DISTRIBUTION OF FORAMINIFERA IN SURFACE SEDIMENTS OF SEGARA ANAKAN LAGOON, CENTRAL JAVA: ITS RELATION TO HEAVY METAL POLLUTION AND ENVIRONMENTAL STRESS

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ABSTRACT

Twenty surface sediments samples from the Segara Anakan Lagoon at the south coast of Java have been used for a study of foraminiferal abundance and morphology in relation to environmental stress. There are three major factors causing environmental stress to the fauna and flora of Segara Anakan Lagoon: strong tidal currents, high inputs of lithogenic material, and high contents of heavy metals. The objective of this study is to investigate the response of the foraminifera to these factors. The results of the paper show that the population and diversity of foraminifera in Segara Anakan Lagoon is very low. The population only consists of ten species. Only one species, Ammonia beccarii, appears as in situ species. This species is low in abundance and shows restricted spatial distribution. One of the specimens shows an abnormal test in that one of its chambers is reduced. This abnormality can be related to the environmental stress prevalent in the ecosystem of Segara Anakan Lagoon.

SARI

Dua puluh percontoh sedimen permukaan dari Laguna Segara Anakan, Pantai Selatan Jawa telah digunakan untuk studi kelimpahan dan morfologi foraminifera dalam kaitannya dengan tekanan lingkungan. Ada tiga faktor utama yang sangat berpengaruh terhadap flora dan fauna di Laguna Segara Anakan, yaitu pasang surut, akumulasi material dan kandungan logam berat yang sangat tinggi. Tujuan dari studi ini adalah untuk mengetahui respon foraminifera terhadap faktor-faktor tersebut. Hasil studi menunjukkan bahwa populasi dan keanekaragaman foraminifera, khususnya bentonik sangat rendah, terdiri dari 10 spesies. Hanya satu spesies, *Ammonia beccarii,* dinyatakan sebagai spesies *in situ* yang mempunyai kelimpahan rendah serta sebaran yang tidak merata. Salah satu spesimen memperlihatkan gejala abnormalitas, yaitu penciutan salah satu kamarnya. Gejala abnormalitas ini dapat dikatakan berkaitan dengan adanya tekanan lingkungan dalam ekosistem di Laguna Segara Anakan.

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INTRODUCTION

The Segara Anakan Lagoon is an estuary of many rivers. The two biggest rivers are the Citanduy and Cibeureum rivers, which carry and distribute material from land. The lagoon is separated from the Indian Ocean by a barrier island, Nusakambangan Island. There are three major factors, which influence the ecosystem of the Segara Anakan Lagoon: strong tidal currents, high inputs of lithogenic material, and high contents of heavy metals (Sarmili, *et al*, 2000).

Firstly, the tidal current system influences the ecosystem because of the narrow openings of Nusakambangan Barrier Island. These openings are located at the eastern and western end of the barrier island. They connect the lagoon with the Indian Ocean (Datun, 1981).

Secondly, the lagoon is characterized by high sedimentation rates, which are mainly caused by transport of lithogenic material by the Citanduy and Cibeureum rivers. This material cannot reach the open ocean because Nusakambangan Island blocks the transport ways. Consequently, the material is accumulated at the bottom of the lagoon, which has caused the lagoon to become shallower (Sarmili, *et al*, 2000).

Lastly, the water of the lagoon shows high concentrations of heavy metals, especially cadmium (Ca), chromium (Cr), copper (Cu), and lead (Pb). In fact, the concentration of Cd, Cr, and Cu in the study area are higher than in the Cilacap waters (eastern part of the study area) and the Jakarta Bay, which are well known as polluted environments. This contamination can be caused by the activities of industrial ships around the lagoon, which use preservative woods, and also from agriculture around the lagoon (Sarmili, *et al*, 2000; Sarmili, 2001). The concentration of Pb is still lower than Jakarta Bay, but it is higher than in other lagoons and bays in Indonesia (Sarmili, 2001). Cd, Cr, and Pb are poisoning for plants, animals, and also for human beings. Cd is the most poisoning element after mercury (Hutagalung and Hamidah, 1982, in Djatin and Muhartoyo, 1986). The order of heavy metals from the most poisoning is $Hg^{2+} > Cd^{2+} > Ni^{2+} > As^{2+} > Cr^{2+} > Cr^{2+} > Sn^{2+} > Zn^{2+}$(NAS in Waldichuk, 1974, in Hutagalung, 1991). In the study area, Pb is mainly derived from the oil refinery (Lacerda, 1994; Sarmili, 2001). Pb is considered to be the most toxic heavy metal for the benthic community (Lacerda, 1994). Furthermore, the nutrient content (total organic carbon) in the lagoon is relatively low because of the influence of the tides and the high sedimentation rate in the study area (Kastanja, 2001).

