Carbon Fluxes of Recent High-Latitude Steppes

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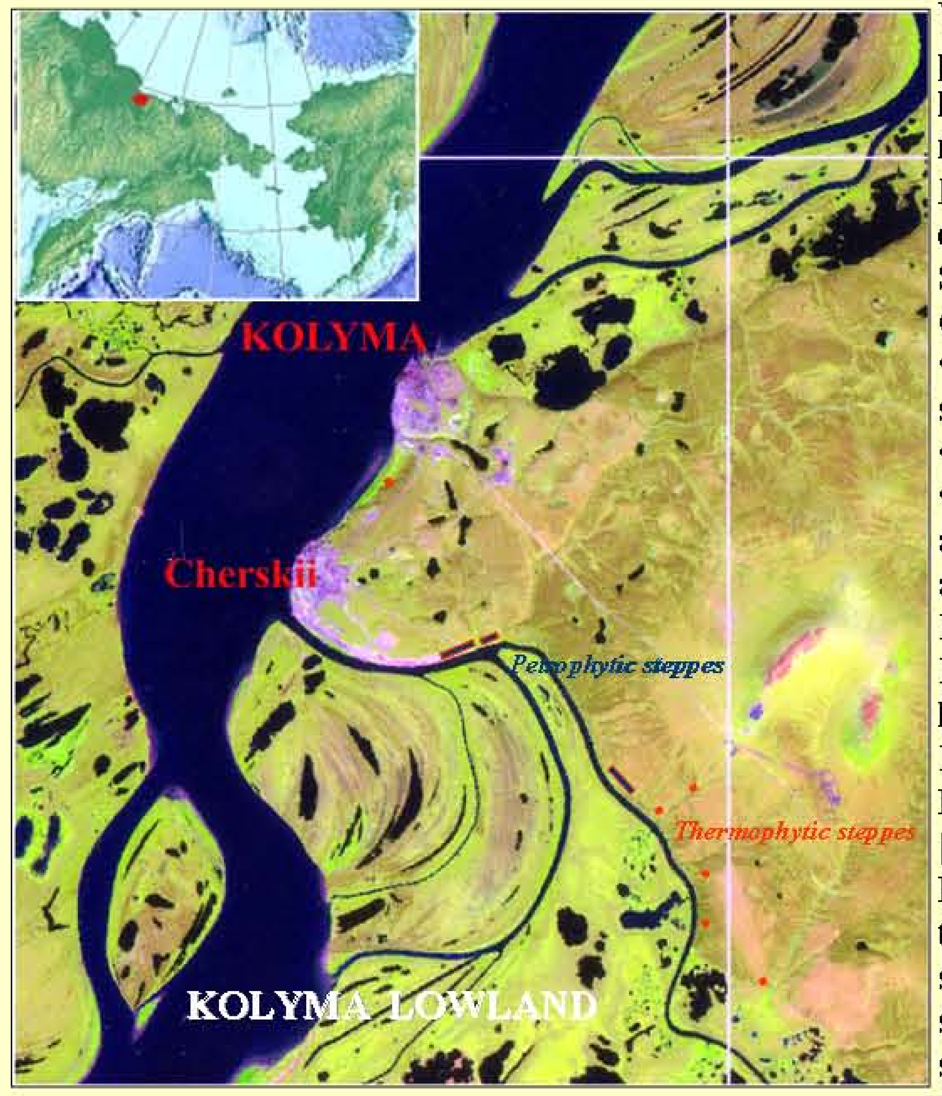
ABSTRACT

Modern high-latitude steppes (HLS) serve as unique information sources about the Late Pleistocene "mammoth" steppe because of the many similarities between these ecosystems. HLS were vast in the Late Pleistocene and now have small relict positions on steep slopes under S, SW and SE aspects in the modern climate. Over a three-year period we studied two types of relict HLS on the Kolyma Lowland, Siberian Arctic, a region where steppes were widespread in the Late Pleistocene. Modern vegetation predominately belongs to the xerophytic-steppen florogenetic complex of North East Asia and resembles other steppe coenosises of the North-East Siberia. HLS soils have high organic matter content and their thermophysical and physic-chemical properties, and the structure of soil profiles, differ from properties of zonal soils of sparse larch taiga. The growing season starts 10-20 days earlier than on other landscapes of the area. Daily and seasonal ecosystem productivity is bimodal with morning and afternoon daily peaks and small resting of plant productivity in the period of high summer temperatures. The polar day increases the photosynthesis time on average 3 – 4 hours per day compared with typical steppes of Eurasia. The steppe carbon budget has a positive carbon balance. Fast seasonal melting - freezing of HLS shorten both the period and volumes of the autumn-winter CO2 emission, which are significant in modern non-steppe landscapes. This has an important paleogeographic meaning. We suppose that this effect contributed significantly to the reduction of the atmospheric concentration of CO2 in the glacial time of the Late Pleistocene, when steppe and tundra-steppe ecosystems of the "mammoth" biome were widespread.

