Analysis of Sedimentation and Salinity Changes in the Coastal Mangrove Forest of Pasarbanggi, Rembang using Sediment Core and Diatom

Dianti[1], Tri Retnaningsih Soeprobowati[2] , Anis Kurniasih[3]

{dianti0025@gmail.com[1] , trsoeprobowati@live.undip.ac.id[2] , anis.kurniasih@live.undip.ac.id[3] }

Department of Geological Engineering, Diponegoro University, Jl. Prof Soedarto SH, Semarang 50275[1]

School of Postgraduate Studies, Diponegoro University, Jl. Imam Bardjo SH, Semarang 50241[2]

Department of Geological Engineering, Diponegoro University, Jl. Prof Soedarto SH, Semarang, 50275[3]

Abstract. The coastal area of Pasarbanggi, Rembang Regency is a mangrove estuary with dynamic sedimentation and ecological processes. This study was conducted to examine the sedimentation and salinity changes using diatoms contained in 50 cm sediment cores. The core divided in 5 cm intervals and processed with digestion, identification and enumeration to determine the changes of diatom habitat zone. The result are: Zone 1 (0-15 cm) dominated by brackish diatom identified in the clay and sand layers intercalation, indicating the influence by tides; Zone 2 (15-50 cm) dominated by freshwater diatoms contained in the thick clay and sand layers with a small amount of organic matter, indicating the influence of freshwater. Therefore, it can be seen that the influence of sea water is increasing over time. Thus, sustainable environmental management is needed, one of which is the preservation of mangrove forests in the coastal area.

Keywords: diatoms, estuary, mangrove, Pasarbanggi, sedimentation

1 Introduction

Coastal areas are included in the transition zone with very dynamic characteristics compared to other environmental systems due to the combined influence of the land and sea environment, so that this area has distinctive fluctuative characteristics and changes its environmental conditions and configuration more frequently over a relatively short period of time [1]. These fluctuative conditions also change the depositional environment and morphology of the coast itself, as happened in the research area located in the Jembatan Merah Mangrove Forest area of Pasarbanggi, Rembang Regency. Rembang regency itself, particularly in its coastal area has very dynamic sedimentation, causing changes to the coastline due to repeated abrasion and accretion processes [2]. Regionally, the northern coast

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of Rembang Regency in the last few decades has experienced accretion due to increased sedimentation that caused the sea lines to retreat relatively and the coastal land area expanded to 6,441 km^2 [3]. The diverse characteristics of the coastal in Rembang also play a role, where on the west coast and its morphology is in the form of a bay, the accretion process is more dominant, contrary to the east coast when the abrasion process is more influental because its steeper and rockier characteristic [4]. This dynamic coastal deposition certainly have further impacts, not only to the surrounding ecology, but also to the people who depend their livelihood from the sea. So, it is necessary to understand a deeper and broader study regarding the environmental and depositional changes that occur in Rembang, one of which is through diatoms.

Diatom is one of the ideal ecological bioindicators because each species has a special habitat niche and is sensitive to changes in environmental parameters such as salinity, temperature and pH [5]. The presence of frustule that is resistant because of silica content also makes diatoms can be preserved well in most sediments [6]. Thus, the changes in the community and diatom species can also be recorded in the sediment, as seen from the diatom frustule assemblage preserved in the sediment. Therefore, diatoms can be used to reconstruct changes in habitat, environment and depositional conditions in the research area.

The research was conducted by sediment core sampling methods and quantitative analysis to calculate the abundance and stratigraphy of diatom species in the sediment. The aim of this research is to examine and reconstruct the environmental and depositional changes in the Pasarbanggi coastal area based on the correlation of diatom abundance and sediment lithology with the salinity habitat zones of the diatom species found.

