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Effect of *Sasa* Invasion on Global Warming Potential in *Sphagnum* Dominated Poor Fen in Bibai, Japan

By

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Key words: Global warming potential, greenhouse gas, poor fen, *Sasa* invasion, *Sphagnum*.

Summary

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Greenhouse gas fluxes in a wetland ecosystem may be dramatically modified by human activities or vegetation change. This study was conducted to evaluate the effect of *Sasa* invasion on Global Warming Potential (GWP) in *Sphagnum*-dominated poor fen at Bibai, central Hokkaido, Japan. Fluxes of CO₂, CH₄, and N₂O at *Sphagnum*-dominated site (Sp) and *Sasa* invasion site (Sa) were measured by a closed chamber method, using a rectangular transparent acryl chamber, 30 cm x 30 cm x 60 cm (length x width x height), to cover whole plant bodies during the measurement. CO₂ flux measured by this method gives an estimate of the net ecosystem exchange (NEE), also known as net CO₂ exchange. Respiration rate was measured by using a shaded chamber. GWP was calculated using a 100-year time horizon recommended by IPCC (factors of 21 for CH₄ and 310 for N₂O).

NEE was significantly higher ($p < 0.05$) at Sa (223.8 g C m⁻² y⁻¹) than at Sp (5.8 g C m⁻² y⁻¹). CH₄ emission was higher at Sp (13.2 g C m⁻² y⁻¹) than at Sa (6.6 g C m⁻² y⁻¹), although the difference between the two sites is not significant. The contribution of CH₄ emission during the snow period (from snow cover to snow melting) to the total annual CH₄ emission accounted for 12% at Sp and 10% at Sa. N₂O emissions were 0.032 and 0.005 g N m⁻² y⁻¹ at Sp and Sa, respectively. The estimated GWP was significantly higher ($p < 0.05$) at Sa (1009 g CO₂ m⁻² y⁻¹) than at Sp (408 g CO₂ m⁻² y⁻¹) and the contribution of CO₂ emission to GWP was greater at Sa (81%) than at Sp (5%). Thus, we conclude that *Sasa* invasion in *Sphagnum*-dominated poor fen contributes to global warming due to increased CO₂ emission.

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Introduction

The atmospheric concentrations of CO₂, CH₄, and N₂O in 1750 were 280, 0.7, and 0.27 ppmv, respectively. In 1998, the concentrations of these gases increased to 365 ppmv (CO₂), 1.745 ppmv (CH₄), and 0.314 ppmv (N₂O), respectively (IPCC 2001).

Wetlands include a lot of carbon and nitrogen in accumulated organic layers. Hence, the changes in greenhouse gas (GHG) fluxes from peat soils are more drastic than those in mineral soils, when changes in vegetation and land use take place. Therefore, changes in GHG fluxes in wetlands that have been subjected to human activities such as agriculture have recently become a subject of much interest and attention (ARMENTANO & MENGES 1986, NYKÄNEN & al. 1995, KASIMIR-KLEMEDTSSON & al. 1997). About 50% of the global wetlands are located between north latitudes 50° and 70° (MATTHEWS & FUNG 1987). These high latitude wetlands are characterized by a large accumulation of organic matter and, many regions in this area are covered with snow or ice in the winter. Some studies have reported that gas exchange between the soil and atmosphere can occur even through the snow pack and frozen soil in wetlands and there are episodic fluxes in the winter until early spring (DISE 1992, ALM & al. 1999, MELLOH & CRILL 1995, 1996, PANIKOV & DEDYSH 2000, HEYER & al. 2002). Winter gas fluxes may play an important role in the annual C and N balance (MAST & al. 1998, ALM & al. 1999).

Global warming potential (GWP) is one of the indexes used to compare the relative radiative effect of different greenhouse gases, converting the annual emission of GHG to CO₂ equivalent (IPCC 1996, 2001). This approach has been used to assess the impact of agricultural activity as compared to a virgin fen (NYKÄNEN & al. 1995); it is also a tool for planning land use and cropping strategies for the mitigation of greenhouse gases (MOSIER & al. 2003, PALM & al. 2003, ROBERTSON & GRACE 2003).

The objective of this study was to evaluate the effect of *Sasa* invasion on global warming in *Sphagnum*-dominated poor fen at Bibai, central Hokkaido, Japan, by comparing the annual fluxes of greenhouse gases (CO₂, CH₄, and N₂O) and the GWP at *Sphagnum* dominated and *Sasa* invading sites.

