The challenges of paleolimnology Indonesia

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Abstract. Paleolimnology had increased sharply as an approach for lake management, but most of the paleontological studies have been carried out in temperate and high-latitude regions. 40% of lakes lie within tropical areas, which represent 32% of surface global water bodies. Paleolimnology is a study of the physical, chemical, and biological features of the lakes in the past. Find the future from the past, prediction of the future condition can be developed from the reconstruction of past condition, based on the fossil preserved in the sediment. Ecosystem services of the lakes are hydroelectricity power, source of drinking water, irrigation, fisheries, tourism, socio-economic religious activities. Those functions have been deteriorated due to sedimentation, pollution, and eutrophication. Water security becomes a problem. Lake sediments as archives that record the climatic and environmental changes in the catchment area. VosViewer had been applied to construct and visualize bibliometric publications indexing by Scopus with the keywords paleolimnology, water resource, renewable energy, climate change, and food security. The result shows that there is a strong relationship between paleolimnology, climate change, and food security. Paleolimnology contributed to SDGs number 6 (water security and sanitation) has an important role in the achievement of SDGs number 2 of food security through adaptation and mitigation of climate change (SDGs number 13), and terrestrial ecosystem, including lakes. This paper will discuss a paleolimnological approach to reconstruct past environmental changes and their challenges in Indonesia.

1. Introduction
Paeolimnology is the study of the physical, chemical, and biological information preserved in the lake sediments, that allows for the reconstruction of natural/anthropogenic change and the interpretation of the past condition of the aquatic ecosystem [1], is evaluating the magnitude and direction of human-induced environmental change in lakes and their catchments [2], is lake sediment records to understand historical lake and landscape development, timing and magnitude of environmental change at the lake, watershed, regional and global scales, and as historical datasets to target watershed and lake management [3]. So, paleolimnology can be defined as the study of freshwater using the physical, chemical, and biological information preserved in the sediment, to reconstruct past condition- as a basis to develop lake management [4].

A large water body that is surrounded by land that naturally origin or man-made as a lentic ecosystem with the size of greater than 2 Ha [5], but [6] stated that the minimum size of the lakes is 0.1 Ha. In Indonesia, a lake is a lentic ecosystem greater than one km² and volume above one million m³ [7].
2. Lakes as a diary book

Naturally, the silting process of the lake cannot be avoided due to the sedimentation process. Generally, sediment input from fluvial will be entered into the lake, the dense bottom flow, intermediate flows, and surface flows. However, when sediments entered the lake with an abundant supply of terrestrial sediment, induce the occurrence of fluvialacustrine delta. Lake sediments are an important part of the lake ecosystem. Land-use changes in the catchment area are well recorded in the lake sediment. This historical archive can be studied within the line evidence of the multiple indicators, like the diary book. The records are diatom, pollen, or other fossils preserved in the sediment. The difference of fossil’s assemblages indicated a different changes in the environment when the organism lives (biostratigraphy). The timing when the changes occurred was showed by chronolstratigraphy [8,9].

The long-term dynamics in the lakes are strongly correlated with climate, hydrological cycles, temperature, soil, and vegetation. A good chronological control has a must to the paleolimnological approach, with a high sediment input. A high sedimentation rate usually has more carbon and more material to analyze (including microfossils), 1 cm = 5 years, but a low sedimentation rate, has less carbon, less material to analyze, and a higher risk of contamination by old carbon. Recent sediment (<150 years) is dated using degradation of $^{210}$Pb for the upper layers sediment core, for 500 – 45,000 years BP is usually generated using $^{14}$C methods [2].

To get good and representative data, coring is essential activities have to be conducted for a continuous record of land-use change. The first step is to determine the potential sources of accumulated materials as based for site selection. Dissection or Russian corer is easily transportable tools for quick subsurface sediments in terrestrial environments. It is capable of retrieving largely undisturbed samples (Figure 1).

![Figure 1. Coring in the lake bank and sediment sample with a good layering collected from Cebong Lake Dieng using Russian corer](image)

To reconstruct past environmental change require death assemblages preserved in the sediment that reflected the condition when those organisms live. Diatom is the best proxies for reconstruction of pH, salinity, and conductivity compare to the pole, Rotifera, Cladocers, Ostracoda, or Copepoda (Table 1) [10].

