Diatom Stratigraphy as a Flood Record in the Lower Tuntang River, Demak, Central Java

Mirza Hanif Al Falah
Department of Environmental Science, Diponegoro University

Tri Retnaningsih Soeprobowati
Department of Environmental Science, Diponegoro University

Hadiyanto, Hadiyanto
Department of Environmental Science, Diponegoro University

Rahim, Aulia
Department of Environmental Science, Diponegoro University

他

https://doi.org/10.5109/6781082

出版情報：Evergreen. 10 (1), pp.272-282, 2023-03. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Diatom Stratigraphy as a Flood Record in the Lower Tuntang River, Demak, Central Java

Mirza Hanif Al Falah[1,2,4], Tri Retnaningsih Soeprobowati[1,2,3,4*], Hadiyanto Hadiyanto[1,2], Aulia Rahim[1,2,4], Barra Madini Noor[3,4], Nur Permatasari[3,4]

[1]Department of Environmental Science, Diponegoro University, 50275, Semarang, Indonesia

[2]School of Postgraduate Studies, Diponegoro University, 50275, Semarang, Indonesia

[3]Department of Biology, Diponegoro University, 50275, Semarang, Indonesia

[4]Cluster for Paleolimnology (CPalim), Diponegoro University, 50275, Semarang, Indonesia

*Corresponding author: trsoeprobowati@live.undip.ac.id

(Received November 30, 2022; Revised January 31, 2023; accepted February 17, 2023).

Abstract: The north coast of Central Java often experiences floods annually caused by land use functions as riparian zone turned into industrial and residential areas. Flooding in Tuntang River can be categorized into upstream floods, local floods, and tidal floods. The study investigates flooding records in Tuntang River based on diatoms. A hundred sediment sample cores were collected from 2 sites, slicing within intervals of 10 cm. Diatom digestion using HCl and H_2O_2 10%. The discovery of marine diatom species in all layers indicates that the Tuntang River has experienced tidal flooding.

Keywords: *Diatom, Stratigraphy, Tuntang River, Flooding, Tidal floods*

1. Introduction

On the north coast of Central Java frequently occurs flooding annually caused by climate change and human activities, involving the development of industrial areas, land clearing for shrimp ponds, and community settlements[1). Flooding is causing several detrimental impacts on the environment particularly in soil load enhancement causing land subsidence. Therefore, the several floods that happen in the area involve local floods, upstream floods, and tidal floods.

Indonesian floods are frequent several in frequency, intensities, and areas affecting over the last ten years due to detriment to the land and watersheds.[2). The previous study by Rudiarto, Handayani, and Setyono[3)] found that floods, tidal floods, and droughts were most common in coastal settlements in Central Java. In the urban area of Central Java, urbanization appears goes to rapidly due to its strategic geographical location supporting a high level of human activity.

Furthermore, watersheds along the north coast of Central Java Province are deemed critical for hydrometeorological disasters such as flooding. Based on 2014 to 2018 data from the Ministry of Public Works and Housing, 368 cases of flooding in Central Java Province, which only appear to be increasing[4)]; this phenomenon also affects the freshwater supply[5)]. In particular, 15 floods occurred on the Tuntang River (2014-2018). In 2014, the flood caused the embankment to collapse and inundated settlements as high as 3 m in Grobogan Regency[6)]. According to the Environment and Forestry Office of Central Java Province, the frequency of flooding on the Tuntang River is in the persistent category (>1 incident/year)[7)].

The Tuntang River originates in Lake Rawapening and empties into Demak Regency, flowing through three sub-districts in Demak Regency: Karang Tengah District, Demak District, and Bonang District. The Tuntang River experienced 13 floods that happened in 2018 causing local activities disruption.

The Tuntang River overflow is caused by a continuous process of sedimentation carried by the river flow, both from the Tuntang River itself and from the Tuntang River's branching streams, such as the Bancak River and the Senjoyo River. The land use transformation significantly affects Tuntang River siltation where previously, a large amount of water was absorbed (infiltrated), and the surface runoff became small. However, as land use changes, surface runoff increases, causing the river to be unable to accommodate the water discharge[9)].

Tidal floods occur at the time that entering of seawater into the mainland, usually during the full moon when the sea level risess8). The happening of floods is taking time to recede for 8-24 hours, therefore transportation disruption; The last incident of flood occurred in early January 2023, causing several disruptions that inhibits transportation, especially since the train line on the north coast was paralyzed due to a pool of water that covered the train line. Rising seawater towards the mainland also causes seawater intrusion. Saltwater intrusion is the impact of lowering the groundwater level in coastal areas; this process is caused by cones of depression and ascension in the groundwater system[10]. The impact felt by the people of Demak is that the groundwater used for community needs tastes salty. Tidal floods also cause shoreline changes of -553.3 – 20.4 m/year[11]. Inundation caused by tidal floods was also recorded up to 0.25 meters. This condition has a direct effect on increasing seawater intrusion into free aquifers[12),13)].

The study examined recordings of water conditions in the Tuntang River to determine the history of flooding using diatoms. The findings from this research are expected to become an early warning system for the community and the government in dealing with floods. The benthic diatom community's ecological preferences and biological characteristics are filtered by selected adaptations and habitat constraints[14),15),16)]. Organic pollution, eutrophication, flow velocity, and other factors influence the distribution pattern of benthic diatom communities[16),17)]. Diatoms are helpful indicators due to their short life cycle and rapid response to environmental changes[18)].

Floodwaters may directly impact the wetland algal assemblage by acting as a source of colonisers that develop within the wetland during and after flooding. Several studies have discovered riverine taxa deposited in wetland surface sediment after flood events[19),20),21),22),23)]. Floodwaters also have indirect effects, such as flushing out wetland algae or changing environmental conditions (e.g., turbidity, nutrients, sediments)[24),25)], so that the pre-flood assemblage is no longer favoured and a different set of species can dominate[26)].

Two sites used as coring points are located 10 km (site 1) and 8 km (site 2) from sea. Because the location point is still classified as freshwater, tidal floods can be proven if marine diatom species are found in the sediment. Several diatom species, such as *Nitzschia palea* and *Synedra ulna*, live in freshwater[27)], and *Chaetoceros* sp., which live in marine waters, have specific habitats that can be used as environmental indicators[28)]. Among the studies are chronological studies to establish a reliable age-depth model[29),30),31),32),33)], pollen[34),35),36)], seawater intrusion[37),38)] and human impact[39),40),41)].

2. Material and Methods

2.1 Study Area

Demak Regency is located at 6º43'26" - 7º09'43" S and 110027’58” - 110048'47" E. Demak has an area of ± 1,149.07 km^2, consisting of ± 897.43 km^2 of land and ± 252.34 km^2 of ocean[42)]. The Tuntang River rises in Lake Rawa Pening and flows downstream through Ambawara Regency, Semarang Regency, Grobogan Regency, and Demak Regency[43)]. While downstream, the river flows through Karang Tengah District, Demak District, and Bonang District before emptying into the Java Sea.

