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Locations Reached by Oil in 2019 and Subsequent Impacts in Environmental Protection Area of Costa dos Corais

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A B S T R A C T

From August 2019 to December 2019, eleven Brazilian coastal states, most of them located in the country's northeast, were reached by oil from a spill of unknown origin. There were oil traces and stains detected in many marine and coastal Conservation Unities (UC), including the Environmental Protection Area of Costa dos Corais (APACC), the widest federal marine UC. This article had the objective to gather information about the locations reached by the oil inside APACC, and about possible socioenvironmental impacts caused by the disaster in the affected municipalities. The geoprocessing software ArcGIS® 10.5 was used for this purpose, as well as research in scientific databases and institutional platforms about social, economic, and environmental aspects of the studied area. The authors verified that the municipalities of Maragogi, Japaratinga, and Porto de Pedras were the ones that presented the highest concentrations of reached locations in APACC and that the sectors of fishery and tourism may have been strongly impacted by this disaster. The results point to the necessity of evaluating, accompanying, and mitigating the oil impacts caused in the area, considering its socioeconomic and environmental relevance, especially related to the preservation of mangroves and coral reefs, and its ecosystemic services, that sustain the fishery and tourism in the region.

Keywords: APACC, geoprocessing, conservation unity, oil spill, socioenvironmental impacts.

Localidades Atingidas por Óleo em 2019 e Impactos Subsequentes na Área de Proteção Ambiental Costa dos Corais

R E S U M O

Entre agosto e dezembro de 2019, a costa do Brasil foi atingida em 11 estados litorâneos, em sua maioria localizados no nordeste do país, por óleo proveniente de um derramamento de origem desconhecida. Foram detectados vestígios e manchas de óleo em diversas Unidades de Conservação marinhas e costeiras, entre elas, a Área de Proteção Ambiental Costa dos Corais (APACC), a maior Unidade de Conservação (UC) marinha federal. Este artigo teve como objetivo realizar um levantamento das localidades atingidas pelo derramamento de óleo dentro da APACC e dos possíveis impactos socioambientais decorrentes deste desastre nos municípios afetados. Para isso utilizou-se o software de geoprocessamento ArcGIS® 10.5, bem como pesquisas em bancos de dados científicos e plataformas institucionais sobre aspectos sociais, econômicos e ambientais da área estudada. Os autores constataram que os municípios de Maragogi, Japaratinga e Porto das Pedras foram os que apresentaram as maiores concentrações de localidades atingidas na APACC e que os setores da pesca e do turismo podem ter sido fortemente impactados por este desastre. Os resultados apontam para a necessidade de avaliar, acompanhar e mitigar os impactos causados pelo óleo na área, visto sua relevância socioeconômica e ambiental, especialmente em relação à preservação dos manguezais e recifes de coral e de seus serviços ecossistêmicos, que sustentam a pesca e o turismo na região.

Palavras-chave: APACC, geoprocessamento, unidade de conservação, derramamento de óleo, impactos socioambientais.

Introduction

Coastal areas are constantly impacted by human activities, which harm coastal ecosystems and the populations that depend on them for subsistence. The impacts have increased in recent years due to oil spill accidents in coastal and marine environments in Brazil (Baptista et al., 2019). These episodes might occur during natural seeps, accidental spills, field exploration and transportation, maritime traffic, ship-to-ship transfer operations, and refinery effluent discharge (Disner and Torres, 2020).

From the 30th of August 2019 to the 30th of December 2019, the Brazilian Institute of Environment and Natural Resources (IBAMA) recorded 990 Brazilian seashore locations reached by oil stains or oil traces from a spill in the Atlantic Ocean. These locations are distributed over 128 municipalities in eleven coastal states, from Maranhão to Rio de Janeiro (IBAMA, 2020b). More than 55 marine and coastal Conservation Unities (UC) were affected (Soares et al., 2020b), and, along with them, ecosystems of rocky shores, rhodolith beds, beaches, mangroves, estuaries, seagrasses beds, and coral reefs (Soares et al., 2020a).

The Brazilian Federal Police concluded the investigation into the oil origin and the company, the commander and the chief engineer of a Greek-fagged ship were named responsible for spilling the material on the Brazilian coast (Soares et al., 2022). Within the oil composition, polyaromatic hydrocarbons, polychlorinated biphenyls, and aliphatic hydrocarbons were detected (SVS, 2019a). Furthermore, the petroleum was characterized as crude, highly weathered, and viscous, with high concentrations of long-chain and medium-chain hydrocarbon and low concentrations of aromatic hydrocarbons. The petroleum also presents a density close to marine water density, allowing the oil to sink when contacting salty water or to mix into residue or sedimentary material (IBAMA, 2020a). These processes are due to the degradation that occurs mostly in the sea, through aerobic microorganisms, while the oil that reaches the shore, more concentrated, mixes into sediments without oxygen availability and persists longer in the environment (Hazen et al., 2016). This oil may return to the water column and be transported to the shoreline due to meteorological events (Lourenço et al., 2020).