The three factors mentioned above form considerable stress for the ecosystem of the Segara Anakan Lagoon, including foraminifera as an element of the benthic community. The knowledge of the influence of these factors on the development of the foraminiferal population is of importance to biologists and paleontologists (Gustafsson and Nordberg, 1999).

Foraminifera, especially benthic forms, are very sensitive to the change of environmental factors, because of their good response to changes in environmental conditions, including heavy metal pollution. Consequently, they are good environmental bioindicators. Benthic foraminifera have been investigated as bioindicators in polluted environments by scientists for almost three decades, These scientists concluded that in a polluted estuary the benthic foraminiferal population will decrease, and some species will show abnormalities in their test morphology (Nagy and Alve, 1987; Alve, 1991; Sharifi, *et al*, 1991; Yanko, *et al*, 1994; Rositasari, 1996; Rositasari and Rahayuningsih, 2000).

Furthermore, in water polluted by heavy metals, shallow-water foraminifera would move to the deeper parts in order to avoid the environmental stress caused by the pollution (Alve, 1991).

In this paper we have studied the foraminiferal distribution and the morphology of foraminiferal tests to show how foraminifera respond to environmental stress in the water of the Segara Anakan Lagoon. The study shows that the foraminiferal distribution and the test morphology can be used as indicators of environmental pollution in the lagoon. The results of this paper have wider applicability as they may be used in the study of environmental conditions in other lagoons in the area.

METHODS

Twenty surface sediments were collected by using grab sampler from water depths up to five meters (Fig.1). Foraminiferal analysis was done by separating the specimens from the sediment particles (picking) from the washed residue (larger than 63 μm). Each species was identified under a binocular microscope and given a name down to the species level with reference to Barker, 1960; Phleger, 1960; Postuma, 1971; Bolli and Saunders, 1985; van Marle, 1991; Yassini and Jones, 1995. Quantitative analysis is performed to obtain the number of specimen of each species in each sample.

Furthermore, we analyzed the number of specimen of each species per 1 g of dry weight in each sample. Then the benthic foraminifera is correlated with the distribution of heavy metal contents using Correlative Analysis by Pearson (Walpole, 1993; Santoso, 2000).

RESULTS

In general, the abundances of both benthic and planktonic foraminifera are very rare (less than 3.18% of 1 g of sediments) in the study area. Foraminifera are found in only nine of twenty samples studied, which are concentrated in the eastern and western parts of the study area. In the eastern part, planktonic foraminifera account for only 3.18% of 1 g dry weight of sediments. The samples consist of ten genera and twenty-two species and are dominated by *Orbulina universa.* As with the eastern part, *Orbulina universa* dominates with 1.29% of 1 g dry weight in the western part of the study area (Fig. 2).

The benthic foraminifera consist of ten species and they are found in only six samples (Fig. 3). In the eastern part, benthic foraminifera account for 3.18% of 1 g dry weight of sediments. They are dominated by *Ammonia beccarii.* In the western part, benthic foraminifera account for 2.59% of 1 g dry weight of sediment. They are also dominated by *Ammonia beccarii.* In one sample in the western part, there is one specimen of *Ammonia beccarii* showing abnormal test morphology, in the form of the reduction of one of its chambers (Fig. 4).

All planktonic foraminifera found in the Segara Anakan Lagoon can be classified as reworked fossils. It is based on the occurrence of an assemblage of planktonic species including *Globigerina bulloides, Globigerina nepenthes, Globoquadrina altispira, Globigerinoides immaturus, Sphaeroidinella subdehiscens, Orbulina universa, Globorotalia acostaensis,* and *Globorotalia siakensis*. This assemblage is similar to that of the zones N3 (Early Miocene) to Recent in the formations of sedimentary rocks in the catchment area of the lagoon (Blow, 1969, zonal scheme in Postuma, 1971). Furthermore, the foraminiferal assemblages are typical of the Early Miocene to

