Journal of Ecotechnology Research, 16[2], 39- 45 (2011)

Original Article

Fish Die-off and Water Quality in Kandy Lake, a World Heritage Site in Sri Lanka

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(Received June 4, 2010, Accepted October 10, 2011)

A massive fish die-off was reported in Kandy Lake, Sri Lanka, in 2009. The maximum number of dead fish was as high as 150 per day. A survey of the water quality of Kandy Lake was conducted in the afternoon on 28 March for the daytime survey and before dawn on 29 March 2010 for the nighttime one. In this research, a hydrographic survey and water sampling at various depths were carried out to determine the cause of the fish die-off. Dissolved Oxygen (DO), nutrients, and heavy metals that could cause a fish die-off were thoroughly analyzed. The lake had sufficient DO to support a fish habitat near the surface layer even in the nighttime. The lake water had high T-N and low T-P concentrations, which could limit the growth of phytoplankton, such as *Microcystis*. No significant lethality was attributed to heavy metals. No conclusive evidence of the cause of the fish die-off was obtained during the investigation period; however, occasional disturbances could inversely affect a fish habitat. Long-term monitoring of the water quality of Kandy Lake seems to be required.

Key Words: water quality, DO, T-N, T-P, heavy metals

1. Introduction

Kandy Lake, developed in 1807 by King Sri Vikrama Rajasinha of Sri Lanka next to the Temple of the Tooth, is located N 07'17'32", E 80°38'24" in central Sri Lanka (Figs. 1 and 2). It is assigned as a world heritage site by UNESCO. The surface area is 14.7 ha, and the perimeter is about 3.3km. It has a small inlet stream at the southeastern corner without perennial flow. Therefore, the lake is thought to be mainly charged from rain water falling directly on the lake water surface and groundwater. The water residence time is considered to be indefinite. The climate of Kandy City is tropical rainforest with an average temperature of 24.6°C. The annual rainfall is 1,840mm[1]. The water monitor *Varanus Salvator*, which inhabits the waterfront, is proof of the high productivity of the lake (Fig. 3).

In Kandy Lake, fish die-offs were repeatedly reported in the later part of 2009. The maximum rate of fish mortality was reported to be approximately 150 per day during the peak in December 2009, and then the number reduced gradually [2]. According to the local government, the whole number of dead fish reached 2,000 in 2009.

It was reported that Kandy Lake was enriched with phosphorus and nitrogen compounds and polluted by some heavy metals, such as lead.[3),4]

Considering all these factors, we conducted a thorough study of the water quality of the lake to

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identify the cause of the fish die-offs in March 2010.

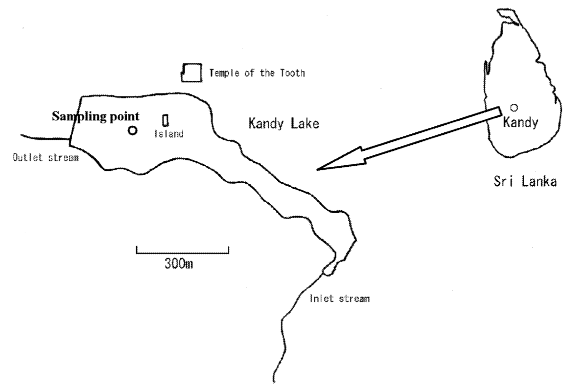

Fig. 1 Map showing the location of Kandy Lake and the sampling point.

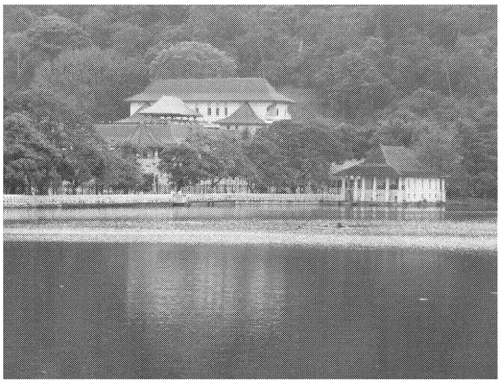

Fig. 2 Photograph of Kandy Lake next to the Temple of the Tooth

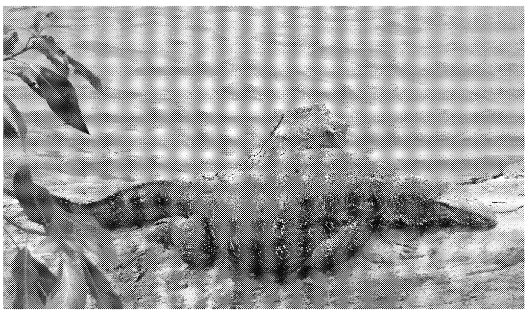

Fig. 3 Water monitor (*Varanus Salvator*)

