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ECOSYSTEMS

Marine fish and benthic biota before the 2019 oil spill: A baseline dataset for monitoring programs and impact assessments at Rio Grande Norte state, Northeastern Brazil

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Abstract: In 2019 an oil spill spread over more than 4000 km of the Brazilian coastline. Monitoring programs that allow for the evaluation of potential impacts on communities and ecosystems and their recovery through time are needed and rely on baseline information previous to the oil spill. Here we compiled qualitative and quantitative data available from 8 studies on fish and benthic species from different habitats of Rio Grande do Norte (RN) from 2007 to 2018. We assessed the number of species from different locations and compiled information on conservation status and human use. We mapped the study areas and habitats and overlapped them with those affected by the oil spill. The RN state has a high diversity of fish (175 species) and benthic species (285 species), of which more than half of fish (52%) and 2% of benthic species are threatened and 72,8% of fish and 7,9% of benthic species are of commercial interest. Information of most habitats is still poorly known (i.e.majority ofthe available data are from unique and punctual sampling), which may weaken future evaluations of the real impact of the oil spill. Nonetheless, it is possible to design reliable monitoring based on our dataset, persistent contamination and future loss of diversity.

Key words: human impact, richness, species distribution, tropical ecosystems.

INTRODUCTION

Oil spills are recurring incidents associated with the petrochemical industry that impacts the marine environment. The spilled oil spreads over the water layer and usually accumulates on the coast reaching several habitats from the benthic, planktonic and nektonic compartments (Beyer et al. 2016). Direct contact with crude oil kills many organisms causing decreases in local diversity and abundance of species that leads to changes in community composition and loss of ecosystem functions in the affected areas (Magris & Giarrizzo 2020, Eichler et al. 2014).

The 2019 oil spill off the coast of Brazil spread over more than 4000 km of the coastline, mostly in the Northeast region (Escobar 2019, Soares et al. 2020). More than 5000 T of fuel oil were collected along the coast across several ecosystems (e.g. mangroves, sandy beaches, reefs, algal banks) impacting at least 55 protected areas (Soares et al. 2020, Brum et al. 2020, Magris & Giarrizzo 2020, Reddy et al. 2021). This incident is considered the worst environmental disaster on tropical coastal regions in terms of spatial extension and duration (Soares et al. 2020), however, the long term environmental impacts of such an oil spill remains unclear.

The release of hydrocarbons from oil spills into marine environments has immediate and acute effects and it is essential to understand how contaminants are released and how they behave in the environment (Cedre 2007, Mendes et al. 2021).

To assess the environmental impact of the oil and the potential recovery of the affected ecosystems over temporal periods, it is necessary to design monitoring programs that include appropriate treatments in space (i.e. inclusion of areas affected by and those unaffected by the oil spill) and time (i.e. before and after the disturbance occurred) (Underwood & Peterson 1988, Underwood 1991). In the case of large oil spills, long term monitoring programs are appropriate since they often have impacts that persist over decades (Hawkins et al. 2002, Puente et al. 2009). Furthermore, it is important to gather baseline data sets previous to the oil spill that will serve as a guideline to define the sampling sites for the monitoring programs. This requires the compilation of data from studies done previously in the overall region affected by the oil spill. This is challenging in the Brazilian context due to its high biodiversity of species and habitat across a long coastline. There are still major gaps in basic ecological and biological knowledge of many species, ecosystems and regions along its coastline as well as about the impacts of contaminants on such biodiversity (Williams et al. 2011, Martinez et al. 2022). Notwithstanding, compiling the available data is a starting point for devising monitoring programs and identifying gaps in research that need to be fulfilled to improve baseline datasets for future environmental impact assessments and local scientific knowledge.

Considering the potential long term impacts of the 2019 oil spill in Brazil, here we provide a baseline dataset to underpin monitoring programs on the coast of the Rio Grande do Norte state. We compiled data from previous studies on the distribution and abundance of invertebrate and fish species from different ecosystems. We then mapped the study areas and overlapped them with those affected by the oil spill. The goal of this baseline dataset is not only to support specific monitoring programs for the oil spill but also to guide researchers in developing future research on environmental impacts.

