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Oil spill in South Atlantic (Brazil): Environmental and governmental disaster

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ABSTRACT

In early September 2019, dense crude oil began to wash the beaches of Brazil's tropical coast. Four months after the first report, the oil has already been found along >3000 km of the Brazilian coastline on >980 beaches and was recently observed along the Amazon coast, making this oil spill the most extensive and severe environmental disaster ever recorded in Brazilian history, in the South Atlantic basin, and in tropical coastal regions worldwide. Four features of this oil-spill disaster make it unique: 1) the characteristics of the oil spill; 2) the characteristics of the affected region in tropical Brazil; 3) the significant number of protected areas (>55) and tropical ecosystems affected by the oil; and 4) the absence of measures and/or flaws in the measures taken by the federal government to address this environmental and social emergency. The affected species and poor human communities in Brazil should receive focused attention in the coming decades owing to the long-term impacts of the oil contamination. Environmental monitoring and response measures must be implemented to minimize the ecological, economic, and social effects of the spill. Biodiversity and climate regulation losses considering blue carbon environments should drive discussions regarding mining accidents and global consequences related to pre-salt oil exploitation, new spill events, and their global impacts. These measures are particularly relevant in areas with high tropical biodiversity and high social inequality, as in the present case, which represents one of the worst-case scenarios of an environmental and governmental disaster.

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1. Introduction

In early September 2019, crude oil began to wash the beaches of Brazil's tropical coast. Four months after the first report, the oil has already been found along >3000 km of the Brazilian coastline on >980 beaches (Fig. 1) and was recently observed along the Amazon coast, making this oil spill the most extensive and severe environmental disaster ever recorded in Brazilian history, in the South Atlantic ocean basin, and in tropical coastal regions worldwide [1]. In this short communication, a brief analysis of this oil-spill disaster is provided, including the associated environmental problems and governmental failures to minimize the damage.

The Brazilian Navy and other governmental authorities are investigating the source of the oil. Their primary hypothesis is that the oil originated from a vessel navigating offshore that conducted illegal oil dumping (intentional discharge) or accidently released the oil. This unidentified ship appears to have spilled the crude oil approximately 700 km (~380 nautical miles) off Brazil's coast. Federal investigators estimated that the ship spilled—either accidently or intentionally—approximately 2.5 million tons of Venezuelan oil, but it is unknown how accurate this estimate is and how much of the spilled oil will reach land [2]. Another hypothesis is that the oil is leaking from a wreck, either old or new [3]. Several wrecks exist in the region, particularly ships that sank during World War II [4], and could be the source of the oil. The third hypothesis is that the oil comes from an extraction platform. However, no problems have been reported in the few platforms that exist in the region. The procedure to the identification of the oil origin is unclear and few details have been publicized. In the few results published, the Hopanos (traditional oil biomarkers) were monitored only by the GC-MS, SIM mode (m/z 191), and based on that it was concluded that the spilled oil was extracted from a Venezuelan oil field [5]. However, according to the modern groundwork of the organic geochemistry forensic science, the first step in source identification of an oil spill is meticulously characterize the oil based on gas chromatography [e.g., flame ionization detection (GC-FID, GCxGC-FID) or mass spectrometer (GC-MS, GC-xGC-MS, using both first and second dimensions], as well as Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS) [6]. Nonetheless, because the origin of the oil is not yet known four months after the first report, none of these three hypothesis can be excluded.

Four features of this oil-spill disaster make it unique: 1) the characteristics of the oil spill; 2) the characteristics of the affected region in tropical Brazil; 3) the significant number of coastal and marine protected areas (MPAs) and tropical ecosystems affected by the oil; and 4) the absence of measures and/or flaws in the measures taken by the federal government to address this environmental and social emergency.

The management of this disaster is more challenging than that of a typical oil spill because the dense crude oil is not observed on the ocean surface; it only appears when it washes up in coastal zones such as sandy beaches and intertidal reefs. Moreover, owing to the ocean circulation in the region, the spread of the oil reached a continental scale along the Brazilian coastline (Fig. 1).

The oil was probably released in the South Equatorial Current or in the waters close to its bifurcation and then transported northward and southward by the western boundary currents. The North Brazil Current, which flows northwestward, transported the oil northward and then westward of the release region, along the continental slope, to Maranhão waters. The Brazil Current that flows southwestward transported the oil southward of the release region, along the continental slope, to Rio de Janeiro waters (Fig. 2). From the continental slope region, where the western boundary currents flow, the oil was probably transported toward the coast by cross-shore currents and then brought to the shore by tidal currents and waves.