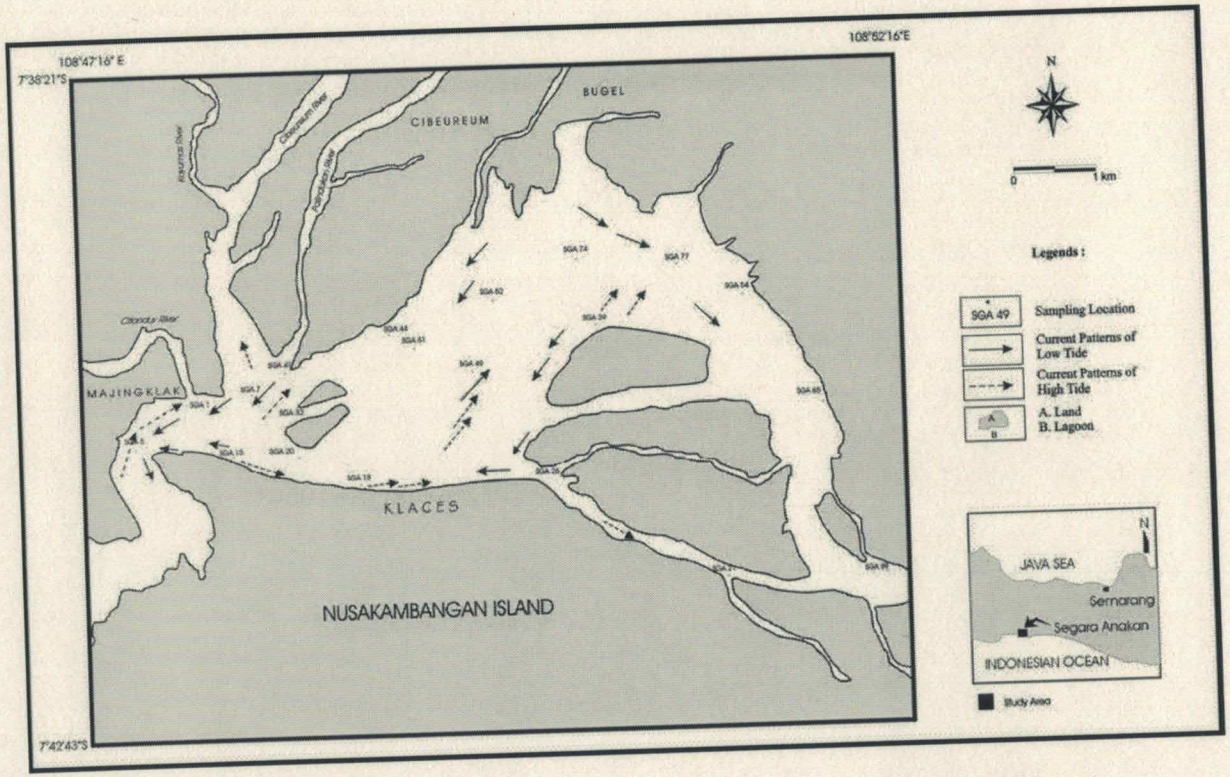


Fig 1. Map of Sampling Location and Current Pattern at Segara Anakan Lagoon, Cilacap, Central Java (Modified after Sarmili, *et al.*, 2000)