2. Methods and Material

2.1 Geological survey

The investigation, which included water and sediment sampling and a geographical survey, was conducted on 28 and 29 March, 2010. Sampling of the lake water started at 14:00 on the 28th when photosynthesis was thought to be at its maximum level, and at 06:00 before dawn on the 29th, when photosynthesis does not take place. The geographical survey was conducted prior to the water sampling. The water depth and geometry were measured with GPS and an ultrasonic depth meter on a boat.

2.2 Sampling

The water samples were taken from the western part of the lake, where the maximum depth was 10m. A small pump was used to obtain water samples at depths of 0.3m, 0.5m, 1m, 2m, 5m, and 9m to establish a depth profile of the water quality for an analysis of mixing status of the lake water. All of the samples were filtrated with a membrane filter with a pore size of 0.45μm to stabilize the water quality, except for one sample taken from 0.5m on 29 March, for the determination of total nitrogen and total phosphorus.

The sediments were also taken from the deepest point of the lake using an Ekman Birge-type bottom sampler for the determination of heavy metals.

In order to investigate stratification of the lake water from the depth profile of the water temperature, six temperature loggers (Onset computer, Tidbit and Tidbit v2) were set at the depths of 0.2m, 0.6m, 1.3m, 2m, 5m, and 10m at a point near the water sampling. Ambient temperature was also recorded by a temperature logger (Onset computer, U20) near the lake.

A qualitative analysis of plankton was conducted to elucidate the water quality from the plankton species. A plankton net (63 μm mesh) was used to collect plankton from the surface of the lake during the daytime investigation on 28 March. The sample was fixed with chloroform on site.

A water sample of Mahaweli River was taken from a water treatment plant that supplies tap water to Kandy City. In the plant, the river water is pumped from the river for treatment, and the sample was taken from a sampling point typically used to obtain raw water.

2.3 Analysis

Dissolved oxygen was measured on site with a DO meter. All other chemical analyses were conducted in the laboratory at Toyama Prefectural University after bringing the samples to Japan. The major ions of water samples were measured with an ion chromatography system (DIONEX IC1500 for cations and DIONEX IC2000 for anions). Both ion chromatographies have a suppressor to reduce the electric conductivity of the base line for accurate analysis. As an eluent solution, 20mM MSA and 23-40mM KOH were used for the cation and anion analyses, respectively. The concentrations of nitrogen and phosphorus in the water were determined with an auto-analyzer (BLTEC SWAAT). Metals in the water samples, except for lead, were determined using an ICP-AES (Perkin Elmer Optima 5300DV-TK). Lead was determined with GFAAS (HITACHI Z-8200). Heavy metals in the sediments were determined with an ICP-AES after microwave digestion with nitrate (Analytik Jena, TOPwave). Mercury in the sediments was determined using the heat vaporization atomic absorption method (Nippon Instrument MA-2). DOC was analyzed with a DOC analyzer (Analytik Jena, multi N/C 3100). Elemental analysis of sediments was conducted with an energy dispersive X-ray fluorescence spectrometer (EDX) (Shimadzu EDX-900HS).

3. Results and Discussion

3.1 Geology

The lake was artificially stemmed at the west end. The depth of the northern part is deeper than that of the southern part. The average depth is 5.1m, and the water volume was estimated to be 745,000 m^3. The retention time seems to be quite long because the outflow had a flow rate of only 10l/min.

3.2 Water quality of Kandy Lake

The transparency of the water in Kandy Lake was 0.3m. The water color was clear, which was different from that of tropical lakes, which is typically brown.

