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Methane budget determined at the ground and water surface level in various ecosystems in Shiga Prefecture, central Japan

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ABSTRACT: A methane budget at the ground and water surface level was estimated in various ecosystems in Shiga Prefecture, central Japan, and its seasonality was measured. Measuring sites were set up in 9 of 11 land use types in Shiga Prefecture, and methane fluxes were measured by the chamber method for 1 yr. Methane emission rates from sources were generally high in summer: the mean emission rate was 19.4 mg CH_4 m^{-2} h^{-1} from a paddy field and 9.6 mg CH_4 m^{-2} h^{-1} from a *Phragmites* swamp in July–August. In 4 main types of forest, atmospheric methane was absorbed by forest soils, at mean rates ranging from 0.01 to 0.12 mg CH_4 m^{-2} h^{-1}. The methane budget of Shiga Prefecture in each season was evaluated on the basis of the following data: A large amount of methane was emitted in summer, about 370 Mg CH_4 d^{-1} in July–August. In winter, however, the methane emission from the area as a whole was much lower than that in summer, owing to a decrease of methane emission from the sources. In particular, forest ecosystems absorbed about 3.4 Mg CH_4 d^{-1} in November–December, an amount exceeding that of the emission from the other land use types. Summing the annual methane emissions and absorption of every land use type and adding the estimates of methane emissions from domestic animals and landfills, the annual net release of methane to the atmosphere in Shiga Prefecture was estimated to be about 34.1 Gg CH_4. Among all land use types, the contribution of paddy fields to the total emission was the highest, at 81.7%. The annual methane absorption by forests was estimated to be about 1.0 Gg CH_4, representing 2.7% of the total emission.

KEY WORDS: Methane budget · Wide area · Emission and absorption · Seasonal change

INTRODUCTION

Atmospheric methane is one of the main greenhouse gases; it absorbs a part of the infrared radiation from the earth's surface, and participates in the global heat budget. In addition, atmospheric methane reacts with the hydroxyl radical (OH), an important oxidant in the atmosphere that also reacts with other hydrocarbons including carbon monoxide (Wuebbles et al. 1989); OH is one of the major active components in atmospheric chemistry. Methane is a biogenic gas produced by strictly anaerobic methanogenic bacteria; after it is released into the atmosphere, most of it is oxidized by OH. The concentration of atmospheric methane is basically determined by this emission and oxidation. The present concentration of methane is about 1.7 ppmv, and its lifetime is about 10 yr (Watson et al. 1990).

The concentration of atmospheric methane remained stable at about 0.7 ppmv until 250 yr ago; since then, it has been increasing continuously up to the present level (Rasmussen & Khalil 1984). Direct measurements of atmospheric methane concentration indicate that the globally averaged concentration increased from 1.52 ppmv in 1978 to 1.68 ppmv in 1987, or at about 1% yr^{-1} (Blake & Rowland 1988). It is suspected that the increase of atmospheric methane concentrations may enhance the greenhouse effect and have an impact on atmospheric chemistry. For

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instance, it was estimated that methane contributed 12% of the total greenhouse forcing added to the atmosphere during the 1980s (Hansen et al. 1989). Moreover, the observed decrease of atmospheric OH radical and increase of tropospheric ozone may be related to the increasing atmospheric methane concentration (Thompson & Cicerone 1986, Thompson 1992). Although, according to Steele et al. (1992), the rate of methane increase has slowed down in recent years, it is still feared that the present rise in concentration will contribute to global warming and climate change in the near future.

Major sources of atmospheric methane are natural wetlands, paddy fields, enteric fermentation by ruminants, leakage of natural gas, biomass burning, etc. The total global methane emission is estimated at 540 Tg yr^{-1}, more than half of which comes from anthropogenic sources including paddy fields and domestic ruminants (Cicerone & Oremland 1988). Sinks of atmospheric methane include mainly the reaction with OH in the atmosphere and, to a lesser extent, the bacterial oxidation in surface soils (Watson et al. 1990). The current increase in methane concentration is mainly caused by increasing anthropogenic methane emissions and the decreasing atmospheric OH (Khalil & Rasmussen 1985). However, a quantitative understanding of this process has not yet been achieved. In particular, uncertainties still remain in the estimation of methane emission from each source.

The purpose of this study was to obtain a methane budget at the ground/water surface level of an area comprising various ecosystems, based on direct measurements. In contrast to many studies which have reported measurements of methane flux from a single methane source, we measured methane fluxes in almost all types of ecosystems in a wide area for a year, enabling us to determine the methane budget of the area as well as its seasonal variation. Moreover, by measuring methane emissions from various sources under the same climatic conditions, we were able to correctly compare their respective emission capacities. Very few studies of this kind exist, but they are necessary for calculating a global methane budget.