Remote-sensing techniques and even low-altitude airplane flights failed to detect the oil before it reached the shores. Owing to its density, the oil is not only affecting the shores' ecosystem but also threatens

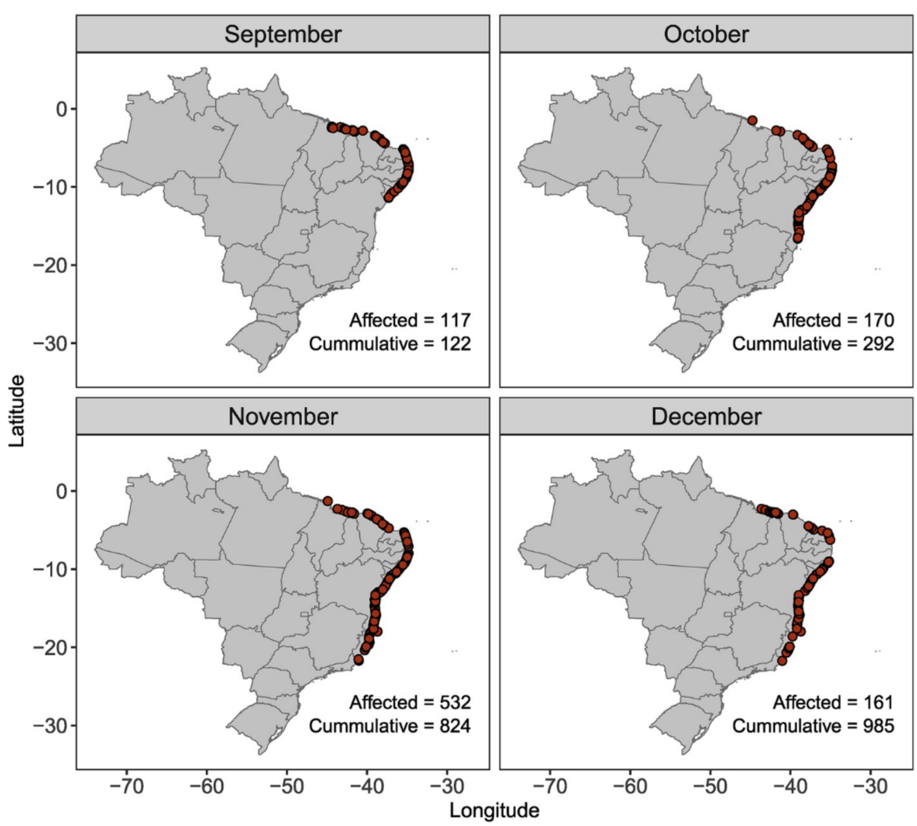

Fig. 1. Most extensive oil-spill disaster ever recorded in the South Atlantic (Brazil). Temporal evolution of the impacted sites between September, October, November and December (2019).

underwater ecosystems (e.g., coral reefs and rhodolith beds), in a manner that is yet to be studied. This is particularly important considering the characteristics of the Brazilian tropical continental shelf, which is a narrow and shallow carbonate–siliciclastic system [7]. The oil is probably still on this seabed and may be transported to the shore by cross-shore currents, winds, and swells, which are common in this region. This indicates that the extent of the environmental and ecotoxicological effects of the disaster has been underestimated.

2. Environmental, economic, and social impacts

The disaster affected nine Northeast and two Southeast Brazilian states, spanning from Maranhão to Rio de Janeiro (Fig. 1). This region has unique demographic features, such as a dense population distribution in the coastal zones (10 of 11 state capitals are located along the coast), and natural characteristics (owing to the diversity of the tropical ecosystems in this region). Additionally, several human activities in this region, such as tourism, artisanal fisheries, nautical sports, and aquaculture, are highly dependent on natural resources. Moreover, this region has high levels of social inequality and poverty [8] which restrict its capacity to litigate and seek redressal for damages.

Although the volume and geographic extension are important factors in determining the seriousness of an oil spill, one of the most important factors is where the oil ends up. Weather conditions and the socioeconomic characteristics of the location and the communities therein determine the extent of the effects of an oil spill [9]. Frequently, poor and underdeveloped countries and regions suffer the most severe and long-term effects (as in this case), owing to the lack of management measures, response strategies, and policy enforcement [9]. This contributes to the increasing poverty rate and the physical, mental, and employment-related displacement of people [10].