The major ion concentrations are summarized in **Table 1.** The water quality of Mahaweli River, a major river flowing through Kandy City, is also shown in the table as a reference. The ion concentrations showed no change with depth until 9m. The low nitrate and sulfate concentrations and high ammonium phosphorus ion indicate that the water was in an anaerobic condition at a depth of 9m. The higher concentrations of most ions than those in Mahaweli River indicate that the water of Kandy Lake was highly concentrated by evaporation due to the long residence time. On the contrary, the lower concentration of nitrate in Kandy Lake than that in the Mahaweli River indicates that denitrification took place in the deeper areas of the lake.

The concentrations of dissolved nitrogen (D-N) and dissolved phosphorus (D-P), as well as that of dissolved carbon (DOC), are shown in **Table 2**. The values are indicated as the dissolved concentration because the samples were filtrated on site before the analyses. The concentrations of T-N, T-P, and TOC of the sample at a depth of 0.5m without filtration are also shown in the same table; however, the values differed little. This may correspond to the transparency of the water in the lake. The nutrient condition of this lake is considered to be eutrophic according to T-N and TOC but oligotrophic according to T-P. The primary production seemed to be limited to phosphorus in the lake.

3.3 Dissolved oxygen

The DO concentration of the top layer (0-0.5m) was supersaturated (262%) during the daytime, while it was not reduced even in the nighttime (195%).

Table 1 Major ion concentrations of Kandy Lake and Mahaweli river near Kandy Lake

Date 2010	Time	Depth m	pH	EC uS/cm	Na^+ mg/L	$NH4^+$ mg/L	K^+ mg/L	Mg^{2+} mg/L	Ca^{2+} mg/L	F^- mg/L	Cl^- mg/L	$NO3^-$ mg/L	$PO4^{3-}$ mg/L	$SO4^{2-}$ mg/L	Grans ALK μeq/l
March 28	13:30	0	8.18	270	17.1	0.05	6.5	8.2	26.5	0.030	25.5	2.0	0.009	7.7	1850
March 28	13:40	0.3	8.18	270	17.2	0.05	6.5	8.3	26.8	0.034	25.1	2.1	0.004	7.6	1918
March 28	13:50	0.5	8.18	270	17.2	0.08	6.5	8.2	26.6	0.039	24.8	2.0	0.000	7.4	1949
March 28	13:55	1	8.08	260	17.2	0.07	6.5	8.2	26.8	0.041	24.3	2.0	0.000	7.3	1861
March 28	14:00	2	8.01	260	17.2	0.12	6.6	8.2	26.8	0.032	24.1	2.0	0.000	7.1	1955
March 28	14:10	5	8.01	260	17.2	0.15	6.5	8.2	26.7	0.037	24.0	1.9	0.004	7.1	1953
March 28	14:30	9	7.93	270	16.1	2.32	6.3	7.9	27.5	0.034	21.9	0.0	0.225	4.3	2264
March 29	5:50	0	8.01	260	17.4	0.09	6.6	8.3	27.0	0.033	23.7	2.0	0.000	7.2	1953
March 29	6:00	0.3	8.17	260	17.4	0.09	6.6	8.3	27.1	0.034	23.5	1.9	0.004	7.0	1898
March 29	6:05	0.5	8.30	260	17.4	0.08	6.7	8.4	27.1	0.037	23.6	1.9	0.000	7.1	1892
March 29	6:10	1	8.15	260	17.4	0.09	6.7	8.4	27.0	0.032	23.6	1.9	0.000	7.1	1923
March 29	6:20	2	8.22	260	17.3	0.08	6.6	8.3	27.0	0.035	23.6	1.9	0.000	7.0	1942
March 29	6:30	5	8.10	260	17.4	0.17	6.6	8.4	27.2	0.035	23.8	1.8	0.000	7.2	1949
March 29	6:40	9	8.07	280	16.2	2.27	6.3	8.0	27.6	0.034	21.9	0.0	0.234	4.0	2170
March 27		Mahaweli river	7.84	89	4.2	0.12	2.9	3.3	8.6	0.037	6.6	2.7	0.000	2.8	664

