Biome, species, and population responses to climate and to climate-change in Siberia and western North America

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Abstract — Our work is governed by the principle that climate is the primary factor controlling the distribution of plants. This climate-plant relationship was recognized long ago (e. g., Plesheev in 1797 and Humboldt in 1807) but even today is poorly understood (Woodward 1987). As a aid, we use the thin plate splines of Hutchinson to develop climate surfaces from which the effects climate and climate-change on the distribution of biomes, species, or climatypes (climatic ecotypes) can be mapped.

Bioclimatic models relating the distribution of vegetation zones to climate have been developed for central Siberia. According to these models, the greenhouse gas scenario of the Hadley Centre should result ultimately in a complete redistribution of vegetation zones over the plains and tablelands of Siberia by the end of this century. Northern vegetation types (tundra, forest-tundra, and northern taiga) which are dominant in the contemporary climate should be replaced by southern types such as the southern taiga and subtaiga, forest-steppe, and steppe move northward. Of these southern types, neither of the latter two currently occur north of 56°. Dark-needled taiga concomitantly should move eastwards following the retreat of permafrost.

Species distributions also have been mapped for *Pinus sylvestris* and *Larix* spp. of Siberia using the three-variate climatic envelope of Box (1999) and for *Picea engelmannii* of western USA using 17 climate variables and a combination of the climatic envelope and a discriminant function of 10 species. Once mapped, distributions can be recast according to climate-change scenarios of the GCM's. For *P. engelmannii* in the region south of 51°N, the 2100 distribution is projected to be 12% of the contemporary. In Siberia, the areal extent of lands potentially suitable for *P. sylvestris* and *Larix* spp. should increase markedly by 2100, although actual distributions will depend on rates of change in permafrost.

As controlled experiments in climate-change, long-term provenance tests are helping to unravel plant-climate relationships. Analyses show that for *P. sylvestris* and *Larix* spp. of Siberia and for *P. engelmannii* of USA, accommodating unmitigated global warming will require a wholesale redistribution of genotypes across the landscape to maintain growth and productivity. Yet, effects of a warming climate should be much more positive for the Siberian species than for *P. engelmannii*, even though the climate is expected to warm 6-8 ºC in Siberia but only 2-3 ºC in western USA. This difference in response results because the distribution of genotypes is controlled not by climate alone, but by an interaction between adaptation to climate and competition. While genotypes occur where they can be competitively exclusive, most nonetheless have been competitively excluded from their climatic optima. Most populations, therefore, exist in climates that are colder than the optimal for their growth, productivity, and survival, with the discrepancy between the inhabited and the optimal climate increasing with the severity of the climate.

In south-central Siberia, *P. sylvestris* and *Larix* spp. inhabit climates that are among the coldest within their respective distributions. Populations tend to exist far from their climatic optima, and effects of a warming climate should be highly positive as cold

tolerant populations are replaced by those of higher growth potential. Some climatypes should disappear; others should arise; but the areal extent of all should change. *P. sylvestris* genotypes projected to be the best suited for the climate of 2100 in the mountains of southern Krasnoyarsk Territory exist today in the Altai Republic and southern Ural Mountains, regions which today are 700-1200 km distant. By contrast, in USA, *P. engelmannii* inhabits the mildest climates within its distribution; populations therefore should exist near or at their climatic optima. Consequently, effects of a warming climate should be highly negative with extirpation commonplace as the contemporary climatypes are pushed upwards and northwards.

Conclusions: (1) when converted to variables of known physiological impact (e. g., degree-days), a change of a few degrees in mean annual temperature is projected to have dramatic effects on the vegetation at all levels of organization, from the biome to the species and population; (2) accommodating global warming will require a redistribution of genotypes within species to maintain adaptedness; (3) the culprit is not so much the amount of change as the speed; (4) maintaining forest growth and productivity in the face of global warming will require the participation of mankind in the evolutionary process; and (5) buy today for your grandkids or great grandkids estates in the soon-to-be equitable Siberian or Yukonian climates.