Thus, the reached ecosystems have been manifesting the direct impacts of the petroleum on the Brazilian coast. Until the 27th of December 2019, IBAMA found 159 animals covered by oil, classified as marine turtles, birds, marine mammals, and others. Among them, there were 113 dead animals, possibly because of suffocation caused by direct contact with the oil (IBAMA, 2019). Due to the petroleum incrustation in sandy beaches and coastal ecosystems, and to its movement under the ocean surface, there were other harmed organisms, as aquatic plants, algae, and plankton – which are the base of food chains of aquatic ecosystems -, benthic organisms, invertebrates, fish, and coral reefs, that harbor various animals. However, these organisms are harmed in different ways and present variable regeneration capacities after contact with crude oil (Saadoun, 2015), and its quantification is more complex (Soares et al., 2020b). There may be, among other effects, damage to DNA, reduced growth, and emergence of malformations, and also a change in the age structure of populations due to the loss of younger fish (Silva et al., 2021).

Besides the mentioned impacts, these ecosystems' unbalance triggers economic and social impacts, due to the human dependency on resources available in nature and on ecosystem services for life quality and socioeconomic development (Sukhdev, 2008; Estevo et al., 2021).

With the beach oil containment and cleaning actions, the involved population was exposed to contamination risk majorly through the skin and inhalation, due to the oil compounds' volatility (Carmo and Teixeira, 2021; Pena et al., 2020). Until November 2019, 78 cases of exogenous intoxication had been notified, in the states of Pernambuco, Ceará, and Bahia (SVS, 2019b). Impacts in human health may be acute and chronic and include possible alterations in reproductive and immunological systems, provoked by polycyclic hydrocarbons, for instance (Pena et al., 2020). Contamination by the oil also may happen indirectly, through feeding, majorly of bivalve mollusks, which tend to bioaccumulate higher concentrations of hydrocarbons than other organisms (Saadoun, 2015).

Furthermore, socioeconomic implications from losses caused by the disaster were observed (Araújo et al., 2020; Richetti and Milaré, 2021). In PE, for instance, from October 2019 to November 2019, harm to fishery products selling was verified. This affects majorly the artisanal fishermen, who depend on these products both for income generation, self and familiar consumption, putting them as the most exposed to contamination risk

(Araújo et al., 2020). On the 29th of November 2019, there was a total of 65,983 artisanal fishermen acting in the sea and/or in the estuary registered in the Informative System of the Fishery Activity General Record (SisRGP) of all municipalities reached by the oil spill until that date (MAPA, 2019).

Artisanal fishery is an important socioeconomic activity in Brazil since, more than producing the greater part of Brazilian fish, it also associates the culture and the traditions of riverside people to the fishing resources and, consequently, to the ecosystems in which they act (Gasalla and Ykuta, 2015; FAO, 2017). This kind of fishery plays "an important role in food security and nutrition, poverty eradication, equitable development, and sustainable resource utilization" (FAO, 2017), so the impacts of the disaster that happened in 2019 in this activity should not be neglected.

Another sphere impacted by the oil spill is tourism, with more evident harm in the Northeast, the most reached area, being significantly dependent on this sector (Ribeiro et al., 2020). In addition, COVID-19 generated negative cumulative impacts on important economic sectors such as hotels, services, and tourism that were already losing revenues because of the oil spill (Câmara et al. 2021).

One of the UCs reached by the oil spill is the Environmental Protection Area of Costa dos Corais (APACC). An Environmental Protected Area (APA) is a UC of the sustainable use group, intending to conciliate the nature conservancy with the sustainable use of part of its natural resources. At the APA, there is a certain degree of occupation by human populations and environmental or cultural attributes significant for them. However, the occupation must be controlled, as well as the biodiversity must be protected and the sustainability of the use of natural resources, assured (BRASIL, 2000).

APACC, created on the 23rd of October 1997 (BRASIL, 1997), is the largest federal marine UC and it is located between the municipalities of Tamandaré/PE and Maceió/AL (ICMBIO, 2020b). Although the decree does not quote the municipalities of Paripueira and Porto Calvo, they are shown as part of APACC in its management plan published in 2013 by Chico Mendes Institute for Biodiversity Conservation (ICMBio) (ICMBIO, 2013).

The UC area presents great biodiversity, including endangered species, sheltered mainly by ecosystems of coral reefs and mangroves (ICMBIO, 2020b). The APACC fish richness represented 44% of all recorded fish species of the Southwestern Atlantic Ocean, highlighting the largescale importance of this UC (Pereira et al., 2021). Besides that, Brazilian reefs are the only ones of the South Atlantic, and APACC is the first federal UC to protect part of coastal reefs distributed along the 3,000 km of northeastern coast (Ferreira and Maida, 2006).

The oil spill that happened in 2019 was the largest environmental disaster in extent that has ever happened in Brazil (Soares et al., 2020a), affecting mainly Northeast states, where APACC is located. The research hypothesis is that the oil spill caused negative impacts on ecosystems and fishing and tourism sectors of affected municipalities. Thus, this article intends to analyze the concentration of the locations reached by oil in this UC and to relate the spill environmental impacts to socioeconomic and environmental consequences to the region, mainly to fishery, tourism, and communities dependent on the income of these activities. For this analysis, the authors considered the known characteristics of the oil, as well as the socioeconomic situations of the affected municipalities and the reached ecosystems, especially the mangroves and coral reefs.