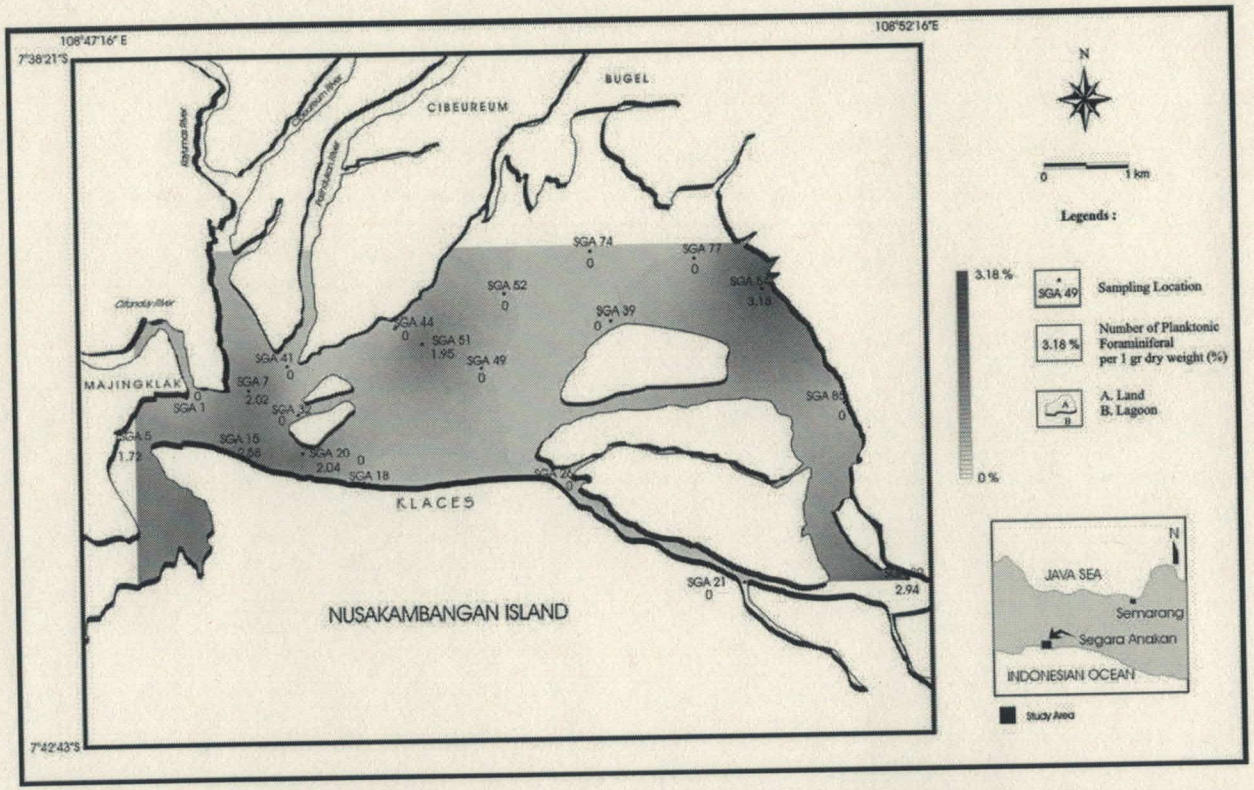


Fig 2. Distribution Map of Planktonic Foraminifera at Segara Anakan Lagoon, Cilacap, Central Java

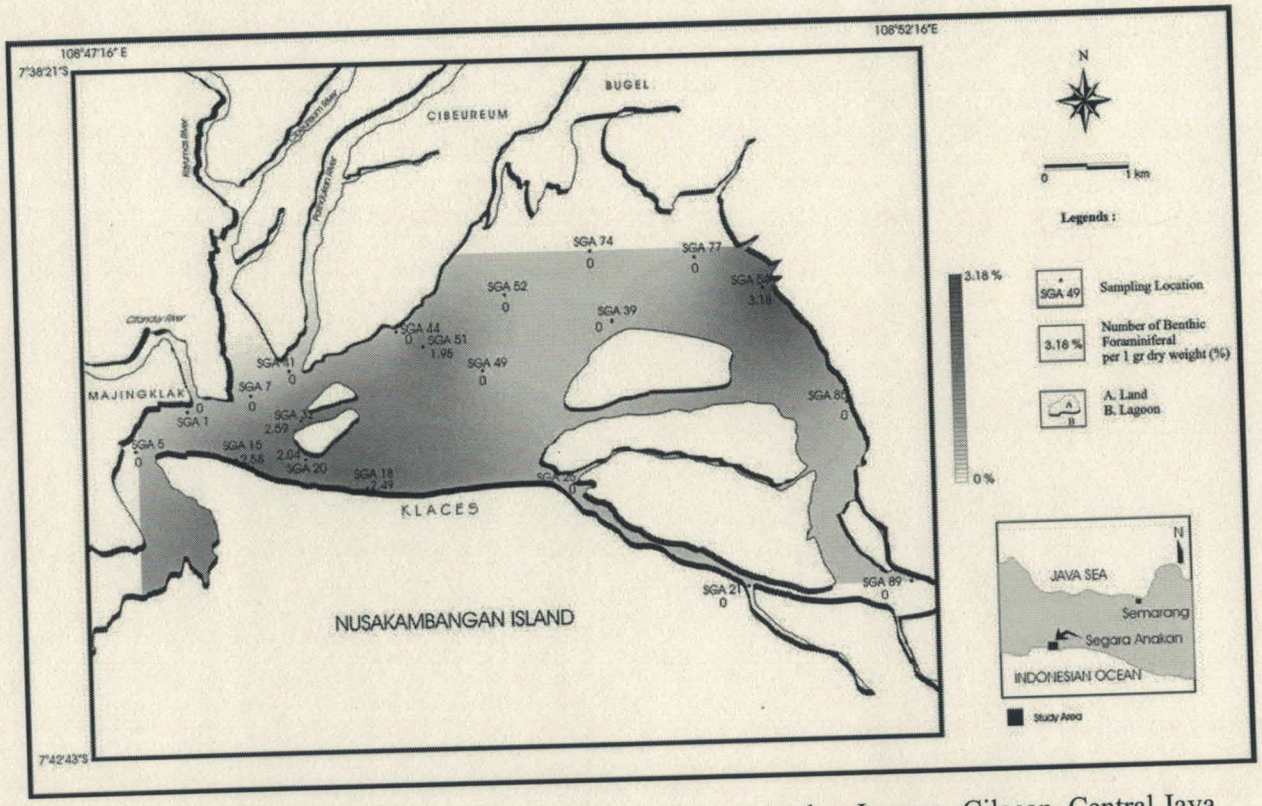
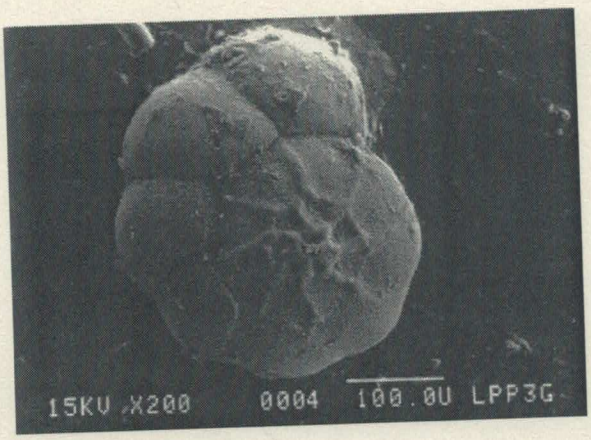


