Methane emissions from the littoral zone of Poyang lake during drawdown periods

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ABSTRACT
Several studies have shown that lake littoral zones often support high methane (CH\textsubscript{4}) emissions. In this study, we measured CH\textsubscript{4} emissions from two vegetation meadows in the littoral zone of Poyang Lake, China, from October 2014 to May 2015. CH\textsubscript{4} emissions in the meadow dominated by \textit{Carex cinerascens} were 11.27 ± 11.29 mg CH\textsubscript{4} m\textsuperscript{-2} h\textsuperscript{-1}, which were significantly higher than emissions in the meadow dominated by \textit{Artemisia selengensis} (2.99 ± 1.67 mg CH\textsubscript{4} m\textsuperscript{-2} h\textsuperscript{-1}). Between-species differences in CH\textsubscript{4} emission were caused by differences in belowground biomass. The results also showed distinct seasonal variation in CH\textsubscript{4} emissions in this area; fluxes reached a maximum at the peak of the growing season and reached a minimum after the summer flood, when plants began to germinate. There were two peak values in the \textit{Carex} meadow, and belowground biomass controlled the seasonality of CH\textsubscript{4} emissions. Our results suggest that plant biomass may be a key factor controlling CH\textsubscript{4} emissions in the littoral zone of Poyang Lake, highlighting that CH\textsubscript{4} fluxes vary with vegetation type in littoral wetlands and demonstrating that spatial variation in CH\textsubscript{4} emissions must be considered when estimating regional CH\textsubscript{4} emissions in Poyang Lake. Considering climate change and the operations of a proposed hydraulic engineering project, changes to the hydrologic regime in this region may significantly affect CH\textsubscript{4} emissions.

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Introduction
Methane (CH\textsubscript{4}) is an important greenhouse gas with a global warming potential approximately 28 times higher than that of CO\textsubscript{2} over a one hundred-year timescale (IPCC 2013). High CH\textsubscript{4} emissions from lakes, with a contribution of 8 to 48 Tg CH\textsubscript{4} yr\textsuperscript{-1}, have attracted increasing interest from the scientific community (Bastviken et al. 2004), and freshwater environments contribute over 20% of total CH\textsubscript{4} emissions to the atmosphere (Khalil and Shearer 1993). However, limited documentation of CH\textsubscript{4} emissions from lakes...
exist (Bastviken et al. 2004; Kankaala et al. 2004), and most existing studies have looked at boreal lakes (Huttunen et al. 2002; Kankaala et al. 2004; Walter et al. 2007). Littoral zones are biogeochemically active ecotones of lake ecosystems and have high productivity (Juutinen et al. 2001; Wang et al. 2006). High emissions of CH₄ from boreal lake littoral zones have been reported (Nykänen et al. 1998; Juutinen et al. 2001). China has more than 2721 lakes greater than 1 km² in area, with a total area of approximately 75,340 km² (Yang and Lu 2014). However, few studies have focused on the littoral zones of lakes in China, especially those that exhibit distinct hydrological variation.

As China’s largest freshwater lake and one of the most important international wetlands, Poyang Lake is a typical subtropical shallow-water lake characterized by dramatic seasonal water level fluctuations. The combined effects of watershed inflows and interactions with the Yangtze River result in significant seasonal variation of approximately 10 m in lake water level (Zhang et al. 2014). When the water level recedes in autumn, the lake littoral zone is dominated by adjacent Carex and Artemisia meadows that account for approximately 20% of the total lake area (Tang et al. 2016). Carex meadows show two distinct growing seasons, one in the spring and the other occurring in autumn after the previous summer’s flooding (Hu et al. 2010), while Artemisia meadows are characterized by only one growing season.

