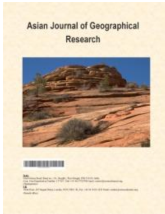

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Causes and Consequences of the Black Sea Ecosystem Pollution with Petroleum Products

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Authors' contributions

This work was carried out in collaboration among all authors. Authors BC and DM designed the study, performed the literature searches and statistical analysis and wrote the first draft of the manuscript. Author MC managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Until the beginning of the 21st century concerns related to the management of protected areas have been reduced to the voluntary initiatives of nature lovers, rarely materializing in specific conservation measures carried out by the authorities or administrators of those areas. As the concern for the management of protected areas is relatively new in Romania and the information related to this subject is relatively scarce, especially those regarding marine ecosystems, we considered necessary this study on the management of marine protected areas in relation to oil pollution. Marine protected areas, in particular, delimited as areas where the main purpose is the protection of nature and cultural values, are important for all segments of society. They have great potential to become models of harmonious society development, promoting more than other protected areas the sustainable resource management. At the same time, the management measures promoted, sometimes imposed, can affect the communities inside or in the immediate vicinity of the areas, and can significantly influence the development of the economy. Recently (as a reference 1970-2020),

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the pollution of the marine environment with petroleum products has gained dramatic accents. The maritime transport of oil, the exploration and exploitation of marine deposits, their processing in refineries located in the vicinity of the coastal area, to which are added other anthropogenic activities, have generated and still generate a number of risk factors, which involve numerous pollution incidents. Navigation accidents of large oil tanks or incidents at offshore drilling rigs caused, in the same period, major environmental disasters, with the most severe consequences. Marine ecosystems in polluted regions have thus suffered major losses and disturbances, which have been felt for a long time. Through this paper we aim to review some aspects of oil pipeline pollution of the Planetary Ocean, respectively the associated pollution in the Black Sea ecosystem. Following the analyzes carried out on the basis of the data from the consulted literature, as well as following other observations, we came to the conclusion that the protected areas associated with the Black Sea, as well as the marine ecosystem itself, are far from being affected by such accidents.

Keywords: Marine environment; pollution; petroleum products; ecology; consequences.

1. INTRODUCTION

Today, oil products and natural gas are the main energy sources of mankind [1]. Since the middle of the 20th century, oil consumption has increased almost continuously, on average, by 8-10% annually, from approx. 510 million tonnes in 1950, 1.98 billion tonnes in 1970, 4.5 billion tonnes in 1993 and more than 6 billion tonnes in 2006 (see Fig. 1) [2]. On the other hand, world crude oil production also continues to increase from 20.9 million barrels per day in 1960 to 65.8 million barrels per day in 1999, reaching 81.7 million barrels per day in 2006.

The evolution of maritime oil transport in world trade has largely followed the trends of consumption and production of petroleum products, experiencing almost every year increases in transport volume, from 1,109 million tonnes in 1970 to 1,990 million tonnes in 2006 (see Fig. 2) [3,4]. However, maritime trade in petroleum products has grown even more dramatically, from 232 million tonnes, in 1970, to 683 million tonnes, in 2006.

The transportation of petroleum products by sea has been, at least for the last five decades, a factor that can lead to a high degree of risk in terms of marine pollution incidents, although oil construction technology has made significant progress. The tonnage of the oil companies increased from about 16,000 tdw, as the oil tanks usually had in 1950, to 250,000 tdw in 1960, so that in 1970 oil tankers of over 500,000 tdw were built (see Fig. 3) [5].

In 2007, the transport capacity of the world oil fleet reached 383 million tdw. After 1970, maritime trade developed significantly in the field of liquefied gas transportation. In recent years, a strong fleet of specialized vessels has developed, based on tanks for the transport of two product categories: LPG (liquefied petroleum gas) and LNG (liquefied natural gas), the fleet itself totaling today over 27 million tdw.

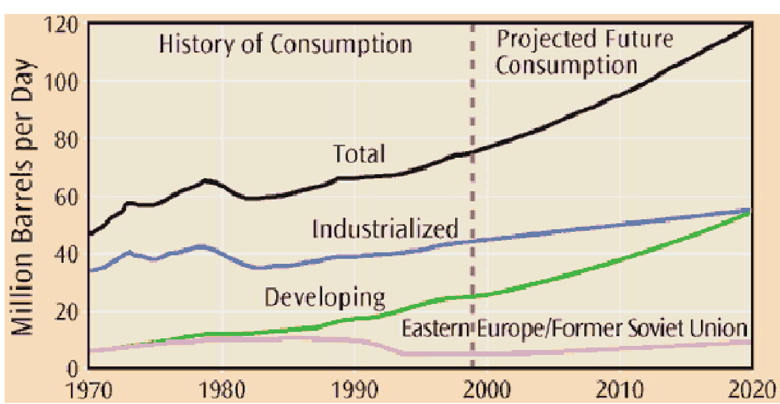

Fig. 1. World oil consumption by region (1970-2020) [2]

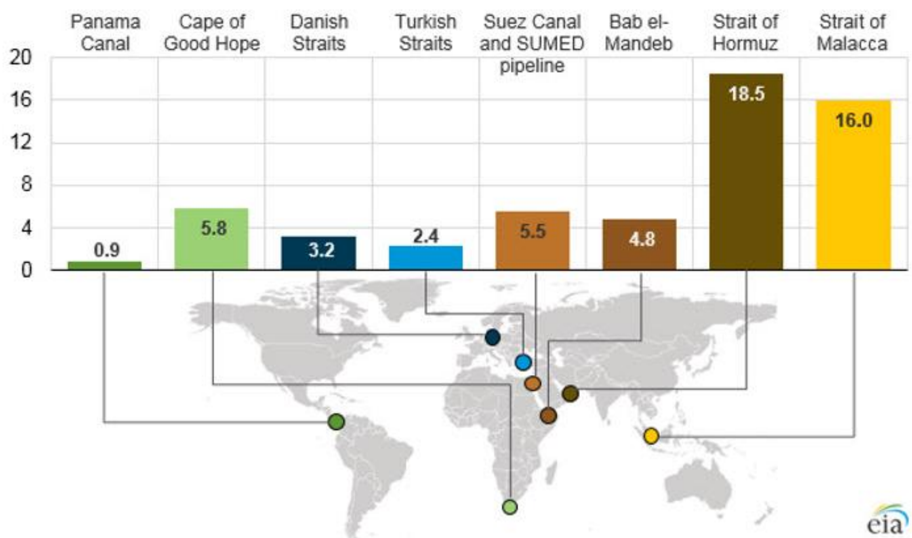

Fig. 2. Petroleum transit volumes, including crude oil and petroleum liquids, through select maritime routes (in milion barrels per day, 2016) [3]