MATERIALS AND METHODS

Characterization of the Rio Grande Norte coastline affected by the oil spill

The coastline of the state of Rio Grande do Norte (RN) has nearly 410 km of extension which is divided into the northern and eastern littoral (IDEMA 2019). Our review is focused on the eastern coastline, where the 2019-2020 oil spill reached 80 locations (Fig.1). The main affected areas (i.e. visual detection of large accumulation of crude oil on the coastline) at the time that the oil spill was spreading over the coast were the intertidal reefs of Nísia Floresta and Tibau do Sul (IBAMA 2019). There are still traces of the oil at these locations since the oil spill occurred, which was last visited in march 2021 by the authors.

The seascape of the RN eastern coast is formed by several habitats such as sandy beaches, dunes, mangroves, estuaries, and intertidal and subtidal sandstone reefs (Fig. 1). The diversity of habitats mentioned above is included in an important ecological and biological area in Brazil that holds a high number of fish and invertebrate species, of which many are endemic (Magris & Giarrizzo 2020).

This coastline contains a marine protected area called APARC (Área de Proteção Ambiental dos Recifes de Corais) that was created in 2001 and extends over the municipalities of

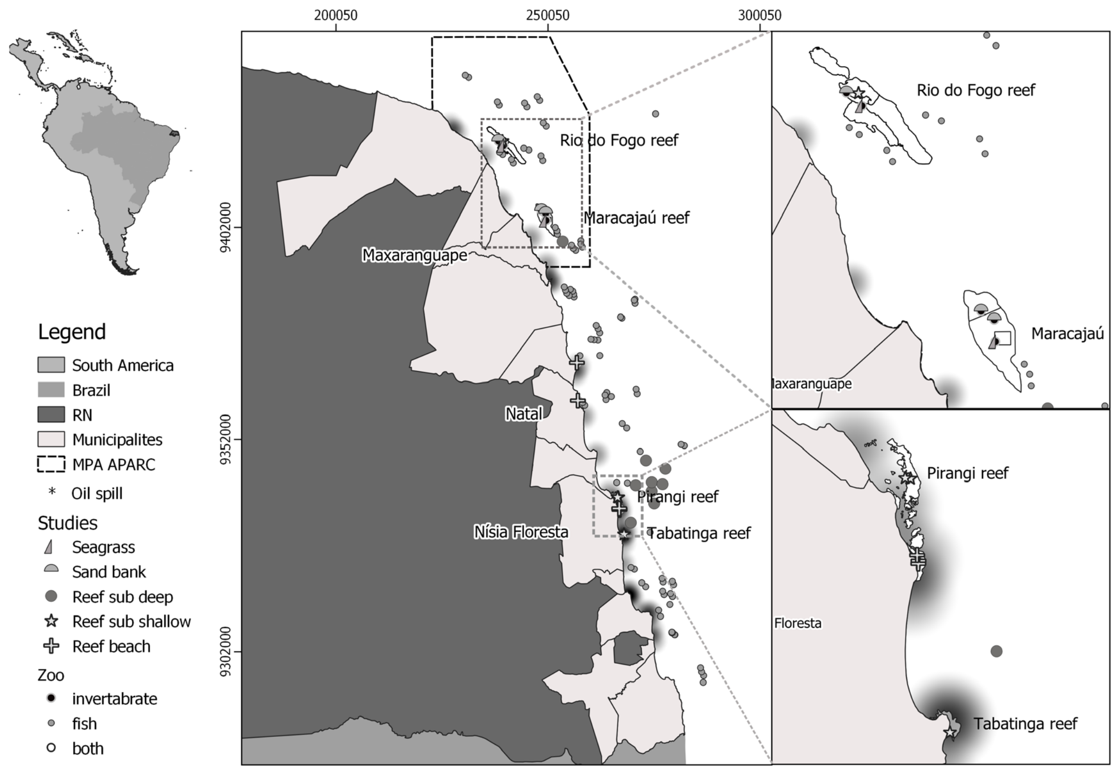

Figure 1. Overlay map of the sample sites and oil spill at study area: invertebrates sampled (black dots), fishes sampled (gray dots) and both (white dots). All Studies Habitat are represented by geometric symbol. Oil spill are represented in black stains with a spreading radius of 3,8 km (merely illustrative).

