26 Vegetation Dynamics at the Tree-Line Ecotone in the Ural Highlands, Russia

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26.1 Introduction

Copious seedling establishment and an increase in stem density just below the actual tree line have been reported for various mountain areas around the world: North America (Kearney 1982; Jakubos and Romme 1993; Little et al. 1994; Taylor 1995; Woodward et al. 1995; Rochefort and Peterson 1996; Lloyd 1997), northern Europe (Ågren et al. 1983; Kullman 1986, 1988) and New Zealand (Wardle and Coleman 1992). A few studies have reported seedling establishment above the tree line and an upward shift of the tree line in the Urals (Gorchakovsky and Shiyatov 1978), eastern Canada (Payette and Filion 1985), and Colorado (Shankman and Daly 1988).

It has been debated whether the observed changes in growth dynamics can be related to climate change or they are within the limits of normal dynamics of the tree-line ecotone (Kullman 1988, 1989; Hättenschweiler and Körner 1995).

We investigated, by using historic fixed-point landscape photographs, changes in forest growth and possible tree line shifts in the Ural Mountains, Russia. The changes we report took place over 70 years in the South Urals and over 35 years in the Polar Urals and correlate with general warming trends in these regions. We visited mountain peaks in the South and Polar Urals and took over 500 repeat photographs between 1995 and 2000. We present four pairs; however, general conclusions are drawn on the basis of all of them.

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26.2 Materials and Methods

26.2.1 Study Areas

Repeat landscape photographs were taken of the peaks of the Bolsoi Taganai Ridge and Iremel Massif (South Urals) and of the Rai-Iz Massif, Tchernaya, Slancevaya and Yar-Keu Mountains (Polar Urals). These two regions were selected to contrast the high-latitude and low-latitude provinces of the Urals. There were many old photographs from these regions as numerous studies have been reported on their geomorphology, soils, vegetation, and on dendrochronology (Tyulina 1929, 1931; Igoshina 1964; Shiyatov 1965, 1983, 1986; Sharafutdinov 1983).

The Iremel Massif (54°32′N, 58°51′E) is the highest in the central part of the South Urals (1586 m a.s.l.). It has a rugged topography, large altitudinal amplitudes (up to 1100 m) and a complex geological structure. The amount of precipitation is over 800–1000 mm year^{-1}. Dense coniferous forests (*Abies sibirica* Ledeb., *Picea obovata* Ledeb.) predominate in valleys and slopes up to 1250 m. There are fragments of a Scots pine (*Pinus sylvestris* L.) sub-belt between 500 and 700 m. Birch (*Betula pubescens* Ehrh., *B. pendula* Roth.), aspen (*Populus tremula* L.) and larch (*Larix sibirica* L.) grow together with the other conifers. The tree-line ecotone is situated between about 1200–1400 m, with open *Picea obovata* forests and tall herbaceous vegetation occupying in the lower part and crooked spruce and birch forests (*Betula tortuosa* Ledeb.), moss-rich short grass meadows, shrubs (*Juniperus sibirica* Burgsd., *Salix* spp.), and moss-grass heaths in the upper half. The alpine zone is above 1400 m. Moss-grass, moss-dwarf shrub and moss-lichen heath communities occupy the more gentle slopes, plateaux and terraces. Steep stony and rocky slopes are covered by lichens and lithophytic communities (Tsvetaev 1960; Gorchakovsky 1975). The vegetation of the tree-line ecotone and the alpine zone is largely natural without such anthropogenic impacts as grazing, fires and logging.