In recent years, the changing climate and operation of the Three Gorges Dam have dramatically altered Poyang Lake’s hydrological regime, particularly by reducing water levels during the drawdown period (Zhang et al. 2012a). The flux in methane from the littoral zone of Poyang Lake will be influenced by these variations, and the distinct hydrologic regimes of Poyang Lake offer scientists a unique opportunity to study the exchange of CH₄ between the lake ecosystem and the atmosphere. However, to our knowledge, carbon fluxes from Poyang Lake have been poorly documented, with only a small number of studies showing greenhouse emissions in this large subtropical lake. Hu et al. (2015a, 2015b) reported the components of ecosystem respiration from a Carex-dominated meadow in Southern Poyang Lake and evaluated CH₄ and N₂O emissions during drawdown periods, and Wan et al. (2010) investigated CH₄ fluxes and ecosystem respiration in a Carex meadow in Banghu (a region of Poyang Lake). Liu et al. (2013; 2017) found that the spatial variability of greenhouse gas effluxes was inhomogeneous in four subregions of Poyang Lake. Limited field measurements of greenhouse gas emissions exist in this region, especially during drawdown periods. Therefore, precise estimation of CH₄ budgets at the regional and national levels requires more observations from the field, and CH₄ effluxes from largely unexplored subtropical lakes are helpful for re-estimating global wetland CH₄ emissions.

The objectives of this study were as follows: (1) to understand CH₄ fluxes and their controlling factors in the littoral zone of Poyang Lake during drawdown periods and (2) to explore the implications for large-scale hydraulic engineering.

**Methods**

**Study sites**

This study was conducted in northern Poyang Lake, located in Xingzi County (29°26′40″N, 116°3′24″E), Jiangxi Province, China. This study site features a typical subtropical humid monsoon climate; the annual mean air temperature is 18°C, with a January average of 5.1 °C and a July average of 29.5 °C. The annual rainfall is 1654 mm, 55% of which occurs between March and June.
The lake receives inflows from five main rivers (the Raohe, Xinjiang, Fuhe, Ganjiang and Xiushui) and discharges into the Yangtze River by a narrow passage. The annual drawdown periods range from 165 to 271 days, depending on local rainfall as well as the hydrologic characteristics of the Yangtze River (Liu et al. 2006; Hu et al. 2010). During drawdown periods, *Carex* and *Artemisia* meadows are distributed zonally along an altitude gradient with extremely obvious borders (Figure 1). *Carex* meadows experience two unique growing seasons, one in the spring and the other during the autumn after the summer floods recede. *Carex cinerascens* is the dominant species, with a coverage of over 95%, and is accompanied by a few species, including *Potentilla limprichtii*, *Cardamine lyrata*, *Polygonum hydropiper*, *Polygonum japonicum*, *Panicum bisulcatum*, *Viola philippica* and *Paris polyphylla*. *Artemisia* meadows are characterized by one growing season, and the dominant plant is *Artemisia selengensis*. Their coverage surpasses 95%, and accompanying species include *Polygonum hydropiper* and *Carex cinerascens*. Detailed information about the study area is provided in Table 1.

**CH₄ flux measurements**

Three plots were established in each plant meadow to measure the CH₄ flux. The interval between any two plots was more than 5 m and less than 10 m, depending on the distribution of the *Carex cinerascens* and *Artemisia selengensis* meadows in the study area. CH₄ fluxes were measured approximately two or three times per month during the drawdown period from October 2014 to May 2015.

CH₄ fluxes were measured by static dark chamber and gas chromatography methods (Wang and Wang 2003). The sample chambers were made of polyvinyl chloride (PVC) pipe with a top chamber and a base collar. One battery-driven (12 V) fan was fixed inside the upper chamber (0.5 m × 0.5 m × 0.5 m) to ensure good air mixing during the measurements. The base frame (0.5 m × 0.5 m × 0.2 m) had a gutter on the top rim that could be filled with water to make an airtight seal with the upper chamber. The base frames were driven 8-10 cm into the soil (depending on soil stability) two days prior to the flux measurements to maintain balance of the system, and they were permanently placed into the soil during the entire experiment. To minimize heating from solar radiation, white adiabatic aluminum foil was used to cover the entire aboveground portion of the chamber. Air in the chamber was sampled using a 60 ml syringe at 0, 10, 20 and 30 min. Gas sampling usually occurred between 9:00 and 11:00. The gas samples were stored in air sampling bags (multilayer polymer with aluminum foil, volume 0.1 L) and taken to the laboratory for CH₄ concentration analysis using a gas chromatograph (GC; Agilent 4890 D, Agilent Co., Santa Clara, CA, USA) within 24 h. The chromatograph was equipped with a flame ionization detector (FID) operating at 200 °C. CH₄ was

