding Türkiye, the region around Muğla province stands out for having the highest share of production. Therefore, the sea area chosen as the basis for this study is the marine region located between Güvercinlik and Göltürkbükü in the Bodrum district of Muğla province, as indicated in Figure 2.

For this purpose, the Potential Incident Simulation, Evaluation, and Control System (PISCES-II), a decision support system, is employed to simulate the scenario. This simulation projects the spread of oil and establishes a timeline for their reach at Environmentally Sensitive Areas (ESA) which contain aquaculture sites, assesses the ensuing percentage of all died bions for each species as well as the current number of species bions for the given time. This research provides a framework that allows aquaculture farms, increasingly valuable economically, to develop emergency response plans for marine pollution. Consequently, each aquaculture region can create its contingency plan, tailored to the specific type of product and the dynamics of its marine area.

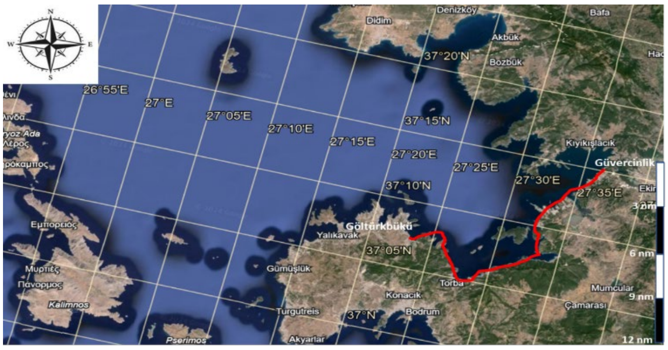

Figure 2. Fish farms region between Güvercinlik and Göltürkbükü (Google Earth, 2024)

Material and Methods

The study aims to reveal how long and to what extent the fish farms located on the coasts of Aydın province in the southeast of the Aegean Sea of Türkiye will be polluted in a possible marine pollution in the framework of a case scenario. For this purpose, the scenario, together with meteorological and oceanographic conditions, was loaded into PISCES-II, an oil spill simulation and decision support system. As a result of the study, it was revealed how the oil will spread within a time period of 60 hours from the beginning of the pollution, how long it will reach the fish production farms and at what rate it will cause fish losses. PISCES-II illustrates both the oil spill's scale and its consequences on fish populations, emphasizing the importance of precise and actionable findings. Given its comprehensive output capabilities, the PISCES-II simulator is ideally suited for this study's objectives. It models the spread of oil, its evaporation, dispersion, sedimentation, and interaction with coastal areas, alongside detailing the deployment of intervention resources like booms, skimmers, and dispersants. In evaluating oil spill models, while wind conditions are considered significant, they are secondary to surface currents, which are the primary determinants for accurate simulations. According to Fingas (2014), surface currents account for 97% of the spill's direction, compared to the wind's 3%. For this study, the winter season was chosen to simulate a worst-case scenario using the PISCES-II simulator, which incorporates both built-in surface current models and additional data from the Turkish State Meteorology Service, highlighting the critical role of morphological changes and currents in affected areas.

Average annual data for weather and seawater temperatures, along with wind conditions, and sea-surface current data, sourced from the Turkish State Meteorology Service (TSMS) and previous studies, were entered into the PISCES II simulator as foundational data. The research modeled the scenario where a 2,500 tons oil spill affected a fish farm that has one million sea bream fish, using these conditions as a basis for the simulation. The initial parameters for the simulation are detailed in Table 1.

Aquaculture and its Role in Global Seafood Production

Notwithstanding notable advancements, the global community is not on pace to eliminate hunger and malnutrition by the year 2030. The deterioration of ecosystems, escalating climate crisis, and the loss of biodiversity are exerting profound impacts on employment, economic stability, and the availability of food across the globe. This predicament highlights the critical necessity for a comprehensive overhaul of agrifood systems to ensure food security, improve nutritional outcomes, and facilitate access to cost-effective, healthy diets, all while preserving employment opportunities and environmental resources. In this context, aquatic foods emerge as pivotal for their contribution to food security and nutrition (FAO, 2022). Aquaculture production exhibits considerable heterogeneity, ranging from small-scale family operations to large-scale multinational enterprises, encompassing a spectrum from rudimentary extensive systems to sophisticated closed production systems, and covering a diverse array of species including algae, bivalves, crustaceans, and finfish. The socio-economic and environmental ramifications of aquaculture are contingent upon these varying factors (Asche et al., 2013; Anderson et al., 2017).