The Rai-Iz Massif and Slancevaya Mountain are on the eastern macroslope of the Polar Ural Mountains (66°46′–66°55′N, 65°36′–65°49′E). They are separated from each other by the Sob River valley. The Rai-Iz Massif is a large ultramafic formation 10 km wide and 15 km long with a maximum elevation of up to 900–1100 m a.s.l. Crystalline shale makes up the Slancevaya Mountain, which is about 3x4 km in size and reaches 417 m a.s.l. This area is situated within the forest-tundra zone. On mountain slopes the tree-line ecotone is of forest-tundra (or subgoltsy) character; above the tree line there is the alpine zone, lower alpine (mountain tundra) and high alpine (the Goltsy Desert; Gorchakovsky 1975). The tree-line ecotone is found in deep valleys and slopes up to 200–300 m, with larch (*Larix sibirica* Ledeb.) and spruce-larch (*Picea obovata–Larix sibirica*) open forests dominating with patches of closed larch-spruce forests with birch (*Betula tortuosa*). A dense scrub of *Alnaster fruticosus* Rupr. often covers the crystalline shale and gabbro slopes. Bushes of different *Salix* species (*S. lanata* L., *S. phylicifolia* L., *S. glauca* L., *S. lapponicum* L.) usually occupy the wettest sites. The shrub layer is mainly represented by *Betula nana* L., *Vaccinium uliginosum* L. and *Ledum decumbens* (Ait.) Small. The alpine zone between about 250 and 650 m is represented by different types of dwarf-shrub heath communities with numerous lichen and moss species. Snowbeds and well-irrigated sites are dominated by meadows. The Goltsy Desert, the approximate upper limit to higher plants, is above 650 m where the vegetation is represented by fragmentary moss-lichen communities with some scattered small herbaceous plants.

26.2.2 Long-Term Weather Data

Based on observational data between 1890–1999 from Zlatoust, South Urals (Fig. 26.1) and Salehard, Polar Urals (Fig. 26.2) weather stations, it was estimated that winters, on average, have become about 4 °C warmer in the Polar Ural area and 3 °C warmer in the Middle to South Urals. Summers for the same period showed smaller changes: 1.4 °C in the Polar Urals and 0.6 °C in the South Urals.

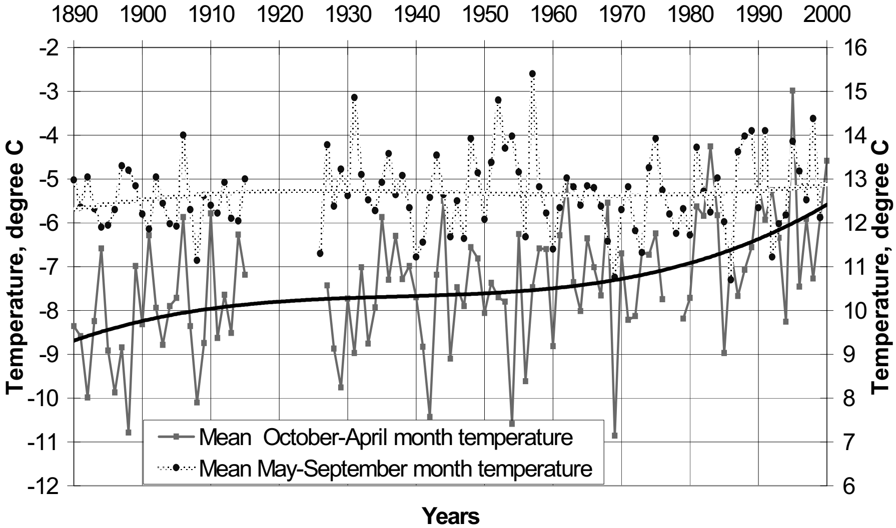

Fig. 26.1. May–September and October–April temperatures at Zlatoust, South Urals, Russia, between 1890 and 1999

