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2021 Brazil experiences second major oil spill and ecological disaster

Abstract

In 2021 oil spill leakage residue and dumped garbage from unknown sources were carried by sea currents and invaded the only oceanic mangrove on an island in the South Atlantic. This tropical biodiverse pristine region of the Archipelago of Fernando de Noronha (PE, Brazil) was acutely affected and suffered chronic impacts that include chemical contamination and economic consequences from this environmental disaster. Here we will show how oil spills and dumped garbage affect the calcareous microorganisms and the ecological chain due to acidification, a known result of low-oxygen environments due to the physical and chemical perturbations of the water and sediment. The diverse biological community of microfossils living in the sediment-water interface tracks the entire marine environment preserved through time. Changes in ocean chemistry can have broad direct and indirect effects on marine organisms and the ecosystems in which they live. Studies indicate that most marine calcifiers (corals, foraminifera, crustaceans, and mollusks) exhibit reduced calcification through increasing ocean acidification. Calcium carbonate ($CaCO_3$) in coral reefs and the shells of other marine calcifiers comes in two different mineral forms: calcite and aragonite. Seawater on the ocean surface near the tropics is supersaturated with the ions needed to form these carbonate minerals. Ocean acidification reduces carbonate ion saturation, making it more difficult for marine organisms to produce the $CaCO_3$ needed to form their shells and structures. This 2021 disaster occurred during the Brazilian government's extensive environmental mismanagement, and it is of urgent necessity to spotlight this tragedy affecting this unique and sensitive habitat showing the ongoing damaging effects that include biological-socio-economic losses not yet sufficiently addressed. Interrelated communities may continue to absorb these deleterious impacts for decades without consideration or compensation.

Keywords: environmental impacts, socioeconomic losses, government, Brazilian coast, oil spill, garbage, disaster

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Introduction

At the end of August 2021, Brazil had its second historically large oil spill on its coast, an event which also included huge amounts of freshly dumped garbage. The first one was in the Northeastern area of Brazil[1-7, 9,11–13,15-23,65,66] in 2019, and this one now is on the only oceanic mangrove area of the Atlantic Ocean (Figure 1).

Figure 1 Fernando de Noronha Island, in the state of Pernanbuco (PE), Brazil.

Oil spillage and dumped garbage occurred in the Preserved Marine Protected Area of the Archipelago of Fernando de Noronha (PE, Brazil), one of the greatest marine diversity areas in the South Atlantic. The climax of the accident was likely to have been on August 16th, 2021 when people started spotting the problem in the mangrove and on beaches (Figure 2).

Figure 2 Oil spill on the Island of Fernando de Noronha.

Caused by the currents, local hydrodynamics, and geography, the oil and the garbage quickly spread around mostly moving via the subsurface (between 50 cm and 1 m deep). The oil spilled is probably formed by a mixture of thousands of hydrocarbon-type compounds, chelated heavy metals, and tons of plastic and other waste.[10] The origin of the spill itself remains an unsolved mystery! A significant amount of garbage and oil has been retired from the mangrove by the civil society volunteers, and no one knows if the spill occurred via a cargo tanker buoyancy problem, leaking or dumping its cargo.

Oil spills can have immediate and visible consequences such as habitat pollution and the death of oiled animals. However, they can also have multiple short and long-term consequences on entire social and ecological systems that rely on uncontaminated environments. Therefore, oil spills should be approached in a broad, integrated, and multidisciplinary way. Integrated scientific approaches should include disciplines and topics such as oceanography (chemistry, physics, and biology), ecology, spatial modeling, geology, toxicology, epidemiology, microbiology, fisheries, sociology, psychology, and economics.

To mitigate the effects of oil spills, it is necessary to have policies and research regarding the severity of oil spills, environmental toxicity of the oil, and acute and chronic toxicity to communities. Besides that, the adverse impacts of the oil spill disaster on Brazil's environment, economy, and society need more international outreach and visibility to find answers and fill data gaps on the geochemistry and identification of the source of the oily and refuse materials. Discussion about environmental monitoring and response measures that must be implemented to minimize the ecological, economic, and social effects of the spill; which is particularly relevant in areas with high tropical biodiversity while also experiencing high social inequality, which is presently the case of this northeastern accident. It is necessary to assess the local oil spill impacts and estimate income generation loss and food security for coastal communities. It is also important to understand how long impacts are expected to last, anticipate collateral damages, and then propose mitigation options and mechanisms to reduce the magnitude of future spills.