In 1970, the majority of seafood was procured from wild stocks, with aquaculture contributing merely 4% to the total agricultural yield. The late 1980s marked a pivotal shift as the plateauing of wild-fish harvesting signaled limited prospects for significant expansion, prompting a notable growth in aquaculture activities. The practice of aquaculture, which entails the cultivation of aquatic organisms including animals and plants, has since maintained its lead in aquatic food production. Presently, the total output from global aquaculture significantly outstrips that of global capture fisheries by a margin exceeding 100 million tons, a fact illustrated in Figure 3 (FAO, 2018, 2022).

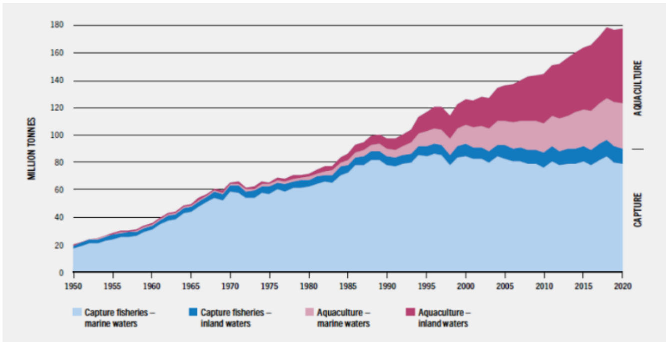

Figure 3. World capture fisheries and aquaculture production (FAO, 2022)

Aquaculture Status in Türkiye

In recent years in Türkiye, significant advancements have been made in aquaculture systems, necessitating the relocation of fish farms to open and deep waters. This shift has mandated the adoption of new techniques suitable for these conditions, leading to improvements that surpass global standards in cage sizes and structures, net, and feeding systems. The production of aquatic products in Türkiye is presented in Table 2, based on an annual basis.

Table 1. Initial settings of simulation (Gürün, 2014; Buyruk, 2019; TSMS, 2022)

Position	Oil type	Wind	Oil spill amount	Air temp.	Water temp.	Wave height	Water density	Name and amount of marine species
37°27′ N 027°03.6′ E	AMULIGAK Group III Viscosity: 15.7 cSt Density: 0.89 g/cm^3	N-NW 5 m/sec	Initial spill: 1000 m^3 Leak spill: 200 m^3/h	15°C	18°C	0.1 mt	1010 kg/m^3	1 million sea bream

Table 2. Aquaculture Statistics in Türkiye (tons) (TUIK, 2023)

Annuals	Capture	Aquaculture	Total
2012	432,442	212,410	644,852
2013	374,121	233,394	607,515
2014	302,212	235,133	537,345
2015	431,907	240,334	672,241
2016	335,320	253,395	588,715
2017	354,318	276,502	630,820
2018	314,094	314,537	628,631
2019	463,168	373,356	836,524
2020	364,400	421,411	785,811
2021	328,165	471,686	799,851
2022	335,003	514,805	849,808

In Türkiye, the production of aquatic products increased by 6% in 2022 compared to the previous year, reaching a total of 849,808 tons. The production from fishing increased by 2% in 2022 compared to the previous year, while aquaculture production saw a 9% increase (TUIK, 2023). The trend of decreasing product quantities from fishing and increasing product quantities from aquaculture indicates a correct orientation of production on a global scale.

Türkiye continues to maintain its position as a net exporter in the trade of aquatic products. In recent years, there has been a significant increase in Türkiye's exports of aquatic products, parallel to the advancements in aquaculture production and processing technologies. The foreign trade statistics of Türkiye's aquatic products, presented annually, are provided in Table 3.

