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ANTHROPOGENIC SHIFT IN THE UPPER BOUNDARY OF THE FOREST ZONE AND ITS PHYTOINDICATION

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The degree and the consequences of lowering the upper border line of forest vegetation in the mountains in consequence of man's activity, the differences between anthropogenic and natural boundaries, and the factors and types of anthropogenic degradation of the upper boundary of forests are discussed. Methodological bases of phytoindication of the deviation of the actual from the potential boundary for estimating the ecological situation in high mountains are defined.

The upper boundaries of mountain forests are highly diverse with respect to the composition of dominating types of woody plants, structure and environmental interaction of forest communities reaching the upper limit, as well as the degree of disruption of plant communities which form the upper border line of the forest under the effect of anthropogenic factors (Gorchakovskii, 1975; Gorchakovskii and Shiyatov, 1977; Plesnik, 1971; Troll, 1973; Holtmeier, 1967, 1974).

At the upper boundary of the forest a contact is observed between the forest (various classes of low forests) and nonforest (shrubbery, undershrub, lichen—moss, and herbaceous) communities, and between them, a zone of struggle for existence. At their point of contact, the forest and nonforest communities remain in a dynamic, disturbable equilibrium. They react sensitively to the smallest changes in the conditions of the medium. The effects caused by man's activity (felling, fires, grazing of cattle, haymaking) affect forest vegetation particularly negatively, and it can therefore be asserted that man acts consciously or unconsciously against forest communities, but favors the competing nonforest communities.

Recently, the study of the upper forest boundary has inspired not only botanists and silviculturists, but also geographers, zoologists, climatologists, glaciologists, and pedologists. This is due to the significance of the upper boundary of forests as an important botanical and geographical, as well as biogeographical border line, and to the possibility of its use as indicator of environmental conditions and natural processes taking place in high mountains.

At their upper limits, the forest communities are extremely unstable, their position is insecure and therefore, the forest boundary is easily vulnerable. The present position of the upper border line of forest vegetation (the actual upper boundary of the forest) may differ considerably from that level at which this border line would have been located, had the anthropogenic influence been excluded (potential forest border line).

In some mountainous regions (Alps, Carpathians) the range of distance between actual and potential forest boundaries reaches in places 400-500 m and over (Holtmeier, 1974; Plesnik, 1971; Midriak, 1976; Schiechtl, 1967). With the increase of this gap, the intensity of torrents, avalanches, and water erosion of the soil also increases, and the area of productivity of upland pastures is reduced, which negatively affects stockbreeding, hunting industry, and recreational use of upland territories. There are places where mountain roads, bridges, electric supply lines, settlements, and tourist bases are exposed to the danger of destruction. Intensification of water erosion of the soil, resulting from destruction of forests at their upper limit, creates a threat to the existence of remnants of highland foresters. Thus, in the Western Czechoslovak Carpathians, the forests on 13% of the area of the considerably lowered present day upper boundary are under threat of destruction (Midriak, 1976). In this connection, in order to fight against elemental calamities, necessity has already arisen to lift the upper boundary of the forest to its potential level, reestablish-

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ing the highland forests. Investigations and experimental work in that direction are conducted in many countries (Austria, Federal German Republic, Czechoslovakia, USSR, and others).

The position of the actual upper boundary of the forest in relation to the potential, the state of forests at their upper limits, reflect the general ecological situation in the uplands caused by the intervention of man in the course of natural processes. The phytoindicational study of the upper forest boundary provides data for estimating the degree of disturbance of the ecosystems and biotopes in the uplands under pressure of anthropogenic factors, as well as for substantiating the measures for restoration of upland forests to their potentially possible level in order to fight against water erosion of soils, torrents, and avalanches.

ANTHROPOGENIC UPPER BOUNDARIES OF FOREST AND HOW THEY DIFFER FROM NATURAL BOUNDARIES

Within the range of Northern Eurasia, the influence of man on the upper border line of forest vegetation is apparently of longest duration and greatest intensity in the densely populated regions of the Alps. According to the data of Holtmeier (1974), in the valleys of cental Alps, anthropogenic influence on the upper boundary of forests had already begun in the Bronze Age and increased gradually as cattle breeding and agriculture developed, reaching its maximum in the Middle Ages. In the densely populated valleys in the Alps, climatic conditions and sharply divided topography limited the living space of the people. Therefore, agriculture and stockbreeding were concentrated primarily on high altitude levels corresponding to the originally wooded territory. In a number of places in the cental Alps, under the influence of man, total deforestation took place on the southern slopes, most favorable for farming, and partial deforestation of most accessible places (moderately sloping hill sides, sides of valleys, terraces, etc.) on the slopes with other orientation. In some high altitude regions, the forest was destroyed in connection with mining developments, mining of rock salt, and charcoal burning. The forests at their upper limits gave way to alpine pastures. Considerable lowering of the upper boundaries of forest took place also in the Maritime and the Ligurian Alps. In place of destroyed high altitude forests, xerophilous herbaceous communities were formed, where no tree species could settle (Barbero, 1966).