Maxaranguape, Touros and Rio do Fogo (IDEMA 2019). Another important area that is on the priority list for conservation is the marine area that includes a reef complex situated at Nísia Floresta because it has a rich fauna with species that are threatened including turtles, manatees and cetaceans (Rocha & Bonilha 2020). The creation of a conservation unit in this area is currently an ongoing process.

The income of local communities are primarily dependent on tourism and artisanal fisheries (Fonseca 2007) and the main artisanal fishing areas are located at municipalities of Tibau do Sul and Baía Formosa (Lima M.S.P., unpublished data), which were hit by the oil spill.

Data compilation

We compiled data from 8 studies (1 published paper, 3 MSc theses and 4 PhD theses) on the distribution and abundances of fish and benthic invertebrates from the eastern coast of RN conducted between 2007 and 2019. The raw data was provided by the authors of the studies since most data was not readily accessible. The surveys were done across 116 sites distributed among 5 different habitats: seagrass beds, subtidal sand bottom, intertidal reefs, shallow subtidal reefs (< 5 m), deep subtidal reefs (13m< x < 27m), and demersal water column strata of fishing areas (6m< x < 53m). Among these sites, 8 were sampled within the APARC and 15 within the conservation priority area of Nísia Floresta (Fig. 1).

Detailed information on the methodology of each study, i.e. sampling sites, habitats, sampling method, sampling unit and sampling effort (i.e. total number of replicates, *N*) is presented in Table I.

Table I. **Information on the sampling methodology applied in each study for data collection of fishes and invertebrates on the eastern coast of RN. *Coordinates of fishing areas are approximate values.**

	MUNICIPALES	LAT	LOG	HABITAT	METOD	SAMPLE UND.	N	REFERENCE
Invertebrates	EXTREMOZ	-5,69447	-35,1953	REEF_beach	Underwater visual censuses	10m²/0,25m²	25 trans/50quadrats	Barboza, unpublished data
		-5,69447	-35,1953			0,04m²	222 rocks	
	MAXARANGUAPE (APARC)	-5,39086	-35,2598	Seagrass	core	0,02m²	72 samples	Viana, unpublished data
		-5,43626	-35,2245	Reef_SUB	Underwater visual censuses	60m²	108 transects	Calado, unpublished data
		-5,37599	-35,2605			10m²	36 transect	Martinez et al. 2012
		-5,37003	-35,2694	Sand_bank	core	0,02m²	72 samples	Viana, unpublished data
		-5,37599	-35,2605		Underwater visual censuses	10m²	27 transects	Martinez et al. 2012
		-5,37599	-35,2605	Reef+ seagrass	Underwater visual censuses	10m²	27 transects	
	NATAL	-5,775222	-35,193443	REEF_beach	Underwater visual censuses	10m²/0,25m²	25 trans/50quadrats	Barboza, unpublished data
	NISIA FLORESTA	-6,007267	-35,105817			10m²/0,25m²	25 trans/50quadrats	
		-6,007267	-35,105817			0,04m²	190 rocks	
		-6,069388	-35,097333			10m²/0,25m²	25 trans/50qua	
	PARNAMIRIM	-5,981779	-35,1082			0,25m²	90quadrats	
	RIO DO FOGO (APARC)	-5,23061	-35,3495	Seagrass	core	0,02m²	72 samples	Viana, unpublished data
Fishes	MAXARANGUAPE (APARC)	-5,43626	-35,2245	Reef_SUB	Underwater visual censuses	60m²	108 transects	Calado, unpublished data
	NISIA FLORESTA	-5,95622	-35,071	Reef_SUB_DEEP	Underwater visual censuses	150m²	6 transects	Grimaldi, unpublished data
		-5,96875	-35,0371				6 transects	
		-5,94965	-35,0369				2 transects	
		-5,92109	-35,0077				3 transects	
		-5,90337	-35,049				3 transects	
		-5,99512	-35,0318				3 transects	
		-5,984	-34,9893				3 transects	
		-6,00552	-35,10623	Reef_SUB	Underwater visual censuses	60m²	10 transects	Souza, unpublished data
		-6,0607	-35,09624					
		-6,00821	-35,10586					
		-5,98159	-35,10985					
	RIO DO FOGO	-5,22199	-35,3518					
Fishing	BAIA FORMOSA*	-6,2	-34,9	Fishing	Gillnet	0,012m²	9	Lima, unpublished data
	MAXARANGUAPE*	-5,5	-35			0,026m²	25	
	NATAL*	-5,7	-35			0,043m²	20	
	PIPA*	-6,1	-35			0,023m²	15	
	RIO DO FOGO*	-5,2	-35,2			0,010m²	7	
	TOUROS*	-5,1	-35,2			0,019m²	13	