![Figure 1. Vegetation meadows showing by field photographs (a, b).](image-url)
separated with a 2 m stainless steel column (2 mm inner diameter) packed with 13 XMS (60/80 mesh, Sigma-Aldrich Co., St. Louis, MO, USA). The column temperature was maintained at 55°C, and the carrier gas was N₂ with a flow rate of 30 ml min⁻¹. The calculations for CH₄ emissions were based on the slope of the linear increase in gas concentrations over time in the chamber during the sampling period. A negative flux value indicated CH₄ uptake from the atmosphere, and a positive flux value indicated CH₄ emissions to the atmosphere (Song et al. 2008).

We calculated the methane flux using the following equation:

\[ F = \frac{dc}{dt} \frac{M}{V_0 P_0 T_0} T H \]  

where \( F \) is CH₄ emissions (mg CH₄ m⁻² h⁻¹); \( dc/dt \) is the slope of gas concentration change with time; \( M \) is the molar mass of CH₄; \( P \) is the atmospheric pressure in sampling site; \( T \) is the absolute temperature during sampling; \( H \) is the height of chamber over the water surface; and \( V_0, P_0, \) and \( T_0 \) are gas mole volume, atmospheric pressure and air absolute temperate under standard conditions.

### Environmental factors

The soil surface temperature and soil temperature at 5 cm depth were measured by a thermometer (JM624 digital thermometer, Jin Ming Instruments, China) during gas sampling. Air temperature outside the chambers was provided by a meteorological station located at the laboratory of Poyang Lake and Wetland Ecosystem Research, Chinese Academy of Sciences. Soil moisture at a depth of 10 cm was recorded using a time domain reflectometer (JS-TDR300, Meridian Measurement, USA). Water level data for the sampling dates were obtained from the website (http://www.jxsl.gov.cn).

The aboveground biomass was measured by harvesting plants from three randomly selected 1 m × 1 m quadrats each month during the drawdown period. The first plant biomass surveys in autumn in the Carex and Artemisia meadows were conducted 10 days after the drawdown area emerged, and biomass measurements in spring for Carex meadows were conducted in early February. Belowground biomass was excavated to a 40 cm depth from three 1 m × 1 m quadrats, which were the same as the aboveground biomass measurement quadrats. All plant

| Characteristics | Carex meadow | Artemisia meadow |
|-----------------|--------------|------------------|
| Dominant species| Carex cinerascens | Artemisia selengensis |
| Elevation (m)   | 14–16        | 15–18            |
| Ecotype         | Hygrophyte   | Hygrophyte       |
| Canopy height (cm) | 15–71     | 18–115           |
| Root length (cm) | 5–13        | 3–8              |
| Density (stems m⁻²) | 224 ± 9    | 811 ± 66         |
| Aboveground biomass (g d.w. m⁻²) | 207 ± 38 | 384 ± 93         |
| Belowground biomass (g d.w. m⁻²) | 1247 ± 416 | 833 ± 338 |
| Total biomass (g d.w. m⁻²) | 1454 ± 412 | 1217 ± 315 |
| Plant total carbon (mg g⁻¹) | 450.5 ± 8.1 | 435.5 ± 10.2 |
| Soil moisture (%) (0–10 cm) | 42.7 ± 3.3 | 34.0 ± 2.7 |
| Soil pH (0–10 cm) | 4.74 ± 0.06 | 4.81 ± 0.16 |
| Soil bulk density (g cm⁻³) (0–10 cm) | 1.60 ± 0.01 | 1.66 ± 0.02 |
| Soil organic carbon (mg g⁻¹) (0–10 cm) | 18.9 ± 3 | 19.9 ± 2.9 |
| Total nitrogen (mg g⁻¹) (0–10 cm) | 8.3 ± 1.3 | 8.3 ± 0.7 |
| Total phosphorus (mg g⁻¹) (0–10 cm) | 1.2 ± 0.2 | 1.2 ± 0.1 |
| Soil C/N ratio | 22.95 ± 0.97 | 23.94 ± 1.77 |

