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Evaluation of seasonal anoxia in Florianópolis North Bay through environmental indicators

Abstract

Foraminifera, as single-celled organisms encased in shell-like structures known as tests, play pivotal roles within marine ecosystems. Their ubiquitous presence and fossilized remains provide invaluable insights into past environmental conditions. However, contemporary challenges posed by human activities imperil foraminiferal populations, notably through pollution-induced hypoxia, a condition characterized by oxygen depletion in aquatic environments.

This study focuses on utilizing foraminifera as bioindicators to assess hypoxia within Florianópolis's North Bay, situated in Brazil. Sediment samples collected in May and October 2014 served as the basis for this investigation. By analyzing both abiotic and biological data, the study uncovered concerning trends, including low oxygen levels and elevated organic matter content in the bay's sediments.

These environmental conditions create favorable habitats for opportunistic species such as *Ammonia tepida*, known for their resilience to fluctuating environmental parameters. Additionally, the presence of an invasive species, *Trochammina hadai*, further complicates the ecological dynamics of the bay. This invasive species, originally from San Francisco Bay and Japan, underscores the interconnectedness of marine ecosystems and the potential consequences of biological invasions.

The findings from this study shed light on the ecological imbalance within Florianópolis's North Bay, highlighting the urgent need for comprehensive management strategies. Addressing the root causes of pollution and hypoxia is paramount to safeguarding the bay's biodiversity and ecological health. Implementing effective conservation measures will be essential to ensure the long-term vitality of this marine ecosystem for future generations.

Keywords: sustainability, oxygenation, foraminifera, environmental indicators

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Introduction

Foraminifera, a group of unicellular organisms characterized by their shell-like structures called tests, play a crucial role in marine ecosystems. These organisms are widely distributed across all marine habitats, from shallow coastal waters to the deepest oceanic trenches, and their fossilized remains are abundant in sedimentary records. The tests of foraminifera, left behind after the organism's death, serve as valuable proxies for reconstructing past environmental conditions and understanding present-day ecological dynamics.

However, the health and abundance of foraminifera populations are increasingly threatened by various anthropogenic activities and environmental stressors. The discharge of natural and synthetic pollutants from human activities, such as the petroleum industry, heavy maritime traffic, and domestic sewage, poses significant risks to marine environments.[1] These pollutants can lead to water quality degradation, marine ecosystems' eutrophication, and ecological processes' disruption.

Industrial waste, in particular, contributes to the eutrophication of marine environments, leading to the proliferation of algal blooms and the depletion of oxygen levels, a phenomenon known as hypoxia. Hypoxic conditions can harm marine fauna and flora, including foraminifera, by reducing habitat suitability and causing population declines.[1] Furthermore, the ecological consequences of hypoxia extend beyond individual species, affecting entire food webs and ecosystem functioning.

In light of these challenges, using benthic foraminifera as bioindicators in environmental studies has become a valuable tool for assessing the health and integrity of marine ecosystems. Foraminifera are highly sensitive to changes in environmental conditions and can effectively integrate short- and long-term variations in their habitats.[1] By analyzing the composition and abundance of foraminiferal assemblages, researchers can identify patterns of environmental change, assess the impacts of anthropogenic disturbances, and inform conservation and management strategies.

Moreover, studies have shown that foraminifera exhibit differential responses to environmental stressors, making them valuable indicators of ecosystem resilience and vulnerability. By monitoring foraminiferal communities in regions affected by hypoxia and other forms of pollution, scientists can track the effectiveness of mitigation measures and prioritize conservation efforts to safeguard marine biodiversity.

In conclusion, foraminifera represent a valuable resource for region analysis and environmental monitoring in marine ecosystems. Their sensitivity to environmental changes and ability to serve as proxies for past conditions make them invaluable tools for studying the impacts of human activities on marine biodiversity and ecosystem functioning. By incorporating foraminiferal data into conservation and management practices, we can work towards preserving the health and integrity of marine environments for future generations. We intend to evaluate seasonal hypoxia and investigate the dynamics and quality of water bodies and the ecological health of the bottom sediment through environmental indicators in an environment that already suffers the pressures of tourism and urban activities.

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Methods

For hypoxia assessment, 29 sediment samples were collected from the North Bay (Baía Norte) of Florianópolis in the South of Brazil (Figure 1).

Figure 2 shows a detailed study area and samples, ten collected in May 2014 and 19 obtained in October 2014. The precise positioning of sampling stations was determined using GPS coordinates, with consideration given to the water depth chosen via an echo sounder.