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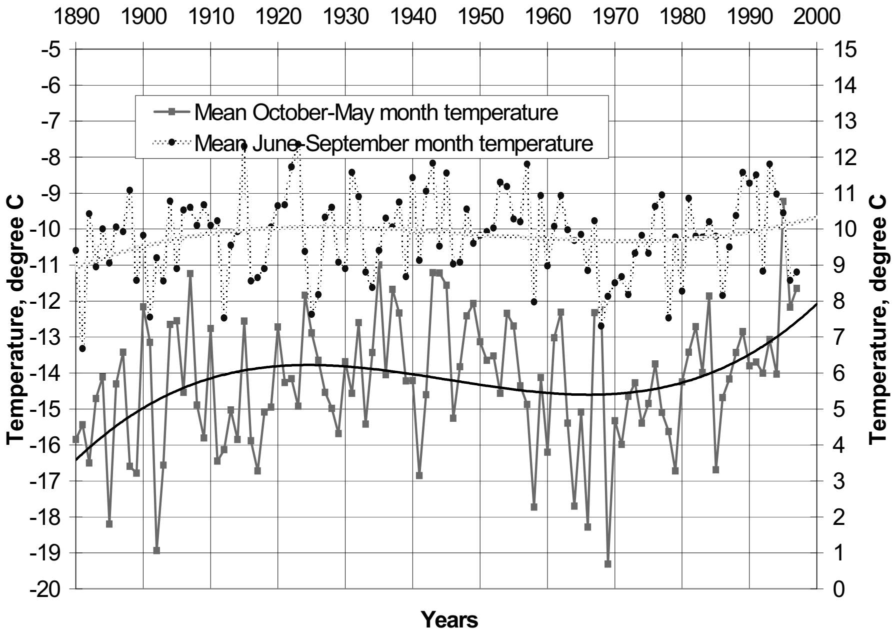

Fig. 26.2. June–September and October–May temperatures at Salehard, Polar Urals, Russia, between 1890 and 1997

26.2.3 Repeat Photography and Image Analysis

From landscape photographs it is possible to estimate many qualitative and quantitative parameters of past and present woody vegetation (such as stand composition and density, cover of tree and bush layers, growth form, height and diameter of trees, fructification). The comparison of old photographs with recent ones may give an indication of the degree of regeneration and mortality of trees, forest cover, and displacement of borders between forest and non-woody communities.

The baseline for comparisons was provided by old photographs taken by L.N. Tyulina in 1929–1931, K.N. Igoshina in 1956–1960 and by S.G. Shiyatov in 1960–1969. Repeat photographs and evaluation of vegetation changes were made in 1976 and between 1996–1999. The location of the points from where the original photographs were taken was made with the help of prints of the original photographs, which were also used to make an on-site evaluation of any vegetation change. The original camera positions were determined by seeking and overlapping the most noticeable, outstanding landmarks (rocks, hills, summits) of different line of horizon. On establishing a point we took a repeat photograph and estimated, calculated and measured different vegetation parameters depending on distance from the photo point to the objects.

Because the same objects were described from different photo points and therefore different distances, the data obtained were corrected and verified twice or more times. Occasional field truthings of visual estimates were made.

In addition to the field comparisons, comparisons of the scanned images of the original and repeat photographs were made by using Adobe Photoshop v5.2 software. We superimposed the two or more images and verified data obtained in the field. We contoured altitudinal lines of former and contemporary borders of closed and low open forests and calculated their altitudinal and horizontal displacement.

26.3 Four Examples of Photo Pairs

The comparison of current and past vegetation showed that trees have regenerated vigorously in low open forests and established in former sites dominated by meadows and moss heath communities over the last 70 years. This is quite clear from an analysis of the image pairs in Figs. 26.3–26.6.

The first pair was taken in 1929 and 1999 (Fig. 26.3) from above the upper limit of low open forest (1490 m) on the abrupt north-west-facing slope of Bolshoi Iremel Peak, South Urals. We estimated that the closed forest on the saddle in the middle of the photograph, behind the bouldery slope in the foreground, has advanced upslope from 1260–1270 to 1320–1330 m since 1929. Spruce (*Picea obovata*) elfin and low open forests became closed (from 10–30 % up to 50–80 %). Trees grew four to six times higher from 1–2 to 6–8 m and their stem forms changed from contorted to shrubby and upright forms (obtained from other photo points). In 1999, many new individuals of spruce were apparent on previously open ground up to 1380–1410 m. There was also an increase in the areas occupied by closed spruce forests on the south-facing slope of the western spur of Maly Iremel from 1220–1230 to 1280–1310 m a.s.l. (far mountain on extreme left-hand side of Fig. 26.3).