Material and Methods

Site description

This study was conducted in Bibai wetlands (43° 19' N, 141° 48' E) in central Hokkaido, Japan at an altitude of 18m and with peat thickness of 4m (KONDO & al. 1997). The type of this wetland is originally poor fen, mainly dominated by *Sphagnum papillosum* Lindb., *Sphagnum magellanicum* Brid., *Carex omiana* Franch. et Savat., *Carex middendorffii* Fr.Schm., *Eriophorum vaginatum* L., *Rhynchospora alba* (L.) Vahl and *Rhynchospora fauriei* Franch.. Drying of this wetland occurs because drainage ditches for agriculture surround this wetland, hence *Sasa* (*Sasa palmata* (Bean) Nakai) has been invading. The original poor fen area was only about 2 ha of the 25 ha total wetland area (Fig. 1). The annual precipitation obtained from nearby meteorological survey point is 1124 mm including snowfall of about 500 mm during the experimental period. (AMEDAS data, Sapporo District Meteorological Observatory). The mean annual temperature is 6.6 °C (20.2 °C in

July, and -7.3 °C in February). There were nine gas sampling points during the no snow condition: five points (A-E) at *Sphagnum*-dominated sites (Sp); two points (F-G) at *Sphagnum*- *Sasa* mixed sites (Sp-Sa); two points (H-I) at *Sasa* invasion sites (Sa). Only three of the nine sampling points were used during the snow and snowmelt conditions: two points (A and E) at Sp and one point (H) at Sa (Fig. 1).

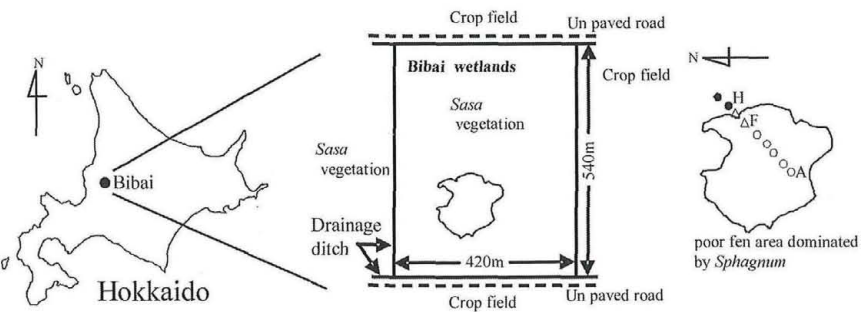


Fig. 1. Map of sampling sites in Bibai wetland, Hokkaido, Japan. The symbols show the three observation sites: Sp (○, A-E, n=5), Sp-Sa (Δ, F-G, n=2), and Sa (●, H-I, n=2).

Chamber measurements

The gas (CO₂, CH₄, N₂O) fluxes were determined by using a closed chamber method. A rectangular transparent acryl chamber, 30 cm x 30 cm x 60 cm (length x width x height), was used to cover whole plant bodies in the chamber during the measurement. Respiration rate was measured by shading the same chamber. This chamber was placed into pre-installed acryl collar (30cm x 30cm), sealed from the atmosphere with water during no snow conditions, and with packed snow in snow condition. The measurements by transparent chamber were conducted every two weeks from June 2002 to November 2003. The measurements in the snow melting period were conducted at about weekly intervals. The measurements by shaded chamber were conducted only during the period of June to November 2003. Flux measurements were conducted mostly between 0900H and 1700H. We conducted whole-day-measurements of CO₂ by transparent and shaded chamber under fine condition two times in June and October 2003. Soil temperature at 3-cm soil depth was measured using a pen type thermometer (CT-410WR, CUSTOM, Japan) simultaneous with gas flux measurements. The soil temperature at 3-cm soil depth was also monitored every hour using a thermo recorder attached to a data logger (TR-52, T&D, Japan) at one sampling point at Sp (point A, Fig. 1) from June to October 2003. Gas samples were collected at 0, 10, and 20 minutes during no snow conditions and at 0, 20, and 40 minutes during snow conditions. Gas samples for measurement of respiration rate were taken at 0, 10 or 20 minutes. The samples (500mL) for CO₂ analysis were drawn from the chamber with 50mL polypropylene syringe and transferred into 1L Tedlar[®] bags. The samples (20mL) for CH₄ and N₂O analysis were drawn with 25mL polypropylene syringes and transferred into glass vials with butyl septa (SVF-10, NICHIDEN-RIKA GLASS, Japan). CO₂ concentration was analysed using infrared CO₂ analyzer (ZFP9, FUJI ELECTRIC, Japan). CH₄ and N₂O concentrations were analysed using gas chromatograph equipped with flame ionization detector (GC-8A, SHIMADZU, Japan), and electron capture detector (GC-14B, SHIMADZU, Japan), respectively. Fluxes were calculated using equation (1):

