Seed zones for *Pinus sylvestris* and *Larix sibirica* to mitigate effects of a drying climate in steppes of southern Siberia

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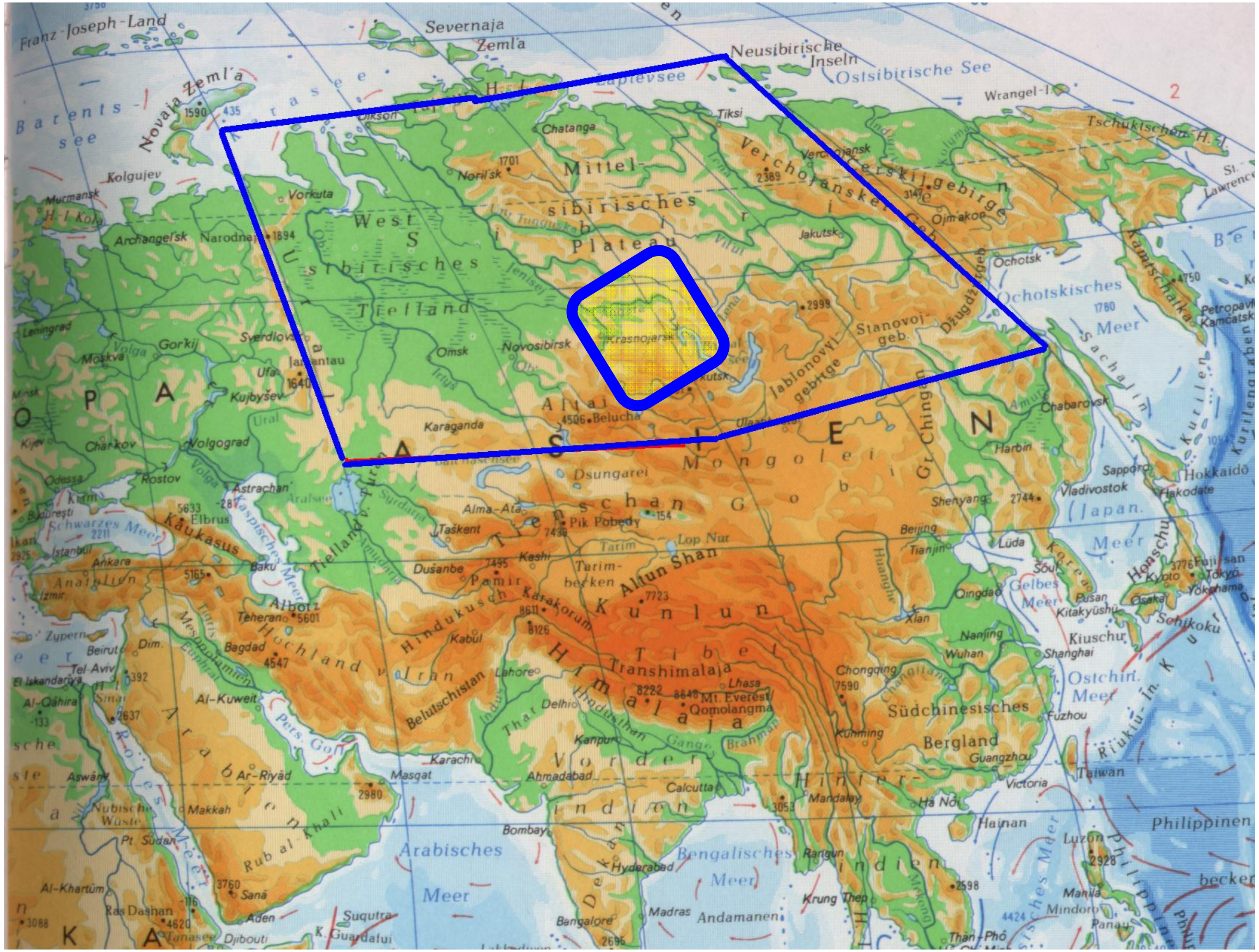
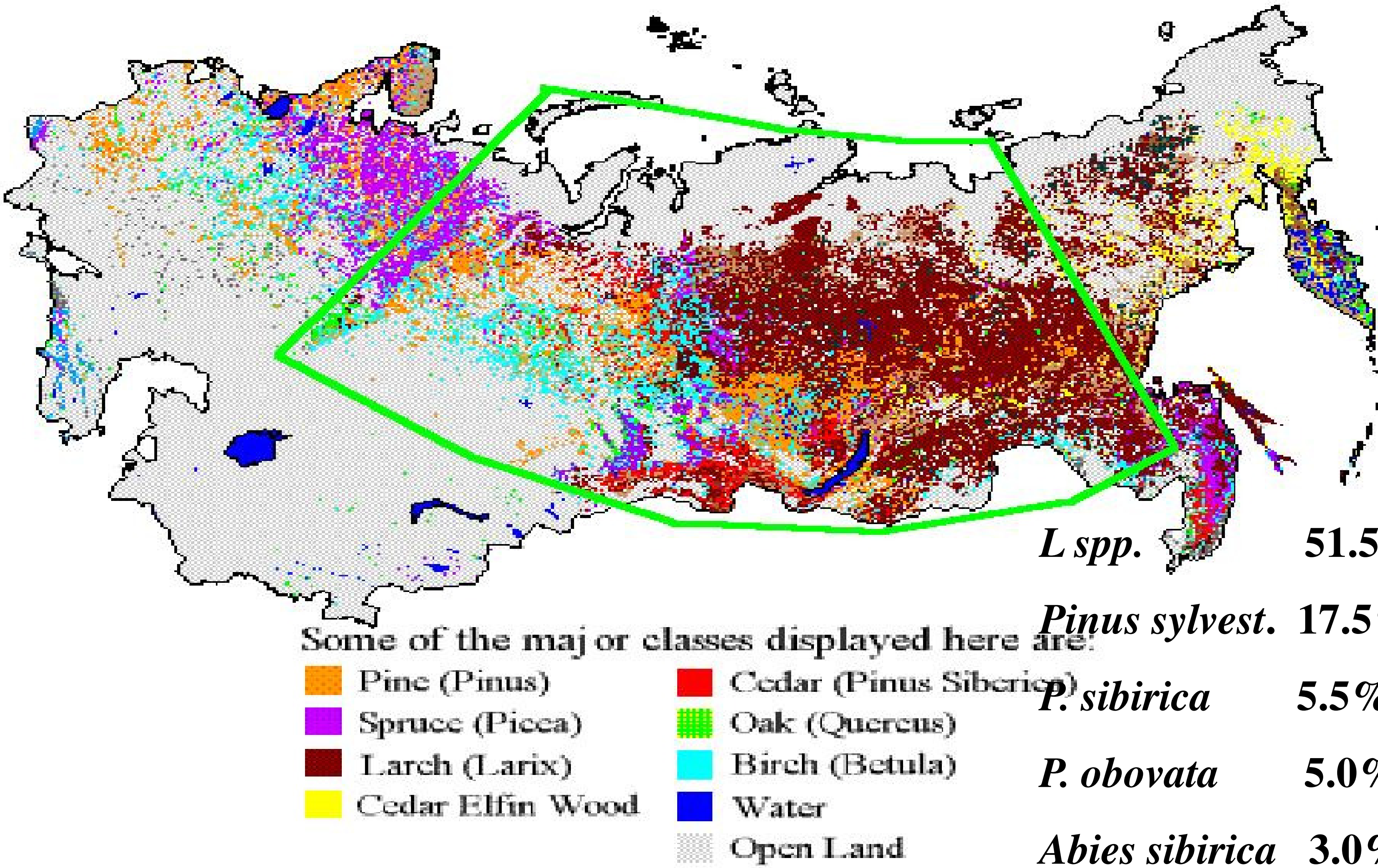
Study Area



1990 Forest Cover Map of the Former Soviet Union



L spp.	**51.5%**
Pinus sylvest.	**17.5%**
P. sibirica	**5.5%**
P. obovata	**5.0%**
Abies sibirica	**3.0%**

CLIMATE

- Underlying principle: ...*climate is the primary factor controlling the distribution of plants*

- Plesheev, 1797; Humboldt, 1807

GOALS

✓Predict possible effects of a changing climate on the vegetation distribution over Siberia using SiBCliM (Siberian bioclimatic vegetation model);

✓Identify "hot spots" of ***forest-to-steppe change by 2080;***

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METHODS

To predict possible effects of a changing climate on the vegetation distribution over Siberia we developed an envelope-type model based on the vegetation classification of Shumilova

Vegetation classification of Siberia of Shumilova

East

South

East Europe	West Siberia	Central Siberia	East Siberia
	Tundra	Polar deserts/ Tundra	Polar deserts/ Tundra
	Forest-tundra: spruce, larch	Forest-tundra: larch	Forest-tundra: larch
	Dark-needled Taiga: spruce, fir, cedar, and Subtaiga: aspen, birch	Light-needled Taiga: larch, pine, and Subtaiga: pine, birch	Larch Taiga (*L. dahurica*)
Forest-Steppe (oak)	Forest-Steppe (aspen, birch)	Forest-Steppe (larch, pine)	Forest-Steppe (larch, pine)
Steppe	Steppe	Steppe	Steppe

Siberian bioclimatic model SiBCliM

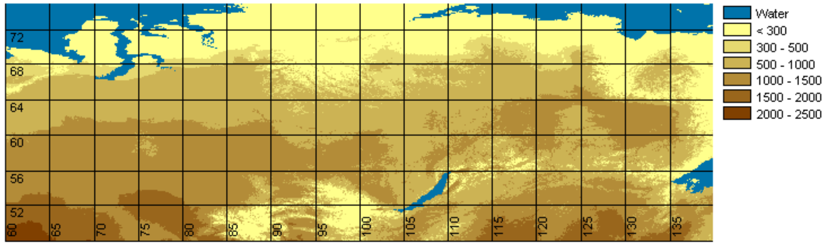
limits “envelopes” for each vegetation class in the Shumilova’s classification based on three principal climatic constrains representing plant requirements for warmth (growing degree-days, above 5^{o}C), and cold tolerance (negative degree-days, below 0^{o}C) water stress resistance (an annual moisture index, AMI, a ratio GDD_5/annual precip)

PERMAFROST

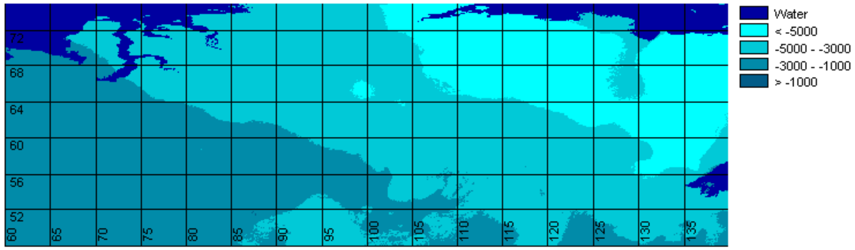
- Permafrost covers 80% of Siberia and is the primary factor controlling the distribution of forests and their composition in central Siberia and Yakutia;
- In dry climate of interior Siberia with 200-300 mm of precipitation, forests are capable of developing only because the melting of permafrost provides additional summer moisture to areas where otherwise the vegetation would be steppe or semidesert (Shumilova 1962);
- Permafrost also limits the northward and eastward spread of major conifer species (*Picea obovata, Pinus sibirica, and Abies sibirica, L. sibirica* and *P. sylvestris*). Only *L. dahurica* (*L . gmelini* + *L. cajanderii*), by contrast, is capable of growing on shallow soils which thaw as little as 10—30 cm during the growing season (Pozdnyakov, 1993).