Upon examining the export-import data, it is observed that in 2022, exports exceeded imports by 136,000 tons in quantity and 1.338 billion USD in value. The trade of aquatic products in Türkiye in 2022 showed the largest increase compared to the previous year, with exports growing by 5% and imports by 10%. The aquatic products exports, amounting to 1.651 billion USD in 2022, were distributed to 103 countries, 67% of which are member states of the European Union (AEPDI, 2023).

Ensuring the security of aquaculture against adverse effects is of vital importance for Türkiye, both in terms of food supply security and the increasing share in exports in foreign trade. The subsequent section presents a scenario of the potential impacts of ship-sourced oil pollution, which could pose a threat to sustainability, through a case scenario analysis.

The Effects of Oil Pollution on Marine Life

Marine research indicates the severe impact of oil pollution on seawater, sediment, and marine life. Particularly, polycyclic aromatic hydrocarbons (PAHs), from industrial waste, ship bilge water, and ship accidents, are widespread in marine areas and cause serious toxicity, including tissue buildup and physiological disruptions. Fish absorb heavy metals from aquatic environments mainly through their gills, body surface, and digestive tract. These metals lead to structural and functional disturbances at both cellular and molecular levels in aquatic life, along with a heightened occurrence of DNA damage. (Levesque et al., 2002). As illustrated in Figure 4, during the primary response phase following stress in aquatic organisms, secondary responses develop from the physiological effects of factors released (Kayhan et al., 2009).

Table 3. Türkiye's Foreign Trade in Aquatic Products (TUIK, 2023)

Year	Export		Import	
	Amount (tons)	Value ($)	Amount (tons)	Value ($)
2012	74,006	413,917,190	65,384	176,402,894
2013	101,063	568,207,316	67,530	188,068,388
2014	115,381	675,844,523	77,551	198,273,838
2015	121,053	692,220,595	110,761	250,969,660
2016	145,469	790,303,664	82,074	180,753,629
2017	156,681	854,731,829	100,444	230,111,248
2018	177,500	951,793,070	98,315	188,965,220
2019	200,226	1,025,617,723	90,684	189,438,745
2020	192,462	1,020,673,539	80,525	127,415,564
2021	238,732	1,376,291,922	104,708	217,179,174
2022	251,416	1,651,496,218	115,189	312,980,444

