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# THE UPPER FOREST LIMIT IN THE MOUNTAINS OF THE BOREAL ZONE OF THE USSR*

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## ABSTRACT

The high-mountain areas of the Boreal Zone of the USSR may be subdivided, according to the composition of physiognomic types of the upper forest limit, into three sectors: the western or Atlantic moderately continental sector with oceanic influences, the central or Siberian strongly continental sector, and the eastern or Pacific monsoon sector. On the extreme flanks of this zone, in the western and eastern sectors, the upper forest limit is formed by deciduous summer-green trees (respectively, *Betula tortuosa* and *B. ermani*). In the central sector, the summer-green coniferous trees (*Larix sibirica, L. sibirica* var. *sukaczewii, L. dahurica*) form the upper forest limit, but in some southern regions of this sector, where the climate is warmer and more humid, some evergreen coniferous trees (*Picea obovata, Pinus sibirica, Abies sibirica*) reach the upper forest limit. The fluctuations of the upper forest limit as a response to cyclic climatic change are determined through the application of a complex of different methods. These include evaluation of the vitality of trees, of changes in their growth patterns, and of natural regeneration of high-mountain forests. The 60-to-80- and 140-to-160-yr climatic cycles have caused the most important influence on the position of the upper forest limit. A tendency for increase in this upper limit has been observed in most parts of the Boreal Zone during the last few decades.

## INTRODUCTION

The pattern of the altitudinal vegetation arrangements and particularly the position of the upper forest limit depends mainly on the location of the specific mountain range within the system of latitudinal zonation of vegetation. The Boreal (coniferous forest, Taiga) Zone is the largest vegetation zone of the USSR, covering approximately 51% of its territory. Many more or less large mountain masses with unforested summits and clearly defined upper forest limits are situated within this zone (Figure 1).

The upper forest limits of the Boreal Zone may be subdivided into two large groups: natural and anthropogenic. Within the first group, according to the main limiting factors,

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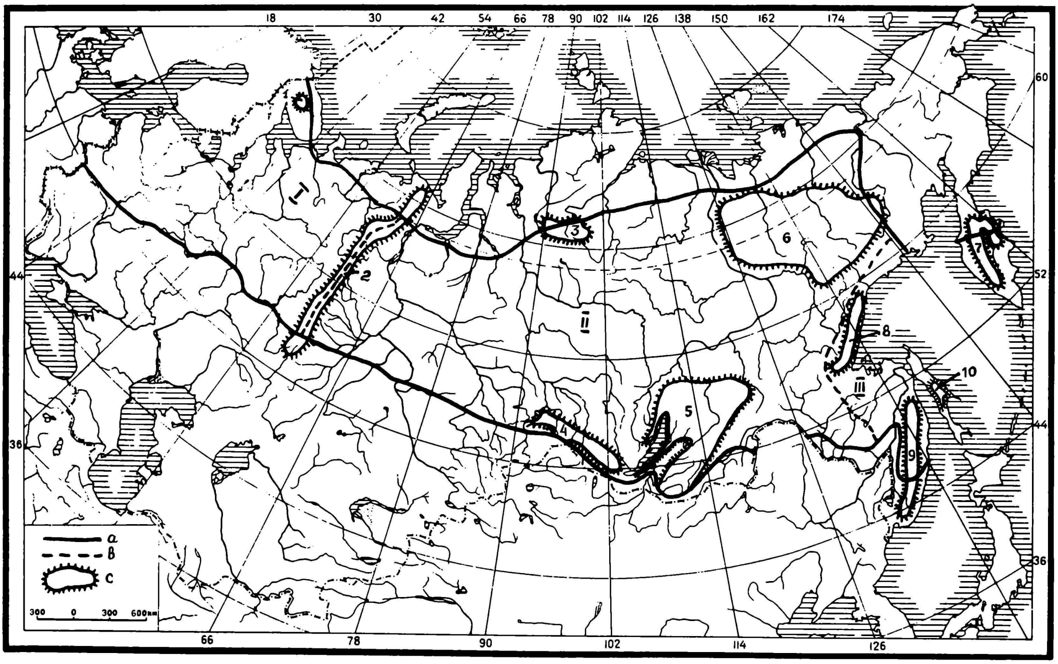


FIGURE 1. Subdivision of high-mountain areas of the Boreal Zone of the USSR according to the character of the upper forest limit. a—boundaries of the Boreal Zone; b—boundary of sectors; c—outlines of the major mountain masses. I—Western or Atlantic sector; II—Central or Siberian sector; III—Eastern or Pacific sector. Mountain masses: 1—Khibiny Mts.; 2—Urals; 3—Putorana Mts.; 4—eastern Sayan Mts.; 5—mountains of Subbaikalia and Transbaikalia; 6—mountains of northeastern Siberia; 7—mountains of Kamchatka; 8—Dzhugdzhur Range; 9—Sikhote-Alin Range; 10—mountains of Sakhalin.

it is necessary to distinguish the following ecological types: climatic (thermic, wind), edaphic, and avalanche. In this paper we will concentrate on the natural upper forest limits (Figure 2) that are primarily controlled by climatic conditions. This is because these are the most important for revealing the general phytogeographic patterns and upper forest limit dynamics.

