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Soil CO_2 Flux in Hövsgöl National Park, Northern Mongolia

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Abstract

We investigated soil CO_2 flux and bare soil respiration in grasslands that are located at the southern edge of the Siberian boreal forest in Northern Mongolia. The study area has warmed by almost 1.8°C over the last 40 years, and the soil and vegetation covers have been changed due to intense nomadic grazing pressure. Bare soil respiration is decreased with increasing grazing pressure, but there was no consistent pattern of total soil CO_2 flux under three distinct grazing levels. Bare soil respiration and soil CO_2 flux were higher on north-facing slopes than on south-facing slopes, due to high organic matter accumulation and the presence of permafrost. Both bare soil respiration and soil CO_2 flux were significantly higher in riparian areas compared with the lower and upper portions of the south-facing slope. Topography has a stronger effect on variability of soil CO_2 flux and bare soil respiration than variability induced by grazing. Inter-annual variability in soil CO_2 flux and bare soil respiration was very high, because of high variability in climate conditions.

Key words: Soil respiration, temperate steppe, topography, slope aspect, grazing

Introduction

Models of global climate predict that the greatest temperature increases due to greenhouse gas concentrations will be between latitudes 45°N and 65°N (Tans *et al*., 1990). The northern boreal forest ecosystem (taiga) lies along these latitudes, and the southern boundary of the Siberian taiga lies adjacent to a temperate grassland ecosystem that is of great interest with respect to carbon, since there are about 181.1 Mt x 10^9 C in these grassland soils to a depth of 1 m (Schlesinger, 1977).

Around 70-80% of Mongolia is grassland and shrubland, with slightly more grassland than shrubland (Tsogtbaatar, 2000). Grasslands have been overgrazed in many parts of Mongolia.

Soil respiration is one of the primary pathways by which terrestrial C is returned to the atmosphere. The efflux of CO_2 from soils is the product of both respiratory activities of roots and soil heterotrophs (Raich & Schlesinger, 1992). Thus, one may expect higher soil CO_2 flux in places with high soil organic C or high root biomass.

Environmental variables that influence soil respiration may be altered with both grazing pressure and topography. Soil temperature is a major factor controlling soil respiration rates in plot scale measurements in other ecosystem types (Kang *et al*., 2003). In addition, soil moisture, soil substrate quality, and vegetation cover influence soil respiration (Kang *et al*., 2003). In many semiarid grassland or shrubland landscapes, toes-lopes are characterized by having higher vegetation cover, finer textured soils, and greater soil organic matter (Burke *et al*., 1999). Since soil respiration is a major component of ecosystem C flux, and the microclimates of Mongolian landscapes vary so strongly, and there is strong potential for high topographic variability in soil respiration.

Published information on how grazing influences soil respiration is inconsistent. In belowground dominant short-grass steppe regions, stable soil organic matter pools are not substantially affected by long term cattle grazing, but are highly variable with respect to topography and microsite (Burke *et al*., 1999).

Our goal was to evaluate soil respiration in response to grazing across a complex landscape of Northern Mongolia, and to seek possible

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explanations for the variability in soil CO_2 flux.

Our first objective was to determine how soil respiration varies across three grazing treatments (lightly grazed, moderately grazed and heavily grazed). We expected less soil respiration with increasing grazing intensity.

• Second, we wished to elucidate how soil respiration varies with slope aspect and position. Since north-facing slopes have a higher soil C than south-facing slopes in the top 50 cm, we hypothesized higher soil respiration in the north-facing slopes. However, this effect could be ameliorated or even non-existent due to the colder soil temperatures of these landscape positions compared with south-facing slopes and the presence of permafrost.

• Third, we wished to understand the variability in soil respiration in three different topographical locations (upper, middle and lower slope areas of the watersheds) of the south-facing slopes. Our hypothesis was that soil respiration rates decrease with increasing altitude, possibly due to lower soil organic matter and coarser soil texture.

• Finally, we wished to evaluate which of the factors (grazing vs. topographic location) play the most important role in determining the annual and inter-annual variability of soil respiration.

Material and Methods

Study area. We conducted this study within the framework of the Long Term Ecological Research program at the Lake Hövsgöl National Park. Mean annual precipitation here is 350 mm and mean annual temperature is 4.5ºC. Over the past four decades, mean annual air temperature has increased by 1.8ºC (Nandintsetseg, 2004).