Data are shown as the mean ± standard error.
samples were measured after drying at 85°C for 48 h to a constant weight. Plant density, canopy height and root length in the quadrats were also recorded.

Soil samples were randomly collected at a depth of 10 cm from each of the plots in November 2014. Soil samples were sieved (< 2 mm) to remove any visible plant crowns, stones, and fine roots. Samples were air dried and analyzed for TP by a UV-1601 spectrophotometer following H2SO4-HClO4 digestion (Lu 1999). Soil organic carbon (SOC) and total nitrogen (TN) were analyzed by combustion with an elemental analyzer (Model CNS, Elementar Analysensysteme GmbH, Germany). Soil pH was determined in a 1:2.5 soil-water suspension using a glass electrode. Soil samples for the analysis of soil bulk density were extracted via a steel cylinder with a volume of 100 cm³ (5 cm in diameter, 5 cm in height).

**Statistical analysis**

The flux data and environmental variables were tested for normality by the Kolmogorov-Smirnov test. We found that the CH4 flux data did not have a normal distribution. Therefore, all the CH4 flux data were normalized using a natural logarithm transformation. The mean CH4 emissions, surface and soil temperatures, soil moisture, and aboveground and belowground biomass for each vegetation type were calculated by averaging the three replicates from each sampling date. We used the nonparametric Mann-Whitney U test to test for differences in CH4 fluxes between different plant meadows. We used Pearson correlation analysis to analyze the relationships between CH4 emissions and environmental variables. Additionally, Pearson correlations were used to examine the autocorrelations between the different environmental variables. We used principal component analysis (PCA) to identify the mutual relationships among different variables. Furthermore, stepwise multiple linear regression analysis was used to examine the associations between CH4 emissions and the principal components. All analyses were conducted using Sigma Plot 11.0 (Systat Software, Inc., San Jose, CA, USA).

**Results**

**Spatial and temporal variations of CH4 emissions**

Spatial variation in CH4 emissions was found between the two different meadow types in the littoral zone of Poyang Lake (Figure 2). CH4 emissions were highest from the Carex meadows (11.27 ± 11.29 mg CH4 m⁻² h⁻¹) and lowest from the Artemisia meadows (2.99 ± 1.67 mg CH4 m⁻² h⁻¹). Emissions from the Artemisia meadows were significantly lower than those from the Carex meadows (p < 0.05).

CH4 emissions in the Artemisia and Carex meadows showed similar temporal variations. The maximum CH4 fluxes occurred at the peak of the growing season, and the minimum fluxes were recorded after the summer flooding when plants began to germinate. CH4 influxes were observed in October and November 2014 for the Artemisia and Carex meadows, respectively. Two extreme CH4 emission events were observed for the Carex meadows, with fluxes of 64.34 and 49.63 mg CH4 m⁻² h⁻¹ in January and March 2015, respectively (Figure 3).

**Relationships between CH4 emissions and key factors**

The ln(CH4 flux) values from the two littoral vegetation meadows were plotted against environmental variables (Figure 4). Significant positive relationships were observed between the CH4 fluxes and belowground biomass and total biomass. Because of the mutual correlations among these environmental variables, PCA was used to identify
the relationships among these environmental factors in the littoral zone. The principal component analysis of physical variables resulted in two components with eigenvalues larger than 1. The two components explained 76% of the total variance. Furthermore, the first component explained approximately 51% of the variance, and several variables (soil temperature at 5 cm, air temperature, water level and ground surface temperature) were significantly positively correlated with the first component. The second component explained approximately 25% of the observed variance. Belowground biomass and total biomass were found to be significantly positively correlated with the second component, which could be influenced by biomass (Table 2).

