Evaluating Seasonal Variations of CO_2 Fluxes from Peatland Areas in the Mongolian Permafrost Region

Saruulzaya Adiya[1*], Tsogt-Erdene Gansukh[1], and Batzorig Batbold[1]

[1]Institute of Geography and Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

*Corresponding author: saruulzayaa@mas.ac.mn

Abstract. Greenhouse gases (GHGs) released from permafrost regions may have positive feedback on climate change, but there is much uncertainty about additional warming from the permafrost carbon cycle. One of the main reasons for this uncertainty is that the observation data for large-scale GHG fluxes are sparse, especially for peatlands with rapid permafrost degradation. This study (1) evaluated the seasonal variation of carbon dioxide (CO_2) fluxes from peatlands in the permafrost region; (2) analyzed the organic carbon content of the soil (SOCC); and (3) estimated emission factors (EFs) for peatlands. CO_2 fluxes were measured at 100 study sites in four different study areas such as the natural area, the fall / summer use area, the spring / winter use area, and the mixed-use area. CO_2 was measured with an EGM-4 instrument with a chamber. Soil samples were collected from the surface at 30 cm depth at all sites. The result showed that the CO_2 fluxes ranged between 1.0 $\mu mol/m^{-2}/s^{-1}$ and 21.8 $\mu mol/m^{-2}/s^{-1}$ at 100 study sites in the spring season, while it ranged between 3.0 $\mu mol/m^{-2}/s^{-1}$ and 35.8 $\mu mol/m^{-2}/s^{-1}$ in the summer season. CO_2 fluxes showed lower values in autumn than in the other two seasons, which may depend on many factors of climate conditions. There were significant seasonal variations in CO_2 fluxes in four different areas. To do so, the EFs in the peatlands were calculated at 169.30 g [CO_2] m^{-2} year-1 (standard error ± 8.93), and 8.91 g [CH_4] m^{-2} year-1 (standard error ± 0.47). More detailed research is needed to develop EFs for peatlands in the Mongolian permafrost region. Then it could be used for the inventory of greenhouse gases in land use areas such as peatlands at the national level.

Keywords: Greenhouse gas, organic carbon in soil, permafrost, peat, and emission factor.

1 Introduction

The carbon cycle of permafrost is one of the most important issues in high-and middle-latitude regions of the northern hemisphere. Approximately 1,460–1,600 Pg (Petagrams) of carbon (C) is stored in permafrost and peat soils [1, 2]. Remnants of plants, animals, and microbes accumulated in permafrost soils over hundreds of thousands of years [3]. As a result of global warming, the microbial decomposition of

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permafrost carbon released greenhouse gases (GHGs) such as carbon dioxide (CO_2) and methane (CH_4) into the atmosphere [4-6]. CO_2 and CH_4 will increase global temperature and have a negative effect on terrestrial ecosystems [7]. Due to global warming, permafrost has gradually thawed in many regions due to increases in ground temperature and the deepening of the thickness of the active layer [8-11].

The permafrost of high-latitude ecosystems contains the most significant C, which is almost twice as much GHG as is currently contained in the atmosphere. Permafrost GHG emissions play an essential role in driving global warming and have a negative effect on terrestrial ecosystems. This feedback can accelerate climate change, but the magnitude and timing of CO_2 fluxes and emissions from wetlands, peatlands, and grasslands in the Mongolian permafrost region and their impact on climate change remain uncertain.

Mongolia is an important component of global permafrost [12, 13] and is a popular research topic in ecosystems dominated by permafrost, having one of the densest observation networks for permafrost in the Northern Hemisphere. Several reports have indicated that permafrost degradation has been detected in Mongolia, and these changes probably have exerted significant impacts on surface energy balances, local hydrological cycles, ecosystem services, and environmental changes in recent decades [14-17]. Although permafrost regions warm faster than other regions of the earth [18], the process of GHG emissions from permafrost regions in the northern hemisphere is not well understood [2]. The main reason for this uncertainty is the lack of observation data on large scales, CO_2 fluxes, and GHG emissions data. Their concentrations in peatlands with permafrost areas are still largely unknown.

Under the Paris Agreement, Mongolia ambitiously increased its target of reducing total GHG emissions to 22.7 percent by 2030, by updating its nationally determined contributions (NDC). However, there is a lack of CO_2 fluxes and their emission factors (EFs) for this land use area in the Mongolian permafrost region, although these are the areas of use predominantly by humans. The objectives of this study were (1) to evaluate the seasonal variation of CO_2 fluxes from the peatlands of the Bayanzurkh soum in the Mongolian permafrost region in detail; (2) to estimate the organic carbon content of the soil (SOCC,%) in peatlands; and (3) to generate EFs for the peatlands.

