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Original Research

Vertical Distribution of Diatoms Analysis to Determine the Condition of Rawapening Lake in the Past through Cluster Analysis with the Bray-Curtis Model

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Abstract

Rawapening Lake is located in Semarang Regency, Central Java Province, Indonesia, and is the center of various activities, including agriculture, fisheries, sources of electrical energy, raw water, tourism, and culture. A 100-cm-long sediment sample was extracted from Rawapening Lake to reconstruct the dynamics of environmental change by observing the preserved diatoms. Diatoms are sensitive to changes in water quality, so their pattern of existence can reflect changes in lake conditions. The sampling location is located at the mouth of the Tuntang River, the only outlet of Rawapening Lake, which has 20 inlets as water sources. Sediment cores were sliced at 1-cm intervals for diatom analysis. Diatom slide mounts were prepared from about 5 grams of dry sediment using 10% hydrochloric acid

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followed by 10% peroxide to remove organic matter and carbonates. A total of 300 valva diatoms were counted for all samples in order to obtain the lowest level of diatom taxonomy. Vertical distribution analysis is used to determine the condition of Rawapening Lake in the past through cluster analysis using the Bray-Curtis model, which is based on depth similarities. The reconstruction of Rawapening Lake, which was carried out based on variations in the abundance and diversity of diatoms vertically, showed that the pH of the waters tended to increase. Indicators that strengthen this statement are the dominance of *A. ambigua*, *A. granulate*, *S. ulna*, and *S. acus*. This can occur due to two things: the occurrence of decomposition of organic material by microorganisms at the bottom of the lake or the use of lime in the manufacture of organic fertilizer from water hyacinth. When it rains, the lime will wash off and enter the lake. Total Nitrogen of 1.773 μg/l in Rawapening Lake indicates that the nutrient enrichment of these waters has reached hypereutrophic levels. The dominance of benthic indicators with high nutrient status indicates that Rawapening Lake has a long history of eutrophication. The condition of Rawapening Lake can be categorized into 3 zones, namely: (a) Zone 3 (90-100 cm layer) is dominated by diatoms *N. palea*, *N. closterium*, and *T. apiculate*, which indicate eutrophic water conditions; (b) Zone 2 (30-40 cm layer) is dominated by *A. distans*, *N. closterium*, *T. apiculata*, *S. ulna*, and *N. radiosa* species, where *A. distans* is widely distributed in clear and oligotrophic waters; (c) Zone 1 (1-20 cm layer) is found *S. pupula* of the genus Sellapora, which is an indicator of lake or river waters with mesotrophic-eutrophic conditions.

Keywords: Rawapening lake, diatoms, cluster analysis, paleolimnology

Introduction

One of the main concerns and focuses of the Sustainable Development Goals (SDGs) is the decline in water quality. The Indonesian government sets policies in the National Medium-Term Development Plan (RPJMN) as an effort to restore and conserve water resources and their ecosystems through the revitalization of lakes, one of which is Rawapening Lake [1]. Rawapening Lake is administratively located in Semarang Regency, Central Java Province, Indonesia. Classified as a semi-natural lake, Rawapening Lake was formed through a process of volcanic eruptions that drained basalt larvae and caused a blockage of the Pening River in the Tuntang area [2]. This volcanic event has changed the Pening Valley, which is a tropical forest, into a swamp and made it a "bowl" type lake. Rawapening has been transformed into a semi-natural lake since the damming of the headwaters of the Tuntang River, which was the only lake outlet during the Dutch East Indies colonial rule in 1912-1916, so that the lake's water level rose. The Rawapening Lake expansion project was carried out again in 1936 until the body of water reached an area of 2,667 hectares in the rainy season and 1,650 hectares in the dry season [3, 4]. The expansion of the lake by the sinking of the valley has had a major impact on changes in its ecosystem, such as the process of peat bogging left over from tropical forests, the formation of floating islands, the invasion of aquatic plants, and also the development of aquatic communities.

Located in a tropical area with warm temperatures, Rawapening Lake has a topography in the form of a basin surrounded by hills and mountains with a slope of between 8% and greater than 30%, such as Mount Telomoyo (1895 m), Mount Butak (1000 m), Mount Balak (700 m), Mount Payung (600 m), and Mount Rong (600 m) [5]. Rawapening Lake water is sourced from rainfall, groundwater, and river water. There are 20 inlets in Rawapening Lake, namely Rengas River, Tukmodin River, Dungrangsong River, Gajah Barong River, Panjang River, Kupang River, Pentung River, Legi River, Ringis River, Tapen River, Tengah River, Galeh River, Klegung River, Sraten River, Parat River, Muncul River, Torong River, Kedung Ringin River, Ngreco River, and Dogbacin River. All these rivers supply about 60% of the water in the lake. The Muncul River has the largest contribution, which is around 20% of the Rawapening water volume [6]. These conditions make the water in Rawapening Lake continue to increase, while the water that comes out is only through one outlet (the Tuntang River). The continuous addition of water also brings various kinds of material from upstream, which settles to the bottom of the lake, triggering siltation.

