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The potential importance of grazing to the fluxes of carbon dioxide and methane in an alpine wetland on the Qinghai-Tibetan Plateau

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Abstract

To assess the impact of livestock grazing on the emission of greenhouse gases from grazed wetlands, we examined biomass growth of plants, CO_2 and CH_4 fluxes under grazing and non-grazing conditions on the Qinghai-Tibetan Plateau wetland. After the grazing treatment for a period of about 3 months, net ecosystem CO_2 uptake and aboveground biomass were significantly smaller, but ecosystem CH_4 emissions were remarkably greater, under grazing conditions than under non-grazing conditions. Examination of the gas-transport system showed that the increased CH_4 emissions resulted from mainly the increase of conductance in the gas-transport system of the grazed plants. The sum of global warming potential, which was estimated from the measured CO_2 and CH_4 fluxes, was 5.6- to 11.3-fold higher under grazing conditions than under non-grazing conditions. The results suggest that livestock grazing may increase the global warming potential of the alpine wetlands.

Keywords: Aquatic plants; Diffusive conductivity; Greenhouse gases; Global warming potential; Livestock grazing

1. Introduction

Although wetlands cover about 5% of the global land surface, the ecosystems contribute significantly to the global greenhouse gases (e.g., CO_2 and CH_4) budget (e.g., Matthews and Fung, 1987). Many wetlands are used for livestock grazing, which may alter greenhouse gas fluxes in these ecosystems (e.g., Jensen, 1985; Robertson, 1997; Morris and Jensen, 1998). Despite the potential importance, little evidence is available to assess the effects of livestock grazing on the greenhouse gases budget in wetland ecosystems.

The Qinghai-Tibetan Plateau is the highest (average 4000 m a.s.l.) plateau in the world, and it has a total wetland area of 50,000 km^2 (Zhao, 1999). These alpine wetlands contain a large amount of soil organic carbon, which is estimated to compose about 0.2% of the global pool of soil carbon (Wang et al., 2002). The large carbon pool in the wetland ecosystems suggests that the

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wetlands on the plateau could become a significant source of CH_4. On the Qinghai-Tibetan Plateau, almost all wetlands are now being managed for livestock grazing. However, we have little knowledge of the effects of livestock grazing on greenhouse gases dynamics in the plateau's wetlands.

The direct effects of livestock grazing on wetlands can be slowing down photosynthetic CO_2 uptake by plants due to the reduction of assimilatory organs. Reducing the aboveground biomass can also change gas transport through plant conduit between soil and the atmosphere. The decease of transporting conductance may increase CH_4 emission from soil, but may also increase the entry of oxygen into soil, which will favor CH_4-oxidizing bacteria and suppress methanogenesis (Epp and Chanton, 1993).

Methane has a much greater global warming potential (GWP) than CO_2. Therefore, it is critical to assess both CH_4 and CO_2 emission if we are to clarify the contribution of a wetland to global warming.

To demonstrate the potential importance of grazing to global warming gases in the plateau wetlands, we measured plant biomass and CO_2 and CH_4 fluxes under experimental grazing and non-grazing conditions. To understand the underlying mechanism, we examined the gas-transport systems of major aquatic plants. We further assessed the grazing impact on the wetland's contribution to the radiative forcing calculated from the measured CO_2 and CH_4 fluxes and the GWP.

2. Methods

2.1. Study site and experiment design

The study site was located in the Luanhaizi wetland at the northeast edge of the Qinghai-Tibetan Plateau (37°35′N, 101°20′E, 3250 m a.s.l.). The catchment was flooded at an average water depth of 30 cm over the growing season, 2002. The annual mean temperature is −2 °C, and the annual precipitation is 500 mm (Klein et al., 2001). Vegetation of the wetland was composed of four major species dominating in different zones along a gradient of water depth. There were three emergent-plant zones, dominated by *Carex allivescers* V. Krez. (*ZCar*), *Scirpus distigmaticus* L. (*ZSci*), *Hippuris vulgaris* L. (*ZHip*), and one submerged-plant zone dominated by *Potamogeton pectinatus* L. (*ZPot*) along a gentle gradient of water depth (Hirota et al., 2004). The wetland is grazed by sheep, yak, and dairy cattle year-round, and it also is a watering place for the livestock.