This paper deals with the future consequences of the acidification in the Archipelago of Fernando de Noronha (PE, Brazil) exposed to the oil spill and dumped garbage in August 2021. As the oil and garbage become camouflaged to the observer over time, this tragic event in the only oceanic mangrove of the South Atlantic will fall into oblivion. Local communities and Nature itself will endure its consequences over time. Here we record the deleterious event because the effects will last for decades.

Impacts from oil on the marine ecosystems

Hydrocarbons released from oil spills into marine environments have immediate and acute effects on living organisms. The rapid influx of CO_2 into the ocean severely threatens marine life, with the shells of some animals dissolving rapidly in the increased acidic seawater. Chronic contamination can have long-term effects on the environment as hydrogen sulphide, methane, and ammonia are released, acidifying the water-sediment interface. To deal with these impacts effectively, it is important to understand how pollutants and contaminants are released and how they behave in the environment. For instance, hydrocarbon petroleum products are highly reactive in aerobic environments due to microbial and photochemical reactions,[5–7] and the Hydrogen sulphide (H2S) is a gas without color and is flammable, poisonous, and corrosive. It is produced as a result of the microbial breakdown of organic materials of crude oil in the absence of oxygen. Its toxicity is similar to carbon monoxide and prevents cellular respiration. Therefore, an early detection of H2S means the difference between death and life.

The medium to long-term contamination effect is a silent impact caused by oil being partially degraded and absorbed by the environment. Concentrations of polycyclic aromatic hydrocarbons (PAHs) enough to affect individual health following oil spill accidents are usual and likely to remain for long periods in some habitats.[8,9] The PAHs in the oil have harmful immunotoxin threatening several wild aquatic species. The consequences of immune toxicity involve damage to the tolerance of organisms, making them more submissive to new diseases and parasitism, detaining population recovery,[10] and teleost fish embryo is reactive to PAHs causing issues related to cardiac development.[8]

A large amount of oil (between 10 to 30%) has been observed on the surface of marine substrates, expanding acute epifauna and infauna loss of life by asphyxiation and contamination. The animals and plants that do not die at the moment of the accident may chronically embody the toxic substance, which then compiles along the food chain.[25] Other serious problems of crude oil in the sediment

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are the acidification and later dissolution of calcium carbonate shells, roaming from microorganisms (foraminifera) to macro-organisms (mollusks) as already noted by[11] studies on the problematic Deepwater Horizon (DWH) event in the Gulf of Mexico (GoM), in April 2010, which show that the composition/accumulation of oil on the seabed was vigorously altered by sediment substrate, composition, texture, sedimentary processes, and accumulation rates.[2]

It is accepted that many types of oil will change sedimentation in multiple ways. Thick and heavy oils, which is the type identified in the Brazilian oil spill, are anticipated to settle on the substrate. Oil sedimentation may increase if the oil mixes with sand and later sinks,[25] which is once more the case of Brazil's coast where the oil has extensively affected its sand beaches.

Various immediate effects can be observed in organisms that are directly exposed to oil, such as birds and turtles that have become soaked in oil. Ingestion, direct contact, and oiling pose immediate threats, compromising animal digestion and leading to eye and nostril irritation. Additionally, exposure may result in the inhalation of toxic vapors, asphyxiation, and suffocation. Particles dispersed in water tend to accumulate in sensitive epithelial tissues, including gills and mucous membranes. This accumulation obstructs these tissues, causing degeneration. Filter-feeder animals like bivalves may ingest sufficient amounts of oil, incapacitating their feeding capabilities. Larger benthic animals such as octopuses, lobsters, and morays, which dwell in burrows and use them for shelter, are most directly impacted by direct oil contact.

Organisms with oil-coated gills struggle to obtain adequate oxygenation, and soluble hydrocarbons enter their bloodstream through the respiratory tract. Another consequence of oil dispersion in the open sea is its impact on plankton surface layers. Plankton, as the foundational element in the food chain, supports a diverse ecosystem of marine mammals, fish, and invertebrates.

