Phytomass change in the mountain forests of southern Siberia under climate warming

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Abstract.

Introduction: Mitigation of climate warming is related to carbon sequestration in vegetation phytomass. The diverse mountain forests of Southern Siberia represent an important part of the boreal forest zone. Because vegetation types are often stratified by relatively narrow elevation bands in mountains, vegetation change due to tree migration can occur more rapidly than in the plains.

Methods: Our goal is to evaluate current phytomass stores and their change under climate warming in the mountain forests of southern Siberia (specifically, the area bounded by 89-94^{o}E longitude and 51-56^{o}N latitude). We develop a mountain vegetation model that predicts a vegetation type based on two climatic indices: Temperature Sums above 5^{o}C (TS_5) and Dryness Index. Phytomass for each vegetation type is calculated as a product of phytomass density and land area. Phytomass density is assigned from the literature. The area of a vegetation type under both current and future climate is calculated by the vegetation model using the spatial distribution of climatic indices over the terrain. Current climatic indices were calculated by coupling a digital elevation model (1 km^2 pixel size) and climatic submodels relating climatic weather station parameters to latitude, longitude, and elevation. Future climatic indices were recalculated according to a climate change scenario with a summer temperature increase of 2^{o}C and an annual precipitation increase of 20%.

Results: In the mountains of southern Siberia, climate warming accompanied by increasing precipitation is expected to create a favorable environment for vegetation to capture more carbon from the atmosphere. Forest ecosystems would expand at the expense of adjacent treeless or sparsely forested ecosystems: into grasslands in the lowlands due to additional moisture, and into subalpine highlands due to additional warmth. Under the climate-warming scenario, one quarter of the area would change from one vegetation belt to another, with total phytomass increasing by 342 Mt (17%). The increase is mainly due to an 86% expansion of the productive and floristically rich chern taiga, which is dominated by the shade-tolerant *Abies sibirica* and *Pinus sibirica*.

INTRODUCTION

Evidence for global warming over the past 200 years is overwhelming (Hulme et al. 1999), based on both direct weather observation and indirect physical and biological indicators such as retreating glaciers and snow/ice cover, increasing sea level, and longer growing seasons (IPCC 2001). A global assessment by the Intergovernmental Panel on Climate-Change (IPCC) found that future global warming could occur at a rate of 0.1°C to 0.4 °C per decade (Houghton et al. 1996; Watson et al. 1996). This rapid rate of change outstrips the ability of all but pioneer species to migrate to suitable new environments. Under the third assessment of IPCC, these estimates are being revised upward (IPCC 2001). Such a dramatic climate warming is anticipated to strongly impact the boreal forest and induce restructuring processes at all hierarchical levels, from forest zones down to ecosystems (Smith et al. 1992; Monserud et al. 1993; Guisan et al. 1996).

Because boreal forests are a huge carbon sink (Isaev et al. 1993; Kolchugina and Vinson 1993; Birdsey and Alexeyev, 1998), they will play a key role in determining the resulting carbon flux and its direction. However, we do not know even the sign of this flux, to say nothing of its total amount (Schulze et al. 1999). This brings up the necessity to determine whether the feedback will work and whether additional carbon will bind with living vegetation phytomass in terrestrial ecosystems, in particular, in the boreal forest.

Our goal is to estimate current phytomass stored in vegetation over mountains of southern Siberia and its change induced by climate warming. We assume that mountain vegetation redistribution due to tree migration will look quite realistic for 50 years because migration across mountains takes place over distances much shorter than across vast plains.

METHODS

We concentrate on the mountains of southern Siberia. Our study area is the Sayan Mountains and Kuznetsky Alatau, bounded by 89-94 °E longitude and 51-56 °N latitude. Climatic interpolating functions were derived using a network of 60 weather stations and a digital elevation model of 1 km resolution (GLOBE 1999). Major climatic parameters (mean minimum and maximum temperature; annual precipitation; cloudiness; vapor pressure deficit) were then interpolated across this surface using a 1 km^2 pixel size.