FIGURE 2. A climatically conditioned forest limit in the polar Urals (Chernaya Mountain).

ATLANTIC SECTOR

In the Khibiny Mountains, the upper forest limit exceeds altitudes of 300 to 600 m above sea level and is represented by *Betula tortuosa* and more rarely by *B. kusmisscheffii*—crook-stem, open forests, which forms a comparatively narrow belt (not wider than 40 to 50 m vertically). There is a slight admixture of shrubby specimens of *Picea obovata* and *Pinus silvestris.* The height of the tree layer is 4 to 6 m; stem diameters range up to 6 to 12 cm, and density of canopy is about 30 to 40%. *Sorbus glabrata, Juniperus sibirica,* and *Betula nana* form the shrub layer. The main components of the herb and dwarf shrub layer are *Vaccinium vitis-idaea, V. myrtillus, V. uliginosum, Linnaea borealis, Trientalis europaea, Deschampsia flexuosa,* and *Solidago virgaurea.* The moss and lichen layer is composed of *Cetraria islandica, Cladonia elongata, C. rangiferina, C. mitis, Lophozia lycopodioides, Pleurozium schreberi, Hylocomium splendens,* and *Dicranum scoparium* (Minyaev, 1963). Associations dominated by *Empetrum hermaphroditum, Vaccinium myrtillus,* and *V. uliginosum* predominate.

On the western slope of the southern part of the polar Urals, in the subpolar and northern Urals where climate is relatively mild and warm, with abundant precipitation, the open, crook-stem forests dominated by *Betula tortuosa* (Figure 3) prevail at the upper forest limit (Gorchakovsky, 1975). Trees are 4 to 8 m in height, their diameter is about 10 to 12 cm, and density is 40 to 50%. The shrub layer is formed by *Juniperus sibirica, Rosa acicularis, Betula nana, Salix glauca, S. arbuscula.* The herb and dwarf shrub layer is composed of *Vaccinium myrtillus, V. uliginosum, Empetrum hermaphroditum, Deschampsia flexuosa, Geranium albiflorum, Veratrum lobelianum, Anemone biarmiensis, Trollius europaeas, Viola biflora, Cirsium heterophyllum, Calamagrostis langsdorffii,* and some other species. *Pleurozium scherberi, Hylocomium splendens, H. pyrenaicum, Cladonia alpestris,* and *C. fimbriata* prevail in the ground layer. Associations dominated in the herb layer by *Vaccinium myrtillus* and *V. uliginosum* are widespread.

In the southern regions of the western slope of the Urals the upper forest limit is in places formed by *Picea obovata* and *Pinus sibirica* low forests; those dominated by *Picea obovata* usually include some *Betula tortuosa* and *Abies sibirica.* The canopy density is about 30 to 70%; trees are 5 to 7 m in height and 12 to 18 cm in diameter. Shrubs such as *Rubus idaeus, Sorbus sibirica,* and *Juniperus sibirica* grow there. The herb and dwarf shrub layer is composed of *Vaccinium myrtillus, Calamagrostis obtusata, C. arundinacea, Linnaea borealis, Trientalis europaea, Polygonum bistorta, Aconitum excelsum, Dryopteris austriaca, Pleurospermum uralense,* and others. Moss cover consists of *Pleurozium schreberi, Dicranum congestum,* and *Polytrichum commune.*

In the shrub forests dominated by *Pinus sibirica,* trees are 6 to 11 m in height, 20 cm in diameter, and the canopy density is 20 to

FIGURE 3. The upper forest limit dominated by *Betula tortuosa* (northern Urals, Serebryansky Kamen Mt.).

25%. The shrub layer is composed of *Juniperus sibirica, Sorbus sibirica,* and others. *Hylocomium splendens, Pleurozium schreberi, Peltigera aphthosa,* and *Nephroma arctica* constitute ground layer. In some places, but very rarely, patches of low forests dominated by *Abies sibirica* may be found at the upper forest limit.

