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Environmental Impact Assessment on Marine Mammals at Urussuquara Beach Following the Fundão Dam Failure

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Abstract: The shoreline of Espírito Santo state, in Brazil, presents a rich and poorly investigated biodiversity, hence, it becomes important to conduct a comprehensive survey of its marine fauna, in order to mitigate and minimize possible future or ongoing impacts arising from the Fundão dam failure, in particular at the Urussuquara beach, which is one of the final places reached by the contamination plume originated at the Fundão dam of Mariana, Minas Gerais. Thus, the survey of marine mammals was performed by the method of Carcass Prospecting and Expedition and Observation method and concluded that there is a negative effect on the species that live in this region due to the dam failure and other anthropogenic activities.
Keywords: Environmental Impacts, Coastal Ecosystems, Sea Mammals, Fundão Dam.

Avaliação do Impacto Ambiental em Mamíferos Marinhos da Praia de Urussuquara após Rompimento da Barragem do Fundão

Resumo: A orla costeira do Espírito Santo apresenta uma biodiversidade rica e pouco investigada, portanto, torna-se importante a realização de levantamentos detalhados sobre sua fauna marinha, a fim de combater e minimizar possíveis impactos futuros ou em cursos decorrentes do rompimento da barragem de Fundão, em especial, a praia de Urussuquara, um dos últimos locais atingidos pela pluma contaminante originada na barragem de Fundão em Mariana-MG. Assim, o levantamento dos mamíferos marinhos foi realizado pelo método de Prospecção de Carcaças e Expedição e Observação de Carcaças e concluiu-se que existe um efeito negativo nas espécies que vivem nesta região devido ao rompimento da barragem e outras atividades antrópicas.
Palavras-chave: Impactos Ambientais, Ecossistemas Costeiros, Mamíferos Marinhos, Barragem de Fundão.

Evaluación del Impacto Ambiental en Mamíferos Marinos de la Playa de Urussuquara después del Rompimiento de la Presa del Fundão

Resumen: El litoral de Espírito Santo posee una biodiversidad rica y poco investigada, por lo tanto, es importante realizar estudios detallados sobre su fauna marina para combatir y minimizar posibles impactos futuros o en curso derivados de la ruptura de la represa de Fundão, en particular, la playa de Urussuquara, uno de los últimos sitios afectados por la pluma contaminante proveniente de la represa de Fundão en Mariana, Minas Gerais. Así, se llevó a cabo un censo de mamíferos marinos utilizando el método de Prospección de Cadáveres y Expedición y Observación de Cadáveres y se concluyó que existe un efecto negativo en las especies que habitan en esta región debido a la ruptura de la represa y otras actividades humanas.
Palabras clave: Impactos ambientales, Ecosistemas Costeros, Mamíferos Marinos, Represa de Fundão.

INTRODUCTION

Espírito Santo State has gone through many economic exploration and production cycles. Due to these causes and facing the uncontrolled urban expansion and the establishment of industrial, real estate, and port ventures (Silva *et al.*, 2018), its marine and estuarine ecosystems were gradually extinguished and degraded. As a consequence, many aquatic faunal species appear on the List of Endangered fauna of Espírito Santo State, as well as on the national (MMA) and international (IUCN) lists, classified in different endangerment categories or even regarded as extinct.

The introduction of xenobiotic compounds into marine environments at alarming levels precipitates the degradation of diverse aquatic habitats, spanning from the photic to the aphotic zones, thereby compromising the integrity of the entire marine trophic network. This phenomenon has contributed significantly to the disruption of environmental homeostasis, exerting a profound impact on marine ecosystems that exceeds their capacity for stability, resistance, and resilience (Silva *et al.*, 2019).

Aquatic mammals are on the top of the food websand can provide important information about the environmental quality (Lodi & Borobia, 2013; Vitorio *et al.*, 2023; Akita *et al.*, 2024). The deepening of the knowledge about aquatic mammals can support innumerable decisions in conservation and sustainable management of natural resources. Such studies are difficult to perform given the environment that they occupy. Since direct and continuous observation of these animals and their behavior can rarely be performed, several methodologies have been developed to understand the biology and the ecological relationships of these animals. We mention as examples the cruise ships and overflights of visual monitoring, passive and active detection (Lodi *et al*, 2015; Pires *et al.*, 2021; Simão *et al.*, 2002; Vitorio *et al.*, 2019), and genetic material collection (Tardin *et al.*, 2008; Tardin *et al.*, 2017).