Demak's history was on the edge of the Java Sea in the 15th century (figure 1). Demak, Jepara, and Semarang regencies used to have boat stops, with Jepara as the center. During the Demak Kingdom, ships used the Tuntang River as a trade route. This river used to be 30 meters wide, allowing large ships from Java Sea to pass through. During the colonial period, the Tuntang River frequently overflowed, causing flooding in Demak Regency, so an embankment was built in the Ploso area of Wonosalam District, directing the flow to Bonang District and eventually into the sea[44), 45)].

Fig. 1: Reconstruction Map on Java Island

Locals use the Tuntang River for agriculture, plantations, ponds, and boat transportation. Rice (677,010 tonnes) from a paddy field area of 21,783 ha dominated agricultural products, while plantations produced tobacco (2,047.15 tonnes) from an area of 2,027 ha. The ponds were dominated by mackerel (*Rastrelliger* sp.) and anchovies (*Stolephorus indicus*) (1,913,687 tonnes) (1,861,864 tons). This has not been supplemented by residential and industrial development because Demak Regency's population increased by 0.69% between 2020 and 2021[46)].

Sampling was conducted on January 26, 2021, using the purposive sampling method. Purposive sampling determines site locations based on differences in location characteristics[47)]. Site 1 (code T1) is near the Pantura Semarang-Demak highway, and site 2 (code T2) is near a rice field area and close to a sewage pipe (figure 2).

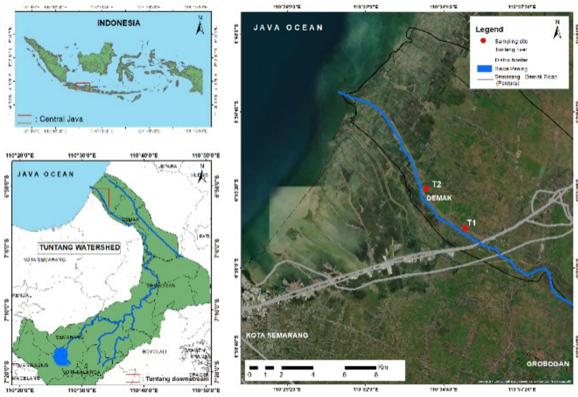


Fig. 2: Two research sites for collecting sedimen samples

2.2 Data Collection

The dissection corer method was used to collect sediment on the riverbank at sites 1 and 2 to a depth of 100 cm each. The sample was then transferred to pipe slats and wrapped in plastic before being transported to Diponegoro University's Integrated Science Laboratory, Faculty of Science and Mathematics. To preserve the stratigraphic layer, the sediment was cut into 1 cm slices and placed in zipped plastic that had been labeled before being frozen at -4ºC. Twenty-two samples were analyzed vertically with intervals of 10 cm at each site. Diatom digestion uses the Soeprobowati method[48] by heating it using 10% HCl and 10% H_2O_2 for 2-3 hours to separate the diatoms from organic and inorganic particles. Aquades solution is used to wash sediments treated with acid. Sample preparation using naphrax with a refractive index of 1.73. Observations were made with a Yazumi XSZ-107 microscope with a magnification of 1000x and identification using references Krammer and Lange-Bertalot[49),50),51),52),53),54),55], Gell[56], Sonneman et al.[57], Taylor et al.[58),59], Bahls et al.[60], Bahls et al.[61], and a photographic view via AlgaBase.org[62] and the diatoms.org website[63].

2.3 Data Analysis

The biological index is calculated using the Shannon-Wiener diversity index (H'), evenness index (e), and dominance index (D). The three indices were computed using PAST 4.12 software[64], Microsoft Excel 2013, and C2 1.7.7 for distribution visualization[65]. The dissimilarity coefficient, Bray-Curtis distance, was used to delineate stratigraphic zones of similar diatom assemblages. The Bray-Curtis dissimilarity is sensitive to species abundance differences, with abundant species being weighted more heavily than rare species[66]. Diatom counts from each site were expressed as relative abundances to account for the effects of rare species. All diatom taxa with fewer than two occurrences and a percentage of less than 2% were deleted from the database[67].

3. Results

A total of 87 species were found at both sites, with *Nitzschia palea* having the highest proportion of species at site 1 and *Fragilaria crotonensis* having the highest proportion of species at site 2 (figure 3). Species with a relative abundance value greater than 2% (> 2%) are considered capable of describing the environment[68].

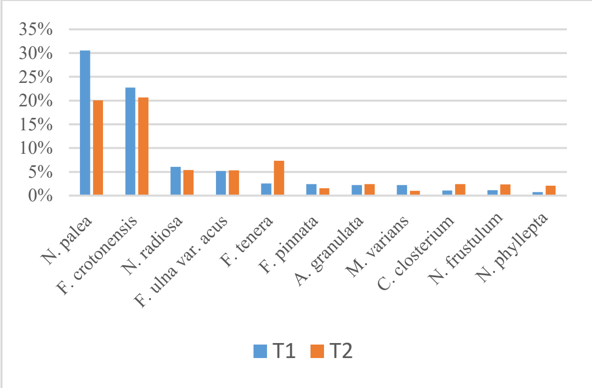
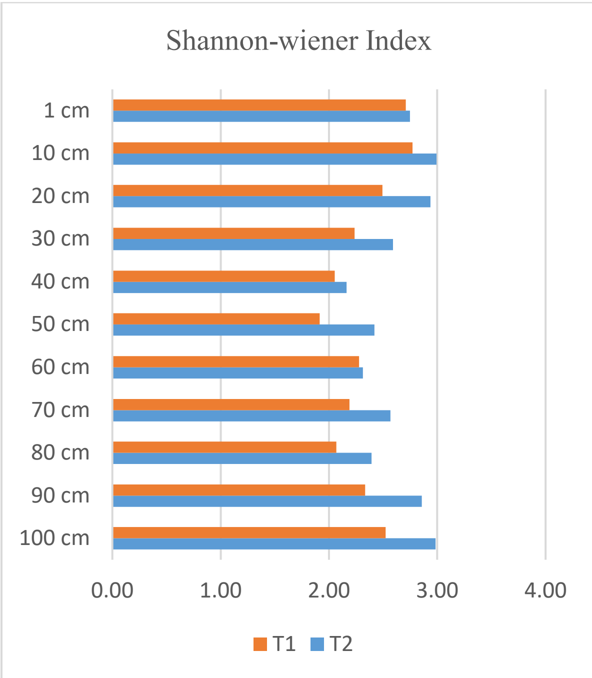
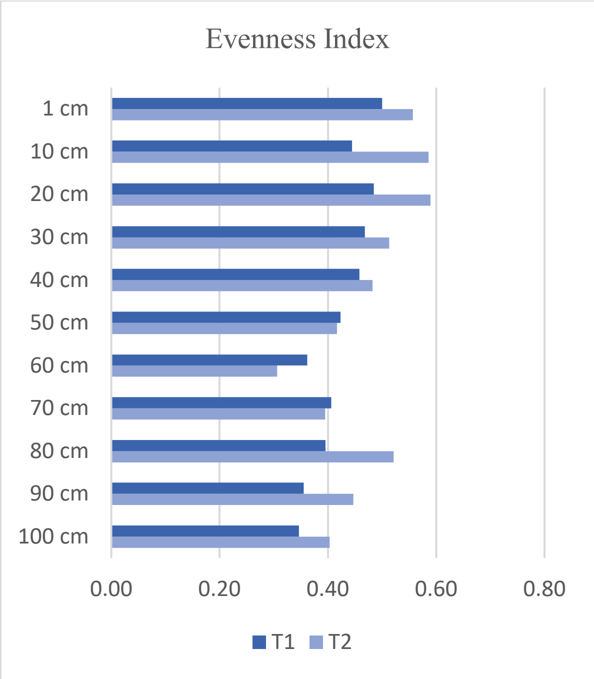


Fig. 3: Diatom abundance comparison from two sites

The Shannon-Wiener diversity index in site one ranges from 1.92-2.78, and site two ranges from 2.16-2.99, indicating that environmental conditions are still favorable. The evenness index (e) is in the 0.36-0.50 range, and site 2 has a 0.39-0.59 range, meaning that the species distribution is low to moderate. The dominance index (D) ranges in site one from 0.11-0.21 and from site two from 0.08 to 0.18, indicating that no species is dominant (figure 4).





