Original Paper

Removal Function of the Yala Swamp (Western Kenya) on Allochthonous Matter Transported from the Yala River

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Abstract

Removal function of the Yala Swamp on allochthonous matter originated in land were examined in comparison of concentrations of macronutrients (NO_3-N, NH_4-N, PO_4-P) as some of components of dissolved inorganic matter, COD in filtrates of water samples as an indicator of dissolved organic matter, particulate inorganic matter expressed as ignition residue and particulate organic matter as ignition loss or particulate organic carbon and nitrogen, between the inflow and the outflow water. Surveys were conducted in September 2010 and 2011, early rainy season and in February 2011, late dry season, at the inflow site from the Yala River and the outflow one, located in Usenge adjacent to Lake Victoria. Removal effect of the Yala Swamp on macronutrients could not be confirmed because almost all valuables measured were concentrations under the limiting of detection (NO_3-N < 0.2 mg N/l, NH_4-N $< 0.05-0.2$ mg N/l, PO_4-P < 0.03 mg P/l). There was no difference in COD of the filtrates between the inflow and the outflow water throughout the investigations. In February 2011, dissolved organic carbon (DOC) in the outflow water was higher than in the inflow one. Particulate inorganic matter (PIM) transported from the Yala River was removed completely in the swamp. Removal effect of the swamp on particulate organic matter (POM) differed seasonally. POM in the outflow water showed a decrease of 60−78% compared with that in the inflow one in September 2010 and 2011, while POM, especially particulate organic carbon and nitrogen, showed a tendency to increase in the outflow water in February 2011. These results

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indicated that removal function of the Yala Swamp on allochthonous matter was complicated and varied with chemical forms of the inflow matter.
Keywords: Yala Swamp, removal function, macronutrients, dissolved organic matter, particulate inorganic and organic matter

Introduction

Highly developed swamps or wetlands are distributed on the shore of Lake Victoria and cover an area of 10,235 km^2 corresponding to 5.6% of the Lake Victoria basin (Kiwango, 2007). In these swamps, emergent aquatic plant community dominated by papyrus (*Cyperus papyrus*) makes remarkable growth. These swamps play important roles in regulation of chemical, physical and biological disturbances in Lake Victoria through the functions removing allochthonous pollutants, controlling a flood and breeding fishes (cf. Horne and Goldman, 1994). Further, the swamps around Lake Victoria have been closely related to livelihood of riparian communities not only as sources of raw materials, handicrafts and fuel but also space of fisheries grazing, agriculture and outdoor recreation (Kayombo and Jorgensen, 2005). Recently, however, these swamps have been destroyed by development of farm land and road construction with urbanization (Ochieng, 2006).

In the Yala Swamp investigated at the present study, development of farm land is in progress on a large scale (Ochieng, 2006, Olago and Odada, 2007). As a result, 65% of the Yala Swamp to act as buffer zone would be lost (Ochieng, 2006). As one of the critical environmental issues in the future, it is anxious that the swamps would be deteriorated in their functions by water level decrease in Lake Victoria associated with increase in dam construction for more electricity in the Victoria-Nile River (Kiwango, 2007). Nakamura (2008) pointed out that the swamps would be one of the important components in the framework of the Integrated Lake Victoria Basin Management. However, there is little information about removal function of the swamps on allochthonous pollutants on the basis of the field surveys, though there are some papers concerned in breeding of fish (Kiwango, 2007, Abila et al., 2008), water-borne disease (Ofulla et al., 2010) and fauna-flora from a viewpoint of biodiversity (Gichuki et al., 2001).

The objective of the present study is to evaluate actual status of removal function of the swamps developing around Lake Victoria on allochthonous matter through the field surveys in the Yala Swamp located in Western Kenya.

Material and Methods

The Yala Swamp located under the equator and 1,134 m above the sea level, is the largest freshwater wetland in Western Kenya supporting three small lakes, covering 175 km^2 in area and taking the water source from the Yala River (Fig. 1).

Surveys were conducted on 2 September, early rainy season, 2010, on 13 February, dry season, 2011 and on 24−25, September 2011 at the inflow site from the Yala River (Stn.1) and at the outflow site (Stn.4) adjacent to Usenge area (Fig. 1). Additionally, water samples were collected in Lake Kanyaboli (Stn.2) and Lake Sare (Stn.3) lying in the swamp.