The toxic oil slicks in the Tropical Atlantic have already affected >55 MPAs (Supplementary Material 1). These MPAs are part of the National System of Nature Conservation Units, Federal Law 9985/2000, which lists 16 management categories divided into two groups: (i) full-protection conservation units, in which no direct use of natural resources, such as national parks and biological reserves, is permitted and (ii) sustainable use units, in which the rational use of environmental resources such as environmental protected areas, areas of relevant ecological interest, and extractive reserves, is permitted [11] (Supplementary Material 1).

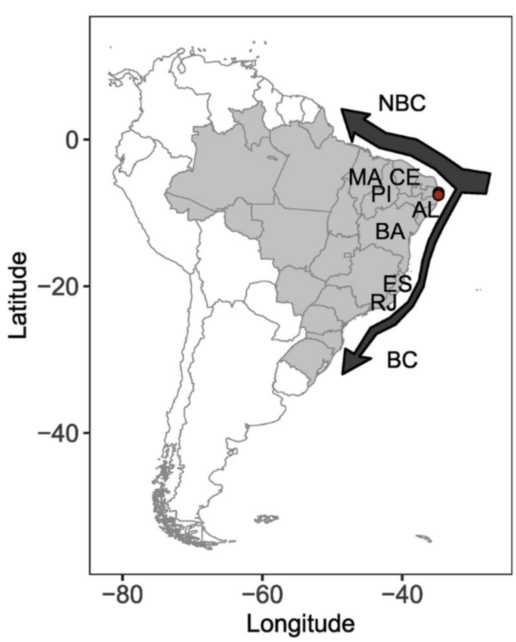

Fig. 2. Circulation dynamics along the Brazilian coast. NBC = North Brazil Current. BC = Brazil Current. MA = Maranhão state, CE = Ceará state. AL = Alagoas state. BA = Bahia state. ES = Espírito Santo state. RJ = Rio de Janeiro state. Red circle show the first site impacted by the oil on 30 August 2019 (Paraíba state). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

The oil reached two of the largest protected coral-reef areas in the South Atlantic:*Costa dos Corais* Environmental Protected Area (EPA) and the Abrolhos Marine National Park (Supplementary Material 1). Created in 1997, the *Costa dos Corais* protected area was the first federal conservation area established to protect the Brazilian reefs on the northeastern coast. Additionally, it is the largest nearshore MPA in the country [12]. Abrolhos Marine Park harbors the largest and most diverse coral-reef complex in the Southwestern Atlantic. The coast of Bahia (mainly south of Abrolhos Bank) is known for its abundant corals [13], prosobranch mollusks [14], and reef fish [15]. The coral reefs in Brazil are the only reefs in the South Atlantic and are characterized by high rates of endemism, biological richness, provision of important ecosystem goods and services [13,16], and vulnerability to local and global impacts [17].

The MPAs that were affected by the oil spill are important to coastal and marine biodiversity as well as the maintenance of ecosystem goods and services, such as food provision; biodiversity maintenance; nutrient cycling; reproduction and nursery areas; and leisure, recreation, and cultural inspiration [18]. However, the MPAs are constantly subject to several human threats [19], including chemical pollution. The effect of this massive crude oil spill is unknown, but it has certainly damaged the structure and function of tropical marine ecosystems [1], having toxic effects on the organisms therein [20]. The crude oil moves beneath the ocean surface, affecting fish, sea turtles, marine mammals, and sea birds. Additionally, the black patches cause massive incrusting on sandy beaches and in coastal ecosystems, likely affecting the structure and dynamics of benthic, planktonic, and nektonic biological communities, as has been observed in other oil spills worldwide [21].

In addition to the effects on these MPAs, the disaster also affected unique and threatened tropical ecosystems, such as marine animal forests [16], sandy beaches [22], intertidal rocky shores [23], rhodolith beds [24], estuarine systems, mangroves, seagrasses [25], and coral reefs [26] (Fig. 2). These ecosystems which possess high biodiversity, constitute two scarcely known biogeographic regions [27]: the North Brazil Shelf and the Tropical Southwestern Atlantic. Moreover, this disaster places additional human pressures on ecosystems already threatened by other stressors, such as overfishing, urbanization, urban contaminants, marine litter, agricultural and industrial effluents, and deforestation [16].