Climatic surfaces for Siberia

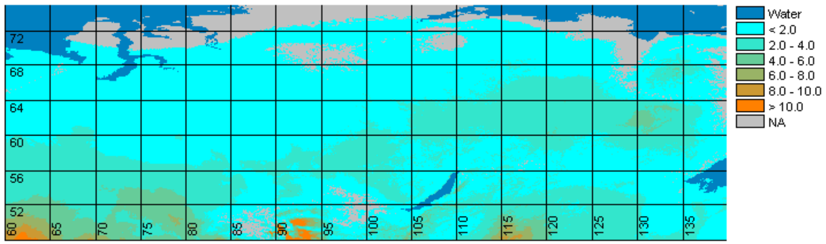
GDD_5



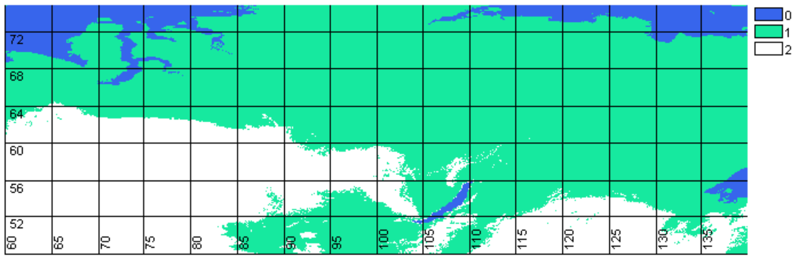
DD_0



AMI = GDD_5/Precipitation



Permafrost border



- Data from about 1000 Siberian weather stations were used to map climatic variables.

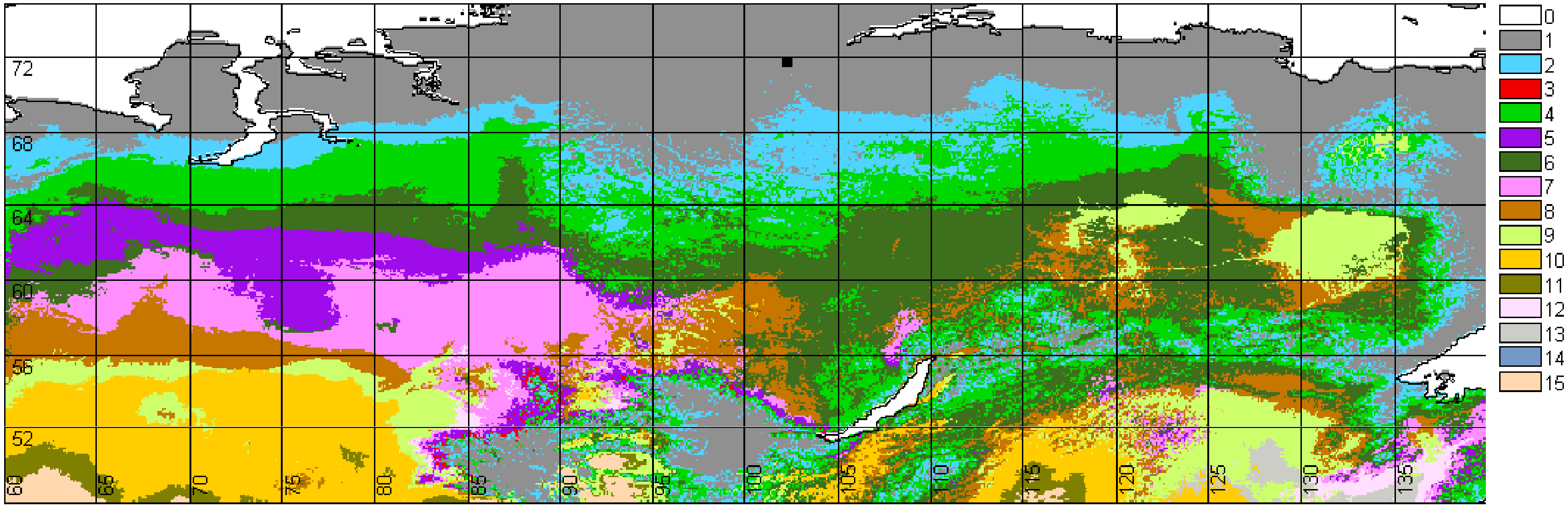
- Hutchinson's (2000) thin plate splines were used to produce climate surfaces on DEM grids (1 km) for monthly temperature and precipitation.

- GDD_5 and DD_0 surfaces were produced from regressions ($R^2 > 0.9$) driven by monthly temperatures (T_1 and T_7).

- AMI was calculated as the ratio of the GDD_5 surface to the precipitation surface.

- Permafrost border (the active layer depth 2 m) was derived from Malevsky=Malevich et al (2003)

Vegetation distribution in Siberia in current climate

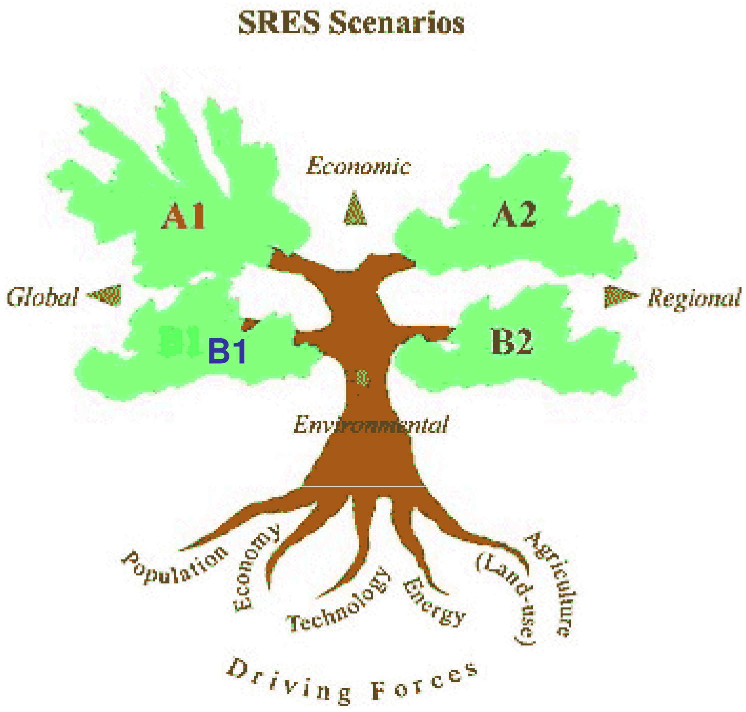


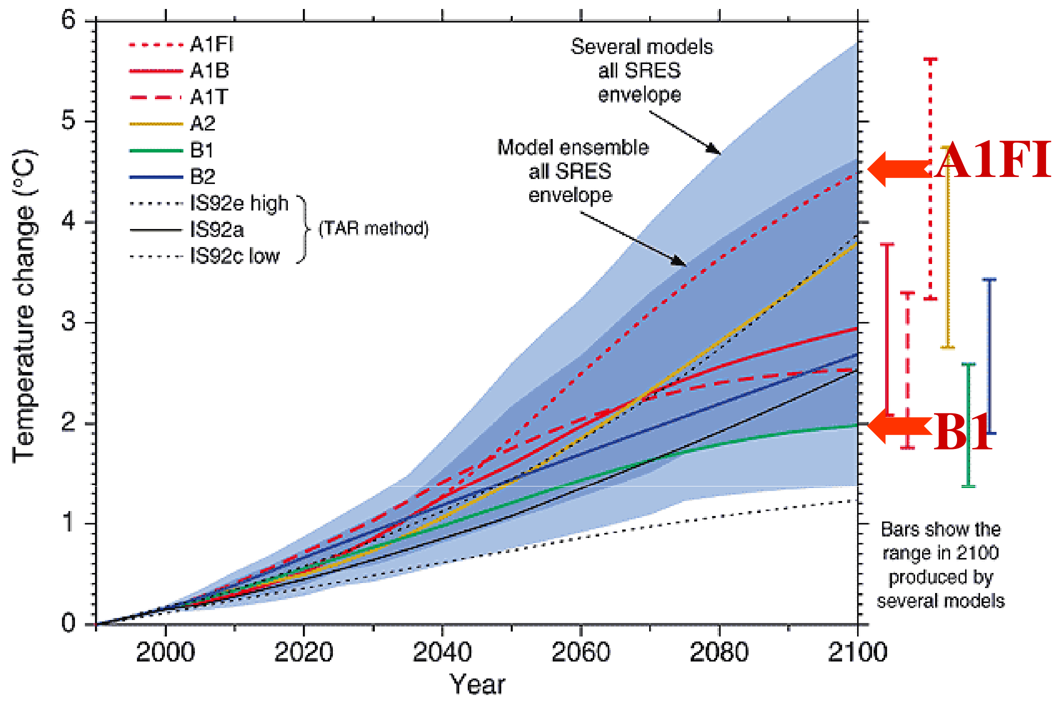
Vegetation classes:

Boreal: ***1 – Tundra; 2** – **Forest-Tundra**; **Northern Taiga**: **3** – darkleaf, **4** - lightleaf; **Middle taiga**: **5** – darkleaf,**6** – lightleaf; **Southern Taiga**: **7** – darkleaf,**8** – lightleaf; **9–Subtaiga+Forest-Steppe**; **10– Steppe**; **11** – **Semidesert**;*

Temperate: ***12** – **Broadleaved**; **13** - **Forest-Steppe**; **14** – **Steppe**, **15** – **Desert**,*

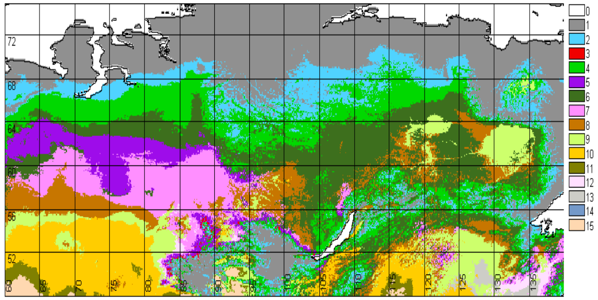
Climate change scenarios (IPCC, 2001)





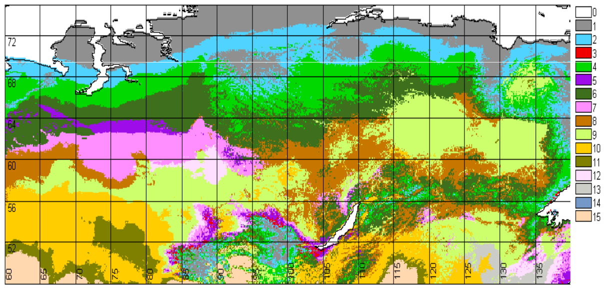
To model vegetation in Siberia under climate change, two climate change scenarios of the Hadley Centre A1FI u B1 were used which reflect opposite ends of the SRES (Special Report on Emission Scenarios) range

Vegetation distribution in Siberia in a changing climate

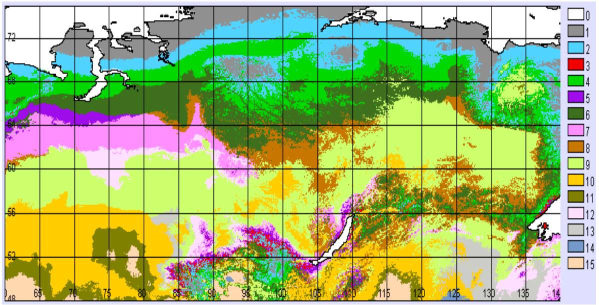


Current climate

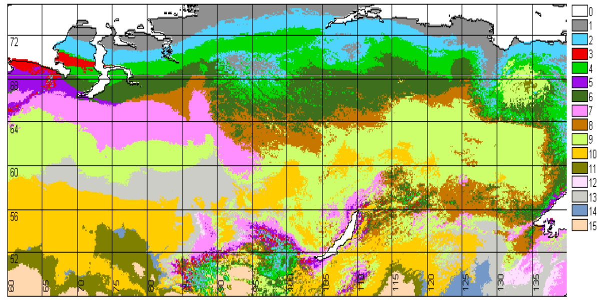
Vegetation change from current climate to 2080 was mapped by coupling our bioclimatic vegetation model SiBCiM with bioclimatic indices and the permafrost distribution calculated from two climate change scenarios