SIBERIAN SECTOR

In contrast to the western slope, the eastern slope of the Urals is characterized by a relatively severe continental climate. Open woodlands dominated by *Larix sibirica* var. *sukaczewii* (Figure 4) prevail at the upper forest limit. Trees are 4 to 11 m high, 6 to 10 cm in diameter, and the canopy density is 20 to 30%. *Betula nana, Salix glauca, S. arbuscula, S. phylicifolia, Ledum palustre,* and *Rosa acicularis* occur in the shrub layer. The herb and dwarf shrub layer includes *Vaccinium uliginosum, V. myrtillus, Empetrum hermaphroditum, Festuca supina, Polygonum bistorta, Calamagrostis lapponica, Hierochloë alpina, Valeriana capitata, Luzula wahlenbergii, L. confusa, Deschampsia flexuosa, Anthoxanthum alpinum, Veratrum lobelianum, Pachypleurum alpinum,* and *Juncus trifidus.* The moss and lichen layer is composed of *Aulacomnium palustre, Polytrichum commune, Dicranum congestum, Stereocaulon paschale,* and *Cladonia amaurocraea.* Associations dominated by *Vaccinium uliginosum, V. myrtillus,* and *Betula nana* are widespread.

On rocky slopes in the southern part of northern Urals the upper forest limit is formed in places by *Pinus sibirica* low forests.

The Putorana mountains are situated primarily in the subzone of northern open Taiga. The upper forest limit formed by *Larix dahurica* open woodlands extends to between 500 and 700 m a.s.l. *Salix lanata, Betula nana,* and *Alnus fruticosa* compose the shrub layer. Open woodlands with a dominance of lichens, green mosses, or lichens and dwarf shrubs in ground layer prevail there (Vodopiyanova, 1976).

In the mountains of northeastern Yakutia (Chersky, Verkhoyansk, and other ranges), *Larix dahurica* dominates the upper forest limit. In the southern mountain regions of this area the upper forest limit exceeds 1200 to 1300 m a.s.l., but in the more northerly regions (Chersky Range) it does not extend above 1000 m. Small groves of *Betula ermani* and rare specimens of *Picea obovata* are found (Rabotnov, 1936) scattered throughout the southern part of this mountain system. Tree stands of larch woodlands are rare; the shrub layer consists of *Betula middendorffii, B. exilis, Rhododendron parviflorum, Alnus fruticosa,* and *Pinus pumila* and is well developed. *Vaccinium vitis-idaea, Empetrum nigrum, Ledum palustre, Arctous alpina, Carex ensifolia, Eriophorum scheuchzeri, E. vaginatum,* and *Dryas punctata* compose the

FIGURE 4. The upper forest limit dominated by *Larix sibirica* (polar Urals, Rye-Iz Mt.).

herb and dwarf layer. The ground layer is formed by *Cladonia alpestris, C. mitis, Cetraria cucullata, C. islandica, Sphagnum warnstorffii,* and *S. girgensohnii* (Sheludyakova, 1938).

In the mountains of the Subbaikal and Transbaikal areas (Aldan and Stanovoy highlands, Great Stanovoy, Tukuringra, Tungir, Kerchinsk, Barguzin, and Baikal ranges), *Larix dahurica* open woodlands predominate at the upper forest limit. In the Baikal coastal area hybrids *L. dahurica* × *L. sibirica* occur in places. A more or less dense understory consisting of *Pinus pumila* is usual in such woodlands. Lichen, shrub, or sometimes green moss associations are widespread. In relatively humid regions (Baikal and Barguzin ranges) dark coniferous trees (*Picea obovata, Abies sibirica, Pinus sibirica*) reach the upper limit; in some areas low open forests dominated by *Betula ermani* are also found. On the Yana-Aldan watershed the upper forest limit extends to 1000 m, in northern Transbaikalia to between 1200 and 1300 m, and in its southern part to 1500 m or even higher (Sukachev, 1912; Sukachev and Poplavskaya, 1914; Tyulina, 1949; Galaziy, 1954; Malyshev, 1957; Panarin, 1966; Siplivinsky, 1967, 1975).

In the eastern Sayan Mountains (Gluzdakov, 1953, 1966; Malyshev, 1957; Dylis, 1959; Krasnoborov, 1961; Cherednikova, 1963) the upper forest limit extends to between 1500 and 2200 m. It is formed by *Larix sibirica* in the central, more continental part of the mountain mass and in regions adjacent to Mongolia and by *Pinus sibirica* in the northern and eastern sections of this mountain area. Rare specimens of *Picea obovata* are found occasionally. The understory of the larch open woodlands is formed by *Betula rotundifolia* and is well developed. On the Kizyr-Kazir watershed *Abies sibirica* and *Pinus sibirica* form the upper forest limit at an altitude of 1500 m (Kuminova, 1946).