The soil cover of the eastern part of the Lake Hövsgöl area is complex due to the mountainous features of the area, exposure differences, the presence of permafrost, and soil parent material. Generally, the study area has sandy loam soils. The valley bottoms contain alluvial peat soils. Prior results indicate that soil microclimate is altered due to grazing, with surface soil temperature increasing and soil moisture content decreasing as a result of heavy grazing (Batkhishig, 2004).

The north-facing slopes are usually more cold and wet, and have permafrost, compared with the south-facing slopes (Sharkhuu & Anarmaa, 2004).

One of the site characteristics is that the non-grazed and lightly grazed watersheds (please see study design below) have a thick litter layer that is lacking in the grazed watersheds, and this layer protects the soil from evaporation, leading to higher soil moisture (Ariuntsetseg, 2004).

Climate conditions. There was high inter-annual variability in weather for the duration of this study (Fig. 1). The 2003 growing season was considerably cooler (7.8ºC), and wetter (127.5 mm precipitation) than 2004 or 2005. This variability was clearly reflected in the respiration data we collected (Nandintsetseg, 2004).

Soil moisture was higher in 2003 (71.86% and 31.29% in the north- and south-facing slopes, respectively) compared to that of 2004 (44.64% and 17.14% in the north- and south-facing slopes, respectively) in both aspects and the north-facing slope always had significantly higher soil moisture

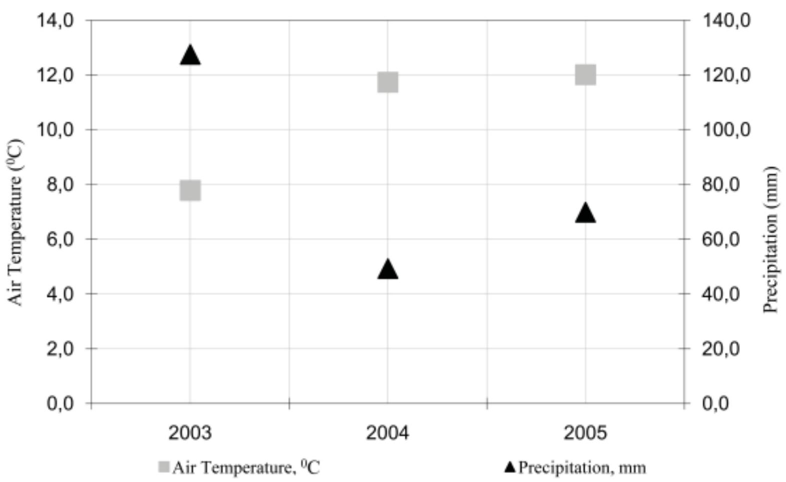

Figure 1. Climate conditions during the growing season for the study.

compared to the south facing slopes (Ariuntsetseg, 2004; Batkhishig, 2004).

Soil temperature was lower in 2003 (13.4^{o}C) compared with 2004 (17.5^{o}C), but on the north-facing slope, soil temperatures were almost same for these two years. Soil temperature was always lower in the north-facing slope compared with the south-facing slope (Ariuntsetseg, 2004; Batkhishig, 2004).

Design and measurements. We selected six tributary stream valleys occupied by different numbers of herder families. The most northern two valleys had more than 3000 livestock (converted into sheep units following the Law on Livestock Tax of Mongolia) in each valley; these are considered to be heavily grazed valleys. The most southern two valleys had less than 500 livestock, and the study area was only infrequently grazed, with non-grazed parts at all during this study. The two middle valleys were considered to have moderate grazing since they had an intermediate number of livestock that graze permanently (439 and 453 livestock in 2003 and 2004, respectively?). Carrying capacity estimate suggests that the two northern valleys are over-grazed, the middle two valleys, though grazed, animals do not exceed beyond the carrying capacity, and the southern two valleys have little to no grazing (Bayasgalan, 2005).

We set transect lines 100 m wide across each valley, extending from the summit of the south-facing slope to the summit of the north-facing slope in each of the valleys. The grassland portion of each transect was divided into south-facing upper, south-facing lower slope, riparian and north-facing lower slopes. The boreal larch forest, which we did not sample, lies above north-facing lower slopes.