In June 2002, we set up two experimental plots, a grazing plot and a non-grazing plot, each containing all four of the vegetation zones mentioned above. In the grazing plot, the grazing intensity was roughly estimated to be about 3.3 sheep units ha^{-1} during the period from May to September 2002. The non-grazing plot (40 × 100 m) was fenced with barbed wire and protected from all livestock. Since the vegetation and other environmental conditions in each vegetation zone were visibly homogeneous before we set the experimental plots, we assumed that all the differences between the grazing and non-grazing plots were due to grazing effects.

2.2. Plant biomass and gas fluxes

Aboveground parts of plants were clipped from three quadrats (0.25 × 0.25 m) in each of the four vegetation zones on 15 September 2002. The clipped biomass was dried at 80 °C for 2 days and then weighed.

Net CO_2 and CH_4 fluxes were measured by the static chamber method (Hirota et al., 2004) between 14:00 and 16:00 local time on two clear days: 15 August in the mid-growing season and 15 September in the late growing season. Both net CO_2 uptake (unpublished data) and CH_4 emission (Hirota et al., 2004) reached a peak between 13:00 and 16:00 at least during the growing season, 2002. The flux measurements were conducted in two vegetation zones, *ZCar* and *ZSci*, which were severely grazed in the grazing plot. Four acrylic frames (21 cm in diameter) were set on the soil surface in both vegetation zones. An upper cylindrical chamber (45 or 60 cm in height) was placed on the frame for the measurement. For more information on the chamber system and flux calculation, see Hirota et al. (2004). We adopted the sign convention of net CO_2 and CH_4 emission from the ecosystem as positive. We measured water depth, soil temperature, and Eh below the chamber at 5 cm depth after gas sampling. None of these environmental parameters was significantly different between the grazing and non-grazing plots (data not shown).

2.3. GWP-based assessment

We calculated global warming potentials (GWPs) of the vegetation zones from measured fluxes of CO_2 and CH_4, and global warming potential (GWP) by using a conversion factor proposed by Lashof and Ahuja (1990).

$$\mathrm{GWPs} = \sum_i \mathrm{GWP_i} \times F_\mathrm{i}, \tag{1}$$

where i indicates the gas species (CO_2 and CH_4 in this study); $\mathrm{GWP_i}$ and F_i indicate the GWP and flux of gas i, respectively. We applied the value of GWP over 20 years; the corresponding values are 1 for CO_2 and 62 for CH_4 (IPCC, 2001). In this study, we treated F_i as mean gas fluxes of all data through the two measurement days ($n = 8$ for each of four cases).

2.4. Diffusive conductivity of CH_4 and plant density

Methane flux (F_{CH_4}, mmol CH_4 min^{-1} $shoot^{-1}$) via the aerenchyma of plants is expressed by the following equation (Yamasaki, 1984):

$$F_{CH_4} = Q(C_b - C_a), \tag{2}$$

where Q (ml min^{-1} $shoot^{-1}$) is the conductivity of CH_4, and C_b and C_a (mmol CH_4 ml^{-1}) denote the CH_4 concentration inside the basal shoot and the atmospheric CH_4 concentration around the shoot, respectively. The values of Q for *C. allivescers* and *S. distigmaticus* were determined at noon on 25 August 2002 ($n = 7$ for each of four cases) according to the method of Yamasaki (1984).

We calculated plant density in both the vegetation zones by counting the number of live shoots inside the chamber on 15 September 2002 ($n = 4$ for each of two vegetation zones).