We then applied a bioclimatic model of southern Siberian mountain vegetation (Monserud and Tchebakova 1996; Tchebakova and Parfenova 2000) for predicting phytomass changes under climate warming. The model describes a vegetation type (a vegetation altitudinal belt) from two bioclimatic parameters: temperature sums (TS_5) and Budyko's (1974) dryness index (Monserud and Tchebakova 1996). To calculate TS_5 used in Russian literature, all positive (>0°C) temperatures for the period with daily temperature above 5°C are summed. This is almost identical to (and highly correlated with) the western concept of growing degree days (GDD_5), which is the sum of temperatures above the 5°C base rather than 0°C (Tchebakova et al. 1994). Budyko's dryness index is based on annual radiation balance and annual precipitation, and is a ratio of annual potential evaporation to annual precipitation (Tchebakova et al. 1994; Monserud and Tchebakova 1996). Sadovnichaya and Tchebakova (1978) first observed that dryness index--but not precipitation--could separate major biome subdivisions (e.g., dark-needled from light-needled Taiga) in the Sayan Mountains.

Eight main vegetation belts are recognized by geobotanists for the mountains of southern Siberia, beginning at the highest elevation belt:

mountain tundra (lichens, mosses, *Rhododendron, Betula rotundifolia*)
subalpine mountain taiga (cold and wet), (*Pinus sibirica* and *Abies sibirica,* including wet subalpine meadows)
subgolets sparse mountain taiga (cold and dry; both dark- and light-needled open taiga)
dark-needled mountain taiga (dominated by *Pinus sibirica* and *Abies sibirica*)
light-needled mountain taiga (dominated by *Larix sibirica* and *Pinus sylvestris*)
dark-needled chern taiga (floristically rich and productive warm taiga mixed with *Populus tremula*),
subtaiga/forest-steppe (*Pinus sylvestris, Larix sibirica* and *Betula pendula*)
steppe and dry steppe (*Caragana, Spirea, Cotoneaster, Stipa, Fescuta, Koellria*)

Climatic limits determining elevation belts across the mountains in southern Siberia are given in Table 1. We also found that the climatic limits of analogous vegetation zones on the plains (Tchebakova et al. 1994) and altitudinal belts in the mountains practically coincide, with differences ranging within ±50 ^{o}C for TS_5 and ±0.2 for DI (Table 1).

Phytomass for each altitudinal vegetation belt was estimated as the product of average phytomass density and the area of a given belt. Phytomass included trees (boles, branches, foliage, and roots) and understory vegetation (shrubs, ground cover); soil organic matter was not estimated. In the absence of sufficient phytomass data in the mountains of southern Siberia, we assumed that phytomass density for a altitudinal belt to be the same as that of an analogous zone in the plains when their climatic limits were similar (Table 1). Average belt phytomass density was assigned from Monserud et al. (1996), which they compiled for vegetation zones based primarily on the data of Bazilevich (1993). Phytomass density of chern taiga was calculated from the data of Polikarpov et al. (1986) and that of Bazilevich (1993) for European conifer-broadleaf forests (Table 2).

Our climate change scenario is an average of temperature and precipitation changes from six GCM's (Watson et al. 1996). This produced a climate change scenario with a summer temperature increase of 2^{o}C and an annual precipitation increase of 20%. This is rather conservative, for the Special Report on Emissions Scenarios used by the IPCC indicate winter warming of 2 to 5 ^{o}C in 50 years for these locations in southern Siberia, depending on scenario assumptions (Hulme and Sheard 1999). Hulme and Sheard (1999) also predict an annual temperature increase of 4-6 ^{o}C for non-Arctic Russia by 2050.

RESULTS

Area

To begin, our Sayan Mountain study area comprises 205.3 x 10^3 km^2 (Table2). Under current climate, the vegetation belt with the largest area is subtaiga/forest-steppe, over 40% of the area. Dark-needled taiga and chern taiga together cover a quarter of the area, and steppe/dry steppe cover 18%. The remaining belts are relatively minor, with mountain tundra the largest at 6%.

Under our climate change scenario, three vegetation belts increase in area: chern taiga nearly doubles, to an 86% increase. Increases for the other two expanding belts are considerably smaller: light-needled taiga increases 1.6 x 10^3 km^2 (+29%), and subtaiga/forest-steppe increases 3.3 x 10^3 km^2 (+4%).

The remaining belts all decrease in area (Table 2). The largest decrease is for dark-needled taiga, a loss of 10.4 x 10^3 km^2 (-47%), followed by mountain tundra, a loss of 6.8 x 10^3 km^2 (-51%). Area shrinkage for the remaining belts was rather large on a percentage basis, ranging from –15% for steppe to –38% for subalpine taiga.

