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Effect of *Sasa* Invasion on CO₂, CH₄ and N₂O Fluxes in *Sphagnum* Dominated Poor Fen in Bibai, Hokkaido, Japan

By

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Key words: Gas exchange, greenhouse gas, *Sasa* invasion, *Sphagnum*, poor fen.

Summary

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In Hokkaido, the northern part of Japan, degradation of natural wetland is occurring due to invasion of *Sasa* vegetation associated with construction of drainages. We measured greenhouse gas (GHG) fluxes at the *Sasa* invaded wetland in Bibai, Hokkaido. GHG fluxes at *Sphagnum*-dominated site (*Sp*) and *Sasa* invasion site (*Sa*) were measured by using a closed chamber method (transparent acryl chamber which covering plants) from July to October 2002. GHG concentration profiles, air filled porosity, and gas diffusion coefficient (D/D_0) of topsoil were also measured.

Water table depth was not significantly different between the sites. Air-filled porosity was significantly lower in *Sa* than in *Sp* ($p = 0.03$). D/D_0 was also lower in *Sa* than in *Sp*. CH₄ emissions ($\text{mg C m}^{-2} \text{ hr}^{-1}$) were significantly lower in *Sa* (2.4 ± 0.64) than in *Sp* (3.7 ± 0.48) ($p = 0.03$), although *Sa* showed a higher CH₄ concentration gradient at ground surface than that of *Sp*. This might be due to poor gas exchange in *Sa*. CO₂ emissions ($\text{mg C m}^{-2} \text{ hr}^{-1}$) were found in *Sa* (13 ± 15), while photosynthetic CO₂ uptake were found in *Sp* (-89 ± 7.0). This could be due to low ability of CO₂ fixation of *Sasa* vegetation, because CO₂ emission from ground surface was probably lower in *Sa* than in *Sp* due to poor soil gas exchange in *Sa*. N₂O fluxes ($\text{mg N m}^{-2} \text{ hr}^{-1}$) were 0.010 ± 0.007 in *Sp* and 0.001 ± 0.002 in *Sa*. Therefore, there was no significant difference between the sites ($p = 0.16$). However, soil N₂O concentrations in *Sa* decreased below the atmospheric N₂O concentration, could be due to N₂O dissolution into the soil water under poor soil gas exchange condition in *Sa*.

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Introduction

Natural wetlands uptake CO_2 and accumulate carbon as peat (CLYMO 1984). Northern wetlands contain about one-third of the total world pool of soil carbon (455Gt C, GORHAM 1991). Natural wetlands produce and emit CH_4 by anaerobic decomposition of organic matter (92 to $237 \text{ Tg CH}_4 \text{ yr}^{-1}$, IPCC 2001), while N_2O emission from natural wetlands estimated to be small and sometimes N_2O uptake has been found (REGINA & al. 1996). These greenhouse gas (GHG) fluxes in wetland ecosystems depend on many environmental and soil factors, such as temperature, solar radiation, precipitation, water table depth, and nutrients (LE MER & ROGER 2001). Global and regional change in climate and environment also alters wetland ecosystems.

In Hokkaido, natural wetland area has decreased from 200,000 ha to 60,000 ha during the past 100 years due to the conversion of wetlands into arable lands through mineral soil dressing and construction of drainage. The remaining wetlands have been degraded by the development of surrounding area (MIYAJI & al. 1997). In eastern Hokkaido, expansion of alder forest at Kushiro wetland has been found due to inflow of sediments from arable lands to the wetland (SHINSHO 1997). On the other hand, in central and northern Hokkaido, natural wetland degradation has been occurring due to the invasion of *Sasa* (dwarf bamboo) vegetation associated with drainage (TAKAKUWA & ITO 1986, TACHIBANA 2002). In the Ishikari River basin, peatlands cover about 55,000 ha (MIYAJI & al. 1997). Bibai wetland is one of them and is surrounded by arable lands and ditches. Therefore, there has been a progressive drying up of the wetland. Along with this process, *Sasa* vegetation has invaded into the *Sphagnum* dominated vegetation (KASUBUCHI & al. 1994) leading to a progressive change in the wetland.

Therefore, the objective of this study is to clarify the relationship between vegetation change and GHG dynamics at Bibai wetlands, in central Hokkaido.