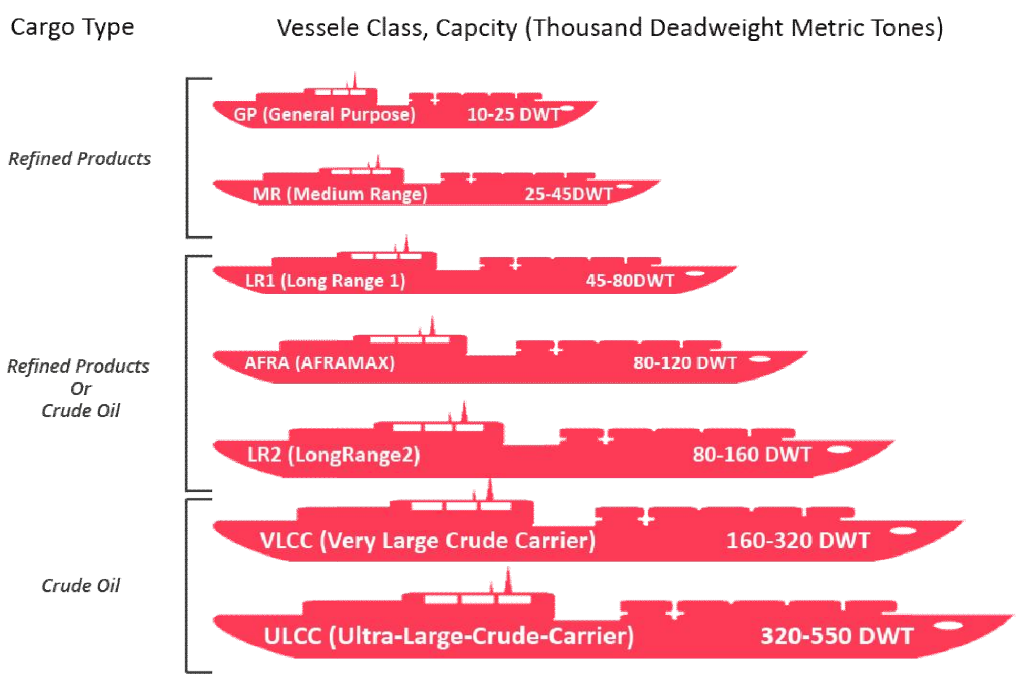

Fig. 3. Oil tanker deadweight tonnage petroleum ship [3]
**where AFRA - Average Freight Rate Assessment scale - fixed*

The exploration and exploitation of oil and gas, from the marine and oceanic fields, has also seen an explosive development in recent years. The year 1950 marks the start of oil exploitation in marine areas, with the help of drilling and extraction platforms. As oil reserves in the mainland began to plummet, oil companies turned more and more to marine extraction, with these resources estimated at 160 billion barrels of oil and 14 billion m^3 of natural gas.

The evolution of the offshore drilling industry has been rapid. At the beginning of 1974, 192 fixed platforms and over 240 mobile platforms were in operation worldwide. The number of these means has increased enormously, today totaling over 6,900 oil installations. In fact, according to a report by the United Nations Secretariat, about 27% of the world's total crude oil and gas comes from the exploitation of marine resources.

2. METHODOLOGY

The documentation phase for this paper started, as was probably the case, from the authors' concerns for applied ecology, for the management of protected marine areas and, last but not least, because they love marine ecosystems. Having at hand a series of extremely relevant studies at the international level (studies from IMO, IOPCFunds and ITOPF), both in terms of protected area management and oil pollution, the authors decided to extrapolate these approaches to the relatively limited space of the Black Sea ecosystem.

The environmental data related to the Black Sea ecosystem was collected and analyzed according to the studies between 1970-2020 from IMO, IOPCFunds and ITOPF platforms, which have proven to be of real use. At the same time, the relevant data was presented in close connection with the data provided as a result of the internal preoccupations of the researches in our country. Thus, the subject of pollution of the marine environment with petroleum products also affects the lands of our country, where there were few studies that made direct reference to the management of marine or even coastal areas.

3. RESULTS AND DISCUSSION

3.1 Causes of the Marine Environment Pollution with Petroleum Products

Pollution of the marine environment with petroleum products is a worrying phenomenon, which has grown unprecedented since the 1960s. The sources and causes of pollution have multiplied year by year, in proportion to the emergence and proliferation of risk factors, especially in the 1970-1985 period. Incidents occurred in the activities of drilling, extraction, transport, transfer operations, loading-unloading, refining, storage, etc. (Fig. 4) [6] generated imminent risks, given to the dangerous properties of petroleum products.

Significant quantities of petroleum products have thus reached the Planetary Ocean. According to a study by the US Academy of Sciences, the average amount of oil that pollutes the world's seas and oceans annually amounts to about 6 million tonnes, of which 3.3 million tonnes only from land sources (refineries in coastal areas, industrial and urban emissions, river input, atmospheric transport, etc), 2.1 million tonnes (approx. 35%) of maritime transport, 600,000 tonnes - of natural emissions from the ocean floor, and 8,000 tonnes - of drilling and marine exploitation activities.