### Pacific Sector

In the mountains of Kamchatka (Median Range, volcanic peaks Klyuchevskaya and others) as well as in Dzhugdzhur Range and in the mountains of Sakhalin, the upper forest limit reaches an altitude of between 700 and 850 m and is formed by open crook-stem *Betula ermani* forests (Tolmachev, 1950; Lyubimova, 1961; Turkov and Shamshin, 1963; Kabanov, 1972). There is a slight admixture of *Larix dahurica* and *Picea jezoensis* in the tree layer. Height of trees is 8 to 16 m; stem diameter maxima attain 20 to 28 cm; and the canopy density is 40 to 70%. In the shrub layer *Pinus pumila, Sorbus sambucifolia, Alnus fruticosa, A. kamtschatica, Juniperus sibirica* are common. The herb layer is very rich in species, and reaches a height of up to 2 m. It includes *Filipendula kamtschatica, Angelica ursina, Ligularia speciosa, Polygonum weyrichii, Thalictrum minus, Equisetum hiemale, Calamagrostis sachalinensis, Veratrum oxysepalum, Cimicifuga simplex, Aconitum maximum, Heracleum dulce,* and *Pleurospermum kamtschaticum.* Associations of open crook-stem birch forests with well-developed herb and shrub layers are widespread.

In the northern and middle parts of the Sikhote-Alin Range (Vasiliyev and Kurentzova, 1960; Kolesnikov, 1968), the upper forest limit reaches 1300 to 1500 m; *Betula ermani* open crook-stem forests predominate, but in some areas they are replaced by an admixture of *Picea jezoensis, Abies nephrolepis,* and *Larix ochotensis.*

### Discussion

An analysis of the data presented shows that the following physiognomic subdivisions of the upper tree limits may be distinguished within the Boreal Zone of the USSR according to the composition of dominant species of trees and to the structure of high-mountain forests.

A. The upper forest limits dominated by summer-green deciduous trees
   (1) Dominated by *Betula tortuosa*
   (2) Dominated by *Betula ermani*

B. The upper forest limits dominated by summer-green coniferous trees
   (1) Dominated by *Larix sibirica* and *L. sibirica* var. *sukaczewii*
   (2) Dominated by *Larix dahurica*

C. The upper forest limits dominated by evergreen coniferous trees
   (1) Dominated by *Pinus sibirica* (Figure 5)
   (2) Dominated by *Picea obovata* (Figure 6)
   (3) Dominated by *Abies sibirica*

The upper forest limits dominated by summer-green deciduous and coniferous trees are widespread, whereas those dominated by

FIGURE 5. The upper forest limit dominated by *Pinus sibirica* (northern Urals, Kolpak Mt.).

evergreen coniferous trees occupy rather limited areas where the local climatic conditions are especially favorable for these more thermophilous arboreal species.

According to the composition of basic physiognomic types of the upper forest limit, the high-mountain areas of the Boreal Zone of the USSR may be subdivided into three sectors:

(1) Western or Atlantic, moderately continental sector with oceanic influences, where *Betula tortuosa* open crook-stem forests are prevalent (mountains of Kola Peninsula, and western part of the polar, subpolar, and northern Urals);

(2) Central or Siberian, strongly continental sector, dominated by *Larix sibirica, L. sibirica* var. *sukaczewii,* and *L. dahurica* open woodlands (eastern part of the polar, subpolar, and northern Urals; mountains of northeastern Siberia, Subbaikalia and Transbaikalia regions; and the northeastern part of the Sayan Mountains);

(3) Eastern or Pacific monsoon sector, dominated by *Betula ermani* open crook-stem forests (mountains of Kamchatka, Dzhugdzhur Range, Sikhote-Alin Range, and the mountains of Sakhalin).

FIGURE 6. The upper forest limit dominated by *Picea obovata* (Urals, Iremel Mt.).

It is therefore evident (Figure 1, Table 1) that, at the extreme flanks of the Boreal Zone, in the Atlantic and Pacific sectors, the upper forest limit is formed by deciduous, summer-green trees (*Betula tortuosa* and *B. ermani,* respectively); only in the southern part of the Pacific sector is there some admixture of evergreen and summer-green coniferous trees. In the Siberian sector, with its strongly continental climate, the upper forest limit is formed primarily by summer-green coniferous trees (*Larix sibirica, L. sibirica*

TABLE 1
*Physiognomic and altitudinal differentiation of the upper forest limit in the mountains of the Boreal Zone of the USSR*

