16. LONG TERM RESPONSE OF THE VEGETATION COMPOSITION TO WATER LEVELS REDUCTION AND WATER CHEMISTRY CHANGES IN SAROBETSU MIRE, A DEGRADED RAISED BOG IN NORTHERN JAPAN

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ABSTRACT: Land-use change around Sarobetsu Mire for agricultural purposes was started as an antidote project against food shortage after World War II. During 1961-1969, a short-cut channel was built to prevent the floods by lowering the water level. This led to the invasion by an exotic species of dwarf bamboo, *Sasa kurilensis* that prefer dry conditions in place of the native *Sphagnum spp.* The reduction in water levels were further affecting the water chemistry, creating ombrotrophic-minerotrophic gradient from east toward the western area. This study assessed the long-term changes in the composition of vegetation which accompanied by the changes in water chemistry regimes. Using canonical correspondence analysis (CCA), it was found that beside hydrological parameters, the succession of vegetation in this degraded bog was closely related to the nutrient contents and surface waters' mineral contents. The results also highlight the influence of hydrologic parameters on water chemistry regime; they control the chemical as well as biotic processes in mire ecosystems.

KEYWORDS: Sarobetsu Mire, land-use change, vegetation composition, CCA, water chemistry.

1. INTRODUCTION

Mires are doomed to be reclaimed as the population increases. Agriculture and peat industry have heavily utilized the mires across time. In some area, the ditching or short-cut channeling have been the single greatest factor changing the nature of the mires. The areas targeted by ditching have became greatly polluted due to the nutrients that are incorporated in the suspended sediments produced by the development (Whigham et al., 1988). Ditching and drainage work have caused the desiccation of mires as well as disturbances in the hydrological balance as a result of the lowered water level of the mires. Changes in the mires' hydrology have reduced peat formation, characteristic of mires, and have caused the emergence of saplings and active growth in tree stands in mires that have previously been open and sparsely stocked. The desiccation of the mires have immense impact on the mire water regime, which further decreased the biodiversity of the ecosystem and greatly reduced the original composition of vegetations.

This study assessed the impacts of the land reclamation to water chemistry and the vegetation composition in Sarobetsu Mire, a degraded mire in Northern Japan, and discussed the mechanisms of the hydrochemical changes.

2. MATERIAL AND METHODS

Sarobetsu Mire is the third largest mire in Japan. The mire is dotted with large and small lakes and marshes, including Penke, Panke and Kabuto marshes and is habitat to 100 kinds of flowers and wild animals. Since the development in the Meiji Era (1867-1911), many parts of the mire were reclaimed as paddies or dry fields. In the beginning, immigrated farmers gave up due to the frequent floods in their farmlands. During 1961-1969, the Hokkaido Development Bureau constructed the main short-cut channel Sarobetsu River to prevent the floods by lowering the water level. This construction succeeded to change the hydrological conditions of the area and increased the productivity of the farmland. However, this canal digging resulted in the lowering of the groundwater table within 1 km of the canals, thus drying up the mire, leading to vegetation changes on the remaining mire, including the invasion of an exotic plant, *Sasa spp.* at the western part of the mire. This species can endanger the diversity of the community due to its characteristics to inhibit tree generation and reduce the richness and abundance of forest floor plants (Nagaike et al., 1999). The eastern part of the mire, in the other hand, has sustained its natural condition.

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We monitored the water levels and water chemistry at five representative points along east-west direction during the period 1993-2003. These points are (Fig. 1): *Point E:* The eastern side of the mire, where ground water level is still high and the natural bog vegetations are preserved. It also can be considered as the hummock surface of the raised bog. *Point W:* About 180 meters on the west direction of point E, represents the '*Sasa* front area', where the boundary between the natural and degraded area exists. *Point W':* 150 meters on the west direction of point W. This is the area where of 0.3 mm-thick and 1.3 m-width vinyl sheet was installed in 1991. This installation is a part of the effort to raise the ground water level and re-establish the bog vegetation. The leaf area index (LAI) of *Sasa* plants in this area is 0.6, a bit higher than point W with LAI of 0.5. *Point WW:* The growth of *Sasa* in this area is vigorous, with LAI value of 1.8, the highest between all sampling points. The ground water level is also very low with dry soil surface, and no *Sphagnum* cover present *Point NC:* The area where the naturally-formed gully systems (known as natural channel) are present and drain the mire toward Sarobetsu River. The *Sasa* plants also grow vigorously with LAI value of 1.3, and no *Sphagnum* cover present.