Diatoms are single-celled eukaryotic algae, siliceous cell walls composed of two valves, together called a frustule, a good bioindicator of trophic status [11-14], acidified water [15,16], salinity [17,18], total phosphate [19], dissolved oxygen [20], conductivity [21-23], human activities [8-9,24-28], coastal environmental change [12,29,30], and urbanization [31].
Table 1. Biological proxies for limnological and paleolimnological studies (S – sediment, W – water, ++ very good indicator, + moderately good indicator, = low indicator, n/a not applicable) [10].

| Inferred variables | Pollen | Diatoms | Rotifera | Cladocera | Ostracoda | Copepoda |
|--------------------|--------|---------|----------|-----------|-----------|----------|
| Temperature        | ++     | n/a     | =        | =         | ++        | =        |
| Humidity           | ++     | n/a     | +        | ++        | =         | ++       |
| Water level        | =      | n/a     | =        | +         | =         | ++       |
| Trophic status     | n/a    | ++      | ++       | ++        | ++        | ++       |
| pH                 | n/a    | ++      | ++       | =         | ++        | ++       |
| Salinity           | n/a    | ++      | ++       | =         | ++        | +        |
| Conductivity       | n/a    | ++      | ++       | =         | ++        | +        |

3. Paleolimnology in Indonesia

Research on paleolimnology in Indonesia is still limited [32]. Paleolimnological approach for lake management had started being used in Indonesia since paleolimnology was considered in the book of Save Indonesia Lake, “Gerakan Penyelamatan Danau” (Germadan) Rawapening [33].

[34] studied about pollen stratigraphy in Balekambang Lake Dieng, [35] studied changes of diatoms and pollen assemblages in Tondano Lake, [11] made a diatom stratigraphy of Rawapening, implying eutrophication history, [8] assessed the diatom assemblage in the 24 cm upper sediment of Warna Lake Dieng in association with human activities, [25], studied about heavy metal changes in Warna Lake Dieng, [36] studied about community structure and species diversity vertically in the area between Warna and Pengilon Lakes Dieng, [38] reconstructed of Maninaju Lake using pollen, and [38] used pollen and diatoms as evidence of seawater intrusion in Semarang.

Research on paleolimnology of tropical lakes have to be rapidly developed due to 40% of world lakes are in the tropical area [39]. The number of a natural lakes in Indonesia is more than 840, hundreds of reservoirs and man-made lake, which many of those lakes are having problems of sedimentation, eutrophication, and pollution [7].

4. Challenges paleolimnology for lake management

Based on the bibliometric analysis using VOS viewer on the Scopus index journals with the keywords of paleolimnology, water resources, renewable energy, food security, and climate change shows that paleolimnology has important roles for food security through adaptation and mitigation of climate change. It is indicated by the yellow color that very strong at paleolimnology. Therefore, paleolimnology supported SDGs number 2 (zero hunger) by SDGs number 6 (clean water and sanitation) that have to be adapted and mitigate (SDGs number 15), particularly on the terrestrial ecosystem, mostly freshwater ecosystem (SDGs number 15). Nationally, the need for research on food security, water, energy, and environment for lake management had stated in RPJMN 2020-2024 [40].
Figure 2. Density visualization of research development for paleolimnology

The water management that appropriately develops based on the ecosystem approach, integration of social, economic, and ecology; water authority, interdisciplinary education, and research [41]. Science, data, technique, and tools paleolimnology appropriate for management [2]. Paleolimnology can play valuable roles in addressing many lake issues, including risk management and disaster preparedness [42].

In temperate regions, the paleolimnological approach had applied for ecosystem management and conservation. The legacy of past long-term changes for ecosystem function is the baselines, reference conditions, and resilience capacity. The direction of, the extent of, and time of changes are the process to determine drivers, mechanisms, and feedbacks. These changes imply ecosystem services, biodiversity, risk, etc. [2].

Traditionally, identification of diatoms for paleolimnological assessment the expertise to identify species using a light microscope. This identification is time consuming related to the minimum number frustule of 300 [43]. The application of e DNA and metabarcoding is a promising alternative for environmental assessment [44]. Environmental DNA (eDNA) is a method of assessing biodiversity based on the samples that are taken from the environment, such as water, sediment, or air, from which DNA is extracted, amplified using universal primers, and sequenced using next-generation sequencing. Based on the data, species presence can be determined, and overall biodiversity can be assessed (Figure 4) [45]. The universal primers are come up from temperate regions, that the diverse species are very different from a tropical areas. This is the most challenge to develop a local primer.
Figure 3. Global ecosystem and biodiversity with eDNA and metabarcoding [45]

5. Conclusion
Research on paleolimnology could not stand alone but require scientific collaboration and coordination. Integration of physical, chemical, and biological approach, holistically strengthen each other. Physically (lithostratigraphy) determine the sediment composition and its sources, chemically dating of the sediment age determine the chronostratigraphy, and biologically, biostratigraphy of fossils assemblage indicated the past environmental condition.

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