STUDY AREA

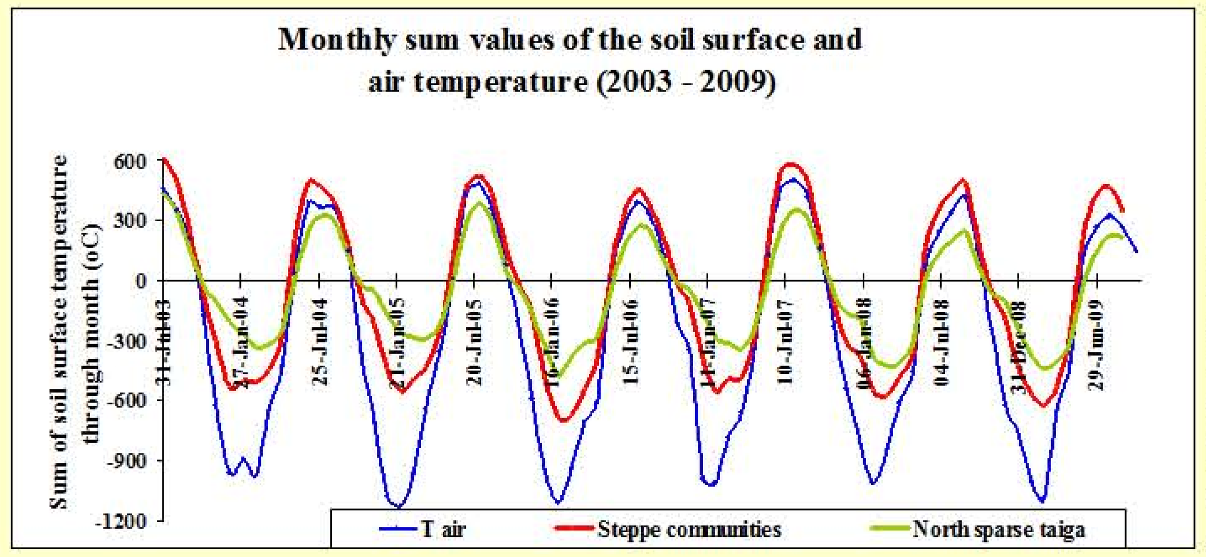


We studied two variants (33 sites of petrophitic and thermophitic steppes) of high-latitude steppes (HLS) that located on right riverside of the Kolyma valley in North-East Kolyma Lowland. The lowland occupies a North-East of vast Arctic Siberian Coastal Plains.

Climate conditions of the study area:
- annual temperature are -7.6 to -13.2° C
summer temperature are +8 and +12° C
- winter temperature are -28 and –35° C
- annual total precipitation are 190 – 300mm and are distributed relatively equally among warm and cold seasons.

In Late Pleistocene HLS were vast in North Eurasia and North America and presented landscape basis of the "mammoth" biome. In particular abundant herbivores of Mammoth Fauna were connected to HLS [1, 2, 3, 4]. HLS was widespread in late-Pleistocene time on the Kolyma Lowland. In the modern climate this aboriginal cold steppes is extreme rare [4, 5]. Now these steppe communities always located only on south aspect along the mountain slopes and the river bluff.

HYDROTHERMIC CONDITIONS



Hydrothermic conditions of HLS strongly differ from zonal boreal forest, forest tundra and tundra [3, 4, 5, 6]. Steppes characterized dynamic and short-time lead seasonal cryogenic processes (thawing and freezing) in comparison with resent zone landscapes. It is closely connected with the highest dryness of soil, when convectional heat exchange is more than conductional. Consequently HLS is characterized by more short-lived winter emission of CO2. Paradoxically, the permafrost has no effect on the biological potential of steppe communities because of the thickest of active layer and aridity of soil.