One of the primary concerns during an oil spill is the bioaccumulation of hydrocarbons. However, it is important to note that many components of oil and petroleum products exhibit some level of biodegradability within the food chain.[4] While evidence of the bioaccumulation phenomenon is limited, it is acknowledged that it can occur under certain circumstances.[37]

Nevertheless, it is recognized that fish, particularly in their early life stages, display heightened sensitivity to petrogenic compounds, experiencing issues such as cardiotoxicity and phototoxicity. Additionally, the carcinogenic nature of polycyclic aromatic hydrocarbons (PAHs) and their effects on metabolic, immune, and reproductive systems further underscores the vulnerabilities of fish.[38] Given the global prevalence of pollutants being discharged into the seas (as depicted in Figure 3), it is imperative to conduct contamination and chemical analyses continuously. These investigations are crucial to ensuring the ongoing health and well-being of ecosystems.

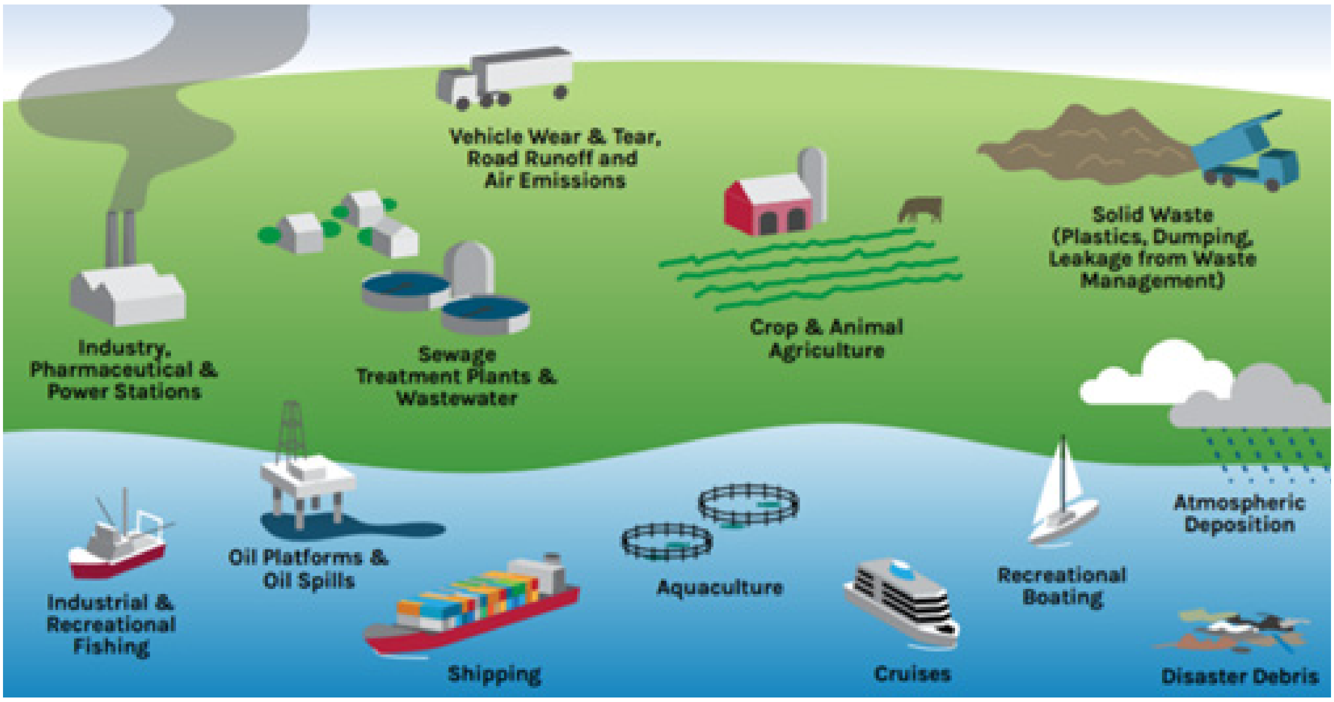

Figure 3 Sources of ocean pollution. Graphic published in Jambeck, J., E. Moss, B. Dubey et al. 2020. Leveraging multi-target strategies to address plastic pollution in the context of an already stressed ocean.