$$F \text{ (mg C or mg N m}^{-2} \text{ h}^{-1}\text{)} = \rho \times V / A \times \Delta c / \Delta t \times 273 / T \times \alpha \quad (1)$$

where F was the gas flux; ρ was the density of gas at the standard condition (CO₂=1.96×10⁶ mg m⁻³, CH₄=0.716×10⁶ mg m⁻³, N₂O=1.96×10⁶ mg m⁻³); V (m³) and A (m²) were the volume and the area of the chamber; $\Delta c / \Delta t$ (m³ m⁻³ h⁻¹) was the gas concentration change in chamber during sampling period; T was the absolute temperature (K); and α was the conversion factor for each gas (CO₂=12/44,

(302)

CH₄=12/16, N₂O=28/44). We discarded the data for CH₄ if r^2 for the linear regressions between concentration and sampling time was below 0.9 (NYKÄNEN & al. 1995) or if the concentration at 0 minute was beyond 3 ppmv (WADDINGTON & ROULET 2000). Gas uptake from the atmosphere to the soil is marked negative (-) while gas emission to the atmosphere is marked positive (+) in this study.

Cumulative flux

We calculated the annual cumulative flux for the period of June 2002 to June 2003, henceforth referred to as year-2002. The cumulative CH₄ and N₂O fluxes were calculated by multiplying the fluxes with the sampling intervals. The CO₂ flux measured using a transparent acryl chamber in the daytime shows NEE in the daytime. To estimate NEE for a whole day (including nighttime), we used equation (2):

$$NEE = R_{tot} + P_G \quad (2)$$

where R_{tot} is the total respiration, which includes respiration of microorganism in soil and plants, and P_G is the gross CO₂ uptake.

The relationship between the soil temperature at 3-cm soil depth (T_3 ; °C) and respiration rate (R_{tot} ; mg C m⁻² h⁻¹) measured by the shaded chamber method was modelled based on the Arrhenius equation, which is described in detail by HU & al. 2004. R_{tot} can be expressed as shown in equation (3):

$$R_{tot} = \exp \left[a \times \frac{1}{273 + T_3} + b \right] \quad (3)$$

where a is the slope of the Arrhenius plot and b is the intercept of the Arrhenius plot. The values of a and b for each site are listed in Table 1. We estimated continuous T_3 data every hour in year-2002 from the relationship between the air temperature obtained by AMEDAS data and the soil temperature measured by thermo recorder in 2003. Hourly R_{tot} (mg C m⁻² h⁻¹) was calculated by using the estimated T_3 data in equation (3). Daily R_{tot} ($R_{tot(day)}$, mg C m⁻² day⁻¹) can be estimated as an integration of R_{tot} per hour within a day (mg C m⁻² h⁻¹).

P_G is calculated by deducting CO₂ flux measured by the shaded chamber from that measured by the transparent acryl chamber. Gas flux measurements were especially conducted intensively before and after 1200H. We assumed P_G as calculated by chamber method to be the maximum gross CO₂ uptake ($P_{G(max)}$). We were able to derive equation (4) from results of the two whole-day-measurements in 2003.

$$P_{G(mean)} \text{ (mg C m}^{-2} \text{ h}^{-1}\text{)} = P_{G(max)} \text{ (mg C m}^{-2} \text{ h}^{-1}\text{)} \times 0.8862 \quad (R^2 = 0.900, n=18) \quad (4)$$

where $P_{G(mean)}$ is the mean of P_G at each measurement point. We used the mean of fluxes measured during 1000H to 1400H as the $P_{G(max)}$. Hence, we calculated $P_{G(max)}$ in year-2002 by substituting NEE and R_{tot} in equation (3). Consequently, P_G per day ($P_{G(day)}$) was calculated using equation (5):

Table 1. The slope (a) and intercept (b) of Arrhenius plot (equation (3)) calculated from respiration rate (CO₂ flux) measured by shaded chamber June to November, 2003.