2 Materials and Methods

2.1 Sampling

The research was conducted in the mangrove forest area of Jembatan Merah, Pasarbanggi, Rembang Regency, which is also an estuary located on the north coast of Java as seen in **Fig. 1.** In terms of physiography and regional geology, the study area is included in the North Coastal Alluvial Plain area whose lithology is composed of alluvium and Holocene-age coastal surface deposits such as gravel, sand and mud. One sediment core sample with a length of 50 cm was taken at coordinates 542856 E 9259553 N (Site 6) with surface water depth of about 30 cm using D-Section Corer. In addition, water quality measurements were also carried out using a Horiba Multi-Parameter Water Quality Checker to measure the temperature, pH, and salinity of the water at the time.

2.2 Laboratory Analysis

Sample were divided into 5 intervals plus 1 cm surface sediment core to be processed through laboratory analysis including digestion, heating and centrifugation to separate the diatom fossils from sedimentary materials. This separation is done by mixing the subsampled sediments with a hydrochloric acid (HCl) and hydrogen peroxide (H_2O_2). The solution is then heated and centrifuged with distilled water continuously until the pH was neutral. Diatom frustules that have been separated are then mounted and observed under an optical microscope with 100 times magnification and minimum requirement of 300 frustules found [7].

2.3 Data Analysis

Data analysis was carried out with the PAST (Palentological Statistics) program version 4.08 [8], to determine the division of diatom clusters which were then visualized using C2 version 1.8 [9], to show the biostratigraphy of each diatom species based on its relative abundance.

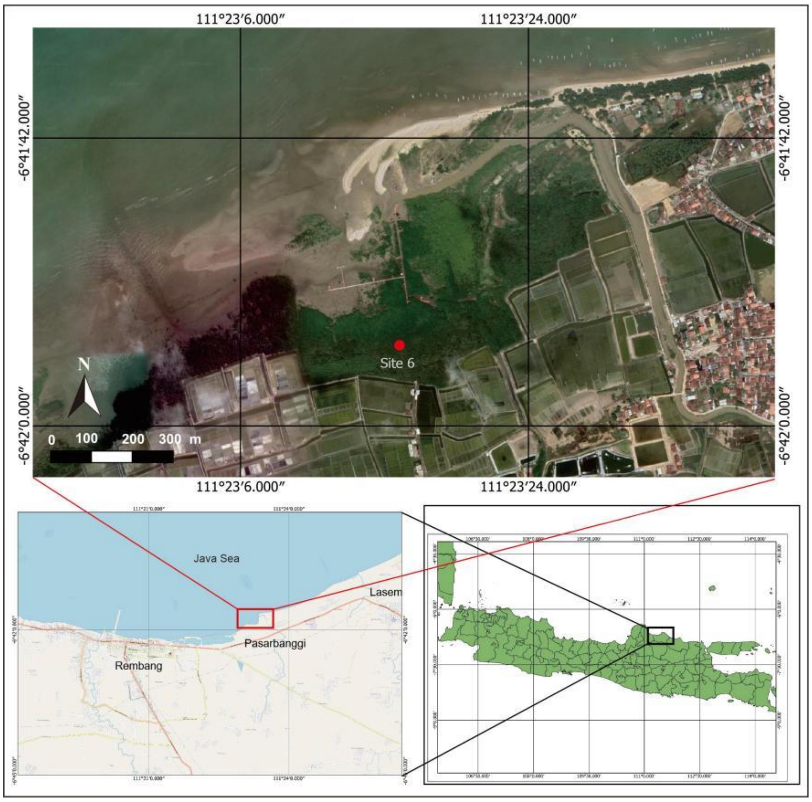
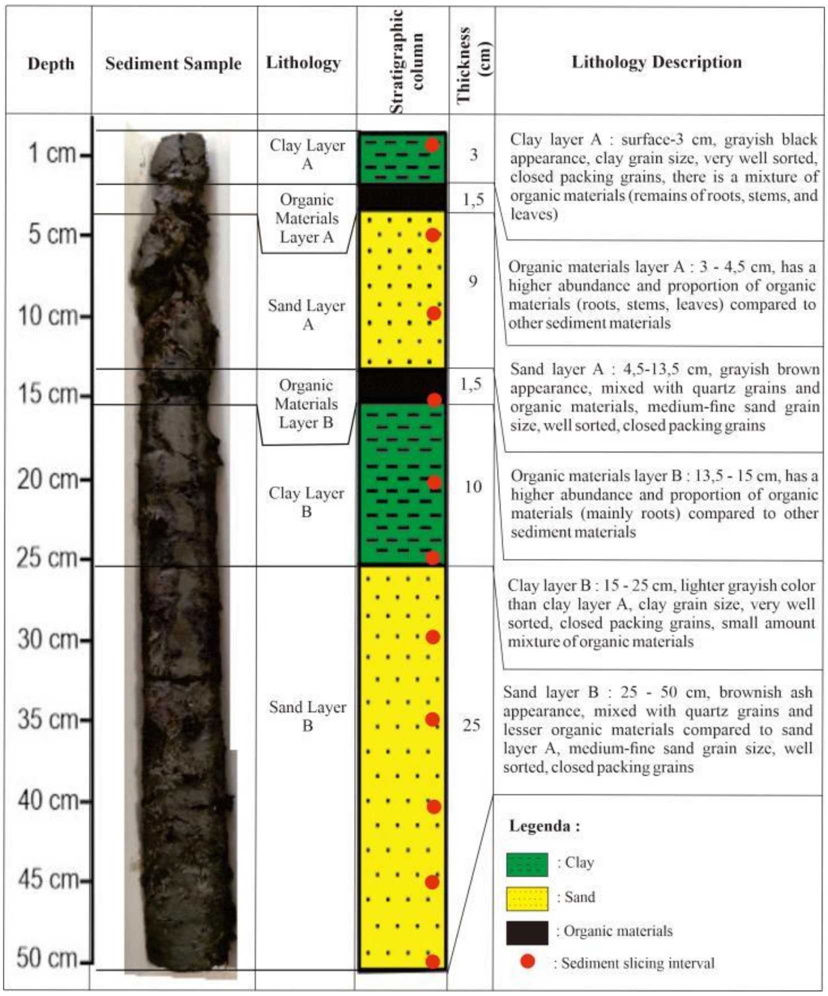