Notably, the municipalities of São Mateus and Linhares, situated within the Espírito-Santense north coastal Mesoregion of Brazil (Brazilian Institute of Geography and Statistics, 2017; Akita *et al.*, 2022), exemplify the paradoxical relationship between biodiversity conservation and the establishment of potentially polluting ventures. In this region, the erstwhile Mata Atlântica biome has been largely supplanted by eucalyptus monoculture, livestock farming, and various agricultural pursuits, including coffee, coconut, and black p.

In parallel, the coastline of these cities have many threatened species, of marine mammals, standing out the cetaceous *Megaptera novaeangliae* (humpback whale), *Eubalaena*

australis (southern right whale), *Physeter macrocephalus* (sperm whale), *Balaenoptera acutorostrata* (common minke whale), *Kogia breviceps* (pygmy sperm whale), *Peponocephala electra* (melon-headed whale), *Pontoporia blainvillei* (La Plata dolphin), *Sotalia guianensis* (Guiana dolphin), *Tursiops truncatus* (common bottlenose dolphin), *Steno bredanensis* (rough-toothed dolphin), *Stenella frontalis* (Atlantic spotted dolphin), *Stenella longirostris* (spinner dolphin), and *Sotalia fluviatilis* (tucuxi) (Flach *at al.*, 2019; Félix, 2011; Lodi & Borobia, 2013; Maricato *et al.*, 2022; Simão *et al.*, 2000;). From all recorded species, among the small cetaceous, two of them stand out, namely *Pontoporia blainvillei* and *Sotalia guianensis*. Regarding the pinnipeds, there are no reproductive colonies in Brazil, however, they perform typical post-reproductive seasonal movements, especially between the winter and spring months, and, during this period, they frequently use the south and southeast coasts of Brazil as a rest area between their displacements (Prado *et al.*, 2016). Seven pinnipeds species have been recorded along the Brazilian coastline (Projeto Boto Cinza, 2013), however, at Espírito Santo State, near the northern coast, occurrences of the *Mirounga leonina* (southern elephant seal) species are recorded, specifically to the municipalities of Linhares and São Mateus.

In 2015, the catastrophic failure of the Fundão dam, operated by the mining company Samarco, occurred. Located approximately 35 km from the centre of the Brazilian municipality of Mariana, in the state of Minas Gerais, the dam's collapse resulted in the release of approximately 16,000 Olympic-sized swimming pools worth of mining waste, which subsequently percolated and extended for approximately 800 km along the Doce River, traversing the states of Minas Gerais and Espírito Santo. The municipality of Linhares was the ultimate point of impact, where the Doce River empties into the ocean (Silva *et al.*, 2018). In the region encompassing Urussuquara and Barra Seca, situated between the municipalities of Linhares and São Mateus, a significant mortality event affecting aquatic biota occurred in January 2016, with notable impacts on ichthyofauna, malacofauna, and carcinofauna. This event was precipitated by an untimely wind that carried a dense mass of particulate matter from the Mariana-MG mining waste (Centro Tamar, 2016; Lelacher *et al.*, 2023).

The protection, management, and conservation of marine ecosystems are grounded in public policies that prioritize the sustainable management and utilization of natural resources, in accordance with various international agreements ratified by the Brazilian Government, such as the Convention on Biological Diversity (CBD) and the United Nations Convention on the Law of the Sea (UNCLOS). Furthermore, these policies are guided by the principles and fundamentals enshrined in the Brazilian National Environmental Policy (Política Nacional de Meio Ambiente,

PNMA), established by Law No. 6,938/1981, which emphasizes the importance of environmental conservation and sustainable development (Lodi & Borobia, 2013; Almeida *et al.*, 2020; Pereira *et al.*, 2023). It is necessary that the government decisions rely on information produced by the scientific community, and that such information is produced in a continuous and standardized manner.

Given all these deleterious impacts on the estuarine and marine ecosystems in Linhares and São Mateus, the seasonal monitoring of cetaceans and pinnipeds at the Urussuquara beach, which was reached by the contaminantion plume, generated by the failure of the dam. The objective of this work was to observe the ecosystem of this region was negatively impacted by the input of contaminants from the dam failure. Besides that, other impacts were observed, such as the installation of gill nets at feeding and nursery zones of marine mammalians, illegal dumping of solid waste, and in natura effluents on the regional aquatic ecosystems.