We measured soil CO_2 fluxes and bare soil respiration using a PP System Closed soil respiration system (www.ppsystems.com). All measurements were taken between 10-12 AM, and 2-6 PM. Measurements were made in two ways. First, CO_2 release from the soil was measured by placing the soil respiration chamber above both the green biomass and the litter layer. We call these measurements “soil CO_2 fluxes”. Second, bare soil respiration measurements were made by placing the soil respiration chamber over bare ground, where all aboveground biomass and litter had been removed. In all cases, we performed measurements of CO_2 release in five randomly selected spots within the 100 m wide transect area in each of the strata, the south-facing upper, the south-facing lower and the north-facing lower slopes, and the riparian areas.

To address the first question on the relationship between grazing and soil respiration, we measured soil CO_2 flux once during the growing season in 2003, 2004 and 2005 in the south-facing lower slope landscape position of all of the study valleys. We measured bare soil respiration once during the summer months in 2003 and 2005 in the same south-facing lower slope landscape position at the same time as when we made soil CO_2 flux measurements.

To address our second question on the aspect and soil respiration relationships, we compared data from the north-facing lower slopes and the south-facing lower slopes. Soil CO_2 flux measurements of the south- and north facing slopes were made at the same time as measurements to answer the above question of grazing, once during the growing season of 2003 and in 2004, while bare soil respiration measurements of the south- and north-facing slopes were made only in 2003.

We used measurements from the south-facing upper slope, south-facing lower slope, and riparian zones to answer our third question, which addressed relationships of topography and soil respiration. Data from different landscape positions were collected in the same years as for the previous question that focused on the relationship between soil respiration and aspect (Table 1).

To address the fourth question about the importance of grazing vs. topographic location on soil respiration variability, we compared soil CO_2 flux data of the south-facing upper, south

Table 1. Study design: years of measurement for each major study question.

	1. Grazing	2. Aspect position	3.Topography	4. Interaction
Soil CO_2 flux	2003 2004 2005	2003 2004	2003 2004	2003 2004
Bare soil respiration	2003 2005	2003	2003	2003

facing lower and the north-facing lower landscape positions from 2003 and 2004 of all study watersheds. For bare soil respiration we could only make comparisons of different topographical locations and grazing interaction for 2003.

Statistical analysis. We tested the effects of grazing across the three grazing treatments (lightly grazed, moderately grazed, and heavily grazed treatments) using JMP IN 5.1 software (SAS Institute Inc (2004)). For the three grazing treatments, we used a two-way analysis of variance (ANOVA) design including three years (2003, 2004 and 2005) as a random effect in the analysis of the soil CO_2 flux. For bare soil respiration, we used the same analysis with only two years (2003, 2005) as a random effect.

For the effects of two different aspects and of three different topographic locations, respectfully, we used data only from the lightly grazed treatments and implemented a one-way ANOVA with bare soil respiration data collected in 2003, and two-way ANOVA with the soil CO_2 flux measurements including the two years (2003, 2004) as a random effect.

For testing the topography and grazing interactions of soil CO_2 flux, we included data from four topographic locations (south-facing upper, south-facing lower, riparian and north-facing lower) along the three grazing treatments (lightly grazed, moderately grazed, and heavily grazed treatments), in two years (2003, 2004). Bare soil respiration variance along the four topographical locations and three grazing treatments were analyzed from one year's data as a two-way ANOVA test. Further, we implemented regression analysis for grazing and topography effects on the soil CO_2 flux and bare soil respiration. The purpose of the latter regression analysis was to determine how much of the variance is explained by grazing or topography.

Results and Discussion

Grazing

Soil CO_2 flux. The average soil CO_2 flux, which incorporated both aboveground leaf processes and belowground respiration, is increased with increasing grazing pressure (Fig. 2). This likely occurred as a result of decreased leaf uptake of CO_2 with increased grazing.

However, if we evaluate the data on a yearly basis, soil CO_2 flux in lightly grazed areas increased dramatically in 2004 after wet cold of 2003, but in 2005 it decreased back to the level of 2003 (Fig. 2). In contrast, in heavily grazed areas, soil CO_2 flux was higher in both wet cold 2003 and dry warm 2004, but decreased in 2005 that had similar climate conditions as 2004. In other words, soil respiration significantly responds to inter annual climate variability depending on level of grazing. In lightly grazed areas, increase of soil CO_2 flux could happen as a result of higher temperature conditions followed after the wet (2003) year while in heavily grazed dry and warm conditions that lasted for 2 years could result significant drop of soil respiration.

The soil CO_2 flux of moderately grazed watersheds had no significant changes among the three years. Generally, we measured lowest soil CO_2 flux in 2005 in all three grazing treatments.