Classification of species

All the listed species were classified according to its conservation status and human usage at the time of carrying out in the 8 studies mentioned here. Conservation statuses were quantified following the IUCN list of threatened fauna. These included the categories: Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN).

Species were also classified according to human use, viz: Aquarium (A), Consumption (C), Artcraf (AR), Fishery discard (F), Recreational fishing (R) and Not Evaluated (NE). These information were obtained from the following scientific publications: Manzoni & Lacava 1998, Carvalho-Filho 1999, Ferreira & Gonçalves 1999, Oshiro 1999, Costa et al. 2003, Gasparini et al. 2005, Frédou et al. 2006, Lage & Jablonski 2008, Leite et al. 2009, Alves & Dias 2010, MPA/Brasil 2010, Garcia-Jr et al. 2015, Pinheiro et al. 2010, Dias et al. 2011, Nunes et al. 2012, Aragão 2013, Duarte et al. 2016, Santana et al. 2016, Gurjão et al. 2017, Marinho-Soriano 2017, Gurjão & Lotufo 2018 and Guabiroba et al. 2020.

RESULTS

We compiled information on 460 species for all the 116 sites sampled on the eastern coast of RN, of which 175 and 285 were fish and invertebrate species, respectively. The habitat with the greatest benthic invertebrate richness was the seagrass beds (208 spp.), followed by the subtidal sediment habitat (79 spp.), and the intertidal (48 spp.) and subtidal shallow (15 spp.) reefs. Regarding fish species, the fishing areas were the richest (99 spp.), followed by subtidal shallow (87 spp.) and deep (70 spp.) reefs (Fig. 2).

Of the main areas affected by the oil spill, i.e. Nísia Floresta and Tibau do Sul, there are previous data for 11 sites and 3 fishing spots (Fig. 1). At Nísia Floresta, there are abundance data of 22 invertebrate species, of which 46 % are from intertidal reefs, and of 91 fish species, mostly from subtidal reefs (78 % of shallow and deep reefs).

With respect to the conservation status, 99 % of the invertebrate species are Not Evaluated (NE). Most of the invertebrate species are from the thesis of Viana M.G. (unpublished data), which are benthic macro-organisms that inhabit sediment and seagrass habitats and are poorly studied. The remaining 2% are classified as least