The composition of the vegetation was studied according to the method of Braun-Blanquet (1964) during summer 2003 and 2004. The vegetations were then classified into bog to rich fen gradient types using the classification of Sjors (1983), Vitt and Chee (1990), Tachibana (1998), and J.K. Jeglum (*pers. comm*). To examine the change in species components in relation to the hydrochemical variables, the surface water chemistry and species frequencies were then used for canonical correspondence analysis (CCA) by using CANOCO Ver. 4.5 (ter Braak, 1986).

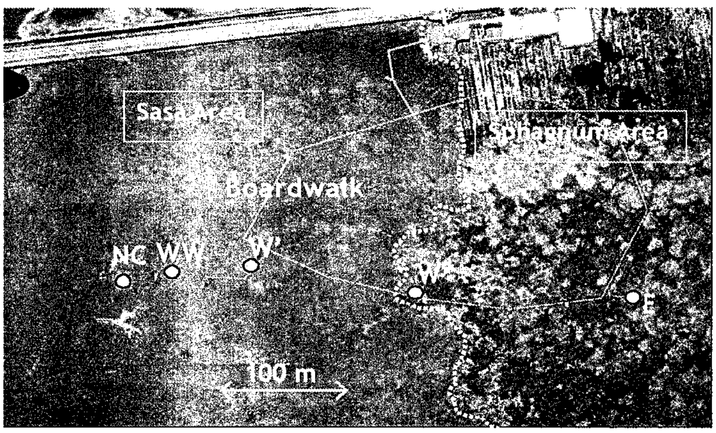

Figure 1. Sampling points drawn on aerial view.

3. RESULTS AND DISCUSSION

Water levels generally responded quickly to precipitation events over 10 mm and when periods of little or no precipitation lasted longer than two weeks, water levels fell noticeably (Fig. 2). Water levels at eastern side of the study site, points E and W (mean water levels, WLmn = -4.4 cm and -8.4 cm, relative to the ground surface) were relatively higher than those at points W' and WW (WLmn = -18.5 and -21.5 cm). The response of water levels of the six monitored points to each precipitation event were also obviously showed the instability toward the degraded area. The variations of water level at points E and W were smaller than those at points W' and WW, indicates that the water level at the eastern side was more stable and had less fluctuation compared to that of degraded area.

This result showed that water levels at the west part of the mire seemed to be affected as the local water table was lowered by the short-cut channel in Sarobetsu River. The pattern of water levels also showed that the soil in the degraded area has a poor water-holding capacity. Much of this may due to the low levels of organic matter present, since organic matter that formed from dead plants creates protective mulch that reduces soil erosion and water evaporation by absorption of water in the soil. These observations are relevant with the fact that *Sphagnum* which usually acts as a huge sponge in the natural bog mire is absent. The low water-holding capacity of the soil is considered to be the result of the low water level which exposes the bare peat, after the loss of *Sphagnum* cover. Once bare peat is exposed, it can be adversely affected by natural weather events easily, and is followed by erosion of the peat mass. According to Bragg and Tallis (2001) the type of gully systems which are formed at the vicinity of point NC are the result of this erosion. These ditches perform main portion of drainage from the bog area to Sarobetsu River, and seem to be the main reason for the distribution of Sasa at the same area with the distribution of ditches (Inoue at al., 1992).

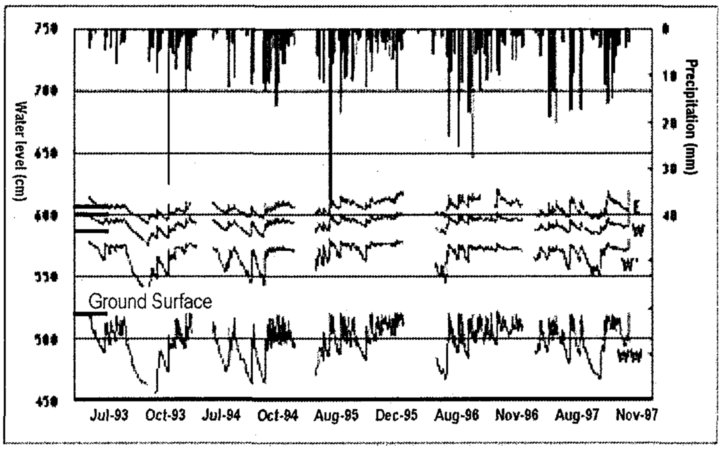

Figure 2. Water level fluctuations and precipitation data (cm) over 1993-1997 sampling period. Ground surface levels at each sampling location are presented as straight line at the left side.

