# Future climate change impacts on pasture biomass in Mongolia

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**Abstract.** The main objective of this study is to estimate pasture biomass changes in Mongolia using the simulation model CENTURY. For the study framework we used the fenced pasture biomass data from 1960's to 2008, over 60 meteorological stations and simulation data of the carbon, nitrogen, aboveground and belowground biomass, potential evapotranspiration, evaporation, transpiration and precipitation data across these grasslands. The simulated climatic and other parameters were estimated meteorological station based and their differences between 2 time periods were calculated. With purpose to make comparison of the present situation to the future situation used Climate Change Scenarios under A2, A1B and B1 emission scenarios by HadCM3 Climate Model for 2020, 2050 and 2080. For the present situation all parameters were long term averages from 1960s to 2008 and the future change estimation used Climate Change scenario A1B and statistical values separately by different ecosystems over following natural zones such as, high mountain, forest steppe, steppe and desert zones.

**Keywords:** Climate change, biomass, dynamics, CENTURY model.

## Introduction

Mongolia is a landlocked country bordering the Russian Federation to the north and the People's Republic of China to the south and has an area of 1,564,116 sq km. The country has a severe continental climate due to the fact that it is landlocked and a great distance from oceans, surrounded by high mountains and at an elevation of approximately 1,500 m above sea level. Consequently, the main characteristics of the climate are its four distinctive seasons, high fluctuations of temperature, low precipitation and distinct climatic differences across both latitudinal as well as in altitude zones. The annual mean temperature is about -8$^o$C to 6$^o$C and the annual precipitation varies from 50 mm in the Gobi desert to 400 mm in the northern mountainous area. About 85% of the total precipitation falls from April to September. The total greenhouse gas (GHG) emissions in Mongolia are comparatively low, but the per capita rate of GHG emissions is relatively high compared to other developing countries because of the cold continental climate and the long heating season which requires high consumption of fossil fuels for energy using technology with low efficiency of fuel and energy usage.

In the coming century, climate change will probably radically change the traditional way of life that has been established in Mongolia for thousands of years. The effects of climate change will cause considerable damage not only to the ecosystem and natural resources, but also to the economic and social sectors of the country. To help mitigate these effects the Government has established an inter-disciplinary and inter-sectoral National Climate Committee (NCC) led by the Minister of Environment and Green Development, to coordinate and guide national activities and measures aimed to adapt to climate change and mitigate GHG emissions.

## Methods

The long-term trends in climatic data (potential evapotranspiration, evaporation and precipitation data) were determined across 60 meteorological stations from the 1960's to 2008. In addition, vegetation biomass data from fenced areas was collected for the same time period. The climate change impact on pasture biomass was determined by separating the observation data range into 2 time periods; before and after 1990. In addition satellite imagery of Normalized Difference Vegetation Index (NDVI) images to determine changes in vegetation cover were compared across the period 1982 to 2006.

Based on statistical interpretation of the global climate models outputs, the HadCM3 model of the HADLEY centre was determined to be the most suitable for Mongolia to determine likely future climate change scenarios (MARCC 2010). The extent of potential shifts in ecosystems and net primary productivity (NPP) was determined using the results of the HADCM3 model and the CENTURY 4.0 model in order to assess the impact of climate change on the ecosystem in the periods 2011-2030, 2046- 2065 and 2070-2099 (Erdenetsetseg 2012).

Biomass from 37 representative sites across Mongolia covering four major ecosystems was then evaluated using the CENTURY model (ver. 4.0) to determine carbon, nitrogen, phosphorus and sulfur dynamics by simulating incremental scenarios of temperature increases of 1,2,3,4 and 5$^o$C and precipitation changes of -30, -20, -10, 10, 20 and 30%. The dryness index (the ratio of total annual precipitation to the annual potential evapotranspiration) was used to estimate ecosystem changes in the future. The future dryness index can reflect possible vegetation and natural zone shifts in the future.

## Results and Discussions

According to meteorological observation data gathered since the 1940s, the mean air temperature has increased and precipitation has decreased in most areas of Mongolia. The trend analysis of the observation data for the period of 1940 to 2008 shows that the annual mean air temperature of Mongolia increased by 2.14°C. Due to global warming, the frequency of extreme high temperatures has increased, while in contrast, the occurrence of extreme low temperatures has decreased. In term of precipitation, there is an increasing trend of winter precipitation and a decreasing trend of summer rainfall.