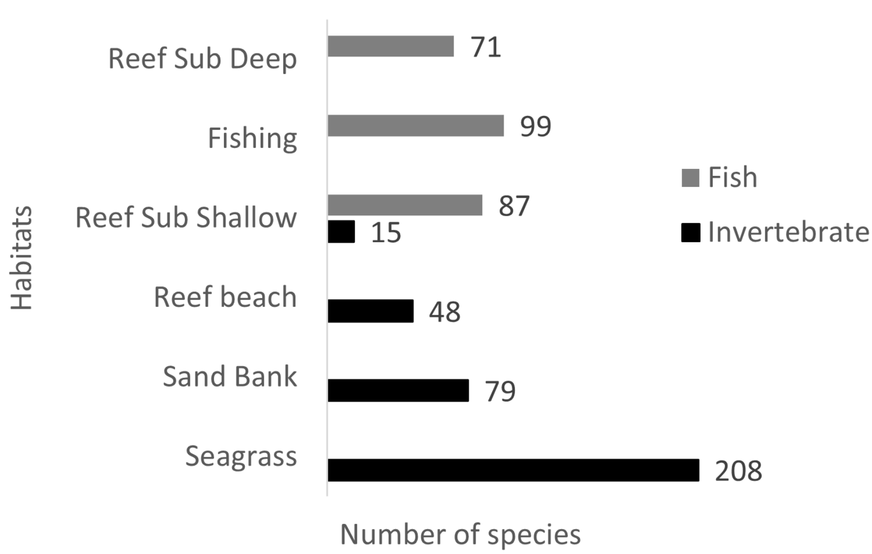

Figure 2. Total number of species of invertebrates and fishes at each habitat on the eastern coast of RN.

concern (LC), which are the coral species *Porites astreoides, Millepora alcicornis e Agaricia humilis* (Supplementary Material - Table SI). Of all invertebrates, the use by humans of 92,1% of the species are unknown (NE). Twelve species (4,1 %) are traded in the aquarium market, 1,7 % are sold in the souvenir and artcraft market, and only 1 % are consumed or used in popular medicine (Fig. 3). The gastropod *Cassis tuberosa,* the sea urchin *Echinometra lucunter* and the seastar *Oreaster reticulatus* were recorded within the environmental protected area APARC and are species within more than 3 categories of human use (suplementary material - Table SII).

More than half of the fish species (52%) were classified as least concerned (LC). Among the other categories, 5 % of the species are threatened (i.e. 1% Endangered - EN; 1% Vulnerable - VU and 3% Near Threatened -NT) viz: the nurse shark *Ginglymostoma cirratum* (VU), the Brazilian basslet *Gramma brasiliensis* (NT), the Brazilian snapper *Lutjanus alexandrei* (NT), the mutton snapper *Lutjanus analis* (NT), the dog snapper *Lutjanus jocu* (NT), the lane snapper *Lutjanus synagris* (NT), the yellowtail damselfish *Microspathodon chrysurus* (VU), the black grouper *Mycteroperca bonaci* (NT) and the parrotfish *Scarus trispinosus* (EN). The remaining 38 % of the fish species were classified as data deficient Fig. 3, Table SIII. Most of the fish species (38,3 %) are destinated to the aquarium trade while 20,9 % are used for human consumption. Nearly 7,2 % of the fishes are discarded in the fisheries and 6,4 % are fished in recreational activities The remaining 27,2% of the fish species were classified as not evaluated (Fig. 3). *Acanthurus coeruleus, Anisotremus surinamensis, Cephalopholis fulva* and *Sparisoma axillare* are appointed in our baseline at least with three human uses (suplementary material - Table SIV).