	A	B	C	D	E	F	G	H	I
a	-9411	-10162	-9802	-13486	-10521	-10521	-9147	-8010	-9896
b	36.85	39.60	38.27	50.71	40.60	30.60	35.97	32.62	38.65
n	10	10	10	10	9	10	10	10	9
R ²	0.91	0.94	0.93	0.92	0.91	0.93	0.89	0.73	0.87

$$P_{G(day)} \text{ (mg C m}^{-2} \text{ day}^{-1}\text{)} = P_{G(mean)} \text{ (mg C m}^{-2} \text{ h}^{-1}\text{)} \times \text{daytime length (h)} \quad (5)$$

NEE during no snow condition was calculated by taking the sum of $P_{G(\text{day})}$ and $R_{\text{tot}(\text{day})}$, while NEE in the snow season was calculated by multiplying the CO_2 flux with the sampling interval.

Global warming potential (GWP)

The GWP of each ecosystem was calculated using the GWP values 21 (for CH_4) and 310 (for N_2O) in a 100-year time horizon recommended by IPCC (1996).

GWP was calculated as follows:

$$\text{CO}_2 \text{ GWP (g CO}_2 \text{ m}^{-2} \text{ y}^{-1}) = \text{CO}_2 \text{ (g C m}^{-2} \text{ y}^{-1}) \times (1 \text{ g CO}_2) \times (44 \text{ g CO}_2 / 12 \text{ CO}_2\text{-C})$$

$$\text{CH}_4 \text{ GWP (g CO}_2 \text{ m}^{-2} \text{ y}^{-1}) = \text{CH}_4 \text{ (g C m}^{-2} \text{ y}^{-1}) \times (21 \text{ g CO}_2 / 1 \text{ g CH}_4) \times (16 \text{ g CH}_4 / 12 \text{ CH}_4\text{-C})$$

$$\text{N}_2\text{O GWP (g CO}_2 \text{ m}^{-2} \text{ y}^{-1}) = \text{N}_2\text{O (g N m}^{-2} \text{ y}^{-1}) \times (310 \text{ g CO}_2 / 1 \text{ g N}_2\text{O}) \times (44 \text{ g N}_2\text{O} / 28 \text{ NO}_2\text{-N})$$

Results and Discussion

Seasonal flux

NEE in the daytime at Sp ranged from -193 to 401 $\text{mg C m}^{-2} \text{ h}^{-1}$, mostly indicating uptake of CO_2 during the no snow condition (Fig. 2). NEE at Sp-Sa ranged from -191 to 96 $\text{mg C m}^{-2} \text{ h}^{-1}$, showing the same fluctuation as that at Sp during summer. NEE at Sa ranged from -141 to 225 $\text{mg C m}^{-2} \text{ h}^{-1}$, mostly recording emission in summer. Fluxes at all sites were near zero during the snow condition, but each site recorded a high emission immediately after the snow melt. The seasonal fluctuation of estimated daily NEE is shown in Fig. 3. NEE at Sp during the no snow condition was mostly uptake. At Sp-Sa, NEE indicated uptake until August, but the degree of uptake was smaller than that at Sp; emission was more common than uptake after August. At Sa, NEE indicated that emission was common throughout the year.

The seasonal pattern of CH_4 flux was similar for all sites, indicating high values from summer to autumn (Fig. 2). During the no snow condition, CH_4 fluxes at Sp ranged from 0.3 to 21.8 $\text{mg C m}^{-2} \text{ h}^{-1}$ while fluxes at Sp-Sa and Sa ranged from 0.2 to 4.8 $\text{mg C m}^{-2} \text{ h}^{-1}$, and from 0.1 to 11.1 $\text{mg C m}^{-2} \text{ h}^{-1}$, respectively. CH_4 fluxes were close to zero at all sites during the snow condition. Immediately after the snow melt, however, high emissions were recorded at Sp and Sa, similar to the trend of NEE. Maximum fluxes at Sp and Sa were 11.8 and 5.5 $\text{mg C m}^{-2} \text{ h}^{-1}$, respectively. Similar CO_2 or CH_4 emission patterns at the spring thaw period were reported by MOORE & KNOWLES 1990, DISE 1992, MELLOH & CRILL 1996, ALM & al. 1999, PANIKOV & DEDYSH 2000. The snow pack insulated the soils from the cold mid-winter air temperature, which allowed microbial activity even during the snow condition (MAST & al. 1998, ALM & al. 1999). We have confirmed that there was a hard snow pack layer near the soil surface in the study area. Diffusion of CO_2 and CH_4 generated in the soil during the winter season was inhibited by the hard snow layer.