STEPPES OF THE KOLYMA LOWLAND

PETROPHYTIC STEPPES

Petrophytic Steppes (PS) located along the right river bluff on the south aspect by 30m belt. Common vascular plant species are *Festuca kolymensis, Calamagrostis purpurascens, Carex pediformis, Veronica incana, Pulsatilla multifida, Silene stenophylla, Dracocephalum palmatum, Thymus diversifolius, Arenaria tschuktschorum, Dianthus versicolor, Potentilla arenosa, Phlox sibirica, Galium verae, Pedicularis venusta, Elytrigia jakutorum, Lychnis sibirica, Allium strictum* and others. Plant cover occupies to 35-70% of surface. Total number of species is approximately 59.

THERMOPHYTIC STEPPES

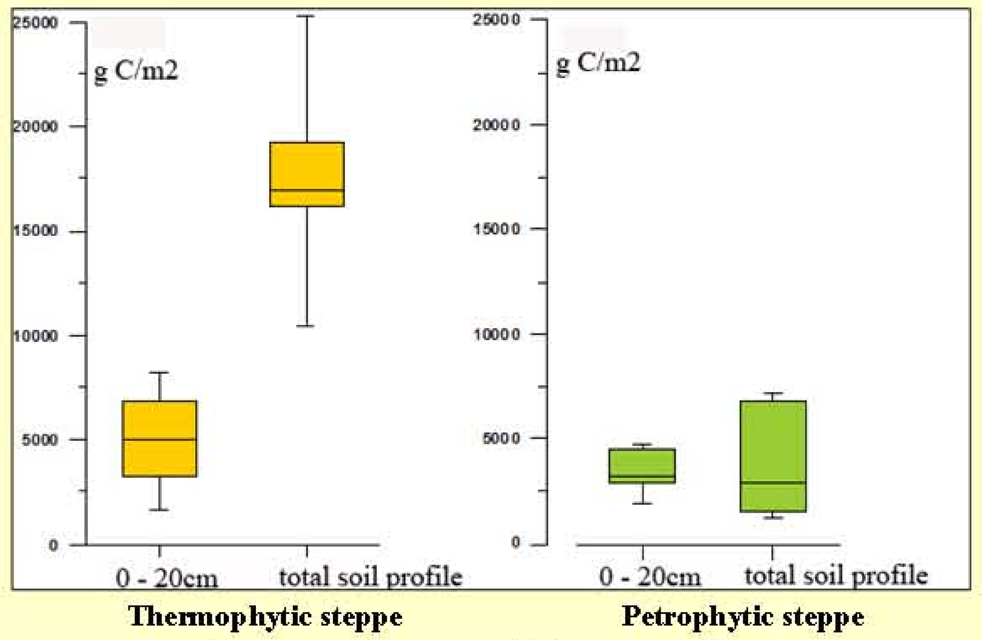
Thermophytic Steppes (TS) located along the right riverside of Kolyma valley on very old fire-sites. The TS is situated on steppe slopes of south aspects as well. In the vegetation dominate *Artemisia dracunculus* and co-dominated *Potentilla tanacetifolia, Veronica incana, Poa attenuata, Calamagrostis purpurascens.* Background plants: *Elytrigia jakutorum, Pulsatilla multifida, Bromus pumpellianus, Allium strictum, Silene stenophylla, Thymus diversifolius, Festuca altaica* and others. Plant cover occupies to 65-90%. Total number of species is approximately 22.

Mean values of phytomass in steppe communities

Steppe communities	Phytomass, g C/m²						Ratio overground/ underground phytomass
	Overground			Underground			
	living	dead	total phytomass	living	dead	total phytomass	
Petrophytic steppe	110	122	232	752	1754	2505	1 : 10.8
Thermophytic steppe	153	435	588	413	963	1376	1 : 2.34

The main bulk of the higher plants of HLS belongs to xerophytic-steppen florogenetic complex of North East of Asia. Steppe flora composition allows stating its relict status.