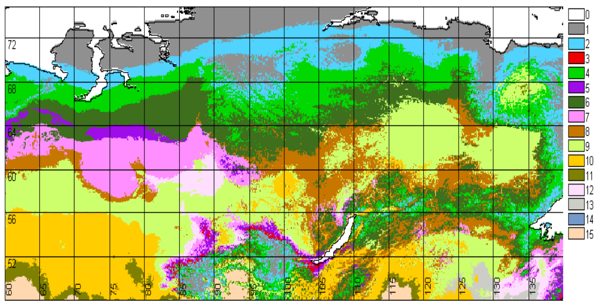
Scenario HadCM3 B1 ***2020***



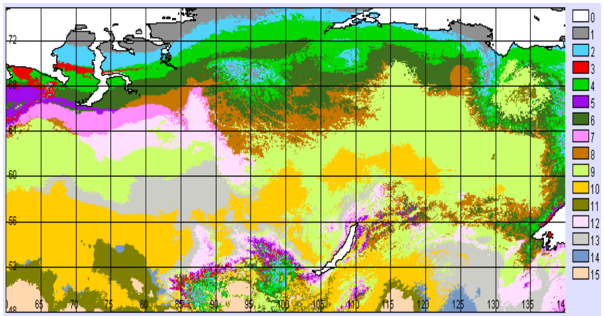
2050



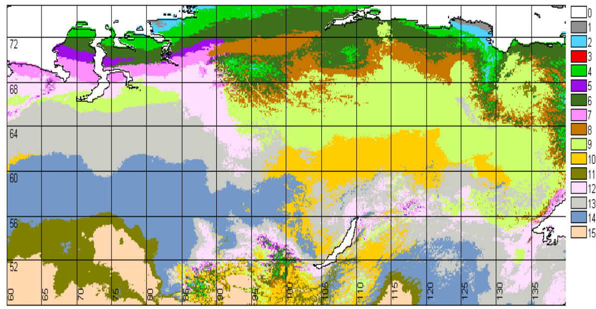
2080



Scenario HadCM3 A1FI ***2020***



2050

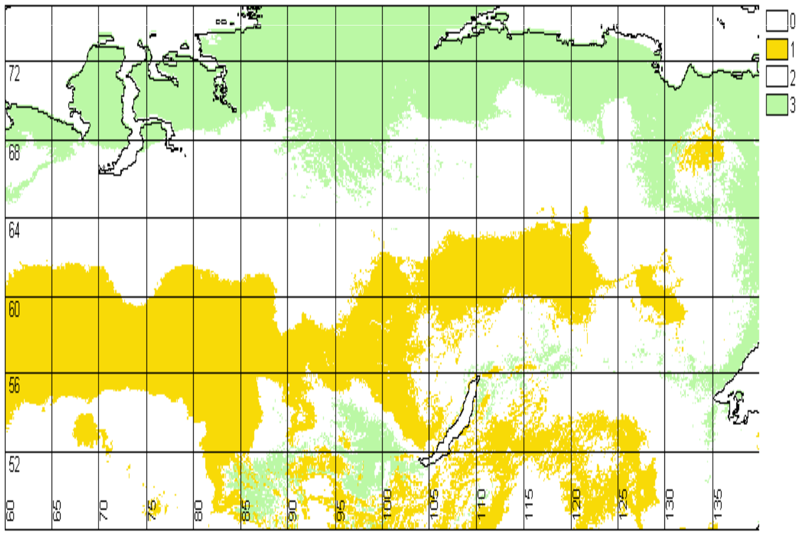


2080

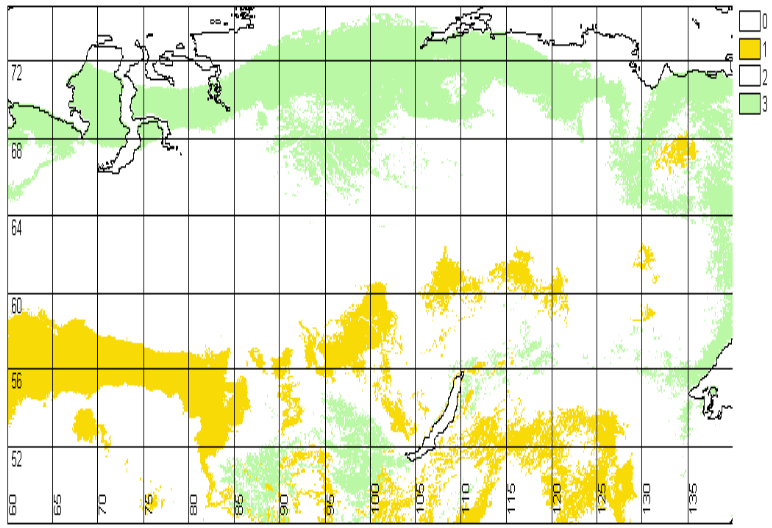
Vegetation "hot spots":

tundra-to-forest (green) and forest-to-steppe (yellow) change by 2080 found as the difference in vegetation in 2080 and current climate

A1FI 2080



B1 2080



Goals

- ➢ Estimate possible effects of a changing climate on the redistribution of the main forest-forming species ***Larix spp***. and ***Pinus sylvestris*** and their climatypes that comprise tree species across Siberia;

- ✓ **Case study**: identify ***Larix sibirica*** and ***Pinus sylvestris*** climatypes for introducing into forest-steppe and steppe habitats in the Minusinsk Valley, southern Siberia, to mitigate effects of predicted aridization of climate;

Definitions

(after Rehfeldt et al, 1999 seq)

- population: genotypes at a provenance;
- provenance: a geographic location;
- seed zone = climatype = climatic ecotype:

  individuals and populations physiologically attuned to the same or similar climate.

Climatypes

- The distributions of *P.sylvestris and Larix spp*. were subdivided into climatypes using climate transfer functions (Rehfeldt et al. 1999 seq.);

- The transfer functions predict the survival and 12-year height of populations from differences in climate between the provenance and the planting site. In such common garden studies, seeds are transferred across climatic gradients and therefore can be viewed as climate-change experiments

Climatypes

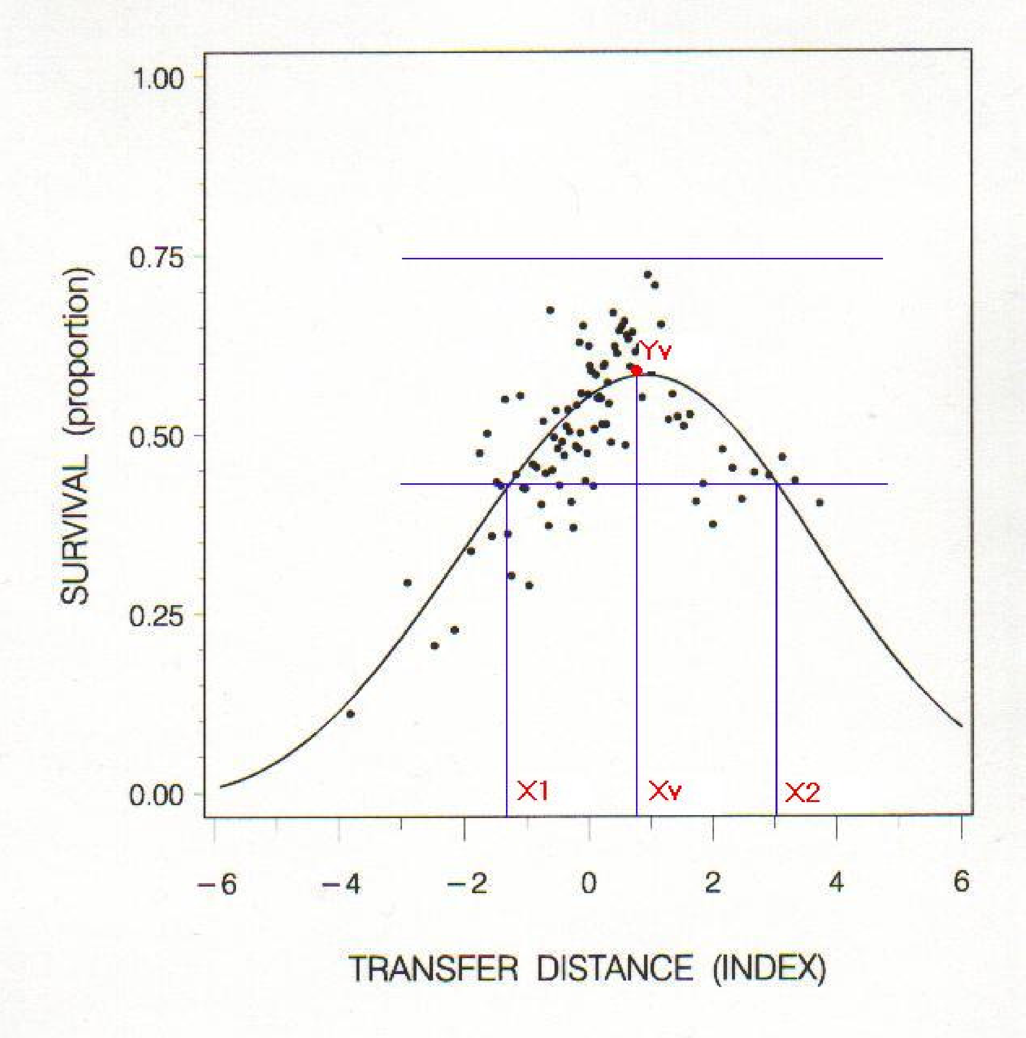
- Transfer functions were constructed using published data on provenance trials established across the former Soviet Union:

  - 313 populations *P.sylvestris* planted on 36 sites;

  - 130 populations of *L. spp* (63 of *L. sibirica*, 42 of *L. dahurica*, and 25 of *L. sukaczewii*) planted on 8 sites;

Transfer functions

(Rehfeldt et al. 1999)



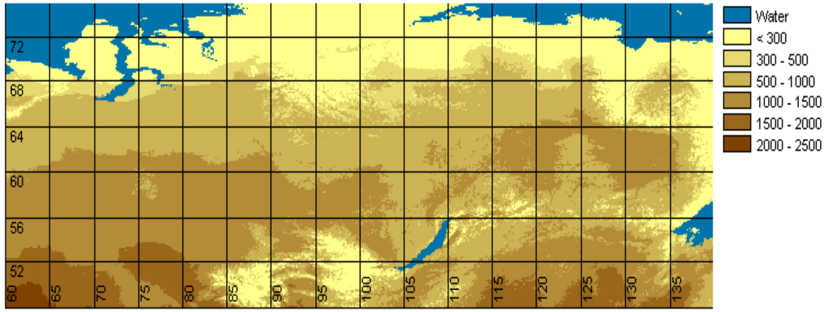
- ✓**The transfer functions were based on a Weibull model;**
- ✓**Three transfer functions were developed driven by 3 climatic indices: summer warmth (GDD_5), winter cold (NDD_0); and moisture (AMI);**
- ✓**Confidence interval about the vertex of the function indicates the climatic limits of the same population (a climatype or a seed zone);**

Climatic distribution of *P. sylvestris* subdivided by these limits defines its 180 potential climatypes across Russia