Figure 1 Detailed study area.

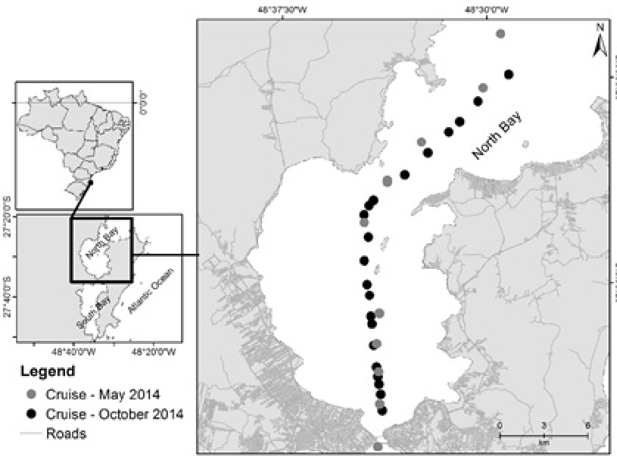

Figure 2 Study area and sampling stations.

Sediment sampling for the analysis of foraminiferal microfauna was conducted using a Van Veen bottom sampler. Upon collection, only the top layer of sediment (approximately the first centimeter) was extracted and carefully placed into jars containing a solution of Bengal Rose (1g/1000ml of alcohol). Bengal Rose stains the protoplasm of organisms alive at collection, while alcohol is added to prevent bacterial degradation.

Following collection, the sediment samples were dried in an oven. Subsequently, a portion of sediment (50cc) destined for microfauna analysis underwent sieving using two successive sieves with mesh sizes of 0.500 and 0.062 mm. After separation, foraminifera specimens were delicately transferred to unique black bottom slides using a brush for further analysis and species identification.

Species identification was carried out using a binocular magnifying glass equipped with a microcomputer, allowing for detailed examination and accurate classification of the foraminiferal specimens. This meticulous process ensured the thorough assessment and precise identification of species present within the sediment samples collected from the North Florianopolis North Bay, thereby contributing valuable data to evaluating hypoxic conditions in the region.

Results and discussions

Abiotic data

Tables 1 and 2 present the abiotic variables recorded during autumn and spring, respectively. In May, during the autumn season, the depth of the sampling locations ranged from 3.5 to 10.5 meters. Surface temperatures ranged from 20.8 to 23.3°C, while bottom temperatures ranged from 22.1 to 20.3°C. Salinity levels varied from 33.7 to 35.3 at the surface and from 33.14 to 35.8 at the bottom. Oxygen concentrations ranged from 4.7 to 6.7 at the surface and from 4.7 to 6.5 at the bottom. Additionally, surface pH exhibited variations from 6.8 to 7.91 (Table 1, Figure 2).

In October, corresponding to the spring season, the depth spanned from 3.18 to 18.7 meters. Surface temperatures ranged between 20.92 and 24.4°C, while bottom temperatures ranged from 20.9 to 23.4°C. Salinity levels ranged from 31.6 to 34.02 at the surface and from 32 to 34.96 at the bottom. Surface oxygen concentrations varied from 4.9 to 11.53, while bottom oxygen levels ranged from 1.78 to 9.67. Additionally, surface pH exhibited variations from 6.8 to 8 (Table 2, Figure 3).

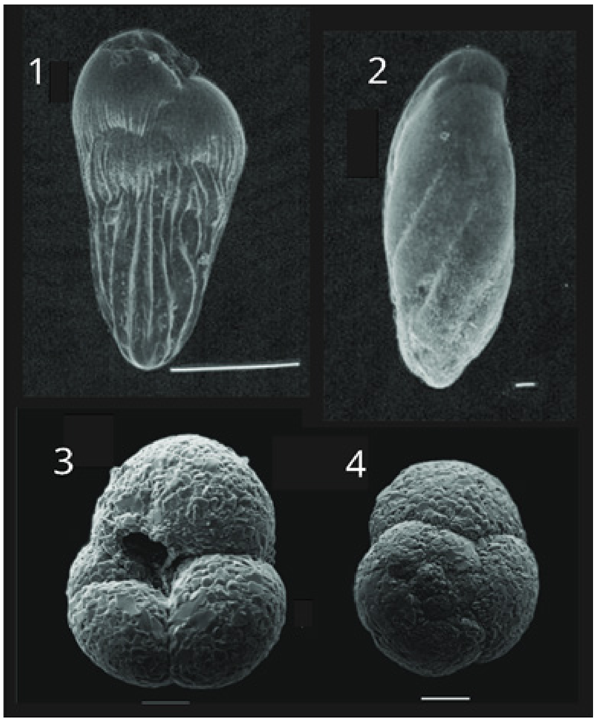

Figure 3 Three most significative bioindicators (1) *Bolivina striatula* (2) *Bulliminela elegantissima*, and the invasive species *Thochamina hadai* (3) ventral (4) dorsal. (scales: 1nm; 10nm, 100nm).