| Mountain area | Lat. (°N) | Dominant species | Elevation (m) | Source |
|---|---|---|---|---|
| Western or Atlantic Sector | | | | |
| Khibiny Mts. | 68 | *Betula tortuosa* | 300-600 | Kozubov and Shaydurov (1965) |
| Subpolar Urals, western slope | 65 | *Betula tortuosa* | 500-600 | Gorchakovsky (1958) |
| Northern Urals, western slope | 65 | *Betula tortuosa,* rarely *Picea obovata* | 700-800 | Investigations *by the authors* |
| Central or Siberian Sector | | | | |
| *Subpolar Urals,* eastern slope | 65 | *Larix sibirica* var. *sukaczewii* | 600-700 | Investigations *by the authors* |
| *Northern Urals,* eastern slope | 60 | *Larix sibirica* var. *sukaczewii* rarely *Pinus sibirica* | 800-1000 | Investigations by the authors |
| Putorana Mts. | 69 | *Larix dahurica* | 500-700 | Vodopyanova (1976) |
| Yakutia, Chersky Range | 65 | *Larix dahurica* | 1000 | Sheludyakova (1938) |
| Yakutia, Oymyakon region | 62 | *Larix dahurica* | 1300 | Panarin (1966), Sheludyakova (1938) |
| Barguzin Range | 54 | *Larix gmelini, Picea obovata, Abies sibirica, Betula ermani* | 1100-1490 | Tyulina (1949), *Siplivinsky* (1967) |
| Northwestern coast of Lake Baikal | 55 | *Larix dahurica, L. sibirica* | 800-1300 | Sukaczev and Poplavskaya (1914) |
| Transbaikalia, Olekminsky Range, Kropotkin Mt. | 54 | *Larix dahurica* | 1300-1400 | Panarin (1966) |
| Eastern Sayan Mts. | 52 | *Larix sibirica, Pinus sibirica* | 1600-2200 | Malyshev (1963) |
| Dzhugdzhur Range Eastern or | 57 | *Betula ermani* | 700-800 | Vasilyev (see |
| Eastern or Pacific Sector | | | | Stanyukovich, (1973) |
| Kamchatka, middle part | 56 | *Betula ermani* | 600-800 | Lyubimova (1961) |
| Sakhalin, Lopatin Mt. | 51 | *Betula ermani* | 800-850 | Tolmachev (1950) |
| Sikhote-Alin Range | 49 | *Betula ermani,* occasionally *Picea jezonensis, Abies nephrolepis, Larix ochotensis* | 1300-1600 | Vasilyev and Kurentzova (1960), Kolesnikov (1968) |

var. *sukaczewii,* and *L. dahurica*); in certain regions of this sector where the regime of temperature and precipitation is more favorable, evergreen coniferous trees (*Picea obovata, Pinus sibirica,* and *Abies sibirica*) occur at the upper forest limit, dominating or codominating with *Larix* spp.

In any specific area the absolute altitude of the climatically conditioned upper forest limit depends mainly on the quantity of solar radiation reaching the surface (function of geographical latitude) and the degree of oceanity (or continentality) of climate. In the northern regions of northern Eurasia the upper forest limit is lower than in the southern regions; the rise in altitude of the upper forest limit from north to south is about 100 m per degree of latitude. The upper forest limit is lower in oceanic than in continental regions. Local deviations of the actual upper forest limit from the optimal climatic limit may be caused by many other factors such as size of mountains, orientation of slopes, character of bedrock, and anthropogenic influences. The lowest levels of the upper forest limit are found in the northern parts of the Atlantic and Pacific sectors of the Boreal Zone (Khibiny mountains, Kamchatka), whereas the highest levels occur in the southern parts of the Siberian sector (Sayan Mountains).

## DYNAMICS OF THE UPPER FOREST LIMIT

For research on the dynamics of the upper forest limit the following characteristics may be considered: vitality of trees, seed productivity, natural regeneration, presence of dead trees, patches and small islands of forests above the present-day forest limit, fluctuations in tree growth rates, age structure of stands, and transition from one growth form to another one. Radiocarbon dating has been applied recently for dating wood remnants (LaMarche and Mooney, 1967). The most informative indices are fluctuations in annual tree rings and the age structure of stands, because this allows the reconstruction of the dynamics of forest limits over long periods and the forecasting of future fluctuations.

Study of the fluctuations of annual tree growth (using dendrochronological methods) of the oldest living trees makes possible the identification of favorable periods for arboreal vegetation. Changes of indices of tree-ring widths are of a cyclic character, as has been shown in many areas of the world; this is caused by cyclic fluctuations of climate and related solar activity. In humid regions of the Temperate and Subarctic zones, the thermal regime of the growing season, especially of the warmest month (July), exerts the primary control on annual radial increment of trees at the upper forest limit (Erlandsson, 1936; Eklund, 1957-1958; Kolitshyuk, 1958; Shiyatov, 1965). Figure 7 shows the results of the division of a dendrochronological series for *Larix sibirica* from the upper forest limit of the subpolar Urals into a few cyclic components using the method of moving averages.