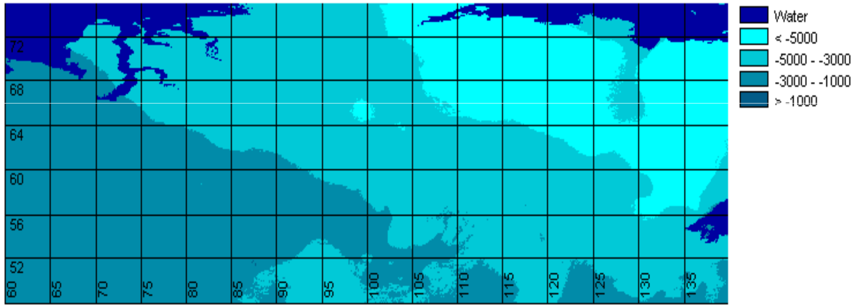
Moisture Index// Degree-days, 5°C	Negative Degree-Days, 0°C					
	-6000-4850	-4850-3700	-3700-2550	-2550-1400	-1400-250	-250-0
0.6-1.8 // 600-1080	1	2	3	4	5	6
1.8-3.0 // 600-1080	7	8	9	10	11	12
…	…	…	…	…	…	…
…	…	…	…	…	…	…
5.4-6.6 // 2520-3000	169	170	171	172	173	174
6.6-7.0 // 2520-3000	175	176	177	178	179	**180**