STUDY AREA AND METHODS

Study area. Shiga Prefecture is located in the center of Japan (Fig. 1) and has an area of 4014 km^2 and a population of 1.2 million. The population density is 302 people km^{-2} which is consistent with the mean population density of Japan (as of 1990). Lake Biwa (674 km^2), the largest lake in Japan, is located in the center of this prefecture. Shiga Prefecture is surrounded by mountain ranges, and the prefecture itself forms a rain basin around the lake. The annual mean air temperature is 14.1°C and the annual mean precipitation is 1654 mm (at Hikone) (see Fig. 2). The forested portions of Shiga Prefecture include a warm-temperate evergreen broad-leaf zone in the lower basin, a cool-temperate deciduous broad-leaf zone in the mountainous area and a wide ecotone between them. Table 1 shows the land use in Shiga Prefecture. The land use distribution in Shiga Prefecture is a good representation of that in the rest of Japan, except for the wide lake area, and it has areal unity and is well-divided from the surrounding prefectures by mountain ranges. These are the reasons why we selected this area for our study.

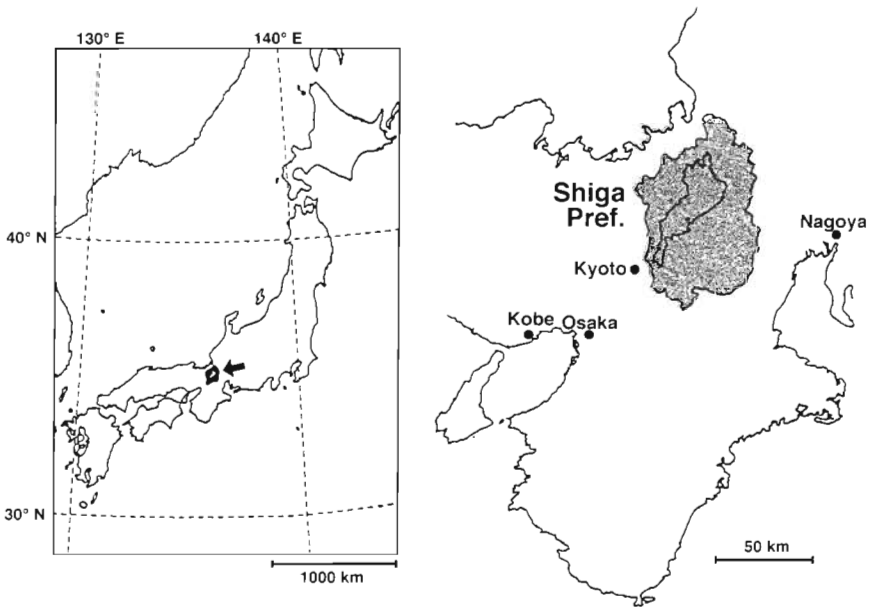

Fig. 1 Location of Shiga Prefecture in Japan

Table 1. Land use in Shiga Prefecture. Source: Hamabata (1986)

Type no.	Land use type	Area (km^2)	Proportion of total area (%)
1	Natural forest	92.23	2.30
2	Secondary deciduous broad-leaf forest	656.30	16.35
3	Pine forest	817.04	20.35
4	Plantation and bamboo thicket	408.08	10.17
5	Shrubs	135.32	3.37
6	Wetland	16.98	0.42
7	Grassland and golf links	68.94	1.72
8	Upland field and orchards	46.16	1.15
9	Paddy fields	767.70	19.13
10	Urban, residential and industrial areas	297.95	7.42
11	Open water	707.28	17.62
	Total	4013.98	100

Measuring sites and methods. In this study, we focused on estimating the total methane budget at the ground and water surface level in Shiga Prefecture. For this purpose, of the 11 land use types present in Shiga Prefecture (Table 1), we selected 9 for measurements (about 90% of the total prefecture area); urban and shrub areas were excluded. The methane emission from Lake Biwa was measured separately in the eutrophic southern basin and in the oligotrophic northern basin. Of the remaing 8 land use types, a single representative measuring site was selected for each land use type after a wide area census measurement. Information on the measuring sites and the number of measuring points at each site are summarized in Table 2. Fig. 2 shows the location of each upland measuring site and measuring points in Lake Biwa.