The stepwise multiple linear regression analysis between the PCA components and CH₄ emissions in the littoral zone indicated that the second component had a significant influence ($r^2 = 0.3091$, $p < 0.05$) and could be described as $\ln(\text{CH}_4, \text{flux}) = -0.0417 + 0.7936 \times \text{component 2}$. 

Figure 2. Methane emissions from different plant meadows from October 2014 to May 2015. The different letters above the boxes indicate significant differences in CH₄ emissions between meadows (nonparametric test followed by Mann–Whitney U test, $p < 0.05$, $n = 45$).

Figure 3. Temporal variation in CH₄ fluxes from October 2014 to May 2015. The error bars show standard error based on three replicates.
Discussion

Spatial and temporal variations in CH₄ emissions from the Littoral zone

The mean CH₄ emission rate from the littoral zone of Poyang Lake was 7.13 ± 8.29 mg CH₄ m⁻² h⁻¹ (ranging from −1.93 to 64.34 mg CH₄ m⁻² h⁻¹) during the drawdown period. This rate was much higher than the rates in the Nanji Wetlands (Southern Poyang Lake) during the drying period, Bang Lake, the pelagic zone of Poyang Lake and

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Table 2. Results of the principal component analysis (PCA) of physical variables in the littoral zone of Poyang Lake.

| Physical variables                  | Component 1 | Component 2 |
|-------------------------------------|-------------|-------------|
| Soil temperature at 5 cm            | 0.896ᵃ      | −0.215      |
| Soil temperature at 10 cm           | −0.239      | 0.467       |
| Air temperature                     | 0.907ᵃ      | −0.152      |
| Water level                         | 0.949ᵃ      | −0.055      |
| Ground surface temperature          | 0.709ᵃ      | −0.193      |
| Aboveground biomass                 | −0.471      | −0.554      |
| Belowground biomass                 | −0.111      | 0.956ᵃ      |
| Total biomass                       | −0.246      | 0.865ᵃ      |
| Variance explained (%)              | 51%         | 25%         |

ᵃCorrelation significant at p < 0.001.

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Figure 4. Relationships between methane emissions and biomass (a, b) in the littoral zone.
many boreal lakes (Table 3), comparable to the rate in the Nanji Wetlands during the drying-wetting period, and lower than the rates from rice paddy fields (ranging from 10.88 to 53.01 mg CH₄ m⁻² h⁻¹) in the same region (Cai et al. 2000). On the basis of a four-year study of CH₄ emissions from the surface of Poyang Lake (Liu et al. 2017), we determined that the CH₄ emissions from the water surface of Poyang Lake were 0.36 mg CH₄ m⁻² h⁻¹. Based on the surface area (3618 km²) (Tang et al. 2016), we further calculated the total CH₄ emissions from the surface as 1.3 Mg CH₄ h⁻¹. With a mean CH₄ emission value of 7.13 ± 8.29 mg CH₄ m⁻² h⁻¹ from the littoral zone of Poyang Lake (715 km² in area) (Tang et al. 2016), the total CH₄ emissions from the littoral zone of Poyang Lake could be estimated to be approximately 5.1 Mg CH₄ h⁻¹, nearly four times the value of the surface. Considering that it represents only approximately 20% of the surface area, the littoral zone of Poyang Lake could be a ‘hotspot’ of CH₄ emissions, which is a finding consistent with other reports (Chen et al. 2009, 2013).