MATERIALS AND METHODS

Study area characterization

The Urussuquara beach is located on the border between the municipalities of Linhares and São Mateus. The study area corresponds to the totality of the Urussuquara beach,with a sampling space of 149.3 ha (Silva *et al.*, 2018), from which 60.8 ha are flooded restinga, 41.4 ha are degraded grassland, 31.3 ha are restinga dense woods, 15.8 ha are restinga open woods, and 0.4 ha are restinga herbaceous formation, typical of the restinga ecosystem (Figure 1).

Figure 1. Map of land use at the Urussuquara beach.
Source: The author.

The climate is characterized, according to Köppen and Geiger (Silva *et al.*, 2018), as Am (tropical monsoon climate) at São Mateus, and Aw (tropical savanna climate) at Linhares, presenting average annual temperature around 24.2° C, featuring a dry and moderate winter, and a rainy summer with high temperatures (Silva *et al.*, 2019). The warmest month, February, presents an average temperature of approximately 26.6° C. Autumn and spring are transition seasons. The pluviometric index is around 1240 mm, being November the month with higher precipitation. Comparing the driest month with the rainiest one, there is a difference in precipitation of 120 mm. The mean temperatures vary over 4.5° C along the year (Silva *et al.*, 2018).

Carcass Prospecting and Expedition and Observation Method

A total of four field campaigns were undertaken between August 2017 and May 2018, with each campaign coinciding with a different season and spanning a duration of ten days. Employing the methodology outlined by Vitorio *et al.* (2023), the sampling effort involved a daily commitment of five hours, resulting in a cumulative total of 50 hours per campaign. The campaigns were conducted during the following periods: late August 2017 (Campaign 1), late November 2017 (Campaign 2), early February 2018 (Campaign 3), and late May 2018 (Campaign 4).

In pursuit of surveying marine mammalian carcasses along the entirety of the Urussuquara beach shoreline, a multidisciplinary team of scientists and researchers from Helium Corp Engenharia employed a suite of equipment, including quadricycles, TASCO (08 x 25) field glasses, a Garmin 64S GPS device, field notebooks, and bespoke data collection forms. Whenever feasible, carcasses were retrieved and stored in drums containing 90% formaldehyde. In instances where collection was not possible, taxonomically informative samples were collected, and georeferenced photographs were taken, with subsequent identification and storage conducted at the Zoology Laboratory of the Federal University of Espírito Santo (UFES).

Expedition and Observation of Marine Mammals

Two cruise trips were conducted on the sea, for each sampling season, considering good conditions of the climatic variables for their undertaking, with a sampling effort of 16 h per trip, in a total of 32 h of sampling effort per campaign, which had as a major objective the interception of marine mammals offshore (Figure 2).

The observational sampling effort on the continent was 5 h per campaign day, in a total of 50 h of sampling effort. On the sea, random routes were performed, until one or more individuals were spotted. Once sighted, the ship would approach at reduced speed, so as to not interfere much with the activities performed by the animals, keeping a minimum distance of 15 m.

The observer was placed at the ship's bow, where data was collected with a photographic camera and georeferenced with the aid of a GPS.

Figure 2. Observation made on the ship searching for cetaceans (Lat -19.379172 Long -39.153096).
Source: The author.

Furthermore, semi-structured interviews were conducted with local stakeholders to gather qualitative data regarding the species encountered during each sampling season. Participants included fishermen from local communities and representatives from the Beaches Monitoring Project (PMP-PETROBRAS), implemented by Scitech, who are responsible for monitoring fauna in the region.

RESULTS AND DISCUSSION

Inventory and Monitoring of Marine Mammalian carcasses

During the inventory and monitoring of carcasses, four specimens were recorded at the Urussuquara beach and listed in Table 1. Three of these were *Megaptera novaeangliae* calves, and one of them was the critically endangered specie *Pontoporia blainvillei (Figure 3)*.

Table 1. Inventory list of marine mammalians occurring at the Urussuquara beach (2017 to 2018).

Date	Family	Species	Latitude	Longitude	Time	Status (MMA| IUCN| IEMA| CITES)
Carcasses sampling						
Winter						
09/05/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.01889335	-39.73011374	09:48	VU; LC; VU; I
Spring						
11/29/2017	Pontoporiidae	*Pontoporia blainvillei* (Gervais & d'Orbigny, 1844)	-19.05389100	-39.72495900	07:00	CR; VU; EP; I
12/02/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.06555600	-39.72276600	09:11	VU; LC; VU; I
12/03/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.06976800	-39.72227800	10:13	VU; LC; VU; I
Sampling by Sight						
Winter						
08/31/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.06730975	-39.61395264	07:55	VU; LC; VU; I
08/31/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.08109.985	-39.57163811	08:15	VU; LC; VU; I
08/31/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.0527684	-39.57661629	08:16	VU; LC; VU; I
08/31/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.03907702	-39.58502769	08:16	VU; LC; VU; I
09/01/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.08710224	-39.71132755	09:23	VU; LC; VU; I
09/03/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.08174877	-39.66347694	15:17	VU; LC; VU; I
09/03/2017	-	*Mysticeti sp.*	-19.06763424	-39.62742805	17:23	-
09/05/2017	Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.01889335	-39.73011374	09:48	VU; LC; VU; I
Spring						
12/01/2017	Balaenopteridae	*Megaptera novaeangliae*	-19.066786	-39.717644	10:23	VU; LC; VU; I