Rawapening Lake is one of 15 national priority lakes in Indonesia because it has economic, ecological, social humanities, and scientific values that have experienced significant environmental damage [7, 8]. Rawapening Lake has a level of vulnerability to environmental changes because it has a high utilization rate. Various activities that take advantage of the existence of Rawapening Lake include agriculture, fisheries, sources of electrical energy, raw water, tourism, and culture, as well as controlling floods [4, 9]. Various activities in the catchment area and the Rawapening Lake water body have spurred a decline in environmental quality, which includes sedimentation, pollution of inorganic materials, decreased water quality, and eutrophication. Eutrophication is the introduction of nutrients, especially excessive phosphorus and nitrogen, into aquatic ecosystems so that primary productivity increases and aquatic plants gain uncontrolled dominance [10-13]. The neolimnological condition of Rawapening, which is experiencing physical eutrophication, can be seen from the abundance of water hyacinth (Eichhornia crassipes) populations, which are growing rapidly. The area of water hyacinth that covers the surface of Rawapening has reached 1,080 ha with a relative growth rate ranging from 6.40-7.26%/day [6], which triggers environmental damage to the lake ecosystem, causing a crisis of fishery resources.

Diatoms are one of the photosynthetic microorganisms in the Bacillariophyte that play an important role in aquatic ecosystems [14], so their presence is easily found in most aquatic ecosystems, with one of the most widely represented groups of algae in swamps [15]. Diatoms have a high adaptability to polluted waters through the mechanism of the multiplication of mucus on their body surface [16, 17]. In addition, diatoms are able to survive in slow to fast currents [18]. Diatom cell walls are made of silicates called frustules, making them fossils in aquatic sediments that can be used for paleolimnological analysis [19, 20]. Taxonomy allows the identification of diatoms up to the species and subspecies levels [21]. Sedimentation processes in lakes produce sediment layers that reflect the historical dynamics of changes in the catchment area [22-24]. The history recorded in each of these sedimentary layers can be reconstructed by referring to the level of nutritional needs or the specific habitat of each taxon of fossil diatoms or by considering the level of species abundance.

Paleolimnological studies using diatoms in lake sediments in Indonesia are generally still limited to determining indicator species and changes in relative abundance over time [20]. This study has been carried out by Dam et al. [25] on Tondano Lake and by Soeprobowati et al. [26] on Dieng Warna Lake. These studies specifically look at the long-term development of lakes and are related to historical dynamics recorded through diatom populations. These conditions may be correlated with changes in well-preserved sediment layers. For this reason, this paper focuses on the potential of diatoms in paleolimnological studies with vertical distribution analysis to determine the condition of Rawapening Lake in the past through cluster analysis using the Bray-Curtis model.

Material and Methods

Area Studies

Rawapening is a volcanic lake in the tropics with warm temperatures, located about 45 km south of Semarang City and about 9 km northwest of Salatiga City. In terms of coordinates, Rawapening Lake is at 7°04’-7°30’ south latitude, 110°24’46’-110°49’06’ east longitude, and an altitude of 460 meters above sea level. The sampling point is in the upper reaches of the Tuntang

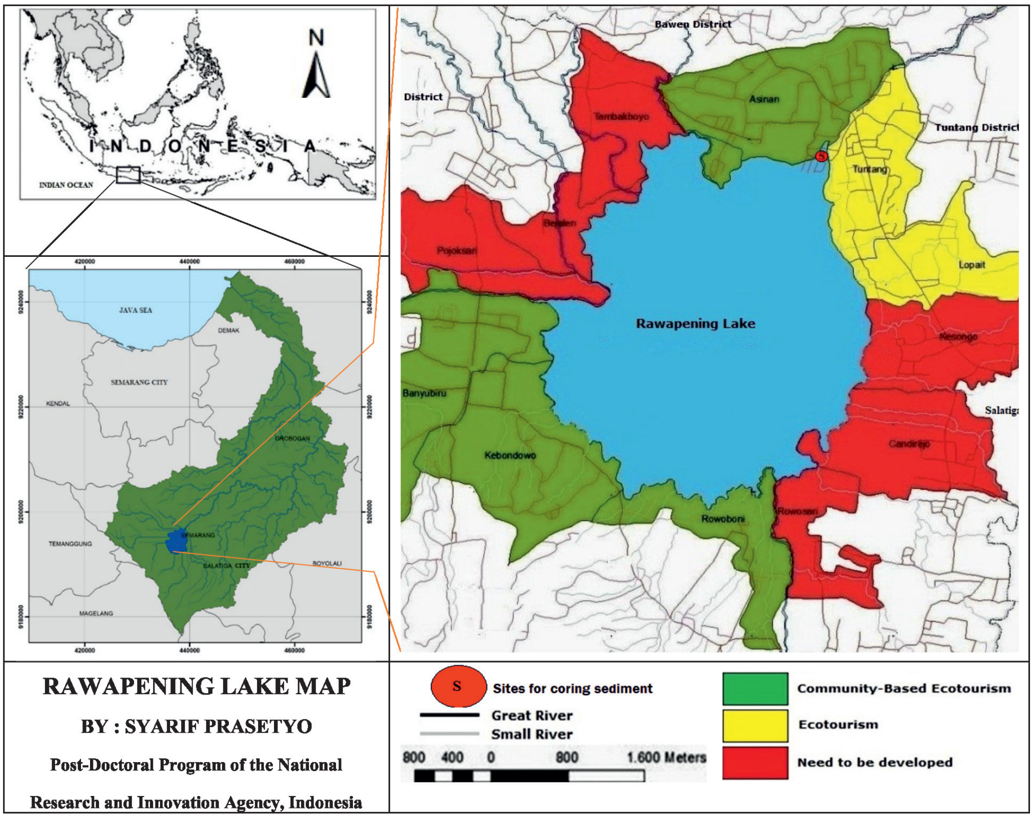

Fig. 1. Sites for coring sediment in Rawapening Lake.