Material and Methods

Site description

Study sites ($43^\circ 19' \text{N}$, $141^\circ 48' \text{E}$) are located in Bibai wetland in the Ishikari River basin in central Hokkaido, northern part of Japan (Fig. 1). The total area of Bibai wetland is only about 25 ha as shown in Fig. 1. The depth of peat soil is about 4 to 5 m. However, the natural wetland is surrounded by open ditches, and *Sasa* have invaded from the open ditches. Only an area of 2 ha maintains the original vegetation of *Sphagnum*. The annual precipitation is 1156 mm, and the average annual temperature is 7.1°C in this area (reference period 1979-2000). We set *Sphagnum*-dominated site (*Sp*) and *Sasa* invasion site (*Sa*) at the center of this wetland (Fig. 1). In *Sp*, vegetation is dominated by sphagnum moss (*Sphagnum papillosum* Lindb.) and sedge plants (*Moliniopsis japonica* (Hack.) Hayata, *Carex middendorffii* Fr. Schm. and *Eriophorum vaginatum* L.). In *Sa*, vegetation is dominated by *Sasa palmata* Nakai and *Gale belgica* Duham. Var. *tomentosa* C.. Above ground biomass and LAI in *Sa* were 232 g dw m^{-2} and 1.3, respectively.

Gas flux measurement

The GHG fluxes from those ecosystems were measured by using a closed-chamber method (YAGI 1997). The transparent acrylic and open bottom chamber (60 cm height and 0.09 m^2

bottom area) was used. During the measurement, plants were kept inside of a chamber. Therefore, we measured gas flux from the ecosystem (not only gas flux from soil surface but also gas emission via plant bodies and photosynthetic uptake of CO_2). The chamber had a gas-sampling tube, a plastic bag to control air pressure inside the chamber and a thermometer to measure the air temperature inside the chamber. Chamber collars (10 cm high and 30 cm wide) equipped with groove on the top, were inserted into the soil to 5 cm deep in June 2002. The groove was filled with water and the chamber was inserted into the groove during gas flux measurement. Boardwalks were built around the sampling plots to avoid disturbances during the measurements.

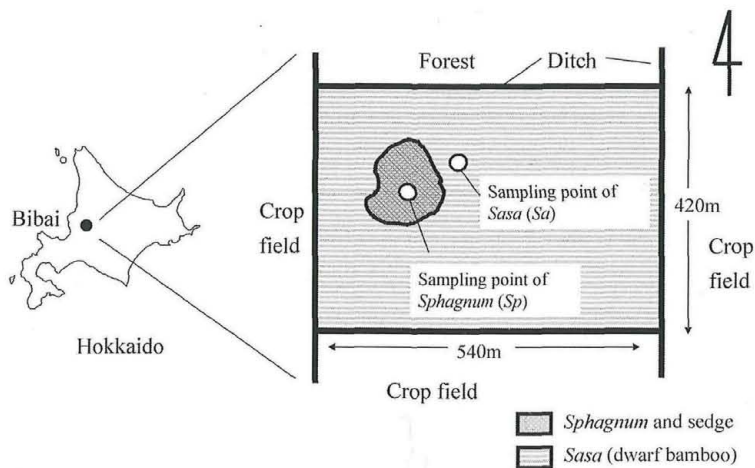


Fig. 1. Location map of the study site in Bibai, Hokkaido.

At 0, 10, 20 (or 40) minutes after the chamber was set up, a 500 mL gas sample was taken into a 1 L Tedlar bag. Then, 20 mL air samples from each of the Tedlar bags were transferred to 10 mL vacuumed brown glass bottles. CO_2 fluxes were calculated by 0 and 10 minutes samples. CH_4 and N_2O fluxes were calculated by linear regression of 0, 10, 20 (or 40) minutes samples. In CH_4 fluxes, linear regression data with $r^2 < 0.9$ were rejected.

Air temperature inside the chamber was recorded during each gas sampling to calculate the gas fluxes. Soil temperature at 3 cm depth and water table depth was measured at the time of gas sampling. To measure the water table depth, a perforated PVC-pipes (3 cm diameter) were inserted into the peat soil near the chamber.

Each gas flux measurements were 5 and 2 replications in Sp and Sa, respectively. Almost all of the flux measurements were conducted in series from 0900 to 1700 on clear day. The gas flux measurements were carried out from 23 July to 23 October 2002, at the frequency of 2 to 6 times per month.

Measurement of gas concentration in soil air

Measurement of gas concentration in soil air was carried out based on MORISHITA & al. 2003. On 30 July 2002, 3 replicates of stainless steel pipes (8 mm in diameter) were installed at depth of 5, 10, 15 and 20 cm. Air of 50 mL was sampled from each pipe and the air samples from the same depth were mixed into a 1 L Tedlar bag. Air samples of the soil surface were also taken. Sampling was conducted 6 times from 30 July to 23 October 2002.