The result of chemical analysis (Fig. 3) also revealed the changes of water chemistry at the area where Sasa thrives. The western part of the mire, represented by point NC, and to a lesser extent, point WW, showed that the ombrotrophy of water regimes have been replaced by minerotrophy due to the influence of mineral-rich ground water flow to the mire basin. At point NC, during the periods of little or no precipitation, surface and groundwater pH increased up to above 6, showing the lost of bog mire system to maintain acidic pH. The loss of *Sphagnum* cover due the reduction in water levels also led to pH increment, since pore-water acidity in unpolluted peatlands is primarily caused by organic acids and H^{+} ions, and the latter is derived from the cation exchange activity of bryophytes, especially *Sphagnum* species (Clymo, 1964; Gorham et al., 1985; Bragazza and Gerdol, 2002).

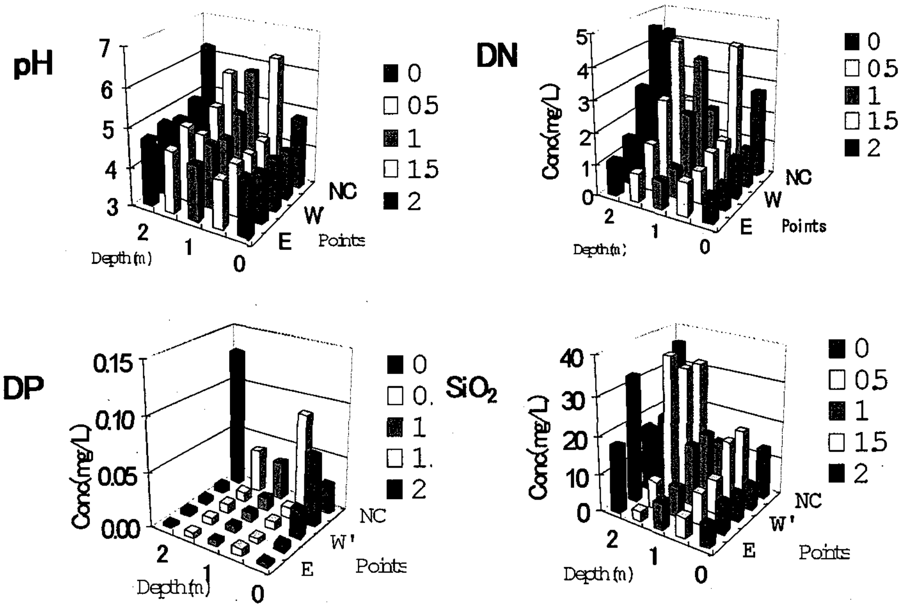

Figure 3. Pattern of water chemistry from east to west (points E-W-W'-WW-NC). Values are presented as averages during 1993 – 2003 study period.

The reduction of water levels will also increase the nutrient contents since they are more concentrated in a smaller amount of water (Fig.3). Furthermore, the higher nitrogen concentration in the soil will also enhance the decomposition of peat as reported by Haraguchi et al. (2003), followed by leaching process which will wash out the degraded mineral and nutrients from the soil and enriches the ground water chemistry during rains and snowmelt periods. During dry periods, the upward movements may occur, and the mineral supplied from below also reaches the surface (Lamers et al., 1999; Reeve et al., 2000). The presence of *Sasa* plants was further causing the hydrochemical changes. Suyama et al. (2000) reported that a single clone of *Sasa* plant can occur over a distance of about 300 m which may able to transfer mineral and nutrient from the surroundings and groundwater, and will be released when this plant die. The evapotranspiration by *Sasa* plants also caused the concentrations at the degraded area much higher. This seemed to be the main reason of the high concentration of Silica in the mire.

Aside from the hydrochemical processes due to the changes in hydrological regime, the reduction in water levels seemed also causing the groundwater inflow from surrounding areas became possible, transporting mineral and nutrients into the mire basin. The subsurface chemical components at the degraded area (point NC and, to a lesser extent, point WW) generally reflect the influence of solute-ladened runoff from the surrounding agricultural areas. In contrast, point E showed the ombrotrophy of the east part, since it is topographically high areas isolated from runoff and ground water.