Material and methods

This is a case study with a qualitative approach analysis of the locations reached by oil in APACC, relating socioeconomic and environmental characteristics of the UC. The applied methodology would be summarized in 3 main stages: data collection and literature review, elaboration of the database, and qualitative and quantitative analysis of the results. Most of the analysis was done using remote sensing through Geographic Information System (GIS) software.

Georeferenced data of the locations reached by oil in 2019 were obtained from .xlsx spreadsheets provided by IBAMA's official monitoring, updated to the period between the 21st of January 2020 and 29th of January 2020. There were also obtained data about population, per capita GDP, and the minimum wages of APACC municipalities and census tracts, provided by IBGE. Finally, the municipalities' Coastal Sensitivity Index (ISL) and activities threatened by oil spills were obtained from the shapefiles from tactical charts of oil sensibility to the basin Sergipe-Alagoas/Pernambuco-Paraíba provided by Ministry of Environment (MMA).

Alongside the data collection, it was conducted a literature review to get information about the oil spill and about the ecosystems, the economic activities, the communities, and the APACC's management plan. These information were searched in governmental data platforms as MMA, IBGE, IBAMA, and ICMBio, responsible for Brazilian UCs, and in articles published in national and international journals, as well as in thesis and dissertation concerning the studied subjects and area.

Also, for the geographic analysis, there were used vector files of Brazillian states, provided by the University of São Paulo (USP), of municipalities and census tracts in Alagoas and Pernambuco, by IBGE, of federal UCs and APACC zoning, by ICMBio, of coral reefs and mangroves, by IBAMA.

From the data collected, and to start the database elaboration, there were made spreadsheets in Microsoft Excel, containing the socioeconomic information of APACC's municipalities and census tracts, which were joined with their vector files. These files were imported into ArcGIS® 10.5, and the points of location reached by oil, georeferenced by IBAMA, were plotted on the map. According to IBAMA (2020b), a location corresponds to 1 km of coast extension in which oil has been detected. In addition to obtaining the total number of coastal Brazilian locations reached in 2019, the points belonging to the APACC area were filtered.

To quantitatively evaluate the oil impact in APACC, a Kernel density map was elaborated, supported by the geoprocessing software ArcGIS® 10.5, based on the plotted points. This analysis aimed to estimate the magnitude of the areas reached by oil in the UC (Câmara and Carvalho, 2004) and to project the generated surface so its behavior could be visualized.

Furthermore, it was generated, through ArcGIS® 10.5, a map of the Gross Domestic Product (GDP) of the municipalities where oil was detected in APACC, as well as of the medium domiciliar income of its census tracts, from the data provided by the Brazilian Institute of Geography and Statistics (IBGE), considering the value of the minimum wage (SM) correspondent to R$510,00 per month (US$306.09) in 2010 (BRASIL, 2010). This map was analyzed together with the Kernel density map to observe locations reached by oil concerning its economic characteristics. Maps representing APACC's zoning, according to its 2013 management plan, and APACC's coral reefs and mangroves, were also produced, to visualize some of the UC environmental characteristics in the affected locations.

To the qualitative analysis, there were used information and studies found in the bibliographical research.

Further, a table was compiled with the municipalities affected by the oil in the studied area, including the information about the municipal population in 2010 and its medium income in 2018, the reached locations concentration, the activities threatened by oil spills, and the approximate medium ISL in the coast of APACC. The ISL is classified from 1 to 10, according to the exposition to tides and waves energy, litoral declivity, substrate type, geomorphology, and biodiversity (MMA, 2002).

A table with general information about the artisanal fishery in APACC was also presented from information contained in its fishery diagnosis published by Barboza (2019).

Results and discussion

According to the data collected by IBAMA, in 2019, oil was detected in 990 locations of the Brazilian coast, 67 inside APACC's area. The concentration of reached points was classified as low, medium, high, and very high class (Figure 1). Soares et al. (2020b) point out that one of the main aspects that determine the gravity of an oil spill is the socioeconomic characteristics of the reached locals, being the economically vulnerable regions usually subjected to the more serious and chronic impacts.

Preliminary evaluations indicated that at least 869,349 people (42.06% related to tourism and 57.94% artisanal fishers) were afected by this spill (Magris and Giarrizzo 2020) and that traditional fishers were the most impacted social group.

Câmara et al. (2021) carried out a socioeconomic vulnerability analysis of establishments located in areas most affected by the oil spill. A total of 53,472 establishments were included in the analysis, comprising by public institutions, companies, tourist attractions and leisure spots. Among them, the highest levels of impact were found in the economic sectors related to food (35.3%), accommodation (17.4%) and activities related to tourism and leisure (3.8%).

It is possible to verify the economic vulnerability of the APACC municipalities affected by the oil spill in the indicated period (Figure 1), since that in all of them, except Maceió, the medium income of the formal workers in 2018 was below two SM (IBGE, 2020a), as specified in

Table 1. The municipality of São José da Coroa Grande/PE, for instance, decreed abnormality due to the disaster, had 5,000 people affected, and spent R$20.000,00 (US$4,961.92) to cleaning actions in 2019 (CNM, 2019).

Also, among the APACC municipalities where oil presence was identified, the ones with the highest concentration of reached locations in 2019 - Maragogi, Japarantinga, and Porto de Pedras -, are also the ones that present some of the highest GDP. The main economic sector in these three municipalities is the agricultural sector, which includes fishery and aquaculture (IBGE, 2016).