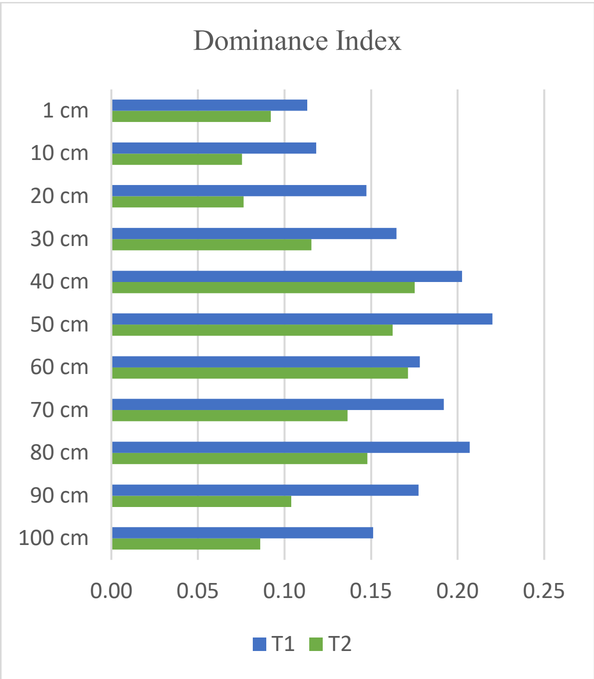


Fig. 4: Shannon-wiener, evenness, dominance index from two sites

The results of dividing the proportions of diatoms at site 1 are based on Guiry and Guiry[62]. They classify diatoms into six habitats, namely freshwater, brackish water, marine water, fresh brackish, fresh marine, and freshbrackishmarine so that the graphical proportions can be seen in figure 6. Marine species were not found at depths of 30-60 cm, indicating that at that depth, it is assumed that tidal floods does not reach the site. However, at 30 and 40 cm, diatoms living in brackish water were found, indicating that intrusive currents at that depth only carry brackish species (figure 5).

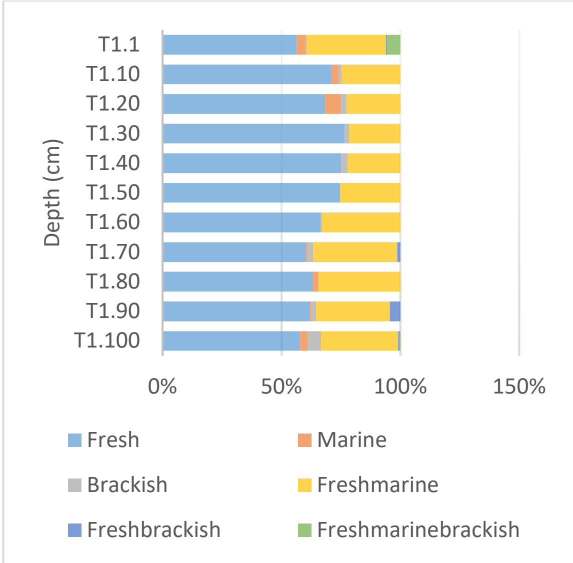


Fig. 5: Proportion between diatom habitats

The proportion of diatoms at site 2 revealed that there was no marine species but found brackish species only at depths of 30 and 40 cm, indicating that the tidal floods that occurred only brought brackish species (figure 6). Both sites revealed that species only lived in all aquatic habitats at the surface and at a depth of 100 cm.

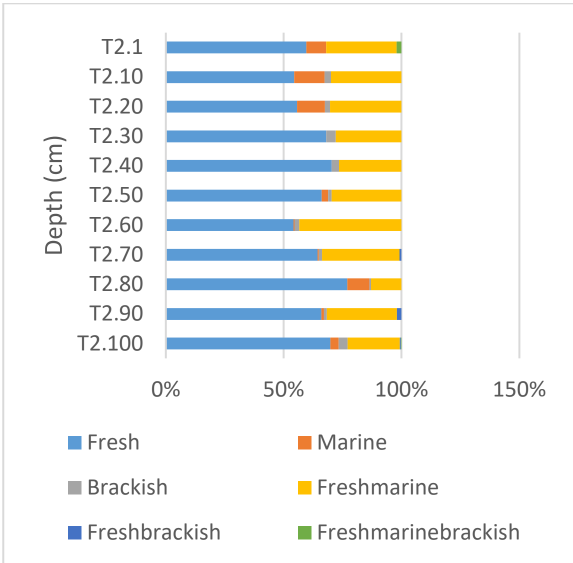


Fig. 6: Proportion between diatom habitats

The results of the bray-curtis cluster analysis divide site 1 into two large zones, with zone 1 divided into two (figure 7). The surface sediments are dominated by species of *Nitzschia palea, Fragilaria crotonensis, Fragilaria pinnata,* and *Navicula phyllepta*. Two marine species appear, namely *Cylindrotheca closterium* and *Tryblionella calida*.

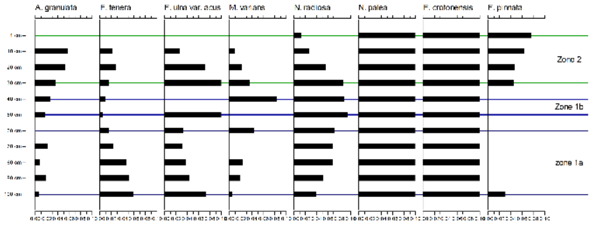


Fig. 7: Diatom stratigraphy

1. Zone 1 (100-40 cm)
This zone consists of two subzones (1a and 1b). Subdivision is based on variations of *Nitzschia linearis* and dominant species switches from *F. crotonensis* to *N. palea*.
2. Zone 2 (30-1 cm)
This zone happens because of abundance from *Cocconeis placentula* and *Eunotia bilunaris*.

b. Site 2
Site 2 is also divided into two significant zones, with zone 1 divided into two parts, 2a and 2b (Figure 8). The surface sediments are dominated by *F. crotonensis, F. tenera,* and *N. palea* species. The appearance of *C. closterium* and *Pleurosigma elongatum* indicates that tidal floods has occurred because both are marine species.