The second pair was taken in 1929 and 1999 (Fig. 26.4) from a small hill (1335 m a.s.l.) on the northern slope of Bolshoi Iremel (flat area with a rock in the foreground). Large differences can be observed in the vegetation on the intermountain saddle running from Bolshoi to the far mountain of Maly Iremel (in the second line) and on the south-west-facing slope of Maly Iremel (on the left-hand side in the background). In 1929, there were many gaps and the *Picea obovata* forest had a cover of about 50 %. In 1999, closed (up to 90 % canopy cover) *Picea obovata* or *Betula tortuosa* forest dominated. Forest cover on the south-west-facing gentle slope of Maly Iremel increased greatly. We estimated that there was an upward shift of the upper forest limit of about 60–80 m along 600–900 m of horizontal front: low open forest from 1280–1300 up to 1340–1360 m and closed forest from 1220–1230 up to 1300–1310 m. The upward movement of closed forest involved an increase from 20 % to 60–70 %

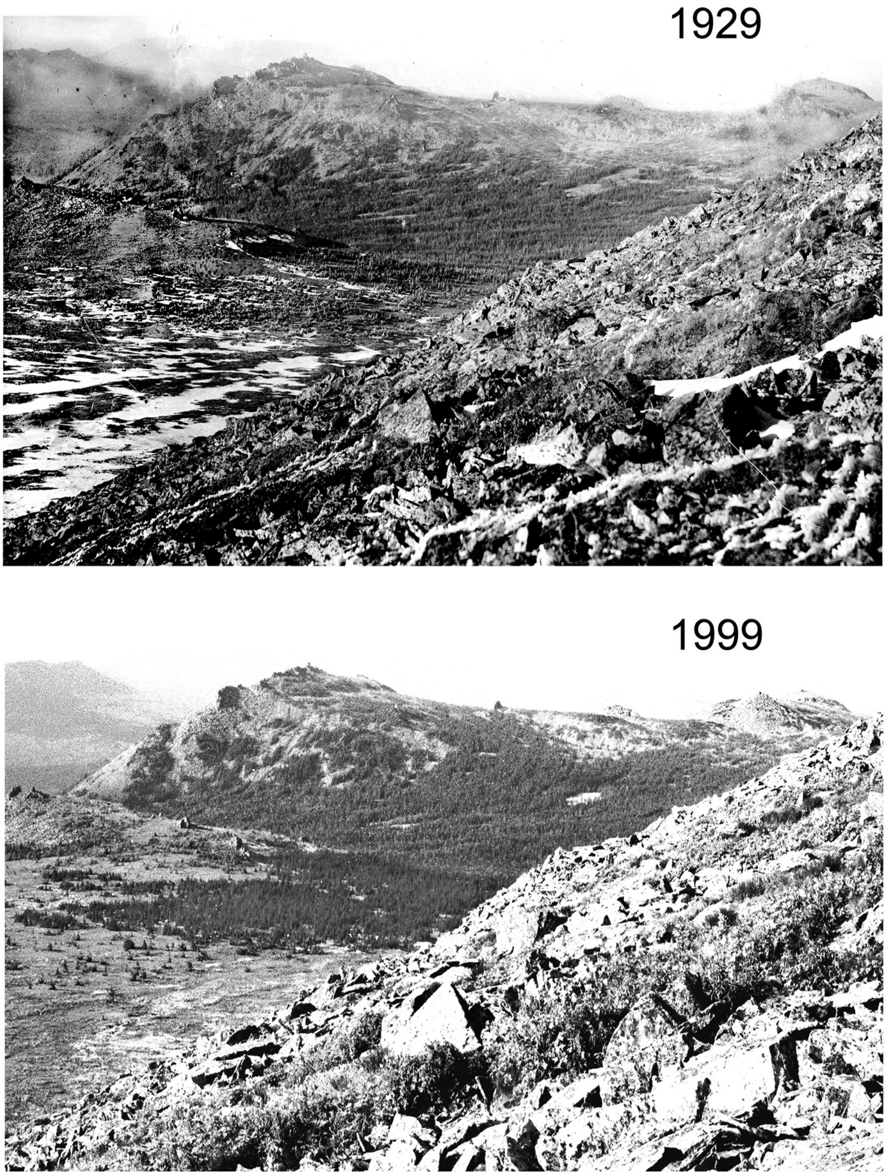

