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Diatom assemblage in the 24 cm upper sediment associated with human activities in Lake Warna Dieng Plateau Indonesia

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ABSTRACT

Lake Warna is a small shallow crater lake on the Dieng Plateau, Central Java, the second highest plateau in the world after Nepal. A 24 cm sediment core was extracted from Lake Warna to reconstruct environmental changes in the Lake and its catchment from preserved diatom assemblages. Diatoms are microalgae in the Bacillariophyte that have silicious cell walls that can be preserved in sediments. As diatom species are sensitive to water quality changes in the assemblages upcore reflect changes in lake condition. Sediment cores were collected from two sites, sliced at 1 cm intervals for diatom analysis and bulked across 3 cm for ^{210}Pb radiometric dating. Examination of diatoms in a 24 cm sediment core from Lake Warna reveals clear correlation with human activities in the catchment area over the past 124 years. The record is divided into 2 zones based on sustained changes in the diatom assemblages. The lowest zone Zone I (21–15 cm, estimated 1935–1954) was dominated by *Frustulia crassinervia* (Brebisson ex W. Smith) Ross, Gomph *onema parvulum* (Kutzing) Kutzing, Pinnularia valdetolerans Mayama & H. Kobayasi, P. viridis (Nitzsch) Ehrenberg, and *Aulacoseira distans* (Ehrenberg) Simonson. Zone II (15–0 cm, estimated 1980–2013), the uppermost zone was dominated by *P. viridiformis* Krammer, *P. latevittata* Cleve, *E. monodon* var. *tro p ica* (Hustedt) Hustedt, S. seminulum Grunow, *P a crosphaeria* W. Smith. *E. zygodon* Ehrenberg, P. gibba Ehrenberg, and *P. viridiformis* Krammer. The 15 cm core from TW3 commenced sediment accumulation 114 years ago and is divided into 2 zones as well. Zone I (15–7 cm, estimated 1901–1981) was dominated by *Brachysira brebissonii* R. Ross, *G. parvulum* (Kutzing) Kutzing, *E. monodon* var. *tropica* (Hustedt) Hustedt, *E. zygodon* Ehrenberg and *S. seminulum* Grunow. Zone II (7–0 cm, estimated 1981–2006) was dominated by *P. viridiformis* Krammer, P. gibba Ehrenberg, Pinnularia viridis (Nitzsch) Ehrenberg, *Sellaphora bacillum* (Ehrenberg) Mann, *S. seminulum* Grunow, and *Stauroneis* sp. These assemblages reflect ongoing acid, clear water conditions for the time represented by the cores. The recent rise in *S. seminulum* Grunow reflects recent lake eutrophication likely owing to the accelerated agricultural and urban development in the lake's catchment in recent decades.

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1. Introduction

The Dieng Volcanic Complex, called the Dieng Plateau, hosts the highest village on Java, located in the Wonosobo and Banjarnegara Regencies, on the slopes of the active Sindoro and Sumbing Volcanoes. The Dieng Plateau, the second highest plateau in the world after Nepal, has many surface manifestations of hydrothermal activity, including hot lakes, fumaroles/solfatara, mud pools, altered rocks, and hot springs. Dieng Plateau is also rich in geothermal resources and is subject to lethal outbursts of gas. The many temples on the Plateau attest to the long establishment of ancient Indian Hindu culture that established a firm footing in Java from about AD 400 (van Bergen et al., 2000). The Dieng Plateau is 14 km long and 6 km wide and geologically consists of late Quaternary to Recent volcanic cones and explosion craters. There are 3 major volcanic activities resulting in volcanic rocks comprising Old Dieng, Adult Dieng, and Young Dieng (Sukhyar, 1994). During the second episode, a number of stratovolcanoes emerged within the depression, producing basalts, basaltic andesites and pyroxene-andesites. Pyroclastic fall deposits, believed to have been erupted from all of these volcanoes, blanket the Dieng and Batur depressions. They are collectively referred to as the 'Dieng tephra' for which dating yielded an age of 16,770 years. A parasitic eruption centered on the southern slope contains an 800 m wide and $>$ 150 m deep crater lake (Telaga Menjer), which is used for hydroelectric power and irrigation. Pangonan and Merdada are two stratocones east of Nagasari. The latter has a crater lake which is used for drinking water by local villagers. This crater, which has been partly filled by a biotite-andesite lava from the third episode, contains a colored lake, Lake Warna (van Bergen et al., 2000).