On the shores of the fjord and in the isles of Fennoscandia, anthropogenic influence on the upper boundary of forests began during the first century of our era, when that territory was captured by Norwegian settlers, and in the Finnish Lapland, only some 400-500 years ago, with transition of the Lapps from hunting and fishing to nomadic reindeer husbandry. Both in northern Norway and in Finnish Lapland, man's influence on the upper limit of forests was manifested to a considerably lesser extent than in the Alps, however, here too, the upper boundary of forest bears traces of fires, sheep and reindeer grazing, and forest felling (Holtmeier, 1974).

In the Western Carpathians the destruction of forests at their upper limits was intensively carried out starting with the 13th century, firstly in connection with cattle and sheep grazing, burning and clearing of carpeting bushes of *Pinus mugo*, and afterwards, in connection with the production of tar and ethereal oils. The destruction of the upper boundary of the forest was manifested particularly strikingly on the gentle slopes formed from basic rocks, where conditions for livestock grazing are most favorable (Plesnik, 1971, 1976; Zatkalik, 1973). In the Eastern Carpathians that process started in the 14th century (Kolishchuk, 1966). Mainly under the effect of sheep grazing and in connection with enlargement of the area of mountain pastures, the boundary of forest in High Tatra descended during the last few centuries on average by 180-220 m, in Belansk Tatra by 280 m, in Low Tatra by 50-160 m, in Western Tatra by 100-150 m, in Great Tatra by 150-200 m, and in Lesser Tatra by 260 m. The maximal descent of the boundary in individual places reaches 400 m (Midriak, 1976).

In the Caucasus, cattle ranching has been practiced for many centuries or even for millenia (Gulisashvili et al., 1975; Khapaev, 1976). A particularly intense pasturage degradation of forest communities in the uplands took place during the last century (Gadzhiev, 1962; Kuliev, 1974; Khapaev, 1974), which in places caused substantial lowering of the upper level of forests.

While in some mountainous regions (Alps, Carpathians, Caucasus), the forests at their upper limits have been subject to man's influence over several centuries or even millenia, in other regions (Ural, Sayans) they remain untouched or almost untouched up to the present time.

TABLE 1. Alternative Symptoms of Natural and Anthropogenic Upper Boundaries of Forests

Natural	Anthropogenic
Reach the possible for the given region, climatically and edaphically determined, maximum level.	Are below the level possible for the given region.
Gradual transition from forest to nonforest communities (with increasing elevation, the height of trees, their thickness, and their increment are gradually reduced, the stands become increasingly thinner).	Transition from forest to nonforest communities is abrupt (trees at the upper range are comparatively high and thick, growth vigorous, stands dense).
Woodless communities above the forest boundaries are similar in their composition and structure to the lower strata of shrub forests (incumbent series of associations find expression).	No similarity is observed between woodless communities above the forest boundaries and the lower strata of the shrub forest (no incumbent series of associations).
Belt of shrub forest is well developed.	The belt of the shrub forest is represented fragmentarily (mainly on fairly inaccessible sections of slopes) or is absent.
Above the forest boundary only individual trees are encountered, primarily of fruticose or prostrate form of growth.	Above the forest boundaries, forest islets are encountered with fairly large trees displaying straight trunks.
With increasing elevation, reforestation sharply fades away above the forest boundary.	On sites where anthropogenic influence is reduced, vigorous reforestation above the forest boundary is observed.
Above the forest boundary, shrub thickets, mesophilous meadows or tundras are common.	Above the forest boundary spread rough meadows and wastelands composed of many forest and weedy plants.

In this connection, the upper boundaries of forest should be divided into two large groups: natural and anthropogenic. Their differentiating traits are shown in Table 1.