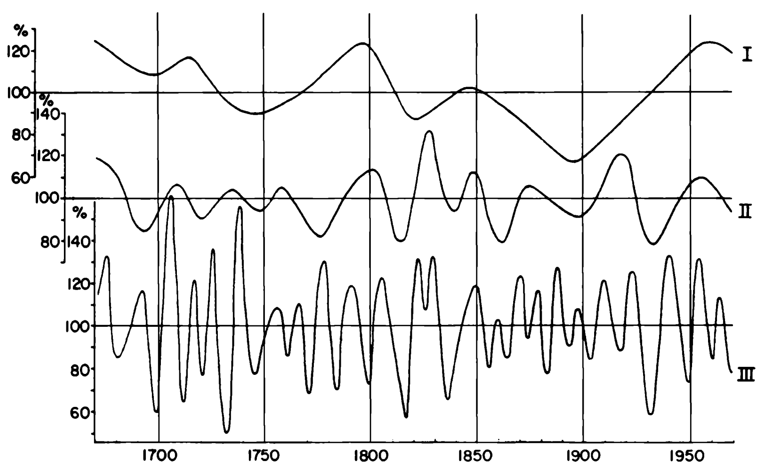


FIGURE 7. Cyclic fluctuations in increment indices for *Larix sibirica* at the upper forest limit in the mountains of the subpolar Urals. I—60-to-80-yr (centurial) cycle; II—22-to-35-yr cycle; III—12-yr cycle.

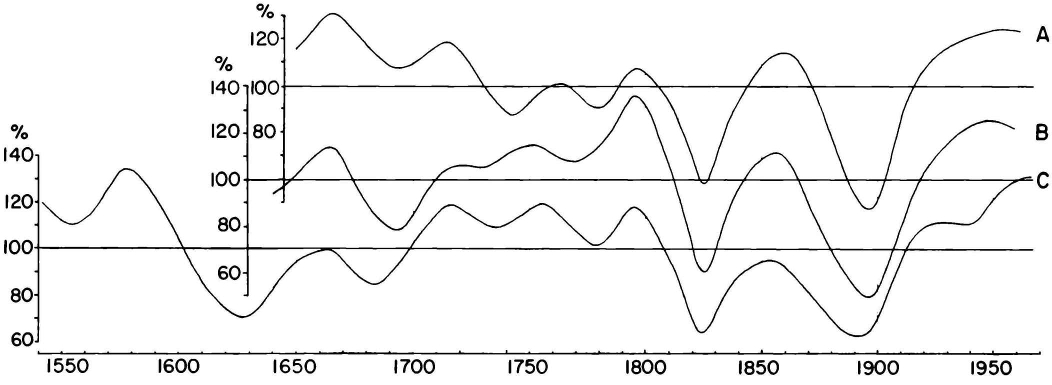


FIGURE 8. Centurial cycle in fluctuations of increment indices of *Larix sibirica* growing at the upper forest limit under different environmental conditions in the polar Urals. A—moderately moist soil; B—dry soil; C—strongly moist drained soil.

The upper curve (I) reveals a 60 to 80 yr cycle. Prolonged depressions of tree growth took place in the middle of 18th and towards the end of 19th centuries; a certain increase of tree growth occurred towards the end of 17th, at the end of 18th, and in the middle of 19th centuries. Figure 8 shows a centurial cycle of tree growth of *Larix sibirica* at the upper forest limit in habitats which differ in moisture regime. In general, the centurial fluctuations are synchronous in spite of differences in edaphic conditions. This finding leads to the assumption that tree growth is conditioned mainly by fluctuations of thermic regime. The most important depressions in tree growth occurred in the first half of the 17th and at the end of the 19th centuries (Figure 8C).

Analyses of age structure of some tree stands in Scandinavia (Siren, 1963) and in the polar Urals (Shiyatov, 1965) showed that abundant natural regeneration, formation of separate age-structure generations, and increase in the level of the upper tree limit (Fig-

FIGURE 9. Young generation of *Larix sibirica* at the upper forest limit which appeared recently in response to the early 20th century climatic amelioration (polar Urals).

FIGURE 10. A small patch of *Larix sibirica* forest located higher than the present-day forest limit that died off at the end of 19th century in response to climatic deterioration (polar Urals).

ure 9) correlate with rather long periods (80 to 90, 160 to 180, 250 to 260 yr) favorable for tree growth, whereas the dying off of tree stands and the lowering of the upper forest limit (Figure 10) correlate with rather long unfavorable periods. Short cyclic fluctuations of tree growth and of climate (duration of 22 to 35 and 12 yr, see curves II and III, Figure 7) do not produce significant changes in the position of the upper tree limit. The analysis of relatively long cycles of tree growth is of great importance for reconstruction of past fluctuations of the upper tree limit.

There follows a short survey of available data concerning displacements and dynamic trends of the upper forest limit in the Boreal Zone of the USSR.