Fig. 26.3. Repeat photographs of the north-facing slope of Bolshoi Iremel Peak, Southern Urals, and the south-facing slope of the western spur of Maly Iremel, taken in 1929 and 1999. In the *foreground*, stony slope; *middle distance*, saddle and summit with cairn marking altitude (1335 m a.s.l.); *far distance*, western spur of Maly Iremel

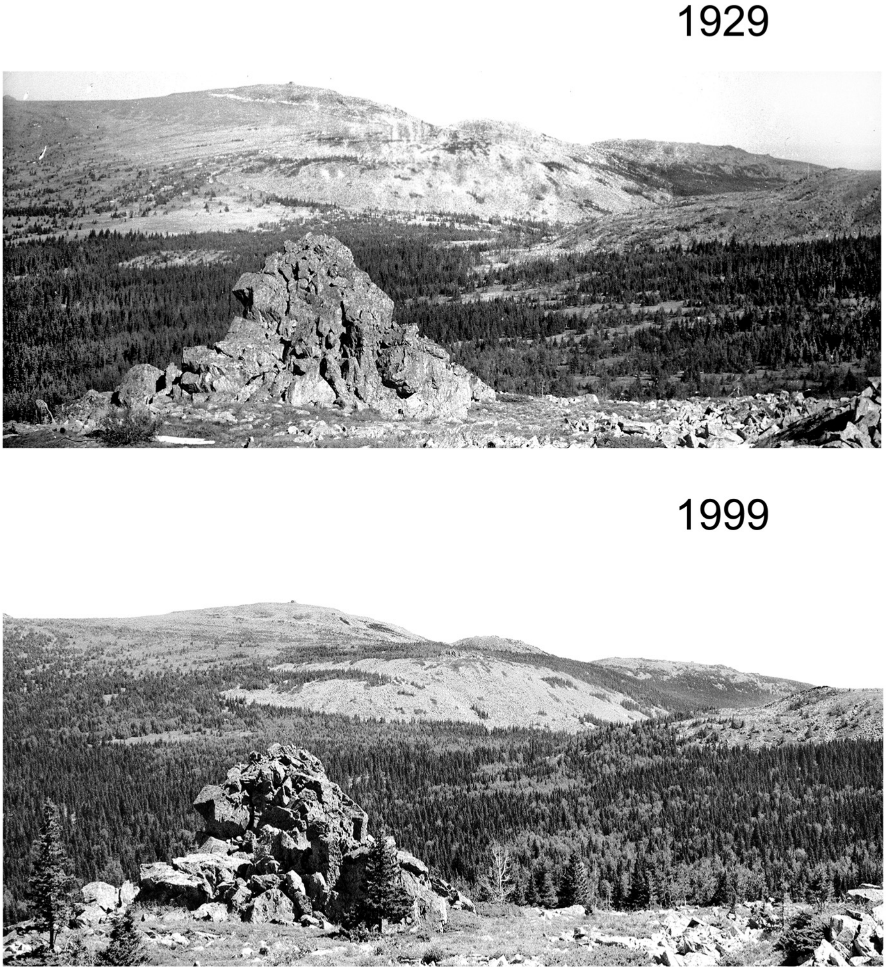

Fig. 26.4. Repeat photographs taken in 1929 and 1999 of the saddle between Bolshoi and Maly Iremel and of the northern extremity of the north-eastern spur of Bolshoi Iremel (*middle distance*) and of the gentle south-west-facing (*left*) and stony south-facing (*right*) slope of Maly Iremel (*far distance*). Pictures taken from a small horizontal platform (with a rock in the foreground) located on the northern slope of Bolshoi Iremel, Southern Urals

in cover in the formerly open forest. Meanwhile a concurrent increase in canopy closure was estimated from 50 % to 80–90 % in the closed forest. An upward shift of open and closed forest boundaries by up to 20–40 m along a 100–300 m horizontal stretch is also well visible on the southern stony slope of Maly Iremel (on the right-hand side in the background).

