

Reconstruction and prediction of climate and vegetation change in the Holocene in the Altai-Sayan Mts, central Asia



Fig. 1 The Altai-Sayan Mts (yellow) on the background of the Eurasian continent.

Study area is the Altai-Sayan ecoregion located in central Asia mainly in Russia (the northern half) and Mongolia (the southern part), with small areas in Kazakhstan and China. The elevation range is up to 4000 m, with the highest point Mount Belukha (4506 m) in the central Altai. Mountains are a good study area for monitoring and modeling vegetation changes in both past and future climates because various landscapes are located across a rather small area where ecosystems are very sensitive to environmental change.

Methods. We used our bioclimatic montane vegetation model, MontBioClim, for predicting vegetation belts (orbiomes) across the Altai-Sayan Mts. Our model is an "envelope-type" model that determines a unique orbiome (unique climatic limits for an orbiome) from three bioclimatic indices: GDD_c, representing plant requirements for warmth, GDD_c, representing plant tolerance to cold, and the annual moisture index (AMI) representing plant tolerance to water stress.

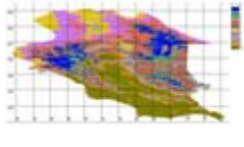


Fig. 2. Vegetation distribution in the Altai-Sayan Mts in the current climate resulted from coupling our MontBioClim with maps of bioclimatic indices driving the model.

Vegetation key: 1 – Tundra, 2 – Subalpine dark-leaf and meadow, 3 – Subgolets light-leaf, 4 – montane darkleaf, 5 – montane lightleaf, 6 – Subtaiga and forest-steppe, 7 - "chern", 8 - Steppe, 9 – Dry Steppe, 10 – Semidesert/Desert

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Goals:

- reconstruct paleoclimate and vegetation across the Altai-Sayan ecoregion during the Holocene (since 10000 to the present) using fossil pollen data and our regional bioclimatic model, MontBioClim;
- predict a future vegetation pattern by the end of the 21st century using climate change projections of the Hadley centre and MontBioClim;
- compare all vegetation maps predicted for the past, present, and future in order to identify analogs between them if available

Methods

Contemporary layers of bioclimatic indices (GDD_c, GDD_c, and AMI) were mapped for current climate on DEM (Fig. 3 A) of the 1 km grid using Hutchinson's (2000) thin plate splines based on data of 180 weather stations with temperature data and 380 weather stations with precipitation data over the region (Fig.3 B,C, D). Climatic layers of January and July temperatures and annual precipitation for each pixel were calculated for each time slice by adding corresponding climate anomalies from the climate change scenarios to the baseline climate (Fig.3)

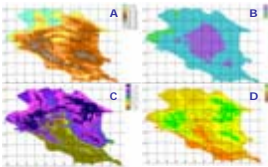


Fig.3. DEM (A) and layers of climatic indices: GDD_c(B), AMI (C), and GDD_c(D) in the Altai-Sayan Mts

Climatic anomalies The past climate change scenarios were constructed by comparing current and reconstructed climates.

We inversely used MontBioClim to predict paleoclimates (growing degree days and annual precipitation) from each reconstructed orbiome in a paleo time. The past vegetation was reconstructed from fossil data in 10 sites (e.g. Fig.4) for 3200 B.P. (the SubBoreal), 5300 B.P. (the mid-Holocene), 8 000 B.P. (the Boreal), and 10 000 B.P. (the PreBoreal). For the 21st century, 2020, 2050, and 2080, climatic anomalies were derived from two climate change scenarios the HadCM3 A1FI and B1 of the Hadley Centre in the U.K. based on the Special Report on Emission Scenarios (SRES). These scenarios reflect opposite ends of the SRES range, the largest temperature increase from the A1FI scenario and the smallest temperature increase from the B1 scenario.

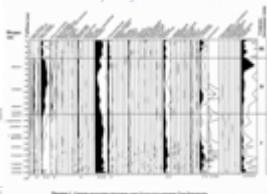


Fig.4. Pollen percentage diagram of the Grusha Lake record, in Tuva, the Altai-Sayan Mts

Pollen-based vegetation reconstruction

To simulate paleovegetation from pollen data, we used the method of Prentice, et al. (1996), the "biomization" of pollen data. We designed a "biome x taxon" matrix indicating which pollen taxa may occur in each biome: "1" was assigned to an orbiome if the taxon may occur and "0" was assigned if it may not. Our "biome x taxon" matrix included 10 orbiomes and 20 dominant taxa identified in surface spectra. An affinity score was calculated for all pollen samples according to the formula of Prentice et al. (1996), and each pollen sample was "biomized" according to its maximal affinity score.