Bare soil respiration. Compared with the soil CO_2 flux, bare soil respiration showed a consistent pattern of decrease with increased grazing pressure (Fig. 2). Recall that the bare soil respiration measurements did not include leaf processes of either respiration or photosynthesis, so that this decrease must result from decreases in either belowground heterotrophic respiration resulting from lower labile organic matter, or reductions in autotrophic respiration associated with plant grazing responses, or both. Bare soil respiration

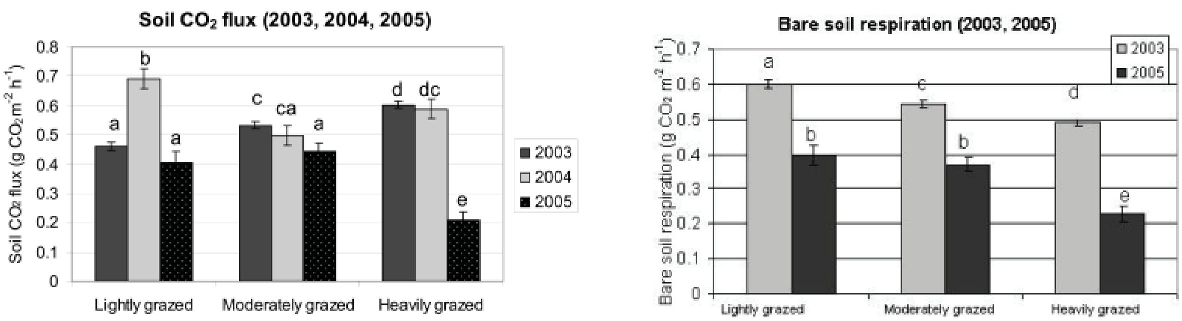

Figure 2. Soil CO_2 flux and bare soil respiration in the three grazing treatments.

was lower in 2005 than in wet cold year of 2003. This could be due to the lower precipitation and thus low soil moisture of 2005.

Slope aspect

Soil CO_2 flux. In the lightly grazed areas, soil CO_2 flux was higher on south-facing slopes than north-facing slopes during 2003 (Fig. 3). This likely occurred because low soil temperature was limiting CO_2 flux on the north-facing slope, and temperatures were warmer on the south-facing slopes, especially in wet cold of 2003. In 2004 dry warm growing season, soil CO_2 flux was higher than in previous years on both aspects, and especially so on the north-facing slope; differences between aspects dissipated.

In the moderately and heavily grazed areas in 2003, we saw similar pattern of soil CO_2 flux as of 2003 lightly grazed area (Fig. 3). However, in these grazing levels, in 2004, we measured significantly lower soil CO_2 flux in south facing slopes. This 2004 drop in south facing moderately and heavily grazed slopes could directly associate with limitation of soil moisture or labile organic materials.

Major differences between two slopes indicated by soil temperature, soil moisture and soil organic matter amount (labile fraction of soil organic