The third pair is of the south-eastern slope of the Rai-Iz Massif, the Polar Urals (in the background), taken in 1962 and 1997 (Fig. 26.5) from the north-

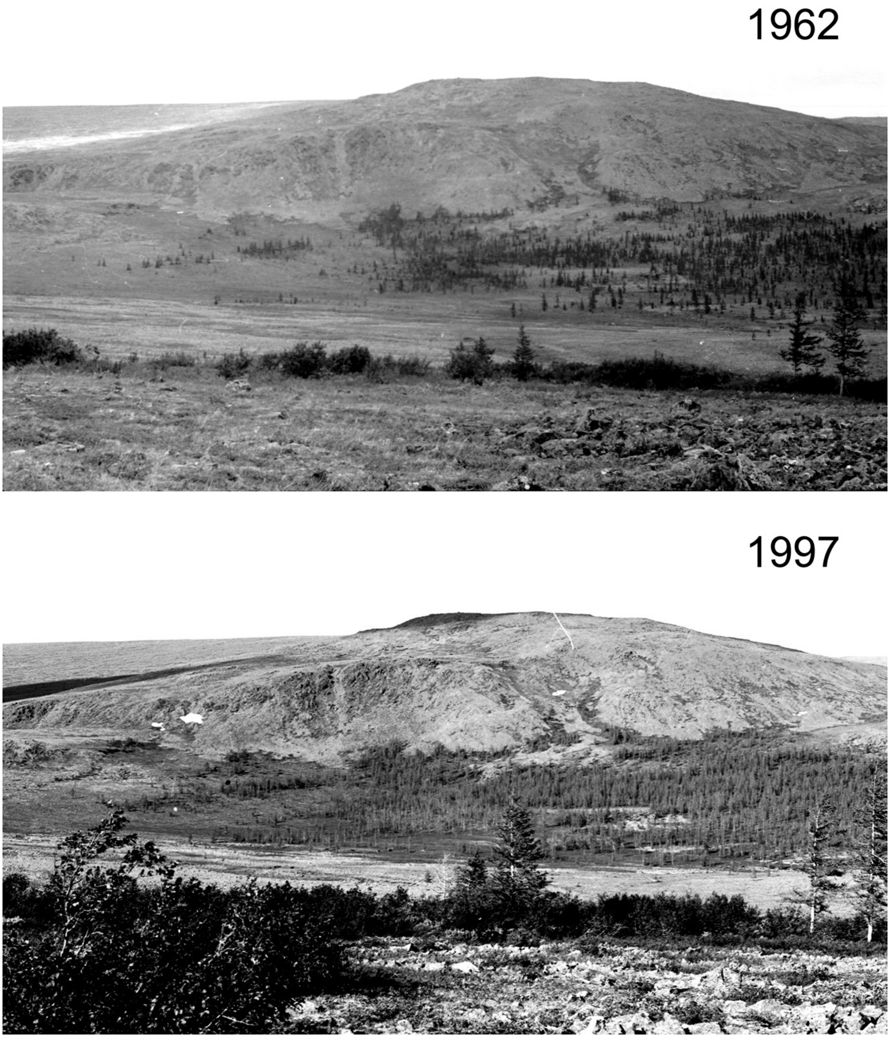

Fig. 26.5. Repeat photographs taken in 1962 and 1997 of the south-eastern slope of the Rai-Iz Massif, Polar Urals

ern slope of the hill, at an elevation of 300 m. There is a woodless valley bottom in the middle distance. The upper limit of *Larix sibirica* open forest is between 280–350 m. A large increase in canopy cover from an initial 20–30 % to 50–70 % occurred on the south-eastern slope between 1962 and 1997. At the same time, the average tree height increased from 8 m to 11–12 m. On gentle slopes of the Rai-Iz Massif the upper open forest communities boundary moved upwards to 20–40 m (obtained from other photo points). The cover and height of the alder layer have increased significantly and young individu-