SOILS

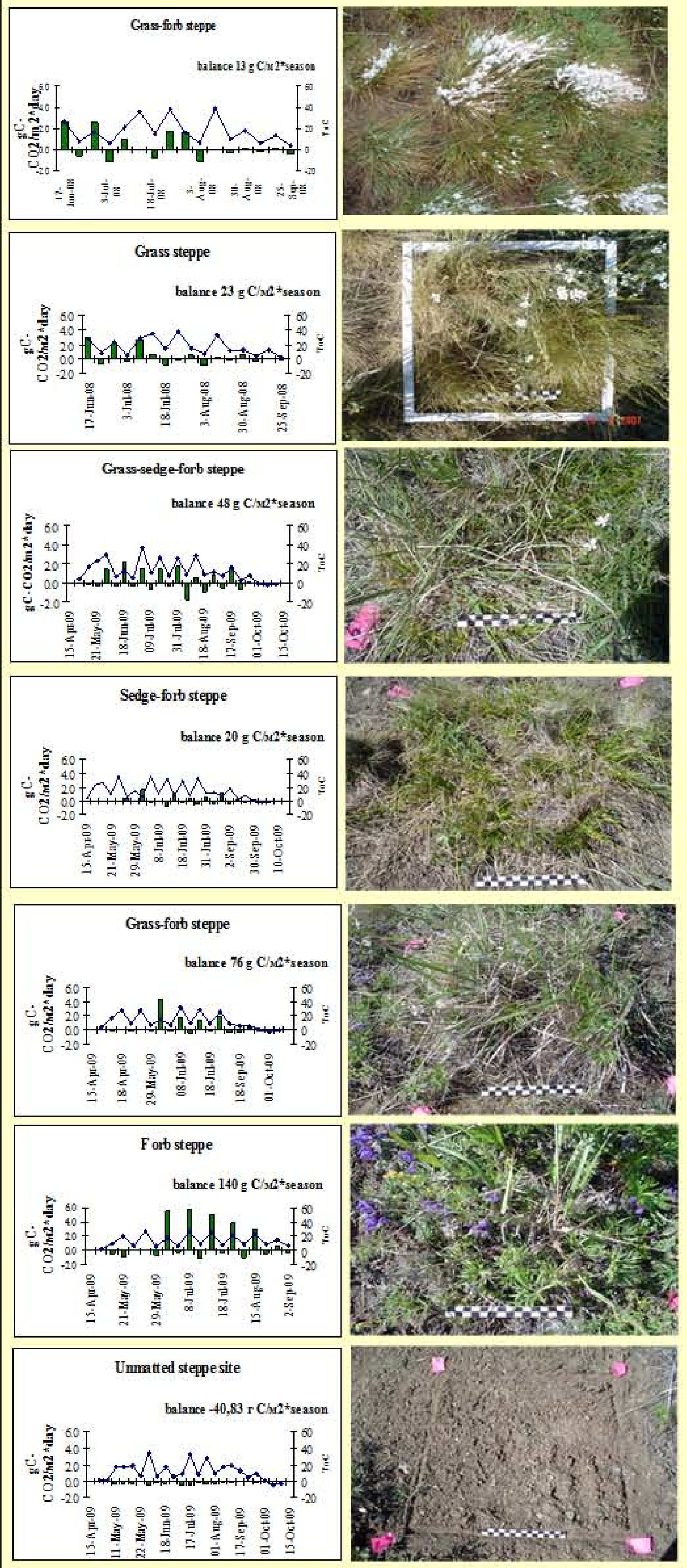


Carbon storage of steppe soils

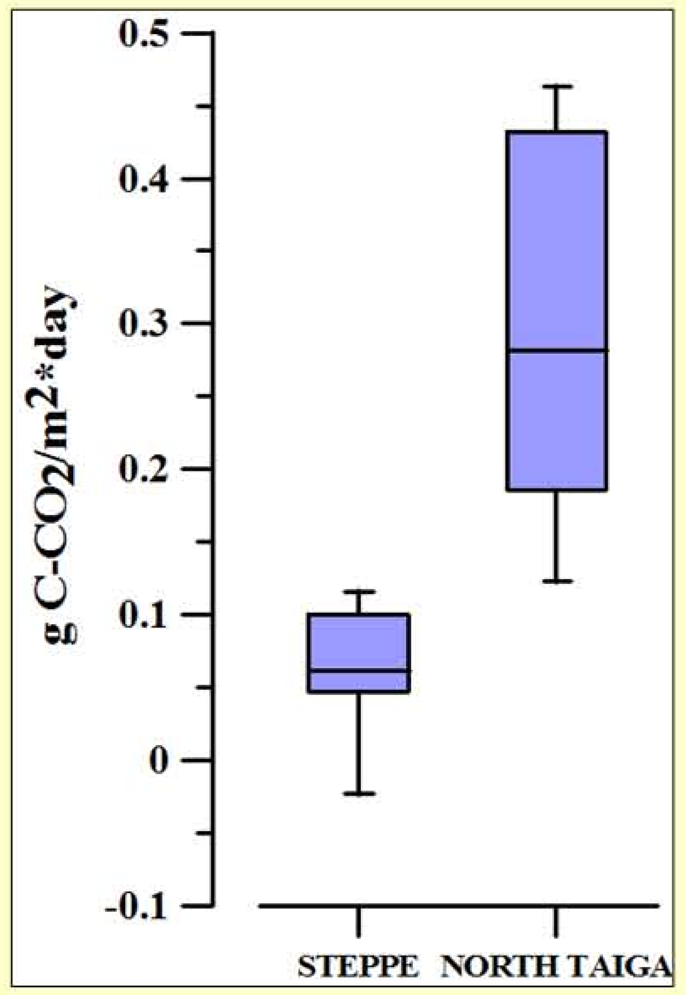
Soil cover of both steppe ecosystems are characterized by an extreme value of soil temperature and highest dryness of soil profiles. They are the most heat provided in the study region. Their structure, thermophysical and physic-chemical properties cardinally differ from the same properties of zonal soils of north sparse taiga. Soils approach to neutral pH, Ca dominates in the exchange adsorption complex and the prevalence of cryoaridic type of soil processes. Steppe soils characterized high content total and dissolved organic carbon, nitrogen and highest value of labile P (to 50mg/100g soil).

CARBON FLUXES*

Seasonal fluxes and Carbon balance at different sites of High-Latitude Steppes



The vegetation on the steppe ecosystem starts 10-20 days earlier, than on non-steppe landscapes of northern taiga. The daily course of the photosynthesis is bimodal with the morning and afternoon peaks, which are especially evident in the period of high summer temperatures. In the conditions of polar day the period of photoactive radiation is increased for 3 – 4 hours on the average in comparison with zonal steppes of Eurasia [7, 10]. The results of lab and field researches show that the aridity of steppen ecosystems is the main factor which limits heterotrophic respiration. In general carbon budget of HLS has a small positive carbon balance, and its values differs not only between steppe variants, but also within each type, that is induced with highly mosaic structure of the vegetation cover.



Comparison of autumn-winter CO2 flux of steppes and north taiga