		(Borowski, 1781)				
Summer						
02/02/2018	Delphinidae	*Sotalia guianensis* (Van Bénéden, 1864)	-19.06.961171	-39.72.160124	15:47	VU; NT; NE; I
02/03/2018	Delphinidae	*Sotalia guianensis* (Van Bénéden, 1864)	-19.08700608	-39.71031719	13:07	VU; NT; NE; I
02/04/2018	Delphinidae	*Sotalia guianensis* (Van Bénéden, 1864)	-19.06185945	-39.71997314	09:58	VU; NT; NE; I
02/06/2018	Delphinidae	*Sotalia guianensis* (Van Bénéden, 1864)	-19.05029515	-39.72115765	08:07	VU; NT; NE; I
02/06/2018	Delphinidae	*Sotalia guianensis* (Van Bénéden, 1864)	-19.07532185	-39.71823941	10:35	VU; NT; NE; I

Legend: Status – MMA: VU (vulnerable), CR (critically endangered); IUCN: LC (least concern), VU (vulnerable), NT (near threatened); IEMA: VU (vulnerable), EP (endangered), NE (no data); CITES Appendix I (threatened with extinction species, which trade will only be permitted under exceptional cases).
Source: The author.

Regarding the monitoring technique using offshore visual observation, seven individuals from the *Megaptera novaeangliae* species and an unidentified Mysticeti were sighted during the 2017 winter period. During the spring sampling, only one individual from *Megaptera novaeangliae* was recorded. The decrease in abundance of *Megaptera novaeangliae* is due to the end of the species reproductive season.

In the 2018 summer sampling campaign, a total of five individuals from *Sotalia guianensis* species was surveyed. The data collected by the offshore visual observation methodology on the Urussuquara beach, are listed in Table 1.

According to the Baleia Jubarte Institute (2017), the year of 2017 presented a record number of stranding of *Megaptera novaeangliae* species in the Brazilian coastline, in a total of 121 specimens, being 26 found in Espírito Santo state. These results are a direct effect of the species populational growth on the Brazilian coast. The Baleia Jubarte Institute (2017) estimates an abundance that already exceeds 17,000 individuals. However, the amount of stranding individuals with signs of death by human action, like entanglement in gill nets, reinforces the concern about the need for monitoring new threats to the whales in Brazil, and the importance of efforts to minimize them. Given that the monitoring programme concluded in May 2018, the dataset was limited in its temporal scope, as the anticipated reproductive season for the

subsequent year was expected to commence in July, thereby falling outside the monitoring period.

Figure 3. A – A carcass of a humpback whale calf in advanced putrefaction stage about 5 m long. Lat -19.01889335Long -39.73011374. B- Vertebra of a prepubertal juvenile humpback whale. Lat -19.069768 e Long -39.722278.
Source: The author.

The *Pontoporia blainvillei* is endemic of the Western South Atlantic Ocean, spread from Itaúnas (18º 25´ S), Espírito Santo State, Brazil (Siciliano, 1994), to San Matias Gulf (41º 09'S), Chubut province, Argentina (Crespo *et al.*, 1998). Its preferential habitat includes coastline regions up to 30 m deep, being occasionally found on estuaries.

Similar to other cetacean species, the La Plata dolphin has a low populational growth rate, varying between 0.6 to 3.8 % (Instituto Chico Mendes de Conservação da Biodiversidade, 2010). This populational decrease, linked to high levels of unnatural mortality, causes the risk to the survival of this species. Due to its coastal habit, the La Plata dolphin becomes more vulnerable to anthropic activities, among which, the gill net fishing affects its conservation the most. Incidental captures on gill nets have a high frequency all over the La Plata dolphin distribution (Prado, 2016). As a result of this fact, the species is currently included on the "Vulnerable" category of the Red List of Threatened Species of the International Union for Conservation of Nature (2019), and "critically threatened by extinction" on the national list of Brazilian endangered fauna (MMA, 2014). During the field activities, a register was performed of *Pontoporia blainvillei* with gill net, being necessary environmental education actions with the human populations that use the coastline in their fishing activities.