The analysis of statistical data on the sources and causes of pollution of oil and petroleum products of the marine environment, published by various international, regional or national institutions, shows that the largest share of quantities polluting the oceans and seas comes from sources on the continent. Along with this category, among the most significant sources of pollution with petroleum products are cited: maritime transport, natural emissions, oil extractions from marine deposits, refineries and oil terminals, as shown in Fig. 5 [7,8]. Thus, industrial emissions, in the form of industrial waste, accumulate most of the oil products that pollute the marine environment globally, holding over 60% of the total.

Although land-based sources supply most of the oil products that pollute the world's oceans and seas, far surpassing all other sources taken together, the incidents with the worst consequences have been and are due to shipping. The ecological disasters caused by the shipping accidents of large oil tanks show that the risks involved in maritime transport are much higher.

During the period 1970-2020 there were over 9,500 incidents of pollution with petroleum products, as a result of operational and accidental discharges from maritime transport, but of these, over 85% are in the category of minor pollution, with discharges less than 7 tonnes. The percentage of spills of over 700 tonnes is less than 5%, and navigation accidents have a share of approx. 40% of the total (see Fig. 6) [9].

Also in the same period there were over 600 collisions, 590 failures, 700 accidents due to the failure of the ship's hull (shipwreck, water holes, and so on), 150 explosions and 2,300 accidents from other causes or unknown causes. Navigation accidents thus hold approx. 50% of the total of over 9,500 incidents, as shown in Fig. 7 [9].

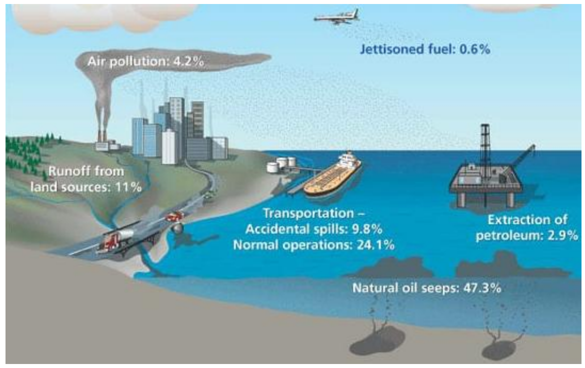

Fig. 4. Tracking the sources and impacts of oil pollution in the marine environment [6]

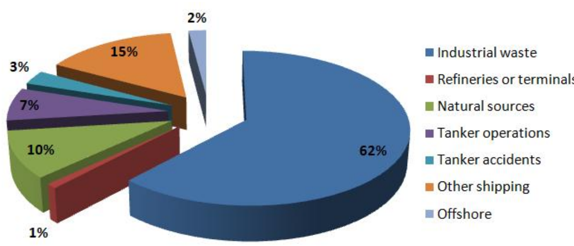

Fig. 5. The most significant sources of marine pollution with petroleum products

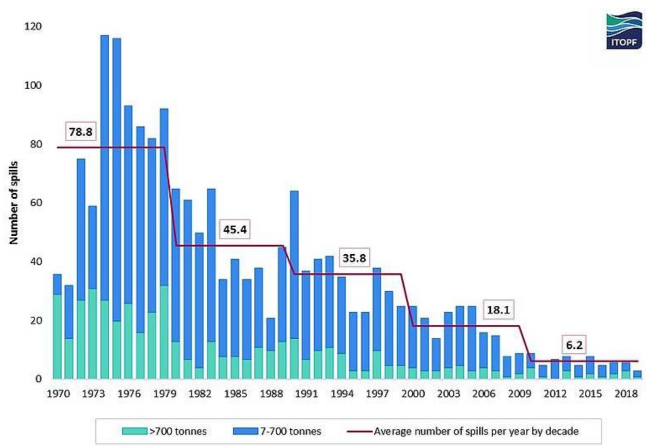

Fig. 6. Number of spills (>7 tonnes) all over the world, 1970-2020 [9]

Table 1. The top of the Major Spills all over the world, 1970-2020 (adapted after [9])

Position	Shipname	Year	Location	Spill size (tonnes)
1	Atlantic Empress	1979	Off Tobago, West Indies	287,000
2	Abt Summer	1991	700 nautical miles off Angola	260,000
3	Castillo De Bellver	1983	Off Saldanha Bay, South Africa	252,000
21	Prestige	2002	Off Galicia, Spain	63,000
36	Exxon Valdez	1989	Prince William Sound, Alaska, USA	37,000
132	Hebei Spirit	2007	South Korea	11,000

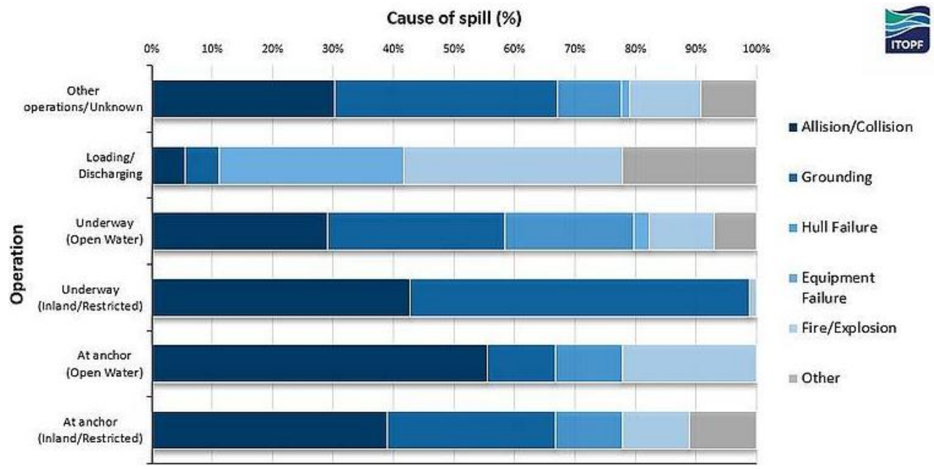

Fig. 7. Incidence of spills >700 tonnes by operation at time of incident and primary cause of spill, 1970-2020 [9]

Operational pollution, in terms of the number of incidents, has the largest share, and is largely the result of poor management in the prevention of marine pollution, both on board ships or in shipping companies and at the terminals oil companies, port operators or bunkering companies. Compared to major accidental spills, operational pollution has not caused as obvious environmental consequences, although globally the annual amount of hydrocarbons from operational sources is about four times higher.