2 Study area

The Bayanzurkh soum is located in the Khuvsgul Mountains in the northern part of the Mongolian permafrost region.

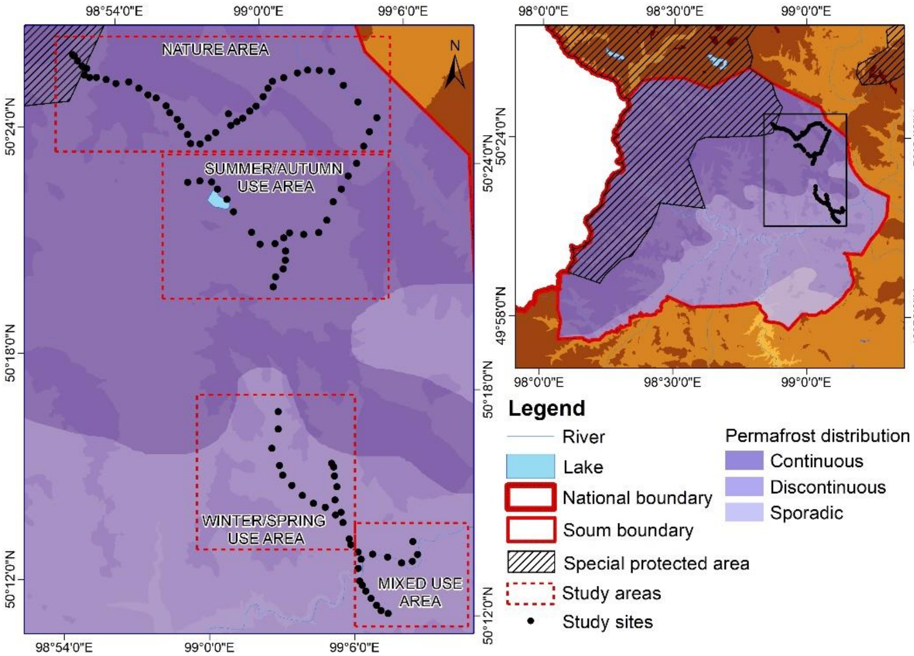

Fig.1. Study sites are selected in four areas of the Bayanzurkh soum such as nature area, summer / fall use area, winter/spring use area, and mixed-use area.

In this study, we selected four study areas on peatlands in Bayanzurkh soum to estimate CO_2 fluxes and soil organic carbon during field measurements in 2022. These study sites were selected in four areas: nature area, fall / summer use area, spring/winter use area, and mixed-use area, which are named for the locations of the herder's camp (Fig.1). The climate condition of Bayanzurkh soum is a continental climate that favours the occurrence of permafrost and peatlands in the mountains. The area is on the southern edge of the Siberian permafrost zones and taiga ecosystem and is composed of high alpine, larch forest, and taiga with peatlands. The mean annual average temperature is less than −4°C [19], the average air temperature in the coldest month of January fluctuates from −30°C to −35°C, and the average air temperature in July the warmest month, ranges from +15 to +10°C [20]. The mean annual total precipitation ranges between 300 and 400 mm. Annual maximum precipitation falls in July to August, or 50–60 % of total precipitation, only for these two months.

3 Method and Materials

3.1 CO_2 and soil sample measurement

Fieldwork was carried out to measure CO_2 flux/concentrations and collect soil samples at 100 sites in different seasons such as spring (15-28 May 2022), summer (01-15

August 2022), and autumn (10-25 September 2022). CO_2 concentrations were measured with the EGM-4 instrument with the chamber and CO_2 fluxes were calculated using field measurement data. These data are very important to validate the EFs and define the relationship between the EFs and SOCC (%) at all study sites. All soil samples were collected at study sites and 4 samples were taken at each site (0-5 cm, 5-10 cm, 10-15 cm, 15-30 cm). Soil samples were carried out from the surface to 30 cm depth and SOCC was calculated in the Soil Laboratory of the Institute of Geography and Geoecology. There are several direct or indirect methods for determining SOCC. This study used the loss-on-ignition method (LOI) to determine the rate of SOCC (percent volume, %) in soil samples at study sites. Furthermore, the thickness of the peat soil was determined at three different sites during fieldwork in September 2022. According to field measurements, we have used 'bure' equipment to drill peat soil and collect soil samples at these sites.