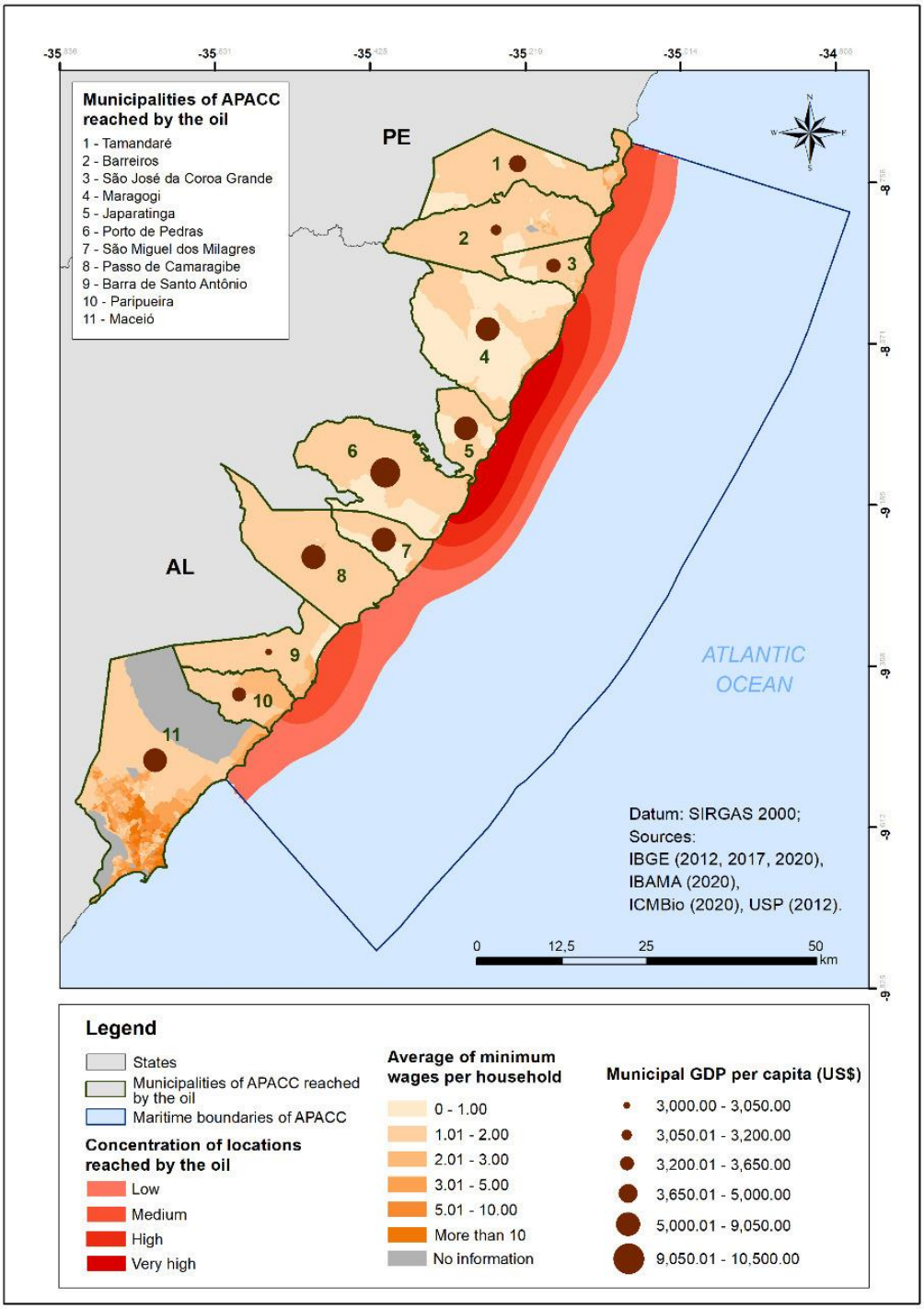

Figure 1. Concentration of the APACC's locations reached by the oil spill between the 30th of August 2019 and the 30th of December 2019, municipal GDP and medium wage by census tracts. Sources: USP (2012); IBGE (2012, 2017a, 2017b, 2020b); IBAMA (2020b); ICMBIO (2020a).

Table 1. APACC's municipalities reached by the oil.

Municipalities	Population in 2010	Monthly medium wage of the formal workers in 2018 (in SM)	Activities threatened by the oil spill	Approximate medium ISL of APACC's coast	Concentration of reached locations
Tamandaré	20,715	1.5	Fishery; tourism; trade; diving; and nautical sports and tours	6	Medium
Barreiros	40,732	1.7	Fishery; tourism; and comércio	6	Medium
São José da Coroa Grande	18,180	1.6	Fishery; tourism; comércio; and diving	7	Medium
Maragogi	28,749	1.8	Fishery; aquaculture; tourism; comércio; diving; and nautical tours	6	Very high/high
Japaratinga	7,754	1.6	Fishery; tourism; and comércio	5	Very high
Porto de Pedras	8,429	1.4	Fishery and tourism	5	Very high/high
São Miguel dos Milagres	7,163	1.6	Fishery; tourism; comércio; and nautical tours	4	Low/ medium
Passo de Camaragibe	14,763	1.8	Fishery; tourism; and comércio	6	Low/ medium
Barra de Santo Antônio	14,230	1.7	Fishery; tourism; and comércio	7	Medium
Paripueira	11,347	1.5	Fishery; tourism; and diving	6	Medium /low
Maceió	932,748	2.8	Fishery; tourism; and diving	5	Low

Source: MMA (2012); ICMBIO (2013); IBGE (2017b, 2020a); IBAMA (2020b).