Fig. 1. Map of the research locations and sediment sampling in Site 6

3 Results and Discussions

3.1 Lithology Description of Sediment Core Sample

Based on the observation of texture and composition, the sediment core sample consists of clay, sand, and organic material layers such as roots and plant remains that also deposited as seen in **Fig. 2**.



Clay layer A : surface-3 cm, grayish black appearance, clay grain size, very well sorted, closed packing grains, there is a mixture of organic materials (remains of roots, stems, and leaves)

Organic materials layer A : 3 - 4,5 cm, has a higher abundance and proportion of organic materials (roots, stems, leaves) compared to other sediment materials

Sand layer A : 4,5-13,5 cm, grayish brown appearance, mixed with quartz grains and organic materials, medium-fine sand grain size, well sorted, closed packing grains

Organic materials layer B : 13,5 - 15 cm, has a higher abundance and proportion of organic materials (mainly roots) compared to other sediment materials

Clay layer B : 15 - 25 cm, lighter grayish color than clay layer A, clay grain size, very well sorted, closed packing grains, small amount mixture of organic materials

Sand layer B : 25 - 50 cm, brownish ash appearance, mixed with quartz grains and lesser organic materials compared to sand layer A, medium-fine sand grain size, well sorted, closed packing grains

Fig. 2. Lithologic description of sediment core sample

Clay layer A composes the surface to a depth of 3 cm of the sediment core sample. This layer has a grayish black appearance with clay grain size, very well sorted and closed packing due to uniform grain size, there is also a mixture of organic material in the form of the remains of roots, stems and leaves.