Biological data

Tables 3 and 4 present the foraminiferal species identified in sediment samples collected during autumn and spring. In May 2014, the predominant living species were *Buliminella elegantissima* (35.75%), *Ammonia tepida* (26.32%), *Bolivina striatula* (7.75%), *Elphidium sp* (6.95%), and *Pseudononion atlantico* (6.85%) (Table 3). *Buliminella elegantissima* and *Ammonia tepida* were consistently found in all samples, demonstrating their resilience to low oxygen levels and high organic matter concentrations. These species, along with Bolivina striatula, exhibit opportunistic traits, enabling them to thrive in environments with elevated concentrations of heavy metals, sewage, and household waste.

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Table 1 The abiotic variables, including latitude, longitude, depth, surface and bottom temperature, salinity, oxygen levels, and surface pH, were recorded during the autumn season (May)

North Bay (FLN) 05/18/2014	Latitude	Longitude	Depth (m)	Surface temp. (°c)	Bottom temp.	Surface Salinity	Bottom salinity	Surface O_2	Bottom O_2	Surface pH
1	27°36	48°31	7	21.8	22.1	33.7	33.61	4.7	4.7	7.42
2	27°34,445	48°33,93w	3.5	21.9	22.1	33.7	33.14	6.7	4.7	7.47
3	27°33,255	48°33,97w	4	21.8	22.1	33.7	35.56	6.5	4.7	7.43
4	27°32,2345	48°34,048w	3.4	20.8	21.79	33.35	33.39	6.3	6.3	7.64
5	27°31,1205	48°33,956w	3.6	21.6	21.79	33.75	33.39	6.6	6.2	7.64
6	27°31,1245	48°33,943w	3.7	23.3	21.9	33.75	34.6	6.1	6.5	7.56
7	27°27,8075	48°34,506w	7	22.1	21.8	34	34.4	6.6	6.2	6.8
8	27°26,3265	48°33,667w	10.5	21.4	20.8	34.2	34.8	6.6	6.2	7.59
9	27°26,2635	48°33,665w	8.6	21.9	20.8	34.8	34.9	6.6	6.2	7.54
10	27°24,8655	48°32,404w	8.9	21.3	20.3	34.9	35	6.7	6.2	7.91
11	27°22,8875	48°30,140w	9	21.6	21.4	35.2	35.3	6.5	6.2	7.6
12	27°20,9155	48°29,504w	9.1	21.4	21.2	35.3	35.8	6.6	6.2	7.67

Table 2 Abiotic variables latitude, longitude, depth, surface and bottom temperature, salinity, oxygen, and surface pH collected in spring (October)