As for the vegetation composition, they are shown in Table 1. The hummock surface of point E was covered by sedges family of *Rhynchospora alba* and *Carex middendorffii*, where *Sphagnum nemoreum Scop* was found to be the main moss cover. Other plants that were found at around point E were also mostly those which can occur in ombrogenous bog. At point W, Other than *Sphagnum papillosum* as the ground cover, dominant vegetations were *Oxycoccus quadripetalus and Carex middendorffii.* The communities *Moliniopsis japonica-Carex middendorffii* were found along the area of point W to point WW, where *Rubus chamaemorus-Sphagnum papillosum* communities are only found in point W'. Point W' was found to be the richest area to host some bog plants as well as some vegetations characterized as fen species, where at point NC, we only could observe the presence of *Ilex crenata var. paludosa* as the remaining natural bog plant. *Sasa kurilensis,* was found to be invading all along and beyond the axis that extends from point W to point NC (See Fig. 1). In addition, this plant was the only one found at point NC in 2003.

Table 1. Species frequencies at the study site in 2003 and 2004.

Pt	Species name	Frequency		Class.	Pt	Species name	Frequency		Class.
		2003	2004				2003	2004	
E	*Empetrum nigrum*	4	3	bog	WW	*Sasa kurilensis*	5	5	invasive
	Myrica gale var. tomentosa	1	1	bog		*Ilex crenata var. paludosa*	3	2	bog
	S. papillosum Lindb	2	4	bog/fen		*Myrica gale var. tomentosa*	0	1	bog
	S. nemoreum Scop.	3	4	bog		*Lycopodium annotinum*	+	+	fen
	Rhynchospora alba	3	3	bog		*Ledum palustre*	1	+	bog
	Carex middendorffii	3	3	poor fen		*Carex middendorffii*	0	1	poor fen
	Chamaedaphne calyculata (L) Moench	1	1	bog		*Moliniopsis japonica*	1	+	fen
	Oxycoccus quadripetalus	2	0	bog		*Rhynchospora alba*	2	0	bog
	Drosera rotundifolia	2	0	bog					
					NC	*Sasa kurilensis*	5	5	invasive
W	*Sasa kurilensis*	2	2	invasive		*Ilex crenata var. paludosa*	0	1	bog
	Myrica gale var. tomentosa	2	2	bog		*Coptis trifolia*	0	+	fen
	Chamaedaphne calyculata (L) Moench	2	2	bog					
	Oxycoccus quadripetalus	4	3	bog	W'	*Moliniopsis japonica*	+	4	fen
	Empetrum nigrum	1	2	bog		*Sasa kurilensis*	3	4	invasive
	Ledum palustre var.diversipilosum	1	2	bog		*Myrica gale var. tomentosa*	3	2	bog
	Moliniopsis japonica	0	+	fen		*Carex middendorffii*	0	2	poor fen
	Carex middendorffii	4	3	poor fen		*Oxycoccus quadripetalus*	+	1	bog
	S. papillosum Lindb	0	2	bog/fen		*Coptis trifolia*	1	+	fen
	Trientalis europaea var. arctica	+	0	fen		*Chamaedaphne calyculata (L) Moench*	1	+	bog
	Andromeda polifolia	+	1	bog		*Ledum palustre var. diversipilosum*	+	2	bog
						Ilex crenata var. paludosa	1	2	bog
						Lycopodium annotinum	3	+	fen
						S. papillosum Lindb	2	3	bog/fen
						Drosera rotundifolia	3	2	bog
						Andromeda polifolia	+	0	bog
						Rubus chamaemorus	2	1	bog
						Sanguisorba tenuifolia	1	1	bog
						Rhynchospora alba	2	1	bog
						Heloniopsis orientalis	1	0	fen
						Trientalis europaea var. arctica	+	1	fen

This composition of plant species revealed the differences along east-west direction. Point E is found to host only bog species, relevant with its ombrotrophic water characteristics. Point W' which was slightly minerotrophic hosted richer vegetation compositions. By means of 'sensitive indicators of minerotrophy' approach, which is using the presence of certain minerotrophic species to indicate if there is some minerotrophic influence of the groundwater since some numbers of plants can be found to occur only in minerotrophic, we may also state that point E is the only unpolluted bog area, since we always could find some minerotrophic species at other places, including point W where we found *Moliniopsis japonica* and *Trientalis europaea var. arctica* even at low frequencies.