The *Sotalia guianensis* species is distributed over the Atlantic coastlines of South and Central Americas where it inhabits estuaries, protected bays, or strictly coastal areas (Espécie *et al.*, 2010). Despite being in habitats that suffer great anthropogenic pressure, the species is

still classified as "Data Deficient" by the IUCN (Tardin *et al.*, 2014). *Sotalia guianensis* presents a seasonal variation following the water temperature. According to Lelacher *et al.* (2023), during the warm seasons, regarding the use of the habitat, areas closer to the coast and with less current intensity are preferred, while during the cold seasons, intermediary classes of distance from coast and areas with moderate currents are preferred. During the sampling by cruise trips, in the summer period, this species was observed closer to the Urussuquara beach, not being observed in other seasons, in which the water is colder (Figure 4).

Figure 4. Geospatial distribution of *S.* guianensis during 2018 summer season at Urussuquara beach.
Source: The author.

The approximation of *Sotalia guianensis* to the coastline at Urussuquara beach, during the warmer seasons, represent risk and vulnerability regarding the use of the habitat, since it is common in fishing communities the use of gill nets, being possible accidental records of this species as occurred to *Pontoporia blainvillei*, during 2017 spring sampling campaigns.

Table 2. Inventory list of marine mammals surveyed by interviews with the Scitech company, responsible for the PMP-PETROBRAS.

Family	Species	Approximate Latitude	Approximate Longitude	Status (MMA|IUCN| IEMA| CITES
		Winter 2017		
Balaenidae	*Eubalaena australis* (Desmoulins, 1822)	-18.743460	-39.677077	EN; LC; EP; I
Phocidae	Mirounga leonina (Linnaeus, 1758)	-18.974267	-39.730456	NA; LC; NE; I
Physeteridae	*Physeter macrocephalus* (Linnaeus, 1758)	-18.766411	-39.643084	VU; VU; VU; I
Pontoporiidae	*Pontoporia blainvillei* (Gervais & d'Orbigny, 1844)	-19.041161	-39.689309	CR; VU; EP; I
Delphinidae	*Sotalia guianensis* (Van Bénéden, 1864)	-18.901954	-39.612408	VU; NT; NE; I
Delphinidae	*Steno Bredanensis* (G. Cuvier in Lesson, 1828)	-19.332911	-39.627924	LC; LC; NE; I
Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.004495	-39.550016	VU; LC; VU; I
Delphinidae	*Tursiops truncatus* (Montagu, 1821)	-19.359316	-39.608937	LC; DD; NE; I
		Spring 2017		
Balaenidae	*Eubalaena australis* (Desmoulins, 1822)	-18.520453	-39.410964	EN; LC; EP; I
Phocidae	*Mirounga leonina* (Linnaeus, 1758)	-18.769289	-39.740043	NA; LC; NE; I
Physeteridae	*Physeter macrocephalus* (Linnaeus, 1758)	-18.531100	-39.227545	VU; VU; VU; I
Pontoporiidae	*Pontoporia blainvillei* (Gervais & d'Orbigny, 1844)	-18.981690	-39.698025	CR; VU; EP; I
Delphinidae	*Sotalia guianensis* (Van Bénéden, 1864)	-19.093752	-39.657270	VU; NT; NE; I
Delphinidae	*Steno Bredanensis* (G. Cuvier in Lesson, 1828)	-19.713019	-39.826234	LC; LC; NE; I
Balaenopteridae	*Megaptera novaeangliae* (Borowski, 1781)	-19.292827	-39.501018	VU; LC; VU; I
Delphinidae	*Tursiops truncatus* (Montagu, 1821)	-19.599461	-39.658867	LC; DD; NE; I
		Summer 2018		
Balaenidae	*Eubalaena australis* (Desmoulins, 1822)	-18.578103	-39.178780	EN; LC; EP; I
Phocidae	*Mirounga leonina* (Linnaeus, 1758)	-19.279292	-39.689573	NA; LC; NE; I
Physeteridae	*Physeter macrocephalus* (Linnaeus, 1758)	-19.284666	-39.447494	VU; VU; VU; I
Pontoporiidae	*Pontoporia blainvillei* (Gervais & d'Orbigny, 1844)	-18.866678	-39.556573	CR; VU; EP; I