Climatic surfaces for Siberia

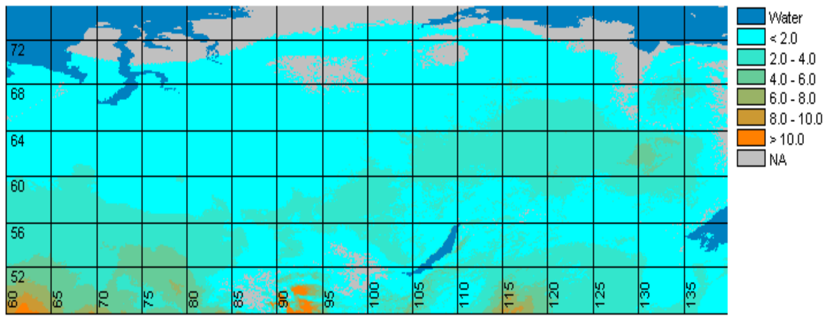
GDD_5



DD_0

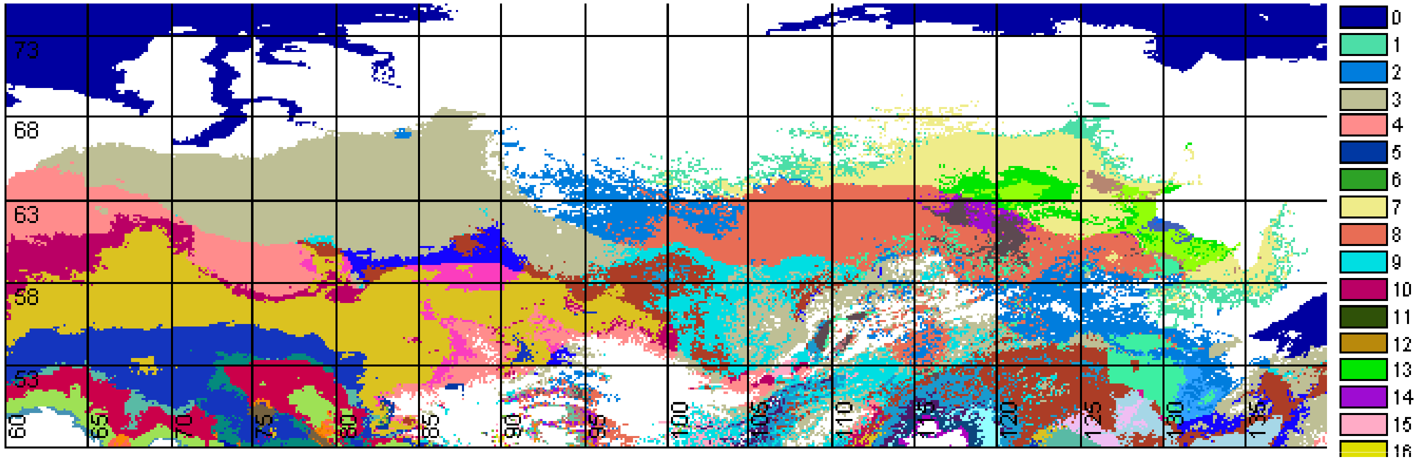


AMI = GDD_5/Precipitation

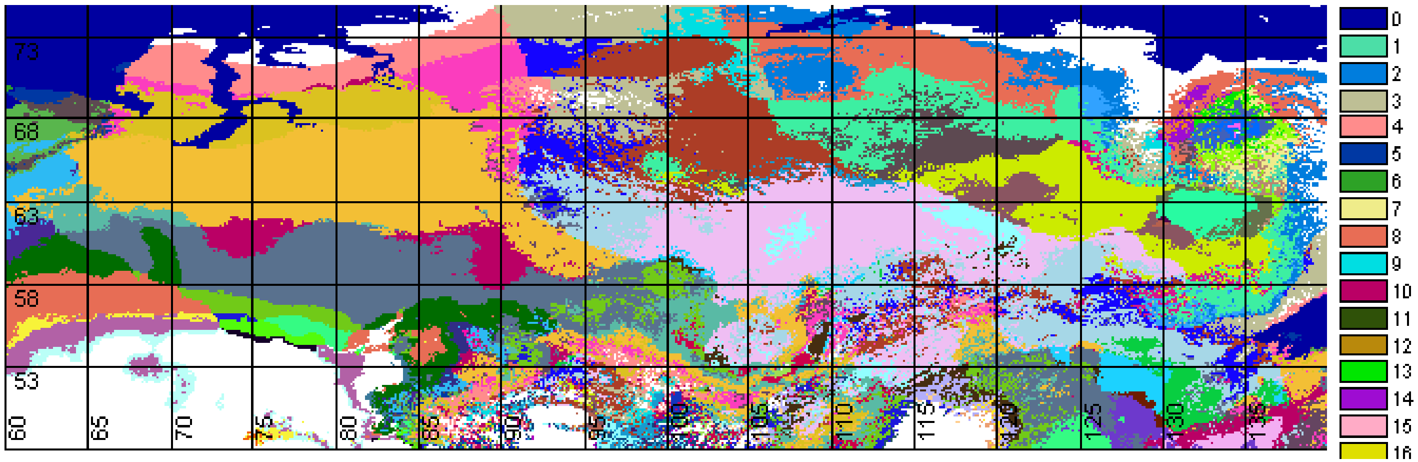


Climatypes distribution for *Pinus sylvestris*

Current

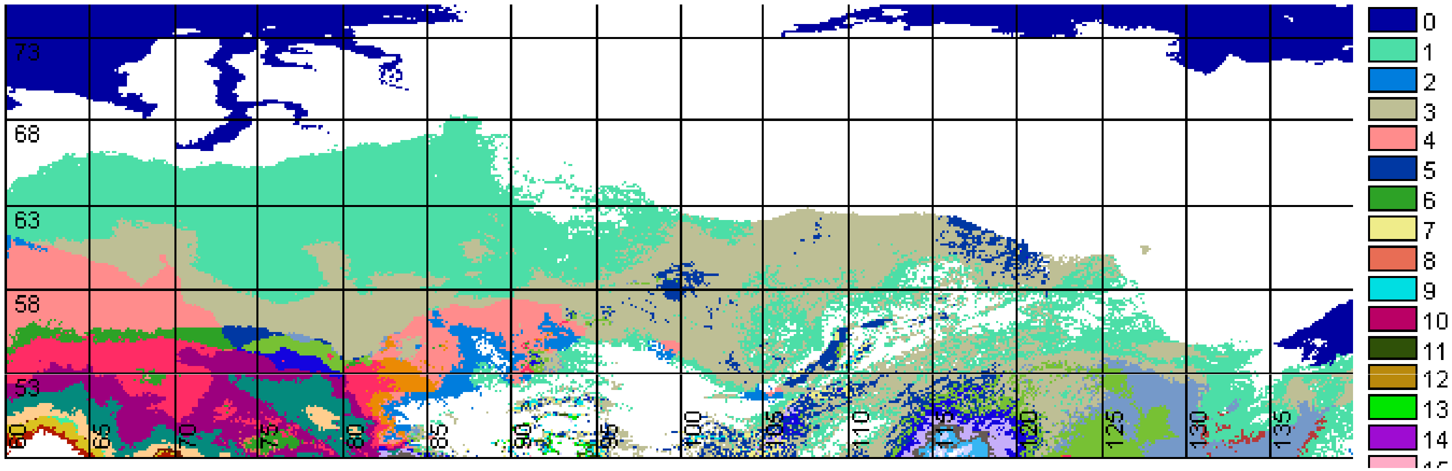


2090

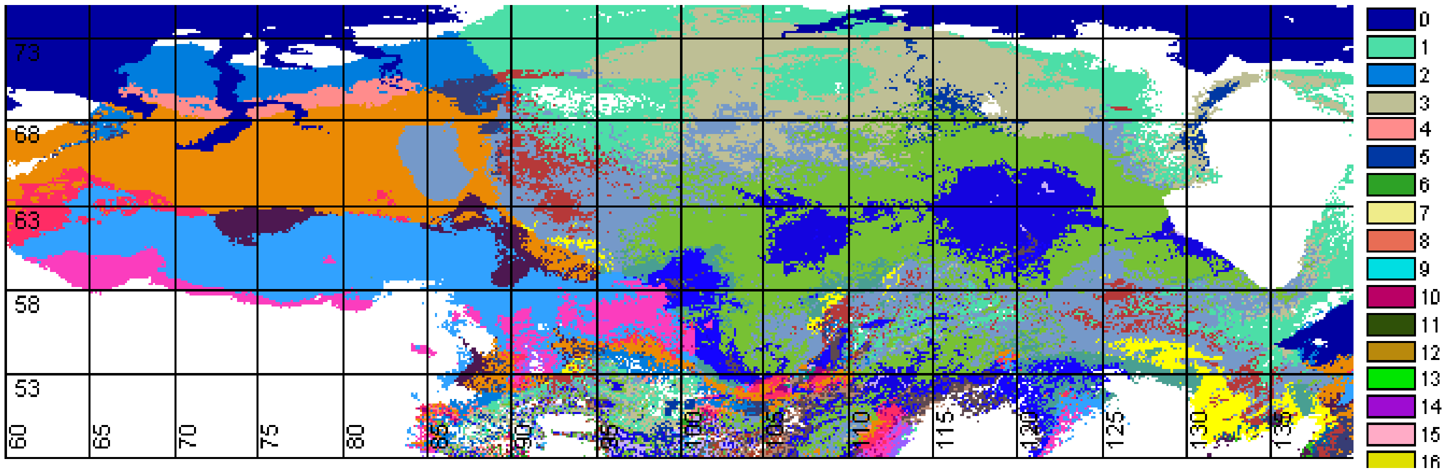


Climatype distribution for *Larix sibirica*

Current

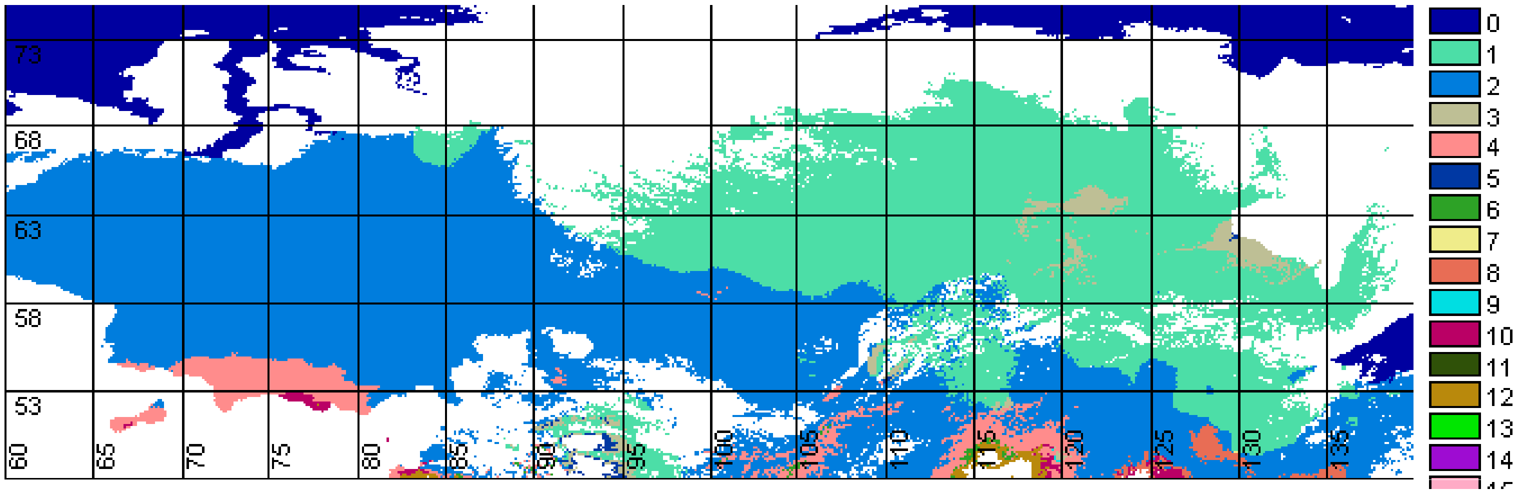


2090

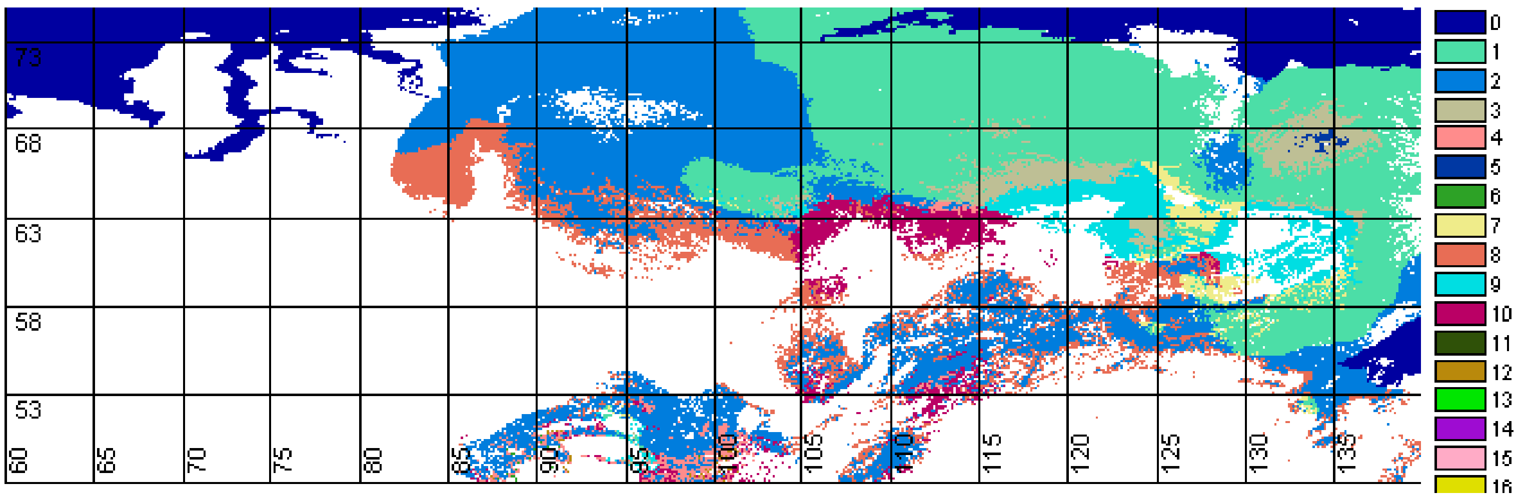


Climatype distribution for *Larix gmelini +cajanderii*

Current

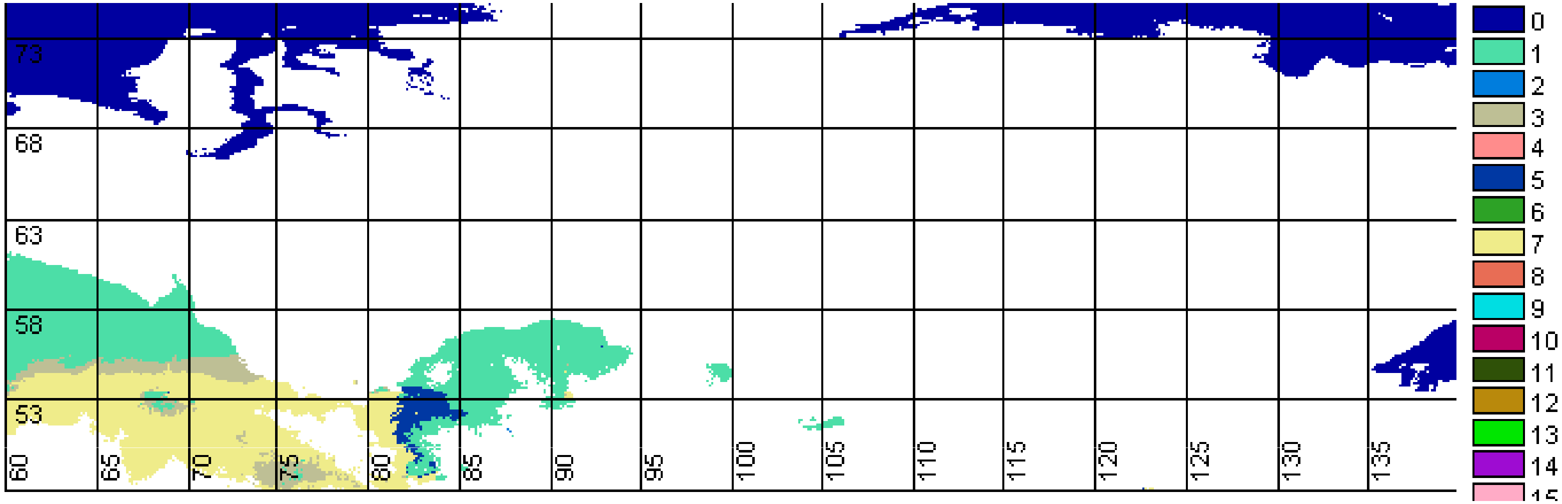


2090