Table 2 Nutrient condition of Kandy Lake

Date 2010	Time	Depth m	D-N mg/L	D-P mg/L	DOC mg/L
March 28	13:30	0	0.86	0.0056	4.3
March 28	13:40	0.3	0.99	0.0045	5.2
March 28	13:50	0.5	0.99	0.0059	2.3
March 28	13:55	1	0.99	0.0046	5.0
March 28	14:00	2	1.00	0.0043	6.2
March 28	14:10	5	1.06	0.0038	5.0
March 28	14:30	9	1.04	0.0996	4.4
March 29	5:50	0	2.00	0.0044	4.7
March 29	6:00	0.3	1.01	0.0046	5.2
March 29	6:05	0.5	1.00	0.0041	4.6
March 29	6:10	1	1.01	0.0041	4.7
March 29	6:20	2	1.03	0.0041	4.6
March 29	6:30	5	1.03	0.0044	4.6
March 29	6:40	9	1.02	0.0041	4.1
March 29*	6:05	0.5	1.20	0.0037	4.3

* Without filtration

The DO concentration was greater than 10mg/l at a depth of 2m for the entire day. Hence, no oxygen deficit sufficiently strong to cause fish mortality was observed near the surface layer of the lake.

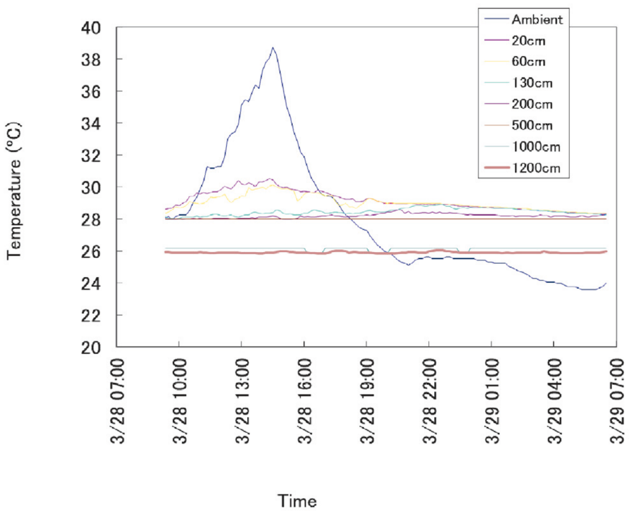

Fig. 4 Depth profile of water temperature

3.4 Water temperature profile

The ambient and water temperature profiles are shown in **Fig. 4**. The ambient temperature reached 38.7 °C in the daytime but decreased to 23.6°C just before dawn.

Table 3 Metal concentrations in water column

Date 2010	Time	Depth m	Al ug/L	Cd ug/L	Cr ug/L	Cu ug/L	Fe ug/L	Mn ug/L	Ni ug/L	Pb ug/L	Zn ug/L
March 27		Mahaweli river	89	0.2	3.5	2.9	69.5	5.6	2.9	ND	145
March 28	13:30	0	25	0.9	10.3	3.7	2.3	3.6	6.8	ND	7.3
March 28	13:40	0.3	7.8	0.9	10.4	3.4	2.7	2.4	7.0	ND	8.7
March 28	13:50	0.5	8.4	1.0	10.9	3.7	2.3	1.9	7.5	ND	5.5
March 28	13:55	1	9.5	1.0	11.1	3.5	2.7	1.2	7.6	ND	3.4
March 28	14:00	2	9.1	1.0	11.2	3.7	3.4	1.3	7.8	ND	5.8
March 28	14:10	5	9.0	1.0	11.4	3.9	2.7	1.3	7.9	ND	6.8
March 28	14:30	9	8.9	1.3	11.9	3.6	1586	1608	8.5	ND	4.1
March 29	5:50	0	8.6	1.0	11.5	3.7	5.7	4.7	8.0	ND	2.2
March 29	6:00	0.3	8.4	0.9	11.3	3.4	3.5	2.3	7.9	ND	1.9
March 29	6:05	0.5	7.5	0.9	11.2	3.4	3.2	2.0	7.8	ND	2.4
March 29	6:10	1	6.7	0.7	10.6	2.7	2.8	1.6	7.2	ND	1.5
March 29	6:20	2	6.1	0.7	10.5	2.9	2.7	1.6	7.1	ND	2.9
March 29	6:30	5	6.1	0.8	10.9	3.0	2.6	2.2	7.5	ND	2.2
March 29	6:40	9	6.5	1.0	11.2	2.1	1437	1584	7.7	ND	2.2

The water temperatures at a depth of less than 5m fluctuated slightly. For example, the water temperature at 0.2m fluctuated between 28.1°C and 30.4°C. The water temperatures below a 5m depth remained constant. The bottom (12m) temperature was constant at 26°C. This temperature profile shows that the lake water was stratified; however, the constant ion concentrations according to the depth show that mixing took place. No driving force of the mixing was observed in this research.