N_2O fluxes at all sites were close to zero throughout the year, but there were occasional emissions at Sp from June to October. N_2O emissions in natural Finnish wetlands were reported to be very low, which ranged from -0.8 to 5.3 $\mu\text{g N m}^{-2} \text{ h}^{-1}$ (REGINA & al. 1996). These episodic emissions in our study sites were shown only at some points at Sp area (results not shown). Further studies on the temporal and

spatial variability of episodic fluxes of N_2O are needed in order to estimate more accurately the annual N_2O flux.

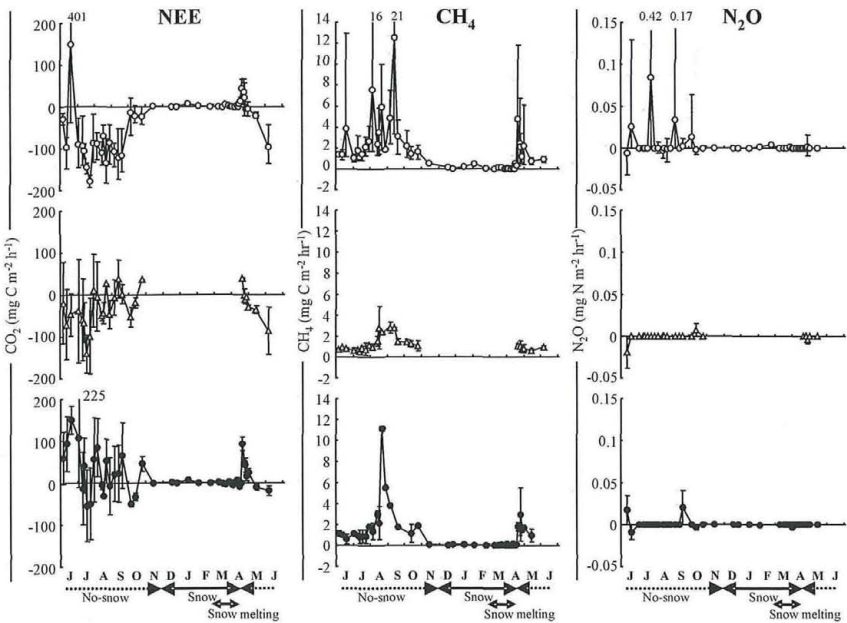


Fig. 2. The seasonal pattern of average fluxes ($\pm$ maximum, minimum) of NEE (Net CO₂ exchange), CH₄ and N₂O measured using a rectangular transparent acryl chamber at Sp, Sp-Sa, and Sa between June 2002 and June 2003. NEE defines as net CO₂ exchange. The symbols show the three observation sites: Sp ($\circ$), Sp-Sa (Δ), Sa ($\bullet$). There was no data for Sp-Sa from November 2002 to mid April 2003.

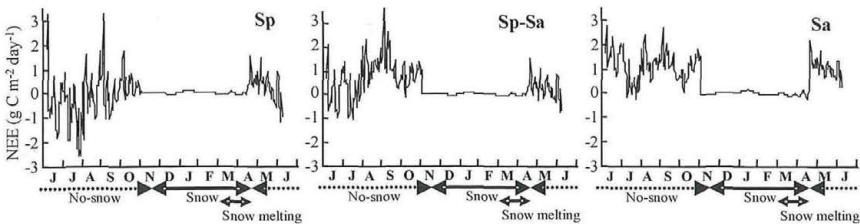


Fig. 3. The seasonal pattern of estimated daily NEE (net CO₂ exchange) at Sp, Sp-Sa and Sa between June 2002 and June 2003. Negative value is uptake of Carbon to ecosystems, positive is emission.