The impact of the oil spill (Fig. 3A) is already being assessed with regard to marine food webs in the affected areas, because similar to plastic, crude oil tends to undergo fragmentation, leading to the accumulation of microparticles at different trophic levels, such as in eggs and larval stages (Fig. 3D), suspension benthic filter feeders, and animals of commercial interest (e.g., lobsters, mollusks, crabs, and fish) [21] (Fig. 3). These microparticles will probably induce significant long-term damage to wildlife and human health along the Brazilian coastline. The oil may have various negative effects on marine organisms (Fig. 3), such as reduced growth, disease, impaired reproduction, impaired physiological health, and mortality [21]. With regard to planktonic invertebrates, a recent study (Campelo et al., unpublished data) revealed oil contamination in copepods and larvae of crabs (Fig. 3D) and polychaetes. Additionally, oil fragments have been observed along the Pernambuco coast (Jaguaribe and Tamandaré EPAs), suggesting this type of impact in other Brazilian MPAs.

Endangered, vulnerable, and migratory species, such as marine invertebrates (Fig. 3E), fish (Fig. 3B), birds, marine mammals, and turtles (e.g., *Eretmochelys imbricata*, *Chelonya midas*-Fig. 3C, and *Lepidochelys olivacea*) have already been affected by oil impregnation and contamination, increasing the potential for bioaccumulation and ecological, social, and economic problems. This environmental impact has already

