Forest adaptation strategies: analysis of long-term post-fire succession in southern Siberia, Russian Federation

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An analysis of succession after natural disturbances assists in predicting the effect of climate change on the possible future composition of Siberian boreal forests in the low-mountain subtaiga.

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Forest species composition and its changes through time can be used to predict potential forest transformations under current and future climate. In the southern Siberian subtaiga in the Russian Federation, fire is the main factor determining biodiversity, regeneration and dominant tree species. The authors analysed post-fire succession over the past 350 years to predict the effect of the increase in fires that is expected to accompany climate change in this region.

Succession is the gradual supplanting of one plant community by another as conditions change, either naturally (e.g. through changing shade conditions under a tree stand) or after disturbance (e.g. fire, storm, flood, pest or disease infestation, clearcut). Most successions have a number of stages in which different collections of species dominate. The final, climax stage is reached when the species composition no longer changes with time in the absence of natural or human-caused disturbances.

Subtaiga characteristics

The mixed forests in southern Siberia are typical of low mountain landscapes in humid continental climates. They consist of Scots pine (*Pinus sylvestris*), Siberian larch (*Larix sibirica*), birch (*Betula pendula*), aspen (*Populus tremula*), Siberian fir (*Abies sibirica*) and spruce (*Picea obovata*, syn. *Picea abies* subsp. *obovata*) with a well developed herbaceous layer. These forests, classified as subtaiga, comprise the zone between "dark" (shade-tolerant) coniferous taiga (with fir, spruce and Siberian pine) and "light" (light-demanding) coniferous forest steppe (with Scots pine and larch). The forest stands are subjected to periodic fires and represent different stages of natural vegetation restoration after fire.

The subtaiga forest zone in southern Siberia (300 to 500 m above see level) differs substantially from the taiga (450 to 650 m above see level) in biodiversity, phenology and the floristic composition of the understorey. While the two zones include the same forest tree species, in the subtaiga fir and spruce are almost absent in watersheds and are located only near rivers. The subtaiga understorey is rich in herbs and grasses, but in contrast to that in the taiga, it has no moss cover.

Succession analysis

The authors reconstructed succession trajectories over the past 350 years in forests of the low mountain landscapes of southern Siberia, Russian Federation, using a combination of a chronosequence approach, detailed descriptions of 2 210 forest inventory units, data from 120 sample plots and geographic information system (GIS) technologies.

Direct methods cannot be used to reconstruct the history of mixed uneven-aged forest stands with complex vertical structure consisting of several species of different ages at every canopy layer. Construction of quasi-dynamic

Pine-larch subtaiga with a stable mixture of birch and aspen and a well-developed layer of herbs and grasses

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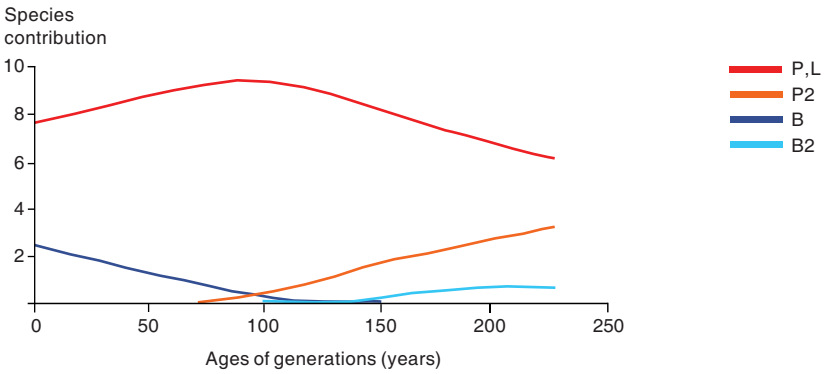
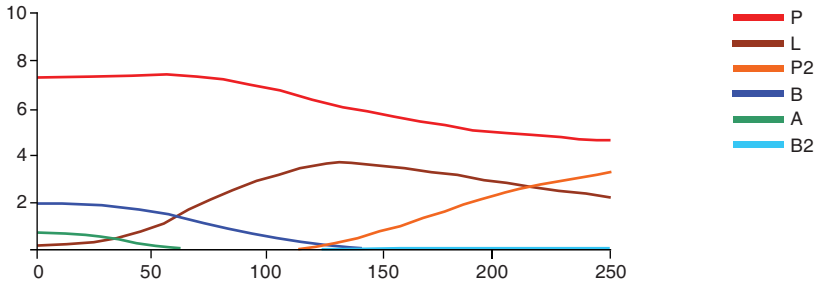
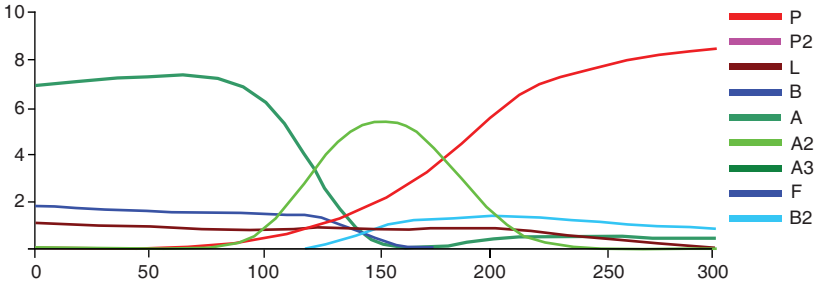
(a) *Pinus sylvestris–Caragana arborescens* stands on sunny steep and stony slopes with periodically dry soils