However, the real ecological catastrophes were caused by the navigation accidents in which the big oil tankers were involved, as a result of which, not infrequently, the quantity spilled by some ships exceeded 50,000 tonnes, reaching even 287,000 tonnes, as in the case of the Atlantic Empress, as shown in Table 1 [9].

From the analysis of the risk factors that were at the origin of the navigation accidents, a part exposed in Table 1, we can highlight the major contribution of 5 categories of factors:

- The risks generated by extreme hydrometeorological phenomena (storms with very strong winds and unleashed sea, hurricanes, tsunamis, etc.);
- The risks determined by acts of war, terrorism and piracy;
- The risks generated by the dangerous physico-chemical properties of certain transported goods, including oil and petroleum products;
- The risks caused by the hidden defects of the ship;
- The risks caused by human mistakes.

A study of the circumstances in which oil tanker shipping accidents occurred shows that more than half of them were due to severe hydrometeorological conditions, most occurring in the Gulf of Mexico, the northeastern coasts of the United States, the Mediterranean Sea, the English Channel, The North Sea, the western Iberian Peninsula, the Sea of Japan and the southern coasts of Africa, during the high frequency seasons of these phenomena. These factors were the cause of some of the famous historical accidents, as in the cases: Torrey Canyon, Amoco Cadiz, Prestige, Castillo de Bellver and others. More than 2/3 of the accidents considered occurred in the cold period of the year, when storms at sea are more violent: in the northern hemisphere - between October and March, and in the southern hemisphere - from March to October.

The acts of war that led to the sinking of oil tankers during the two world wars are well known, and nowadays a new risk has appeared, that of terrorism, which does not bypass maritime transport either. Thus, the French oil tanker Limburg, with 57,000 tonnes of oil on board, was subjected to a terrorist attack in the Aden Gulf area in 2002. Due to the emissions of gases produced in tanks, oil and petroleum products present a high risk of fires and explosions. Therefore, special measures are required on board these ships both in terms of inert gas equipment, warning and fire extinguishing, and management for the safety of navigation and operation of cargo. The sinking of the Romanian oil tanker UNIREA, of 88,285 tdw, which took place off the coast of Bulgaria, 40 Mm southeast of Cape Kaliakra, in 1982, was caused by fire and explosions caused by gas accumulations.

The hidden defects of the ship, of the equipment and installations on board can have one of the most serious effects on the oil companies. A number of oil tankers that were torn in two, or that suffered damage to the steering gear, cars or radar equipment and that resulted in shipwrecks were suspected of hidden defects. Although other causes have been cited, in the accidents suffered by the oil tankers Prestige, Erika and others, the shipowners requested expertise to prove that the wreckage of the respective ships in two was due to hidden defects.

Human errors are often cited as the cause of frequent oil tanker navigation accidents. It is estimated that more than half of navigation accidents involve the mistakes of commanders or crews. In some cases, accidents could be avoided by taking measures to prevent certain risks. The case of oil tanker Exxon Valdez, which failed in the Alaska Gulf, is the most bizarre example. The ship's captain was accused of driving the ship while intoxicated, causing an ecological disaster with particularly severe effects.

Studies by IMO, Lloyd's, ITOPF and other institutions involved in naval management show that the leading causes of oil tanker shipping accidents include non-compliance with safety rules and measures, through the easy registration of ships under the flag of compliance by keeping ships older than 15 years in service, thus subjecting ships to additional risk factors.

Many shipping companies register their vessels under the flag of states such as Liberia, Panama, Singapore, the Bahamas, Cyprus, Malta, and so on, not only to pay lower taxes and duties, but also to pass more easily inspections, not very demanding. Because of this cause, a large proportion of ships under the flag of complacency do not meet all the requirements for the navigation safety and the maritime transport safety, being exposed to possible navigation accidents.

According to ITOPF statistics, out of a sample of 100 oil tankers, where accidental spills of over 1,000 tons were registered, 66 oil tankers were sailing under the flag of complacency. Regarding the old ships, it was found that most of the lost ships are over 13 years old. In fact, the average age of the world's oil fleet is approx. 10 years, but ships over the age of 20 represent 13.6% of the total. Practically speaking, all major accidents in which oil tanks broke in two and then sank occurred on ships over the age of 13.

Marine pollution of petroleum products can also be caused by acts of war against oil offshore installations. In 1991, for example, during the Gulf War, Iraqi troops, retreating from Kuwait, opened the taps of huge oil tanks in the conflict zone and set fire to the wells, triggering the largest oil spill in history. About 60 million barrels (150 times more than in the case of Exxon Valdez) flooded large areas of land and coastline, with some of the voluntary discharges reaching the Persian Gulf.

Prior to allied bombing, Iraqi soldiers had already spilled tens of millions of barrels, blowing up numerous Kuwaiti oil terminals to prevent an invasion from the sea. The formed oil blanket covered over 1,600 km of coastline, the sandy beaches especially sought after by tourists, have turned into a lifeless place. The ecological catastrophe caused severely affected the entire ecosystem of the Persian Gulf.

3.2 Consequences of Pollution of the Marine Areas with Petroleum Products

Of all forms of pollution, the most severe impact on marine ecosystems is associated with oil pollution. Oil, spilled in large quantities, covers considerable areas and significantly affects water quality and marine life. The most disastrous consequences have been caused by oil spills into coastal regions, and especially in areas where the oil slick has been concentrated on small or shallow areas: the Gulf of Alaska, the Bay of Biscay, the Persian Gulf, the English Channel (see Fig. 8) [9].