Chemical analyses of water samples were conducted on macronutrients (NO_3-N, NH_4-N, PO_4-P) being some of components of dissolved inorganic matter (DIM), chemical oxygen demand (COD) of filtrates and dissolved organic carbon (DOC) as indicators of dissolved organic matter (DOM), ignition residue as particulate inorganic matter (PIM), and ignition loss, particulate organic carbon (POC) and nitrogen (PON) as indicators of particulate organic matter (POM).

Water samples were filtrated through glass fiber filter (type GF/C, Whatman, Maidstone, UK) pre-ignited at 450℃ for 4 hours. Filtrates were used for analyses of macronutrients, COD and DOC. Macronutrients' concentrations and COD were measured with the Digital Pack-Test Multi (DPM-MT, Kyoritsu Chemical-Check Corp., Tokyo, Japan) after having been reacted with the respective Pack-Test reagents. Filtrates collected on 13 February 2011 were kept in brown-color vacuum vials under the frozen condition and used for analyses of DOC, and fluorescence properties of DOM. DOC concentrations were measured by the high temperature catalytic oxidation method (Yoshioka et al., 2002), and fluorescence properties of DOM were determined by the three-dimensional fluorescence measurements using a spectro-fluorometer (F-700, Hitachi High-Technologies Co., Tokyo, Japan) (Yoshioka et al., 2007). Samples for analyses of PIM and POM were collected on Whatman GF/C glass fiber filters pre-ignited at 450℃ for 4 hours and weighed previously. Filters loaded with particulate matter were kept in a desiccator with silica gel under the frozen condition and dried at 40-50℃ for 5 hours before ignition. These filters loaded with particulate matter were measured their dry-weight and ignited at 450℃ for 6 hours. After ignition, the filters were weighed again. Ignition residue (mg DW/l) as an indicator of PIM was obtained by subtracting dry-weight of the filter loaded with particulate matter after ignition from that of the filter before ignition. POM expressed as dry-weight (mg DW/l) was estimated by the dry-weight loss of the filter due to ignition. POC and PON of the samples collected on Whatman GF/C glass fiber filters were measured with an automatic high sensitive NC analyzer (SUMIGRAPH, NC-22A, Sumika Chemical Analysis Ltd., Osaka, Japan) after drying the samples. In addition to these components, water temperature, pH, dissolved oxygen and

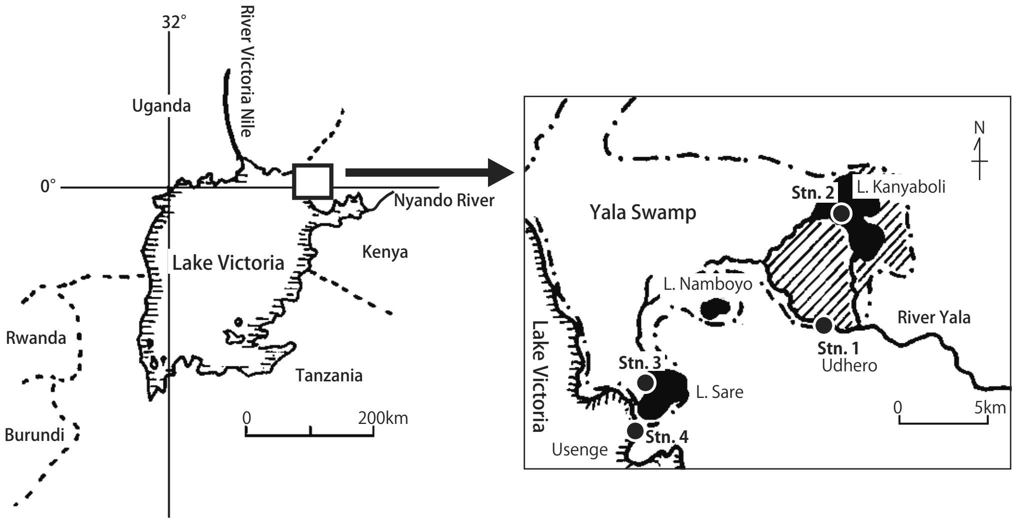

Fig. 1. Map of the Yala Swamp, showing location of the sampling stations. The reclaimed area of the swamp is shown by oblique lines

conductivity were measured on 13 February and 24−25 September 2011 at Stns. 1, 2, or 3 and 4 with a Multi-Parameter Water Quality Meter (WQC-24, DKK-TOA Co., Tokyo, Japan).