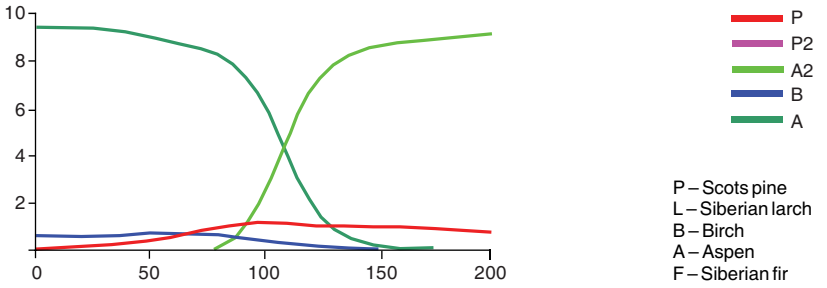
(b) *Pinus sylvestris–Spirea media–Carex macroura* stands on moist soils



(c) *Pinus sylvestris–Pteridium aquilinum* and *Crepis sibirica–Carex macroura* on moist soils on sunny slopes



(d) Mixed forest stands dominated by aspen with a well-developed layer of tall herbs and grasses *(Pteridium aquilinum, Calamagrostis arundinacea, Brachypodium pinnatum, Lilium martagon, Lathyrus gmelinii)* on concave slopes



Second and third generations of trees are indicated by number. The share of each generation of tree species (according to detailed forest inventory data) is estimated in relative units as a part of total volume.

Long-term tree species dynamics in different forest types of the low mountain subtaiga zone (200 to 450 m above sea level)

trajectories was based on the grouping of stands of different ages growing in the same environment, with similar initial conditions and histories of development.

Twelve successional tracks or lines of succession, each comprising several succession stages, were found for the subtaiga belt with a humid continental climate. Six successional tracks were found for the higher-altitude fir taiga belt with a more humid, less continental climate.

The Figure illustrates the composition of communities and changes up to the climax stage (200 to 350 years) for different forest types of varying soil moisture and richness, reconstructed from forest inventory data. Owing to frequent surface fires these stands have not yet reached the climax stage, but the last stages of their development can be considered a quasi-climax or quasi-equilibrium state.

Birch is abundant only during the first seven to twelve decades (Figure, a–c). After its decline Scots pine and larch become the main species. Fir and spruce are sparse in most sites within the subtaiga zone.

The replacement of Siberian larch and Scots pine by Siberian fir is observed only on the border of subtaiga and fir taiga. However, this process has not reached the climax stage in the areas studied because of repeated fires; mature Scots pine stands form a subclimax in this humid variant of low mountain subtaiga.

Among the deciduous forest stands, conditions are suitable for aspen stands on fertile and moist soils. The rich diversity of herbs in the understorey (e.g. *Carex macroura*, *Calamagrostis arundinacea*, *Vicia unijuga*) proves that the system is well adapted to fire. Aspen stands occupy a niche that is favourable for many species. The well-developed layer of herbs and grasses prevents regeneration of light-demanding coniferous tree species such as Scots pine and Siberian larch. An undergrowth of shade-tolerant conifers (Siberian fir, spruce, Siberian pine) sometimes appears

under the aspen canopy, but the lack of atmospheric humidity and the periodic surface fires, especially in spring, do not allow them to dominate.

Succession trends show that under subtaiga climatic conditions, only the most fire-tolerant tree species such as Scots pine and Siberian larch will dominate, characteristically for 250 to 350 years. Siberian larch is well known as a fire-tolerant species, but in humid subtaiga it gives way to Scots pine and birch, as they produce more seeds and are therefore quick to establish instead of or under larch. Either first- or second-generation Scots pine stands prevail in the final succession stages.

Conclusions

The analysis suggests that the predicted increase in fires that will result from climate change in southern Siberia will likely result in a reduction of larch and shade-tolerant conifers in favour of Scots pine, birch and aspen, along with non-tree plant communities of bushes, grasses and herbs. The plant communities in such forests will be similar in species diversity to many communities currently existing in forest-steppe and steppe zones.

The warming and increasingly humid climate can be expected to cause changes in the composition of forest ecosystems which may not be favourable from the economic point of view. Nevertheless the ecological functions of the forest ecosystems will not decrease. Moreover, aspen and birch are excellent forest species for carbon sink creation because of their fast growth. However in the subtaiga zone fires in spring and in autumn remain the most critical factor in the survival of tree species generations.

Sustainable forest management aims to help any natural regeneration. Controlled burning may be recommended in some sites to prevent large fires and to encourage regeneration of Scots pine and larch.

Finally, management plans for plantations of Siberian pine, currently the most economically valuable tree species in the subtaiga, must take into account the increased risk of destructive surface fires and emphasize fire protection. ◆

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