A growing body of research indicates that ocean acidification has adverse effects on marine organisms. These impacts include decreased skeletal growth in reef-building corals, a diminished ability of free-swimming zooplankton to maintain a protective carapace (zooplankton being crucial for marine food webs), a reduced rate of calcium carbonate production in marine algae (including green algae and crusty green algae), lower survival rates in marine larval species (including commercial fish and shellfish), and impaired developmental stages in invertebrates (encompassing fertilization, egg cleavage, larvae, settlement, and reproduction). Additionally, there are observed excessive carbon dioxide (CO_2) levels in the blood (CO_2 toxicity) of fish and cephalopods, along with significantly reduced growth and fecundity in certain invertebrate species. Beyond calcification and metabolic performance, the effects of declining pH (increased acidity) extend to interactions between species at different life stages, changes in competitive pressures (e.g., algae outperforming corals), shifts in

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predation dynamics within responding communities, alterations in the behavior of fish larvae due to sensory function deterioration, and reduced recruitment success. Furthermore, interactions with other stressors such as nutrient input, sea surface temperature rise, and sea level rise will influence how marine communities respond to high CO_2 conditions. The environmental coastal impacts resulting from oil spills also vary depending on the type of coast involved.

The susceptibility of diverse substrates to oil varies significantly, encompassing rocky shores, gravel beaches, sand, fine sand, mangroves, and coral reefs.[4,37] The impacted coastal areas extend beyond sandy beaches, encompassing a wide range of ecosystems such as estuaries, mangroves, reefs, coastal lagoons, riverbanks, and more. Although volunteers have responded by removing larger, more visible patches of oil and debris from the beaches, there has been no corresponding effort from the government thus far.

Finer oil particles present on the sand can impact a highly diverse benthic community, comprising mega, macro, and meiofauna, including crustaceans, Polychaeta, nematodes, and mollusks.[39,40] These organisms play a crucial role in the benthic trophic chain, connecting with other environments by serving as food sources for various animals in the water column. The extent of contamination in the trophic web requires further investigation.

One of the significant consequences of heightened ocean acidity pertains to the production of calcium carbonate structures such as shells, skeletons, and plaques- a process known as calcification. Acidification disrupts the carbonate chemistry balance in seawater, diminishing the pH and the availability of carbonate ions crucial for corals and other marine calcifiers in constructing their skeletons. This disruption results in a reduction in the rate and quantity of calcification among a broad spectrum of marine organisms, ranging from plankton to mollusks and reef-building corals.

The decline in dissolved carbonate ions within seawater carries significant implications for coral reef ecosystems. Given that reef-building corals rely on carbonate to construct their skeletons, the reduction in carbonate ion concentrations is anticipated to result in weaker and more fragile coral skeletons, accompanied by slower rates of coral growth. Over time, this scenario may accelerate coral reef erosion, surpassing the rate at which coral structures can calcify, ultimately diminishing the competitive capacity of coral species for space.[60–64]

For corals and other calcifying organisms, such as sea urchins and crustaceans, decreased calcification brings about several consequences, including increased vulnerability of corals to bleaching and disease. It also diminishes the organisms' ability to defend themselves against predators, compete for food and habitat, and alter their behavior patterns. Furthermore, reduced ability to tolerate ultraviolet radiation, elevated bioerosion rates, and heightened susceptibility to cyclone damage are additional repercussions of reduced calcification.

Laboratory investigations have scrutinized the impact of ocean acidification on various coral types and coralline algae, revealing a spectrum of responses ranging from a 3% to 60% decline in calcification rates to a twofold increase in atmospheric CO_2. A recent study conducted on brain corals in Bermuda observed a 25% decrease in calcification rates since the 1950s, with ocean acidification identified as a probable contributing factor.