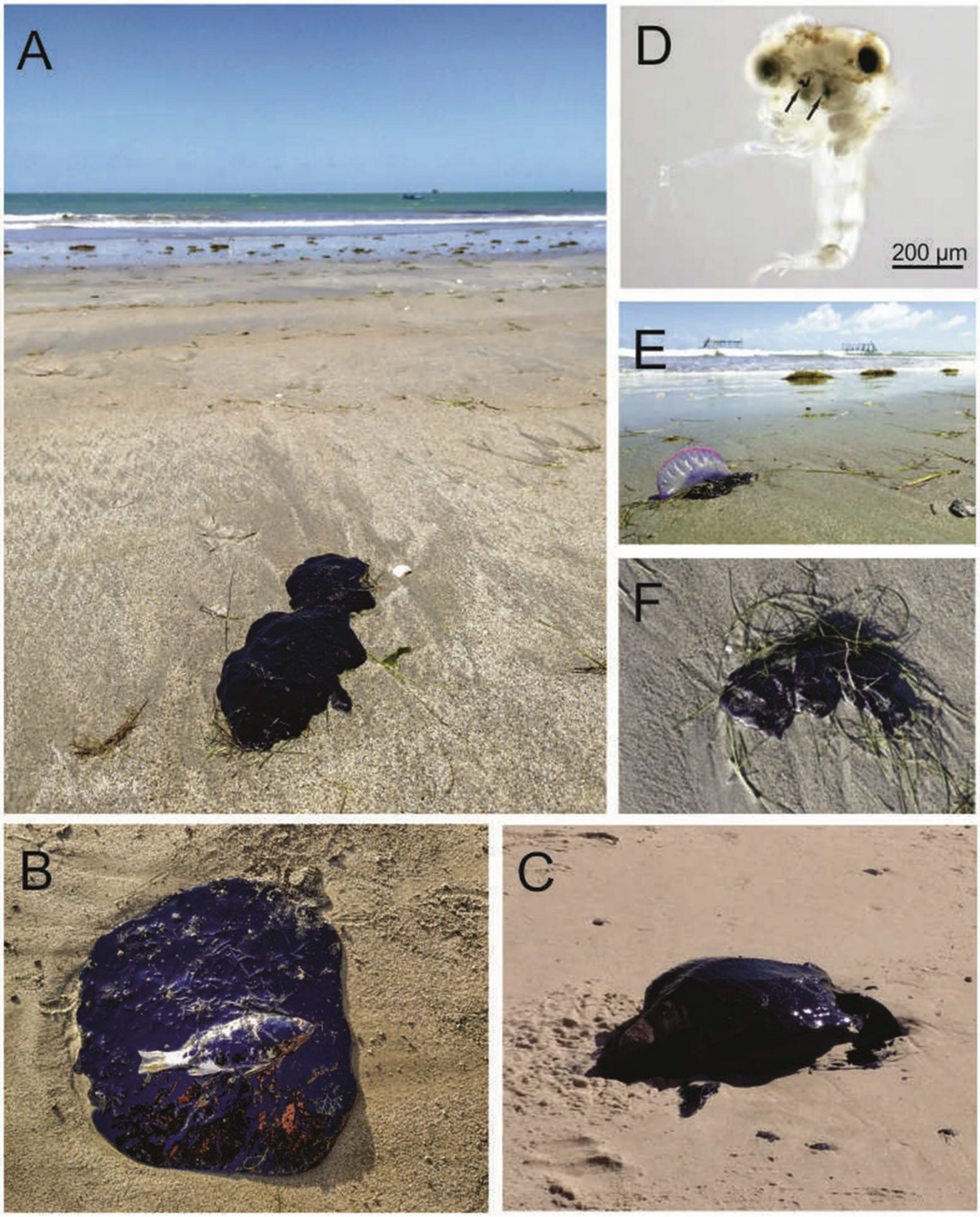

Fig. 3. (A) Oil spill on Brazilian beaches and the resulting damage to different species, leading to long-term negative consequences: (B) fish; (C) Marine turtle *Chelonya midas* covered with oil; (D) zooplankton (crab larvae (zoea 1) with mouth apparatus (arrows) possibly oiled) pelagic invertebrate; (E) Portuguese man-of-war *Physalia physalis* with its tentacles oiled, as well as macroalgae and marine plants; (F) seagrass impregnated with oil.

affected tourism and fishing and extraction activities in traditional and artisanal communities. Initial estimates indicate that >159,000 fishers distributed along the Northeast coast have been affected [28]. However, since 2011, the federal government has not updated the number of fishers in Brazil, suggesting that this number is a considerable underestimation. Additionally, this oil spill has repercussions for public health owing to the contamination of water, sediments, and seafood, and it may have long-term negative effects on the food security of vulnerable communities in northeastern Brazil, which is one of the poorest regions in the country [8].

3. Governmental inaction and implications

Although the circumstances of the oil spill remain unknown, from the first report of the oil, the Brazilian Federal Government has exhibited tremendous inertia with regard to coordination with non-governmental organizations, the military, civil society, states, and Brazilian municipalities [1]. Oil-spill responses involve many actors and require strong coordination and transparent guidelines [29] in territorial waters (12 nautical miles) and in the exclusive economic zone (200 nautical miles).

This governmental inertia, in addition to the continental scale of the oil spill and its unknown cause, may have amplified the ecological, social, and economic impacts [1]. The inaction by the federal government was reinforced by considerable budget cuts for public policies [30], which included reductions in funding and human resources and the recent termination of two committees of the National Contingency Plan of Oil Spills (PNC) with multiple stakeholders: the executive committee and the support committee. The failure of the Brazilian government to act has potential legal consequences: the government's liability is based on the acceptance of the risks of this inaction [31].

Oil-spill surveillance and response measures are important for reducing the risks of oil disasters, and they include PNC. When spills occur, two types of models are critical for response efforts: tactical and strategic [32,33]. Tactical models are implemented post-spill and include prescriptions for the cleanup equipment, the location(s) of equipment dispatch, the length of deployment, and appropriate operational tactics (e.g., mechanical removal, application of dispersant, *in situ* burning, and boom placement) [28]. In contrast, the strategic elements of spill responses are generally implemented prior to spills, requiring planners to consider the locations where spills may occur and their potential frequency, size, and duration. Importantly, the strategic and tactical response models are strongly coupled, in both theory and practice [33].

However, there was a lack of immediate and coordinated adoption of the Contingency Plan for Oil Pollution Incidents (PNC) in Waters under National Jurisdiction, which was elaborated in 2013 [1]. As mentioned previously, two committees that were fundamental to the structure of this plan were terminated at the beginning of 2019 by the federal government: the executive committee, which represented the national authority of the plan and was responsible for its initiation, and the support committee, which was charged with fostering responsiveness, including proposing the conclusion of international cooperation agreements [34]. This delayed the governmental response to the oil spill, which was essential for environmental protection and the minimization of economic and social losses [1,35]. Among the lawsuits that have already been undertaken, the Federal Public Prosecutor's office from the Northeast States filed a lawsuit against the federal government to enforce the activation of this plan and to mitigate the damage caused by the oil spill.

The delay in the implementation of the PNC, along with the termination of both executive and support committees, is a significant part of the problem, as timing is critical for achieving effective cleanup and reducing the environmental impact, cleanup costs, damage compensation, and environmental restoration [36]. Nevertheless, other issues must be highlighted. In the past, throughout the world, many oil-related accidents had delayed responses owing to a lack of PNC, but even in modern times, when many nations have PNCs, oil-spill responses are not very effective. Efficient contingency plans demand adequate investments in equipment and permanent training for the team and must be revised continually to ensure preparedness [37]. Additional issues to consider are the political commitment to oil-spill prevention, the investment in preparedness, and the ratification of international agreements [38]. The oil-spill response within governmental budget is questionable and can be reduced due to internal affairs, as they may vary depending on the government or economic situation of the country [38]. One strategy is to use the "polluter pays" principle and to establish an oil-spill response organization through the oil refineries and tanker shipping companies operating in the country, which will increase the amount of resources and the capacity to respond to large oil spills [39]. In Brazil, another important issue is the continental scale of the country, which makes even an effective PNC very difficult to implement. An excellent strategy is to extend preparedness and oil awareness to the regional and local levels through training or the establishment of regional contingency plans in the major coastal states for an effective oil-spill response [39].