Experiments and observations in accidental oil spills have revealed that the toxicity of various petroleum products has very different effects on marine organisms. In general, it has been observed that hazardous toxicity is caused by the concentration of volatile compounds in petroleum products, including, but not limited to, light and aromatic paraffins (gasoline, toluene, xylenes, naphthalene etc). These compounds are more soluble in water than in hydrocarbons, which creates the toxic effect of polluting sources.

Pollution of petroleum products from the seas and oceans has reached such an extent in recent years that, according to many experts, marine ecosystems would need many years for a complete recovery, both in terms of biotope health, and in terms of rehabilitation of all species of flora and fauna that have suffered as a result of pollution. The ecological consequences of oil spills caused by oil tanker accidents, coastal refineries or offshore oil rigs, followed by the discharge of massive amounts of oil into the sea, have proved to be particularly serious, and, sometimes, even catastrophic for marine ecosystems.

Studies of oil spills show that the impact of oil pollution on benthic and pelagic organisms is considerable. For example, in the North Atlantic alone, according to some estimates, oil pollution would cause the death of approx. 500,000 birds. The causes of death of seabirds are attributed to effects such as: loss of feathers, difficulty in wings, inability to move, impaired intestinal and glandular functions by which birds get fresh water from seawater, loss of water-repellent quality of feathers which leads to inability to maintain body heat in contact with water.

The effects of oil pollution have decimated populations of marine flora and fauna of the most diverse, both as genera and species: benthic and pelagic fish, oysters and mussels, gastropods, crustaceans, dolphins, seals, sea otters, penguins, phytoplankton and zooplankton, coral colonies, seaweed, and the list goes on. Moderate doses of oil fractions have also been shown to reduce the photosynthetic activity of algae and phytoplankton. At the same time, fish that live in contaminated areas accumulate hydrocarbons in muscle tissues, which makes them practically unfit for consumption.

Some species of marine fauna among fish, crustaceans, various microorganisms and bacteria, can consume or absorb certain amounts of petroleum products from polluted areas (see Fig. 9) [10]. It has been shown that the tissues of many marine organisms can retain for a long time some fractions of the spilled oil. In fact, in the body of fish and marine organisms, these fractions are transformed into various substances by metabolic processes. The concentration of hydrocarbons in their body increases more when these creatures feed on contaminated microorganisms, thus registering a higher mortality rate.

The effects used in the fight against pollution, especially detergent-based dispersants, which in some cases were more serious than the effects produced by the oil cloth, also had negative effects, even to the death of organisms. (see Exxon Valdez, Torrey Canyon, and others).

The expansion and evolution over time of oil products discharged into the marine areas can decisively influence marine ecosystems. The length of the polluted coastline depends very much on the type of petroleum products, on the hydrometeorological factors (wind, currents, flow, waves) [12], on the viscosity, density and flow point of crude oils, which can contribute considerably to the dispersion of the oil slick offshore, or they can deflect it ashore, sometimes pushing it over very long distances, even hundreds of marine miles.

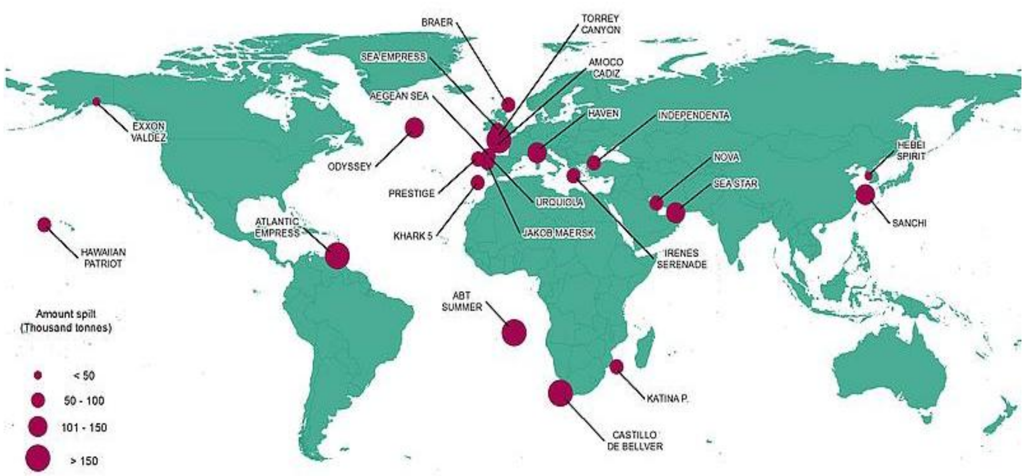

Fig. 8. Location over the globe of major spills, 1970-2020 [9]

The efficiency of forces and intervention means for depollution can have important effects on the evolution of the petroleum product film. At the time of discharge, a polluting cloth (also called "film" or "web") forms on the surface of the water. Hydrocarbons, generally having a lower density than seawater, remain afloat and only heavier fractions, such as fuel oil or some processing products such as asphaltene, can have a slight immersion, remaining in suspension. to the surface.

However, the oil products that arrived in the marine environment do not remain unaltered, under the action of the environment they undergo various transformations, which makes, over time, the concentration resulting from a spill to gradually decrease. This also explains the fact that, although every year, quantities of hydrocarbons of the order of millions of tons are discharged into the oceans, the global concentration does not know a significant increase. As shown in recent studies, the analysis of the content of petroleum products present in ocean waters showed that in offshore waters the concentration is less than 1 ppb, and in coastal waters is about 1-10 ppb.