Beyond the widely affected sandy beaches, the reach of oil extended to various habitats, including rocky outcrops and highly vulnerable areas like mangroves. These habitats are not uniform, exhibiting unique local coastal hydrodynamic regimes and distinctions in shape, size, and substrate nature. Mangroves, as sheltered ecosystems with low hydrodynamics, create conditions conducive to the accumulation of fine sediments that retain contaminants over extended periods. They are particularly susceptible to this form of pollution due to the potential impairment of aerial root breathing by a thin oil layer. Moreover, mangroves serve as habitats for numerous permanent and seasonal species, some of commercial interest to fisheries, utilizing these areas as nursery sites during sensitive periods of their life cycle.[4,41] Given the significant connectivity of species in the marine environment, oil pollution in mangroves can have repercussions on ecological productivity in the short, medium, and long term, compromising biodiversity and fisheries. Depending on the incident's characteristics, such as intensity and repetition, and the type of polluting agent, these invertebrates may face suffocation.[4]

Research incorporating models of oil distribution, destination, and effects, coupled with toxicity tests on various species, indicates that comprehensive conclusions regarding the damages caused by oil spills to natural resources emerge only after several years of continuous monitoring and information gathering.[42] Inadequate cleaning, negligent monitoring, and insufficient research, as exemplified by Brazil's previous experiences, not only prolong the time required for reaching conclusions but also yield insufficient and inconclusive data.

The repercussions of oil spills extend beyond environmental impacts, significantly affecting human livelihoods, social structures, cultural practices, and economic activities. Coastal tourism experiences an immediate downturn as tourists become apprehensive about potential health effects stemming from direct contact with oil.[43] Coastal tourism holds a pivotal role in the Brazilian tourism sector, given the country's consistently favorable weather, especially in this archipelago. While the quantification of economic effects on tourist operators is still pending, it is anticipated that they may be less severe compared to the impact on artisanal fishermen and their families- who represent some of the most economically vulnerable coastal groups- local subsistence communities, and commercial fisheries dependent on the sea.

Fisheries will inevitably face significant impacts as contamination risks directly interfere with fish sales, leading to a substantial decline in income for artisanal fishers. Women employed in fisheries, such as gleaners, are particularly vulnerable due to their reliance on habitats like mangroves and sandbanks and the exploitation of filter-feeding animals like mollusks, which are highly sensitive to oil contamination.[48] Consequently, a coastal oil disaster may exacerbate gender vulnerability within fishing communities.

Potential government support is likely to benefit only a limited portion of fishers based on bureaucratic requirements, such as registration with the fisheries secretariat, and granting them fishing licenses. Even if less bureaucratic measures are adopted, such as having villages and local fishing associations identify fishers, compensation may only be temporary and is unlikely to fully mitigate their economic losses. This is because fish from Brazilian artisanal fisheries are integral to complex value chains, often characterized by invisible links and no associated taxes.[49,50]

Furthermore, fishermen and their families face varying degrees of health issues, ranging from those resulting from direct contact with oil to psychological concerns linked to the socioeconomic uncertainty triggered by the spill, such as the fear of job loss and food insecurity.[51] These effects can persist for extended periods and are often overlooked by governments in regions where oil disasters have occurred.[52,53]

Results

Oil mixed and garbage of all kinds have been found in the oceanic mangrove in 2021 indicating problems for the future. Therefore, there is a high range of impacts and threats on the marine biota which are yet to be evaluated, especially given that the area affected is on a preserved marine area. Up to now, the extent of the event is not yet measured, however, we have data from 2019, where an oil spill severely affected one of Brazil's most beautiful areas in the northeast reefal tourist area of Pirangi with the worst environmental accident ever noted in any tropical coastal region globally.[65,66] The oil, constituting a complex chemical mixture comprising thousands of hydrocarbon-type compounds, including heavy metals, has spilled onto beaches, estuaries, and reef areas, impacting a multitude of ecosystems. The immediate and evident outcomes, such as habitat pollution and the mortality of oiled animals, underscore the fact that this oil spill disaster carries both immediate and enduring consequences for ecological systems that depend on the now contaminated environment for their survival.

Sediment and water samples from 55 stations in "Pirangi Reef (Rio Grande do Norte, Brazil)", which experienced an oil spill in October 2019, underwent a prior examination in 2013 and 2014, revealing no signs of oil patches or other intrusions in the sediment or water during those years. Following the oil spill, we sampled 25 new sites across reef areas, sandy sediments, and macroalgae substratum to compare temporal data post the catastrophic event. Our findings indicate that over 95% of unconsolidated sediment samples, including certain corals, displayed evidence of oil in 2019, a stark contrast to the absence of any such evidence in 2013 and 2014.