Pasture observation data analysis confirms that pasture biomass has dropped by approximately 20-30% and plant biodiversity has decreased in the last 40 years (Bolortsetseg *et al.* 2002). Remote sensing analysis of different satellites revealed that areas without grass (or barren) increased by 46% from 1992 to 2002. In 2006, the barren areas almost tripled, while forest areas decreased by more than 26% during the same period (Khudulmur *et al* 2006). In a linear trend analysis of the Normalized Difference Vegetation Index (NDVI) of NOAA satellite data from 1982 to 2001, the NDVI had either decreased or had not changed in 69% of the total area, and most of the changes that had occurred were observed in forest steppe and steppe (Erdenetuya 2004). Thus, the ground observation and satellite monitoring both confirm pasture degradation in Mongolia.

### *Impacts of climate change*

The HadCM3 model predicted that winters will become milder and snowy, while summers will become hotter and drier even though there will be a slight increase of precipitation based on overall climate change assessment. Changes in annual precipitation will increase driven predominantly by increases in winter precipitation. Summer precipitation received in the June to August period is predicted to decrease by 2-4% in 2011-2030 but increased by 0-4% in 2046-2065 and by 7-11% in 2080-2099. Correspondingly winter precipitation is projected to increase by 0-14% (2011-2030), 14-23 (2046-2065) and by 32-55% (2080-2099). For temperature effect the results of HADCM3 model forecast that the intensity of warming in the summer season is higher than winter with temperature increases estimated to be 1.1-1.4°C during 2011-2030, 2.7-3.6°C for 2046-2065 and 3.7-6.3°C for 2080-2099. Winter temperatures are likely to increase by 0.2-0.7°C (2011-2030), 1.6- 2.5°C (2046-2065) and 3.0-3.8°C (2080-2099) (Dagvadorj 2010).

### *CENTURY modelling*

An impact assessment of climate change on rangeland was conducted, based on the CENTURY 4.0 model results. According to biomass changes, the negative effect of the predicted increase in temperature of more than 3°C was not offset by a 20% increase in precipitation in the forest steppe and the steppe. However, a precipitation increase by 20% would be favourable for pasture production in the Altai Mountains and the desert steppe in Mongolia. The pasture biomass would decrease in almost all areas, especially in the forest steppe and the steppe.

According to net primary production (NPP) of the ecosystems estimated by the CENTURY 4.0 models, the natural zones of Mongolia which are widespread along the horizons, namely gobi desert, desert steppe/semi-desert, steppe, forest steppe and high mountains, from south to north, and these ecosystems will shift to the north especially in the 2080s due to increased temperature and evapotranspiration. The steppe zone is likely to be pushed by the semi-desert zone from the south and will decrease significantly in size. By 2080, forest-steppe and steppe areas will decrease, as a result of a decrease in rainfall and an increase in temperature in the growing season (Dagvadorj 2010).

The results of this suggest that at the current NPP of the taiga forest (>2960g/m$^2$) is expected to increase. This is especially noticeable during the years 2020 to 2050. However, with ongoing changes in temperature, it is predicted that, by 2080 the forest-steppe could become a steppe. But the SRES A2 scenario shows that the rate of warming would be slow and as a result the process of forest-steppe turning into steppe would also be slow.

The steppe zone (current NPP = 131-250g/m$^2$) is likely to be encroached on by the semi desert zone from the south and will decrease significantly. Due to climate warming, the semi-desert zone will push the steppe zone to the north by 2080. By 2080 both forest-steppe and steppe areas will have decreased; this will be caused by an increase in temperature in the growing season (June to September). Even, if the amount of precipitation increases by up to 1.6-2.7 mm, the temperature is likely to increase by 4-7°C which will cause higher evapotranspiration and thus driving these shift in ecosystems.

The area of desert (NPP = 60g/m$^2$) will expand to the north. Although the amount of precipitation is expected to increase in the semi-desert and the desert zone, they are likely to expand; increased temperatures will greatly increase evapotranspiration.

### *Rangeland future changes*

It is a challenge to estimate the future of grassland ecosystems in the long term, for this depends on the following factors: (1) changes in pasture land use; (2) future climate change and extreme conditions such as droughts and hot temperatures; (3) anthropogenic and technology pressures such as population growth, air pollution, use of chemicals to destroy weeds, insects and rodents, and other socio economic issues; and (4) ecosystem changes. In the study of grassland changes, some factors such as grazing intensity, soil erosion and fires were not considered.