River, Asinan Village, Bawen District (7°16’04”LS 110°26’50”E), which is the only outlet of Rawapening Lake (Fig. 1). The upper outlet of the Tuntang River was chosen because it is very important to study the impact of human activities on the catchment area in the past. The sampling locations have complex environmental characteristics, namely residential areas, agricultural areas, the tourism industry, and water hyacinth compost processing industries that apply quicklime. The majority of these activities have developed since the construction of dams during the Dutch East Indies colonial administration.

Sample Collection

This research was carried out from December 2019 to October 2020. Diatoms were chosen as the main paleolimnological tool. Intensive sampling of sediments for diatom extraction and water quality at the sampling point (Fig. 2). The physico-chemical variables analyzed included DO, temperature, turbidity, and pH *in-situ* with 9 replications, and then the measurement results were averaged. Water samples were taken for analysis of total N and total P with the Indonesian National Standard, SNI 6989.57-2008: surface water sampling. Water samples taken for measurement of total N and total P were collected in 1 L clean plastic bottles for 9 replicates, whose analysis results were averaged like other physico-chemical parameters. The sediment for diatom analysis was obtained with the help of a Russian Corer and then stored intact in the half pipe and wrapped in plastic wrap. Samples were put into a quarantine room with biosafety levels 1 and 2 (Stillwell 304) to minimize microbial contamination from outside. The quarantine process lasts for 1 week, after which the samples are dried on a special rack for 3 weeks so that the water content contained in the sediment decreases. After passing through the quarantine process, the sample is cut into sub-samples of diatoms at 1 cm intervals. The intervals between the cuts aim to prevent mixing between diatom species on each surface [27].

The diatoms were extracted following the procedures of Battarbee et al. [28], where the digestion of subsamples in 10% HCl solution was followed by 10% H2O2 solution with repeated washings using distilled water between stages. Samples were placed on slides, and a minimum of 300 diatom valves were identified on each slide under a binocular microscope with 1,000x magnification, soaked in oil immersion [9]. If possible, the observed diatoms are identified down to the species level or to the genus level according to [29-31]. As for consultations in taxonomy and nomenclature, the Guiry approach is used [32].

Data Analytics

The research results were processed statistically using the Shapiro-Wilk method to assess data normality, and all statistical tests used a significance level of 0.05. Repeated measurements of the physico-chemical samples of the water were carried out nine times. As for diatom analysis, there is no repetition because

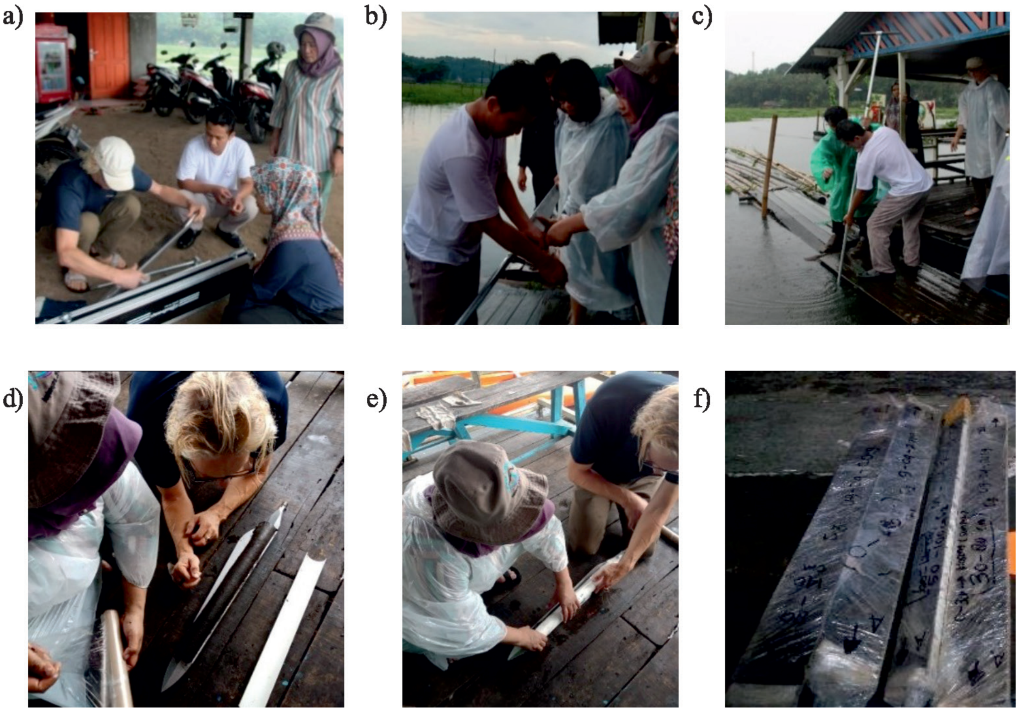

Fig. 2. Series of Sediment Coring Activities in the Upper Tuntang River (Rawapening Lake Outlet), Corer Installation a), Seeting Corer Before Use b), Sediment Coring c), Sediment Results Coring d), Sediment Wrapping Using Plastic Pipes e), and Wrapped Sediments for Further Analysis f).