Table 2. Summary of methane flux measurement points at each measuring site. Measurements were not taken in shrub and urban areas (Type nos. 5 and 11). n: number of measurement points

Type no.	Measuring site (dominant or cultivated species)	n
1	Climax evergreen oak forest (*Castanopsis cuspidata*)	10
2	Secondary deciduous broad-leaf forest (*Quercus serrata*)	10
3	Secondary pine forest (*Pinus densiflora*)	10
4	Plantations (*Chamaecyparis obtusa*)	10
6	Swamps (*Phragmites australis*)	40
7	Lawn ground	5
8	Tea plantations (*Thea sinensis*)	10
9	Paddy fields (*Oryza sativa* L.)	10
11	Lake Biwa	
	Southern basin	8
	Northern basin	10

All measurements of methane flux at the ground or water surface level were carried out by the chamber method: chambers were put on the ground or the water surface, and the methane flux was determined from the methane concentration change in each chamber. Measurements at each study site were conducted at roughly 2 mo intervals from April 1991 to March 1992 except for wetlands, which we could measure from August 1991 to January 1992 (the flux measurements could not be conducted during February and March because of the exceptionally high water level).

The following 3 types of chamber were used according to the various conditions in the study sites:

Type 1 (for dry ground surfaces): a cylindrical plastic chamber (27.5 cm diameter, 30 cm height) with a sampling port and a vent port on the roof. It was placed on the ground surface with its base about 2 cm into the soil (10.7 l air volume) and was closed.

Type 2 (for covering plants): a cylindrical chamber (30 cm diameter) which consisted of a hard plastic pipe (bottom), soft plastic film (side) and a plastic disk (roof) with 3 stainless steel pipes (1 cm diameter) for its frame. The chamber height was 1 m (for rice plants in paddy fields) or 3 m (for reeds in wetlands). A sampling/vent port was attached at 0.8 m height (for rice plants) or 1.5 m height (for reeds) on the side. The chamber covering the plants was placed into the water (on the bottom) or, if the area was dried up, 2 cm deep into the soil, and was closed.

Type 3 (for water surfaces): a cylindrical plastic chamber (28 cm diameter, 12.5 l volume; or 25 cm diameter, 5.3 l volume) with wooden floats. A sampling port and a vent port were attached to the roof. It was floated out onto the water surface in wetlands or on the lake and was closed.

Measurements at each study site were conducted using the following procedures for the various land types (cf. Table 2).

Forests: Each study site was selected at 4 representative forest types: (a) A climax natural forest (Type no. 1 in Table 1); this was a broad-leaf forest consisting primarily of evergreen oaks (*Castanopsis cuspidata* and *Quercus paucidentata*), with a total of more than 25 tree species. (b) A secondary deciduous broad-leaf forest (Type no. 2); this was an abandoned charcoal coppice forest of *Quercus serrata* (10 to 15 cm in DBH, diameter at breast height) with bushy undergrowth. (c) A secondary pine

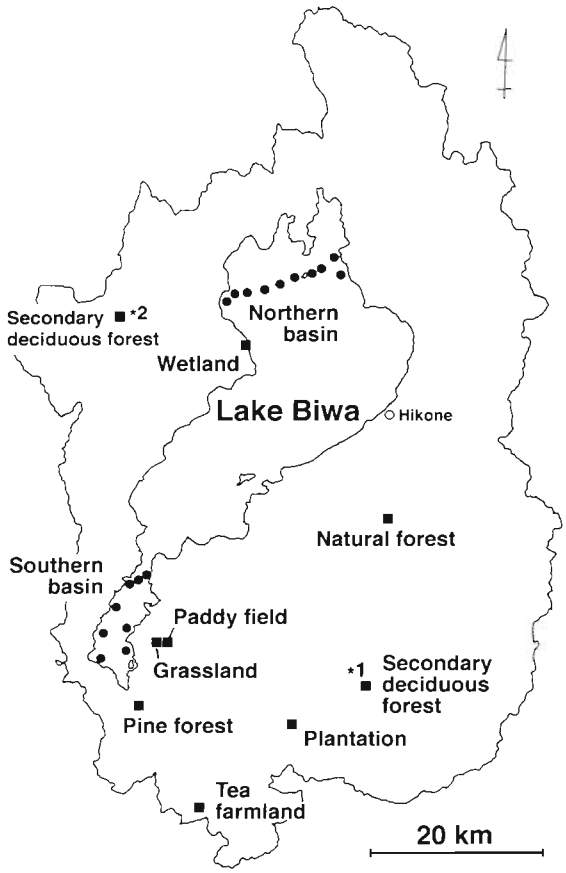

Fig. 2. Sites of methane flux measurements in Shiga Prefecture. *1: From June to November; *2: from November to March

forest (Type no. 3); this consisted of old Japanese red pines (*Pinus densiflora*) of 20 to 30 cm DBH with several evergreen tree species at the second stratum. (d) A *Chamaecyparis obtusa* plantation (Type no. 4); this was an old plantation with trees of more than 30 cm average DBH, without any distinct forest floor vegetation. The methane flux was measured at 10 measuring points on the forest floor at each forest site. A Type 1 chamber was put on the litter layer at each measuring point, and the air (1 l) inside the chamber was collected twice at 1 h intervals (1 h and 2 h after the chamber was set up). When the forest floor was covered with snow, chambers were placed on the snow.