Delphinidae	*Sotalia guianensis* (Van Bénéden, 1864)	-19.069602	-39.711621	VU; NT; NE; I
Delphinidae	*Steno Bredanensis* (G. Cuvier in Lesson, 1828)	-19.130882	-39.673353	LC; LC; NE; I
Delphinidae	*Tursiops truncatus* (Montagu, 1821)	-19.461643	-39.672252	LC; DD; NE; I
		Autumn 2018		
Phocidae	*Mirounga leonina* (Linnaeus, 1758)	-19.664290	-39.840742	NA; LC; NE; I
Delphinidae	*Sotalia guianensis* (Van Bénéden, 1864)	-19.379172	-39.153096	VU; NT; NE; I
Delphinidae	*Steno Bredanensis* (G. Cuvier in Lesson, 1828)	-19.837883	-39.666365	LC; LC; NE; I
Delphinidae	*Tursiops truncatus* (Montagu, 1821)	-20.080368	-39.858222	LC; DD; NE; I

Legend: Status – MMA: VU (vulnerable), CR (critically endangered); IUCN: LC (least concern), VU (vulnerable), NT (near threatened), DD (Data Deficient); IEMA: VU (vulnerable), EP (endangered), NE (no data); CITES Appendix I (threatened with extinction species, which trade will only be permitted under exceptional cases).
Source: The author.

All eight marine mammal species surveyed by interview have some category of endangerment. On 01/25/2017, the rescue of an individual of *Mirounga leonina* species at São Mateus was performed (Figure 5), and the release happened on 06/12/2017, at the Guriri beach, according to the Institute of Research and Rehabilitation of Marine Animals (Irpam, 2017). This very individual visits the coast of Espírito Santo State since 2012, indicating that the São Mateus coastline is within its *home range*, being the beaches of this municipality priority areas for the conservation of this species.

On 08/19/2017, the stranding of a juvenile male of the species *Megaptera novaeangliae* (Figure 5B) was recorded, on the same beach in which the *Mirounga leonina* individual was released. The *Megaptera novaeangliae* individual died on the same day of its stranding, hence, being the same individual sampled during the carcasses monitoring, presented in Figure 4.

Figure 5. A – *Mirounga leonina* rescued at São Mateus. B –*Megaptera novaeangliae* stranded at São Mateus coast.
Source: Scitech.

Environmental Impacts After the Mariana-MG Disaster

All the surveyed marine mammalian species have as *home range* the marine and estuarine ecosystems that were negatively impacted by the environmental disaster of Mariana-MG. This environmental disaster originated in the Doce River basin, with the resultant waste plume extending into the coastal waters and estuaries of Espírito Santo, coinciding with the peak reproductive period of various marine mammal species, including the Guiana dolphin (*Sotalia guianensis*), the bottlenose dolphin (*Tursiops truncatus*), and the Franciscana dolphin (*Pontoporia blainvillei*), which typically breed between June and September in this region. Notwithstanding, the waste plume spread over the coastline of the Espírito Santo state, being accumulated at the mouth of the Doce River.

The Ipiranga River, situated within the Urussuquara region, which flows northwards into the Barra Seca River in the state of Espírito Santo, exhibited elevated fish mortality rates from January 2016 onwards, persisting until the present time of this scientific investigation. This phenomenon had a profound impact on the local economy, with a latency period of 19 months following the arrival of the particulate matter emanating from the mining waste, specifically in July 2017 (Silva *et al.*, 2018).. Possibly, this impact has also been felt by the marine mammal community, especially the piscivores, like the individuals from Delphinidae and Phocidae families.

According to Silva et al. (2018), the influx of waste from the Fundão dam had a profound impact on the marine ecosystem at Linhares-ES and São Mateus-ES, with direct consequences also observed at Urussuquara beach. The water quality parameters, including total dissolved solids (TDS), dissolved oxygen (DO), and hydrogenionic potential (pH), were found to be in non-compliance with the standards set forth in CONAMA Resolution No. 357/2005. Furthermore, the electrical conductivity parameter exhibited significant changes. The physical-chemical monitoring of the Espírito Santo coastal waters conducted by Silva et al. (2018) following the Fundão dam failure revealed that, in September 2017, the average concentrations of TDS exceeded 500 ppm, while the conductivity surpassed 1000 µS/cm. These values exceeded the acceptable limits stipulated in CONAMA Resolution No. 357/2005. Additionally, the average pH value of 8.53 recorded in May 2018 for the estuarine ecosystem was also deemed non-compliant with the resolution, highlighting the far-reaching consequences of this environmental impact (Table 3)).