Analysis of gas concentration and calculation of flux

CO₂ concentrations were analyzed with infra-red CO₂ analyzer (Fuji ZFP5). CH₄ and N₂O concentrations were analyzed with a gas chromatograph (SHIMADZU GC-8A, GC-14B) equipped with a flame ionization detector and a electron capture detector, respectively. Gas fluxes were calculated as follows:

$$F = \rho \times V / A \times \Delta c / \Delta t \times 273 / (273 + T) \times \alpha$$

where, F is the flux (mg C m⁻² hr⁻¹ for CO₂ and CH₄ and mg Nm⁻² hr⁻¹ for N₂O), ρ is the gas density (CO₂ = 1.98×10⁶ mg m⁻³, CH₄ = 0.716×10⁶ mg m⁻³, N₂O = 1.98×10⁶ mg m⁻³), V is the volume of the chamber (m³) and A is the bottom area of the chamber(m²), Δc/Δt is the ratio of change in the gas concentration change inside the chamber during sampling period (m³ m⁻³ hr⁻¹); T is the air temperature inside the chamber (°C) and α is the conversion factor for CO₂ and CH₄ to C and N₂O to N (CO₂ = 12/44, CH₄ = 12/16, N₂O = 28/44). The minimum detectable concentration of CO₂, CH₄ and N₂O were ± 1.0, ± 0.1 and ± 0.01 ppmv, respectively.

Physical properties and degree of peat decomposition

On 6 May 2003, 5 undisturbed soil samples (100 cm³ cores) were collected from 0 to 5 cm depth at the surface layer of each site. Three phase distribution and gas diffusion coefficient (D/D₀) of these cores were measured by using the method recommended by OSOZAWA 1997. On 15 November 2003, contiguous 10-cm peat samples (from surface to 50 cm depth) were collected from each site. The peat samples were air-dried and ground for determining total carbon and nitrogen content by using a NC analyzer (SUMIGRAPH NC-1000).

Results

The GHG fluxes, precipitation, soil temperature (3 cm), and water table depth during the measurement period are shown in Fig. 2, and the averages of them are given in Table 1. Water table depth of *Sp* and *Sa* varied from -1 to 19 cm, and 0 to 18 cm, respectively. There was no significant difference between the sites (Table 1). CO₂ uptake (-193 to 20 mg C m⁻² hr⁻¹) were frequently observed in *Sp*. While, CO₂ emissions were found in *Sa* (-135 to 155 mg C m⁻² hr⁻¹). CH₄ emissions in *Sa* (0.19 to 11 mg C m⁻² hr⁻¹) were lower than in *Sp* (0.92 to 22 mg C m⁻² hr⁻¹). N₂O flux was almost trace and several episodic emissions (0.42 mg N m⁻² hr⁻¹ in maximum) found in both sites. There were significant differences of CO₂ (p = 0.01) and CH₄ (p = 0.03) fluxes between *Sp* and *Sa* (by Wilcoxon's rank-sum test).

Table 1. Differences in GHG fluxes and water table (mean ± standard error) between *Sp* and *Sa*. The p-value were obtained by Wilcoxon's rank-sum test. Asterisks (* and **) denote significant difference at the 0.05 and 0.01 level, respectively.

	<i>Sphagnum</i> (<i>Sp</i>)	<i>Sasa</i> (<i>Sa</i>)	p-value
CO ₂ , mg C m ⁻² hr ⁻¹	-89 ± 7.0 (n = 63)	13 ± 15 (n = 26)	0.008**
CH ₄ , mg C m ⁻² hr ⁻¹	3.7 ± 0.48 (n = 56)	2.4 ± 0.64 (n = 16)	0.026*
N ₂ O, mg N m ⁻² hr ⁻¹	0.010 ± 0.007 (n = 65)	0.001 ± 0.002 (n = 2)	0.16
Water table, cm	9.1 ± 0.65 (n = 65)	10.3 ± 0.83 (n = 24)	0.20

The C content and C:N ratio above 20 cm depth were lower in *Sa* than in *Sp* (Fig. 3), suggesting that decomposition of peat surface is more advanced in *Sa*

than in *Sp*. There was a significant difference between *Sp* and *Sa*, for air-filled porosity ($p = 0.034$), solid ratio ($p = 0.003$), and dry bulk density ($p < 0.001$) (Table 2). The invasion of *Sasa* vegetation caused a decrease in air-filled porosity and increase in solid ratio at peat surface. There was no significant difference of D/D_0 between *Sp* and *Sa*. However, *Sp* showed a positive correlation of D/D_0 with air filled porosity, but *Sa* had low D/D_0 , regardless of increase in air-filled porosity (Fig. 4).