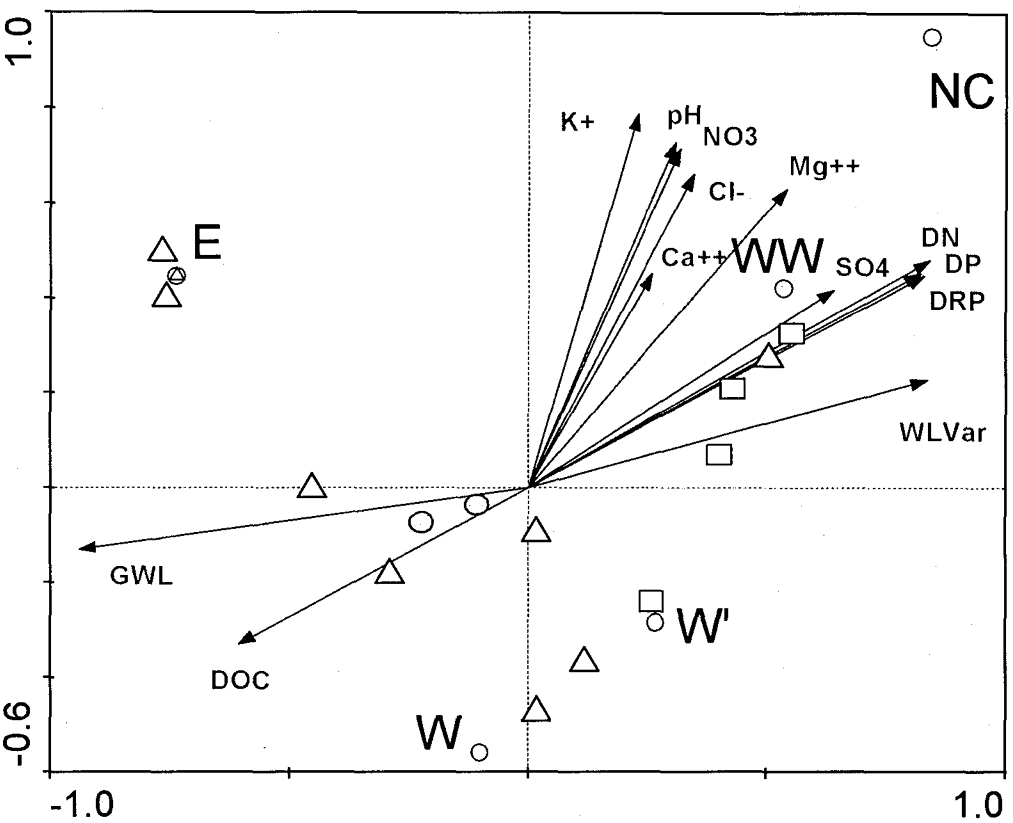

Figure 4. Canonical correspondence analysis of the five sampling points studied. Environmental variables were significant in forward selection (Monte Carlo test, $p < 0.005$). The vegetations were classified into bog (△), poor fen (◯), fen (□) and invasive (□) species.

Canonical correspondence analysis (Fig. 4) revealed a plant community sequence along the environmental factors. Along axis 1 which explains 58% of the variance of all data, the microtopography of hollow-hummock gradient was found in a consistent path from west to east direction. We also can find minerotrophic-ombrotrophic gradient depicted in this axis. DOC concentration and ground water level negatively correlated with this arrangement, whereas the range of water level, DN, DRP and DP concentrations showed positive correlation at similar magnitudes. At smaller magnitudes, SO_4^{2-} and Mg^{2+} also showed positive correlations. The second axis which is less explained the variance (26% of total variance) is more correlated to mineral and inorganic ion contents, where pH, K^+, NO_3^-, and Cl^- showed the highest correlations. This may be explained by the fact that the surface pH as well as mineral contents at points E, W, W' and WW are quite similar to each other, whereas point NC showed immense differences to other sampling points. The presence of these two axis in the relationships between plant communities with the environmental factors may be similar to thee findings of Vitt and Chee (1990) which also found the difference between bryophytes and vascular plants in their responses to water chemistry. Vascular plants are more sensitive to the nutrient contents, where moss species are more responsive to the concentrations of minerals.

CCA ordination also revealed the importance of hydrological variables to the composition of vegetations. Both mean water level and water level variation showed high amplitudes in relations with bog-fen vegetational gradient. Water chemistry parameters which showed high amplitudes in this gradient are the nutrient contents (DN, DRP and DP) and DOC concentration. The mineral contents showed importance in different spectrum, with lower significance.

4. CONCLUSION

This study revealed the influence of hydrologic parameters on water chemistry regime; they control the chemical as well as biotic processes in mire ecosystems. However, beside hydrological parameters, the succession of vegetation in this degraded bog was also closely related to the surface nutrient and mineral contents.

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