Table 3. Univariate parameters for the abiotic collected variables at the seasonal periods for the marine and estuarine ecosystems at Urussuquara-ES. In red are found all the variables that are not in accordance with the CONAMA resolution nº 357/2005.

Winter 2017							
Estuarine Ecosystem	**pH**	**ºC**	**Conductivity (µS/cm)**	**TDS (ppm)**	**DO (mg/L)**	**Secchi Disk (m)**	**Total Depth (m)**
x̄	7.02	22.80	**1,039.17**	**518.67**	**4.83**	0.62	1.27
S	0.23	0.38	37.35	20.03	1.23	0.10	0.80
S²	0.05	0.15	1,394.97	401.07	1.52	0.01	0.65
Sx	0.09	0.16	15.25	8.18	0.50	0.04	0.33
cv%	3.24	1.68	3.59	3.86	25.58	15.94	63.49
Marine Ecosystem	**pH**	**ºC**	**Conductivity (µS/cm)**	**TDS (ppm)**	**DO (mg/L)**	**Secchi Disk (m)**	**Total Depth (m)**
x̄	8.46	23.18	**962.67**	**507.67**	41.97	4.28	11.67
S	0.20	0.08	14.53	40.37	1.48	0.35	7.28
S²	0.04	0.01	211.07	1629.87	2.19	0.12	53.07
Sx	0.08	0.03	5.93	16.48	0.60	0.14	2.97
cv%	2.34	0.34	1.51	7.95	3.53	8.14	62.44
Primavera de 2017							
Estuarine Ecosystem	**pH**	**ºC**	**Conductivity (µS/cm)**	**TDS (ppm)**	**DO (mg/L)**	**Secchi Disk (m)**	**Total Depth (m)**
x̄	7.49	25.92	29.96	15.10	**1.51**	0.50	2.35
S	0.25	0.19	1.91	0.79	1.54	0.00	1.12
S²	0.06	0.04	3.66	0.62	2.38	0.00	1.25
Sx	0.10	0.08	0.78	0.32	0.63	0.00	0.46
cv%	3.39	0.75	6.38	5.22	102.13	0.00	47.52
Marine Ecosystem	**pH**	**ºC**	**Conductivity (µS/cm)**	**TDS (ppm)**	**DO (mg/L)**	**Secchi Disk (m)**	**Total Depth (m)**
x̄	8.42	26.50	36.80	18.61	15.59	3.67	10.83
S	0.15	0.13	5.58	1.52	5.56	3.87	6.05
S²	0.02	0.02	31.10	2.31	30.96	14.97	36.57
Sx	0.06	0.05	2.28	0.62	2.27	1.58	2.47
cv%	1.78	0.48	15.15	8.17	35.70	105.51	55.82
Verão de 2018							
Estuarine Ecosystem	**pH**	**ºC**	**Conductivity (µS/cm)**	**TDS (ppm)**	**DO (mg/L)**	**Secchi Disk (m)**	**Total Depth (m)**
x̄	7.24	25.96	34.26	17.32	**4.10**	0.38	2.42
S	0.33	0.61	4.16	2.48	1.26	0.13	1.23
S²	0.11	0.38	17.35	6.16	1.58	0.02	1.51
Sx	0.14	0.25	1.70	1.01	0.51	0.05	0.50
cv%	4.57	2.37	12.16	14.34	30.67	34.67	50.77

Marine Ecosystem	pH	°C	Conductivity (µS/cm)	TDS (ppm)	DO (mg/L)	Secchi Disk (m)	Total Depth (m)
x̄	8.43	26.87	48.45	27.75	19.61	3.67	12.42
S	0.16	0.15	1.63	1.24	4.31	4.19	6.40
S²	0.02	0.02	2.66	1.53	18.58	17.58	40.94
Sx	0.06	0.06	0.67	0.51	1.76	1.71	2.61
cv%	1.86	0.57	3.37	4.46	21.98	114.35	51.53
Outono 2018							
Estuarine Ecosystem	pH	°C	Conductivity (µS/cm)	TDS (ppm)	DO (mg/L)	Secchi Disk (m)	Total Depth (m)
x̄	7.47	24.33	31.24	21.17	**4.05**	0.38	2.42
S	0.55	0.52	8.41	5.28	0.07	0.13	1.23
S²	0.30	0.27	70.65	27.87	0.01	0.02	1.51
Sx	0.22	0.21	3.43	2.16	0.03	0.05	0.50
cv%	7.34	2.12	26.91	24.93	1.81	34.67	50.77
Marine Ecosystem	pH	°C	Conductivity (µS/cm)	TDS (ppm)	DO (mg/L)	Secchi Disk (m)	Total Depth (m)
x̄	**8.53**	25.00	50.92	28.47	25.26	1.67	12.42
S	0.24	0.00	1.42	0.95	6.10	1.44	6.40
S²	0.06	0.00	2.01	0.90	37.21	2.07	40.94
Sx	0.10	0.00	0.58	0.39	2.49	0.59	2.61
cv%	2.79	0.00	2.79	3.34	24.15	86.26	51.53

Source: Silva *et al.* (2018).