Upland fields and orchards (Type no. 8): A tea plantation was selected as the study site because it represented a relatively large proportion (20.5%) of this land use category in Shiga Prefecture. The methane flux was measured at 10 points on the soil surface in the tea plantation by the same methods as those used in the forests.

Grasslands, bare lands and golf links (Type no. 7): A lawn ground in Shiga Prefectural Junior College was selected as the study site. Five measuring chambers were set onto the grass-covered soil surface, and measurement was carried out by the same methods as those in the forests.

Paddy fields (Type no. 9): Measurements were carried out at 10 measuring points in a paddy field belonging to the Faculty of Agriculture of Shiga Prefectural Junior College. During the cultivation period (May to October), Type 2 chambers (1 m height) were set onto the paddy soil and enclosed the above-ground system of rice plants. The air (1 l) in the chambers was collected 3 times at 30 min intervals (i.e. just after setting up, and 30 and 60 min thereafter). During the non-cultivation period, the Type 1 chambers were used. The air (1 l) in the chambers was collected 3 times at 1 h intervals (just after setting up, and 1 and 2 h thereafter).

Wetlands (Type no. 6): A tall reed swamp at the northwestern beach of Lake Biwa was selected as the study site. The reed swamp occupies the largest area of all the wetland vegetations in Shiga Prefecture. The reed *Phragmites australis* grows widely around the drift line of the lake. Methane flux measurements were performed using 4 procedures, according to the following site conditions: (a) with plants at a flooded location, (b) without plants at a flooded location, (c) with plants at a non-flooded location and (d) without plants at a non-flooded location. The measurements were conducted at 10 points for each site condition. In case (a), a Type 2 chamber (3 m height) was set onto the flooded soil and included 1 or 2 reed stems. The air (2 l) in the chamber was collected 3 times at 30 min intervals (just after setting up, and 30 and 60 min thereafter). In case (b), a Type 3 chamber (12.5 l) with a float was placed onto the flooded water surface, and air samples were collected using the same method as in case (a). In case (c), a Type 2 chamber (3 m height) was put onto the soil surface and included 1 or 2 reed stems. The air samples (2 l) in the chamber were collected 3 times at 50 min intervals (just after setting up, and 50 and 100 min thereafter). In case (d), a Type 1 chamber was set onto the soil surface, and the air was sampled using the same method as in case (c).

Lake (Type no. 11): Measurements were performed in the southern and northern basins of Lake Biwa. Methane flux from the water surface was measured continuously at 10 points in the northern basin and 8 points in the southern basin (see Fig 2). A set of 3 to 5 Type 3 chambers (5.3 l) with floats was put onto the water surface at each measuring point and fixed by a buoy with an anchor. The air inside the chamber was collected once (2 l) 2 to 4 h after setting up.

Soil measurements: Soil conditions (upper 5 cm) were also measured. In the forests, soil pH and Eh (oxidation-reduction potential) were measured several times at every measuring point with a pH meter (Horiba H-7SD). Soil porosity was also measured once

at 4 to 7 points at each forest site using a soil 3-phase meter (Daiki DIK-1120). At the wetland site, soil Eh was measured at every measuring time at 3 to 5 points in both flooded and non-flooded locations.

Air sample processing: All air samples were collected in tedlar bags (1 or 2 l) and analyzed with a gas chromatograph (Hitachi 263-30) equipped with a flame ionization detector (FID) and a 2 ml injection loop. The column was molecular sieve 5A (2 m by 3 mm) which was kept at 100°C. Helium was used as the carrier gas at a flow rate of 50 ml min^{-1}.

Methane fluxation measurements: The methane emission or absorption rate was determined by the change in methane concentration inside the chamber. The mean emission rate was calculated by averaging 2 sequential measurements at each measuring point in the methane sources. In sinks, the absorption rate was determined by the gradient of the concentration curve at the beginning point (atmospheric methane concentration) of the measurement.

RESULTS AND DISCUSSION

Methane flux for each land use type

Forests

Seasonal changes of methane flux on the forest floor of the 4 types of forest vegetation are shown in Fig. 3. Atmospheric methane was absorbed by the soil throughout the year at all 4 forest sites. Methane absorption rates of the climax evergreen broad-leaf forest floor (open circles in Fig. 3) were 0.08 mg CH_4 m^{-2} h^{-1} or more except for July; these absorption rates were the highest among the 4 forest types. The exceptionally low rate in July may have been caused by heavy rain just before the measurements. At the other 3 forest sites (secondary deciduous broad-leaf forest, pine forest, plantation), methane absorption rates were less than 0.06 mg CH_4 m^{-2} h^{-1}. The soil Eh (ca +400 mV) and pH (ca 4.5) values in the 4 forest types were not very different, but soil porosity was higher at the climax forest site (83.5%) than at the other 3 forest sites (74.9 to 78.3%). High soil porosity or coarse soil texture may cause easier diffusion of air into the soils and higher soil microbe activities, and may accelerate methane absorption into the soils (Born et al. 1990). The higher methane absorption rates in the climax evergreen broad-leaf forest were probably the result of its higher soil porosity compared to the other 3 forest sites.