the database is based on vertical sediment layers. The diatom species obtained were counted and standardized, and the relative abundance of the total valvae abundance was calculated in each sample. Furthermore, the transformation is carried out to the Log(N+1) form in order to simplify the calculation process [33, 34]. The diatom abundance in Rawapening Lake is expressed as the number of individuals per gram. According to Scherer [35], the number of diatom species in an individual per gram can be calculated by the formula:

$$T = \frac{\left\{\frac{NxB}{AxX}\right\}}{M}$$

Explanation:
T : The number of microfossils per unit mass
N : Total number of microfossils counted
B : Amount of filtered water (ml)
A : Amount of prepared water sample (ml)
X : Number of slides
M : Sample mass (gr)

The diatom community structure obtained was analyzed using the Shannon-Wiener diversity index (H') approach, the uniformity index (E), and the dominance index (D'). Relative abundance is determined based on the number of valve diatoms. Diatom species that had <2% relative abundance were excluded from the analysis, and the remaining assemblages were illustrated in a vertical distribution chart using C2 version 1.7.7 [36]. Then the data were analyzed according to inter-layer categories using the Bray-Curtis clustering model to obtain a diatom distribution pattern in Rawapening Lake. This analysis used PAST software (Paleontological Statistical Software Package for Education and Data Analysis) version 2.17c [37]. These results will describe the distribution of each species at each depth studied. This will make it easier to analyze the changes that occur at each depth.

Results and Discussion

Result

The process of fossilization of Rawapening Lake diatoms is going well, as can be seen from the diatoms that were found in most of the intact valves. From the 100-cm-long sediment coring results in the upstream outlet of Rawapening Lake, 47 species of diatoms were identified. Identification of the diatoms found in this study was accomplished by comparing the species descriptions in published flora and comparing the

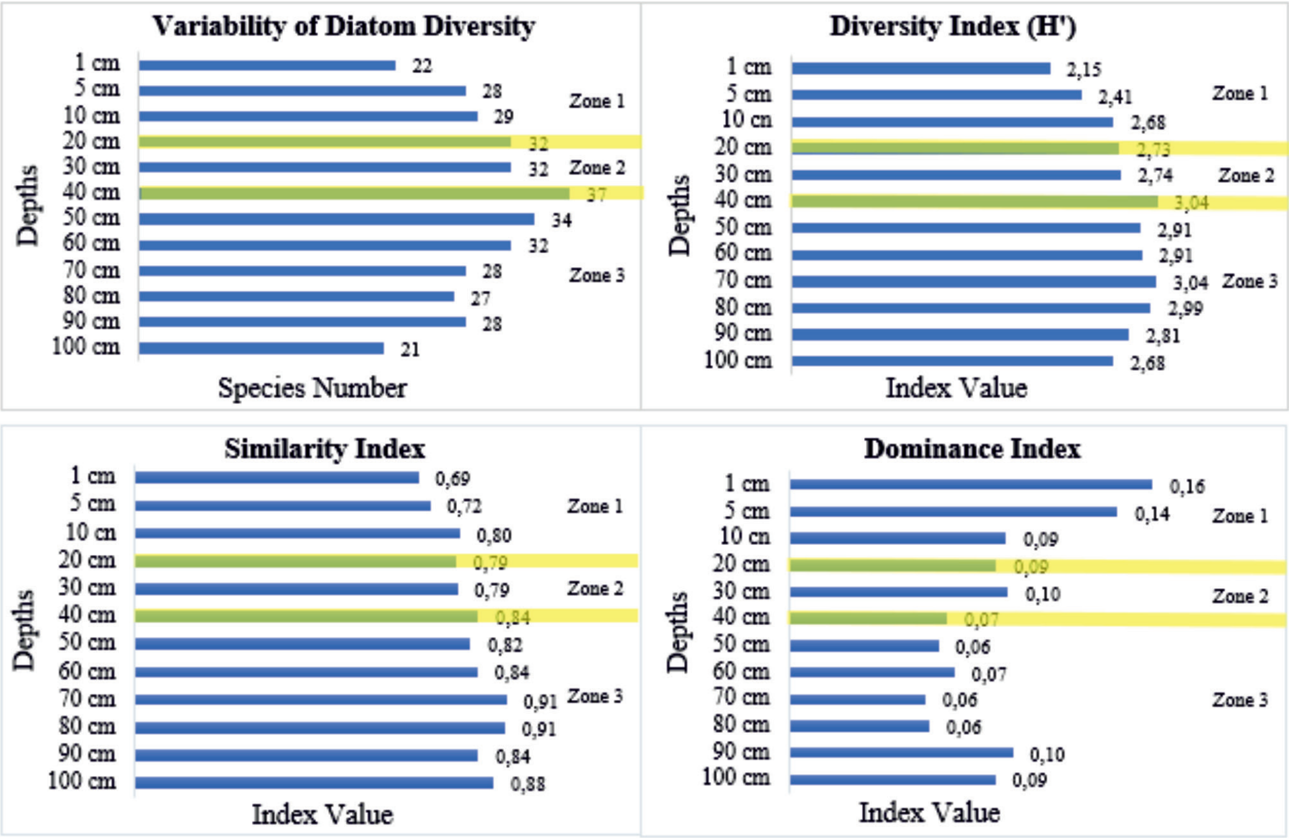

Fig. 3. Variability of the number of species, the diversity index, the uniformity index, and the diatom dominance index in Rawapening Lake.