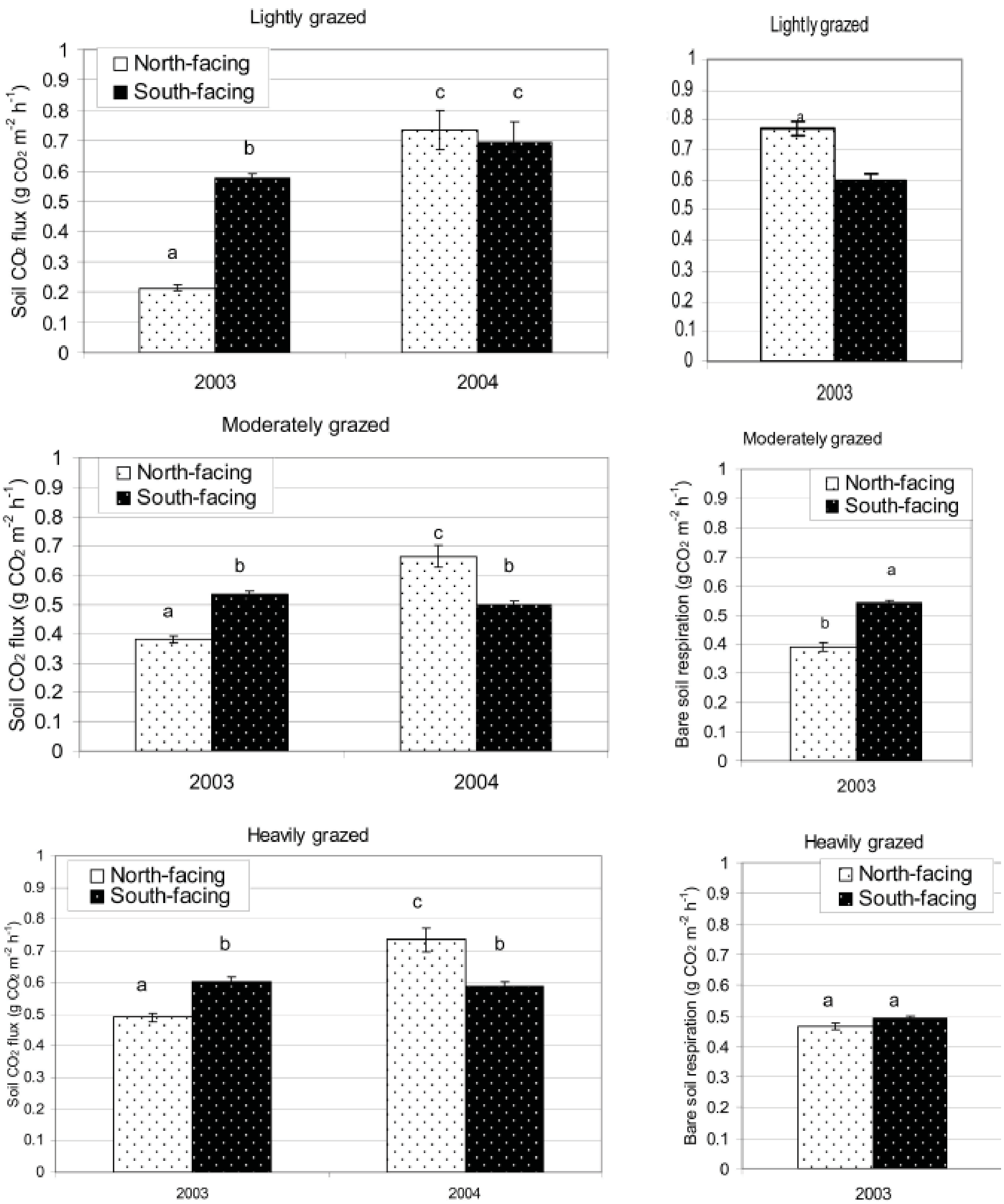

Figure 3. Soil CO_2 flux and bare soil respiration in the north-facing and south-facing slopes.

matter). One may expect lower soil temperature, higher soil moisture and more labile materials in north facing slopes.

Bare soil respiration. In lightly grazed watersheds, soil respiration rates, measured without litter and green biomass, were higher in the north-facing slopes than the south-facing slope in 2003 (Fig. 3) and in 2005. In the wet and cold 2003, bare soil respiration was higher than during dry, warm 2005 year, likely due to low soil moisture in the dry warm 2005. As before, bare soil respiration was consistently lower in dry areas (heavy grazed areas) compare with wet areas (not grazed areas).

Topography

The riparian (R) area almost always had significantly higher soil CO_2 flux than both the upper south-facing and lower south-facing slopes (Fig. 4). This may have occurred either because of the high level of soil organic matter that concentrates in lowlands or higher soil moisture. The upper south-facing slope had significantly lower soil CO_2 flux compared with the other landscape positions.