In this study, we did not find a clear seasonality of methane absorption rates at any of the forest sites, although rates were slightly higher in fall from September to November. In addition, at the secondary deciduous broad-leaf forest site, methane absorption was even observed in January and March when the forest floor was covered with ca 30 cm of snow, although the rates were very low (0.02 and 0.01 mg CH_4 m^{-2} h^{-1}, respectively). These results imply that forest soils absorb atmospheric methane even in snowy periods.

Paddy fields

The methane flux from the soil and water surfaces of the paddy field showed a distinct seasonal trend (Fig. 4). During the cultivation period, from the middle of May to the end of October, the highest flux of 19.4 mg CH_4 m^{-2} h^{-1} was recorded at the end of July when the paddy field was flooded. After drainage, however, the methane flux decreased to 1.0 mg CH_4 m^{-2} h^{-1} at the end of September. After the harvest, methane emission was not observed until just before cultivation started in the following spring. These results imply that methane emission from paddy fields occurs only during cultivation periods, particularly

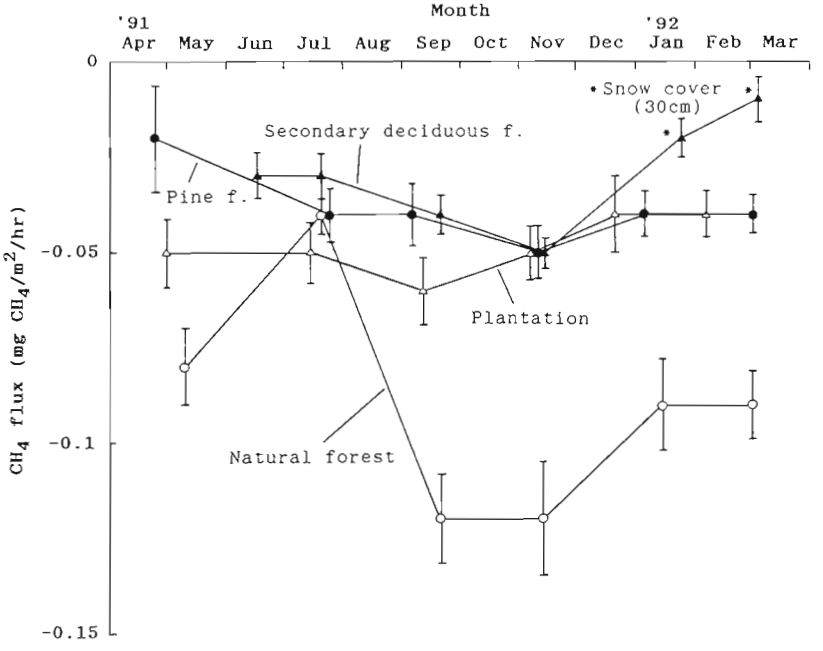

Fig. 3. Seasonal change of methane flux on the floor of 4 types of forest. Vertical lines are standard errors