Fishery, composed mainly of family labor, is the main economic activity in the greatest part of the UCs that comprehend mangroves, like APACC. The fishery is an activity that integrates the fishermen's identity since it persists through the generations. Besides the capture itself, the fish commercialization, fish processing, and handicraft confection are also part of the fishing activity (Leão et al., 2018). According to Barboza (2019), there are thousands of fisherman families in the UC - from which a great part does not have General Fishery Registry -, living in more than 40 communities. The most common fishery environments are beaches and mangroves, and the most captured species are the shellfishes, factors that provide a higher exposition of this population to the oil. Some fishers interviewed by Estevo et al. (2021) within the APACC described health impacts, including skin diseases and diarrhea outbreaks after direct oil exposure. Table 2 gathers some of the information about the fishery in APACC.

Thus, besides the contamination risk to which the fishermen are exposed, they are also economically injured by the oil spill, since they depend on fishery both as a feeding source and as an income source (Araújo et al., 2020). According to Barboza (2019), of each fishery in APACC, about 28% are destined to familiar consumption, from which is obtained a medium gross income of R$104,01 (US$25.80). Ferreira and Quinamo (2022) report that the oil spill increased and gave more visibility to the small-scale-fisheries' real problems, showing socio-environmental stressor such as garbage pollution, sewage, and orver-fishing.

Hence, after the beginning of the oil appearance on the beaches in 2019, the socioeconomic impacts were direct. In Porto de Pedras/AL, more than 1000 oysters in the reproduction phase were contaminated by the oil (Farias, 2019). In PE, the fish and shrimp selling decreased; and the selling of shellfishes, oysters, mussels, and crabs dropped in from 80% to 100%, being the most affected one (Araújo et al. 2020).

This decrease, more than a direct consequence of the contamination, is also due to the population's apprehension of consuming the fishery products (Mengue et al., 2019).

Table 2. Characteristics of artisanal fishery in APACC.

Municipalities	Quantities of fishing locals	Main roles of the production chains	Main buyers	Main kinds of captures performed
Tamandaré	52	Capture/fishery	Region's houses	Harvesting of shellfish
Barreiros	17	Capture/fishery	Region's houses	Handline/longline
São José da Coroa Grande	37	Capture/fishery	Middlemen	Harvesting of shellfish
Maragogi	70	Capture/fishery and processing	Region's houses	Harvesting of shellfish
Japaratinga	44	Trade	Region's houses	Harvesting of shellfish
Porto de Pedras	36	Capture/fishery	Region's houses	Gillnetting
São Miguel dos Milagres	43	Capture/fishery	Middlemen	Gillnetting
Passo de Camaragibe	57	Capture/fishery	Middlemen	Gillnetting
Barra de Santo Antônio	50	Capture/fishery	Region's houses	Harvesting of shellfish
Paripueira	54	Capture/fishery	Region's houses	Harvesting of shellfish
Maceió (Ipioca)	29	Capture/fishery	Region's houses	Handline/espinhel

Source: Barboza (2019).

In addition to economic impacts, psychological damage is commonly reported in communities affected by these events. A study done with the resident population around the Niger River Delta in Nigeria showed that high levels of emotional stress were found in people affected by the oil spill in the region (Nriagu et al., 2016). The work of manually clearing the affected areas can be quite stressful as it is usually done by locals who previously fished in the same region to sell and feed their families (Euzebio et al., 2019). These individuals are more likely to develop depression and post-traumatic stress disorder, like the workers involved in the cleanup of the Gulf of Mexico disaster (Kwok et al., 2017).

Beyond fishery, tourism is an important economic activity in APACC (Table 1). At the municipalities located in AL, that compound the main touristic region of the state, the main attraction are the beaches, although there are also tours by the shore, the natural pools and the mangroves, fauna observation, diving, and use of nautical toys. The major part of the tourists is from other Brazilian regions, especially from the Southeast (PAPP, 2017). This process of domestic tourism is an important factor of regional inequalities reduction in the country (Ribeiro et al., 2020). Moreover, the environmentally preserved areas are the ones mainly responsible for the tourism development in the Costa dos Corais region, which presents a precarity of basic infrastructure (Duda, 2013). In PE, one of the more important cities to tourism is Tamandaré, which is part of APACC and had 6 locations reached by the oil in 2019 (IBAMA, 2020b).

Consequently, the oil spill is economically harmful to the tourism sector because it decreases the tourist attraction of the beaches due to contamination (Ribeiro et al., 2020). According to the authors, regarding the percentual alteration of Regional Domestic Gross in Northeast Region, the disaster impact in the coast is 10 to 15 times greater than the countryside, and the coastal regions more

affected are those that depend more on fishery and tourism, like APACC.

Besides that, the efforts to solve the oil spill crisis were forced to stop (or slow down) due to COVID-19 and the economic crisis, leaving the society with less tools to mitigate the damage to poor communities, promote adequate impact assessment or restoration plans (Magalhães et al., 2021).