## WESTERN OR ATLANTIC SECTOR

### *Khibiny Mountains*

Investigations of the vegetation of the Khibiny Mountains (Anufriev, 1922; Chechchot, 1925; Korchagina and Korchagin, 1932; Nekrasova, 1938; Solonevich, 1940; Kryuchkov, 1957) resulted in the discovery of remnants of strongly weathered thick trunks of pine and birch between 100 and 160 m above the present-day position of the upper forest limit. On this basis it was assumed that the forest vegetation was degrading at its upper limit during the present epoch. Kozubov and Shaydurov (1965) made a radiocarbon analysis of a sample of pine wood taken from a weathered trunk and determined its age as 600 ± 90 yr BP. Using this date and information on the altitudinal distribution of prostrate and erect growth forms of pine, they came to the conclusion that the last period of higher forest limit ended about 800 to 900 yr ago. During this period the upper forest limit extended to between 520 and 550 m a.s.l. in comparison to the present-day limit which is between 360 and 365 m a.s.l. Subsequent deterioration of climate caused a lowering of the upper forest limit to 230 to 300 m a.s.l. This was followed by a further rise of the upper forest limit beginning about 200 to 250 yr ago; a process that has been particularly intensive during the last 30 or 40 yr. Data collected by Kryuchkov (1957) also proves present-day advance of forests into mountain tundra areas. He observed the spread of *Betula tortuosa* to higher areas during the last 20 to 40 yr on the southern slope of Yursporlak Mountain which seemed to be the result of a warming trend. Analysis of annual tree growth in this region (Vozovik *et al.*, 1971a) showed that higher than average increments occurred during the periods 1825 to 1830, 1850 to 1860, 1925 to 1930, and about 1945. Lower than average increments were observed for 1820, 1840 to 1845, 1870 to 1915, and 1935 to 1940. On the basis of dendrochronological data, two periods of intensification of avalanche activity (1810 to 1862 and 1919 to 1960) were also identified; during these periods lowering of the upper forest limit took place on mountain slopes under the influence of avalanche destruction (Vozovik *et al.*, 1971b).

### *Western Slope of the Urals*

Explorers who worked on the western slope of the polar, subpolar, and northern Urals during the second half of the 19th and early 20th centuries collected data which indicated degradation of forests at their upper limit

(Kovalsky, 1853; Shennikov, 1923; Govorukhin, 1929; Korchagin, 1940). In the early 1940s, data on improvement of growth conditions for arboreal vegetation and on advance of forests into high-mountain tundra areas began to appear (Govorukhin, 1947; Tikhomirov, 1941; Igoshina, 1952; Ovesnov, 1952; Gorchakovsky, 1975). It was concluded that this was a reflection of the early 20th-century warming trend.

CENTRAL OR SIBERIAN SECTOR

*Eastern Slope of the Urals*

The lowering of the upper forest limit on the eastern slope of polar, subpolar, and northern Urals was noticed during the second half of the 19th and in the early 20th centuries (Kovalsky, 1853; Fedorov and Ivanov, 1886; Sukachev, 1922; Gorodkov, 1926, 1929; Sochava, 1927, 1930). A reversal of this trend has been observed since about 1940 (Govorukhin, 1947; Tikhomirov, 1941; Kuvaev, 1952; Igoshina, 1952; Gorchakovsky, 1975). In the polar Urals, the dynamics of the upper forest limit during the last 300 to 350 yr was reconstructed by analysis of the increments of old trees and the age structure of stands of open larch woodlands (Shiyatov, 1965, 1967). It was found that displacement of this borderline was conditioned by cyclic fluctuations in climate with cycles of about 160 to 180 yr. During warmer periods such as 1630 to 1690, 1780 to 1850, and 1920 to 1960, the upper forest line rose and during cooler periods such as 1690 to 1750 and 1850 to 1920 it lowered. During the last 10 to 15 yr (Shiyatov, 1974) deterioration of climate (descending branch of centurial cycle) has occurred and the first signs of degradation of tree vegetation were beginning to occur in the high mountains of the subpolar Urals.

*Putorana*

Widespread death of *Larix dahurica* stands situated lower than the present-day upper forest limit was observed in this area (Lovelius, 1970a). Dendrochronological analysis showed that the trees perished during the second decade of the 19th century; very low values of annual increments coincide with this cool period. During the last decades, especially between 1930 to 1940, a considerable increase in larch growth has occurred. It seems that climatic conditions for forest growth at the upper limit have become more favorable.