Phytomass

Generally, phytomass density of these mountain vegetation belts fell into two groups (Table 2): the high density (100-200 t ha^{-1}) of the forest forming belts (dark-needled taiga, chern taiga, light-needled taiga, and subtaiga/forest-steppe), and the low density (15-26 t ha^{-1}) vegetation of steppe and the open and sparse high elevation belts (mountain tundra, subalpine mountain taiga, subgolets sparse mountain taiga).

Under current climate, the greatest concentration of phytomass (91%) is in three of these high density forest belts: subtaiga/forest-steppe (982 Mt; Mt=10^6 tons), chern taiga (546 Mt), and dark-needled taiga (319 Mt). Nearly half of the phytomass in the Sayan Mountain system is in the subtaiga/forest-steppe belt. The remaining belts either have low phytomass density, small area, or both. Steppe is the largest of these, 55 Mt.

Under climate change, the Sayan Mountain complex is predicted to have a net increase of 342 Mt of phytomass, a 17% increase. By far the largest increase is for chern taiga, an increase of 467 Mt. This is an 86% increase, and largely comes at the expense of an adjacent and closely related belt, dark-needled taiga (a loss of 149 Mt). The next largest change is for subtaiga/forest-steppe, an increase of 39 Mt (+4%).

Table 3 documents the change for the future climate scenario for each vegetation belt, by area. Large shifts are apparent for all vegetation belts (26% of the total area), indicating a broad redistribution of vegetation across this mountainous landscape. The only belt that retains all of its current-climate area is chern taiga, which expands greatly into neighboring forested vegetation belts. Clearly, the increase in temperature and precipitation hypothesized for this climate change scenario is quite favorable to the development of chern taiga, the belt with the largest phytomass density.

DISCUSSION

Under current climatic conditions, subtaiga forests and forest-steppe predominate in the Achinsk-Krasnoyarsk basin and on the foothills of the Sayan Mountains. Together they account for about half of the total vegetation phytomass in the study area. Low to middle elevations in the mountains are dominated by dark-needled forests, half of which are chern taiga. More than 40% of the total phytomass is in dark-needled forests, even though these vegetation belts cover only one quarter of the region's area. Each of the remaining vegetation belts account for only 1-3% of the total phytomass.

Under our climate change scenario (2^oC climate warming and increasing precipitation), the total phytomass of the region is predicted to increase by 342 Mt, an increase of 17% (Table 2). This translates into an average increase of some 2 kg m^2. Chern forests are anticipated to become the major contributor to phytomass accumulation, since the warmer climate will be most favorable for these highly productive forests. The contribution of light-needled taiga and forest-steppe is predicted to be small but positive, and should compensate for phytomass lost from both high elevation belts and steppe. These high elevation vegetation belts (mountain tundra, subalpine taiga and subgolets, and mountain steppe) are all predicted to decrease in area and phytomass under climate change. Dark-needled mountain taiga forests decrease their area by half, and constitute the largest loss in phytomass of any of the vegetation belts. However, this land will be converted to chern taiga, the most productive and highest density vegetation belt (Table 3).

In Table 3 we analyze the restructuring of the vegetation belts under climate change by tracking the change in area from one belt to another. Main diagonal elements of Table 3 indicate no change in the specified area of a given vegetation belt; this is 74% of the area. Off-diagonal elements all indicate a change from the belt listed in the vertical column (current climate) to the belt listed on the horizontal row (future climate). Additional heat and moisture will promote phytomass increment as follows. Treeless ecosystems will be encroached upon by forest. Subalpine taiga and subgolets open forests, for example, would expand to cover 50% of today's tundra, while light-needled forests and subtaiga would expand to cover almost 20% of today's rather large steppe area. The present forest ecosystems would be replaced by higher productivity forests. For example, closed taiga forests will replace 70-75% of the current open woodlands. The productive chern forests will replace three fourths of dark-needled taiga and even 8% of subtaiga (Table 3). While over 50% of today's light-needled ecosystems will be replaced by subtaiga, their phytomass will remain almost the same, because both ecosystems have similar phytomass densities. The net effect of all of these changes would result in a significant phytomass increase for the region.