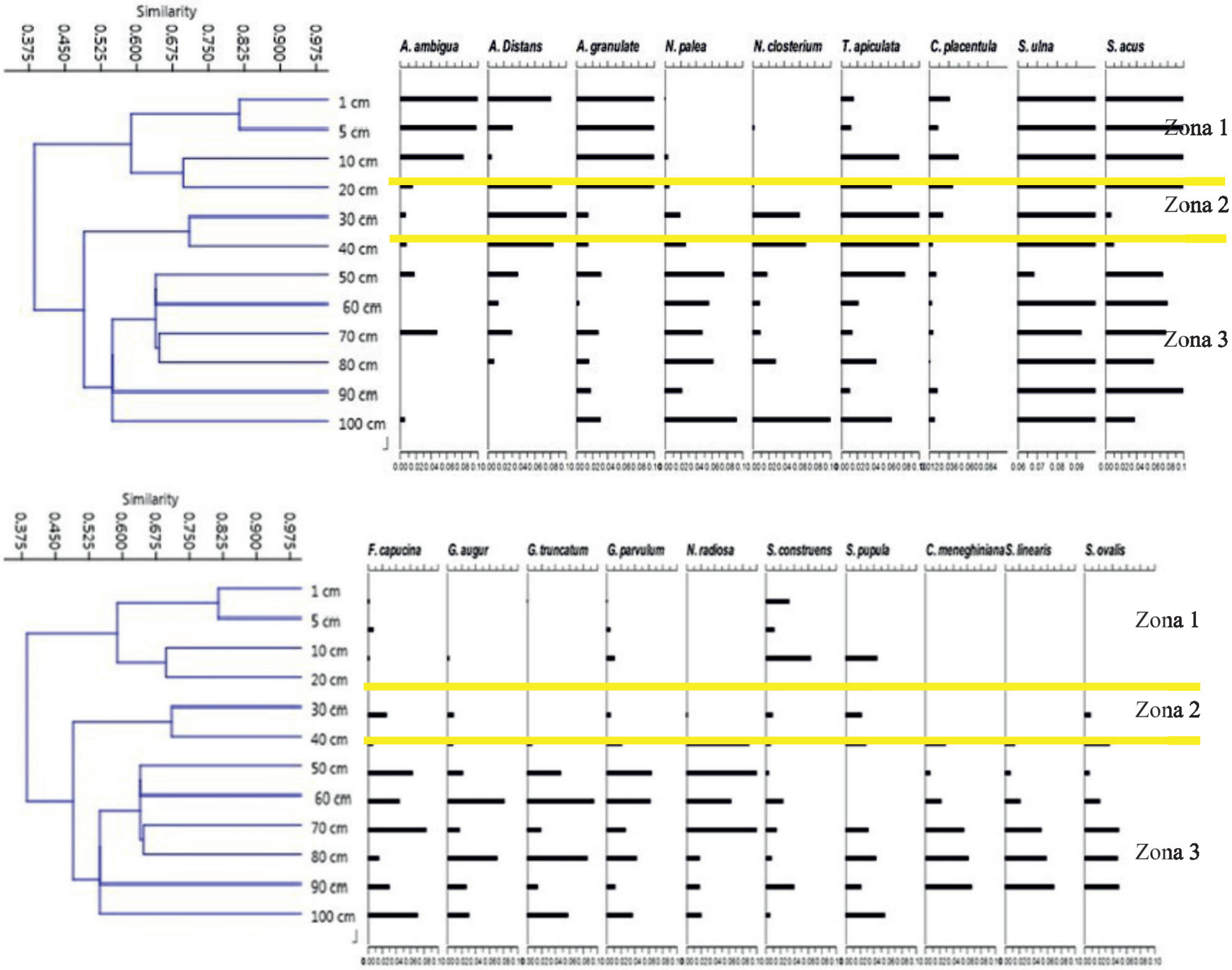

Fig. 4. Cluster Analysis and Stratigraphy of Diatoms in Rawapening Lake.

morphometric conditions of the valves measured by microscopy (length, width, striae density, etc.) with the published ranges. When any of the observed valvas from the Rawapening Lake sediments did not clearly match the published species traits, the diatoms were assigned an affinity status.

The results of calculating the variability of the number of species and analyzing Rawapening Lake diatom index data (Fig. 3) obtained a diversity index value (H') ranging from 2.15 to 3.04. The H' value is divided into three zones based on the diversity of diatoms, which are found at the depth of the sediment layers observed. The uniformity index (E') of Rawapening Lake diatoms is in the range of 0.69-0.91. The E' value is divided into three zones based on the uniformity of diatoms, which are found at the depth of the sediment layers observed. The average dominance index (D') for all depths is 0.06. The D' value is divided into three zones based on the dominance of diatoms, which are found at the depth of the sediment layer observed.