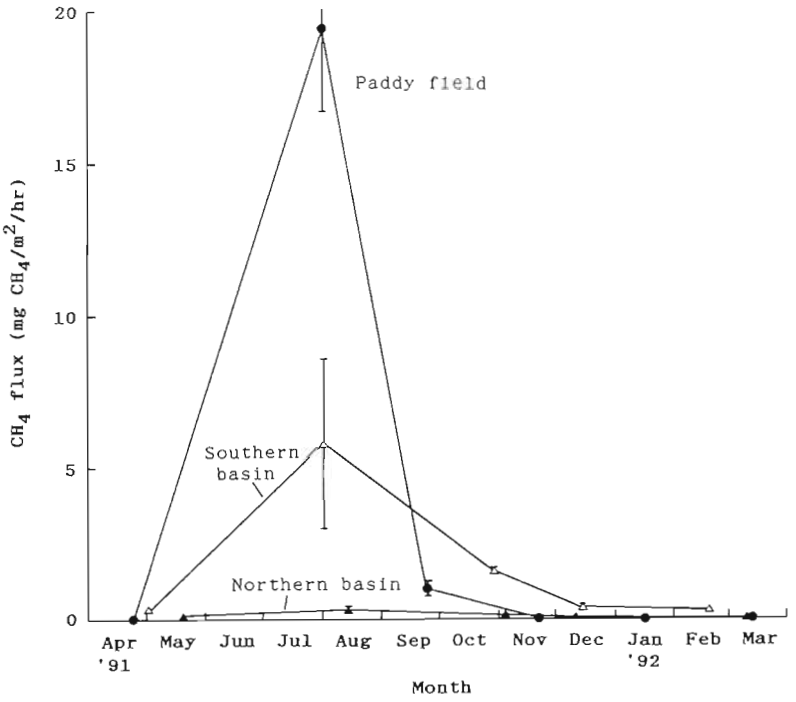

Fig. 4. Seasonal trend of methane flux from paddy fields and from the southern and northern basin of Lake Biwa. Vertical lines are standard errors

under flooded conditions. The seasonal trend and values found in this study are comparable to the precise measurements of methane flux from paddy fields in Japan obtained by Yagi & Minami (1990).

Wetlands

The methane flux measurements in the wetlands were conducted from August to January. Fig. 5 shows the mean methane flux under the 4 site conditions examined: flooded with plants (FP), flooded without plants (FN), non-flooded with plants (NP) and non-flooded without plants (NN). Methane fluxes from flooded locations (FP and FN) were always much higher than those from non-flooded locations (NP and NN). This result was probably due to the reducing conditions of soils at each location: the mean Eh values ranged from −170 to −150 mV at flooded locations and from +330 to +400 mV at non-flooded locations during the measuring period, and no seasonality was observed in Eh values. Furthermore, methane fluxes with plants were higher than those without plants at almost every measuring time, at both flooded and non-flooded locations. For example, in August, methane fluxes at FP, FN, NP and NN were 31.3, 6.0, 1.0 and 0.1 mg CH_4 m^{-2} h^{-1}, respectively. The results imply that a part of the methane produced in soils may be emitted into the atmosphere through plants in wetlands as well as in paddy fields (Cicerone & Shetter

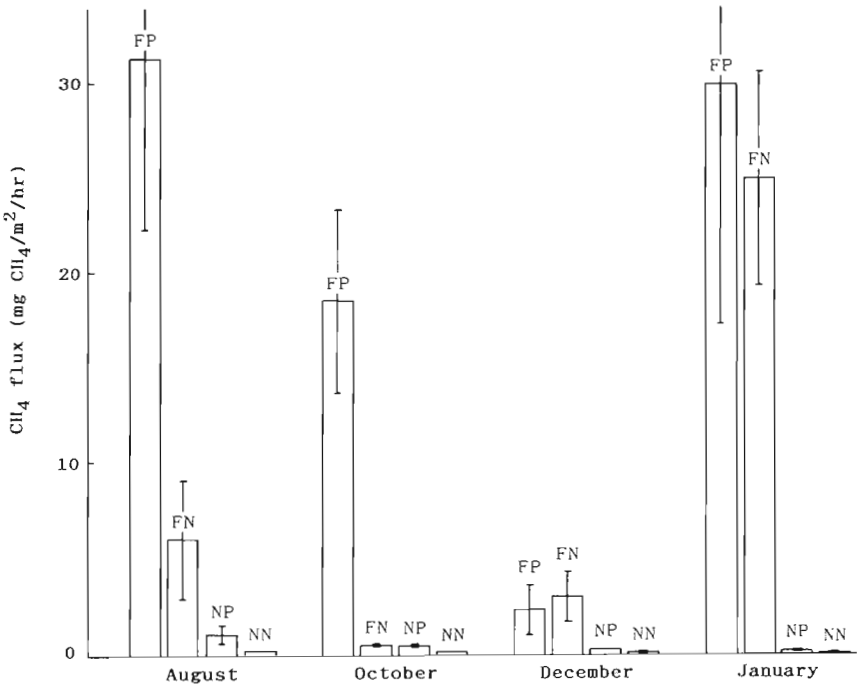

Fig. 5. Seasonal change in methane flux from 4 types of wetland: flooded with plants (FP), flooded without plants (FN), non-flooded with plants (NP) and non-flooded without plants (NN). Vertical lines are standard errors

1981, Holzapfel-Pschorn & Seiler 1986, Nouchi et al. 1990).

The seasonal trend of methane flux from the wetland site was basically dependent on temperature change. At non-flooded locations the methane fluxes decreased with decreasing temperature from August to January: from 1.0 to 0.1 mg CH_4 m^{-2} h^{-1} at NP and from 0.1 to 0.02 mg CH_4 m^{-2} h^{-1} at NN. However, at flooded locations, although fluxes decreased from August to December — from 31.3 to 2.3 mg CH_4 m^{-2} h^{-1} at FP and from 6.0 to 3.0 mg CH_4 m^{-2} h^{-1} at FN — they increased markedly again in January, to 29.7 and 25.0 mg CH_4 m^{-2} h^{-1} at FP and FN, respectively; the Eh values did not change significantly throughout the measuring period, as mentioned above. At flooded locations, a large mass of dead organic matter floating around the shoreline was carried to the measuring sites in January because of the change in water level. This dead organic matter contained a large amount of methane, and thus the methane fluxes from FP and FN were abruptly high in January.