A slightly higher concentration was highlighted, based on the analysis, of course, near the oil rigs, where values of 2-20 ppb were recorded. Unlike the oceans, in sea waters it has been estimated that, in general, the concentration of hydrocarbons is approx. 3 ppb offshore, 20-50 ppb in territorial waters, and can reach values of 100-1,000 ppb in areas effectively polluted with petroleum products. These values are average and differ from one ecosystem to another, depending on several factors, among which we can mention: the volume of discharges from various sources, the intensity of maritime traffic, sea characteristics (surface, volume of water, degree of opening and concentration of biodegradable factors), respectively the intensity of the hydrometeorological phenomena effects (wind, waves and currents) [12], as in Fig. 9.

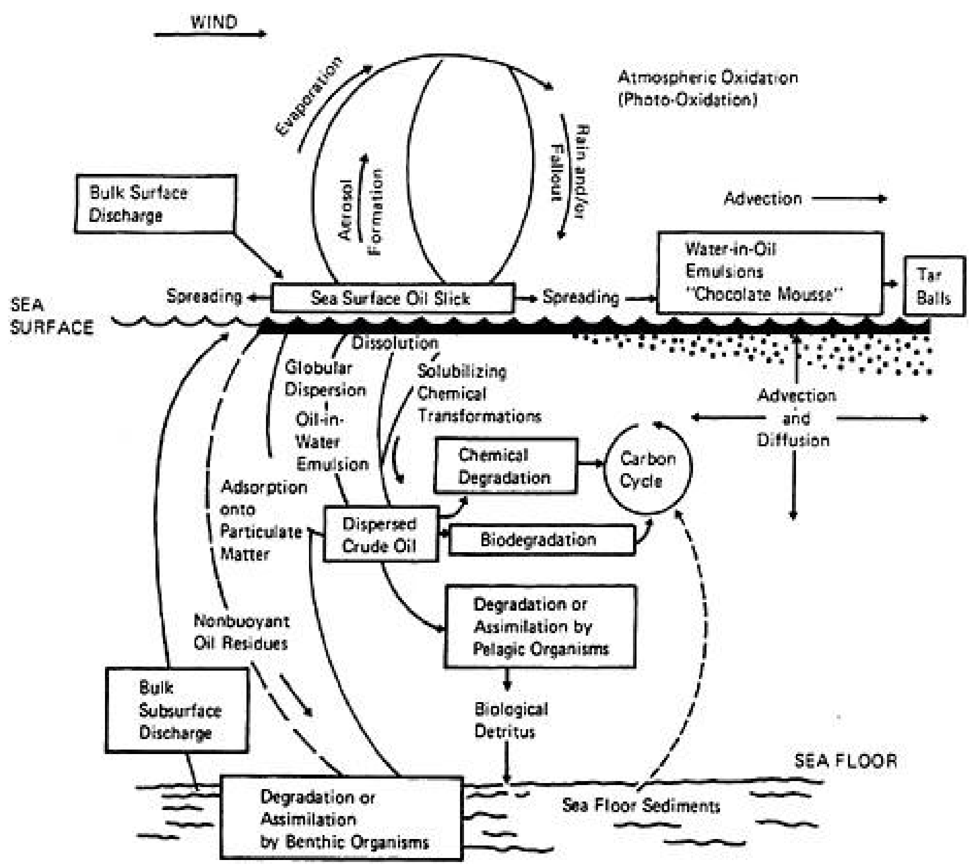

Fig. 9. Major open-ocean oil fate and transport processes [11]

One of the most representative cases for the study of the ecological consequences of oil pollution is the oil spill caused by the failure of the Amoco-Cadiz oil tanker. The observations and activities undertaken in an extensive research program have led to important findings and conclusions on the long - term impact of oil pollution on a valuable marine ecosystem. Moreover, from the conclusions issued, it emerged that the pollution caused by the discharge of 223,000 tonnes of crude oil affected approx. 300 km from the coast, and led to the destruction of 260,000 tonnes of marine biomass, on an area of approx. 250,000 polluted hectares. According to IFREMER estimates, between 19,000 and 37,000 birds and hundreds of millions of fish perished in that ecological accident. The coastal area was polluted with 50-60,000 tons of oil, and in the region affected by the oil spill, approx. 30% of the fauna and 5% of the flora were destroyed.

Another famous case, and at the same time interesting to follow, was Exxon Valdez, resulting in the spill of 40,000 tonnes of oil in Prince William Bay, Alaska Bay. This oil slick has had catastrophic ecological consequences, as it has occurred in a sensitive maritime area, populated with dolphins, seals, sea otters, being a place of refuge for many migratory birds. The sensitivity of the habitat was also increased by the physical characteristics of the sea basin in which the pollution took place, this being a bay with a relatively narrow opening, with shallow depths and dotted with many small islands. The spilled oil polluted approx. 1,770 km of coastline, including the coastline of the Gulf of Alaska, as well as the coasts of nearby islands. The marine ecosystem has been severely affected, with pollution killing 35,000 birds, 1,000 sea otters, 300 seals, 250 eagles, 25 whales and millions of fish. The local population, who make a living from fishing, would endure a dramatic period, as fishery resources, especially salmon and herring, were actually decimated.

Another consequence of the pollution of the surface layer of the seas and oceans with petroleum products is the alteration of the ocean-atmosphere contact surface. Petroleum products can negatively influence, on the one hand, the transfers of matter within the biogeochemical circuits, and on the other hand, the flows of caloric energy at the interface between the two environments. It has been estimated that one tonne of oil can cover 12 km^2 of ocean, which means that at the annual amount of millions of tons dumped across the Planetary Ocean, the sea surface contaminated by this form of pollution would be tens, maybe even hundreds of millions km^2.

Due to the current concentration of pollutants on the surface, the ocean (which plays an important role in the exchange of gases with the atmosphere, absorbing some of them) takes up decreasing amounts of atmospheric CO_2, so that excess CO_2 of anthropogenic origin contributes to amplifying the greenhouse effect. At the same time, the ocean surfaces polluted with petroleum products, but also with other categories of pollutants (detergents, pesticides, PCBs), reduce the processes of photosynthesis, evaporation and formation of oxygen and marine aerosols, with a decisive role in atmospheric circulation and in support of hydrometeorological phenomena.