Phytomass distribution across the mountains of southern Siberia demonstrates that most productive forest ecosystems occur in mountains (Fig.1a), on the background of the steppe and forest-steppe zonal vegetation at lower elevations. Forest ecosystems are represented by dark-needled taiga and chern taiga with phytomass density about 150 t/ha and 200 t/ha, respectively (Table 2). Dark-needled taiga is dominated by the shade-tolerant *Pinus sibirica* and *Abies sibirica,* and covers the windward slopes of the Kuznetsk Alatau and the western and eastern Sayan Mountains (Monserud and Tchebakova 1996). Shade intolerant light-needled taiga (dominated by *Larix sibirica* and *Pinus sylvestris*) is found on the drier leeward slopes of these mountains.

Because vegetation will remain the same as today on 74% of the total area, much of the phytomass density distribution across the area will remain the same as under current climate (see "Unchanged" category in Fig.1b). For example, 100% of chern forests, 92% of subtaiga and forest-steppe, and 81% of steppe would remain at their current locations. The greatest relative increase in phytomass density is anticipated in two distinctly different environments: at high elevations on windward slopes, with the replacement of subalpine taiga by mountain taiga; and at lower elevation on leeward slopes, where steppe would be replaced by subtaiga/forest steppe. Although these changes are large on a relative scale, they involve fairly small areas and therefore would not to impact the total phytomass balance significantly. The largest phytomass increase will be induced by the replacement of dark-needled taiga by chern taiga because this replacement is expected to occur on a vast area (17 x 10^3 km^2) and difference between phytomass densities of these ecosystems is fairly large, over 50 t ha^{-1}.

Clearly, the mountains of southern Siberia will increase in productivity under this climate change scenario. This would be associated with a greater opportunity to sequester carbon. However, elevated temperatures under this future climate scenario could increase ecosystem respiration. Respiratory losses should be taken into account to evaluate the carbon balance of these boreal forests before an accurate estimate of carbon sequestration can be made (Schulze et al. 1999).

Finally, to try to put these large numbers into perspective, we make a novel comparison between the carbon extracted from coal and the carbon stored as phytomass for the same area and period. Southern Siberia is remarkable for containing two of the world's seven greatest coal basins: the Kuzbass basin (9 $x10^{11}$ tons) and the Kansk-Achinsk basin (5 $x10^{11}$ tons of coal reserves). The Kansk-Achinsk basin is located in our southern Siberian study area. During 1960-1990, Ivanov et al. (1994) estimate that about 125 Mt of carbon was excavated (C content of this coal is 70%). Assuming the same rate of coal excavation for the next 50 years (4.2 Mt yr^{-1}) predicted for the climate to warm, we estimate $2.1*10^8$ tons of carbon would be excavated from coal in this territory. From Table 2, we estimate 10 $x10^8$ tons of carbon accumulated in current living phytomass across this territory (assuming 50% C content). By comparison, we predict vegetation around this territory would be able to sequester $12*10^8$ tons of carbon after 50 years by means of only belt redistribution under this climate warming. Furthermore, the net increase in carbon from phytomass due to climate change is 1.7 $x10^8$ tons, which is very close to the $2.1*10^8$ tons of carbon that would be excavated from this major coal basin at the historic rate for the same period.

CONCLUSION

In the mountains of southern Siberia, climate warming accompanied by increasing precipitation is expected to create a favorable environment for vegetation to capture more carbon from the atmosphere. Forest ecosystems would expand at the expense of adjacent treeless ecosystems: into grasslands in the lowlands due to additional moisture, and into subalpine highlands due to additional warmth. Most favorable climates will occur on windward northerly and westerly slopes where the productive and floristically rich chern forests are predicted to nearly double in area. In these mountains, total phytomass under global warming is estimated to increase by 342 million tons, approximately 171 million tons of carbon.

REFERENCES

Bazilevich, N.I., Biological productivity of ecosystems of northern Eurasia, Nauka Press, Moscow, 296 pp., (in Russian), 1993.

Birdsey R.A. and Alexeyev V.A. (Eds.) 1998. Carbon storage in forests and peatlands of Russia. USDA Forest Service. Northeastern Research Station. General Technical Report NE-244. 137 pp.

Budyko, M. I. 1974. Climate and Life. Academic Press, New York. 508 pp.