Fig 3. Distribution Map of Benthic Foraminifera at Segara Anakan Lagoon, Cilacap, Central Java

A)



B)

Figure 4. A) *Ammonia beccarii* in normal condition (Photo courtesy: Auliaherliaty, 2001)
B) *Ammonia beccarii* in abnormal condition (Reduction one of its chambers)

Recent in West Java Basin are also characterized by these planktonic foraminifera (Pringgoprawiro, *et al*, 1978). Some species found in the sediments of this study show a relative age to Recent age, although as Recent specimens, they will not be able to live in shallow-water. Therefore, it can be assumed that all planktonic specimens are classified as reworked fossils.

Except for *Ammonia beccarii,* all species of benthic foraminifera are also reworked fossils, because they are all typical of deep-water environments. *Ammonia beccarii* is the only one which lives in the Segara Anakan Lagoon. It has a very low abundance (2.41% - 2.49%). Its highest abundance is in two samples in the western part, SGA 15 and SGA 18 (Fig. 3).

The abundance of *Ammonia beccarii* per 1 g sample of dry weight shows no significant correlation with the contents of Cd (0.221), Cr (0.314), Cu (0.232) and Pb (0.029).

DISCUSSION

The eastern part of the study area is very suitable for the accumulation of foraminifera and other materials because this area is more protected. The area is the farthest from the ocean and the rivers, Consequently, the current is rather weak, despite of there being a small connection in the southeast that links the lagoon with the ocean. This connection, however, is very narrow. Furthermore, the connection is partially blocked by sand bars (Fig.1) which have been accumulated as a result of the growth of mangroves.

Foraminifera have also been accumulated in the western part, where the rivers and the ocean meet. Two big rivers, the Cibeureum and Citanduy rivers, enter the lagoon in the western part, near the inlet of the ocean. The material supplied by the rivers is accumulated in this area.

Only *Ammonia beccarii* can live and survive in the Segara Anakan Lagoon, although with low abundance. *Ammonia beccarii* is cosmopolitan species typically dwelling in littoral and neritic environments, and indicative of estuarine environments (Debenay, *et al*, 1998; Rositasari, 2000). The species can adapt well to changes of environmental factors because of their simple body structure and short living cycle (Rositasari, 1997b). It generally shows great abundance and wide geographic distribution. Consequently, it is very important for environmental and geological studies.