Bare soil respiration showed the same pattern

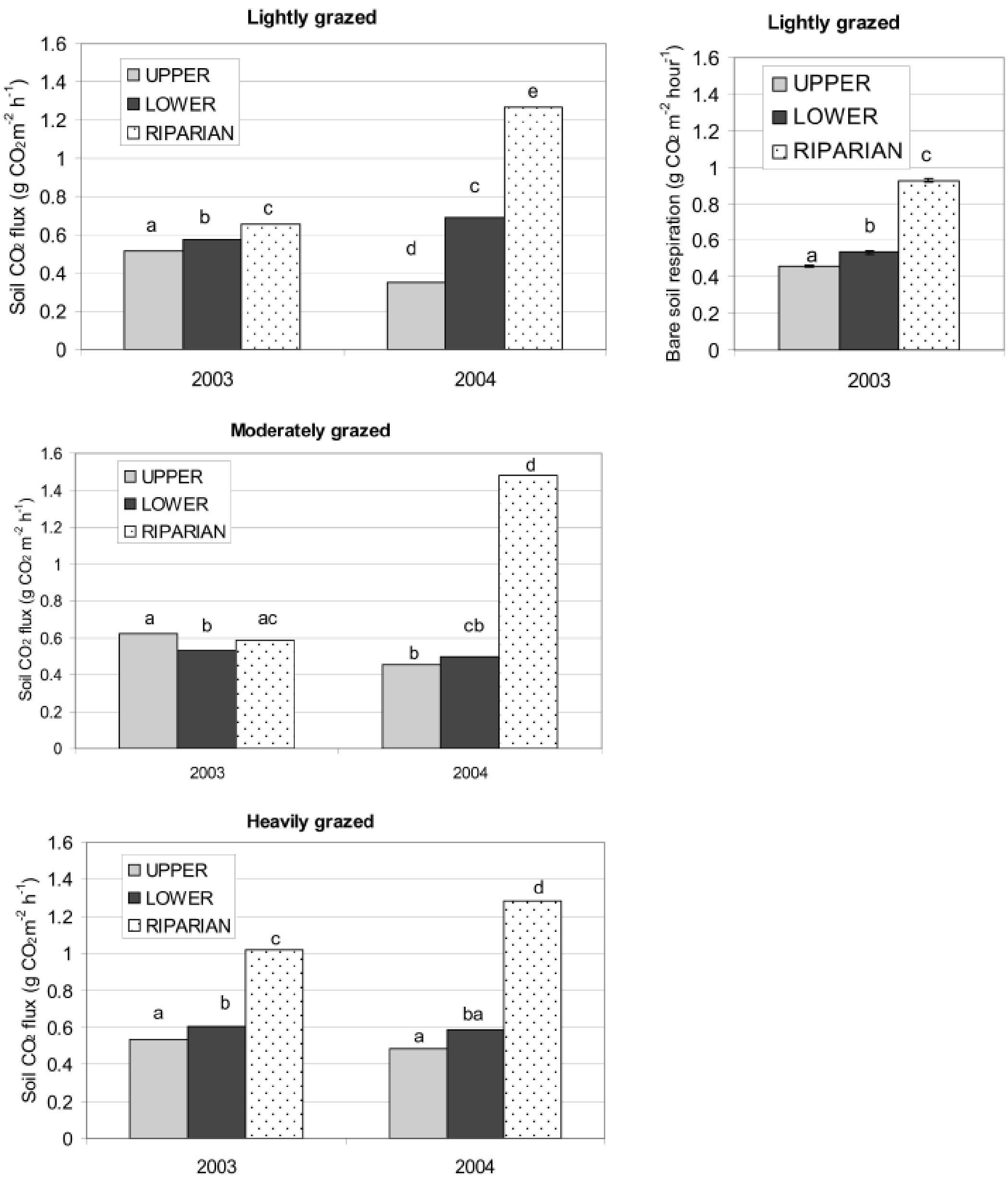

Figure 4. Soil CO_2 flux and bare soil respiration in the south-facing upper, south-facing lower and riparian landscape positions.

as soil CO_2 flux among the different topographic locations. It was higher in the riparian zone than of the upper south-facing and the lower south-facing slopes (Fig. 4).

Conclusion

Grazing, slope aspect, and topography are all had significant effects on soil CO_2 flux and bare soil respiration. However, the spatial variability conferred by topography explained a great deal more of the variation than grazing, for both soil CO_2 flux and bare soil respiration (Table 2). These results are similar to those found by Burke *et al*. (1999) in short grass steppe, where topography had a more important influence on biogeochemical dynamics than grazing. In this Mongolian system, soil microclimate and substrate quantity are likely the major proximal controls over respiration; temperature appears to be the major limitation to respiration for much of the landscape. Similarly, though the influence of grazing was small, the effects may be interpreted as the response to changes in soil microclimate, with higher soil temperatures under heavy grazing that resulted in higher respiration rates during the coolest year.

Table 2. Relative importance of topography and grazing effects to the soil CO_2 flux and bare soil respiration variability. Values are r^2, or the proportion of the variability explained by topography or grazing.

	Topography	Grazing
Soil CO_2 flux	0.17	0.03
Bare soil respiration	0.24	0.01

Though we were not able to statistically test the effect of climatic variability, it is clear from the inter-annual variability and its influence on spatial variability that climate is the most important factor influencing CO_2 flux in this system. Locations with sufficient substrate quality and moisture responded to increases in temperature with increased soil CO_2 fluxes, or with increased sensitivity to moisture content. These results are important, given the documented increases in air temperature for this region, and the predictions of continued temperature increases.