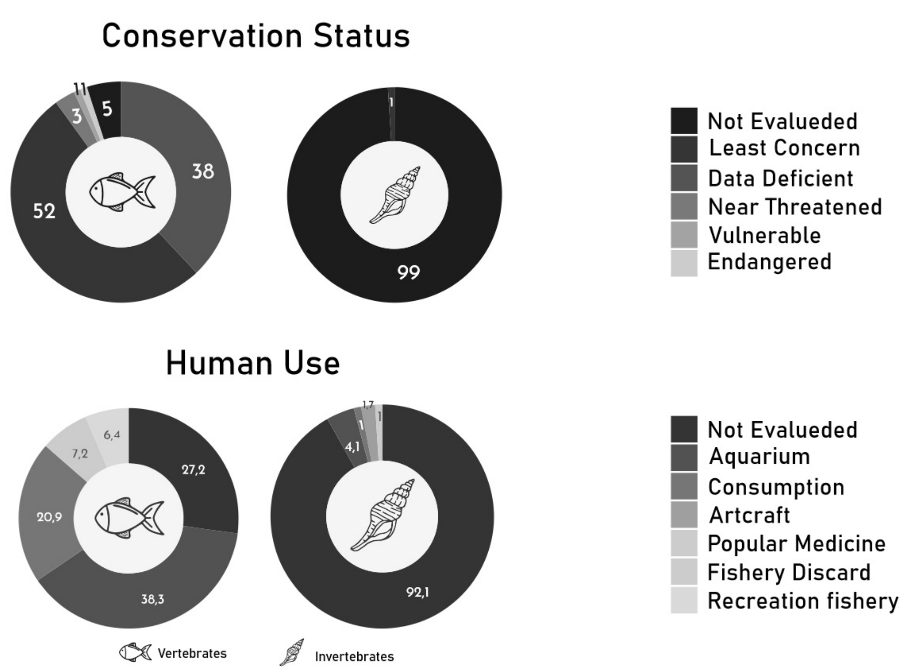

Figure 3. Percentage of conservation categories (Data Deficient -DD, Least Concern - LC, Near Threatened -NT, Vulnerable - VU, Endangered - EN) and Human use (Aquarium (A), Consumption (C), Artcraft (AR), Fishery discard (F), Recreational fishing (R), Medicine (M) and not evaluated (NE)) of benthic invertebrate and fish species at the eastern coast of RN.

DISCUSSION

The total number of species, i.e. 460 species, compiled here for the different habitats demonstrates the high diversity of the eastern coastline of RN, which is expected for marine tropical areas (Soares et al. 2016). Although we compile data from only 8 available studies, the dataset on species distribution is representative of most local marine habitats since the sampling sites were distributed along the entire eastern RN region. The species richness recorded here is likely underestimated since some studies focus on specific taxonomic groups (e.g. epifaunal molluscs in Martinez et al. (2012), epifaunal molluscs and echinoderms in Barboza A.R.P., unpublished data) and there is no information of species from estuarine habitats, which were also affected by the oil spill (Soares et al. 2020). Thus, the baseline dataset presented here is a snapshot of the marine benthos and marine fishes previous to the oil spill sampled in different studies between 2007 and 2019 excluding estuarine habitats and several pelagic organisms from the open sea. In fact, the baseline presented here is not intended to be an exhaustive review of the species that occur on the eastern coast of RN, but to complement the previous benthic and ichthyological studies carried out in the region (for crustacea and fishes distribution see Souza-Junior et al. 2015, Vale et al. 2015, Alencar et al. 2013, 2014, França et al. 2020, Lane-Medeiros et al. 2021, Garcia-Jr et al. 2015).

The concern with the lack of basic information of species distribution previous to oil spills in this region has been previously raised as an obstacle for planning appropriate monitoring programs to detect environmental changes due to human disturbances (Williams et al. 2011). Our findings emphasize the urgent need to increase studies that provide more robust baseline information on the distribution and abundance of species, so natural variability in populations can be properly distinguished from variations caused by anthropogenic disturbances, such as the oil spill. That said, adaptive monitoring programs to evaluate potential effects of the oil spill on the eastern coast of RN can be planned based on the dataset available, which may foster management strategies to recover and conserve regional marine biodiversity (Castège et al. 2013, Soares et al. 2020). Such monitoring programs shall be carefully planned considering some limitations of the available data.

The methods used to survey the species are different in terms of sampling size, apparatus and effort. Any data collection for future comparisons should preferably follow those adopted in Brazilian monitoring programs such as the REBENTOS protocol for invertebrates (Turra & Denadai 2015) and Lang et al. (2015) for fish assemblages.

A second point is with respect to spatial and temporal variability. Marine populations naturally vary in abundances at different spatial and temporal scales depending on several biological (e.g. competition, recruitment, resource supply) and environmental factors (tides, currents, temperature) (Posey et al 1998, Underwood & Peterson 1988, Harper & Williams 2001, Alvarado 2008, Pardal et al 2021). As we pointed above, this dataset provides a snapshot of different species sampled at different locations and at different periods. Monitoring programs should define monitoring sites considering affected and unaffected (control) areas with previous data over a long-term period, allowing for the distinction between potential changes associated with natural and human disturbances (Underwood 1991). From the baseline data presented here in this study, and with a proper sampling design, it is possible to detect potential changes in richness (number of species) and the abundance of more sensitive species as both would be expected to decline because of oil contamination (Castège et al. 2013).