Cluster analysis of the coring results of Rawapening Lake sediments as deep as 100 cm using the Bray-Curtis model, which is based on similarities between depths, can be grouped into 3 zones, namely the upper zone (zone 1), the middle zone (zone 2), and the lower zone (zone 3), which are separated by a yellow line (Fig. 4). The upper zone (zone 1) is a layer of sediment at a depth of 1 cm-20 cm that is dominated by the species *A. granulata*, *A. distans*, *A. ambigua*, *T. apiculata*, *S. ulna*, and *S. acus*, which appear in the layer 1 cm-20 cm. The middle zone (zone 2) is a layer of sediment at a depth of 30-40 cm dominated by *A. distans*, *N. closterium*, *T. apiculata*, *S. ulna*, and *N. radiosa* species. The lower zone (zone 3) is a layer of sediment at a depth of 90-100 cm that is dominated by diatoms *N. palea* and *N. closterium* and *T. apiculate.*

Discussion

The paleolimnological approach to the Rawapening Lake research utilizes biological information stored in sediments, which is expected to be the basis for solving water quality problems. Knowing the quality of water in the past can help predict the quality of water in the future. History is not just a retelling of the past; it also has a deeper meaning as a reminder and warning. This paleolimnological study of Rawapening Lake utilizes diatoms as an important instrument for assessing lake conditions in the past by looking at the community structure and vertical distribution of diatoms.

Rawapening Lake Diatom Community Structure

The results of the analysis of diatom community structure in Rawapening Lake are divided into three zones based on the distribution of diversity, uniformity, and dominance of diatoms found at the depth of the sediment layer. The highest diversity index (H') was 3.04 at a depth of 40 cm for 37 species and at a depth of 70 cm for 28 species. The lowest diversity index (H') was 2.15 at a depth of 1 cm. The diatom diversity index ranged from 2.15 to 3.04, indicating that the diversity was moderate to stable. This condition is in accordance with the division of criteria according to Odum [38], namely, H<1 means the biota community is unstable, and H = 13 means the biota community is stable.

The physical and chemical characteristics of the waters greatly influence the presence of diatoms in the waters [39]. Diatoms are very sensitive to environmental changes such as temperature, pH, light intensity, and nutrient conditions and are able to achieve higher growth rates compared to other phytoplankton groups [40–42], so that the pattern of their existence can reflect changes in lake conditions. The average temperature of the waters of Rawapening Lake is 31.65ºC, which is still in the proper range for aquatic organisms. This is in accordance with the opinion of Koswara [43], that temperatures in the tropics ranging from 25 to 32ºC are still suitable for the growth of aquatic organisms. Significant differences in water temperature can affect the metabolic activity of organisms. The low diversity index (H') at a depth of 1-10 cm ranging from 2.15-2.68 was caused by the dominance of *A. distans*, *A. granulata*, *S. ulna*, and *S. acus*. These diatom species are indicators of fertile waters with trophic status ranging from mesotrophic to eutrophic. This is in accordance with previous results that *A. distans* and *S. ulna* are oligotrophic species with phosphorus ranging from 20-1,000 g L1 and pH 5-9 [44]. The average pH value of the waters in Rawapening Lake in this study was 7.25. Based on the content of total nitrogen (TN) and total phosphorus (TP), the waters of Rawapening Lake fall into the mesotrophic to hypereutrophic category (Table 1). Nutrient concentrations (N and P) are influenced by the use of fertilizers on agricultural land, the use of detergents, and the disposal of industrial waste [45]. Nutrient concentrations can reflect the fertility status of the waters, as indicated by the abundance of diatoms.

Table 1. Water Quality of Rawapening Lake.

No.	Parameters	Mean Measurement Results
1.	Temperature (ºC)	31.65
2.	DO (mg/l)	8.62
3.	pH	7.25
4.	Turbidity (NTU)	180.80
5.	Total Phosphorus (µg /l)	94
6.	Total Nitrogens (µg /l)	1,773

The aquatic ecosystem of Rawapening Lake is increasingly stable in layers of sediment with a depth of 40-70 cm and a diversity index (H') touching 3.04. At this depth, the most abundant species are *T. apiculata*, *S. ulna*, and *N. radiosa*. The species *T. apiculata* and *S. ulna* are an indication that Rawapening Lake is experiencing eutrophication [44]. These species are very tolerant of pollution and prefer waters with eutrophic conditions [39].

The surface diversity index (H') value at a depth of 1-10 cm is lower than that at a depth of 40-70 cm. This condition can occur because the water hyacinth weeds fill the surface of the water, making it difficult to penetrate into the water. This is in accordance with the high turbidity value of Rawapening Lake, which is 180.80 NTU. The low penetration of light into the water results in decreased photosynthetic activity by phytoplankton [46]. In addition, the environment of Rawapening Lake is currently surrounded by rice farming and horticulture, which allow fertilizers and pesticides to leach into bodies of water. Based on the diversity of diatoms found at the depth of the sediment layers observed, Zone 3 (depth 70-100 cm) has the highest diversity index (H') of 3.04, Zone 2 (depth 30-60 cm) has the highest diversity index (H), and Zone 1 (1-20 cm depth) has the lowest diversity index (H') of 2.73. The graph illustrates that the deeper the lake, the higher the diversity of diatoms, and this indicates that the Rawapening Lake ecosystem is more stable. The stability of these water conditions can be seen from the mean DO value of Rawapening Lake, which is 8.62 mg/L. The DO content of water >5 mg/L is good for phytoplankton and zooplankton [47]. This is in line with the opinion of Damar et al. [48], that the high abundance of phytoplankton can contribute to high levels of dissolved oxygen, which is the result of the photosynthesis process.