FACTORS AND TYPES OF ANTHROPOGENIC DEGRADATION OF THE UPPER LIMIT OF FORESTS

On the upper boundary of mountain forests act various anthropogenic factors: pasturage of livestock, hay cutting, tree felling, fires, waste products of industrial concerns, recreational activity. Sometimes, some of these factors act jointly in various combinations. Nevertheless, it is usually possible to distinguish the main factor which exerts decisive influence on the nature and position of this botanic-geographical border line. Depending on the main factor, we can distinguish the following types of anthropogenic degradation of the upper forest boundaries: pasturing, hay mowing, forest felling, pyrogenic, technogenic, and recreational.

Pasturing Type. This type is formed as a result of degradation of the forest vegetation on its upper limit under the effect of summer grazing of domestic livestock (sheep, goats, cattle, reindeer) and of animals protected by man (bison, mountain goat, chamois). This is the most widely spread type of upper forest boundaries in many mountainous regions. The grazing season in the upland lasts usually no more than 3-3$^{1}/_{2}$ months. The animals damage the shoots and young growth of woody plants, deform the trees' crowns, compact the soil and enrich it with nitrogen. Particularly intense is the destruction of young growth of deciduous woody plants (Kolishchuk, 1966). Discontinuation of renewal of vegetation under the canopy of open woodlands and Krummholz leads eventually to the disappearance of the tree stratum and to lowering of forest boundary.

In place of contracted forests, secondary grasslands of low productivity and heathlands are formed, as well as matgrasses, bilberry heaths, tussock-grass meadows, docks and weed aggregations (Schiffers, 1953; Gadzhiev, 1962, 1974; Komendar, 1966; Malinovskii, 1966; Abachev, 1971; Cherkesov and Teberdiev, 1974; Schiechtl, 1967; Plesnik, 1976). Along livestock driveways and on resting places, the vegetation is destroyed almost totally, which on steep slopes leads to soil erosion losses. The grass swards on postforestial pastures are of low density and heterogenous structure. The below-ground mass exceeds considerably the above-

TABLE 2. Types of Anthropogenic Degradation of the Upper Boundary of Forest and Their Characteristic Features

Type	Factors of degradation	Main features
Pasturing	Damage to young trees and young growth (as a result of trampling down and grazing by both domestic animals and those protected by man)	Young trees with grazed-off foliage and deformed crowns; absence of live branches in high trees up to the level of 2.0 to 2.5 m; predominance of rough postforestial meadows and wastelands, reduced density of grasslands, low shoot development; scantiness of plants palatable for cattle, abundance of synanthropic plants including nitrophilous species; great number of plants resistant to trampling, unpalatable and inedible toxic and prickly plants; increased heterogeneity of vegetative cover resulting from destruction of the sod and formation of groups of cattle resting places; considerable predominance of the underground phytomass over the aboveground one; scantiness and damage of young growth and its parterre distribution outside the paths.
Hay mowing	Destruction of shoots and young growth during hay cutting,	Absence and scantiness of young growth; dried up or regenerating basal parts of young woody plants which were cut during mowing; predominance of meadows with forest plants in their composition; abundance in the sward of plants resistant to mowing, in particular, grasses; presence of weedy plants, particularly on sites of ricks and straw stacks; parterres of shrubs with traces of undercutting along the peripheries.
Felling area	Felling of trees for preparation of fuel and building materials, clearing of forest covered areas for agricultural land, roads, buildings, and industrial structures.	Trunks and logs with traces of ax or saw; meadowy forest glades and wastelands of regular geometrical shape (felling areas); individually standing large trees or parterres; fragments of groupings characteristic for burnt clearings on sites of burning the felling waste; secondary postforestial groupings of photophilous tall or intermediate herbaceous vegetation; presence of weedy plants, particularly in the vicinity of buildings and dumps.
Pyrogenic	Destruction or damage of trees by fire.	Remains of burnt trees; traces of fire damage on the trunks of live trees (pyric dry patches, etc.); charcoal on the soil surface and its upper horizons; mass development of plants characteristic for the forest burnt areas and requiring increased ash content of the substrate; secondary postforestial groupings of herbs and shrubs, characteristic for burnt forest areas.
Technogenic	Destruction or damage of trees as result of industrial pollution of air and soil.	Dead standing trees and dying with dry tops and traces of damage on foliage by aerosols from industrial plants; reduction of annual increment of trees in height and in diameter; absence or low

TABLE 2 (continued)