For reference, macronutrients' concentrations were measured at the lower reaches of the Nyando River flowing into Lake Victoria having land farm on a basin scale on 2 September, 2010 and 13 February, 2011 (Fig. 1).

Results and Discussion

Water temperature, pH, dissolved oxygen (DO) and conductivity measured at the sampling stations in the swamp were summarized in Table 1. Water temperature in the swamp was within the range of 24.5℃ at Stn.1 (the inflow site) to 26.5℃ at Stn.2 (Lake Kanyaboli) on 13 February 2011 and 23.8℃ at Stn.1 to 27.4℃ at Stn.2 on 24−25 September 2011, indicating that seasonal fluctuation of water temperature is little. The pH value ranged from 7.2 at Stn.1 to 8.0 at Stn.2 on 13 February 2011 and from 7.3 at Stn.4 to 7.8 at Stn.2 on 24−25 September 2011. The pH values obtained were relatively high as compared with a range of 3.0−7.0 reported from other swamps (Horne and Goldman, 1994). One of the reasons of the high pH values seemed to reflect photosynthetic activity of phytoplankton in lakes lying in the swamp. Dissolved oxygen (DO) concentration was unsaturated and showed a tendency to decrease from 6.7 mg O_2/l at Stn.1 to 5.3 mg O_2/l at Stn.4 on 13 February 2011, corresponding to 92−74% of the percent saturation, and from 7.0 to 6.3 mg O_2/l on 24−25 September 2011, corresponding to 95−89% of the percent saturation. Conductivity was not different between the inflow and outflow water and ranged within 7.8−8.7 mS/m on 13 February and 8.3−11.0 mS/m on 24−25 September 2011, though it was high in Lake Kanyaboli ranging within 32.5−33.9 mS/m.

Removal effects of the Swamp on macronutrients and DOM

Removal effect of the Yala Swamp on macronutrients (NO_3-N, NH_4-N, PO_4-P), one of the components of dissolved inorganic matter, could not be made clear because these macronutrients measured were concentrations under the limiting of detection except for PO_4-P on 13 February 2011 having shown a tendency to increase from 0.03 mg P/l in the inflow water at Stn.1 to 0.09 mg P/l in the out-

Table 1. Water temperature (WT), pH, dissolved oxygen (DO) and electric conductivity (Con) at the sampling stations in the Yala Swamp

	Stn.1 (inflow)	Stn.2 (L. Kanyaboli)	Stn.3 (L. Sare)	Stn.4 (outflow)
WT 13 Feb., 2011	24.5	26.5	−	25.6
(℃) 24-25 Sep., 2011	23.8	27.4	26.5	25.0
pH 13 Feb., 2011	7.2	8.0	−	7.3
24-25 Sep., 2011	7.6	7.8	7.6	7.3
DO 13 Feb., 2011	6.7	6.0	−	5.3
(mg O_2/l) 24-25 Sep., 2011	7.0	5.9	6.2	6.3
Con 13 Feb., 2011	7.8	33.9	−	8.7
(mS/m) 24-25 Sep., 2011	11.0	32.5	9.0	8.3

flow one at Stn.4 (Table 2). More sensitive pack-test reagents are required for measurements of macronutrients in the Yala Swamp. It was shown by the present survey that macronutrient's concentrations were considerably low as compared with those except for NH_4-N at the lower reaches of the Nyando River, one of rivers flowing into Lake Victoria (cf. Table 2) and world averages of NO_3-N (1.0 mg N/l), NH_4-N (0.05 mg N/l) and PO_4-P (0.1 mg P/l) in rivers (Horne and Goldman, 1994). These data suggested that the Yala Swamp was under the little polluted conditions.