Predicted changes to ecosystem biomass and carbon (C) pools for the periods 2011-2030, 2046-2065 and 2080-2099 from the base period 1961-2008 estimated under HadCM3 climate scenario of the HADLEY Centre model under the A1B Green House Gas (GHG) emission scenario are shown in Tables 1, 2 and 3. Here, climate change projection over Mongolia was estimated based on SRES (Special Report on Emission Scenarios 2000) TAR

**Table 1. Results of HadCM3 model by HADLEY centre**

| Period | GHG SRES | Temperature change, $^{o}C$ | | | Precipitation change, % | | |
|---|---|---|---|---|---|---|---|
| | | 2011-2030 | 2046-2065 | 2080-2099 | 2011-2030 | 2046-2065 | 2080-2099 |
| Annual | A2 (high) | 1.0 | 2.7 | 5.0 | 2 | 9 | 15 |
| | A1B (mid) | 0.9 | 3.0 | 4.6 | 0 | 7 | 16 |
| | B1 (low) | 0.8 | 2.1 | 3.1 | 3 | 6 | 11 |
| Winter | A2 | 0.7 | 2.3 | 4.2 | 14 | 19 | 55 |
| | A1B | 0.2 | 2.5 | 3.8 | 0 | 23 | 41 |
| | B1 | 0.2 | 1.6 | 3.0 | 7 | 14 | 32 |
| Summer | A2 | 1.1 | 3.1 | 6.3 | -2 | 4 | 7 |
| | A1B | 1.4 | 3.6 | 5.6 | -4 | 3 | 11 |
| | B1 | 1.2 | 2.7 | 3.7 | 2 | 0 | 8 |

**Table 2. Past, current and future changes in ecosystem biomass and carbon for Mongolian ecosystems**

| Vegetation zones | Aboveground biomass ($g/m^2$) | Change in aboveground biomass (%) | | C | Change in C (%) | |
|---|---|---|---|---|---|---|
| | 1961 - 2008 | 2011-2030 | 2046 - 2065 | 1961 - 2008 | 2011-2030 | 2046 - 2065 |
| High mountains | 13.89 | -17.43 | -22.46 | 2921.99 | -1.02 | -1.78 |
| Forest steppe | 68.22 | -28.41 | -37.45 | 5445.12 | -6.30 | -9.47 |
| Steppe | 38.52 | -22.40 | -31.46 | 3328.60 | -5.76 | -8.40 |
| Desert steppe | 8.93 | -4.30 | -7.36 | 1857.47 | -0.32 | -1.06 |

**Table 3. Changes in potential evapotranspiration (PET) and precipitation (Pr) in future scenarios**

| Vegetation zones | PET | Change in PET (%) | | Precipitation | Change in Precipitation (%) | |
|---|---|---|---|---|---|---|
| | 1961 - 2008 | 2011 - 2030 | 2046 - 2065 | 1961 - 2008 | 2011-2030 | 2046 - 2065 |
| High mountains | 69.80 | 35.76 | 47.66 | 8.17 | -1.34 | -1.91 |
| Forest steppe | 67.75 | 34.70 | 46.46 | 20.25 | -0.79 | -1.90 |
| Steppe | 74.53 | 31.93 | 42.81 | 15.40 | -1.52 | -2.74 |
| Desert steppe | 94.00 | 24.98 | 38.09 | 7.10 | 4.09 | 3.94 |

IPCC (MARCC 2010). The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, resulting in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other scenarios. The A1B scenario describes a technological change in the energy system. A1B is defined as not relying too heavily on one particular energy source, based on the assumption that similar improvement rates apply to all energy supply and end use technologies balance one another. The B1 scenario describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1scenario, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives (IPCC Special Report on Emission Scenarios 2000).

## Conclusions

The intensity of warming in the summer season is higher than winter and the amounts are 1.1-1.4$^{o}$C in 2011-2030, 2.7-3.6$^{o}$C in 2046-2065 and 3.7-6.3$^{o}$C in 2080-2099. Winter temperatures will increase by 0.2-0.7$^{o}$C, 1.6-2.5$^{o}$C and 3.0-3.8$^{o}$C in the corresponding periods. Precipitation in the summer season is predicted to increase by less than 10%, which is smaller than the winter precipitation rise compared to their normal climate. The summer precipitation will have decreased by 2-4% in 2011-2030, increased by 0-4% in 2046-2065 and 7-11% in 2080-2099. The winter precipitation is projected to increase by 0-14% (2011-2030), 14-23% (2046-2065) and 32-55%, (2080-2099). Biomass changes during the periods 2011-2030, 2046-2065 and 2080-2099 from the base period 1961-2008 were estimated under HadCM3 climate scenario of HADLEY centre and A1B emission scenario, and for most areas the biomass tended to decrease.

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