The high sulfur content, and possibly other elements, causes this lake's colorful state which ranges from blue to yellowish-green, and sometimes brownish, especially when exposed to sunlight. The color is a reflection of sunlight by sediment/rock at the bottom of the lake or refraction from fine sediments within the water. Red and yellow colors are a reflection of the sulfur deposits, and the white color comes from the deposition of limestone rocks and quartz. Now however, the only color visible is mostly blue on account of the sediment surface (Soeprobowati et al., 2017). In terms of chemical composition, Lake Warna is the most interesting crater lake in the Dieng area. The original shape of the crater has been modified by a lava flow and now the water occupies <1 km^2. Gas bubbles with a sulfurous odor can be seen rising to the lake surface. The water has a pH of about 3 (van Bergen et al., 2000) to 5 (Soeprobowati et al., 2017) which may fluctuate depending on seasonal conditions. The lakes chemistry is unusual with high concentrations of sulfate and chloride. Strong emissions of CO_2-rich gas are variable but have been intense enough to occasionally kill animals, warranting the closure of a path on the north side of the lake (van Bergen et al., 2000).

Dieng plantations over the years only used a monoculture system with potatoes as the main commodity. The slope of the land in Dieng area ranges from 35% to more than 45%, therefore, the farmers developed tillage systems terracing on contours as far as the tops of the hills. The erosion rate has reached 161 tons/hectare/year. About 7758 hectares of land has become critically unstable and has high erosion rates. In 2007, the Dieng area was 63.22% dominated by non-forest areas and this increased to 66.1% in 2010 (Mulyana, 2008). Lack of vegetation cover and the use of monoculture systems had induced sedimentation and damaged the ecosystems within this important watershed, such as Tulis and Serayu (Fig. 1, Pradana et al., 2015).

Lake Pengilon (Pengilon = mirror), located next to and connected to Lake Warna, is also notable. The two lakes host specific ecosystems that differ from other lakes. However, due to land use changes in the surrounding area both lakes are now facing environmental degradation. The land use in the surrounding area is dedicated to intensive agriculture with the main crops being vegetables, especially potatoes. Agricultural practices for plantation potato production use water from Lake Pengilon to irrigate the plants by pumping and irrigation. Agricultural practices expose soils to erosion, which contributes sediment to the lake via surface runoff. The volume of the lake is gradually decreasing due to water abstraction. Further, the overuse of fertilizer for agricultural production contributes nutrients to the lake leading to eutrophication (Sudarmadji and Pudjiastuti, 2015).

Diatoms are microalgae that can be found in most aquatic ecosystems. Their silicious cell walls are often well preserved in sediments so diatoms are particularly useful for reconstructing environmental history. Different species have distinct optima to given environmental variables, and they are taxonomically distinct allowing identification to species and sub species level (Smol, 2008). They are highly sensitive to variations in the aquatic environment so they can be used as bioindicators of lake conditions. The lake's sediment reflects the history of changes in the catchment area (Battarbee et al., 2011; Di et al., 2013; Tolkkinen et al., 2014; Gell and Reid, 2014). This history can be reconstructed by reference to the nutrient requirements or typical habitats of each fossil taxon, or by consideration of their relative species abundance.

Palaeolimnological studies offer an opportunity to understand past and present lake condition and so, from the inferred trajectory, to predict future conditions. Preliminary research was conducted on the water quality of Lake Warna over the period of 2014–2015. Diatoms are particularly sensitive to pH and the acidification of surface waters is known to negatively impact on aquatic organisms, reduce diversity, and induce shifts in community structure. Diatoms can act as an early detection mechanism for decreasing pH and so can flag the need for the implementation of mitigation measures.

Hustedt (1937–1939) found *E. septentrionalis* lived in acid waters (pH ca.3) of the sulfur-springs of Sumatra. Negoro reported these varieties occurring as epiphytes from many highly acidic environments in Japan (DeNicole, 2000). The presence of *E. septentrionalis* in Lake Warna may be on account of the influence of the sulfur springs as was recorded in Sumatra (Soeprobowati et al., 2017).

Studies on diatoms in Indonesian lake sediments have in general been very limited in the analysis to determine indicator species and the changes of relative abundance through time (Soeprobowati et al., 2018). Notable among these are Dama