According to the Tamar Center (2016), a significant mortality event affecting fish populations occurred in the Ipiranga River during the second semester of 2016 and the first semester of 2017, which can be correlated with the failure of the Fundão dam. The presence of suspended solids in the water column can have indirect effects on aquatic life, including the attenuation of light penetration, increased water temperature, and a consequent reduction in dissolved oxygen levels (Silva *et al.*, 2018). Furthermore, the Tamar Center (2016) reported high concentrations of iron in the mining waste that percolated through the Doce River basin. Water rich in Fe3+ ions can exhibit increased turbidity when exposed to oxygen in the air (Corcóvia, 2012; Lelacher *et al.*, 2023; Matta *et al.*, 2022). Electrical conductivity, a measure of the water's ability to conduct electrical current, is influenced by the presence of dissolved substances that dissociate into anions and cations. As the ionic concentration of the solution increases, so does the potential for electrolytic action, and consequently, the capacity for conducting electrical current (Silva *et al.*, 2019). Additionally, electrical conductivity can be used as a proxy for water transparency, as it affects the passage of light through the water column (Silva *et al.*, 2018).

These parameters are crucial for maintaining life in marine and estuarine ecosystems. Alterations in total dissolved solids and electrical conductivity can lead to decreased productivity in aquatic ecosystems, resulting in reduced food availability for marine mammals inhabiting Urussuquara beach, regardless of their trophic position.

CONCLUSIONS

The municipality of Linhares, in the state of Espírito Santo (ES), located about 800 km from the Fundão dam, was the last legal district to be impacted by its mining wastes. The database generated by the monitoring of marine mammals at Urussuquara beach indicates that these individuals have in their life history an ecosystem negatively impacted by the input of contaminants that originated at the failure of the Fundão dam, in Mariana, Minas Gerais.

The disaster denoted the connectivity between marine, estuarine, and terrestrial areas, albeit apart geographically, through the hydrographic network. It highlights the importance of the whole Doce River basin, the main hydric resource of the Espírito Santo state, for the maintenance of the synergy and homeostasis of the marine ecosystems along the Espírito Santo coastline, as the case of the marine mammal community. Besides the impacts resulting from the failure of the Fundão-MG dam, are also evident the classical impacts to the marine fauna, as the placement of gill nets in feeding and nursery zones of marine mammals, illegal dumping of solid wastes and *in natura* effluents into the aquatic ecosystems if the region.

Therefore, it is of utmost importance the continuity of the monitoring of the physical-chemical environment of the marine and estuarine ecosystems at Linhares-ES and, consequently, of the Urussuquara beach, as well as the continuation of the survey of the marine mammals of this region, given that this area is of great relevance for the *home range* of these animals, being a priority *locus* to the protection and conservation of a worldwide important biodiversity.

The findings of this investigation highlight the importance of marine mammals, as apex predators, in maintaining the ecological balance of marine ecosystems. The *Pontoporia blainvillei*, a threatened species that inhabits the coastal waters of the northern coast of Espírito Santo, is an exemplary case of the importance of these animals. However, this species faces numerous challenges, including bycatch in fishing nets, which is one of the main threats to its survival. Furthermore, the toxic sludge resulting from the rupture of the Mariana dam may exacerbate these threats, as it contains heavy metals such as mercury, arsenic, and lead,

which can accumulate in the tissues of marine mammals and affect their health and reproduction.

This situation is reminiscent of the environmental disaster caused by the Exxon Valdez oil tanker, which spilled approximately 41 million litres of oil into the Alaskan waters in 1989, resulting in one of the most significant environmental catastrophes in history. The company responsible for the tanker was required to pay billions of dollars in compensation and environmental repairs. It is essential that concrete measures are taken to protect this species and its habitats, including the implementation of sustainable fishing practices and the mitigation of the environmental impacts caused by the toxic sludge. Furthermore, it is necessary to review and strengthen Brazilian environmental legislation to reduce the risks of similar environmental impacts and protect the marine biodiversity of the region.

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