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Effects of agricultural projects on nutrient levels in Lake Bera (Tasek Bera), Peninsular Malaysia

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A B S T R A C T

Lake Bera is the largest natural lake in Peninsular Malaysia and was designated as its first RAMSAR site in 1994. The lake has a total catchment area of 593.1 km^2, although approximately 340 km^2 of the original tropical rain forest cover has been converted to oil palm and rubber plantations since 1972. Research was conducted to determine the soil nutrient contents in the areas of developed land and to correlate historical variations in nutrient concentrations and eutrophication at the lake with anthropogenic activities. Thus, soil samples in areas of different land use in the catchment area were collected in addition to two cores in the bottom sediments of Lake Bera. In total, 132 samples were analyzed for total carbon (TC) and total nitrogen (TN) contents as well as fallout ^{210}Pb and ^{137}Cs radioisotope activities. Sediment profile dating was performed using the constant rate of supply (CRS) model; the resultant sediment ages were verified by ^{137}Cs horizons. Soils in cleared forest areas exhibited the lowest average nutrient content and ^{137}Cs inventory with an average loss of carbon, nitrogen and ^{137}Cs, of 54.6%, 31.2%, and 74%, respectively, in comparison with soils in areas of undisturbed forest. Clear-felling and burning during forest conversion were identified as the two main mechanisms that disrupted the nutrient cycles in the lake catchment. The total concentrations of nutrients in the bottom sediment profiles in the main open water and in the north of Lake Bera decreased in the order of TOC > K > TN > S > Mg > C. The results highlight a clear correlation between variations of nutrient contents in the lake sediments with anthropogenic and natural events dates using the CRS model; the C/N ratio has remarkably increased four times since oil palm plantations were developed in 1981. This result indicates an upward increase in eutrophication during and following land-use changes. The results also suggest long-term increasing acidic conditions in Lake Bera, leading to a reduction in exchangeable cation contents (Ca, Mg, and K), organic matter preservation, and an incremental addition of SO_4 (sulfate) and NO_3 (nitrate) ions, particularly in the top layer of the sediment column. This situation will result in Lake Bera being on the verge of considerable ecological risk, as illustrated by very low dissolved oxygen contents, high levels of nitrate, and a reduction in the fish population.

1. Introduction

1.1. Background and scope of work

Agronomic development projects have significantly modified the original tropical rainforest cover of Malaysia. Increasing global demands for oil palm and favorable agro-climatic conditions have resulted in a rapid increase of agricultural development projects since 1961 and have led to the establishment of almost 20 million hectares of oil palm plantations. Although oil palm cultivation has long been advocated as a sustainable farming practice (Basiron, 2006), it does have significant effects on the nutrient contents in soils and lake sediments (MPOC, 2007; Chiew and Rahman, 2002; ECD, 2002; Wakker, 2004).

Historical variations in the nutrient contents of soil profiles have been the scope of several studies (Craft and Richardson, 1998; Guo et al., 2003; Mabit et al., 2008b; Martinez et al., 2010) because of the importance of nutrients for sustainable agriculture and the tracing of anthropogenic activities in the catchment area. Lake sediments

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have also been widely investigated to detect such historical variations and to trace eutrophication in watershed areas and their association with heavy metal contamination (Ueda et al., 2009; Flower et al., 2009; Rippey et al., 2008; Routh et al., 2007; Alvarez-Iglesias et al., 2007; Bonotto and de Lima, 2006; Covay and Beck, 2001; Hongve et al., 1995; Nagao et al., 1999).

Previous studies in Peninsular Malaysia (Tanaka et al., 2009; Sultan and Shazili, 2009; Neergaard et al., 2008; Wüst et al., 2003; Phillips and Bustin, 1998; Midmore et al., 1996; Malmer, 1990) have mainly emphasized the importance of nutrient contents in soils and sediments as indicators of soil erosion and deposition and eutrophication. Neergaard et al. (2008), for instance, used the ^{137}Cs technique to investigate soil erosion resulting from the conversion of forest land into agricultural areas, although these authors did not examine the geochronology of deposition of the sediments in sink areas. A literature review also highlighted this absence of work in the application of radioisotopes to detect historical variations in nutrient contents and eutrophication in lake sediments. The main aim of this research was therefore to investigate the effects of anthropogenic activities on the nutrients in the catchment area and to trace historical variations in nutrient contents in the sediments at Lake Bera using radioisotopes.