According to UNCLOS (United Nations Convention on the Law of the Sea) provisions, it is up to the coastal state (i.e., Brazil) to adopt internal regulatory systems or to implement bilateral or regional agreements for the protection and preservation of marine resources, as well as for enforcement of environmental public policies in its jurisdictional waters. However, the fact that occurred in the Northeast of Brazil, whose proportions and losses of this environmental disaster cannot yet be concluded since it has not yet finished, has made evident the insufficient inspection and regulation of the use of marine spaces under Brazilian jurisdiction, which should include marine spatial planning, greater availability of means of inspection *in loco*, and monitoring of maritime traffic in real time. Tracking ships in areas without cellphone and VHF (Very High Frequency) radio coverage, e.g., open waters far from land, is possible. This requires the ship or boat to have its own device that automatically sends information through a VHF radio or low-orbit satellites when it is too far from land. This device is called an Automatic Identification System. The Brazilian maritime authority does not provide technological instruments for the monitoring of Brazilian marine waters in real time; therefore, the federal government is developing the Blue Amazon Management System (SisGAAz). However, this system has been undergoing reformulation since 2015 for budgetary adjustments.

Finally, 120 days after the first appearance of the oil, different volumes of oil washing up on coasts have been reported in new localities and MPAs, indicating that the magnitude of this environmental disaster is unknown. Volunteers have actively joined efforts through social networks and have undertaken mechanical removal via cleanup actions at several tropical beaches without proper support from the Federal government. Moreover, recent budget cuts from the federal government with regard to science [40,41] and environmental protection [30] undermine the capacity of Brazilian institutions to understand the effects of the disaster on the economy, biodiversity, public health, and environmental quality in the South Atlantic. Thus, information is lacking, and the government appears to underestimate the environmental, social, and economic consequences of the disaster. The disaster highlights the importance of establishing science-based solutions involving multiple stakeholders to avoid extensive and long-term impacts at continental and global scales [1].

4. Conclusions

The affected tropical species and poor human communities in NE Brazil should receive focused attention in the coming decades owing to the long-term impacts of the oil contamination. Environmental monitoring and response measures must be implemented to minimize the ecological, economic, and social effects of the spill. To elucidate the magnitude of the disaster and to contribute to the restoration of the affected tropical ecosystems, we emphasize the urgent need for research focusing on the following issues: (1) the degree and effects of environmental contamination; (2) the environmental toxicity of crude oil and its residues; (3) the biodegradation and the microbial response to the spill; and (4) the monitoring of the acute and chronic impacts on marine and coastal biota and traditional human communities. Moreover, we highlight the importance of conducting research on chemical contaminants and their ecotoxicological effects at different biological levels of organization, e.g., species, community, and ecosystem levels. Particularly important is the development of community-based restoration efforts to assist in the long-term recovery of the resources and communities along the tropical Brazilian coastline [42]. To approach such issues, researchers must evaluate how they can contribute given their expertise. It is important to determine where we can cooperate, rather than compete with each other, at the national and international levels in the spirit of a collective mission to save the ecosystems.

Transnational arrangements and substantial international assistance with regard to mitigation, restoration, and adaptation tools are necessary to reduce the negative socioenvironmental consequences of this extensive oil-spill disaster. Biodiversity and climate regulation losses considering blue carbon environments (e.g., seagrass meadows, marine animal forests, mangroves, and rhodolith beds) [16,43] should drive discussions regarding mining accidents and global consequences related to pre-salt oil exploitation, new spill events, and their global impacts. These measures are particularly relevant in areas with high tropical biodiversity and high social inequality, as in the present case, which represents one of the worst-case scenarios of an environmental and governmental disaster.

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Appendix A. Supplementary data

Supplementary data (summary of MPAs affected by the oil spill and Portuguese version of this article) to this article can be found online at https://doi.org/10.1016/j.marpol.2020.103879.

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