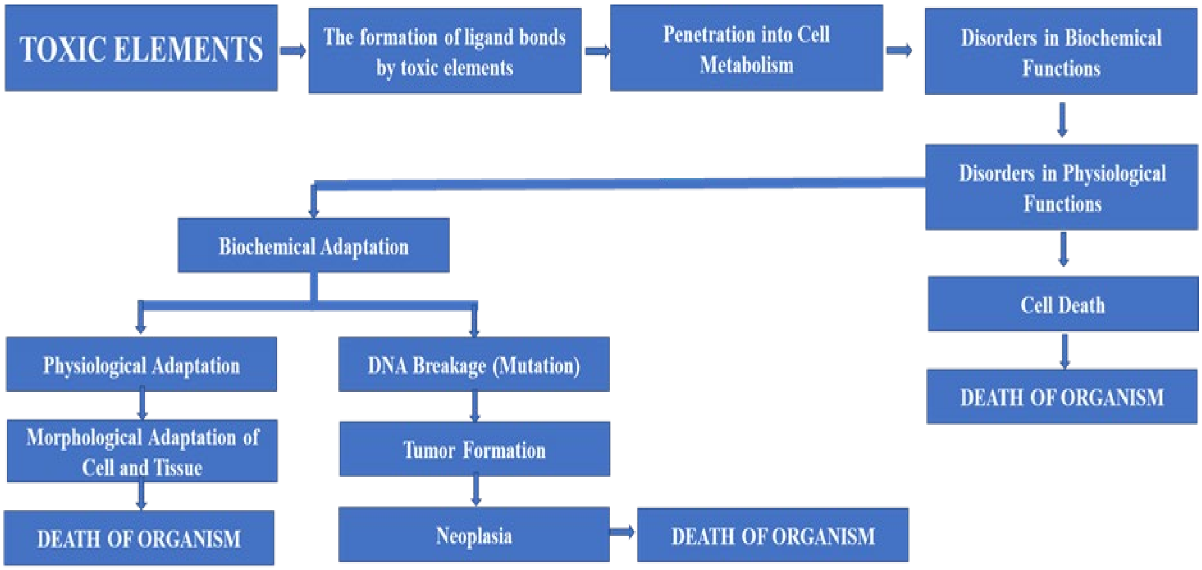

Figure 4. The biological responses and physiological pathways of toxic elements in organisms (Kayhan et al., 2009)

Table 4. Aquatic toxicity of water-soluble fractions of common oils (Fingas, 2014)

Oil Type	Specific Type	Species	Common Name	LC_{50} (mg/L)[1]	Time (hr)
Gasoline		*Daphnia magna*	Water flea	20 to 50	48
		Artemia	Brine shrimp	5 to 15	48
			Rainbow trout larvae	5 to 7	48
Diesel fuel		*Daphnia magna*	Water flea	1 to 7	48
		Artemia	Brine shrimp	1 to 2	48
			Rainbow trout larvae	2 to 3	48
Light crude	Alberta sweet mixed blend	*Daphnia magna*	Water flea	6 to 12	48
		Artemia	Brine shrimp	10 to 20	48
			Rainbow trout	10 to 30	96
			Frog larvae	3	96
	Arabian light	*Daphnia magna*	Water flea	10	48
Medium crude	Cook inlet	*Fundulus*	Fish	50	96
			Scallops	2	96
			Salmon	2	96
			Crab	1	96
Heavy Crude	Arabian heavy	*Daphnia magna*	Water flea	5 to 8	48
Intermediate	IFO-180	*Daphnia magna*	Water flea	1 to 8	48
Fuel oil		*Artemia*	Brine shrimp	0.8 to 4	48
			Rainbow trout larvae	2	96
Bunker C		*Daphnia magna*	Water flea	0.5 to 5	48
		Artemia	Brine shrimp	0.3 to 3	48
			Rainbow trout larvae	2	96

Note: [1] LC_{50} is the lethal toxicity to 50% of the test population at the water concentration, specified in milligrams per liter (mg/L), which is approximately the equivalent of parts per million.

Exposure to toxic substances can result in either fatal or non-fatal outcomes. Fatal exposure is typically quantified by the lethal concentration 50 (LC_{50}), which is the amount of the toxin required to kill 50% of a species' test population within a certain duration. For instance, studies on the impact of various crude oils on the water flea, *Daphnia magna*, indicate that a concentration ranging from 5 to 40 milligrams per liter (mg/L) over 24 hours proves to be fatally toxic. The measurement in mg/L is roughly equal to parts per million (ppm). On the other hand, sublethal exposure adversely affects the test organism without causing immediate death during the observation period. An example of this is observed when Daphnia magna experiences disorientation after being exposed to a 2 ppm concentration of crude oil in water for 48 hours (Fingas, 2014). Crustaceans such as crabs, lobsters, and shrimps, especially species that live buried in the seabed, are the most sensitive to oil pollution. They are affected by petroleum concentrations of 1-10 ppm. Bivalves like mussels and fish species are sensitive to 5-50 ppm, while gastropods and marine plants (algae) are sensitive to concentrations of 10-100 ppm (Tolay, 1998). Table 4 details hydrocarbon concentrations that prove fatal to a range of aquatic life, encompassing both freshwater and marine species.

The susceptibility of fish to hydrocarbons significantly depends on their age, where adult fish generally exhibit lower sensitivity compared to juvenile fish. For instance, research indicates that adult salmon are up to 100 times more resistant to aromatic hydrocarbons than their juvenile counterparts. Additionally, juvenile salmon display 70 times greater resistance than salmon eggs. Numerous investigations have demonstrated that fish larvae or newly hatched fish tend to be more vulnerable than the eggs of fish. Considering that the fish produced in the farms' focus point of this study are still in their growth phase, their sensitivity to oil pollution is significantly heightened. The subsequent section of the study focuses on the vulnerability of sea bream cultivated in fish farms located in the southern Aegean Sea of Türkiye to medium crude oil pollution.