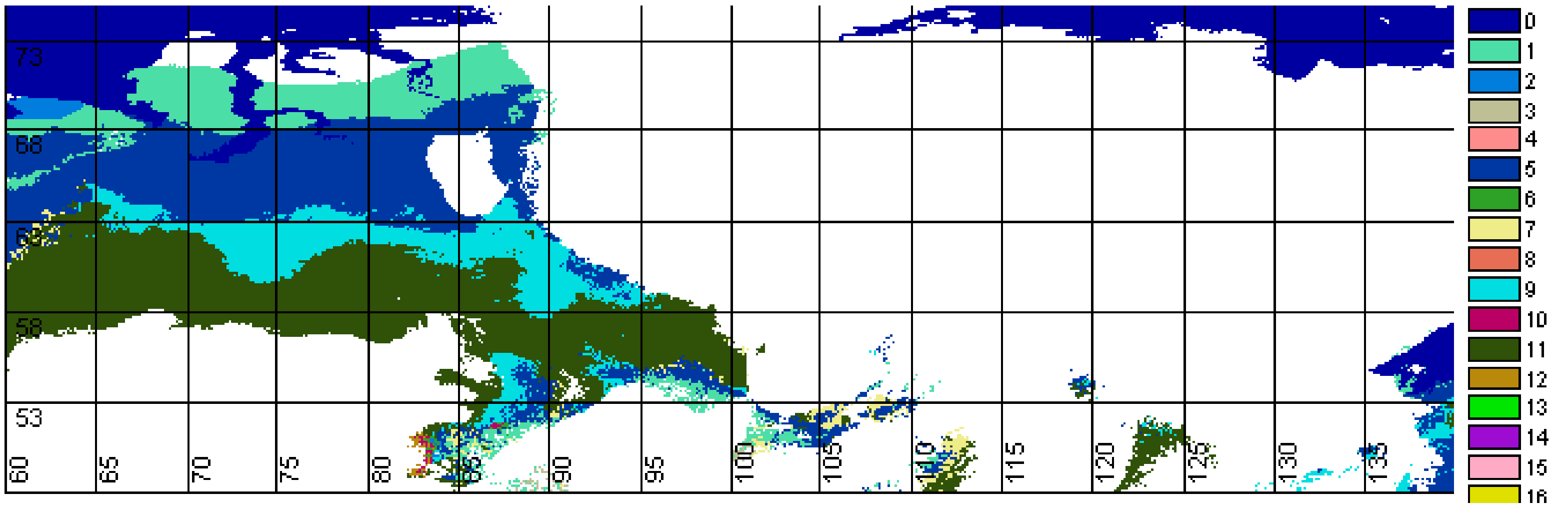


Climatype distribution for *Larix sukaczevii*

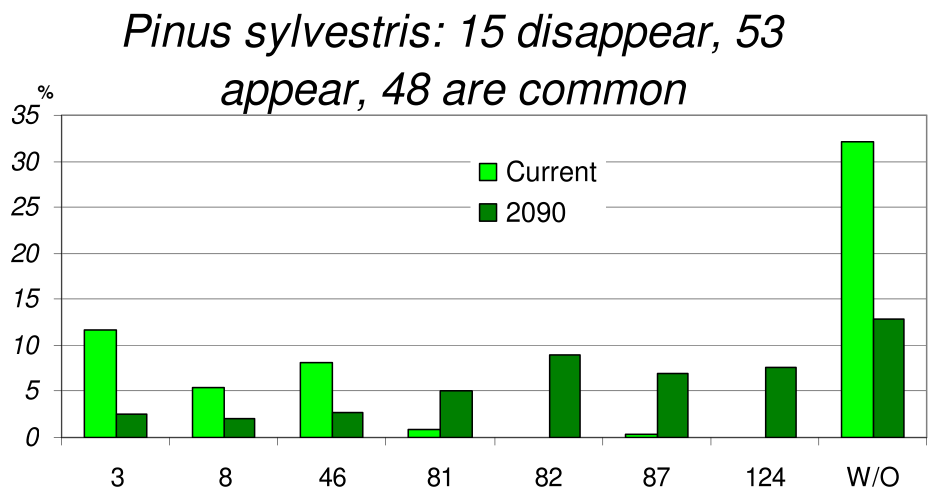
Current

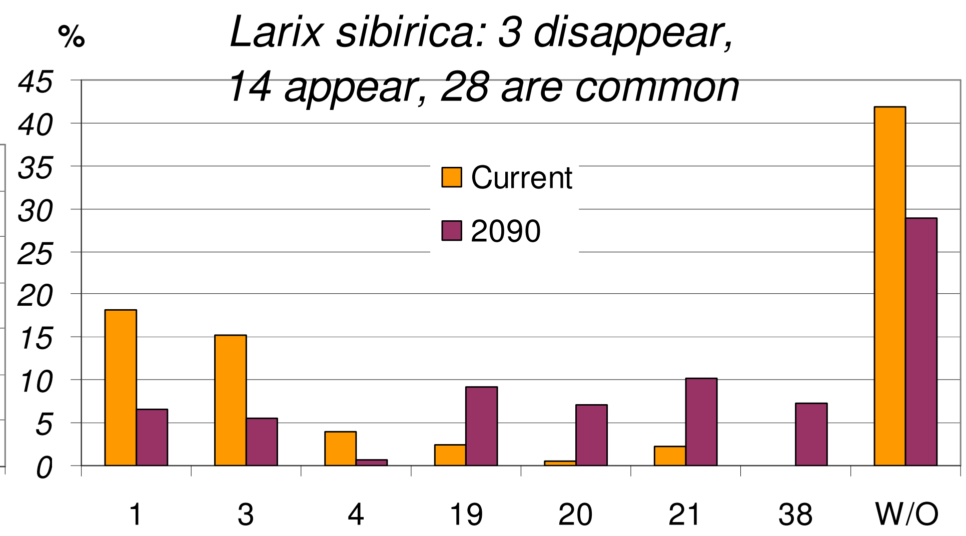


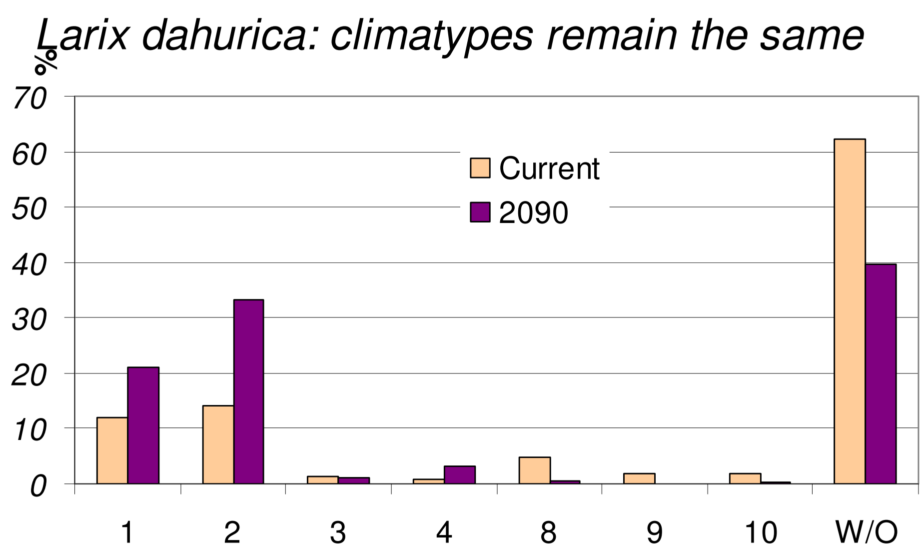
2090

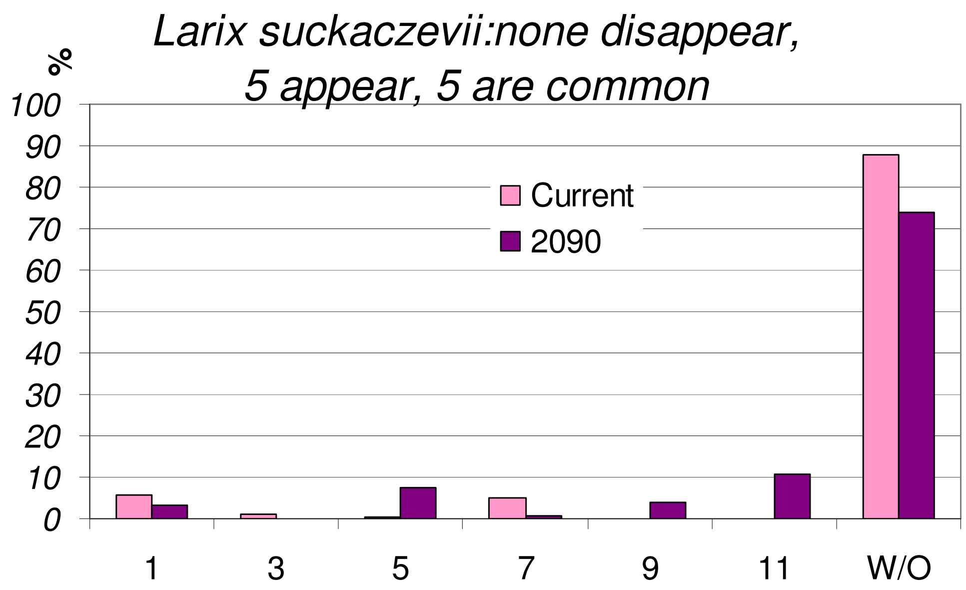


Area change of pine and larch climatypes by 2090



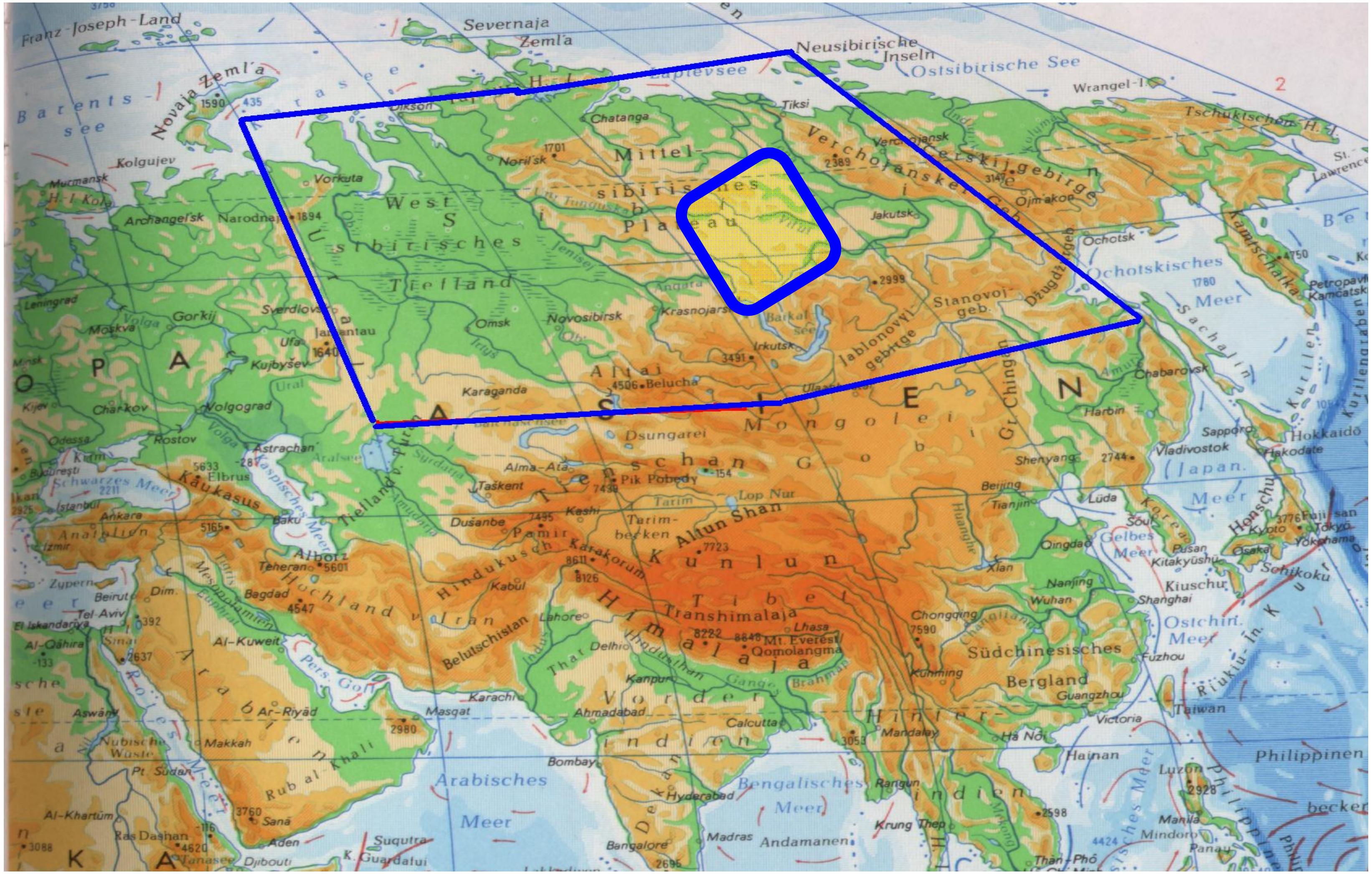






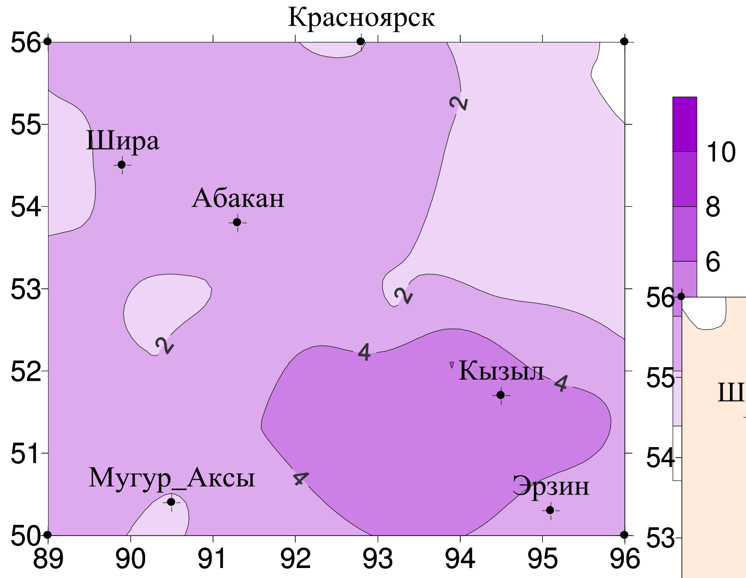
Case study:

to guide the intra-specific transfer of seeds of *Pinus sylvestris* and *Larix sibirica* for reforestation of a predicted forest decline in the Minusinsk Valley, southern Siberia, under climate warming