1.2. Study area

Lake Bera and its catchment area (BLC) are located in the central part of Peninsular Malaysia, between latitudes 2°53′00″ and 3°10′00″ N and longitudes 102°30′30″ and 102°47′00″ E (Fig. 1). The catchment area covers approximately 600 km^2 and was originally covered by primary rainforest, although five Federal Land Development Authority (FELDA) schemes from 1970 to 1995 have resulted in 292.86 km^2 of the original forest being converted into oil palm and rubber plantations (Henson, 1994; MPOC, 2007). The BLC was designated under the Convention of Wetlands as the first RAMSAR Site in Malaysia in 1994 with the FELDA districts being called buffer zones. Soil conservation management practices, however, have never really been applied within the buffer zones either before or after establishment of the RAMSAR site. A recent land use map of the Bera Lake catchment prepared with the aid of the geographical information system (GIS) technique and a satellite image (SPOT 5, 2009) of 10-m spatial resolution further demonstrates that there has been agricultural development and encroachment into the RAMSAR site by local residents. Because the local residents have cleared an area of 47.14 km^2 since 1994, the total area of cleared natural forest within the Lake Bera catchment reached a maximum value of 340 km^2 in 2010. The remaining area is covered by wetlands and pristine lowland rain forests (forest and reed swamps).

Lake Bera and its catchment are located between the eastern and western mountain ranges of the Peninsula with the highest hills being only approximately 140 m above sea level (Wüst and Bustin, 2004). A digital elevation model (DEM) of the catchment area indicates that as much as 50% of the area comprises low lands where the slope varies between 0° and 4°.

Lake Bera and its catchment were separated into 12 hydrological sub-catchments; open water was only observed in the northernmost part in sub-catchment 3. The overall flow of streams in the catchment is northwards with sub-catchments 4–12 draining into the south end of Lake Bera. Two other streams from sub-catchments 1 (Kelangton stream) and 2 drain into the middle and northern part of the Lake, respectively. Lake Bera drains through an outlet stream in its northernmost part into the Bera River, which flows northwards into the Pahang River.

The study area has a humid tropical climate with two monsoon periods. Heavy rainfall occurs during the Northeast (November–March) and Southwest (June–August) monsoons, while there is less rain in April, May, September and October. The mean annual temperature is approximately 30 °C and ranges from 25 °C to 38 °C (Chee and Peng, 1998). Rainfall records from 1970 to 2009 at the Fort Iskandar Station, which is located at the midpoint of the catchment, indicate that the minimum and maximum annual rainfall was 1000 and 2602 mm, respectively. Field observations and laboratory analyses indicate that the soils within the catchment are ferralsols; the soils have brownish-yellow, yellow and red colors and developed on Triassic as well as post-Triassic continental sedimentary rocks. These ferralsols have maximum and average thicknesses of 1.0 m and 0.2 m, respectively.

In the catchment area, carbonaceous shale, siltstone and rhyolitic tuff of the Triassic Semantan Formation are observed to overlie thick bedded to massive mudstone, tuffaceous sandstone and siltstone of the Permian Bera Formation. The Semantan Formation is overlain by post-Triassic conglomerate, pebbly sandstone and sandstone of the Redbeds Formation (Hutchison and Tan, 2009). Outcrops demonstrate that these sedimentary strata are located on the right flank of a broad NW-SE trending syncline, with the strata dipping 45–60° toward SE. Within the wetlands and open waters of Lake Bera, organic and peat deposits have accumulated from approximately 4500 BP (Morley, 1981).

2. Materials and methods

2.1. Sampling

Thirty-five soil samples were collected with a bulk core sampler to a depth of 25 cm at sites of different land use in the Lake Bera catchment. To investigate nutrient depth profiles near the main body of open water, soil sample were collected at 2-cm intervals using a rectangular metal frame of 875 cm^2 in area and a scraper plate to a depth of 24 cm, where rock fragments were the main soil component and there was little clay content.

Two core samples of the Lake Bera sediments were also collected using a newly developed core sampler that was designed to collect a 2-m undisturbed sample with a high recovery rate and minimum sediment column compaction. A portable Hydro Lab 5 unit was also used to determine the water quality of Lake Bera.

2.2. Sample preparation and analytical methods

2.2.1. Total organic and total carbon analysis

The sediment cores were preserved in a freezer at a temperature of 4 °C before being sliced at 2.0 ± 0.2-cm intervals. The soil and sliced core samples were dried at 60 °C and then ground for further analytical procedures. A total of 65 samples of 1.0–1.5 g each from Cores 1 and 2 were then weighed and mixed with 1–2 ml of 1 M hydrochloric acid to remove inorganic carbon before being dried at 100–105 °C for approximately 10 h to remove the acid (Schumacher, 2002). Samples of 0.5–2.0 mg were then weighed and analyzed for total carbon (TC) and total nitrogen (TN) using a Perkin Elmer 2400 Series II CHNS/O Elemental Analyzer.

An organic analytical standard (acetanilide-C6H5NH) was used for quality control and quantitative analysis. For the quality control procedure, the acetanilide standard sample was used as the conditioner with testing of five blank-tin aluminum samples. Calibration was continued until positive results of C < 50, H: 100–200, and N < 16 were obtained. Three replicate acetanilide samples of 0.5–2.0 mg were then weighed and analyzed using the Perkin Elmer 2400 Series II CHNS/O Elemental Analyzer. The calibration factors for carbon, hydrogen and nitrogen were determined to be 71.09 ± 0.3%, 6.71 ± 0.3%, and 10.36 ± 0.3%, respectively, according to instrumental instructions. The organic analytical standard (acetanilide) was run for every four samples. CHN analysis was