Fishery and tourism are some of the ecosystem services provided by coral reefs and mangroves, in addition, to support to diving and coastal protection, by the reefs (Barbier, 2012), and to nutrient cycling, biodiversity maintenance, landscape conservation, and stocking or remotion of atmospheric carbonic gas, by the mangroves (Almeida and Júnior, 2018).

The mangroves and reefs are present along all APACC's coast, including where there was a high concentration of locations reached by the oil spill (Figure 2). According to Maida and Ferreira (2006), these ecosystems are fundamental for APACC's artisanal fishery, which have as its main environments the beach, the mangrove, the river, the outside sea (beyond the reefs), and the inside sea (between the coast and the reefs) (Barboza, 2019). Further, the medium ISL to the studied place is approximately 6 (MMA, 2012), therefore, it is necessary to evaluate the impacts of the oil spill in the environment, because it presents a risk to the coastal environments as much as to the human activities of the region, especially artisanal fishery, and tourism.

The mangroves, trees adapted to water-covered environments, with low available oxygen and unconsolidated surfaces, retain sediment between its trunks and roots, including pollutants (Schaeffer-Novelli, 2018a), like the oil. Mangroves impacted by oil present acute and chronic impacts. In the short term, from some days to six months, some trees might die. Between one and five years, the impacts may not be lethal, allowing the ecosystem to recover. However, if the trees die, it is possible the permanent degradation of the ecosystem in the long term, as much as its recovering, that takes between five to more than 25 years, since the growing of new plants is necessary, taking at least 25 years for them to reach maturity (Duke, 2016).

Some of the common impacts of oil spills in the mangroves are suffocation of their typical aerial roots and reduction of the leaves' transpiration and breathing taxes, taking to eventual defoliation (Connolly et al., 2020), besides the death of trees, decreased growth of the reminiscent trees, morphological changes, and deformations (Duke, 2016).

The mangroves destruction directly impacts the coral reefs (Ferreira and Maida, 2006). The reefs are originated from the calcium carbonate accumulation from skeletons and reminiscent sediments of animals from the maritime bottom and the plants of tropical and subtropical shallow environments. The main reef builders are the reefs (NOAA, 2010).

The impact of the oil in the reefs depends on how the exposition to the pollutant occurs, which can be: direct when the surface oil covers the reefs and the acute impacts tend to be more probable; by dissolved oil or oil suspended in the water column, which also causes acute toxic impacts; and subterranean, when the oil has density near or greater than the seawater, as the oil that reached the Brazilian coast in 2019 (NOAA, 2010; IBAMA, 2020a).

Turbulent events may continue to expose the corals to oil taken to the water column, and the impacts depend on the concentrations and time of exposition. The corals are also affected by chronic exposition when large quantities of oil remain in coastal environments like the mangroves after the cleaning end, as in APACC. Crude oils, like the one present in this spill, present a higher risk to the reefs regarding the acute toxicity than heavy fuel oils. The oil toxicity increases with exposition to light, a phenomenon called phototoxicity, so the corals are more sensitive to the impacts of the pollutant due to the environment in which they develop, where there is good light infiltration. The tolerance of the corals to the oil is variable mainly according to its physical form. However, negative impacts on the coral are manifested mainly in the long term, as the oil bioaccumulation in its tissues (NOAA, 2010; IBAMA, 2020a).

The chronic impacts of the oil in the coral reefs may be lethal or not. The non-lethal impacts involve changes in biological functions, as fertility reduction and reproductive success, and early development, which significantly influences coral survival. Bioenergetic factors of the reefs are also affected, in more or less severe ways if the oil spill is added up to other disturbance, like the rise of the water temperature, that has caused Brazilian Northeast reefs bleaching, including in the APACC area, making them more susceptible to diseases and competition (Chamorro, 2020).

Concerning the fauna, the mangroves include protozoa, bacteria, and fungi that colonize the debris from local biomass, crustaceans and other invertebrates, fishes, and birds (Schaeffer-

Novelli, 2018b). The reefs, more than the corals, also shelter algae, fishes, crustaceans, mollusks, manatees, and other marine beings (Maida and Ferreira, 2006). Due to the interdependency between flora and fauna, if plants were affected, animal will be also impacted. The crabs, for instance, influence the structure of the mangroves, and sessile sponges protect the mangroves' roots and help in the nutrients' absorption (Duke, 2016).