Analysis of benthic foraminiferal fauna data reveals the loss of 26 species, including symbiotic species. In 2013 and 2014, 44 foraminiferal species were identified, while in 2019, after the oil spill, only 18 species survived the impacts of the accident, facing challenges such as habitat loss and dissolution caused by acidic sediment contaminants. Furthermore, our observations highlight that 59% of all species were unable to tolerate the altered environment and have disappeared, with 50% of symbiotic species also becoming extinct. This significant reduction in the number of species following the 2019 oil spill underscores that the extent of contamination extends far beyond previous assumptions, with a substantial decrease in diversity among benthic species.

As of now, there is no available estimate for the quantity of oil that persists in marine sediments, estuaries, mangroves, or the extent of infiltration into the Brazilian sand beaches, or in the marine preserved Archipelago of Fernando de Noronha. (https://g1.globo.com/pe/pernambuco/blog/viver-noronha/post/2021/08/14/fragmentos-de-oleo-e-lixo-oceanico-sao-encontrados-nas-praias-de-fernando-de-noronha.ghtml).

Discussion

Nearly four years after the initial signs of the major oil spill in 2021, crucial aspects, including the origin, extent, and cause of the spill, as well as specific characteristics of the oil, remain unclear due to ongoing governmental investigations. This lack of clarity has significantly hindered immediate and subsequent actions. There is still no estimate for the quantity of oil that persists in marine sediments, estuaries, and mangroves, or the extent to which it has infiltrated Brazilian sand beaches. The magnitude of the first major oil accident in the northeastern part of Brazil cannot be accurately measured solely by the amount of oil removed and observed on beaches and coastal areas.

In the case of significant oil spills or incidents involving dumped garbage, like the one under consideration in this report, prompt containment and waste removal are essential. However, these actions should not be isolated; they should be complemented by the implementation of comprehensive and effective strategies, incorporating protocols for waste containment, cleaning, and removal.

During the 2019 oil spill disaster, the federal government's response was notably delayed. It took more than 40 days for them to enact the Contingency Plan for Oil Pollution Incidents (PNC from Portuguese), which had been in place since 2013. The implementation of the plan only occurred after facing pressure from the Federal Prosecution Service on two occasions. This delay was partly attributed to the prevailing political climate in 2019, marked by the systematic dismantling of Brazilian environmental programs, as evidenced by various actions throughout the year.[56]

In a significant move in April 2019, less than four months before the oil spill, the federal government eliminated several councils, committees, commissions, and collegiate bodies associated with the federal public administration through Decree 9,759 / 2019. This included the dissolution of two committees integral to the PNC, providing insight into the prolonged implementation process. The extent of the environmental setback was further exacerbated by the lack of transparency, as the federal agency IBAMA, the Brazilian Institute of Environmental and Renewable Natural Resources, only released information on the affected locations along the Brazilian coast through a map update on March 19, 2020.

In response to public pressure in December 2019, the government reluctantly issued a research call with a meager budget of around $320,000 USD (with a maximum allocation of USD $25,000.00 per project). This amount was deemed insufficient for a comprehensive investigation into the full extent of the damage caused by the oil spill incident. Simultaneously, during the same period, the Ministry of Science, Technology, and Innovation (MCTI) launched an emergency initiative under the "Ciências do Mar" (Ocean Sciences) program. This program, designed to guide actions from 2019 to 2030 with the aim of managing knowledge for the conservation and sustainable use of the sea, allocated approximately $1.4 million USD to support established research groups (INCTs and PELDs) in conducting studies on the impacts of oil spills. While the latter amount may seem substantial, it falls short of the necessary funding, and the presence of cumbersome bureaucratic processes continues to hinder the timely and effective delivery of results. Conversely, certain state governments, although their funding may be deemed insufficient, have displayed greater proactivity by allocating comparatively larger amounts of financial support. These state-level initiatives have also engaged in partnerships and collaborations with a spectrum of entities, including public and private research institutions, associations, universities, and non-profit organizations.