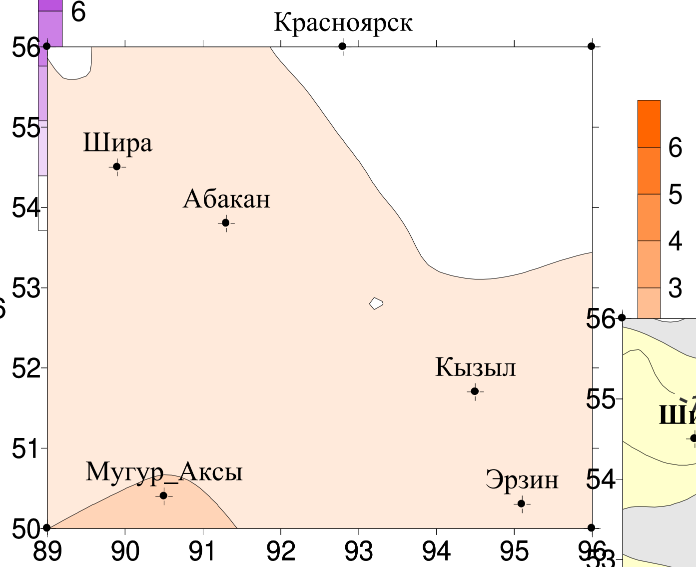


Climatic anomalies at 2000 in southern Siberia

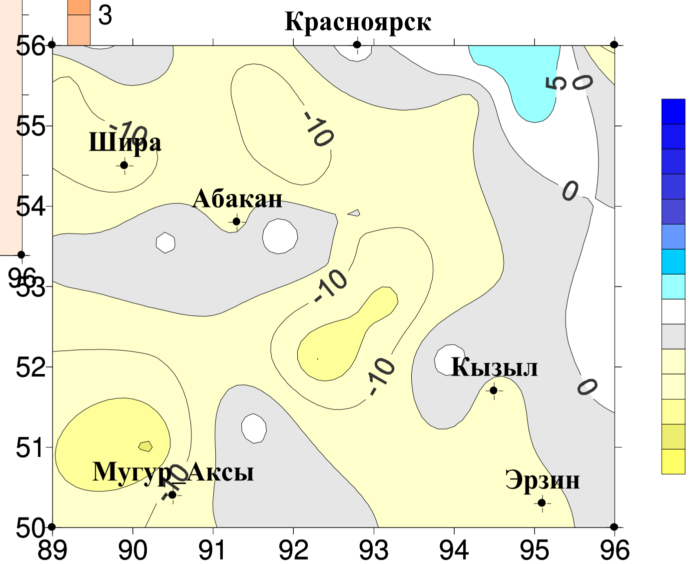
January



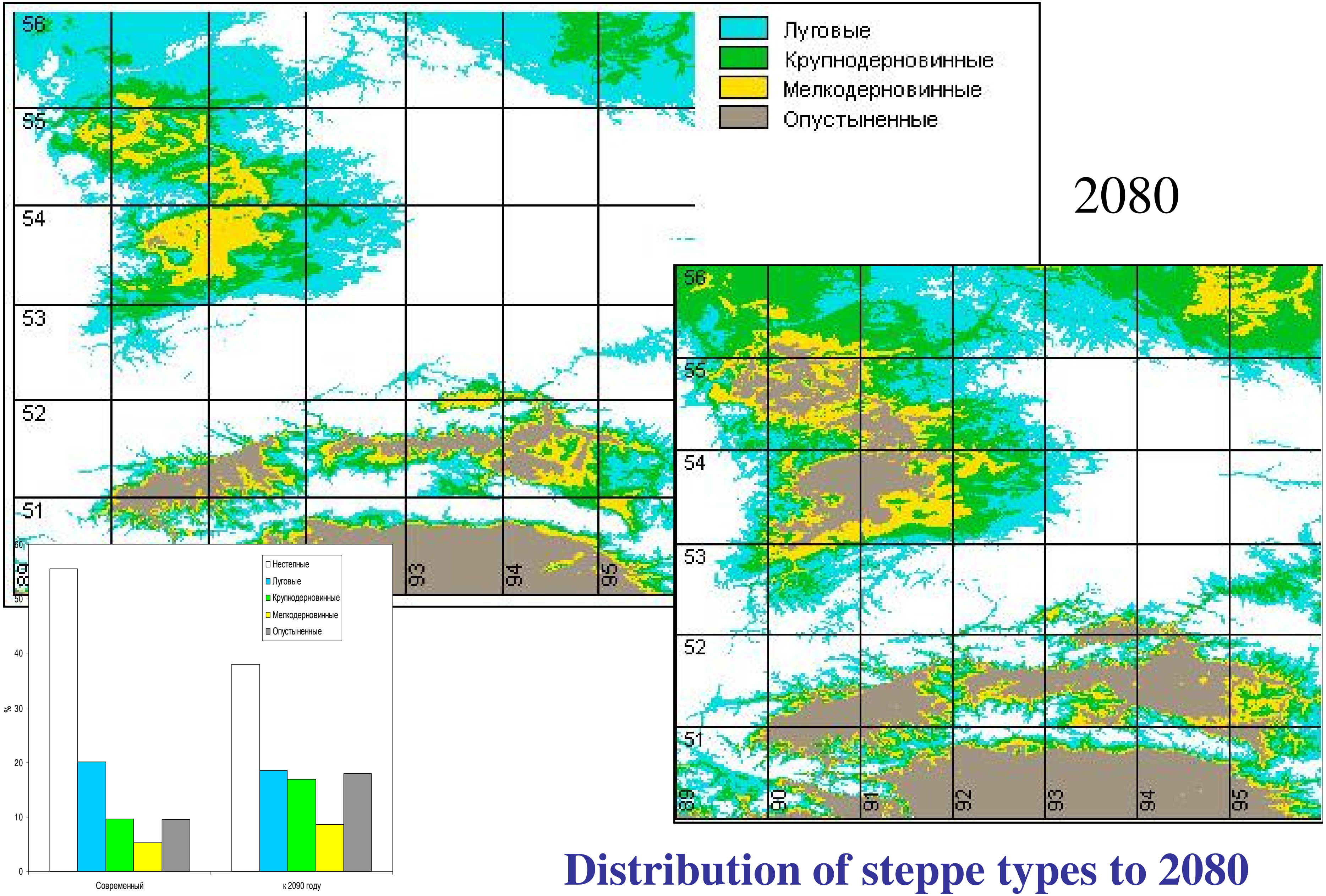
July



Precipitation



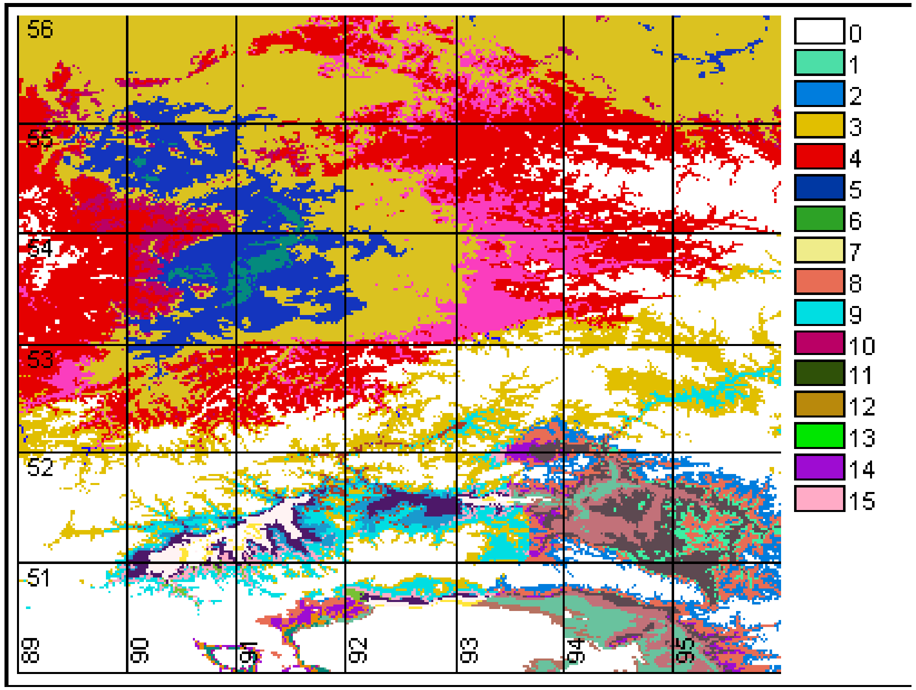
Steppe distribution in a warming climate

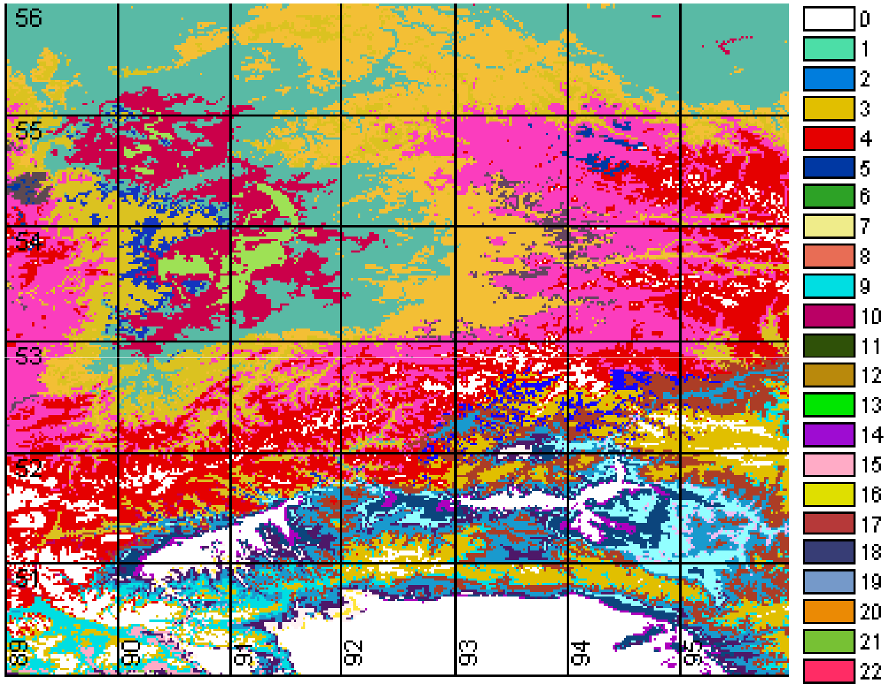


Distribution of steppe types to 2080

Pine climatypes of southern Siberia in a warmed climate

Current ***2090***





In total: 13 climatypes out of 180 possible .

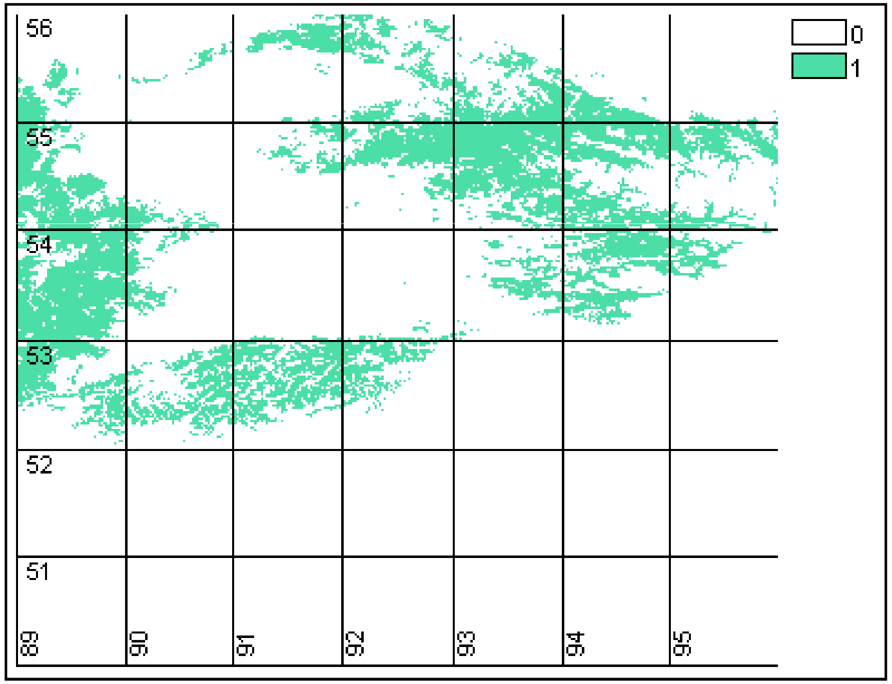
4 climatypes cover 42% of the area.

In total: 18 climatypes out of 180 possible .