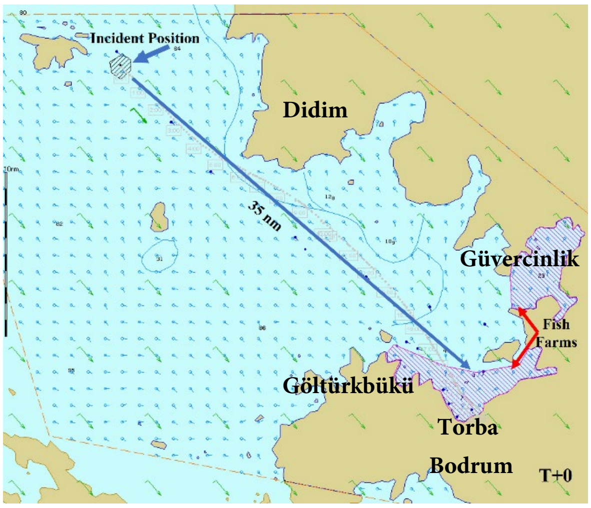

Figure 5. The initial position of the scenario

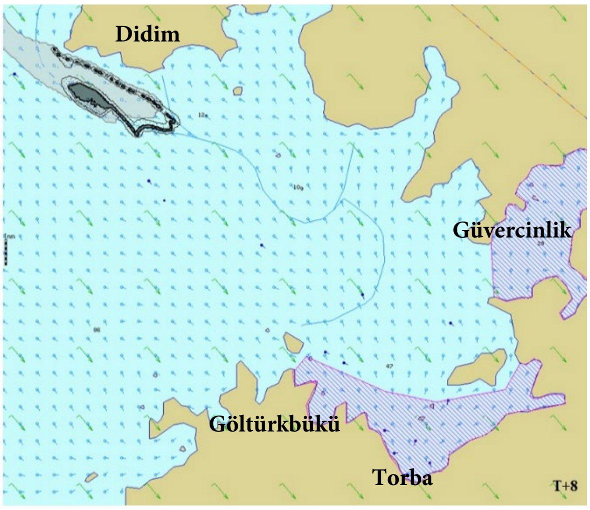

Figure 6. Oil pollution after 8 hours

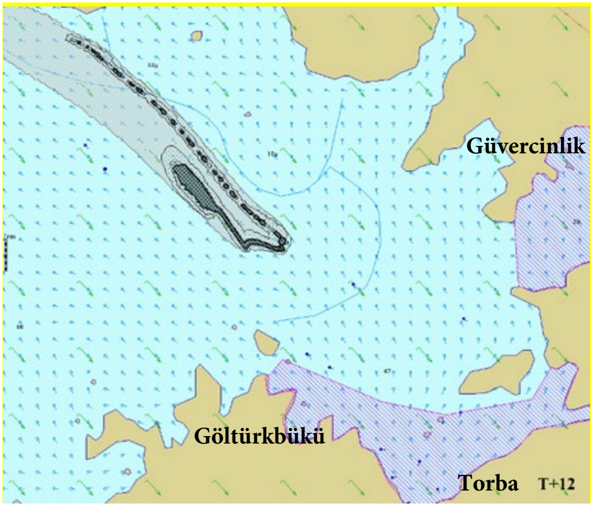

Figure 7. Oil pollution after 12 hours

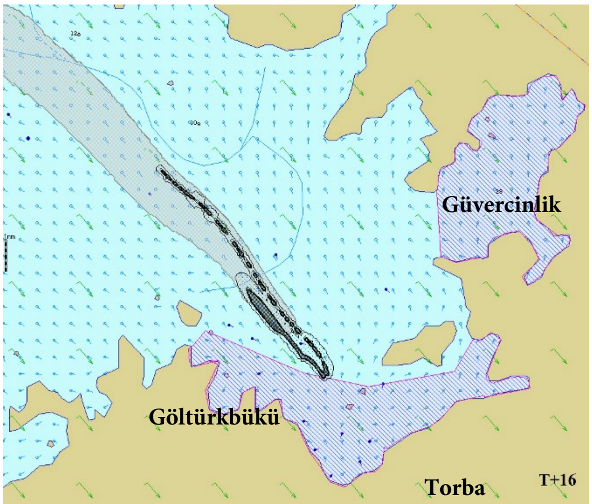

Figure 8. Oil pollution after 16 hours

In this context, the study initially considered adopting the LC_{50} value of 50 mg/L as indicated in Table 4. However, the table provides a general outlook on the sensitivity of marine species to aquatic toxicity without considering aquaculture or wildlife. Considering the aquaculture sea bream will be juvenile, obviously fish will be more sensitive as mentioned before. Therefore, LC_{50} values were set to the simulation as 10 mg/L for 48 hours. Besides, "LC_{50}" and "Time LC_{50}" indicate oil concentration sufficient for the death of half of the bions of the given species, and the time period, in which they die due to the given concentration, which is revealed under test environment conditions. Considering the other effects such as atmospheric and oceanographic variables and the oil weathering process, these values are alterable. Specifically, time and amount of oil dispersion[2] in the fish farm may alter the Time LC50, which is also not a linear proportion.

Results and Discussion

In this section, the primary focus is on an incident that occurred near the aquaculture production farms located along the coast of Aydın province in the southern Aegean Sea of Türkiye, at a position of 37°27′ N-027°03.6′ E, approximately 35 nautical miles away. Initially, a total of 1,000 tons and subsequently 200 tons per hour, culminating in a total of 2,500 tons of crude oil, leaked into the sea. The scenario crafted outlines how the prevailing meteorological and oceanographic conditions facilitated the spread of this oil spill to the sea bream production farms. The scenario was simulated using the PISCES decision support system, illustrating the dissemination of the oil in the sea, and the time it took to reach the fish production farms, as depicted in Figures 5-8.