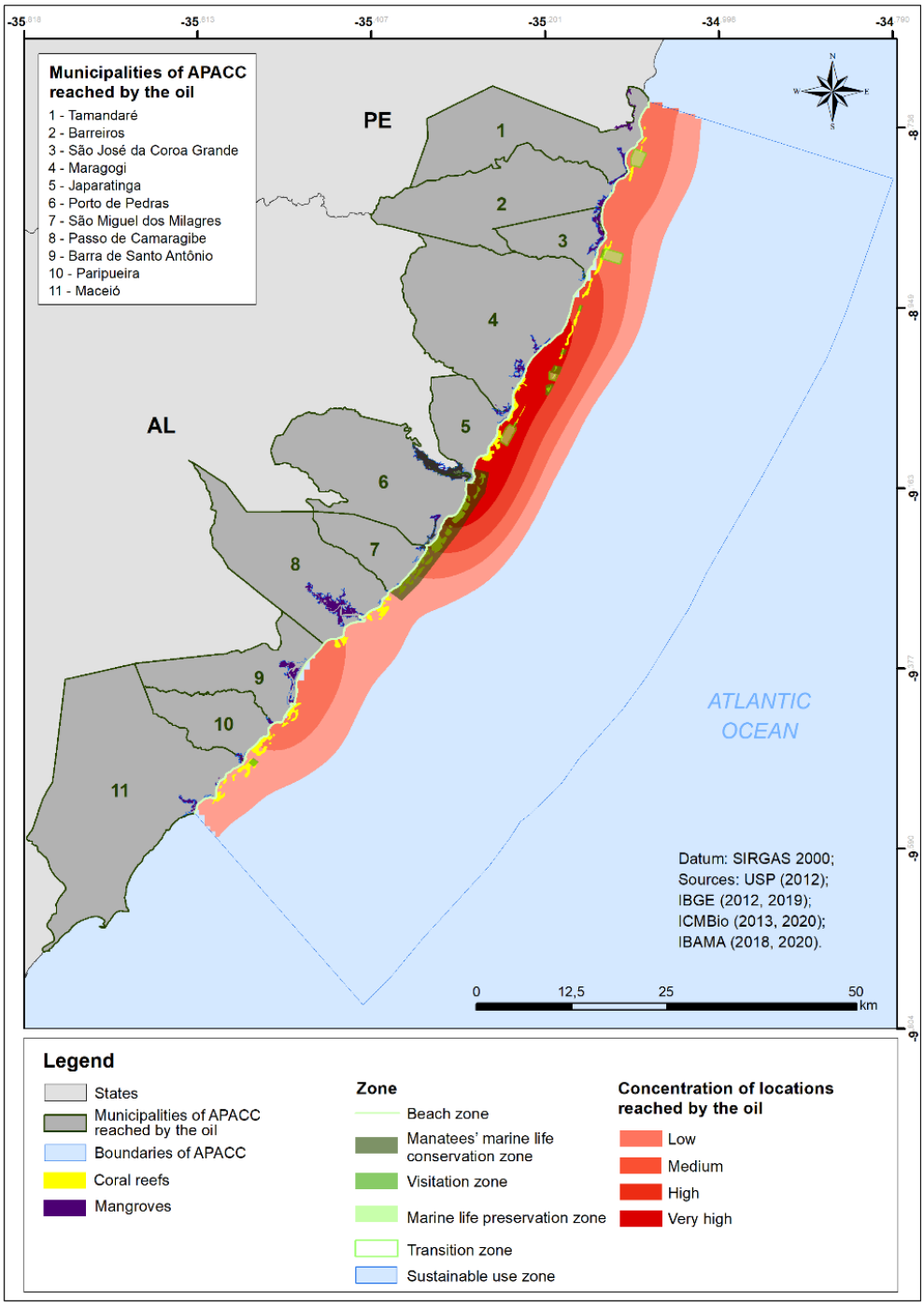

Figure 2. Concentration of the locations reached by the oil spill between the 30th of August 2019 and the 30th of December 2019, mangroves, coral reefs, and APACC's zones. Sources: USP (2012); IBGE (2012, 2019); ICMBIO (2013, 2020a); IBAMA (2018, 2020b).

The fishes do not tend to retain and accumulate oil compounds, however, their metabolism may be injured (Saadoun, 2015). From the oil spill caused by the Deepwater Horizon in 2010, Magnuson et al. (2018) verified harms in the vision of estuarine fishes in early life stages

exposed to the polycyclic aromatic hydrocarbons present in the crude oil. In the case of the crustaceans, the greater part can eliminate the hydrocarbons quickly. On the other hand, the bivalve mollusks accumulate those pollutants and tend to pass them to their predators (Saadoun, 2015). Among them are the shellfishes, one of the main products of artisanal fishery in the Brazilian Northeast (Araújo et al., 2020), including in APACC, where shellfishing is the main kind of fishery practiced (Table 2).

Further, observing APACC's zoning, which divides the UC into zones with certain management specifications (Brasil, 2000), may be relevant to the analysis of the oil spill impacts, because it enables the establishment of different priorities of monitoring and mitigation in each reached area since the different zones present distinct demands (ICMBIO, 2013).

APACC's zoning foreseen in its 2013 management plan divided its area into sustainable use zones (ZUS), beach zones (ZP), conservation zones (ZC), which includes the manatees' marine life conservation zone (ZCVMPB), fishery exclusive zones (ZEP), visitation zones (ZV), marine life preservation zones (ZPVM), and transition zones (ZT) (ICMBIO, 2013).