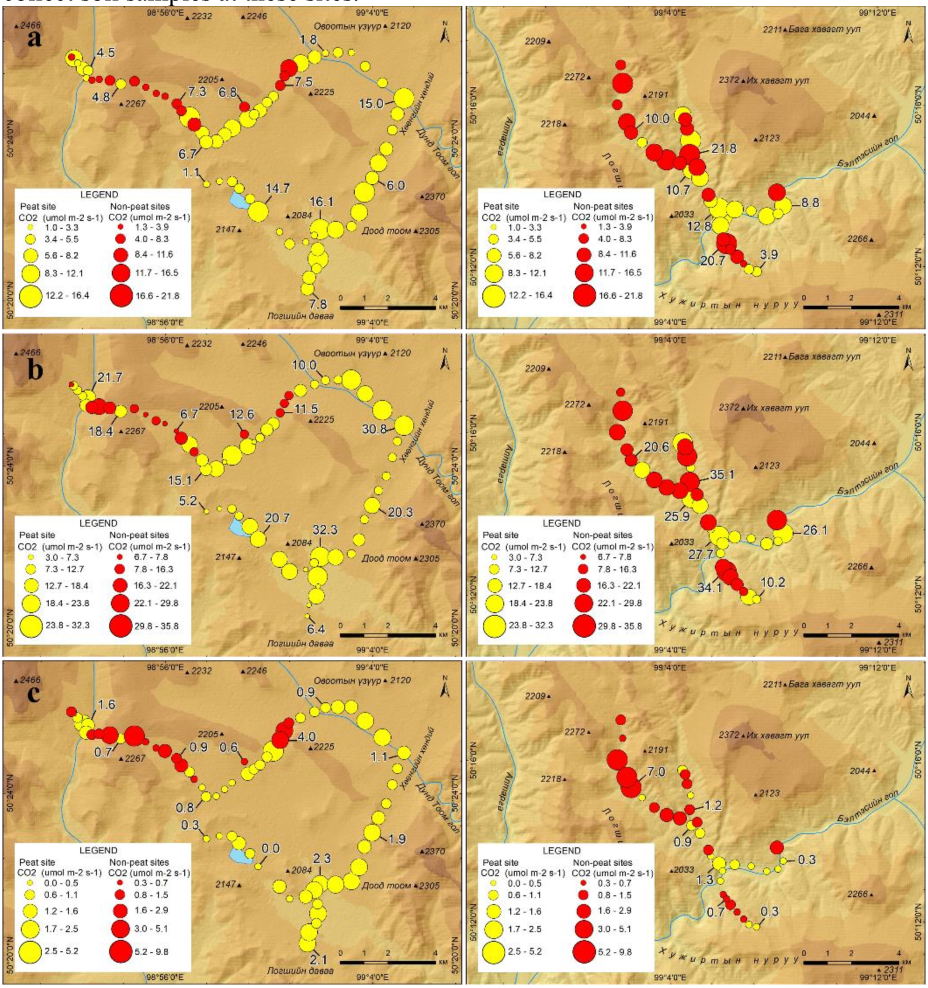

Fig.2. CO_2 fluxes at 100 study sites classified by peat and nonpeat sites: (a) Spring; (b) Summer; and (c) fall.

3.2 Emission factor (EF)

An emission factor is defined as the average emission rate of a given GHG for a given source, relative to units of activity [21]. In the case of Bayanzurkh soum, the source is carbon in the soil under anaerobic and aerobic conditions. Activities are defined by temperature, moisture, and porosity. The EF unit is g GHGs m^{-2} yr^{-1} as the total GHG weight per square metre during a year, and this factor is estimated by several types of methods, as mentioned in the literature review and methodology sections. We calculated the EFs at study sites in Bayanzurkh soum using the method of IPCC guideline volume 2 [21].

4 Results and Discussion

4.1 Seasonal variation of CO_2 fluxes

Based on field measurement data, we calculated CO_2 fluxes (µmol/m^{-2} /s^{-1}) at all study sites for three seasons in 2022 (Fig.2).