Oil spills can cause multiple negative impacts across marine communities. In the short term it may cause physical oil fouling of megafaunal individuals (turtles, birds, dolphins reference) to entire populations (Huettel et al. 2018) and, finally, habitat loss (Magris & Giarrizzo 2020). In the medium and long term, the deleterious effects of oil can be better assessed by measuring the polycyclic aromatic hydrocarbons - PAHs in organisms together with appropriate biological responses (for benthos see the studies by Suzuki et al. 2015, Bellas et al. 2008) and for fish, Ainsworth et al. 2018, Sturve et al. 2014, Pulster et al. 2020, for example).

Based on this, it is important to maintain in the long term the initiatives to monitor the levels of PAHs in the biota of the eastern coast of RN that already exist, such as the one carried out recently by the LOC/UFRN/INCT AmbTropic GT Óleo team (Mendes et al. 2022). Such initiatives will provide a baseline dataset of biota contamination for future references. From our study, we suggest monitoring of persistence of contaminants in the scleractinian corals (eg. *Siderastrea cf stelatta*, *Porites astreoides, Millepora alcicornis or Agaricia humilis,* e.g), the abundant invertivores fishes (e.g Haemulidae species), the predators fishes (e.g Lutjanidae and Serranidae species) since they are widely found in the present study and perform important functions in the tropics food chain (Froese & Pauly 2021). Other species to be monitored would be the abundant and structuring species on the coast of RN (e.g algae, seagrass, zoanthids, etc). They provide habitat for many species and many ecological functions. In addition, they are easy to sample. This is a plus for maintaining a long-term monitoring program.

Finally, monitoring programs shall consider the pressure of other local human activities (e.g. domestic sewage, fisheries, tourism). This allows the evaluation of habitat and biodiversity recovery as well as interactive effects of stressors on local ecosystems, which information is crucial for improving management strategies to mitigate the impacts of oil spill (Crain et al. 2008, Martinez et al. 2022). Some of the species listed here already have a long history of overexploitation fisheries and are harvested for food, medicine, the artcraft and aquarium market.

Based on our results, we would also suggest the inclusion of a number of invertebrate species such as the king helmet *Cassis tuberosa*, the sea urchin *Echinometra lucunter*, the seastar *Oreaster reticulatus* and fish species such as *Acanthurus coeruleus, Anisotremus surinamensis, Cephalopholis fulva* and *Sparisoma axillare* as these species had been assigned to a total of three different human uses in our baseline data. Equally, it is also important to mention that the region contaminated by the oil spill also suffers from intense fishing, and there is still little knowledge about the conservation status (38% DD) and human use (27,2% NE) of most of the fish species listed here. Therefore, developing adaptive monitoring programs that consider local human activities will provide useful information for management strategies focused on ameliorating environmental quality, facilitating ecosystem recovery and conserving natural habitats (GESAMP 1995).

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SUPPLEMENTARY MATERIAL

Table SI. **List of benthic invertebrates recorded at different habitats of the eastern coast of RN with their total abundances and conservation statuses (Evaluated (NE), Least Concern - LC). Species are listed as the current accepted name according to the World Register of Marine Species (last access: March 2021). *NI- not identified.**

Table SII. **List of benthic invertebrates recorded at different habitats along the eastern coast of RN with their respective human use. The categories were classified as: Aquarium (A), Consumption (C), Craftsmanship (CR), Fishery discard (F), Recreational fishing (R), Medicine (M), Data deficiente (DD) and Evaluated (NE). Species are listed as the current accepted name according to the World Register of Marine Species (last access: March 2021). *NI- not identified.**

Table SIII. **List of fish species recorded at different habitats of the eastern coast of RN with their total abundances and conservation statuses (Data Deficient -DD, Least Concern - LC, Near Threatened -NT, Vulnerable - VU, Endangered - EN). Species are listed as the current accepted name according to the World Register of Marine Species (last access: March 2021). *NI- not identified.**

Table SIV. List of fishes recorded at different habitats of the eastern coast of RN with their respective human use. The categories were classified as: Aquarium (A), Consumption (C), Craftsmanship (CR), Fishery discard (F), Recreational fishing (R), Medicine (M) and not available or unknown (NA). Species are listed as the current accepted name according to the World Register of Marine Species (last access: March 2021).

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