Using the constructed "biome x taxon" matrix, each paleo orbiome was then simulated from a pollen spectrum for 3200, 5300, 8000, 10000 B.P. in ten sites across the Russian part of the Altai-Sayans (an example in Fig. 4). Then, MontBioClim was inversely used to predict average climatic indices for each orbiome in each paleo time of the Holocene.

Coupling four paleoclimates in 3200, 5300, 8000, and 10000 B.P. with MontBioClim, we reconstructed and mapped vegetation over the Altai-Sayan ecoregion for the major Holocene periods correspondingly: the present, SubBoreal, Late Atlantic, Boreal, and PreBoreal (Fig.5).

Methods. Kappa statistics were used to compare the maps. The kappa statistic is an index which compares the agreement against that which may be expected by chance. Possible values range from 1 perfect agreement, 0 no agreement, -1 complete disagreement (Landis and Koch 1977).

Table 1. Kappa statistics showing agreement between the montane vegetation over the Altai-Sayan Mts during the Holocene

TIME SLICE	TIME SLICE										
	2080 BI	2080 A1FI	2050 BI	2050 A1FI	2020 BI	2020 A1FI	0	-3200	-5300	-8000	-10000
2080 BI	1.0										
2080 A1FI	0.4	1.0									
2050 BI	0.77	0.29	1.0								
2050 A1FI	0.86	0.47	0.65	1.0							
2020 BI	0.48	0.23	0.62	0.4	1.0						
2020 A1FI	0.41	0.19	0.56	0.32	0.85	1.0					
0	0.13	0.13	0.17	0.13	0.29	0.35	1.0				
-3200	0.24	0.26	0.22	0.28	0.25	0.22	0.22	1.0			
-5300	0.08	-0.08	0.13	0.04	0.06	0.08	0.04	-0.03	1.0		
-8000	0.11	-0.05	0.17	0.07	0.1	0.12	0.1	-0.01	0.8	1.0	
-10000	0.21	0.22	0.22	0.21	0.24	0.24	0.27	0.62	-0.02	0.0	1.0

The agreement is "very good" (kappa >0.7), "good" (k= 0.65-0.7), "fair" (k= 0.4-0.55), and "poor" (k<0.4). Red is 'very good' match, yellow is good, pink is fair, black is poor.

Results. The vegetation distribution in the PreBoreal and SubBoreal phases was similar (Table1) with kappa $\kappa = 0.82$, because the climate was both cooler and dryer especially in the PreBoreal. During those times, cold tundra and subgolets (open light-needed taiga) and dry steppe and semidesert increased in area (Fig. 5). Boreal and mid-Holocene vegetation was similar ($\kappa = 0.80$), in a warmer and wetter climate compared to the present. During this phase, between 8000-5300 B.P., there were climatic conditions favorable for dark-needed taiga including "chern" taiga and subtaiga. Cold orbiomes like tundra disappeared, and subalpine-subgolets open forests substantially decreased. Boreal steppe shrank, and climates became more suitable for temperate steppe, forest-steppe, and new habitats for temperate broadleaved mixed forests (with linden) arose (Fig. 5). The Holocene vegetation distribution across the Altai-Sayan region was not similar to current vegetation distribution: kappa statistics varied between 0 and 0.27.

The climate in the 21st century as predicted from GCMs will be warm and dry which would cause a decrease in forests, a disappearance of tundra, and an increase of forest-steppe, steppe and semidesert. Refuges for broadleaved forests like a 5000 ha linden "inland" in the foothills of Kuznetskii Altai may significantly extend by the end of the century and new temperate habitats may arise.

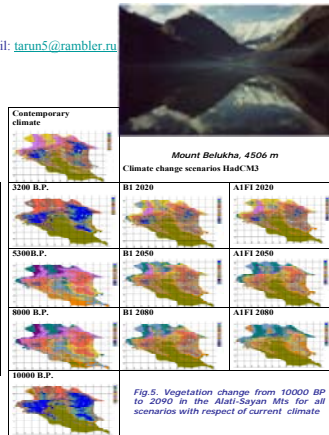


Fig.5. Vegetation change from 10000 BP to 2090 in the Altai-Sayan Mts for all scenarios with respect of current climate

Conclusion.

Paired intercomparison between all simulated vegetation maps for eight time slices (2080, 2050, 2020 A.D., the present, 3200, 5300, 8000, and 10000 B.P.) during the Holocene showed that no analogs between future and paleo vegetation distribution in the Altai-Sayan Mts were found. However, in literature the mid-Holocene was suggested as an analog of the current mid-21st century climate. Climates 5300-8000 B.P. were warmer and wetter compared to warm and dry climates across the 21st century resulted from general circulation model projections.

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