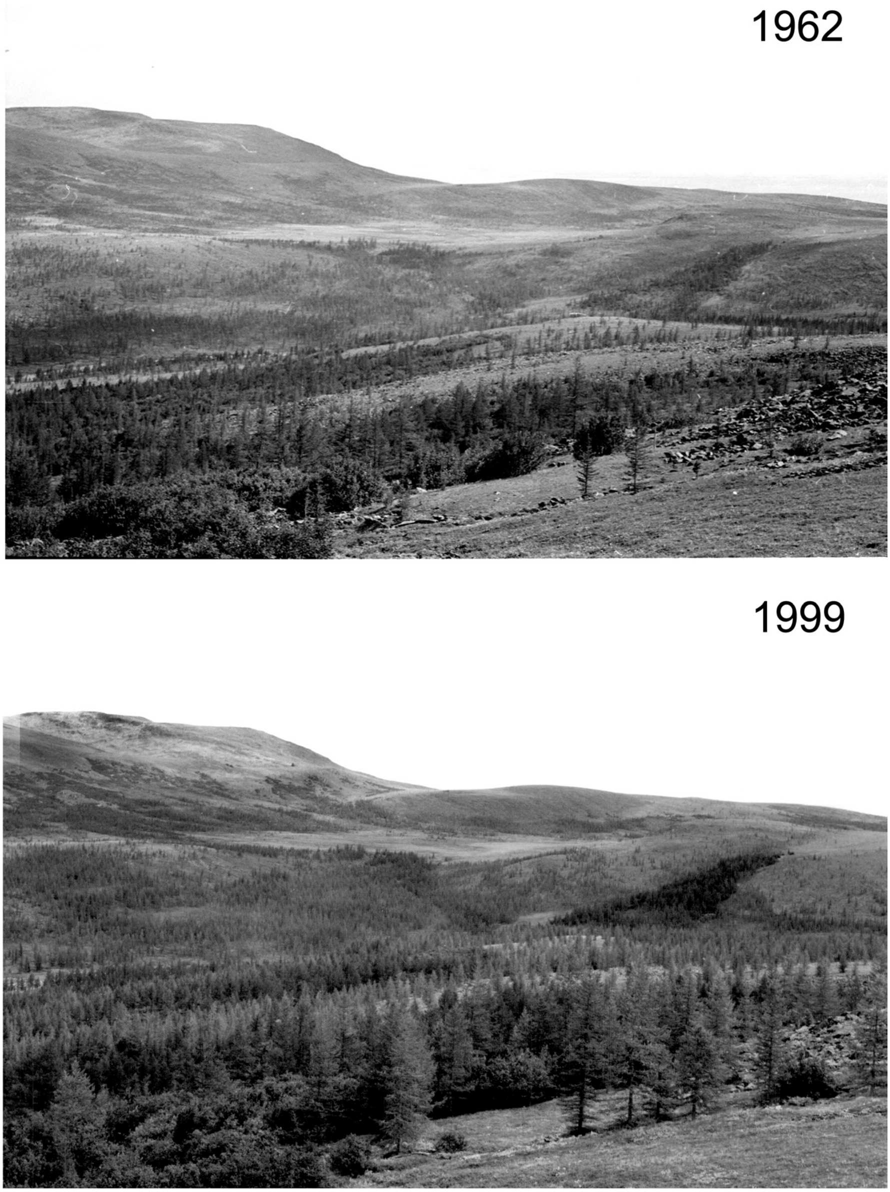

Fig. 26.6. Repeat photographs taken in 1962 and 1999 of the north-eastern slope of Slancevaya Mountain (220 m a.s.l.), Polar Urals. *Larix sibirica* growing at its upper limit in the foreground and in the background

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als and patches of *Alnaster fruticosus* occupied many previously open sites in 1997.