These results show that methane emission from wetlands is affected by temperature, water level, the presence of plants, etc., and that the seasonal trend of methane flux does not correspond simply to the temperature change but instead reflects the interaction of various factors.

Lakes

Seasonal changes in the methane flux from the water surface of Lake Biwa are shown in Fig. 4. In the southern basin, methane flux attained a maximum of 5.8 mg CH_4 m^{-2} h^{-1} in August and decreased to a minimum of 0.27 mg CH_4 m^{-2} h^{-1} in February. A similar seasonal pattern was observed in the northern basin, with a maximum of 0.27 mg CH_4 m^{-2} h^{-1} in August and a minimum of 0.02 mg CH_4 m^{-2} h^{-1} in March. These results show that the methane flux from the lake water surface has a clear seasonal trend corresponding to the change in water temperature.

Comparing the methane flux in the southern basin with that in the northern basin, the former exceeded the latter by a factor of 3.6 to 27. This difference might have been due to 2 reasons. The first is the difference in water depth between the 2 basins: the depth of the southern basin is less than 10 m, while that of the northern basin is much greater, about 100 m at the deepest point. This causes a difference in bottom water temperature, particularly in summer, and more methane may be produced in the warmer bottom substratum in the southern basin. Furthermore, some of the methane produced at the bottom of the lake is oxidized before it reaches the surface (Rudd & Hamilton 1978, Panganiban et al. 1979, Harrits & Hanson 1980), so more methane might be oxidized by the water in the deep northern basin than in the shallow southern basin. The second reason is that the water in the southern basin is more eutrophic than that in the northern basin (LBRI & ILEC 1988). Therefore, the bottom substratum in the southern basin was subject to higher reducing conditions, accelerating methanogenesis.

From these results, it was concluded that methane flux from the surface of lakes is highly affected by the temperature, depth and trophic conditions of the water.

Other land use types

Almost no methane was emitted from the tea plantation and the lawn area during the study periods, though on rare occasions very low methane emissions were observed at some measuring points. This suggests that these land use types are not a significant component of the methane budget in Shiga Prefecture.

Methane budget in Shiga Prefecture

The methane flux of each land use type is summarized in Table 3. The reported fluxes for forests (including shrubs) are the average of those at the 4 forest sites. High methane emission rates were observed in the wetlands in July–August and January and at the southern basin of Lake Biwa in July–August, and very high values were observed at the paddy fields in July–August. The methane flux of 19.4 mg CH_4 m^{-2} h^{-1} at the paddy fields during the flood season (July–August) was the highest value observed among all land use types. In contrast to the methane emission

Table 3. Methane flux of each land use type (mg CH_4 m^{-2} h^{-1}). –: no data

Type	Area (km^2)	Apr–May	Jul–Aug	Sep–Oct	Nov–Dec	Jan	Feb–Mar
Forest	2109	–0.05	–0.04	–0.07	–0.07	–0.05	–0.05
Wetland	17	–	9.63	4.93	1.39	13.62	–
Grassland	69	–	0	0.01	0	0	0
Farmland	46	0.15	0	0	0	0	0
Paddy fields	768	0	19.43	1.01	0	0	0
Southern basin	58	0.36	5.83	1.59	0.34	–	0.27
Northern basin	616	0.10	0.23	0.06	0.03	–	0.02

Table 4. Daily methane emission from each land use type (Mg CH_4 d^{-1})

Type	Area (km^2)	Apr–May	Jun	Jul–Aug	Sep–Oct	Nov–Dec	Jan	Feb–Mar
Forest	2109	−2.28	−2.16[a]	−2.02	−3.29	−3.42	−2.40	−2.28
Wetland	17	3.02[b]	3.48[a]	3.93	2.01	0.57	5.56	3.02[b]
Grassland	69	0[b]	0[a]	0	0	0	0	0
Farmland	46	0.17	0.08[a]	0	0	0	0	0
Paddy fields	768	0	179[a]	357	18.6	0	0	0
Southern basin	58	0.50	4.31[a]	8.12	0.75	0.47	0.43[c]	0.38
Northern basin	616	1.48	2.44[a]	3.40	0.89	0.44	0.37[c]	0.29
Total	3631	2.89	187	370	19.0	−1.94	3.96	1.41

[a]Estimated (average of emissions and absorptions in Apr–May and Jul– Aug)
[b]Estimated (average of emissions from Jul–Aug to Jan or to Feb–Mar)
[c]Estimated (average of emissions in Nov–Dec and Feb–Mar)

from these sources, the forest was the only sink on the land due to the methane absorption by the forest soils, though the rate was very low (around 0.05 mg CH_4 m^{-2} h^{-1}). This methane absorption rate was comparable to the methane emission rate at the northern basin of Lake Biwa.