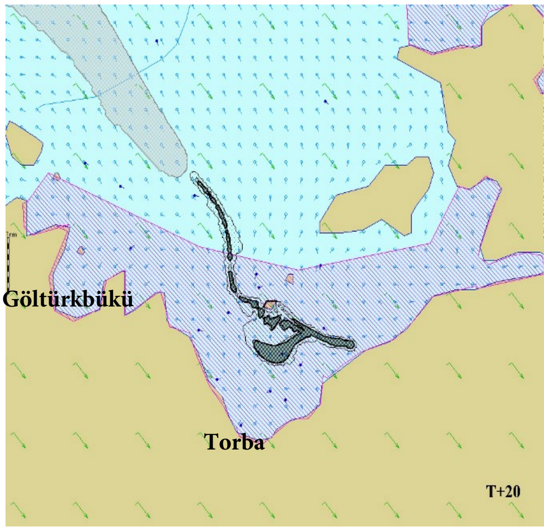

Figure 9. Oil pollution after 20 hours

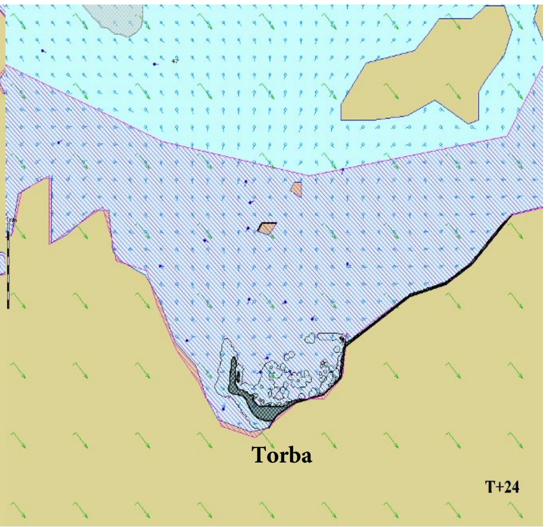

Figure 10. Oil pollution after 24 hours

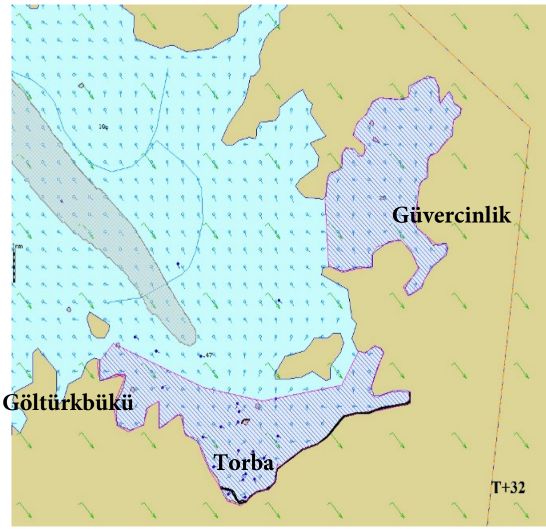

Figure 11. Oil pollution after 32 hours

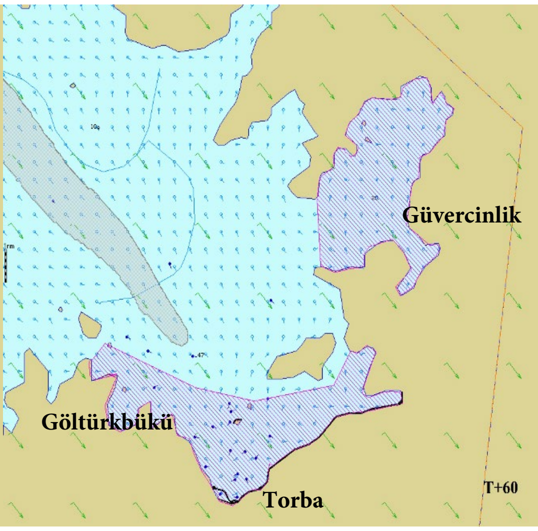

Figure 12. Oil pollution after 60 hours

[2] Natural dispersion is a process of transformation of some part of oil into minute drops as a result of wave motion, these drops remaining in a suspended state in the water column. The speed of natural dispersion depends on the sea state being inversely dependent on oil viscosity.

Table 5. Weathering processes data of the oil during 60 hours

Time	Amount spilled, t	Amount floating, t	Amount evaporated, t	Amount dispersed, t	Amount stranded, t	Amount sunk, t	Max thickness, mm	Slick area, km²	Viscosity, cSt
04:00	1,670	1,502	114	58.1	0	0	7.9	4.5	211
12:00	2,545	2,245	212	92	0	0	4.6	18.7	960
24:00	2,545	2,133	276	98.1	41.7	0.1	177	2.4	1,722
36:00	2,545	2,100	283	98.7	67.3	0.1	769	0.3	1,784
48:00	2,545	2,097	286	98.8	67.7	0.2	741	0.2	1,803
60:00	2,545	2,095	287	98.9	67.9	0.2	750	0.1	1,814

Table 6. Environmentally Sensitive Area (ESA-Fish Farm) status at the end of 60th hour

Report	Time	Date	Duration		
Begin	10:27	02.04.2024	Total time: 60 hours		
End	22:13	04.04.2024			
ESA – 1 Polluted	02:15	03.04.2024	Duration of Pollution of ESA: 44 hours		
Species	**LC_{50} (mg/l)**	**T LC_{50} (h)**	**Dead %**	**Initial amount**	**Current amount**
Sea Bream	10	48	32%	1,000,000 t	680,486 t

As depicted in Figure 8, the oil pollution occurring 35 nautical miles offshore reaches and contaminates the southern fish production farm approximately 16 hours later. Following the arrival of the oil at the farm, the spread within the area and the time it takes to reach the shore are illustrated in Figures 9-12.

From the moment of the incident until the 60th hour, Figure 12 illustrates the final state of the pollution, while Table 5 presents the oil weathering behaviors for this period.