Our study showed positive correlations between CH₄ emissions and total plant biomass and belowground biomass (Figure 4a,b), but there was no significant relationship with aboveground biomass. This finding suggests that plant roots primarily contributed to the CH₄ emissions of the littoral zone during drawdown periods, and a similar result was reported by Hu et al. (2015b). Plant biomass affects CH₄ emissions, as organic material from plant roots via root decay and root exudation may serve as a substrate for methanogens. Additionally, plant species with aerenchyma may directly transport CH₄ from the anaerobic zone of the soil to the atmosphere (Schimel 1995). The higher belowground biomass in the Carex meadows than in the Artemisia meadows explained the difference in the CH₄ fluxes in the littoral zone of Poyang Lake (Table 1, Figure 2).

In our study, the beginning of the growing season showed comparatively low CH₄ emissions, while peak emission rates appeared in the peak growing season. This temporal pattern of CH₄ emissions was consistent with that in other studies (Alm et al. 1999; Kankaala et al. 2004; Chen et al. 2008). The reason for this pattern may be that plant biomass controls the temporal variations in methane emissions. Two extreme CH₄ emission events were observed in the Carex meadows during the drawdown period in our study. In Poyang Lake, there was no obvious standing water on the soil surface of the littoral zone, there was relatively low soil moisture during the drawdown period, and drying is known to cause the episodic release of entrapped CH₄ due to changes in soil structure (Windsor et al. 1992; Denier van der Gon et al. 1996). This flush of CH₄ may have contributed to the observed peak in CH₄ flux during the drawdown period in our study. Similarly, Hu et al. (2015b) observed extreme CH₄ emission events for a Carex meadow in Poyang Lake during the soil drying-wetting transition periods, and the ecosystem CH₄ emission rate for drying-wetting periods was approximately 228 times that for the drying transition periods. However, we did not detect this change in our study. CH₄ fluxes differed considerably even within a short (1–50 m) distance in the littoral wetlands (Juutinen et al. 2001; Kaki et al. 2001). This large spatial variation suggests that a fine-scale investigation should be performed. The shorelines of the lake are not regular, and the sediment quality and density, biomass and species composition of the littoral vegetation vary with short distances, thus impacting the spatial variation in CH₄ fluxes (Kankaala et al. 2003). Moreover, Poyang Lake has been characterized by dramatic annual and interannual water level fluctuation, and hydrology is a major variable controlling many complicated biogeochemical processes in wetlands. Dramatic changes in hydrological conditions should result in considerable differences in processes such as greenhouse gas fluxes (Altor and Mitsch 2008). Therefore, long-term multisite methane flux monitoring studies are urgently needed to more reliably estimate the methane flux from the littoral zone of Poyang Lake.
Table 3. Comparison among previously reported CH$_4$ emissions from the littoral and pelagic zones.

| Location                                           | Zone                              | CH$_4$ flux (mg m$^{-2}$ h$^{-1}$) | Sampling period      | References                  |
|----------------------------------------------------|-----------------------------------|-----------------------------------|-----------------------|----------------------------|
| China, Xingzi County, northern Poyang Lake         | Carex cinerascens and Artemisia   selengensis meadow                      | −1.93−64.34                    | Drawdown period        | This study                 |
| China, Nanji Wetlands, southern Poyang Lake        | Carex cinerascens meadow          | 2.28−16.96$^a$, −0.13−0.23$^b$    | Drawdown period        | Hu et al. 2015b            |
| China, Bang Lake, southern Poyang Lake             | Carex cinerascens meadow          | 0.023−0.44                       | March                  | Wan et al. 2010            |
| China, Poyang Lake                                 | Pelagic zone                      | 0.31−0.4                         | Annual                 | Liu et al. 2017            |
| Finland, Lake Mekrijärvi and Heposelkä             | Littoral zone                     | −0.2−14.2                        | June to November       | Juutinen et al. 2001       |
| Finland, Lake Ekojärvi                             | Littoral zone                     | 1.1−27.2                         | July                   | Kankaala et al. 2003       |
| Finland, Lake Alinen Rautjärvi                      | Littoral zone                     | 1.28−3.84                        | May to November        | Kankaala et al. 2005       |
| Canada, Lake Laurentians                           | Pelagic zone                      | 1.33−13.67                       | May to August          | Rasilo et al. 2015         |
| China, Meiliang Bay in Taihu Lake                  | Littoral zone                     | −1.7−131                         | Annual                 | Wang et al. 2006           |
| China, Three Gorges Reservoir Region               | Littoral zone                     | −0.69−104.3                      | July to September      | Chen et al. 2009           |
| East Antarctica, Lake Mochou                        | Littoral zone                     | 0.14                              | December to February   | Zhu et al. 2010            |