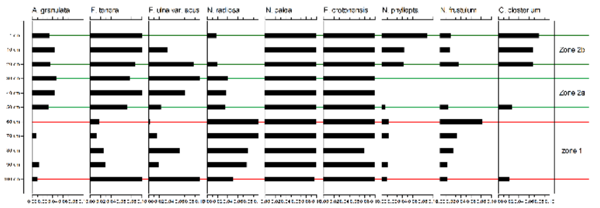


Fig. 8: Diatom stratigraphy

1. Zone 1 (100-60 cm)
This zone happens because of the abundance of *Achnanthidium reimeri* dan *Achnanthidium saprophilum*.
2. Zona 2 (50-1 cm)
This zone consists of two subzones (2a and 2b). Subdivision is based on variations of *Naviculla rostellata, Hantzschia amphioxys,* and *Eunotia incisa* also dominant species switches from *F. crotonensis* to *N. palea* (50-30 cm) and back again at 20-1 cm.

4. Discussions

The overflow of the Tuntang River flood can originate from different sources; the opening water gate of the upper reaches of Rawa Pening Lake, rainfall during the rainy season, and tidal floods. Stratification that occurs in tropical climates is happening annually, which is different from the waters region in the four seasons[69]. This phenomenon can be proven by discovering diatom species in six existing habitats assuming that marine and brackish species were carried toward the mainland due to intrusion. The significant economic and environmental impacts of saltwater intrusion into freshwater aquifers and drainage basins are natural ecosystem degradation and pollution of municipal and industrial water sources, agriculture, and industry[70]. Diatoms are particularly effective at reconstructing past environmental changes in the water body and basin characteristics. Diatoms are particularly useful for documenting changes in sea level because they are abundant in natural aquatic environments. Many species prefer waters with specific salinities or reflect the specific nature of temporary changes in water level[38].

The diversity index (H') with the lowest value was found in the sediment with a depth of 50 cm, which is 1,92, with 16 species found, and the highest value was found in the sediment with a depth of 10 cm, which is 2,78 with 36 species found. Site 2 has the lowest depth of 40 cm, 2,16, with 18 species found. The 10 cm had the highest value of 2,99 and 34 species. The diversity index in the sediment indicates a moderate level of diversity. The diversity index will rise as water quality improves[71].

The dominance of *N. palea* species at site 1 at depths ranging from 1 to 50 cm indicates a higher nutrient level and pollutant area[72]. *N. palea* is a cosmopolite diatom used as a bioindicator of water quality due to its toxicity tolerance[73]. *N. palea* was found throughout the environmental gradient levels, was resistant to organic and heavy metal pollution, and was frequently found in eutrophic lakes[74]. The *Navicula* and *Nitzschia* genera have movements that allow them to move to nutrient-rich areas. They may be associated with (fine) suspended sediments and/or are a common resident of lotic systems where sedimentation frequently occurs[75],[76]. Both genera survive by moving through sediments toward the light and avoiding being buried beneath particles, which keeps them from depositing[77]. The mesotrophic to highly eutrophic nutrient states that can provide the most competitive microhabitats for eutrophic and pollution-tolerant diatom taxa, specifically *Melosira, Navicula, Encyonema,* and *Nitzschia* species[15],[16],[78].

The dominance of *N. palea* shifted in a depth of 60-100 cm at site 1 to become the dominant of *F. crotonensis*. The dominance of *F. crotonensis* species further suggests well-mixed water with high Si availability but relatively poor light conditions[79],[80], ion concentrations in the water were increased and reduced water volume[77],[81] high-conductivity environments, such as brackish/halotolerant/halophilic *N. linearis*[82],[83], pollution-tolerant species with eutrophication and enrichment with organic material, like *N. palea*[84]. As long as the availability of nutrients demonstrates an important limiting factor derived from the light[85]. Local research on Subang Lake revealed that light attenuation limits photosynthetic activity to the upper layers, while decomposition activity dominates the deeper layers[69],[86].Changes in the dominance of these two species also occurred at site 2, with *N. palea* only dominating the depths of 40 cm, 50 cm, and 80 cm. In contrast, the other eight layers were dominated by *F. crotonensis*.

Melosira varians, which was thought to be a good indicator of eutrophic habitats in South African lowland streams characterized by mesotrophic conditions and influenced by agriculture[87]. *Encyonema* is a well-known freshwater genus frequently associated with eutrophic or nourishing conditions. *Encyonema minutum*, for example, has been described as a polluted water indicator[88]. Previous research found that *E. minutum* was closely linked to higher nutrient concentrations from agriculture and sewage water in the Andean river basin[89].

A study by Wiklund et al.[90] divided diatom categories into four based on their relation to flooding: strong flood indicators, strong non-flood indicators, moderate flood indicators, and moderate non-flood indicators. *G. angustum, G. gracile, R. gibba, N. fonticola* and *C. microcephala* (strong flood indicators). *E. turgida, N. cryptocephala* and *C. halophila* (strong non-flood indicators). *A. minutissima, C. placentula* (<15 µm), *G. parvulum, E. adnata, N. paleacea* and *N. radiosa* (moderate flood indicators), and four taxa (*C. placentula* (>15 µm), *N. palea, N. minima*, and *G. clavatum*) were identified as "moderate non-flood indicators".

So in, this study at site 1 indicated that upstream flooding and local flooding occurred in a continuous frequency with indications of the emergence of species *A. ambigua* (90 cm, 70-40 cm), *A. granulata* (100-70 cm, 50 -10 cm), *M. varians* (100-80 cm, 60 cm, 40-10 cm), *N. radiosa* (all depth). All depths at site 1 have an abundance of diatoms indicating that flooding often occurs downstream of the Tuntang River. The Tuntang River is one of the national priority rivers being restored due to the disturbed ecosystem due to the frequency of sedimentation and continuous flooding.

At site 2, the emergence of species *A. ambigua* (100-90 cm, 70-30 cm), *A. granulata* (100-90 cm, 70 cm, 50-1 cm), *M. varians* (90 cm, 50-10 cm), and *N. radiosa* (except 10 cm). This also indicates that each depth has species that indicate the occurrence of upstream and local flooding. Another study found that *C. placentula* decreased when major floods occurred[26]. The difference between *C. placentula* in studies conducted in Peace-Athabasca Delta (PAD), USA[90] and Tualatin River, USA[26] is because, in Peace-Athabasca Delta (PAD), USA also paid attention to the details of the size of the species which over the 15 µm range.

The relative abundance of planktonic diatoms (*A. granulata, C. invisitatus, C. pseudostelligera*) increased in the wetland (USA) during high-magnitude floods. Meanwhile, other species, such as *A. italica* and *M. varians*, were found to be abundant during the rainy season in Lake Broa, Brazil[91]. The genus Aulacoseira is an indicator of storms and swift water currents, as evidenced by the abundance of this species in waters with mixed water, such as Huguang Maar Lake[92], Rocky Mountain Lakes[93], Hidden Lake[94], and Alpine Lakes[95].