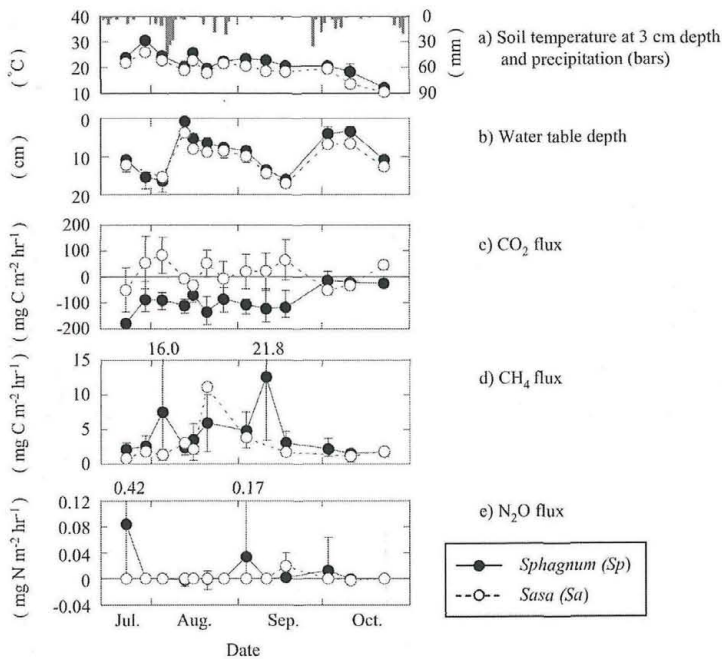


Fig. 2. Temporal variations in soil temperature at 3 cm depth (a), precipitation (a, bars), water table depth (b) and average GHG fluxes (c, d and e; positive and negative value represent emission and uptake, respectively). Error bars show maximum and minimum values.

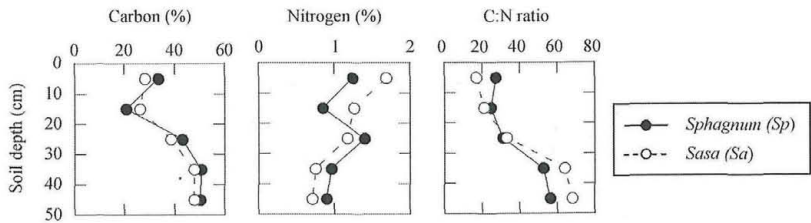


Fig. 3. Distributions of carbon and nitrogen content and C:N ratio of peat (0 - 50 cm).

Table 2. Differences in three phase distribution and gas diffusion coefficient (mean ± standard error) at peat surface (0 - 5 cm) between *Sp* and *Sa*. The p-value were obtained by t-test. Asterisks (* and **) denote significant difference at the 0.05 and 0.01 level, respectively.

	<i>Sphagnum</i> (<i>Sp</i>) (n = 5)	<i>Sasa</i> (<i>Sa</i>) (n = 5)	p-value
Air filled porosity, m ³ m ⁻³	0.26 ± 0.033	0.11 ± 0.046	0.034*
Water filled porosity, m ³ m ⁻³	0.69 ± 0.026	0.79 ± 0.042	0.072
Solid ratio, m ³ m ⁻³	0.058 ± 0.008	0.10 ± 0.006	0.003**
Dry bulk density, Mg m ⁻³	0.065 ± 0.006	0.12 ± 0.005	<0.001**
Gas diffusion coefficient (D/D ₀)	0.018 ± 0.010	0.003 ± 0.002	0.19

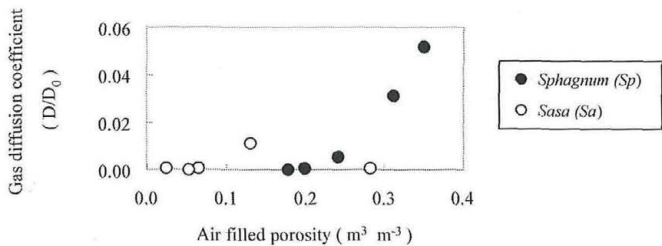


Fig. 4. Relationship between air filled porosity and gas diffusion coefficient (D/D₀).