In the midst of the ongoing mystery surrounding the origin of the oil and dumped garbage in 2021, any scientific effort aimed at clarification would be expected to be embraced. However, the scientific community in Brazil has encountered a smear campaign intended to undermine the credibility of its findings and opinions. This campaign is particularly pronounced when academics speak out against environmental and/or human rights violations, making the investigation into an oil spill a particularly sensitive matter, as it intersects with both of these critical issues.[59] Despite the passage of a significant amount of time, none of the hypotheses regarding the origin of the spill have been confirmed, primarily due to a lack of scientific consistency in the available data.

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Conclusion

Global crude oil and natural gas production reached its zenith, with an estimated daily output of 89 million barrels in 2011 (more than a decade ago). About half of this production is transported via the sea. Consequently, coastal regions worldwide face exposure to oil spills resulting from accidents or illicit practices. This has led to the widespread presence of crude oil, particularly in marine sediments near harbors and marinas. Oil spills contribute to the alteration of the chemical composition of oil by facilitating the breakdown of its components.

The discharge of thousands of tons of petroleum hydrocarbons (PHs) has a profound impact on marine environments, inflicting severe ecological and economic damage, primarily through the induction of ocean acidification. The process of oil spills results in the release of hydrogen sulfide (H2S), ammonia, and methane, contributing to a decline in sediment pH and reduced concentrations of dissolved oxygen in the water.

Tourism and sewage pollution have already impacted marine ecosystems. The 2019 oil spill in the Northeastern region, followed by another in Fernando de Noronha in 2021, further worsened the situation. These incidents, along with occasional accidents, leaks, and tank cleaning by boats, have collectively led to a decline in biodiversity in the modern era due to various anthropogenic sources. To illustrate, pollution resulting from practices like tanker washing and ballast water discharge is estimated to add roughly 2 million tons annually to the global total. The recent release of substantial quantities of contaminants and debris into this oceanic mangrove presents a notable obstacle to current methods and technologies employed in oil spill treatment. Consequently, an immediate imperative exists for the advancement and refinement of bioremediation techniques. These techniques are crucial for playing a central role in contingency plans designed for marine oil spill responses. Action is required to assess the damage caused to local coastal communities for future generations, as well as to preserve the environmental quality of the marine and coastal regions. The ongoing dissolution of organisms will eventually lead to the complete disappearance of microfauna, expected to occur at least one year after the accident. These deleterious effects, resulting from human activities, have yet to be adequately addressed by the authorities in the current Brazilian Ministry of Environment.

Future directions

The 21st century still carries significant risks related to oil production, transportation, consumption, and the pollution caused by waste. This underscores the pressing necessity for the adoption of novel policies advocating cleaner and safer production methods, complemented by ambitious disaster prevention and mitigation plans. When disasters strike, they should serve as instructive experiences, guiding us in averting similar events and ensuring that the most vulnerable elements in both nature and society are not disproportionately affected. Addressing these challenges is a collective societal responsibility, necessitating the collaboration of academia and government to thoroughly investigate such disasters and account for their consequences, even when public attention wanes due to shifting media interests. These endeavors call for cooperative partnerships where the scientific community is not held solely responsible for societal issues but is instead regarded as a gateway to innovative solutions for disaster management and the prevention of future environmental challenges faced not only by Brazil but also by the global community.

Having established government protocols is crucial for immediate responses to oil removal, compensating for socioeconomic losses, and assessing contamination levels in habitats, organisms, and humans. Alongside these urgent actions, it's vital to focus on habitat recovery and continuous monitoring to ensure environmental health. A comprehensive approach requires integrating diverse scientific knowledge, especially in understanding the cumulative stressors affecting reef environments, such as elevated water temperatures leading to coral bleaching in tropical reef ecosystems along the Brazilian coast, exacerbated by pollution and contamination.

The pressing need for a shift in our approach to natural resource usage and oil exploration can no longer be ignored. By 2100, the pH of oceans is projected to drop below 7.8 from the current 8.1, signifying a significant increase in acidity given the logarithmic nature of the pH scale- a 0.1 unit drop represents a 25% rise in acidity. Recognizing these challenges, it's imperative that we initiate the necessary changes.

Without proper monitoring, the impacts of events like oil spills are not connected to their long-term consequences, hindering the implementation of protective and mitigative measures for future disasters. It is crucial to address and engage in discussions regarding strategies for mapping the impact on benthic habitats to enhance our responses effectively.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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