3.3 The Situation of Oil Pollution of the Black Sea Ecosystem

The Black Sea, with a surface area of approx. 421,600 km^2, twice as large as the territory of Romania, is one of the world's largest inland marine environments, and, at the same time, the inland sea most isolated from the World Ocean. The total volume of sea water is estimated at 547,000 km^3, most of which is unsuitable for life, being contaminated with hydrogen sulfide. Its only connection to the rest of the world's oceans, via the Mediterranean, is through the narrow Turkish Straits (Bosporus) at Istanbul. It is also connected to the Sea of Azov (through the Kerch Strait), in the North East [13,14].

The length of the Black Sea basin (west-east), between the shores of the Burgas Gulf in Bulgaria and the mouth of the Inguri River in Georgia is 1,148 km. The maximum width (north-south) between Oceakov (Ukraine) and Cape Ereğli (Turkey) is 610 km, and the minimum width on the meridian of the southern extremity of the Crimean Peninsula (Cape Sarici), 263 km. The average depth of the Black Sea is 1,271 m. The maximum depth reaches 2,212 m (towards the central-southern part, at a point located 111 km from the southern shore) [15].

The numerous streams that flow into the Black Sea have a radial arrangement and varying lengths. Their hydrological regime differs according to the regions they pass through. Most rivers flow on the northwest coast: the Dniester (1,411 km), the Dnieper (2,285 km), the Bug (857 km), whose mouths have been transformed into estuaries, further south, the Danube river (2,860 km), and in Bulgaria, Provadiyska (119 km) and Kamchya (244 km) [15].

An important water supply is received by the Black Sea from the Don (1,950 km) and the Kuban (870 km), through the Sea of Azov. The hydrographic network drains a basin area of 2,402,119 km^2 - as shown in Fig. 10 [15], of which the Danube basin has 805,000 km^2. Due to the great isolation of the Black Sea from the world ocean, inland waters largely influence the hydrological elements of the sea.

Marine currents are, in the form in which they manifest themselves, another peculiarity of the Pontic basin. The factors that trigger the appearance of currents are: winds, difference in density, temperature and salinity horizontally and vertically, differences in submarine relief, river discharges, water exchange with the Mediterranean Sea and the Sea of Azov.

Occasional waves and surface currents are reflected in the transport of alluvium along the coast, in its erosion and in the leveling of the coastal platform, but also in the maritime transport of oil. The wave regime is closely related to the wind regime, which determines and influences it. The highest frequency is the waves with a low height of 0.5-1 m. During storms the waves reach a maximum height of 4-5 m, even 6 m.

In addition to Turkey, the Black Sea is bordered by Romania, Bulgaria, Ukraine, the Russian Federation and Georgia, as shown in Fig. 11 [14]. Though 90% of its water volume is anoxic, the surface waters to a depth of 50 m are fed by rivers that are naturally rich in nutrients, producing a low salinity environment that has been traditionally rich in fish and other species.

Although it does not have a high biological diversity, the Black Sea forms a complex ecosystem with unique features in terms of physico-chemical and biological characteristics. The environment conducive to life generally takes place on the continental marine platform, up to a depth of 150-200 m and is largely influenced by environmental conditions and water dynamics. The marine ecosystem consists of biotope (water, geographical and climatic factors, mineral elements) and biocenosis (all living organisms in the biotope, belonging to various species) - as shown in Fig. 12 [15], which together form a integrated ensemble and in permanent interaction.

Fig. 10. The Black Sea river basin [15]

Fig. 11. Major open-ocean oil fate and transport processes [14]

And because we were still talking about fish species, we must mention that the Black Sea is known, for example, for its anchovies, its three species of dolphin and its sturgeon. Coastal development, river diversion, over-exploitation of resources, introduction of other species, pollution and other activities have, however, led to a marked degradation in the quality of the marine environment, especially due to a high level of eutrophication. Some of the most significant effects have been the change in species composition and the collapse of certain commercial fish stocks, since the late 1970s.

Specific features of the Black Sea make it very vulnerable to disturbances to its ecosystems. As we mention before, pollution inputs and other factors have radically changed Black Sea ecosystems since the 1970s, and seriously threatened biodiversity, fishing and marine activities. In that context, in 1992, the six coastal countries (Bulgaria, Georgia, Romania, the Russian Federation, Turkey and Ukraine) signed and ratified the Convention on the Protection of the Black Sea against Pollution. Since then, the Black Sea Commission (BSC), acting on the mandate of the Black Sea countries, is responsible for the sustainable management of the Black Sea ecosystem.

The Black Sea's environmental problems are only partly the result of oil products pollution, the large majority of oil input is chronic rather than accidental. Three potential sources of oil spills are production activities, loading activities at terminals and shipping accidents involving tankers. Unlike the nearby Caspian Sea, the Black Sea is not a major production area for oil, though initial exploration has shown that reserves off the west coast of Georgia may be significant. For the present, however, the spill risk from production seems to be minimal. The Black Sea is, however, subject to a substantial and increasing transit trade in crude and refined products from Russia, Georgia, Kazakhstan and Azerbaijan.

Marine terminals include older facilities dating from the Soviet era as well as state-of-the-art terminals recently built by international consortia. All terminals are subject to some risk, but the newer terminals are likely to be safer, as they are being built and operated to high international standards. Older terminals, on the other hand, may lack reception facilities for slops, use older transfer systems, do not have the same first response capabilities and lack access and procedures for escalating to higher tier response. One example of an entirely new pipeline and terminal system is that operated by the Caspian Pipeline Consortium from Kazakhstan to Novorossiysk in Russia. This state-of-the-art pipeline and terminal system was commissioned in 2001, and is currently operating at 1 million tonnes per month, one fifth of its final expected capacity.