The proportion of diatoms found indicates a difference in the rate of tidal floods at both sites. At site 1, no marine species were discovered at depths ranging from 30 cm to 60 cm, but brackish species were found only at depths of 30 cm and 40 cm. Marine species were not found at site 2 except at depths of 30 cm and 40 cm, but brackish species were. The marine species discovered at the two sites were *C. closterium, P. elongatum, T. calida*, *T. apiculata*, and *T. littoralis*. *C. closterium* is a model marine diatom widely distributed in the marine environment[96),97]. *P. elongatum* had a positive correlation with increased dissolved oxygen concentrations, nutrients (DIP and NO_2), and elevated trophic levels (TRIX) during higher rainfall periods[98]. Saltwater infiltration into groundwater systems raises the height of the freshwater-saltwater interface, affecting coastal ecosystems such as marshes[99].

The influence of seawater was also found in research in the Banjir Kanal Timur, Semarang (BKT)[38], which is about 5 km from the mouth of the Tuntang River. Marine diatoms were found abundant in the bottom layer, so it is assumed that the influence of seawater on BKT began in 1855. Meanwhile, the influence of seawater in Demak Regency was also caused by land subsidence, with the most significant tidal flood peak in 2005, with a height of 1.5 m.

5. Conclusion

Diatoms able to describe environmental conditions because of their rapid adaptation to environmental changes. Flood records at sites 1 and 2 show that upstream flooding and local flooding occurred at all depths, based on indications of the appearance freshwater species of *A. granulata, A. ambigua, M. varians,* and *N. radiosa*. While floods originating from sea tides are proven by carrying marine species such as *C. closterium, C. closterium, P. elongatum, T. calida, T. apiculata*, and *T. littoralis*. This flood phenomenon can be used as a reference in flood prevention measures downstream of the Tuntang River. Floods due to upstream and local floods have resulted in several socio-economic losses for the community, primarily in agricultural areas. While floods originating from seawater tides result in the mixing of seawater and fresh water.

Acknowledgments

This research was funded by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia in the Program Magister menuju Doktor untuk Sarjana Unggul (PMDSU) program through Diponegoro University with contract number 345-43/UN7.6.1/PP/2022, and Research for International Publication (RPI) from Diponegoro University with the contract number 569-58/UN.7.D2/PP/VII/2022.

References

1) A. Sarasadi, I. Rudiarto, A. Faradila, "Adaptation Strategy of Tidal Flood Handling a Case Study in Sayung Sub-District, Demak," *Forum Ilmu Sosial.*, **48** (*2*) 93-99 (2021). https://doi.org/10.15294/fis.v48i2.31204.
2) M.L. Hakim, "Dampak alih fungsi lahan terhadap keberlanjutan suplai air di Waduk Sutami, Malang, Jawa Timur," *Widyariset.*, **13** (*3*) 27–34 (2010). http://dx.doi.org/10.14203/widyariset.13.3.2010.27-34.
3) I. Rudiarto, W. Handayani, J.S. Setyono, "A regional perspective on urbanization and climate-related disasters in the northern coastal region of central Java, Indonesia," *Land.*, **7** (*1*) (2018). https://doi.org/10.3390/land7010034.
4) M. Isa, F.X. Sugiyanto, I. Susilowati, "Community resilience to floods in the coastal zone for disaster risk reduction," *Jamba: Journal of Disaster Risk Studies*., **10** (*1*) 356 (2018). https://doi.org/10.4102/jamba.v10i1.356.
5) M.W. Shahzad, K. Thu, B.B. Saha, K.C. Ng, "An Emerging Hybrid ulti-Effect Adsoption Desalination System," *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*., **1** (*2*) 30-36 (2014). doi: 10.5109/1495161.
6) Office of Public Works, Water Resources and Spatial Planning, Central Java Province, "Recap of the Central Java Flood Natural Disaster Event Inventory," *Pusdataru Open Data Provinsi Jawa Tengah*, https://pusdataru.jatengprov.go.id/opdt/ (accessed January 26, 2023).
7) Watershed Management Center and Pemalijratun Protected Forest, "Dissemination Of Classification Results Of Classification Of Watershed Areas," Semarang, Indonesia (2019).
8) "Open Data Demak Regency," http://103.47.60.179/fi/ (accessed November 19, 2022).
9) I. Maulana, S.A. Lukita, S. Suharyanto, S. Pranoto, " Perencanaan Pengendalian Banjir Sungai Tuntang di Desa Trimulyo Kabupaten Demak," *JURNAL KARYA TEKNIK SIPIL S1 Undip.,* **6** (*4*) 447-459 (2017).
10) D.A. Widiarso, T. Winarno, W. Haryanto, "Pengaruh Intrusi Airlaut dan Banjir Pasang (Rob) terhadap Sifat Specific Gravity dan Unit Weight Tanah Lempung Aluvial di Kota Semarang," *Jurnal Geosains dan Teknologi*., **3** (*3*) (2020).
11) E. Trihatmoko, H.S. Wiguna, T.B. Sanjoto*, et al*, "Penelitian Pendahuluan (Preliminary Research) Intrusi Air Laut di Desa Sriwulan, Demak, Indonesia," *Indonesian Journal of Oceanography*., **2** (*4*) (2020).
12) R. Meyer, P. Engesgaard, T.O. Sonnenborg, "Origin and Dynamics of Saltwater Intrusion in a Regional Aquifer: Combining 3-D Saltwater Modeling With Geophysical and Geochemical Data," *Water Resources Research*., **55** (*3*) 1792–1813 (2019). https://doi.org/10.1029/2018WR023624.
13) K. Nisa and T. Yulianto, "Aplikasi Metode Geolistrik Tahanan Jenis Untuk Menentukan Zona Intrusi Air Laut di Kecamatan Genuk, Semarang," **15** (*1*).
14) R. Gudmundsdottir, S. Palsson, E.R. Hannesdottir, J.S. Olafsson, G.M. Gislason, B. Moss, "Diatoms as indicators: The influences of experimental nitrogen enrichment on diatom assemblages in sub-Arctic streams," *Ecol Indic*., **32** 74–81 (2013). https://doi.org/10.1016/j.ecolind.2013.03.015.
15) X. Chen, Z. Bu, M.A. Stevenson, Y. Cao, L. Zeng, B. Qin, "Variations in diatom communities at genus and species levels in peatlands (central China) linked to microhabitats and environmental factors," *Sci Total Environ*., **568** 137–146 (2016). https://doi.org/10.1016/j.scitotenv.2016.06.015.
16) R. Chen, Y. Teng, H. Chen, B. Hu, W. Yue, "Groundwater pollution and risk assessment based on source apportionment in a typical cold agricultural region in Northeastern China," *Sci Total Environ*., **696** 133972 (2019). https://doi.org/ 10.1016/j.scitotenv.2019.133972.
17) T. Mangadze, R.J. Wasserman, T. Dalu, "Use of Diatom Communities as Indicators of Conductivity and Ionic Composition in a Small Austral Temperate River System," *Water Air and Soil Pollution*., **228** 428 (2017). https://doi.org /10.1007/s11270-017-3610-3.
18) S. Kafouris, E. Smeti, S. Spatharis, G. Tsirtsis, A. Economou-Amili, D.B. Danielidis, "Nitrogen as the main driver of benthic diatom composition and diversity in oligotrophic coastal systems," *Sci Total Environ*., **694** 133773 (2019). https://doi.org/ 10.1016/ j.scitotenv.2019.133773.
19) M.B. Hay, J.P. Smol, K.J. Pipke, L.F.W. Lesack, "A diatom-based paleohydrological model for the Mackenzie Delta, Northwest Territories, Canada," *Arctic and Alpine Research.,* **29** 430–444 (1997).
20) M.C. Thoms, R.W. Odgen, M.A. Reid, "Establishing the condition of lowland floodplain rivers: a palaeo-ecological approach," *Freshwater Biology* **41** 407–423 (1999).
21) M.B. Hay, N. Michelutti, J.P. Smol, "Ecological patterns of diatom assemblages from Mackenzie Delta lakes, Northwest Territories, Canada," *Canadian Journal of Botany*., **78** 19–33 (2000).
22) P.A. Gell, I.R. Sluiter, J. Fluin, "Seasonal and interannual variations in diatom assemblages in Murray River connected wetlands in north-west Victoria, Australia," *Marine and Freshwater Research* **53** 981–992 (2002).
23) B.E. Medioli and G.R. Brooks, "Diatom and theocamoebian signatures of Red River (Manitoba and North Dakota) floods: data collected from the 1997 and 1999 spring freshets," *Journal of Paleolimnology*., **29** 353–386 (2003).
24) D.L. Engle and J.M. Melack, "Consequences of riverine flooding for seston and the periphyton of