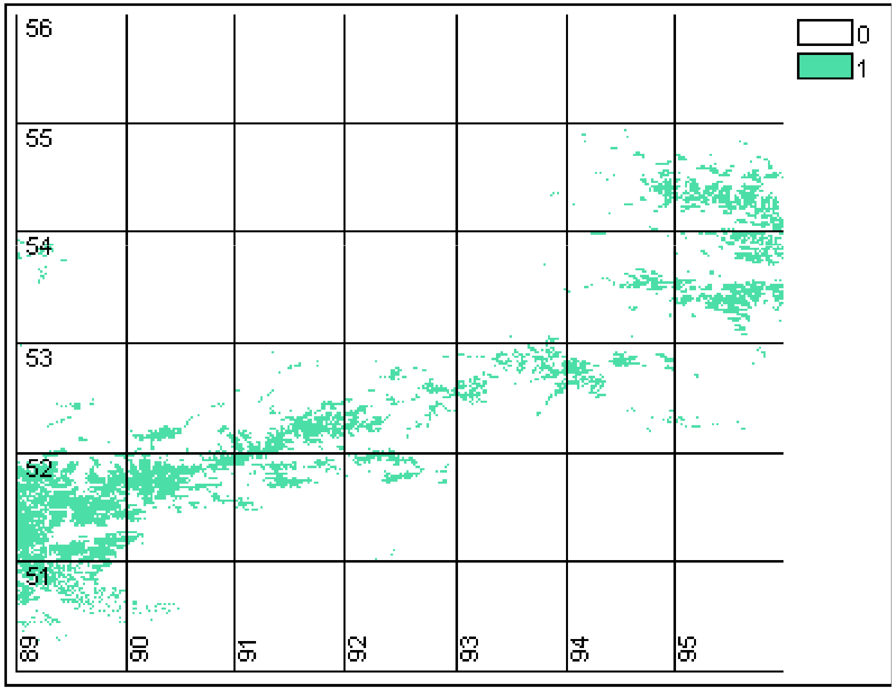
2 climatypes would cover 50% of the area.

Distribution of the Pinus sylvestris climatype #4 in a warming climate

Current climate

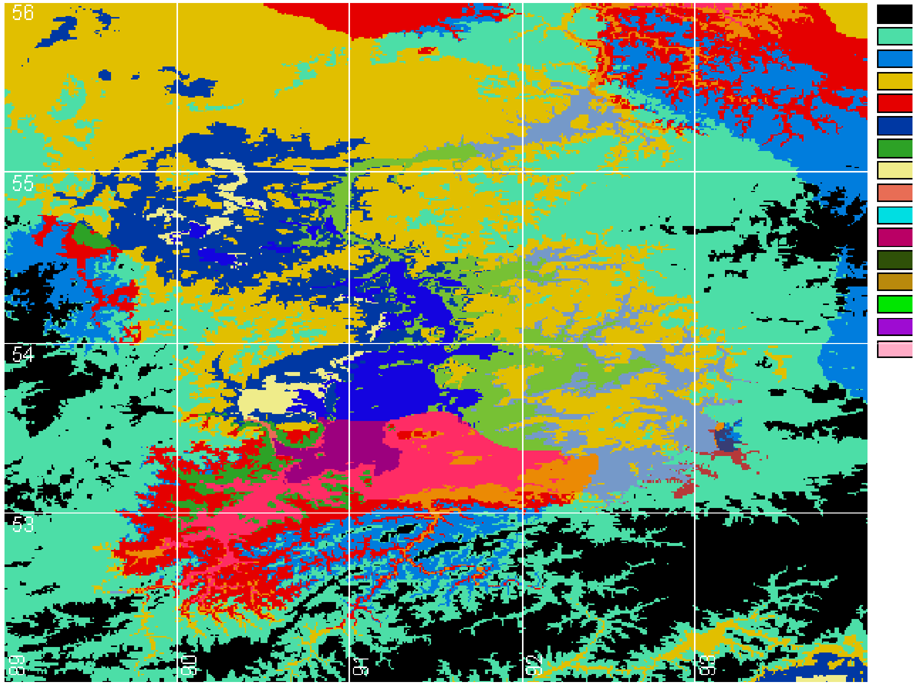


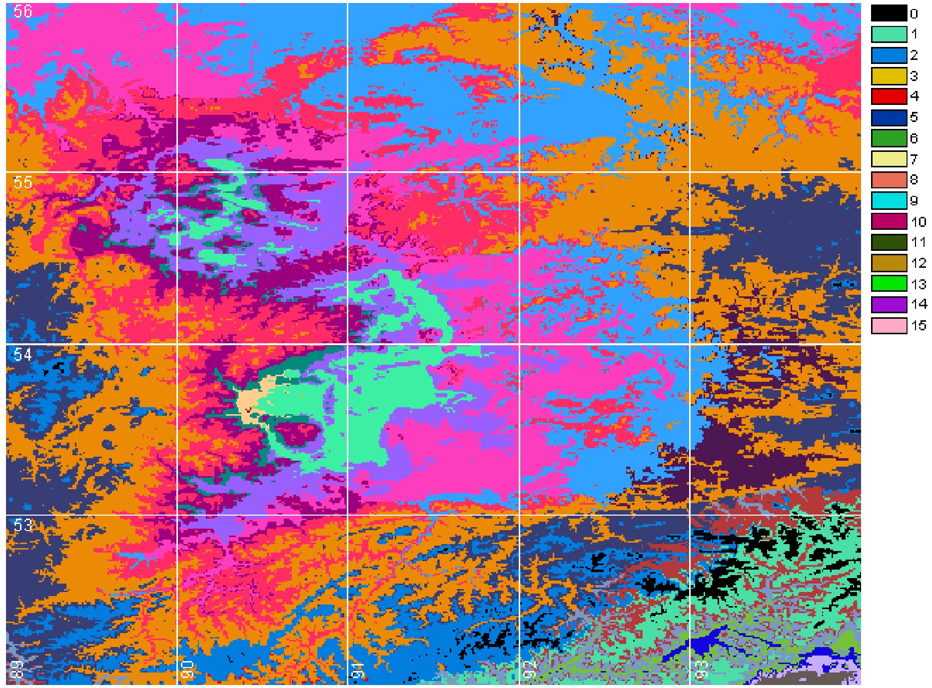
2090



Larch climatypes of southern Siberia in a warmed climate

Current — *2090*





In total: 13 climatypes out of 48 possible .

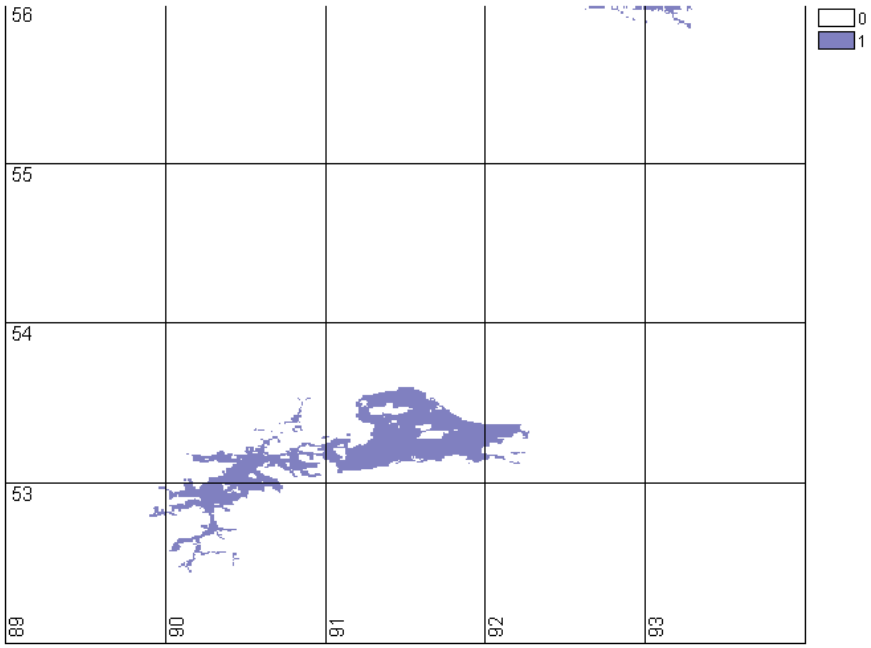
3 climatypes cover 65% of the area.

In total: 17 climatypes out of 48 possible .

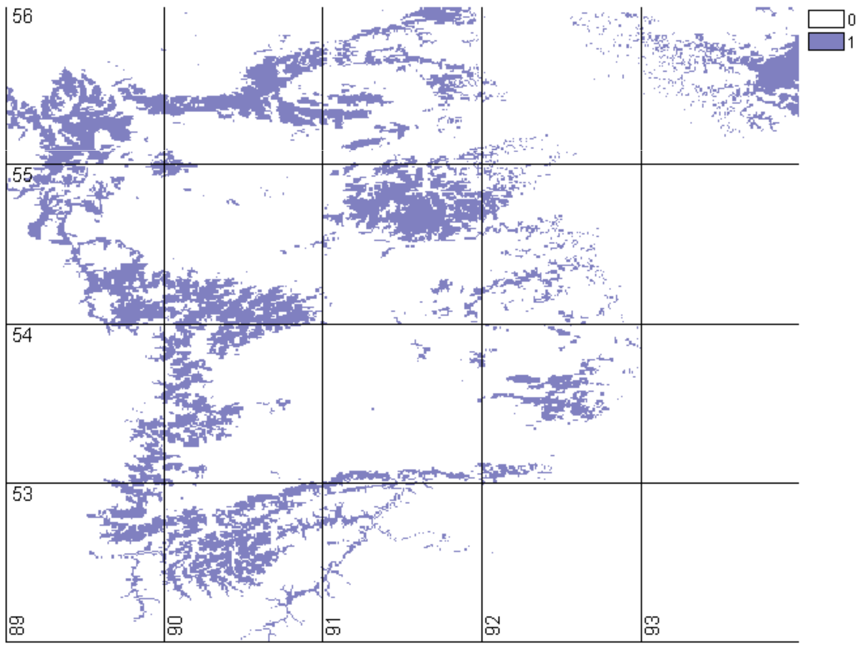
7 climatypes cover 60% of the area.

Distribution of the Larix sibirica climatype #22 in a warming climate

Current climate



2090



Possible means to mitigate a forest decline in southern Siberia in a warming climate

- Forest-steppe, steppe and semideserts would increase 55-75% in Siberia according to Hadley Center climate change scenarios B1 and A1FI;

- *Pinus sylvestris* and *Larix sibirica* are conifers which may be used to reforest declined forests in the Minusinsk Valley, southern Siberia;

- The best fitted to a warmed climate climatypes of *Pinus sylvestris* and *Larix sibirica* should be introduced to the Minusinsk Valley from the foothills of the Altai Mts, 700 km away, and northern Kazakhstan, 1200 km away of the valley, in order to maintain forests over the area.

Conclusions

- ✓ Predicted climate change would impact vegetation in Siberia at all hierarhic levels - biome, ecosystem, species and population;

- ✓ Siberian vegetation will be greatly disturbed by 2080;

  Habitats for northern vegetation classes (tundra, forest-tundra, and taiga) would shrink, habitats for southern vegetation (forest-steppe, steppe and semidesert) would expand up to 55-75%;

- ✓ Biomes and major tree species may shift northwards as far as 600-1000 km;

- ✓ Because of a predicted drier climate, forest-steppes and steppes rather than forests would dominate over half of Siberia; Desertification is predicted to occur in the south of Siberia;

Conclusions

- ✓ Dominant Siberian tree species and their climatypes would be completely redistributed under predicted climate change. Some climatypes would disappear but more would arrive to this area, and about a half may be in common;

- ✓ To mitigate effects of a warming climate in southern Siberia the climatypes of *Larix spp*. and *Pinus sylvestris* best fitted to a warmed climate should be introduced from remote territories, sometimes located as far as 1000 km from the temporary climatypes;

- ✓ Man's role will be to assist the natural processes to assure that the appropriate tree species and their climatypes track their climatic optima in a timely manner. Assistance would be to transfer seeds from their contemporary location to the future site of their climatic optima.

  Without the intervention of mankind, accommodating the warming expected by 2100 may require many centuries.