One way of adaptation of the species to environmental change is a variation of the species morphology to the degree of abnormality (Nagy and Alve, 1987; Alve, 1991; Sharifi, *et al*, 1991; Goldstein and Moodley, 1993; Yanko, *et al*, 1994; Rositasari, 1997a; 1997b; 2000; Debenay, *et al*, 1998; Rositasari and Rahayuningsih. Many scientists have investigated the abnormality of *Ammonia beccarii* and have suggested that the occurrence of abnormality is caused by heavy metal pollution (Nagy and Alve, 1987; Alve, 1991; Sharifi, *et al*, 1991; Yanko, *et al*, 1994; Rositasari, 1997a; 2000). The conclusion is that there are seven different modes of abnormality (deformation) such as: (1) double apertures, (2) reduced size of one or more chambers, (3) protuberances on one or more chambers, (4) twisted or distorted chamber arrangement, (5) enlarged apertures, (6) aberrant chamber shape, and (7) twinned forms. The finding of an abnormality in the test morphology, in the form of a reduced chamber, of one specimen shows that there are environmental stress factors prevalent in the Segara Anakan Lagoon. Also, as *Ammonia beccarii* is one of the three species besides *Elphidium excavatum* and *Haynesina germanica* that can usually adapt to heavy metal pollution (Sharifi, *et al*, 1991), the

abnormality suggests that levels of heavy metal pollution are rather high in the lagoon.

However, it can be concluded that there are two other factors besides heavy metal contamination that may cause test deformations (Geslin, *et al*, 1998). These factors are a change of physical and chemical parameters and a shortage of nutrients in the environment. Consequently, another cause of this abnormality could be a change of physical parameters. Such a change is a common process in the lagoon due to its location which is influenced by both saline and fresh water inputs. The abnormality can also be caused by low nutrient levels in the Segara Anakan Lagoon, which are caused by the tides and the high sedimentation rate (Kastanja, 2001).

It has been shown that environmental stress does not only affect the morphology of the test but also affects foraminifera by decreasing their population and diversity (Nagy and Alve, 1987; Alve, 1991; Rositasari, 1993; 1996; 2000; Rositasari and Rahayuningsih, 2000). A low population in a polluted lagoon is caused by the migration of some species to a better living environment (Alve, 1991). Although *Ammonia beccarii* is a cosmopolitan species, it has almost been terminated in the lagoon. Consequently, the low abundance of this species shows that the levels of environmental stress must be very high in the Segara Anakan Lagoon.

The correlation coefficients of heavy metals contents with the distribution of *Ammonia beccarii* are very low and show a negative index. However, as the correlation is not significant, tidal currents and high sedimentation rates due to river input are the biggest factors affecting the distribution of foraminifera. The high levels of heavy metal contents in the lagoon are likely to have affected the test morphology of *Ammonia beccarii,* as shown by the abnormality of a reduced chamber in one specimen from the western part of the study area.

CONCLUSION

In the Segara Anakan Lagoon, the abundance of specimen and species of foraminifera are very low. Considering that *Ammonia beccarii* is the only species that can live and survive in the area, we conclude that Segara Anakan Lagoon offers a living conditions of low quality for foraminifera because of environmental stress. The main factors that affect the distribution of foraminifera are tidal currents and high sediment inputs from rivers. This is proven by the occurrence of specimens that are concentrated in small locations in the eastern and western part of the study area. High sedimentation rates in the lagoon make it impossible for foraminifera to develop. As the sedimentation rates in the study area are very high, it is difficult to show a relationship between environmental factors, especially heavy metals contents, and the biotic community. This is because the sedimentation also controls the accumulation of heavy metals. High sedimentation rates results in high concentrations of heavy metals in the lagoon because the main source of heavy metals are fluvial inputs (Lacerda, 1994).

Heavy metal pollution also affects the population of foraminifera in the lagoon. Although the correlation coefficients of the heavy metal contents with the distribution of foraminifera are very low, they are likely to have affected the morphology of *Ammonia beccarii.* In contrast, a change in physical parameters and low nutrients levels are not considered to have affected the morphology. An abnormal morphology is one of the ways for *Ammonia beccarii* to respond to environmental stress. However, the species will disappear if environmental stress increases.

In order to better understand the natural development of the lagoon it is essential to study sediment cores for foraminiferal distribution. Also, heavy metal contents in deeper sediment horizons may allow to be obtained background levels of both biotic and abiotic environmental factors. The chemical analysis of foraminiferal tests is also recommended. Moreover, a larger number of surface samples needs to be investigated.

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