floating meadows in an Amazon floodplain lake," *Limnology and Oceanography*., **38** 1500–1520 (1993).

25) A.I. Robertson, S.E. Bunn, P.I. Boon, K.F. Walker, "Sources, sinks and transformations of organic carbon in Australian floodplain rivers," *Marine and Freshwater Research.,* **50** 813–29 (1999).

26) C.L Weilhoefer, Y. Pan, S. Eppard, "The effects of river floodwaters on floodplain wetland water quality and diatom assemblages," *Wetlands* **28**, 473–486 (2008). https://doi-org.proxy.undip.ac.id/10.1672/07-114.1.

27) S. Moisset, S.K. Tiam, A. Feurtet-Mazel, S. Morin, F. Delmas, N. Mazzella, P. Gonzales, "Genetic and physiological responses of three freshwater diatoms to realistic diuron exposures," *Environ Sci Pollut Res Int*, **22** (*6*) 4046-55 (2015). doi: 10.1007/s11356-014-3523-2.

28) S. Malviya, E. Scalco, S. Audic, *et al*, "Insights into global diatom distribution and diversity in the world's ocean," *PNAS*, 113 (11) E1516–E1525 (2016). https://doi.org/10.1073/pnas.1509523113.

29) I. Hajdas, B. Zolitschka, S.D. Ivy-Ochs, *et al*, "AMS radiocarbon dating of annually laminated sediments from lake Holzmaar, Germany," *Quat. Sci. Rev*., **14** (*2*) 137-143 (1995). https://doi.org/10.1016/0277-3791(94) 00123-S.

30) I. Hajdas, G. Bonani, B. Zolitschka, "Radiocarbon dating of varve chronologies: soppensee and holzmaar lakes after ten years," *Radiocarbon.*, **42** (*3*) 349-353 (2000). https://doi.org/10.1017/S0033822200030290.

31) A. Lang, and B. Zolitschka, "Optical dating of annually laminated lake sediments A test case from Holzmaar, Germany," *Quat. Sci. Rev*., **20** (*5-9*) 737-742 (2001). https:// doi.org/10.1016/S0277-3791(00)00067-6.

32) B. Zolitschka, "Absolute dating of late Quaternary Lacustrine sediments by high resolution varve chronology," *Hydrobiologia.*, **214** 59-61 (1991). https://doi.org/ 10.1007/BF00050932.

33) B. Zolitschka, A. Brauer, J.F.W. Negendank, H. Stockhausen, A. Lang, "Annually dated late Weichselian continental paleoclimate record from the Eifel, Germany," *Geology.*, **28** (*9*) 783-786 (2000). https://doi.org/10.1130/0091-7613(2000)282.0.CO;2

34) S.A.G. Leroy, B. Zolitschka, J.F.W. Negendank, G. Seret, "Palynological analyses in the laminated sediment of lake Holzmaar (Eifel, Germany): duration of lateglacial and preboreal biozones," *Boreas*., **29** (*1*) 52-71 (2000). https://doi.org/ 10.1111/j.1502-3885.2000. tb01200.x.

35) T. Litt, C. Scholzel, N. Kühl, A. Brauer, "Vegetation and climate history in the Westeifel Volcanic Field (Germany) during the past 11 000 years based on annually laminated lacustrine maar sediments," *Boreas.*, **38** (*4*) 679-690 (2009). https:// doi.org/10.1111/j.1502-3885.2009.00096.x.

36) A.F. Lotter, H.J.B. Birks, B. Zolitschka, "Late-glacial pollen and diatom changes in response to two different environmental perturbations: volcanic eruption and Younger Dryas cooling," *J. Paleolimnol*., **14** (*1*): 23-47 (1995). https://doi.org/ 10.1007/ BF00682592.

37) Z-X. Zhou, R-C. Yu, C. Sun, M. Feng, M-J. Zhou, "Impacts of Changjiang River discharge and Kuroshio intrusion on the diatom and dinoflagellate blooms in the East China Sea," *Journal of Geophysical Research: Oceans*, **124** (*7*) 5244–5257 (2019). https://doi. org/10.1029/ 2019JC015158.

38) T.R. Soeprobowati, S.W.A. Suedy, A.A. Lubis, J. Miller, "Pollen and diatom evidence of sea water intrusion, east flood canal (Banjir Kanal Timur), Semarang, Indonesia," *Environmental Earth Sciences*, **79** 462 (2020). https://doi.org/10.1007/ s12665-020-09186-x.

39) B. Zolitschka, "Human History Recorded in the Annually Laminated Sediments of Lake Holzmaar, Germany," *Proc. Workshop*., **14** 17-24 (1992).

40) B. Zolitschka, J. Mingram, S.V.D. Gaast, J.H.F. Jansen, R. Nauman, "Sediment logging techniques," In: Last, W.M., Smol, J.P. (Eds.), Tracking Environmental Change Using Lake Sediments, *Springer Netherlands.*, **1** 137-153 (2002). https://doi.org/10.1007/0-306-47669-X_7.

41) B. Zolitschka, K-E. Behre, J. Schneider, "Human and climatic impact on the environment as derived from colluvial, fluvial and lacustrine archives examples from the Bronze Age to the Migration period, Germany," *Quat. Sci. Rev*., **22** (*1*) 81-100 (2003). https://doi.org/10.1016/S0277-3791(02) 00182-8.

42) M.A. Marfai, "The hazards of coastal erosion in Central Java, Indonesia: An overview," *Malaysia Journal of Society and Space.*, **7** (*3*) 1- 9 (2011). ISSN 2180-2491.

43) Semarang Environment Agency, "Laporan Informasi Kinerja Pengelolaan Lingkungan Hidup. Semarang," (2017).

44) Herwanto, "Mercusuar Islam di Tanah Jawa [Motion Picture]," (2013).