Organic material layer A is found at a depth of 3 cm to 4.5 cm with a thickness of 1.5 cm. This layer of organic material consists of plant remains in the form of roots, stems and leaves that have been deposited within sediments with a higher abundance and proportion compared to other sedimentary materials.

Sand layer A with a thickness of 9 cm is composed of sand mixed with quartz grains and organic material in the form of plant roots with the appearance of grayish brown, medium-fine sand grain size, well sorting and closed packing.

Organic material layer B is composed of plant remains similar to organic material layer A but dominated by abundant plant roots compared to other sedimentary material. This layer is 1.5 cm thick and comprises the sediment core from 13.5 cm to 15 cm deep.

Clay layer B has a thickness of 10 cm with a lighter grayish color appearance compared to clay layer A. This layer has a mixture of organic material but a small amount, clay grain size with very well sorted and closed packing

Sand layer B as the last layer has the greatest thickness of 25 cm. The appearance is brownish ash in color, the grain size is medium-fine sand, well sorted and closed packing. This layer also contains a mixture of quartz but has less organic material compared to sand layer A.

From the description of the sediment core samples, it is interpreted that in the surface layer to a depth of 15 cm, the influence of sea water is more dominant than fresh water. The intercalation of clay, organic material and sand layers that relatively thin indicates a less stable depositional energy. Weak settling energy indicates calm current conditions that has deposited fine sedimentary materials such as clay, while high settling energy indicates strong currents and carried coarser-sized materials such as sand. Therefore, the intercalation of clay and sand layers shows fluctuating depositional energy which is interpreted to have occurred due to tidal influence.

Then at a depth of 15-50 cm, it consists of a thick layer of clay B and sand B. The existence of clay and sand layers also shows differences in depositional energy. Because it requires greater settling energy, coarse sediment material is difficult to suspend well compared to fine sediment material that can be transported far from the sediment source by suspension. Therefore coarse sediment material is usually deposited near the main channel, in this case is a river that does pass through the sediment sampling area in this study. Whereas clay material is deposited in calm depositional currents and away from the influence of turbulence (e.g. waves) so it is commonly found in parts of river floodplains, land far from open coasts or parts of the deep sea that are less affected by waves and strong currents. The presence of a mixture of organic material of plant remains indicates that this layer was deposited under the influence of the terrestrial environment.

3.2 Diatom Distribution

Based on microscopic observations that have been made on 11 samples, 101 types of diatom species were found with a total of 611 individuals. Of the 101 types of diatom taxa found, 91 species are benthic diatoms and 10 species are planktonic diatoms. Based on its habitat, 65 species of freshwater diatoms were found, followed by marine diatoms with 21 species and brackish diatoms with 15 species.

Freshwater diatoms were mainly found in the middle to bottom depths of the sediment core with a total number of 390 individuals. This group of freshwater diatom species was dominated by *Denticula elegans* (60 individuals), *Staurosirella pinnata* (38 individuals), *Synedra ulna* (32 individuals), *Nitzschia linearis* (20 individuals), and *Achnanthidium minutissimum* (19 individuals).

Whereas at surface depths up to 15 cm, brackish to marine diatoms dominated with a total number of 122 individuals for brackish diatom species and 99 individuals for marine diatoms. The brackish diatom species group was dominated by *Tryblionella granulata* (36 individuals), *Denticula subtilis* (21 individuals), and *Tryblionella hyalina* (19 individuals). Meanwhile, the marine diatom species group was dominated by *Navicula mannii* (17 individuals), *Thalassionema nitzschioides* (14 individuals), and *Tryblionella coarctata* (13 individuals). All of thid dominant species that have been found can be seen in **Fig. 3**.