Rawapening Lake diatom uniformity index is in the range of 0.69-0.91. The lowest diatom uniformity index (E) at a depth of 1 cm was 0.69, and the highest at a depth of 70 and 80 cm was 0.91. That means diatoms found at all depths have an even distribution, are not dominated by a species, and have the same chance of survival. The determination of the standard for evenness is based on Kerb's statement [49], namely: a) the distribution is uneven, there is a dominance of species, and the chances of survival are not the same (0-0.40); b) the distribution is quite even, there is a dominance of species, and the chances of survival are starting to be unequal (0-0.60); c) even distribution, no dominance of species, and the same chance of life.

The lake surface sediments (zone 1), although included in the category with a high uniformity index, namely 0.69-0.79, are still the lowest compared to the lower zone. In zone 2, the uniformity index (E) ranged from 0.79 to 0.84, and in zone 3, it was from 0.84 to 0.91. In zone 1, the genera of Aulacoseira, namely *A. granulata*, *A. distans*, and *A. ambigua*, were found in numbers. In zone 2, there are *T. apiculata*, *C. placentula*, and *E. didon*, which appear a lot. In zone 3, *E. pectinalis var. pectinalis*, *C. meneghiniana*, and *S. linearis* were the most common. As for the genus Synedra, namely *Synedra ulna* and *S. acus*, they appear in abundance in each layer of sediment. The most common species of N. itzschia palea occur in zones 2 and 3. Certain Nitzschia in waters are usually associated with trophic levels of water and are tolerant of oligotrophic waters. Nitzschia is easy to find in waters that have moderate to high conductivity and are tolerant of high organic matter.

The dominance index (D) of diatoms is calculated to determine whether there is a dominant species in the sediment layer of Rawapening Lake. The smallest dominance index with a value of 0.06 at a depth of 50 cm, 70 cm, and 80 cm. The highest dominance index is 0.16 at a depth of 1 cm, followed by 0.14 at a depth of 5 cm. As for the depths of 30 cm and 90 cm, the dominance index is 0.10. The overall depth dominance index average is 0.06.

According to Magurran [50], the dominance index ranges from 0 to 1. A scale of 0-0.40 indicates a low dominance level, a scale of 0.41-0.60 is a moderate dominance level, and a scale of 0.60-1.00 is a high dominance level. According to this reference, the dominance index of all Rawapening Lake sediment layers from the surface to a depth of 100 cm is low. The dominance index close to zero indicates that, in general, the community structure is in a stable state and there is no ecological pressure on the biota in the Rawapening Lake habitat.

Rawapening Lake Diatoms Vertical Distribution

The large number of diatom genera that are tolerant of alkaline, neutral, and acidic water conditions is an indicator of changes in water quality in the Rawapening Lake ecosystem. The increase or decrease in nutrients that occur in Rawapening Lake is related to the use of the lake area, including changes in land use in the water catchment area. Diatoms are able to reveal changes in sediments and have water quality references for each species found, so that the waters around which there is land (both for agriculture and for community use) can be analyzed for changes through the identification of diatoms [20].

The abundance of diatom species found in each sediment layer can be used to reconstruct the condition of Rawapening Lake. This is in accordance with the statement of Soeprobowati [51], namely, that reconstruction is the activity of reconstructing past conditions based on clues to organisms stored in sediment layers so that they reflect environmental conditions when these organisms were deposited.

The reconstruction of the condition of Rawapening Lake shows that the surface sediment (1 cm layer) has the least species diversity, namely 22 species. The deeper the diversity of diatom species found, the more diverse they are, with the highest number of species in the sediment layer with a depth of 40 cm, namely 37 species. This condition is caused by the burden of environmental changes over time. This is in line with Soeprobowati et al. [52], who argue that deeper layers have more stable environmental conditions compared to the layers above them.

Based on the results of the calculation of the diversity index (H’), the lower sediment layer tends to have a more stable ecosystem community than the upper sediment layer. The upper sediment layer (1 cm) has an H’ of 2.14, while the lower the H’ value, the higher it is at 3.04 at a depth of 40 cm to 70 cm. The upper sediment layer tends to have a low H’ value because it is still affected by environmental changes due to sedimentation, water flow, stirring, or other activities. This condition can be assessed by the frequent finding of diatoms from the Fragilariaceae family, namely *S. ulna*, *S. acus*, *S. inaequalis*, and *F. capucina*, which indicates that eutrophication occurred at the time of sedimentation. As for the lower layer, it tends to be more stable because it has experienced precipitation [51].

The 90-100 cm layer (zone 3) is dominated by *N. palea*, *N. closterium*, and *T. apiculate* diatoms. These three species are indicators of high nutrient concentrations that confirm the enrichment status of Rawapening Lake at that time based on this stratigraphic study. This is in line with Soeprobowati et al. [44], who stated that *N. palea* is an epipelic or epiphytic diatom that is widespread in eutrophic waters.