There was no significant difference in COD of the filtrates between the inflow water at Stn.1 and the outflow one at Stn.4 throughout the investigations, though the COD increased in Lake Kanyaboli (Stn.2) and/or Lake Sare (Stn.3) in the swamp (Table 3). This fact suggested that DOM transported from the Yala River was refractory and little decomposed photochemically and biologically in the swamp. Yoshioka et al. (2007) reported that DOM in rivers was almost all refractory, too. On the other hand, dissolved organic carbon (DOC) measured on 13 February 2011 at Stn.4 (2.7 mg C/l) was significantly higher than that at Stn.1 (1.8 mg C/l), an increase by 1.5 times, indicating rather a ten-

Table 2. Macronutrient's concentrations at the sampling stations in the Yala Swamp and at the lower reaches (Ahero) of the Nyando River

		Stn.1 (inflow)	Stn.2 (L. Kanyaboli)	Stn.3 (L. Sare)	Stn.4 (outflow)	Nyando River
NO_3-N	2 Sep., 2010	< 0.20	0.24	−	< 0.20	1.03
(mg N/l)	24-25 Sep., 2011	< 0.20	< 0.20	< 0.20	< 0.20	−
	13 Feb., 2011	< 0.20	< 0.20	−	< 0.20	0.93
NH_4-N	2 Sep., 2010	0.05	< 0.05	−	< 0.05	< 0.05
(mg N/l)	24-25 Sep., 2011	< 0.20#	< 0.20#	< 0.20#	< 0.20#	−
	13 Feb., 2011	< 0.05	< 0.05	−	< 0.05	< 0.05
PO_4-P	2 Sep., 2010	0.03	0.03	−	< 0.03	0.11
(mg P/l)	24-25 Sep., 2011	< 0.03	< 0.03	< 0.03	< 0.03	−
	13 Feb., 2011	0.03	< 0.03	−	0.09	0.27

The limiting of detection of Pack-Test reagent used on 24-25 September, 2011 was different from that of previous two surveys and < 0.20 mg N/l.

Table 3. COD in filtrates and dissolved organic carbon (DOC) at the sampling stations in the Yala Swamp

		Stn.1 (inflow)	Stn.2 (L. Kanyaboli)	Stn.3 (L. Sare)	Stn.4 (outflow)
COD	2 Sep., 2010	10	13	−	10
(mg O/l)	24-25 Sep., 2011	15	20	30	15
	13 Feb., 2011	5	9	−	6
DOC (mg C/l)	13 Feb., 2011	1.8	6.4	−	2.7

dency to be subjoined in the swamp (Table 3). Difference in the horizontal variation of COD and DOC at Stn.4 on 13 February, 2011 suggested addition of DOM originated in the Yala Swamp, which is hardly oxidized by the COD pack-test reagents (potassium permanganate) under the room temperature. It was suggested that DOM originated in the Yala Swamp was somewhat different in quality from that originated in the Yala River. It was shown that the Yala Swamp lacked in removal function on DOM transported from the Yala River and rather might be one of the DOM sources for Lake Victoria.

As a result of fluorescence properties' analysis, protein-like matter was not detected in any DOM samples taken on 13 February, 2011 from the swamp. Taking into consideration the fact that protein-like matter is a product formed on biodegradation processes of phytoplankton (Yoshioka, et al., 2007 and 2010, Yamada, et al., 2012a and 2012b), refractory DOM joined in the Yala Swamp seemed not to be originated in phytoplankton but in peat and/or emergent plants.

COD of the filtrates at Stn.1 (the inflow site) in September, early rainy season, was higher than in February, late dry season. It was considered that, in September, much DOM originated in land flowed into the Yala River with flooding of rainwater, while in February DOM flowed little into the river because of no precipitation. Seasonal change in the COD of the Yala River, as an indicator of DOM, seemed to have been closely related to precipitation around the river basin.

Removal effects of the Yala Swamp on particulate inorganic and organic matter

Particulate inorganic matter (PIM) expressed as ignition residue of particulate matter decreased drastically 15−46 mg DW/l at Stn.1 to 0.0 mg DW/l at Stn.4 throughout the investigations (Table 4). This result indicated that PIM flowing from the Yala River was completely removed in the swamp. PIM was mainly composed of red clay originated in farm and waste lands around the Yala River. Ignition residue obtained from the Nyando River where farm land expands on a basin scale was extraordinarily high value of 232 mg DW/l measured on 2 September, 2010 as compared with that in the Yala River (cf. Table 4). When large-scale development of farm land in the Yala River Basin goes forward in the future, loading of PIM originated in farm land will increase in the same way as the Nyando River. Taking into consideration increase in PIM from the Yala River in the future, it will be required to examine removal capacity of the swamp on PIM for preservation of chemical, physical and biological functions.