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References

Ariuntsetseg L. 2004. Impacts of Nomadic Livestock on a semi-arid Boreal steppe plant community of Northern Mongolia. In C. E. Goulden, J. Tsogtbaatar & B. Mendsaikhan (Eds.): *The Dynamics of Biodiversity Loss and Permafrost Melt in Lake Hövsgöl National Park, Mongolia*. Institute of Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, pp 135-165.

Batkhishig O. 2004. Soil morphology and Chemistry. In C. E. Goulden, J. Tsogtbaatar & B. Mendsaikhan (Eds.): *The Dynamics of Biodiversity Loss and Permafrost Melt in Lake Hövsgöl National Park, Mongolia*. Institute of Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, pp 45-100.

Bayasgalan A. 2005. Nomad land use and livestock grazing impact. In C. E. Goulden, J. Tsogtbaatar & B. Mendsaikhan (Eds.): *The Dynamics of Biodiversity Loss and Permafrost Melt in Lake Hövsgöl National Park, Mongolia*. Institute of Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, pp 53-80.

Burke I. C., Lauenroth W. K., Riggle R., Brannen P., Madigan B. & Beard S. 1999. Spatial variability of soil properties in the shortgrass steppe: The relative importance of topography, grazing, microsite, and plant species in controlling spatial patterns. *Ecosystems* 2, 422-438.

Kang S. Y., Doh S., Lee D., Lee D., Jin V. L. & Kimball J. S. 2003. Topographic and climatic controls on soil respiration in six temperate mixed-hardwood forest slopes, Korea. *Glob. Change Biol.* 9, 1427-1437.

Raich J. W. & Schlesinger W. H. 1992. The Global Carbon-Dioxide Flux in Soil Respiration and Its Relationship to Vegetation and Climate. *Tellus B*. 44, 81-99.

Sharkhuu N. & Anarmaa S. 2004. Permafrost study. *In The dynamics of biodiversity loss and permafrost melt in Lake Hövsgöl National Park, Mongolia,* Eds C E Goulden, J Tsogtbaatar and B Mendsaikhan. pp 101-133. Geoecology Institute of Mongolian Academy of Sciences, Ulaanbaatar.

Tans P. P., Fung I. Y. & Takahashi T. 1990. Observational Constraints on the Global Atmospheric Co2 Budget. *Science* 247, 1431-1438.

Tsogtbaatar J. 2000. Forest policy development in Mongolia. In (Ed.): Forest policy development in Mongolia. Ulaanbaatar, pp. 60-69.

Хураангуй

Бид энэхүү өгүүлэлд Сибирийн тайгын ойн өмнөд хэсэгтэй залгаа орших Умард Монголын хээрийн биотопд хийсэн хөрсний CO_2-ийн эргэлт болон хөрсний амьсгалын хэмжилтийг үр дүнг танилцуулж байна. Судалгаанд хамрагдсан газар нутаг сүүлийн 40 жилд 1.8°С хэмээр дулаараад байгаа ба нутгийн зарим хэсгийн бэлчээр талхлагдсаны улмаас хөрс, ургамлан нөмрөг нь ихээхэн өөрчлөгдөж байгаа юм. Бэлчээрийн талхлагдлын хэмжээ ихсэхийн хэрээр хөрсний амьсгалын эрчим буурч байсан бол хөрсний CO_2-ийн эргэлт бэлчээрийн талхлагдлаас хамаарч нэгэн жигд өөрчлөгдөхгүй байлаа. Харин хөрсний CO_2-ийн эргэлт болон хөрсний амьсгалын эрчмийн аль аль нь уулын ар хажуу ба эргийн бүсийн дагуу буюу өөрөөр хэлбэл хөрсний чийг сайтай, температур багатай, хөрсний органик бодис ихтэй хэсэгт илүү өндөр үзүүлэлттэй байлаа. Хөрсний CO_2-ийн эргэлт болон хөрсний амьсгалын хэмжилтэд бэлчээрийн талхлагдлаас үүдсэн ялгаанаас илүү топографийн нөлөө илүү мэдрэгдэж байсан боловч өгөгдлийг ерөнхийд харвал уур амьсгалын өөрчлөлт илүү нөлөөтэй байж болох юм.

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