$^a$The flux rate range during the drying-wetting transition period.

$^b$The flux rate range during the drying period.
Implications for large-scale hydraulic engineering

In this study, we made a preliminary estimation that the CH$_4$ emissions from the littoral zone (covering only 20% of the surface area) were approximately four times the total CH$_4$ emissions of the surface of Poyang Lake. Therefore, the littoral zone could be an important source of CH$_4$. In recent years, changing climate conditions and operation of the Three Gorges Dam have dramatically altered Poyang Lake's hydrological regime, particularly by reducing the water level during the drawdown period (Zhang et al. 2012a). In addition, hydrarch succession in Poyang Lake wetlands may expand wetland vegetation communities in the littoral zone (Zhang et al. 2012b). In our study, the littoral zone showed high emission rates of CH$_4$ from the soil (7.13 mg CH$_4$ m$^{-2}$ h$^{-1}$), and the pelagic zone emitted 0.36 mg CH$_4$ m$^{-2}$ h$^{-1}$. Therefore, variability in vegetation zones as a result of a rapid decrease in water level during the drawdown period might increase the CH$_4$ flux from the Poyang Lake wetland in the future.

The construction of a dam at the outlet of Poyang Lake has been proposed for maintaining the lake water level by controlling the flow between Poyang Lake and the Yangtze River and partially resolving the seasonal dryness of the lake. Scientists have argued that this project will fundamentally change the ecosystem of Poyang Lake (Li 2009). However, the vast littoral zone of the lake will be submerged once hydraulic engineering is implemented, and methane emissions from the littoral zone will decrease significantly when the lake water level is high enough to submerge the structures of the plants involved in gas exchange (Juutinen et al. 2003). Considering that the littoral zone is a ‘hotspot’ of CH$_4$ emissions in Poyang Lake, the proposed dam might help reduce methane emissions from Poyang Lake. To precisely predict this scenario, long-term studies of CH$_4$ fluxes in the littoral zone, vegetation changes with climate change and the effects of hydraulic engineering projects are needed. In addition, we should pay more attention to lakes such as Poyang Lake that have distinct hydrological variations because climate change and proposed hydraulic projects could influence regional greenhouse gas emissions.

Our results showed that greater spatial variation in methane emissions existed in the littoral zone of Poyang Lake during the dry season, with the lowest emissions (2.99 ± 1.67 mg CH$_4$ m$^{-2}$ h$^{-1}$) in the Artemisia selengensis meadow and the greatest (11.27 ± 11.29 mg CH$_4$ m$^{-2}$ h$^{-1}$) in the Carex cinerascens meadow. In addition, spatial variation in CH$_4$ emissions must be considered when estimating regional CH$_4$ emissions from Poyang Lake. The littoral meadow showed distinct seasonal variation in CH$_4$ emissions; the fluxes reached a maximum at the peak of the growing seasons, and the minimum occurred after the summer flood, when plants began to germinate. Belowground biomass controlled the spatial and seasonal variations in CH$_4$ emissions. Climate change and hydraulic engineering projects might significantly influence CH$_4$ emissions from Poyang Lake. We noted that adequate sampling for methane fluxes is difficult to perform and has an important influence for adequate evaluation of methane emissions. Future efforts are needed to fully understand the spatial variation in CH$_4$ emissions and long-term temporal changes.

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Disclosure statement

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