GLOBE Task Team (Hastings, D.A., P.K. Dunbar, G.M. Elphingstone, M. Bootz, H. Murakami, H. Maruyama, H. Masaharu, P. Holland, J. Payne, N.A. Bryant, T.L. Logan, J.-P. Muller, G. Schreier, and J.S. MacDonald, eds.). 1999. *The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0.* National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder, Colorado 80303, U.S.A. Digital data base on the World Wide Web (URL: http://www.ngdc.noaa.gov/seg/topo/globe.shtml).

Guisan A., Holten J.I., Spichiger R., Tessier L. (Eds.). 1995. Potential Ecological Impacts of Climate Change in the Alps and Fennoscandian Mountains. Geneve. 195 p.

Houghton, J.J.; Meiro Fiiho, L.G.; Callander, B.A. [and others], eds. 1996. Climate-change 1995: the science of climate-change. Contribution of Working Group I to the second assessment report of the

Intergovernmental Panel on Climate-Change. Cambridge, England: Cambridge University Press. 584 p.

Hulme, M.and Sheard, N. 1999. Climate change scenarios for the Russian Federation. Climatic Research Unit, Norwich, UK. 6 p.

Hulme, M., Sheard, N., and Markham, A. 1999. Global climate change scenarios. Climatic Research Unit, Norwich, UK. 6 p.

IPCC (Intergovernmental Panel on Climate Change). 2001. Climate Change 2001: The Scientific Basis. Working Group I contribution to the IPCC Third Assessment Report. (URL: http://www.ipcc.ch/).

Isaev A.S., Korovin G.N., Utkin A.I., Pryajnikov A.A., and Zamolodchikov D.G. 1993. Carbon pool evaluation in phytomass of forest ecosystems of Russia. *Russian J. Forest Science* 5: 3-10 (in Russian).

Ivanov V.I., Isaev A.S., Maltsev Y.M. and Semenov V.N. (Eds). 1994. Atlas of Krasnoyarsk Territory and Republic of Khakasia. Novosibirsk. Roskartografia. 84 pp.

Kolchugina T. and Vinson T. 1993. Carbon sources and sinks in forest biomes of the former Soviet Union. *Global Biogeochemical Cycles* 7 (2): 291-304.

Monserud R.A., Tchebakova N.M., and Leemans R. 1993. Global vegetation change predicted by the modified Budyko model. *Climatic Change* 25: 59-83.

Monserud R.A., Tchebakova N.M., Kolchugina T.P., Denisenko O.V. 1996. Change in Siberian phytomass predicted for global warming. *Silva Fennica* 30(2-3):185-200.

Monserud R.A. and N.M. Tchebakova. 1996. A vegetation model for the Sayan Mountains, Southern Siberia. *Canadian Journal of Forest Research* 26: 1055-1068.

Polikarpov, N.P., N.M. Tchebakova, and D.I. Nazimova, *Climate and Montane Forests in Southern Siberia*, Nauka Press, Novosibirsk, 225 pp., (In Russian), 1986.

Sadovnichaya, E. A. and Tchebakova, N. M. 1978. Radiation factors of altitudinal zonality in the West Sayan Mountains. *In* Polikarpov, N. P. (*Editor*). Multidisciplinary forestry research in Siberia. Institute of Forest and Wood, Siberian Division, USSR Academy of Sciences, Krasnoyarsk. pp. 6-19. (In Russian).

Schulze E.-D., J. Lloyd, F.M. Kelliher, C. Wirth, C. Rebmann, B. Lueker, M. Mund, A. Knohl, I. Milyukova, W. Schulze, W. Ziegler, A. Varlagin, A. Sogachev, R. Valemtitni, S. Dore, S. Grigoriev, O. Kolle, M. Panferov, N. Tchebakova, and N.N. Vygodskaya. 1999. Productivity of forests in the Eurosiberian boreal region and their potential to act as a carbon sink - a synthesis. *Global Change Biology* 5:703-722.

Smith T.M., Weishampel J.F., Shugart H.H. 1992. The responce of terrestrial C storage to climate change modeling C dynamics at varying spacial scales. *Water, Air, and Soil pollution* 64: 307-326.

Tchebakova, N.M., Monserud, R.A., and Nazimova, D.I. 1994. A Siberian vegetation model based on climatic parameters. *Can. J. For. Res.* 24: 1597-1607.