Particulate organic matter (POM) expressed as ignition loss decreased from 15−10 mg DW/l in the inflow water (Stn.1) in September 2010 and 2011 to 4.0−2.8 mg DW/l in the outflow one (Stn.4), while there was no difference in the ignition loss between the inflow and the outflow water in February 2011 (Table 4). Particulate organic carbon (POC) in September 2010 and February 2011 showed the same tendency as POM in the fluctuation pattern; POC decreased from 1.93 mg C/l at Stn.1 to 0.21 mg C/l at Stn.4 in September 2010 while it ranged from 0.94 mg C/l at Stn.1 to 1.08 mg C/l at Stn.4 in February 2011 (Table 4). Particulate organic nitrogen (PON) decreased from 0.19 mg N/l at Stn.1 to 0.00 mg N/l at Stn.4 in September 2010, while it showed a tendency to increase from 0.10 mg N/l at Stn.1 to 0.13 mg N/l at Stn.4 in February 2011 (cf. Table 4). POC:PON ratio (by atoms) was not significantly different among the stations and ranged from 10:1 to 12:1 (Table 5). The ratio obtained here was higher than Redfield ratio (C:N=6.7:1) being general elementary composition of phytoplankton (Redfield, 1958), suggesting that POM in the Yala Swamp was mainly allochthonous origin.

In comparison of POM expressed as ignition loss at Stn.1 with that at Stn.4, it was shown that 60－88% of allochthonous POM were removed in September, while any removal of the POM was not found in February. POC as an indicator of POM showed the same tendency as the POM. This fact suggested that the Yala Swamp was different in removal effect on allochthonous POM between seasons.

Van Bruggen (Muyodi et al., 2006) reported that 50－85% of suspended solids (SS) were removed through aquatic macrophyte zone in tropical wetlands. To compare removal rates of SS in the Yala Swamp with those by Van Bruggen, the rates of SS in the swamp were calculated using data on PIM and POM, corresponding to SS (PIM +POM), of the inflow water at Stn.1 and the outflow one at Stn.4 in Table 4. Removal rates of SS in the swamp obtained were 74, 87 and 95% in February 2011, September 2010 and 2011, respectively. Removal rates of SS in the swamp were higher in September than the maximum rate by Van Bruggen.

It was demonstrated that removal function of the Yala Swamp on allochthonous matter was

Table 4. Particulate inorganic matter (PIM), particulate organic matter (POM), particulate organic carbon (POC) and nitrogen (PON) at the sampling stations in the Yala Swamp and at the lower reaches (Ahero) of the Nyando River

		Stn.1 (inflow)	Stn.2 (L. Kanyaboli)	Stn.3 (L. Sare)	Stn.4 (outflow)	Nyando River
PIM#	2 Sep., 2010	15	－	－	0.0	232
	24-25 Sep., 2011	46	1.5	0.8	0.0	－
(mg DW/l)	13 Feb., 2011	17	0.0	－	0.0	－
POM#	2 Sep., 2010	15	－	－	4.0	40
	24-25 Sep., 2011	10	7.0	3.6	2.8	－
(mg DW/l)	13 Feb., 2011	6.0	8.0	－	6.0	－
POC	2 Sep., 2010	1.93	0.81	－	0.21	5.11
(mg C/l)	13 Feb., 2011	0.94	3.16	－	1.08	－
PON	2 Sep., 2010	0.19	0.09	－	0.00	0.86
(mg N/l)	13 Feb., 2011	0.10	0.34	－	0.13	－

Ignition residue and ignition loss were expressed as dry weight (DW) of PIM and POM, respectively.

Table 5. POC:PON ratios at the sampling stations in the Yala Swamp

	Stn.1 (inflow)	Stn.2 (L. Kanyaboli)	Stn.3 (L. Sare)	Stn.4 (outflow)
POC:PON ratios (by atoms)				
2 Sep., 2010	12:1	11:1	－	－#
13 Feb., 2011	11:1	11:1	－	10:1

PON was not detected.

complicated and different in chemical forms of the matter. Further, it was suggested that field survey was essential to understanding of actual functions of swamps or wetlands being biologically, chemically and physically heterogeneous and diversified.

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