3.5 Metals

The concentrations of heavy metals as well as aluminum and iron in the water column of Kandy Lake are summarized in **Table 3**. The high concentrations of iron and manganese indicate the anaerobic condition in the deepest zone. None of heavy metals seemed to have a high enough concentration to adversely affect the aquatic lives.

The concentration of aluminum, which adversely affects the gills of fish with a concentration more than 50μg/l, did not exceed the threshold level. The very high concentration of zinc shown in Mahaweli River may have been the result of the use of zinc-coated pipes in the water treatment plant from which the water sample was taken.

Heavy metal concentrations of the sediments are shown in **Table 4.**

Table 3 Heavy metal concentration in the sediments.

Cd	Cr	Cu	Ni	Pb	Zn	Hg
		mg/100g-dry sediment				μg/100g-dry sediment
1.0	11	12	7.0	1.3	19	1.8

The result of the elemental analysis of the sediments was as follows; Cd 1.0mg/100Fe 59.8%, Si 27.7%, K 3.8%, Ti 2.0%, Ca 1.2%, Mn 1.2%, Ba 1.0%, Zn 0.35%, Cr 0.17%, Rb 0.16%, Cu 0.15%, Ga 0.08%, Y 0.08%, Sr 0.07% and Zr 0.05%.

The heavy metal analysis and the elemental analysis did not show a crucial level of toxicity

3.6 Plankton

Colonized diatoms, *Melosira* and *Aulacoseira*, were detected in the sample, while no cyanobacterial colonies were observed. The zooplankton community in Kandy Lake was a typical tropical one, in which a calanoid copepod (not identified at the genus/species level) was a dominant herbivore. In lakes and ponds, calanoids tend to be abundant at high temperatures. However, species richness was very low: two rotifers (*Brachionus forficula* and *Keratella* sp.) were only the zooplankton except for the copepod. One possible factor to explain the absence of cladocerans is contamination by toxic chemicals (e.g. pesticides) since they are the most sensitive group to such stresses (for review, Hanazato, 2001). Nevertheless, additional research is needed to clarify the causality.

3.7 Cause of the fish die-offs

The quality of the water in most of the lake did not indicate adverse conditions for aquatic life. However, the water near the bottom seemed to have no dissolved oxygen but showed high Fe and Mn concentrations as well as a nitrate deficit. In addition, a high concentration of ammonium ions, probably produced by the oxygen deficit condition, was observed near the bottom. It is possible that the deep water, with low dissolved oxygen and high ammonium ion concentrations, caused the fish die-offs when the deep water was mixed with the surface water. During the survey, no destruction of the stratification was observed; however, the unity of the concentrations of major ions and metals along the depth indicated that mixing had taken place.

Although the driving force of the mixing was not identified in this research, it could be attributed to fluctuations in ambient temperature and/or to heavy rain. In addition, the possibility remained that infectious disease or pesticide use caused the fish die-offs.

4. Conclusions

The water quality and the metals in the sediments of Kandy Lake, Sri Lanka, were analyzed in order to determine the cause of frequently reported fish die-offs. The lake was stratified in the survey period; however, mixing of the water column was assumed because of the unity of the water quality along the depth. A lake with low DOC and plentiful DO may provide a good habitat for fish. Crucial heavy metals were not detected in the water body and the sediments. The results of the survey revealed no conclusive evidence of fish death; however, the fish die-offs could be attributed to the mixing of the deep water, which had low oxygen and a high concentration of ammonium ions, with the surface water. The possibility of infectious disease or pesticide use could not be dismissed.

Acknowledgment

This research was partially supported by the Sumitomo Foundation.

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