The ZP goes from the medium-high water line until the medium-low water line follows APACC's coastal line. The ZCs are destined to ensure habitats of threatened species and species characterized as feeding resources. Until the moment, the only ZC implemented is the ZCVMPB in Porto de Pedras and São Miguel dos Milagres, where the concentration of oiled points was from low to very high (Figure 2). The ZV are Galés, Barra Grande, Taocas and Ponta de Mangue in Maragogi, Piscinas de Paripueira, Prainha de São José da Coroa Grande, and Piscina Natural do Picão in Japaratinga (ICMBIO, 2013; ICMBIO, 2016; ICMBIO, 2018). Currently, there are four ZPVM in APACC, in Tamandaré, São José da Coroa Grande, Maragogi and Japaratinga. The ZTs surround the ZPVM in 100 meters. The ZEPs have the objective of guaranteeing the sustainability of the use of the fishing resources and contributing to the economic sustainability of different groups of the fishing sector (ICMBIO, 2013). These last zones still were not delimited in APACC. However, the fishing diagnosis published in 2019, developed from interviews with 1439 fishermen of the region, listed 489 fishing locals distributed by the coast of its municipalities (Barboza, 2019). At last, ZUS coincides with the limits of APACC, because it covers all of its area not delimited by the other zones (ICMBIO, 2013).

Most of the zones are near the coast of the municipalities where there was a medium to a very high concentration of locations reached by oil (Figure 2).

The unified coordination of the Federal Government as response and monitoring of the oil was demobilized on the 20th March of 2020 (IBAMA, 2020c). This work concentrated on the locations reached in 2019, and in the period monitored by IBAMA in 2020, there was oil identification in one more location of APACC, in Passo de Camaragibe/AL. However, since the guarantee of reefs conservation and mangrove protection are some of the objectives of APACC's management plan (ICMBIO, 2013), and considering its socioeconomic importance, due to the impacts caused by the oil spill, the recuperation of the affected environments is essential to APACC and the accomplishment of its zoning's purpose.

According to Duke (2016), the mangroves' structural recuperation takes at least 30 years, and the whole fauna recuperation and mangrove recuperation may take even more time than the forests. However, there are variations accordingly with the characteristics of each environment affected and of the oil that reached them, like oil concentration and dispersion, quantity, species tolerance, and tides intervals (Soares et al., 2006; Duke, 2016). The oil persistency in the mangroves also influences its recuperation, with the possibility of delaying it (Soares et al., 2006). Information about the impacted mangroves area is necessary, as much as about near sediments, deforestation, and rehabilitation of these areas. The best alternative is to assist the natural processes (Duke, 2016).

Soares et al. (2006) studied the process of mangrove regeneration of a river located in Guanabara Bay, Rio de Janeiro, impacted by an oil spill in January 2000. The results pointed that after five years the forest was in its initial stage of regeneration, although there were vestiges that it was still under the negative influence of the oil withheld in the substrate.

Concerning the harmed coral reefs, they may take from decades to hundreds of years to recover, when it occurs, which also changes accordingly to the disaster location and with its magnitude, among other factors. Some of the recovery criteria observed are coral cover, species diversity, and local reefs' characteristics, compared to the places that were not affected or to data of the same corals before the disaster. In the case of the corals exposed to crude oil, the tendency is that

they recover more rapidly than the ones that suffer mechanical impacts. Part of the recuperation of the coral reefs concerns other affected environments, like the mangroves (NOAA, 2010).

Silva (2019) evaluated APACC's reefs resiliency, in other words, the capacity of giving sequence to activities or ecosystem services despite disturbances, according to its zoning. The ZPVMs cover the areas with greater resiliency, and the ZVs, the ones with the lowest resiliency, relating to the greater presence of anthropic impacts. Many reefs in São Miguel dos Milagres, a municipality that is very impacted by tourism, exploration, and pollution, presented a low potential of resiliency. In the municipalities of Maragogi and Japaratinga, some of the municipalities with the greater concentration of locations reached by the oil spill in 2019, the ZPVMs also present a high potential of resiliency according to their coral cover. As factors of critical importance, the high connectivity presented by the APACC reefs studied had a great positive influence on its resiliency potential, while the pollution was one of the indicators that harmed it more. Therefore, pollution caused by the oil spill also can decrease the reefs' resiliency, especially in the ones located in ZVs, where they presented lower resiliency and where there were detected directly oil traces and stains.

Conclusions

This work presented an analysis of points where oil concentration was identified coming from the spill that happened in 2019 in APACC's locations, relating them to socioeconomic and environmental aspects relevant to the region. The necessity of identifying and quantifying the impacts caused by the disaster is imperative, since its consequences extrapolate the ecosystems, reaching the economic and social spheres. Thus, studies of evaluation, accompaniment, and mitigation of the impacts caused by the spill, both acute and chronic, are necessary, considering the socioeconomic characteristics of APACC, its management zones, and the high interconnectivity between the coral reefs and mangroves, in which the respective impacts caused by the oil influence mutually one another, and the other affected ecosystems.

Furthermore, according to the presented results, the population of the UC's municipalities reached by the oil spill present a low medium income, significantly dependent on the fishery and tourism. As the ecosystem imbalance may directly harm these sectors, it is crucial for this relation to be also understood completely so adequate decisions may be taken according to the local communities' necessities. However, it is important to stress that the quantification of these impacts is more complex than its identification since the recovering of the reached ecosystems depends on many variables and needs to be extended for a long period, as much as the socioeconomic injures that may reverberate locally and nationally.

Thus, the disaster consequences contribute as much to the aggravation of the social inequalities of the region and as to the obstruction of the sustainable development planned to APACC. Considering the UC's social, environmental, and economic importance it is necessary that the causes of the disaster continue to be investigated by the competent agencies, and that its effects be under constant scientific observation so they may be mitigated and avoided in possible similar occurrences in the future.

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