Cumulative flux

Cumulative NEE at Sp was $5.8 \text{ g C m}^{-2} \text{ y}^{-1}$, whereas those at Sp-Sa and Sa were 128.9 and $223.8 \text{ g C m}^{-2} \text{ y}^{-1}$, respectively, showing a significant increase with *Sasa* invasion (Table 2). Cumulative CH_4 flux at Sp was $13.2 \text{ g C m}^{-2} \text{ y}^{-1}$, while those of Sp-Sa and Sa were 6.3 and $6.6 \text{ g C m}^{-2} \text{ y}^{-1}$, respectively; it decreased with *Sasa* invasion (Table 2). We think that the water table is one of the factors that influence CH_4 flux. Ground water level at Sp was higher than those at Sp-Sa and Sa (data not shown), although differences among the sites were not significant. CH_4 emission during the winter including the snow melting period accounted for 12%, 16%, and 10% of the total annual CH_4 flux at Sp, Sp-Sa, and Sa, respectively (data not shown). DISE 1992 reported that winter flux accounted for 21% of the total annual flux in Minnesota bog. Winter fluxes from New Hampshire wetlands, located at almost the same latitude as the site of this study, accounted for 2.0-9.2% of the annual flux (MELLOH & CRILL 1996), which is close to the values we obtained in this study. Cumulative N_2O fluxes at Sp-Sa and Sa were 0.003 and $0.005 \text{ g N m}^{-2} \text{ y}^{-1}$, respectively. These fluxes were lower than what was obtained ($0.02 \text{ g N m}^{-2} \text{ y}^{-1}$) at Finnish fen (NYKÄNEN & al. 1995). On the other hand, N_2O flux at Sa was $0.032 \text{ g N m}^{-2} \text{ y}^{-1}$. Considerable N_2O emissions were measured from drained bogs and fens (NYKÄNEN & al. 1995, ALM & al. 1999). Thus, there is a need to pay attention to the water condition of our research wetlands in order to minimize N_2O emission from these sites.

Table 2. Comparison of average cumulative NEE (net CO_2 exchange), CH_4 and N_2O fluxes ($\pm$ S.D.) at Sp (n=5), Sp-Sa (n=2), and Sa (n=2) sites.

	Sp	Sp-Sa	Sa
NEE ($\text{g C m}^{-2} \text{ y}^{-1}$)	$5.8 \pm 31.1a$	$128.9 \pm 120.5b$	$223.8 \pm 25.8b$
CH_4 ($\text{g C m}^{-2} \text{ y}^{-1}$)	3.2 ± 3.5	6.3 ± 1.7	6.6 ± 6.2
N_2O ($\text{g N m}^{-2} \text{ y}^{-1}$)	0.032 ± 0.038	0.003 ± 0.003	0.005 ± 0.010

Gas emission to the atmosphere is marked positive. The ANOVA reveals a statistically significant differences between the sites ($p < 0.05$). The different letters indicate a statistically difference.

Global warming potential

The GWP at each site, estimated based on the contribution of individual greenhouse gases, is shown in Table 3. A positive value indicates enhanced global warming. The GWP at Sp was $408 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$, >90% of which was contributed by CH_4 ; the GWP at Sp-Sa was $652 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ while it was $1009 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ at Sa. NEE accounted for about 80% of the GWP at Sp-Sa and Sa; in contrast, only 5% of the GWP at Sp was due to NEE. The contribution of NEE to GWP showed a tendency of considerable increase with *Sasa* invasion. The differences in ecosystem respiration rate (R_{tot}) among sites were minimal, but there were large differences on P_G , which ranged from $-1774 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ at Sp to $-1067 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ at Sa. *Sasa* invasion of *Sphagnum*-dominated poor fen contributes to global warming due to the accelerated CO_2 emission caused by the decrease in CO_2 fixation. This study showed that NEE is one of the important factors that control greenhouse effect in wetlands. A

decrease in NEE in Finnish wetlands was reported to be mainly induced by a decrease in photosynthesis during the wet and dismal summer (NYKÄNEN & al. 2003). In addition, boreal peat lands can lose carbon during warm and dry summers when there is a decrease in water table, causing an increase in respiration and decrease in photosynthesis (ALM & al. 1999, WADDINGTON & ROULET 2000). Thus, we plan to conduct further studies to compare the effect of climate or hydrological condition on GWP.

Table 3. Global warming potential ($\pm$ S.D., $\text{g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$) estimated based on the contribution of NEE (net CO_2 exchange), CH_4 and N_2O at Sp (n=5), Sp-Sa (n=2), and Sa (n=2) sites.

Site	P_G	R_{tot}	NEE	CH_4	N_2O	GWP
Sp	-1774 ± 207	1795 ± 169	21 ± 114	370 ± 98	16 ± 19	$408 \pm 129\text{a}$
Sp-Sa	-1358 ± 557	1830 ± 115	473 ± 442	178 ± 46	2 ± 1	$652 \pm 394\text{ab}$
Sa	-1067 ± 734	1887 ± 639	820 ± 95	186 ± 173	2 ± 5	$1009 \pm 73\text{b}$

A positive value indicates enhanced global warming. The ANOVA reveals a statistically significant differences between the sites ($p < 0.05$). The same letter indicates the absence of a statistically difference.

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