North Bay (FLN) 10/20/2014	Latitude	Longitude	Depth (m)	Surface temp. (°c)	Bottom temp.	Surface Salinity	Bottom salinity	Surface O_2	Bottom O_2	Surface pH
1	27° 35,3995	48° 33'84	18.7	22.7	20.9	32.3	32.6	8.3	8.05	7.92
2	27° 58'20	48° 56'66	6.63	22.5	22.5	32.45	32.45	9.8	7.55	7.47
3	27° 57'07	48° 56'64	4.5	22.43	22.46	32.17	32.24	7.63	7.35	7.43
4	27° 33'44	48° 34'00	3.8	23.8	21.3	31.6	32	7.35	7.73	7.64
5	27° 33'09	48° 34'05	3.5	24	23.4	32.41	32.44	7.28	2.6	6.9
6	27° 32'30	48° 34'15	3.23	24	23.4	32.78	32.74	6.82	2.3	6.8
7	27° 31'52	48° 34'21	3.18	23.8	23	33.27	33.47	7.32	2.14	6.8
8	27° 31'23	48° 34'26	3.25	23.5	22.9	33.58	33.58	6.49	1.78	6.4
9	27°30'47	48° 34'31	3.5	23.4	22.8	33.62	33.62	4.9	4.68	7.1
10	27° 30'08	48° 34'40	4	24.4	23.1	33.64	33.64	4.83	4.81	7.2
11	27° 29'20	48° 34'50	4.76	23.5	23	33.53	33.63	5.05	4.32	7.1
12	27° 28'34	48° 34'35	5.59	24	23.2	33.69	33.56	7.85	7.04	7.67
13	27° 27'52	48° 34'51	7.13	23.4	22.9	33.61	33.43	7.26	7.18	7.3
14	27° 27'19	48° 34'33	8.73	22.7	23	33.59	33.69	8.08	6.1	7
15	27° 27'00	48° 34'16	9.92	22.9	22.7	33.77	33.66	7.62	7.35	7.54
16	27° 26'07	48° 33'01	11.39	22.7	22.5	33.9	33.99	8.04	8.5	7.91
17	27° 25'26	48° 32'16	9.04	22.7	22.4	33.87	34.24	9.2	9.67	7.6
18	27° 24'50	48° 31'40	9.63	22.1	22.2	33.89	34.71	8.21	8.37	7.67
19	27° 24'13	48° 31'00	10.25	22.3	22.3	34.01	34.96	8.49	8.47	8
20	27° 23,38	48° 30'33	10.25	22.8	22.1	34.02	34.83	11.53	8.32	7.6
21	27° 22'40	48° 29'20	9.36	20.92	22.13	33.89	34.71	11	8.1	7.67

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Table 3 Foraminiferal species from sediment collected in autumn (May)

Species Autumn (May) / number of individuals	1	3	4	5	6	7	8	9	10	11	Absolute frequency	Relative frequency
Ammonia rolshauseni								7		12	19	1.89
Ammonia tepida	44	38	5	31	23	26	20	35	31	12	265	**26.32**
Buliminella elegantissima	42	58	18	33	26	46	41	36	39	21	360	**35.75**
Hanzawaia boueana										2	2	0.20
Haynesina germanica	1								1	1	3	0.30
Elphidium sp.	12	1		3	3	10	22	6	3	10	70	**6.95**
Pseud. atlanticum	2				5		5	16	15	26	69	**6.85**
Buccella peruviana	1				1					2	4	0.40
Bulimina sp.		1									1	0.10
Bulimina marginata									2	6	8	0.79
Bulimina pulchella					1						1	0.10
Bolivina striatula	8		1	1	23	1	10	15	9	10	78	**7.75**
Quinqueloculina patagonica	3									2	5	0.50
Trochammina inflata	2	1	38	14		8		2	2		67	**6.65**
Trochammina hadai		7	7	18	9	2	1		2		46	**4.57**
Gaudryina exillis			1								1	0.10
Paratrochammina Clossi					1						1	0.10
Fissurina lucida					1		2			2	5	0.50
Lagena striata								1	1		2	0.20
Total	115	106	70	100	93	93	101	118	105	106	1007	100.00

Source: The authors, 2019.

In October 2014, the predominant species observed were *Buliminela elegantissima* (32.27%), *Ammonia tepida* (31.95%), *Elphidium sp* (15.16%), *Bolivina striatula* (7.03%), and *Trochammina inflata* (3.51%) (**Table 4**). This month exhibited lower oxygen values and higher concentrations of organic matter compared to May 2014, indicating potentially more stressed environmental conditions.

It's important to highlight that the October 2014 samples revealed the presence of an invasive species, *Trochammina hadai*, comprising 4.57% in autumn and 3.19% in spring of the total assemblage. We posit that fluctuations in oxygen levels accompanying this recent colonization have impacted the ecological dominance of this benthic community. This finding corroborates previous evidence of *Trochammina hadai*'s introduction to Brazil and subsequent spread to various estuarine and coastal zones, where it exerts influence on native fauna.