45) I. Naafii'aa I, and Nurini, "Arahan Perancangan Ruang Publik Dengan Pendekatan Konsep Riverfront Di Sungai Tuntang Kabupaten Demak," *Jurnal Teknik PWK.*, **4** (*3*) 373-388 (2015).

46) Demak Central Bureau of Statistics, "Demak Regency in Figures. Demak," (2022). ISSN : 0215-5222.

47) B.A Prahardika, and W.M.L.D. Styawan, "Studi Keanekaragaman Diatom Epilitik Serta Potensinya Sebagai Bioindikator Kualitas Perairan Sungai di Coban Tarzan Kabupaten Malang," *Journal of Tropical Biology*, **8** (*2*) 116-124 (2020). https://doi.org/10.21776/ub.biotropika.2020.008.0 2.07

48) T.R. Soeprobobowati, S.D. Tandjung, S. Sutikno, S. Hadisusanto, P. Gell, "The minimum number of valves for diatom identification in Rawapening

Lake Central Jawa," *Biotropia.*, **23** (*2*) 96–104 (2016). https:// doi. org/ 10. 11598/ btb. 2016. 23.2. 486.
49) K. Krammer, H. Lange-Bertalot, "Bacillariophyceae. 1. Teil: Naviculaceae. in Ettl, H., Gerloff, J., Heynig, H. and Mollenhauer, D. (eds) Süsswasser flora von Mitteleuropa, Band 2/1," Gustav Fischer Verlag: Stuttgart, New York, 876 pp (1986).
50) K. Krammer, H. Lange-Bertalot, "Bacillariophyceae. 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. in Ettl, H., Gerloff, J., Heynig, H. and Mollenhauer, D. (eds) Süsswasserflora von Mitteleuropa, Band 2/2," VEB Gustav Fischer Verlag: Jena, 596 pp (1988).
51) K. Krammer, H. Lange-Bertalot, "Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae In Ettl, H., Gerloff, J., Heynig, H. & Mollenhauer, D. (Eds.). Süsswasserflora von Mitteleuropa," **2** (*3*) 1-576 (1991).
52) K. Krammer, H. Lange-Bertalot, "Bacillariophyceae 5. English and French translation of the keys. In: Büdel, B., Gärtner, G., Krienitz, L. & Lokhorst, G. M. (eds.). Süßwasserflora von Mitteleuropa," **2** (*5*) 311 pp (2000).
53) K. Krammer, H. Lange-Bertalot, "Susswasserflora Von Mitteleuropa, Bd. 02/1: Bacillariophyceae: Teil 1: Naviculae," Spectrum, Berlin (2004).
54) K. Krammer, H. Lange-Bertalot, "Susswasserflora Von Mitteleuropa, Bd. 02/2: Bacillariophyceae: Teil 2: Bacillariphyceae, Epithemiaceae, Surirellaceae," Spectrum, Berlin (2004).
55) K. Krammer, H. Lange-Bertalot, "Susswasserflora Von Mitteleuropa, Bd. 02/3: Bacillariophyceae: Teil 3: Centrales, Fragillariaceae, Eunotiaceae," Spectrum, Berlin (2004).
56) P.A. Gell, J.A. Sonneman, M.A. Reid, M.A. Illman, A.J. Sincock, "An Illustrated Key to Common Diatom Genera from Southern Australia," Cooperative Research Centre for Freshwaater Ecology Identification Guide No. 26, Albury (1996). ISBN: 9781876144272.
57) J.A. Sonneman, A. Sincock, J. Fluin, *et al*, "An Illustrated Guide to Common Stream Diatom Species from Temperate Australia," Cooperative Research Centre for freshwater Ecology, Albury (1999).
58) J.C. Taylor, W.R. Harding, C.G. Archibald, "An Illustrated Guide to Some Common Diatom Species from South Africa," Water Research Commission. South Africa (2007).
59) J.C. Taylor, C. Cocquyt, "Navicula nielsfogedii J.C. Taylor & Cocquyt sp. nov., a new diatom (Bacillariophyta) from tropical and sub-tropical Africa," *Journal of the Czech Phycological Society*., **16** (*2*) (2016).
60) L.L. Bahls, "Diatoms from Western North America 1. Some New and Notable Biraphid Species," Montana, USA (2017).
61) L.L. Bahls, B. Boynton, B. Johnston, "Atlas of diatoms (Bacillariophyta) from diverse habitats in remote regions of western Canada," *PhytoKeys.*, **105** (*4*) 1-186 (2018).
62) "AlgaeBase," https://www.algaebase.org (accessed November 1, 2022).
63) "Diatoms of North Maerica," https://diatoms.org (accessed November 1, 2022).
64) Ø Hammer, D.A.T. Harper, "Paleontological Data Analysis," Blackwell (2006).
65) S. Juggins, "The European Diatom Database User Guide Version 1.7.7," University of New Castle, New Castle, UK (2016).
66) C. Ricotta, and J. Podani, "On some properties of the Bray-Curtis dissimilarity and their ecological meaning," *Ecological Complexity.*, **31** 201–205 (2017). https://doi.org/10.1016/j.ecocom.2017.07.003.
67) I. Karaouzas, E. Smeti, E. Kalogianni, N.T. Skoulidis, "Ecological status monitoring and assessment in Greek rivers: Do macroinvertebrate and diatom indices indicate same responses to anthropogenic pressures?" *Ecol Indic*., **101** 126–132 (2019). https://doi.org/10.1016/j.ecolind.2019.01. 011.
68) T.R. Soeprobowati, T.R. Saraswati, J. Jumari, K. Sari, P.Gell, "Diatom index of Galela Lake, Halmahera, Indonesia in relation to human activities," *Int. J. Environ. Sci. Technol.*, (2022). https://doi.org/10.1007/s13762-022-04463-7.
69) G.K.S. Singh, P. Kuppan, M. Goto, et al., "Physical Water Quality and Algal Density for Remediation of Algal Blooms in Tropical Shallow Eutrophic Reservoir," *Journal of Novel Carbon Resource Sciences.*, **7** 33-41 (2013)
70) P.M. Barlow, and E.G. Reichard, "Saltwater intrusion in coastal regions of North America," *Hydrogeology Journal*., **18** 247-260 (2010). https://doi.org/10.1007/s10040-009-0514-3.
71) Z. Hao, L. Xingguo, P. Enle, G. Wenli, X. Shuzhong, "Studies on effects of ecological restoration on water quality in Dalian Lake," *Chin. J. Environ. Eng*., **4** (*8*) 1790–1794 (2010).
72) T. Bere, and J.G. Tundisi, "The effects of substrate type on diatom-based multivariate water quality assessment in a tropical river (Monjolinho), São Carlos, SP, Brazil," *Water Air Soil Pollut.*, **216** 391–409 (2011). https://doi.org/10.1007/s11270-010-0540-8.
73) H.T.T. Hang, L.T.P. Quynh, D.T. Thuy, "Diatom composition in the red river near Son Tay, Ha Noi," *Vietnam J. Sci. Technol*., **55** 90–96 (2017).
74) L. González-Paz, C. Delgado, I. Pardo, "Understanding divergences between ecological status classification systems based on diatoms," *Science of the Total Environment.*, **734** 139418 (2020). https://doi.org/10.1016/j.scitotenv.2020.139418.
75) A.L.M.D. Fabricius, N. Maidana, N. Gómez, S. Sabater, "Distribution patterns of benthic diatoms in a Pampean river exposed to seasonal floods: the Cuarto River (Argentina)," *Biodivers. Conserv*., **12** (*12*) 2443–2454 (2003). https://doi.org/10. 1023/ A: 1025857715437.