Tchebakova N.M. and Parfenova Y.I. 2000. Vegetation belts redistribution under global warming across the Lake Baikal basin. *Geography and natural resources* 2: 64-68 (in Russian).

Watson, R.T., Zinyowera, M.C. and Moss, R.H. (Eds). 1996. Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific- Technical Analyses. Contribution of Working Group II to the second assessment report of the Intergovernmental Panel on Climate-Change. Cambridge Univ. Press. 800 ð.

Table 1. Comparison of climatic limits for vegetation zones in the plains of Siberia (Tchebakova et al. 1994) and elevation belts in the mountains of southern Siberia.

Vegetation Zone (Plains)	Climatic limits for zones (Plains)		Elevation belt (Mountains)	Climatic limits for belts (Mountains)	
	Temperature sums, base 5°C	Dryness Index		Temperature sums, Base 5°C	Dryness Index
Tundra	< 700	-	Mountain Tundra	< 700	-
Forest-Tundra	700-1100	< 2.0	Subalpine-Subgolets sparse forest	700-1150	< 2.2
Northern, middle, and southern dark-needled taiga	1100-1950	< 1.1	Mountain dark-needled and chern taiga	1150-1900	<1.0
Northern, middle, and southern light-needled taiga	1100-1950	1.1-2.0	Mountain light-needled taiga	1150-1900	1.0-2.2
Light-needled subtaiga and forest-steppe	1950-2250	1.1-2.0	Mountain light-needled subtaiga and forest-steppe	1900-2300	1.0-2.2
Steppe	> 2250	> 2.0	Mountain steppe	> 2300	> 2.2

Table 2. Area (10^3 km^2), percentage of current climate area, and phytomass (Mt=10^6 t) of mountain vegetation belts under current and future climates.

Vegetation belt	**Area under current climate**		**Change in Area under climate change**		**Phytomass density**	**Phytomass under current climate**	**Change in Phytomass under climate change**
	(10^3 km^2)	(% of Total)	(10^3 km^2)	(% of Belt)	(t ha^{-1})	(10^6 t)	(10^6 t)
Mountain Tundra	13.2	6.4	-6.8	-51.5	18.0	24	-12
Subalpine taiga	8.9	4.3	-3.4	-38.2	26.3	23	-9
Subgolets taiga	7.1	3.5	-1.5	-21.1	26.3	19	-4
Dark-needled taiga	22.3	10.9	-10.4	-46.6	143.0	319	-149
Chern taiga	27.7	13.5	23.7	85.6	197.0	546	467
Light-needled taiga	5.6	2.7	1.6	28.6	113.0	63	18
Subtaiga/forest-steppe	82.7	40.3	3.3	4.0	118.7	982	39
Steppe	34.5	16.8	-5.1	-14.8	15.3	53	-8
Dry steppe	3.3	1.6	-1.4	-42.4	6.0	2	-1
Total	205.3	100.0	0.0	0.0	-	2030	342

Table 3. Percentage change in vegetation area under climate change (10^3 km^2). Main diagonal elements of Table 3 indicate no change in the specified area of a given vegetation belt. Off-diagonal elements all indicate a change from the belt listed in the vertical column (current climate) to the belt listed on the horizontal row (future climate).

Vegetation Belt	**Current climate** (10^3 km^2)									**Total Area under Future climate** (10^3 km^2)
	Mountain Tundra	Subalpine taiga	Subgolets taiga	Dark-needled taiga	Chern taiga	Light-needled taiga	Subtaiga/ Forest-steppe	Steppe	Dry Steppe	
Mountain Tundra	6.5									6.5
Subalpine taiga	3.4	2.1								5.5
Subgolets taiga	3.3		2.3							5.6
Dark-needled taiga		6.8		5.1						11.9
Chern taiga				17.2	27.7	0.3	6.2			51.4
Light-needled taiga			4.8			2.2		0.2		7.2
Subtaiga/Forest-steppe						3.1	76.5	6.3		85.9
Steppe								28.0	1.4	29.4
Dry Steppe									1.9	1.9
Total Area under Current climate	13.2	8.9	7.1	22.3	27.7	5.6	82.7	34.5	3.3	205.3

Fig. 1. Phytomass distribution under current climate (a) and its change under a new climate (b) over the mountains of southern Siberia, t/ha