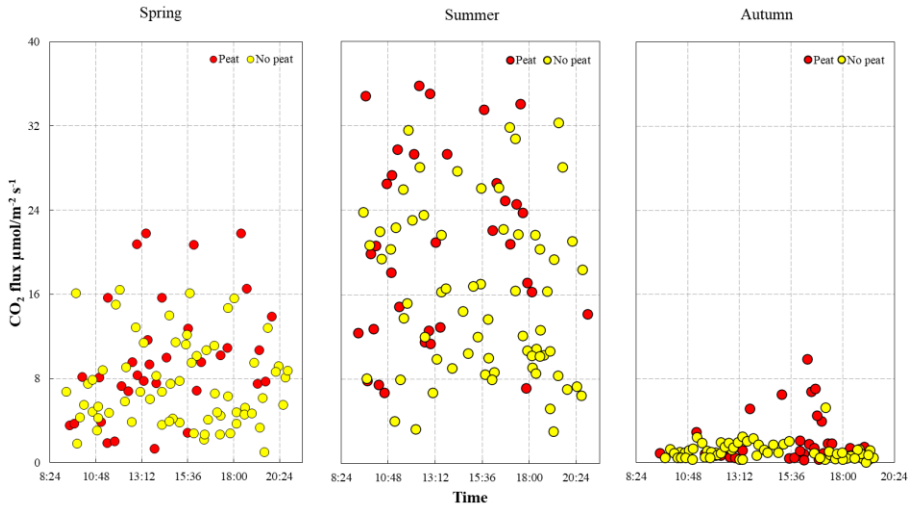

Fig.3. CO_2 flux from peatland and non-peatland at the moment by measurement time in day (n=100).

According to our result, CO_2 fluxes ranged between 1.0 μmol/m^{-2} /s^{-1} and 21.8 μmol/m^{-2} /s^{-1} at 100 study sites in the spring season, while it ranged between 3.0 μmol/m^{-2} /s^{-1} and 35.8 μmol/m^{-2} /s^{-1} in the summer season. The CO_2 fluxes were observed at 0.8 μmol/m^{-2} /s^{-1} and 9.8 μmol/m^{-2} /s^{-1} in the autumn season (Fig.2). CO_2 flux measurements are very sensitive depending on daytime, sunlight and cloud, soil, biomass, and temperatures (Fig.3). We have tried to determine the relation between CO_2 flux and daytime at peat and non-peat sites. Different values of CO_2 fluxes could be observed at peat and no peat sites in the spring, summer and fall seasons. We estimate the CO_2 flux peaks in the afternoon related to temperature and light. Some measurements in late evening dropped below 0 which means that the opposite process between the atmosphere and peat is stimulated. CO_2 fluxes were observed with less values in autumn than in other seasons, which may depend on many factors of the local environment and climate conditions. Based on the results mentioned above, we compared the estimated CO_2 fluxes in four study areas, such as the nature area, the summer / fall use area, the winter / spring use area, and the mixed use area (Fig.4). The average value of CO_2 fluxes was higher in the winter / spring areas used for the spring and summer seasons than in the other study areas. When comparing three seasons, CO_2 fluxes were observed at higher rates in the summer season. The seasonal variation of CO_2 flux rates in Bayanzurkh was similar to other peatland and permafrost regions [22]. We found a CO_2 release even in the summer, which indicates that these areas are net CO_2 sources, that is, soil organic carbon is mineralized and CO_2 is released from peatlands in Bayanzurkh soum.

4.2 SOCC (%) and the thickness of the peat soil

We collected soil samples at four levels at the sites in this study. The results of the average SOCC at study sites in four different study areas decreased from 0-5 cm to 20-30 cm (see Fig.5). When comparing SOCC values and study areas, it is observed that in the nature area, those values are higher than in the summer / fall use area, the winter / spring use area and the mixed use areas. However, the average SOCC values were different in May, August, and September 2022. We assumed that SOCC may depend on study areas related to the location of the herder's camp and the number of livestock. The maximum thickness of the peat soils was 50 cm at site 1, 60 cm at site 2, and 50 cm in the Bayanzurkh soum, respectively. Peat soil samples were taken from 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and 50-60 cm at each study site to analyze SOCC (%). At different depths, SOCC in all peat soil samples was summarized at these sites. That the SOCC values decreased slightly from the top of the soil to the bottom (from 0-10 cm to 40-50 cm and 50- 60 cm).