*Eastern Sayan*

Data on dynamics of the upper forest limit here are contradictory. There are indications (Kuminova, 1946; Gluzdakov, 1953, 1966) that the upper forest limit is falling at the present time. This opinion is based on the occurrence of weathered trees, patches of tree stands, as well as of typical forest plant species, and podzol-like soils, above the present-day upper forest limit. This possible lowering of the forest limit is connected with an intensive tectonic uplift of this mountain mass (up to 6 cm $yr^{-1}$) or with increasing climatic aridity. Krasnoborov (1961) who worked in the region of the Kuturchinsky Belogorye Range has not found any signs of forest limit displacement. In the upper part of the Mana River basin, Dylis (1959) found small patches of dead forests and many trees that had perished long ago but were still erect in open woodlands. In addition he found signs of the appearance of young groves in previously woodless mountain tundra areas. This was interpreted as indicative of a generally stable present-day position of the upper forest limit with small vertical displacements occurring on certain sections of slopes as a result of episodic climatic fluctuations. Replacement of light-needled coniferous forests by dark-needled forests (Krasnoborov, 1961) as well as replacement of *Pinus sibirica* by *Abies sibirica* (Dylis, 1959) were noted. Analysis of increments of five larch trees growing at the upper forest limit showed that during the last 100 to 120 yr there has been a period of intensification of tree growth connected probably with increasing warmth (Lovelius, 1966).

*Subbaikal and Transbaikal mountains*

Studies by Galaziy (1954) carried out in the Khamar-Daban Range showed that a rather intensive advance of arboreal vegetation into mountain tundra took place during the last 5 to 7 decades. During this time the upper forest limit extended between 30 and 80 m higher. This may be considered as the result of improving climatic conditions (increase in air and soil temperatures). Successful regeneration by *Pinus sibirica* above the present upper forest limit have been noticed also by Smirnov (1957) in the Khamar-Daban Range. Tyulina (1949) observed successful regeneration of *Betula ermani, Abies sibirica,* and *Picea obovata* in mountain tundra and subalpine meadows in the Barguzin Range. Panarin (1966) recorded the same for *Larix dahurica* at the upper part of *subgoltsy* belt (transition zone between forests and mountain tundras) in the northern regions of Transbaikalia (Chersky Range). As far as the high mountains of southern Transbaikalia are concerned (Borschovsky Range) there are no signs of lowering of the upper forest limit (Siplivinsky, 1975).

### EASTERN OR PACIFIC SECTOR

#### *Kamchatka*

A general displacement of the altitudinal vegetation belts was observed in the Median Range (Turkov and Shamshin, 1963). *Picea jezoensis* is intruding beneath a canopy of *Betula ermani* crook-stem open forests and *B. ermani,* in its turn, is invading the mountain tundra areas immediately above the upper forest limit. Dendrochronological studies carried out in the region of Klyuchevskaya knoll show that increase in tree growth at the upper forest limit lasted from the end of the 19th century until the 1970s (Lovelius, 1970b).

#### *Sikhote-Alin*

The present-day upper forest limit is rising slowly, although this process is restrained by the absence of soil cover on many slopes and by fires (Ponomarenko, 1961; Rozenberg, 1966; Kolesnikov, 1968; Kurentzova, 1968). Intrusion of *Picea jezoensis* and *Abies nephrolepis* into the *Betula ermani* crook-stem open forest belt and penetration of *B. ermani* into formations of *Microbiota decussata* and *Pinus pumila,* as well as into subalpine meadows, supports this contention. Tree height, growth rate, and increment have intensified during the last 30 to 40 yr. Healthy condition of young trees and absence of mass dying off of trees at the upper limits have been noted.

## CONCLUSION

Summing up the analysis of the dynamics of the upper forest limit in the mountains of the Boreal Zone of the USSR, it may be noted that apparent contradictions in data concerning the character of interrelations between forest and tundra vegetation can be explained by the concept of cyclic fluctuations of climate. Forestry studies have revealed the occurrence of climatic cycles with various amplitudes ranging between 5 to 6 and 800 to 900 yr. This has been seen in the Khibiny Mountains, in the Urals, in the northern part of Siberia, and in Kamchatka. Longer climatic cycles (thermic regime) with amplitudes of 60 to 80 and 140 to 160 yr and more, have the most significant influence on the displacement of the upper forest limit.

At the present time a slow rise in the upper forest limit can be observed in the Boreal Zone of the USSR. Most researchers relate this rise to the increasing warmth that has taken place in the Northern Hemisphere during the first half of the 20th century. However, fires and other human activities have suspended this trend in some high-mountain areas. An actual lowering of the upper forest limit may be occurring on the southern spurs of the western Sayan Mountains and in some mountain regions of Transbaikalia as a response to increasing aridy and epeirogenic upheavals. The lowering of temperature, forecasted by climatologists and heliogeophysists (Viteliye, 1962; Gedeonov, 1969) for the end of the 20th and the beginning of the 19th centuries, should produce a lowering of the upper forest limits in many mountain areas of the Boreal Zone.

The upper tree limit in the Boreal Zone of the USSR is yet but little disturbed by anthropogenic influences. But modern exploitation of natural resources in mountain areas creates a major threat. Therefore, the problem of biological conservation of areas bordering the upper forest limit demands urgent attention.

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