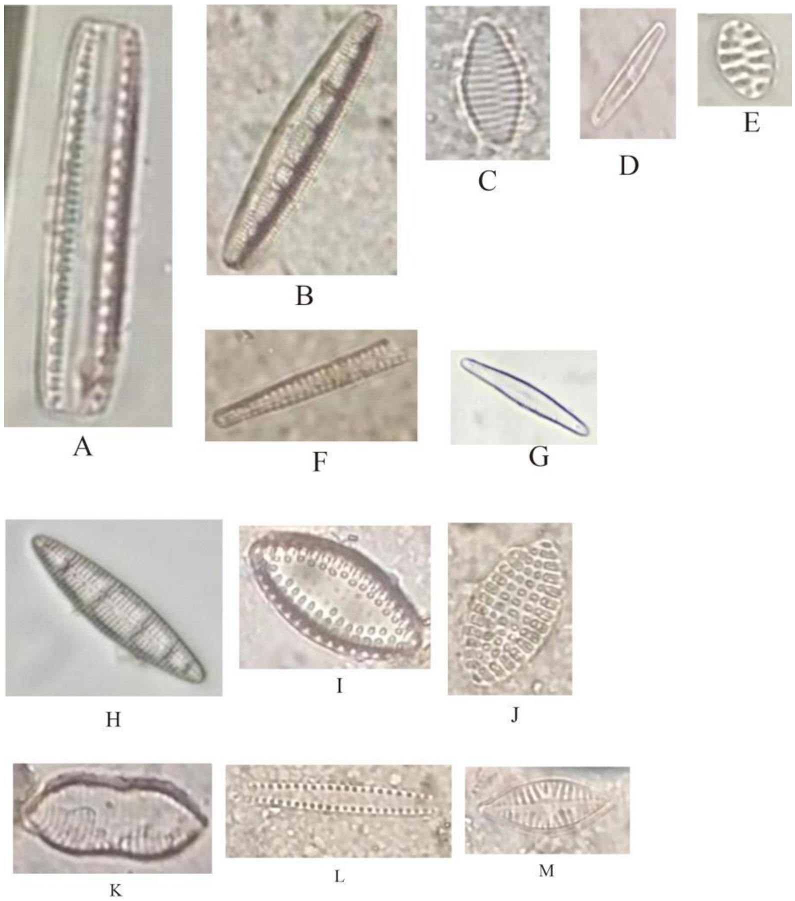


Fig. 3. Dominant diatom species based on the number of individuals found in this study, including Nitzschia linearis (A), Denticula elegans (B), Staurosira construens (C), Achnanthidium minutissimum (D), Staurosirella pinnata (E), Synedra ulna (F), and Gomphonema gracile (G) as freshwater diatoms; Denticula subtilis (H), Tryblionella hyalina (I), and Tryblionella granulata (J) as brackish diatoms; Tryblionella coarctata (K), Thalassionema nitzschioides (L) and Navicula manii (M) as marine diatoms

3.3 Cluster Analysis and Halobian Classification

The determination of diatom habitat zones is based on cluster analysis using the PAST program and the Bray-Curtis similarity index as seen in **Fig. 4**. Based on cluster analysis, there are two groups of diatoms at the similarity value limit of -0.2, namely diatoms at depths of 1-15 cm and diatoms at depths of 20-50 cm. This division shows that the diatom species have a similar relationship in one cluster group and are different from diatom species in other clusters.