4.3 Emission Factors (EFs)

EFs of carbon dioxide (CO_2) and methane (CH_4). To estimate average values of EF for peatlands in Bayanzurkh soum, EFs were measured: 153.43 g [CO_2] m^{-2} year-1 (standard error ± 8.93), and 8.08 g [CH_4] m^{-2} year-1 (standard error ± 0.47) in spring, 327.19 g [CO_2] m^{-2} year-1 (standard error ± 15.89), and 17.22 g [CH_4] m^{-2} year-1 (standard error ± 0.84) in summer, and 27.26 g [CO_2] m^{-2} year-1 (standard error ± 2.95), and 1.43 g [CH_4] m^{-2} year-1 (standard error ± 0.16) in autumn, respectively. Furthermore, we need to expand field CO2 measurements at all sites in the peatland and develop EFs in the study area. Then it could be used for the inventory of greenhouse gases in land use areas such as peatlands at the national level.

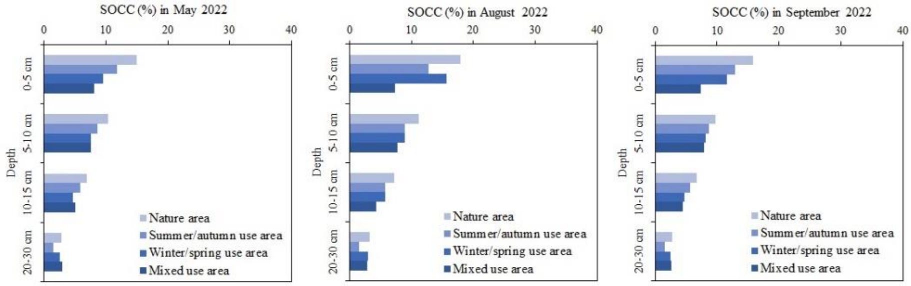

Fig. 4. SOCC in four different study areas in spring (15-28 May 2022), summer (01-15 August 2022), and fall (10-25 September 2022).

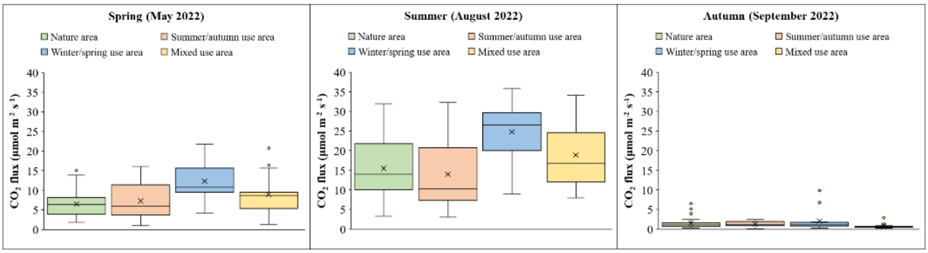

Fig.5. CO_2 fluxes in four different study areas and three seasons.

4.4 Distribution of peat soils in four study areas

The SOCC (%) in the soils had a positive relationship with the distribution of the peat soils. The distribution of the peat soil depends on the surrounding area and the number of livestock and herders in the study area of Bayanzurkh soum. We found peat soils in the nature area at 15 sites, while the summer/autumn use area peat soils are not observed at study sites. Whereas, at 13 sites in winter/spring use areas, and 6 sites in mixed-use areas, it could be observed, respectively. The average SOCC (%) values were observed in spring, summer, and fall. We assumed that SOCC (%) may depend on study areas related to the location of the herder's camp and the number of livestock. We found that the trends are different from each other in all seasons based on our results. The organic carbon content of the soil in the continuous and discontinuous permafrost zones is generally higher because the existence of permafrost favours the preservation of organic matter of the soil in seasonal variations [22]. During the last decades, permafrost has actively degraded in Mongolia, and SOCC has decreased in permafrost regions [23].

5 Conclusions

In this study, we have estimated seasonal variations of CO_2 fluxes at 100 sites in the peatlands of Bayanzurkh soum, Khuvsgul province, based on three seasonal field campaigns. The EFs and accuracy of our study showed fewer measurements and shorter duration than similar studies in other countries and regions. Thus, uncertainty and error accuracy should be carefully checked when used in small basins and precision calculations. Our results also showed EFs in the study area using field measurements in 2022. SOCC (%) such as peat soil availability and influence on species composition. However, this study found that peat soil differences in four study areas. The distributions of the peat soil and SOCC depended on the surrounding area and the number of livestock and herders. Therefore, the local community or this study should pay attention to the study area to reduce the impact on herders and livestock. GHGs released from peatlands in permafrost regions have positive feedback on climate change, but there is much uncertainty about additional warming from the permafrost carbon cycle. The degradation of permafrost due to global warming dramatically changes the productivity and carbon dynamics of mountain ecosystems in Bayanzurkh soum. Therefore, the measurement of GHG emissions in the field should be extended to a longer-term monitoring.

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