Upon analyzing Table 5, it is observed that approximately 100 tons of the oil were naturally dispersed both on the water surface and within the water column, while 0.2 tons have settled to the seabed. In terms of the oil's viscosity, it is noted that the initial value of 15.7 cSt escalated to 1814 cSt by the end of the 60th hour. In scenarios of potential increases in sea and wind conditions, the natural dispersion of the oil across the sea surface and into the water column, followed by the penetration of water molecules into the oil molecules (emulsification), and the eventual sinking and sedimentation of the oil to the seabed will accelerate. Under these circumstances, the fish mortality rates at the end of the 60th hour provided in Table 6 below are expected to rise further.

Upon examining Table 6, it is revealed that within 44 hours from the 16th hour, when the pollution reached the farm, 32% of the fish in the farm died. As expressed in the preceding paragraph, the alteration of conditions and the progression of time are likely to result in an increase in the fish mortality rate.

Conclusion

This study serves as an illustrative scenario analysis, shedding light on the potential impact and timeline of marine pollution on the aquaculture industry, which is of growing importance for food security not only in Türkiye but also globally. It reveals that production facilities located along Türkiye's southern Aegean coasts, approximately 35 nautical miles away, have a window of about 16 hours to respond to a potential oil spill, under varying atmospheric and oceanographic conditions. It was found that by the end of the 44th hour, 32% of the sea bream species had perished due to contamination at these facilities. The simulation values presented in this work can be adjusted based on different seasonal atmospheric and oceanographic conditions, types of aquaculture species, and pollution scenarios, thereby diversifying situational scenarios.

The critical relationship between environmental factors and marine life vitality is underscored. The presence of hydrocarbons in water, resulting from oil spills, significantly reduces the oxygen levels available to aquatic organisms, leading to hypoxia or even anoxia. Moreover, the increased viscosity of water due to oil contamination can impair fish's ability to move, feed, and further exacerbating the mortality rate. Furthermore, the cumulative effects of prolonged exposure to pollutants can lead to sub-lethal impacts, such as reproductive failures, decreased growth rates, and increased susceptibility to diseases, which may not be immediately apparent but can significantly affect population dynamics over time. Metallic pollutants measured in living organisms as an indicator of environmental pollution can often reach high levels, especially in aquaculture. In this way, toxic substance residues taken with food at low levels continuously affect the environment and human health significantly. Therefore, conducting comprehensive environmental impact assessments following such incidents is essential to devise effective mitigation and restoration strategies that can help minimize long-term ecological damage and promote the resilience of affected marine ecosystems.

Numerous predictions suggest a significant rise in future aquaculture production. This growth is expected to positively impact public health and boost economic opportunities. Farmed seafood plays a crucial role in the global food system and should be regarded as equally important as terrestrial animal and crop production. Although the aquaculture sector has expanded rapidly, it has been somewhat disorganized. To enhance aquaculture's role in food security, better information sharing and improved extension support are essential. Within the framework of these issues, the contribution of the aquaculture industry to both food security and the national economy is increasing in Türkiye as well. Given the increasing economic value of the aquaculture industry within countries' Gross Domestic Products and its significance for food security, it is imperative to consider this industry as a national asset that needs protection. The Eastern Black Sea, where the country's fish farms are concentrated, has the potential to be increasingly exposed to marine pollution through both underwater oil pipelines and East-West axis tanker transport. Similarly, the Aegean Sea and aquaculture production facilities, especially in the southeast, face the risk of pollution due to North-South axis tanker transport and increasing maritime traffic. Previous tanker accidents and resultant marine pollution have led to significant social and economic losses, highlighting the necessity for countries to prepare for such incidents, develop contingency plans, and maintain pollution intervention equipment. Consequently, Türkiye has formulated emergency response plans to protect coastal facilities and ports, against oil pollution. Similarly, the aquaculture industry must have equivalent plans in place. Future research should simulate possible scenarios like the one presented in this study, delineate the pollution spread timeline to aquaculture sites, establish alternative locations for production ponds, and conduct drills to familiarize responsible personnel with the plans, enhancing their readiness and response capabilities.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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