The analysis of foraminiferal species abundance among samples collected in May 2014 revealed the following descending order of significance: *Bulliminela elegantíssima* (35.75%), *Ammonia tepida* (26.32%), *Bolivina striatula* (7.75%), *Elphidium* sp (6.95%), and *Pseudononion Atlantic* (6.85%). Notably, *Bulliminela elegantíssima* and *Ammonia tepida* were consistently present in all samples. These species' prevalence suggests environmental conditions characterized by low oxygen levels and high concentrations of organic matter, likely of both natural and anthropogenic origins. *Ammonia tepida*, recognized as an opportunistic species, exhibits a remarkable capacity to tolerate environmental fluctuations that may challenge other species' survival, as supported by various studies.[1–4] Additionally, *Ammonia tepida* demonstrates resilience to elevated concentrations of heavy metals, sewage, and household waste, as evidenced by research findings.[5–8]

In contrast, the samples collected in October 2014 exhibited a similar trend, with *Bulliminela elegantissima* (32.27%), *Ammonia tepida* (31.95%), *Elphidium* sp (15.16%), *Bolivina striatula* (7.03%), and *Trochammina inflata* (3.51%) emerging as the most significant species in descending order. Despite the persistence of low oxygen levels and high concentrations of organic matter compared to May 2014, some species composition variations occurred. An invasive species from San Francisco Bay and Japan, *Trochammina hadai* (McGann, 2014), representing 3.19% of the total assemblage, was identified in the October 2014 samples. Introducing an invasive species adds complexity to the ecological dynamics of the Florianopolis North Bay. It may have implications for native species interactions and ecosystem processes since these agglutinated foraminifera *Trochammina hadai*´s have first appearance in the Brazilian coastal waters of Flamengo Inlet, Ubatuba, São Paulo State in 2010.[9] By 2014 and 2015, the species was found alive at this place in 78% of the samples, with relative abundance reaching 18%. Eichler et al.[9] (op. cit) have suggested this recent colonization was most likely the result of an introduction by anchor mud on commercial fishing boats and recreational vessels or from fishing bait, and the species proliferation due to its suitability to live in anthropogenically-induced stressed environmental conditions of the inlet that has affected the ecological dominance of this benthic community. The three most significative bioindicators are illustrated in Figure 3: *Bulliminela elegantissima*, *Bolivina striatula*, and *Trochammina hadai*.

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These findings underscore the importance of monitoring foraminiferal communities as bioindicators of environmental health and ecosystem integrity. The dominance of opportunistic species like Ammonia tepida highlights the ecological resilience of foraminifera in response to anthropogenic disturbances. Continued research efforts are crucial for better understanding the long-term impacts of environmental changes and invasive species introductions on marine ecosystems.[10–12]

Conclusion

Given the collections made in several points of the North Florianopolis North Bay and the significant presence of specific bioindicators such as *Bulliminela elegantissima* and *Bolivina striatula*, low concentrations of oxygen and high concentrations of organic matter are identified in the place, which may be caused by anthropogenic influences in the environment.

This low oxygenation and the high content of organic matter in the sediments is a favorable environment for the occurrence of the invasive species *Trochammina hadai*. The widespread presence of *Bulliminela elegantissima* and *Bolivina striatula*, both known bioindicators of environmental stress, suggests significant ecological imbalances within the bay ecosystem.

The observed low oxygen levels and elevated organic matter content point towards potential anthropogenic impacts, likely stemming from urbanization, industrialization, and agricultural runoff in the surrounding areas. These human-induced factors can contribute to the degradation of water quality and the alteration of sediment characteristics, creating favorable conditions for the proliferation of invasive species like *Trochammina hadai*.

The presence of *Trochammina hadai* in such environments underscores the vulnerability of ecosystems to biological invasions, highlighting the need for comprehensive management strategies to mitigate the spread of invasive species and preserve native biodiversity.

Furthermore, identifying specific bioindicators like *Bulliminela elegantissima* and *Bolivina striatula* serves as valuable indicators of ecosystem health, providing crucial insights into the overall environmental conditions and potential stressors affecting the Florianópolis North Bay.

Addressing the root causes of environmental degradation, including pollution and habitat destruction, is essential for promoting the resilience and sustainability of marine ecosystems, safeguarding their ecological integrity for future generations.

In conclusion, the findings from the collections in the Florianopolis North Bay underscore the complex interplay between natural processes and human activities in shaping coastal ecosystems. Effective conservation and management efforts are imperative to address the bay's environmental challenges and ensure its long-term health and vitality.

Given the collections made in several points of the Florianopolis North Bay and the large presence of specific bioindicators such as *Buliminela elegantissima* and *Bolivina striatula*, low concentrations of oxygen and high concentrations of organic matter are identified in the place, which may be caused by anthropogenic influences in the environment. This low oxygenation and the high content of organic matter in the sediments is a favorable environment for the occurrence of the invasive species *Trochammina hadai*.

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Conflicts of interest

The author declares that there are no conflicts of interest.

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