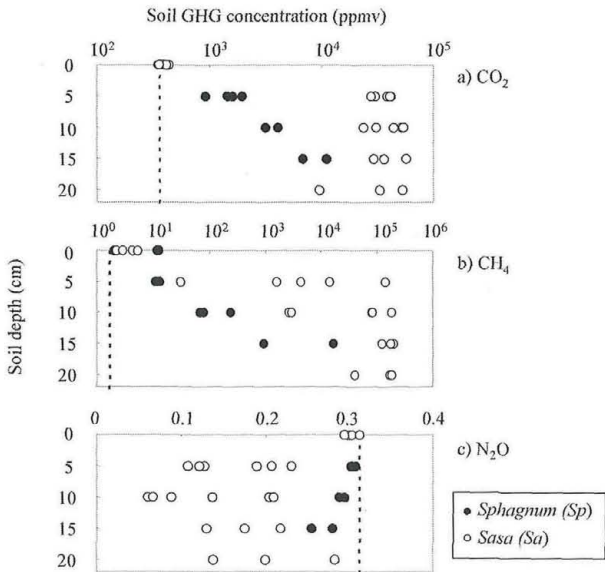


Fig. 5. Greenhouse gas concentrations in soil air during measurement period. Dotted line (---) denotes atmospheric concentration.

The soil CH_4 and CO_2 concentrations in *Sa* had increased remarkably at 5 cm depth (Fig. 5), causing a higher gradient of soil gas concentrations in *Sa* than in *Sp*. Soil N_2O concentrations in *Sa* had decreased as compared to those in *Sp*.

Discussion

CH_4 emissions were lower in *Sa* than in *Sp* (Fig. 2, Table 1). However, this did not correspond to the prediction from the result of CH_4 concentration gradient in soil (Fig. 5). There are three major pathway of CH_4 emission from wetland (CONRAD 1996): ebullition, diffusion through soil, transport via sedge plant which have developed aerenchyma (WHITING & al. 1992, KELKER & CHANTON 1997). In *Sa*, there was no transportation of CH_4 via sedge plant bodies and diffusion of CH_4 could be small due to low air filled porosity and low gas diffusion at the surface of the soil (Table 2, Fig.4). Therefore, CH_4 emissions were lower in *Sa* than in *Sp*, and higher soil CH_4 concentrations in *Sa* than in *Sp* were found.

CO_2 emissions were higher in *Sa* than in *Sp* (Fig. 2, Table 1). In this study, gas fluxes were measured by transparent chamber, therefore CO_2 flux consisted of photosynthetic uptake and respiration in addition to diffusion flux through soil surface. Many researchers have reported the increase of organic matter decomposition rate associated with a decrease in groundwater depth in peatland (MOORE & DALVA 1993, FROLKING & al. 2001). However, there was no significant difference in the water table depth between *Sa* and *Sp* (Table 1). In addition, CO_2 emission by diffusion through soil could be suppressed due to poor soil gas exchange which was similar to CH_4 . Therefore, higher CO_2 emissions in *Sa* might be due to higher plant respiration and lower photosynthesis in *Sa* than in *Sp*. The low CO_2 fixation of *Sasa* vegetation might be due to the inhibition of plant growth caused by high water table and soil moisture (TAKAKUWA & ITO 1986).

In *Sa*, N_2O concentrations were lower in soil than in atmosphere, suggesting that N_2O consumption had occurred in the soil. However, N_2O uptake from atmosphere was not found (Fig. 2), instead N_2O emission was sometimes found. This indicates that gas diffusion at the soil surface might be strongly suppressed. In addition, not only N_2O production but also CO_2 production might have occurred through the decomposition of only very thin surface peat layer. It seems that the strong suppression of surface gas diffusion had reduced oxygen supply to the deeper layer peat in *Sa*. In the groundwater, which contains little dissolved oxygen, N_2O consumption via denitrification (reduction to N_2) had occurred (MÜHLHURR & HISCOCK 1998). FRENEY & al. 1978 had also reported that saturated soil absorbed N_2O by denitrification in laboratory experiments. The dissolved N_2O could have decrease and gaseous N_2O in soil could have dissolved into the groundwater. These processes might have caused the low soil N_2O concentration in *Sa*.

In conclusion, *Sasa* invasion to *Sphagnum*-dominated wetland may change the trend of GHG fluxes and accumulation in soil through the change in physical properties of peat surface and suppressing gas diffusion.

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