* measurements were made with IRGA Li-Cor 6200

Consequently HLS is characterized by more short-lived autumn-winter emission of CO2. The modern winter fluxes of CO2 observed in north taiga, forest tundra and tundra have significant values in the annual carbon budget its landscapes [8]. Evidently this phenomenon was less obvious in cryoaridic climate of the Late Pleistocene grass-dominated ecosystems. We suppose that it was one of the plausible reasons that reduced global atmospheric CO2 concentration [9] in during glacial periods when the "mammoth" steppe ecosystem were vast and had zonal status. A study of the carbon budget of the modern high-latitude steppes provides valuable information about its zonal and circumpolar predecessor – Pleistocene steppes and the tundra-steppes of "mammoth" biome.

CONCLUSIONS

- **The main bulk of vascular plants of steppes belongs to xerophytic-steppen florogenetic complex of North East Asia and have relict status**
- **The dynamics of the top-phytomass of modern high-latitude steppes resemble typical steppes of Eurasia**
- **Growth season of HLS is more prolonged in comparison with growth seasons of north taiga landscapes**
- **More short-lived autumn-winter emission of CO2 of HLS in comparison with north forest and tundra that probably had influence upon forming of of the atmospheric concentration of CO2 in the Late Pleistocene**
- **Ecological niche of north relict steppes declines as a result global warming in Arctic and extension of competition with shrub and dwarf-shrub layer of modern landscapes**

ACKNOWLEDGEMENTS

This study was supported by Russian Academy of Science (grant RFBR 07-05-00313-a) and NSF

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