3. Results

3.1. Plant biomass and gas fluxes

In the non-grazing plot, aboveground biomass in the different vegetation zones increased from the deeper water to the drier edges of the wetland. The biomass for *ZPot*, *ZHip*, *ZSci*, and *ZCar* was 174, 230, 419, and 489 g dry weight m^{-2}, respectively. In the grazing plot, the aboveground biomass in the shallower zones *ZCar* and *ZSci* decreased (by 85.9% and 87.2%, respectively) significantly compared with that in the non-grazing plot (paired *t*-test; $P<0.001$). The deeper zones, *ZPot* and *ZHip*, however, showed no significant difference in aboveground biomass between the two plots (paired *t*-test; $P<0.01$).

Net CO_2 uptake was significantly lower in the grazing plot than in the non-grazing plot, and was similar in *ZSci* and *ZCar* (both decreased by ca. 80.5%). Methane emissions differed significantly between these two vegetation zones (Fig. 1). The CH_4 emissions from *ZSci* and *ZCar* were four times and twice as high, respectively, in the grazing plot as in the non-grazing plot. These differences in CO_2 and CH_4 fluxes between the two experimental plots were observed in both August and September.

The values of GWPs over 20 years estimated for *ZSci* and *ZCar* were significantly higher in the grazing plot than in the non-grazing plot (Table 1).

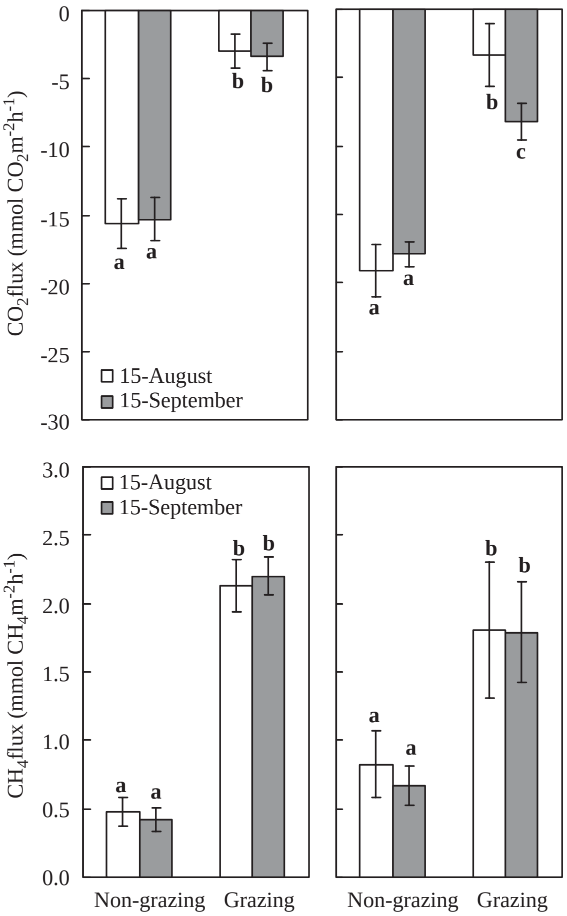

Fig. 1. Net CO_2 and CH_4 fluxes in grazing and non-grazing plots. A positive (negative) value indicates gas emission from (uptake by) the wetland. *ZSci* and *ZCar* indicate *S. distigmaticus*-dominated zone and *C. allivescers*-dominated zone. Mean ± SD are shown ($n = 4$). Different letters indicate a significant difference by one-way factorial ANOVA, $P<0.001$.

Table 1
Mean GWPs in two vegetation zones dominated by *S. distigmaticus* and *C. allivescers* in grazing and non-grazing plots over the two measurement days ($n = 8$ for each of four cases)

Vegetation zone	Treatment	GWPs (over 20 years) mean (SD)
S. distigmaticus	Non-grazing	12.2 (1.3)
	Grazing	137.0 (6.1)
C. allivescers	Non-grazing	18.5 (2.4)
	Grazing	106.5 (19)

3.2. Diffusive conductivity

Diffusive conductivity (Q) of *S. distigmaticus* and *C. allivescers* was significantly larger in the grazing plot than in the non-grazing plot (paired *t*-test; $P<0.01$ and $P<0.05$, respectively). The value of Q for grazed *S. distigmaticus* approximately doubled, whereas that for grazed *C. allivescers* increased by about 15%. Plant