76) O. Izagirre, A. Serra, H. Guasch, A. Elosegi, "Effects of sediment deposition on periphytic biomass, photosynthetic activity and algal community structure," *Sci. Total Environ*., **407** 5694–5700 (2009). doi: 10.1016/j.scitotenv.2009.06.049.
77) A-M. Klamt, K. Hu, L. Huang, *et al*, "An extreme drought event homogenises the diatom composition of two shallow lakes in southwest China," *Ecological Indicators.*, **108** 105662 (2020). https://doi.org/10.1016/ j.ecolind. 2019.105662.
78) C. Wang, S. Lek, Z. Lai, L. Tudesque, "Morphology of Aulacoseira filaments as indicator of the aquatic environment in a large subtropical river: The Pearl River, China," *Ecol Indic.*, **81** 325–332 (2017). https://doi.org/ 10.1016/ j.ecolind.2017.06.020.
79) C. Tian, H. Pei, W. Hu, *et al*, "Variation of phytoplankton functional groups modulated by hydraulic controls in Hongze Lake, China," *Environ. Sci. Pollut. Res*., **22** 18163–18175 (2015). https://doi.org/10. 1007/ s11356-015-4830-y.
80) J. Foets, C. Cocquyt, B.V. de Vijver, "Diatom succession during the last few decades in a small pond at the Botanic Garden Meise, Belgium, based on paleolimnological analyses," *Nova Hedwigia.*, **146** 303-313 (2018).
81) J. Brasil, J.L. Attayde, F.R. Vasconcelos, *et al*, "Drought induced water-level reduction favors cyanobacteria blooms in tropical shallow lakes," *Hydrobiologia.*, **770** 145–164 (2016). https://doi.org/10.1007/s10750-015-2578-5.
82) G. Hofmann, M. Werum, H. Lange-Bertalot, "Diatomeen im Süßwasser-Benthos von Mitteleuropa: Bestimmungsflora Kieselalgen für die ökologische Praxis; über 700 der häufigsten Arten und ihrer Ökologie," Gantner (2011).
83) I.Y. Olodo, C. Cocquyt, Y. Abou, K. Kokou, "Seasonal variations and distribution of diatom flora of Lake Ahémé (Benin, West Africa)," *Bot. Lett*., **167** (*1*) 160-173 (2020). DOI: 10.1080/23818107.2019.1657495.
84) H.V. Dam, A. Mertens, J. Sinkeldam, "A coded checklist and ecological indicator values of freshwater diatoms from The Netherlands," *Netherland J. Aquat. Ecol*., **28** 117-133 (1994). https://doi.org/10.1007/ BF02334251.
85) World Health Organization, "Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management," eds. by I. Chorus, J. Bartram World Health Organization (WHO), Geneva (1999).
86) P. T.Arumugam, and J. I. Furtado, "Enrichment and Recovery of a Malaysian Reservoir," *Hydrobiologia*, **11** (*1*) (1980). doi: 10.1007/978-94-009-9203-0_31.
87) C.R. Petersen, N.Z. Jovanovic, M.C. Grenfell, P.J. Oberholster, P. Cheng, "Responses of aquatic communities to physical and chemical parameters in agriculturally impacted coastal river systems," *Hydrobiologia.*, **813** (*1*) 157–175 (2018). https://doi.org/ 10.1007/s10750-018-3518-y.
88) I. Lavoie, S. Campeau, F. Darchambeau, G. Cabana, "Are diatoms good integrators of temporal variability in stream water quality?" *Freshwater Biol*., **53** (*4*) 827–841 (2008). DOI: 10.1111/j.1365-2427.2007. 01935.x.
89) X. Lu, L. Tian, S. Tao, Y. Liu, Y. Fan, "The response of benthic diatom community to anthropogenic eutrophication of a river basin under agricultural influence in NE China," *Journal of Freshwater Ecology.*, **37** (*1*) 495-511 (2022). DOI: 10.1080/02705060.2022.2124321.
90) J. Wiklund, B. Natalie, H. Roland, W. Brent, "Epiphytic diatoms as flood indicators," *Journal of Paleolimnology*., **44** 25-42 (2010). 10.1007/ s10933-009-9383-y.
91) M.S. Nardelli, D.C. Bicudo, S.C. Sampaio, C.M.d.S. Cordovil, "Structure and species composition of diatom community during the wet season in three floodplain lakes of Brazilian Pantanal," *PLoS ONE*., **16** (*5*) (2021). https://doi. org/10.1371/journal.pone.0251063.
92) Wang, L., Li, J., Lu, H., Gu, Z., Rioual, P., et al, "The East Asian winter monsoon over the last 15,000 years: its links to high-latitudes and tropical climate systems and complex correlation to the summer monsoon," *Quat Sci Rev*., **32** 131–142 (2012).
93) Stone, J.R., Saros, J.E., Pederson, G.T, "Coherent late-Holocene climate-driven shifts in the structure of three Rocky Mountain lakes," *Holocene*, **26** 1103–1111 (2016).
94) Stone, J.R., Saros, J.E., Spanbauer, T.L, "The influence of fetch on the Holocene thermal structure of Hidden Lake, Glacier National Park," *Front Earth Sci* **7** 28 (2019).
95) Leira, M., Filippi, M.L., Cantonati, M, "Diatom community response to extreme water-level fluctuations in two Alpine lakes: a core case study," *J Paleolimnol.,* **53** 289–307 (2015).
96) Y. Li, J. Gao, F. Meng, J. Chi, "Enhanced biodegradation of phthalate acid esters in marine sediments by benthic diatom Cylindrotheca closterium," *Science of The Total Environment.*, **508** 251-257 (2015). https://doi.org/10.1016/ j.scitotenv. 2014.12.002.
97) F. Zhang, Z. Ding, H. Gong, J. Chi, "Effects of microphytobenthos Cylindrotheca closterium on the fate of di-n-butyl phthalate in an aquatic microcosm," *Marine Pollution Bulletin.*, **140** 101-106 (2019). https://doi.org/10.1016/j.marpolbul. 2019. 01. 033.
98) M.V.J. Cutrim, F.S.Ferreira, A.K.D. dos Santos, *et al*, "Trophic state of an urban coastal lagoon (northern Brazil), seasonal variation of the phytoplankton community and environmental variables," *Estuarine, Coastal and Shelf Science*., **216** 98-109 (2019). https://doi.org/10.1016/j.ecss. 2018.08.013.

99) A.W. Pramita, and D.N. Sugianto, "Effect of seawater intrusion on groundwater in the Demak coastal area Indonesia: a review," *IOP Conf. Ser.: Earth Environ. Sci.*, **896** 012070 (2021). DOI 10.1088/1755-1315/896/1/012070.