The Black Sea terminal for the pipeline can currently load 100,000 tonnes of crude oil on to two ships simultaneously. It augments an older terminal in Novorossiysk area and will provide crude oil for as many as 600 Suezmax tankers per year, once full operational capacity has been achieved. As with most other Black Sea terminals, most of the exported crude oil can be expected to travel to destinations outside the Black Sea, though some may cross to Bulgaria, Romania and Ukraine.

Fig. 12. Major aspects within the Black Sea ecosystem [15]

Shipping-related risks are clearly a strong argument in support of long-distance pipelines routed directly to external seas, for example to Ceyhan on Turkey's Mediterranean coast. Such long-distance pipelines would make it possible to avoid lengthy barge-rail-truck-pipeline transfers, as well as trans-Black Sea shipments. The fact that the Caspian's export capacity is being held back by poor transit routes makes it likely, however, that any new capacity would only augment, rather than replace, the older capacity. The main implication for oil spill risk is that as long as export amounts are increasing, new pipelines will add to the total tanker traffic, rather than lead to the immediate closure of older routes.

Given the current relatively low tanker traffic density, the few natural maritime hazards, and the straightforward sea and climatic conditions, it is not surprising that the Black Sea has proved a relatively safe area for shipping to date. While the historical occurrence of major tanker spills within the Black Sea itself has been low, there have been a number of major incidents in the narrow and congested Bosporus waterway and its approaches.

The most noteworthy of these were the INDEPENDENTA (1979) - see Fig. 13 [16], FAHIRE GUNERI (1984), JAMBUR (1990), NASSIA (1994), and VOLGONEFT-248 (1999). Vessel traffic in the 30 km-long Bosporus has grown to about 50,000 vessels per year, with approximately 5,000 of these carrying crude oil or LNG.

All of the Black Sea states have passed the stage of writing draft national oil spill contingency plans. All six Black Sea states have ratified the 1992 Bucharest Convention on the Protection of the Black Sea against Pollution. In the present context the importance of the Convention (and its Emergency Protocol) is its stipulation that the Contracting Parties endeavour to maintain and promote either individually or through bilateral or multilateral co-operation, contingency plans for combating pollution of the sea by oil or other harmful substances. In line with the Convention, a Black Sea Commission (BSC) was established with a Permanent Secretariat in Istanbul.

Also known as the Black Sea Commission or Istanbul Commission, this organisation includes among its tasks the co-ordination of intergovernmental meetings on environmental issues related to shipping safety. One of the most important of its recent accomplishments has been the production of a draft Black Sea Contingency Plan (BSCP) for oil spill response in accordance with the Emergency Protocol to the Bucharest Convention.

Fig. 13. An exemplification image from INDEPENDENTA (1979) hazard [16]

Fig. 14. An exemplification image for Black Sea pollution with oil products [17]

A further product of the Bucharest Convention was the creation of thematic working centres for key regional environmental issues, even for the Black Sea pollution with oil products, as shown in Fig. 14 [17]. The one for spill response, the regional Emergency Response Activity Centre was established in 1994 in Varna (Bulgaria) to assist with pollution preparedness and response.

In terms of training, the International Maritime Organization (IMO) [18] and The International Oil Pollution Compensation Funds [19] have sponsored national and regional training courses at all levels in a number of the Black Sea countries. Spill response exercises in the Black Sea tend to be localised rather than larger scale or even internationally-organised exercises. As for the physical preparation for oil spills of all sizes in the Black Sea, much work remains. Terminals and oil companies have the best supplies of equipment, all of which is held ready for small spills. For spills outside oil loading/discharge facilities there are some contractors in Turkey, Russia and Romania with oil spill response experience, though these mostly have non-specialised equipment.

The causes of pollution of the Black Sea ecosystem with petroleum products are analyzed, as a rule, in relation to the two forms of pollution, which are covered by the pollution with petroleum products of the marine environment, respectively operational and accidental. Operational pollution is generated, as expected, by spills that occur unintentionally, mainly in the following situations: during the loading-unloading of oil tanks, during bunkering operations (filling of heavy and light fuel for ship's engines), during the ship's voyage, by evacuating ballast and bilge water without sufficient purification, while stationed in ports, when there are leaks when cleaning oil tankers in order to switch to the transport of other types of oil, etc. Accidental pollution is generally caused by navigation accidents, the most significant of which are: collisions, strandings, shipwrecks due to rupture of the hull or water holes, fires, explosions, etc.

About 110,000 tonnes of oil are discharged annually in the Black Sea basin, which makes the effects of pollution felt in the ecological balance of the entire basin. Continental sources pollute the Black Sea the most. The Danube alone spills 53,000 tonnes a year, almost 50% of the total amount of oil spilled annually into the sea.

Among other land sources, the following are highlighted: 30,000 tonnes of oil come from domestic wastewater, 15,000 tonnes come from industry, including the oil industry and the remaining 12,000 tonnes are the input of other sources, including shipping. Pollution due to oil spills as a result of shipping accidents is insignificant, this sea basin being so far protected from such major accidents.

4. CONCLUSION

Oil pollution has long ceased to be the only problem for geologists or economists. It greatly complicates the equations that politicians have to solve and is slowly becoming a factor of social life that cannot be ignored, inducing directly or indirectly relationships that are not always easy to grasp. In its absence, social communities demand from leaders actions whose effects are often unpopular, create pressure on decision-making processes, the state becoming either a rationalizer or a vector of power policy.

As has been shown so far, the world's oil pollution has reached such an extent in the last 50 years (1970-20200 that, in the opinion of many experts, marine ecosystems would need years of complete recovery, both in terms of the biotopes health, as well as in terms of rehabilitation of all species of flora and fauna that have suffered as a result of pollution.

As for the Black Sea ecosystem, relatively poor in biocenosis, it has been affected by oil pollution, both from an operational and accidental perspective, but the pollution itself has not been significant; in fact, more attention is paid to the area in terms of resource management, which involves special intervention and conservation measures.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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