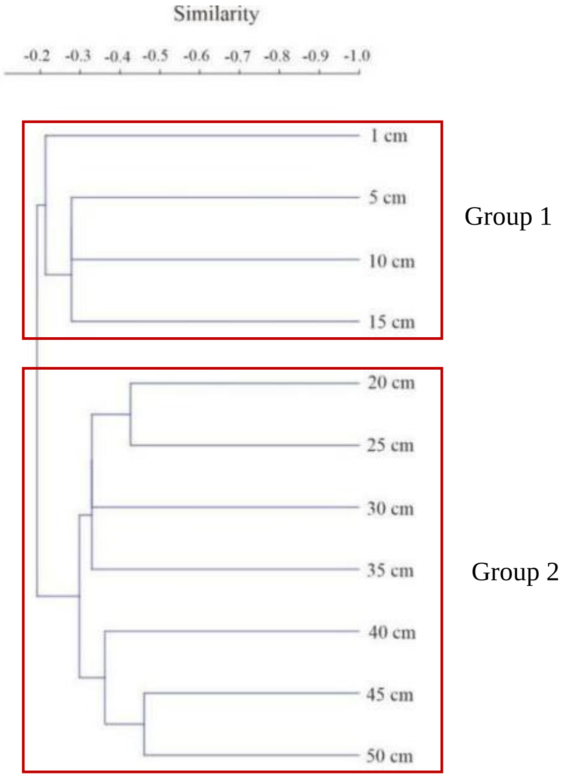


Fig. 4. Results of diatom clusters with Bray-Curtis similarity index

To determine the diatom habitat zone, species with relative abundance >2% were used, including *Achnanthidium minutissimum* (3%), *Denticula elegans* (14%), *Denticula subtilis* (4%), *Gomphonema gracile* (3%), *Nitzschia linearis* (3%), *Staurosira construens* (4%), *Staurosirella pinnata* (8%), *Synedra ulna* (7%), and *Tryblionella granulata* (3%). The diatom groups were then classified based on and salinity tolerance according to the halobian classification [10], as seen in **Table 1**. The salinity tolerance according to halobian classification consist of: (1) polyhalobous, indicating marine habitat diatoms with salinity levels greater than 30 ppt; (2) mesohalobous, indicating brackish habitat diatoms with salinity 2-30 ppt; and (3) oligohalobous, indicating freshwater diatoms with salinity tolerance less than 2 ppt.

Table 1. Salinity tolerance and type of life of the diatom species studied

Diatom species	Salinity tolerance	Type of life
Achnanthidium minutissimum	*oligohalobous mesoeuryhaline*	benthic
Denticula elegans	*oligohalobous*	benthic
Denticula subtilis	*mesohalobous holoeuryhaline*	benthic
Gomphonema gracile	*oligohalobous pleioeuryhaline*	benthic
Nitzschia linearis	*oligohalobous mesoeuryhaline*	benthic
Staurosira construens	*oligohalobous mesoeuryhaline*	planktonic
Staurosirella pinnata	*oligohalobous oligoeuryhaline*	benthic
Synedra ulna	*oligohalobous mesoeuryhaline*	benthic
Tryblionella granulata	*mesohalobous holoeuryhaline*	benthic

3.4 Determination of Diatom Habitat Zones

From the cluster analysis and halobian classification, it can be seen that there are two zones of diatom habitat, namely Zone 1 which covers a depth of 1-15 cm and Zone 2 which covers a depth of 15-50 cm as seen in **Fig. 5**.

In Zone 1, the dominating species is the brackish diatom group (mesohalobous) with the dominance of *Tryblionella granulata*. *Tryblionella granulata* has a dominant abundance at a depth of 5 cm where the lithology is sand. This is because relatively large diatoms such as *Tryblionella granulata* are commonly found in coarse sediments such as sand, while smaller diatoms are commonly found in finer sediments such as clay. The presence of this species decreased with depth until it was no longer found at depths below 15 cm, indicating more neutral habitat conditions and lower salinity at these depths.

Zone 2 has a higher abundance and distribution of diatom species compared to Zone 1 with the dominance of freshwater diatom groups such as *Synedra ulna*, *Denticula elegans*, *Staurosirella pinnata* and *Staurosira construens*. These groups of diatom species are oligohalobous salinity-tolerant diatoms that exhibit freshwater salinity tolerance. In this zone, diatom species with relatively smaller sizes are found, namely *Gomphonema gracile* and *Achnanthidium minutissimum* which are most commonly found at depths of 20 cm and 25 cm where the lithology is clay.