The number of *C. placentula* species is decreasing in Zone 1. This species from the genus Cocconeis responds to the low presence of nitrate in the waters, although it is tolerant of eutrophication [53], so that increasing the nitrate content in the waters will inhibit the growth rate of these diatoms. Species *S. ulna*, *S. acus*, *C. meneghiniana*, *G. augur*, *G. truncatum*, *G. parvulum*, and *F. capucina* found in zone 1 are very tolerant of living in waters with high organic content up to a total phosphorus content of 20-1,000 g L^{-1} and pH 5-9 [9]. The presence of these species in the zone 1 sediment layer indicates that Rawapening Lake is in an alkaline condition. This situation is in accordance with the statement by Kowalska and Wojtal [54], that Fragilaria grows in a mesotrophic and slightly alkaline environment. Meanwhile, the reconstruction of the environmental conditions of Rawapening Lake conducted by Soeprobowati et al. [52], reflects the dominance of *F. capucina* and *L. goeppertana*, M. atomus, *N. radiosa*, *N. palea*, and *T. apiculata*, reflecting eutrophic but clear waters in 1967-1974.

Layers 30-40 (zone 2) are dominated by *A. distans*, *N. closterium*, *T. apiculata*, *S. ulna*, and *N. radiosa* species. Some of the species found in Zone 2 indicate that the waters of Rawapening Lake at that time were clear and deep but already eutrophic. *N. radiosa* and *T. apiculata* reflect eutrophic waters, but they are clear. Soeprobowati et al. [9], explained that *A. distans* species are widely distributed in oligotrophic and clear waters. The transition to the plankton of *A. distans* will be accompanied by a decrease in benthic and epiphytic taxa.

Layers 1-20 (zone 1) are dominated by species *A. granulata*, *A. distans*, *A. ambigua*, *T. apiculata*, *S. ulna*, and *S. acus*, which appear from layers 20 cm to 1 cm. These diatom species show that, during the sedimentation process, Rawapening Lake has clear water and is in oligotrophic conditions. This is in accordance with the research of Soeprobowati et al. [52], which stated that the oligotrophic species A. distans initially dominated Rawapening Lake. The presence of *S. construens* in Zone 1, which is quite abundant in the 20 cm to 10 cm layer, indicates that the water quality is in alkaline conditions, especially in the process of forming the 10 cm deep sediment layer. Meanwhile, *S. pupula*, which is a diatom from the genus Sellaphora, is a species that can be found in lakes or rivers with mesotrophic-eutrophic conditions and also in waters with high conductivity [55]. *A. granulata*, *A. distans*, *A. ambigua*, *S. ulna*, and *S. acus* in zone 1 were found to be increasingly dominant in the 5 cm to 1 cm layer. This community was initially dominated by oligotrophic species with clear water conditions, such as *A. distans*. However, this condition underwent a transition period in 1990 to be dominated by *A. granulata* and finally *A. ambigua*. This is interpreted as a shift to a turbid water phase that allows phytoplankton to thrive but sacrifices benthic or epiphytic taxa that require clear water [52]. This shows that from 1990 until now, the pH of Rawpening Lake has varied between 6.5 and 9. The high abundance of *A. distans* and *A. ambigua* in Rawapening Lake is related to the total water phosphorus [56]. In this study, the results of TN measurements were 280 µg/l – 2,240 µg/l and TP 5 µg/l – 156 µg/l, so the waters of Rawapening Lake have entered the hypereutrophic phase.

Synedra's dominance from 1967 until now shows that Rawapening Lake as a whole is still fresh and mesoeutrophic. *S. ulna* is a common species that survives in the upper sediments. The population represents a low planktonic form, as can be seen clearly in the study of sediments taken at the mouth of the Tuntang River, Rawapening Lake. *S. ulna* is classified as a tolerant species, found in Indonesian rivers and lakes with high organic content, a total phosphorus content of 20-1,000 g/L, and a pH of 5-9 [52]. This means that the dominance of S. ulna in the surface layer of sediments confirms the validity of the existence of *A. granulata* and *A. ambigua* as indicators of the fertility of the waters of Rawapening Lake.

The reconstruction of Rawapening Lake, which was carried out based on variations in the abundance and diversity of diatoms vertically, showed that the pH of the waters tended to increase. Indicators that strengthen this statement are the dominance of *A. ambigua*, *A. granulate*, *S. ulna*, and *S. acus*. This can occur due to two things: the occurrence of the decomposition of organic material by microorganisms at the bottom of the lake or the use of lime in the manufacture of organic fertilizer from water hyacinth. When it rains, the lime will wash off and enter the lake [51].

Conclusions

The dominance of benthic indicators with high nutrient status indicates that Lake Rawapening has a long history of eutrophication. The condition of Rawapening Lake can be categorized into 3 zones, namely: (a) Zone 3 (90-100 cm layer) is dominated by diatoms *N. palea*, *N. closterium*, and *T. apiculate*, which indicate eutrophic water conditions; (b) Zone 2 (30-40 cm layer) is dominated by *A. distans*, *N. closterium*, *T. apiculata*, *S. ulna*, and *N. radiosa* species, where *A. distans* is widely distributed in clear and oligotrophic waters; (c) Zone 1 (1-20 cm layer) is found *S. pupula* of the genus Sellapora, which is an indicator of lake or river waters with mesotrophic-eutrophic conditions.

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Conflict of Interest

There is no conflict of interest in this research.

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