On the basis of the data in Table 3, the daily methane emission and absorption rates for the total area occupied by each land use type in Shiga Prefecture were calculated for each period (Table 4). Daily emission in the wetlands was rather low, at most 5.6 Mg CH_4 d^{-1}, despite high methane fluxes because the total area of the wetlands was relatively small. In contrast, daily emission in the paddy fields was extremely high in July–August, 357 Mg CH_4 d^{-1}, because they had high methane fluxes and occupied a wide area. The area of the southern basin of Lake Biwa is only about one-tenth that of the northern basin, but the daily methane emissions from the southern basin were always higher than those from the northern basin, particularly in summer. Daily absorption by the forest soil was 2.02 to 3.42 Mg CH_4 d^{-1}, which was comparable to the emission from the wetlands and the northern basin of Lake Biwa; these absorption levels are reached despite the low absorption rate, due to the large area occupied by the forests. The daily net methane flux at the ground and water surface levels in Shiga Prefecture in each period is shown at the bottom of Table 4. The total daily emissions were 187 to 370 Mg CH_4 between June and August, owing to the high methane emission rates from the paddy fields. In the other periods, total daily emissions did not exceed 19 Mg CH_4. Indeed, the total daily methane absorption by the forest soil exceeded the total daily emission from all the other measured land use types in November–December.

Table 5 shows the annual methane emission and absorption for each land use type in Shiga Prefecture, estimated from the data in Table 4. Annual methane emissions by domestic animals and at landfills were estimated from data in Crutzen et al. (1986), Kinki Agricultural Administration Bureau (1990) and Japan Environmental Sanitation Center (1990). The annual emission from paddy fields was 28.6 Gg CH_4 (81.7% of the total), that from landfills was 2.5 Gg CH_4 (7.1% of the total), and that from domestic animals was 1.6 Gg CH_4 (4.6% of the total). The annual emission from wetlands, where high methane flux was observed, was only 1.0 Gg CH_4 (3.0% of the total). The results show that paddy fields were the main methane source in Shiga Prefecture. When we compared natural sources with anthropogenic sources, we established that most of the methane emission was from anthropogenic sources (i.e. upland fields, paddy fields, domestic animals, and landfills), and it amounted to about 33 Gg CH_4 (ca 93% of the total).

Table 5. Annual methane emission in Shiga Prefecture

Type	Gg CH_4 yr^{-1}	(%)
Wetland	1.04	(3.0)
Grassland	0.00	(0.0)
Farmland	0.01	(0.0)
Paddy fields	28.62	(81.7)
Southern basin	0.77	(2.2)
Northern basin	0.48	(1.4)
Domestic animals	1.6[a]	(4.6)
Landfill	2.5[b]	(7.1)
TOTAL	35.05	
Forest	−0.95	(2.7)
NET EMISSION	34.10	

[a]Estimated from Crutzen et al. (1986) and Kinki Agricultural Administration Bureau (1990)
[b]Estimated from Japan Environmental Sanitation Center (1990)

The annual emission from all the sources in Shiga Prefecture was estimated at 35.05 Gg CH_4. In contrast, the annual absorption by the forest vegetation was 0.95 Gg CH_4 (2.7% of the total emission). Finally, the total annual net flux in Shiga Prefecture was the emission of about 34 Gg CH_4. In this study, the methane flux from urban areas was excluded, because it would have been negligible, as shown by Tyler et al. (1990). Therefore, we believe that our estimation of the annual methane emission from Shiga Prefecture is close to the actual emission.

Watson et al. (1992) estimated the proportionate contribution of major methane sources to global emission to be 22% by wetlands, 16% by enteric fermentation, 12% by paddy fields, 6% by landfills, etc. Comparison of these values with the present results indicates that the contribution of paddy fields was disproportionately high in Shiga Prefecture. In contrast, the contribution of wetlands was much lower than that of wetlands to the global methane emission. These results are directly due to the differences in land use rates. Shiga Prefecture is located in the center of Japan, and the climate, vegetation, population density and land use types are representative of those in Japan, except that paddy fields occupy a larger area (13.6% in Shiga Prefecture and 7.5% in Japan; Statistics and Information Department, Ministry of Agriculture, Forestry and Fisheries, Japan 1993). Thus, we believe that the present results in Shiga Prefecture represent the characteristics of methane emissions and absorption patterns in Japan.

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