Based on the stratigraphy of diatom assemblages and the division of habitat zones based on salinity tolerance, it can be seen that the dominant influence of both sea water and fresh water occurs alternately. This result is also supported by the difference in sedimentary layers between the two zones.

Initially, the study area had low salinity, based on the dominance of freshwater diatoms in Zone 2 and the lithology interpreted to have been deposited under the influence of the river. Ecological conditions then changed in Zone 1 where there was an increase in salinity levels which made the study area brackish, based on the dominance of brackish diatom groups in the form of *Tryblionella granulata* and lithologies interpreted to have been deposited under tidal influence. This increase in salinity levels could be caused by more seawater entering the area or a reduction in the influence of the river as the main channel moves further away and is replaced by seawater intrusion.

The result of this classification is also align with the recent measurement of water salinity at the research site that showed an average value of 9,49 ppt as seen in **Table 2**, which is included in mesohaline. This result is the same as the salinity tolerance of *Tryblionella granulata* (mesohalobous) whose abundance increases with surface depth of sediment core that certainly also indicate its higher abundance over time and indicating the mesohaline salinity in the water at the time.

Table 2. Water quality measurement using Horiba tool in the sampling site on March 2022

Measurement	First measurement (U1)	Second measurement (U2)	Third measurement (U3)	Average
Temperature (^{0}C)	31,9	32,31	32,46	32,22
pH	7,04	6,98	6,98	7,00
Salinity (ppt)	16,62	5,95	5,91	9,49