The fourth pair was taken of the Slancevaya Mountain, Polar Urals (ca. 220 m) in 1962 and 1999 (Fig. 26.6) from the north-eastern slope. The upper tree line forming species is *Larix sibirica* and the dark patches are dense alder scrub (*Alnaster fruticosus*). The cover of larch stands increased at least two-fold between 1962 and 1997. Larches occupied many open sites and formed open stands at the upper former tree line.

26.4 Discussion

The comparison of historic landscape photographs is relatively rarely reported, as it is often difficult to determine the exact points from where the original photographs were taken (Kullman 1979; Shiyatov 1983). After examining more than 500 historic photographs from the Ural Highlands, we judged that the method was suitable for a study of vegetation dynamics because there are readily identifiable landmarks which make camera orientation relatively easy. Overall, there appeared to be abundant and vigorous regeneration present with few standing and fallen dead trees all over the Ural Highlands. There appeared to be a remarkable upward shift of the upper limit of open forest, especially on gentle slopes. *Picea obovata* (South Urals) and *Larix sibirica* (Polar Urals) have regenerated and propagated best and increased their relative cover. On gentle slopes with well-developed soil, upper limits of closed and open forests were estimated to be up to 60–80 m higher in the South Urals than 70 years earlier and by 20–40 m higher in the Polar Urals than 40 years earlier. A clear increase in forest canopy cover along the contours of up to 600–900 m over the last 70 years could be detected in the South Urals. In less favourable conditions on the steep boulder fields, or in damp hollows, an upward shift of up to 20–40 m altitudinal and 100–300 m of horizontal expansion were estimated in the South Urals.

Weather data has shown that at the end of the nineteenth and the beginning of the twentieth century, on average, the mean monthly temperature for May–September (warm season) was about 12.3 °C and October–April (cold season) was about –8.7 °C, indicating a cold climate in the South Urals (Fig. 26.1). In the Polar Urals the mean June–September temperature was about 8.9 °C and October–May temperature was –16.4 °C for the same period. From that period until c. 1960, a general warming occurred. In the South Urals the increase for warm seasons was c. 0.4 °C and for cold seasons c. 0.9 °C. In the Polar Urals warming was more pronounced: 1.2 °C for warm seasons and 2.6 °C for cold seasons on average. In the 1960s and early 1970s, a slight summer cooling occurred, which was more marked in the Polar Urals. Finally, warm season temperatures increased up to about 12.9 °C in the South Urals and up to about 10.3 °C in the Polar Urals by the late 1990s. In the Polar Urals, cooling by 0.9 °C was also apparent for cold seasons, followed by a period of sharp warming to about −12.1 °C at the present time. There were gradual changes to the cold seasons, i.e. a warming from −7.6 up to about −5.4 °C since 1930 to present in the South Urals.

The warm and relatively wet climate of the twentieth century appears to have resulted in an improvement in conditions for the growth and survival of woody plants at the upper limit of their distribution. This may explain the abundant tree regeneration and their establishment at the tree-line ecotone and including the lower alpine zone, especially between 1960 and 2000. Expanding forest cover reduced the area of grasslands and alpine heath in the alpine zone by about 10–30 %.

26.5 Conclusions

1. Landscape-scale changes in montane forest growth in the Urals, Russia, were analysed by using repeat photography. The changes reported took place over 70 years in the South Urals and over 35 years in the Polar Urals and correlate with general warming trends in these regions.
2. There was an abundant regeneration and increase in the relative cover of *Picea obovata* (South Urals) and *Larix sibirica* (Polar Urals). The line of closed forest appeared to have advanced up to 60–80 m higher than it was 70 years earlier in the South Urals and by 20–40 m higher than 40 years earlier in the Polar Urals.
3. The closing of open forest and expansion appear to have reduced the area of non-woody vegetation in the tree-line ecotone by about 10–30 %.

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