Table 2
Diffusive conductivity (Q) measured in two aquatic plant species, *S. distigmaticus* and *C. allivescers*, in grazing and non-grazing plots ($n = 7$ for each of four cases) and plant density in both the vegetation zones ($n = 4$ for each of four cases)

Species	Treatment	Plant density	Diffusive conductivity	
		(shoot m^{-2}) mean (SD)	Q per shoot ($mL\,s^{-1}\,shoot^{-1}$) mean (SD)	Q per basal cross-sectional area ($mL\,s^{-1}\,cm^{-2}$) mean (SD)
S. distigmaticus	Non-grazing	208 (18)	3.15 (0.7)**	64.9 (7.5)**
	Grazing	203 (20)	6.04 (1.1)	119 (6.3)
C. allivescers	Non-grazing	49.5 (4.4)	4.43 (0.8)*	15.6 (1.4)*
	Grazing	51.2 (5.5)	5.06 (0.3)	18.3 (0.7)

*$P < 0.05$.
**$P < 0.01$.

density showed no significant difference between the grazing and the non-grazing plots in both vegetation zones (Table 2).

4. Discussion

From the short-term measurement, we estimated that about 85% of aboveground biomass was reduced by grazing. Decreased aboveground biomass can lead to a decrease in the assimilatory capacity of emergent plants. Morris and Jensen (1998) reported that grazing decreases the aboveground net primary productivity (ANPP) and affects the carbon cycle in grassland ecosystems. Data compiled from the world's grasslands show that grazing consumes 75% of ANPP (Frank et al., 1998). However, the grazing effect on NEP depends on the intensity and timing of grazing, the target ecosystem, and climate (Belsky, 1987; LeCain et al., 2002).

Little attention has been given to assessment of the impact of grazing on the performance of gas transport systems of aquatic plants. Gas transport is a vital function of aquatic plants: it both supplies the belowground parts of the plant with oxygen for respiration and removes unnecessary gases through the development of aerenchymatous tissues (e.g. Brix, 1989). Grazing will unavoidably reduce the transporting distance from soil to the atmosphere and thus increase diffusive conductivity of CH_4 (Table 2), which will eventually increase CH_4 emissions via grazed aquatic plants (Fig. 1). Gas transport mechanism and location of ports for CH_4 transport differ among aquatic plants (Brix et al., 1992; van der Nat et al., 1998). The difference in the transport system will explain the different diffusive conductivity in the two species under grazing conditions (Table 2). Schimel (1995) also demonstrated that clipping shoots of *Eriophorum angustifolium* did not significantly change CH_4 emission but clipping those of *Carex aquatilis* increased CH_4 emission. Because livestock prefer aquatic plants that live in shallow water over those that live in deep water, the grazing intensity differed among vegetation zones. Such species-specific responses to grazing (clipping) and differences in grazing intensity among macrophyte plants are likely to result in spatial variability in CH_4 emissions within a wetland.

Besides increasing CH_4 emission via individual plants by changing diffusive conductivity, another impact of grazing will be considered to reveal totally the impact of grazing on CH_4 emission from the wetland. Our results showed that the degree of increasing ecosystem CH_4 emission was higher than that of increasing diffusive conductivity in both grazing vegetation zones (Fig. 1 and Table 2). Since plant density was similar between the two plots in both vegetation zones (Table 2), ecosystem CH_4 emission may enhance by increasing CH_4 emission via other paths, such as diffusion and ebullition from the soil (Schimel 1995), induced by soil disturbance.

In this study, grazing significantly reduced the aboveground biomass and NEP, and enhanced CH_4 emissions in the short-time period. However, grazing will lower C provision for CH_4 production, which in turn will reduce ecosystem CH_4 emission in a long-term period, because plants makes a great contribution to C for CH_4 production in wetlands. To clarify the importance of grazing impact on wetland ecosystems, further studies on the impact of grazing on greenhouse gas fluxes in wetland ecosystems over long periods and/or on large spatial scales are urgently required in the future.

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