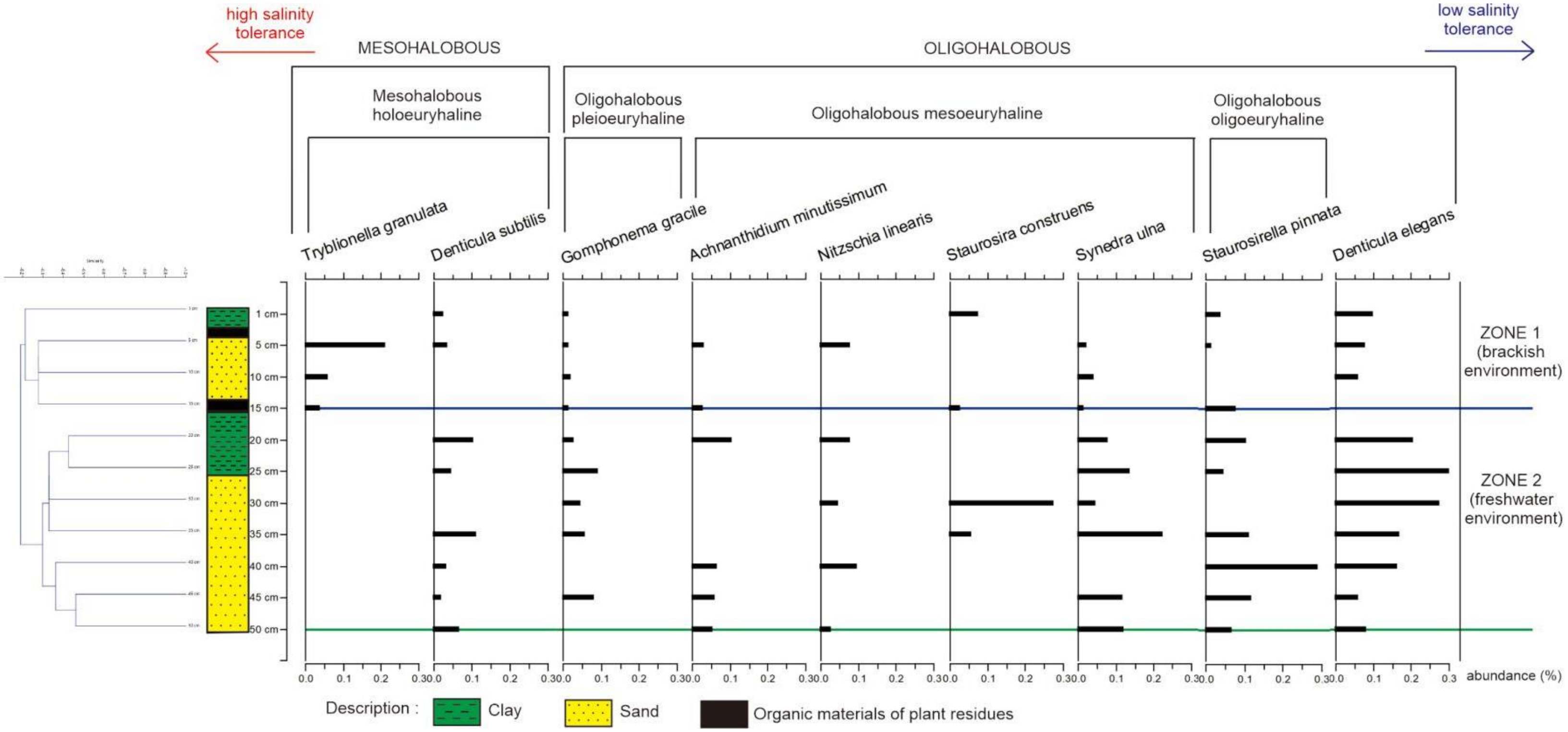


Fig. 5. Division of diatom habitat zones based on salinity tolerance

These results show that over time, the influence of seawater is increasingly dominating in the study area which affects not only the ecology but also sedimentation there, especially since the coast in the northern region of Rembang has very diverse characteristics and a very dynamic sedimentation process with repeated accretion and abrasion processes, so it is feared that it can have a negative impact on the environment and people's lives in the study area.

Therefore, mangrove forest conservation needs to be preserved so that sedimentation and abrasion rates can be neutralized, because with mangrove vegetation, waves and abrasion rates can be dampened. The rate of sedimentation originating from land also does not directly enter the sea so that they can be well controlled and doees not damage the ecosystem there due to sediment buildup which can ultimately increase the potential for erosion [11].

Based on the results of this study, it can also be concluded that diatoms can indeed be used as an ideal bioindicator to study and reconstruct environmental changes and depositional conditions in coastal areas, seen from the results of diatom abundance data in accordance with other supporting data such as sediment variations. Therefore, diatoms can be used not only as an ecological review of the past, but also as a consideration and projection in the future regarding the dynamic ecological changes in coastal areas because the classification result is also align with the modern measurement, so that appropriate steps can be taken to minimize negative impacts that may occur in the future and more sustainable management of coastal areas.

4 Conclusion

Based on the correlation of stratigraphic data of sedimentary layers with diatom species assemblages, as well as the calculation of diversity and abundance indices, it is concluded that the study area has very dynamic ecological and sedimentation conditions with the dominance of alternating freshwater and marine influences.

There was a change in diatom habitat zone from zone 2 (15-50 cm) with low salinity and pH conditions, seen from the dominance of freshwater diatom species assemblages (*Denticula elegans, Synedra ulna, Staurosira construens, Nitzschia linearis, Gomphonema gracile, Achnanthidium minutissimum* and *Staurosirella pinnata*) and clay and sand layers mixed with organic material, indicating deposition that was more influenced by freshwater (river).

The ecological conditions of the study area then changed in zone 1 (0-15 cm) which experienced an increase in salinity and pH, seen from the dominance of brackish diatom species groups (*Tryblionella granulata* and *Denticula subtilis*) and a mixture of clay, sand and organic material with a relatively thin layer thickness, indicating fluctuating depositional energy caused by tidal influence. So that, from time to time the influence of sea water increasingly dominates in the study area which can cause changes in ecological conditions and sedimentation.

Therefore, conservation and preservation of mangrove forests must continue to be carried out to neutralize the impacts of ecological changes and sedimentation that may occur in the future for the sake of community survival and sustainable ecological management of coastal areas.

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