Type	Factors of degradation	Main features
		development of epiphytic lichens on barks of trees.
Recreational	Destruction of trees and young growth, compaction of soil in resting areas	Sharp contrast between synanthropic vegetation along the paths, ski tracks, on the peripheries of camping areas, etc., and the almost natural outside of greatly frequented places; abundance of plants resistant to trampling down on paths, sports grounds and camping sites; group distribution of young trees outside the network of paths, tracks, etc., delayed growth of trees in height and in diameter, dying off of their tops.

ground mass (Prilipko et al., 1974). Species composition of grasslands is greatly changed: Species which are palatable and nonresistant to treading (predominantly representatives of tall herbaceous vegetation) disappear or become scanty. In the mountains of the Polar and Subpolar Ural, Central and Eastern Siberia, where grazing of caribou is conducted, the lichen cover is destroyed in the first place (Igoshina, 1937, also Authors' own observation). The role of unpalatable plants (prickly, toxic) and those species which are resistant to trampling, aswell as of plants of open and steppe habitats (Gadzhiev, 1962) increases in these pastures. The weeds of field and forests, cosmopolite plants, appear in great number, particularly in places used as resting places by the livestock, where peculiar weed groupings are formed (Schiffers, 1953; Gadzhiev, 1962, 1974; Vagabov, (1974). The resting places are usually changed from year to year, therefore, the weed groupings cover considerable areas. For instance, in the uplands of the Caucasus, per 100 ha of pastures there are 5-6 (8) resting places, each of which covers an area of the order of 800-1000 m^2 (Gadzhiev, 1974).

Reestablishment of forest communities on the sites of secondary grasslands and heathlands after grazing is discontinued takes place comparatively rapidly. Colonies in the Carpathians are at first overgrown with shrubs, and then shoots of spruce appear (Kolishchuk, 1966). If the soil was preserved and the grass sward is not very high and dense, then usually after 10-15 years a lot of viable regrowth appears (Komendar, 1966; Adygezalov, 1971; Khalikov and Shekileev, 1971; Gulisashvili et al., 1975). When the soil is lost through erosion, reestablishment ot previous vegetation is long delayed. Often the reestablishment of initial vegetation occurs through the change of the tree species, the forest generators. Thus, in the Carpathians, beech forests are regenerated through a stage of spruce (Kolishchuk, 1966). In the Lesser Caucasus, the strongly eroded slopes are first grown over by birch, willow, rowan, and juniper. Later spruce settles in, and subsequently, as the soil layer is formed, the pine forests are replaced by Krummholz hornbeam-beech communities (Khalilov, 1974).

Hay Mowing Type. This type is strongly marked mainly in southern mountains (Caucasus, Tyan-Shan, Central Ural) where the area of hayland has been increasing because of the destruction of upland forests. In the Caucasus, the subpalpine postforestial meadows are the main source of hay making (Gadzhiev, 1974). However, in pure form, this type is not often encountered, since in spring and autumn livestock is sometimes grazed on haylands. During hay-mowing, shoots and young growth of woody plants are destroyed. Although mowing itself does not lead to destruction of mature trees, the absence of regeneration leads eventually to replacement of forests by meadows, which results in lowering the upper boundary of the forest.

Frequently repeated mowing of the sward exerts considerable influence on the renewal of herbaceous plants. For some species (leguminous and Cruciferae), this influence is negative, for others (Gramineae) it is positive. Annual mowing also causes impoverishment of the soil and deterioration of decomposition conditions of dead vegetable matter (Gadzhiev, 1974). Fairly productive herbal-grassy meadows are formed as a result of mowing (Shiffers, 1953; Gadzhiev, 1974). On hay fields many weedy plants appear, particularly on sites of ricks and straw stacks.

After discontinuation of mowing, reforestation on the hay fields occurs comparatively rapidly, and shoots appear first of all around forest edges.

Felling Area Type. This type is widely represented in mountainous regions, where at the upper limit of forest vegetation felling and grubbing both of individual trees and of entire stands and islets of forest were or are conducted. According to the testimony of V. I. Komendar (1966), in the Ukrainian Carpathians upland forests were felled to build dwelling for herdsmen (kolib), for fuel, and to make shingles. The wood was frequently used inefficiently. Before felling, the trees were usually ringed. Areas occupied by ringed trees run into several hectares. In the Carpathians, the beech forests suffered more from felling than the spruce forests (Yaroshenko, 1951). In the 19th century in the Eastern and Western Carpathians, large areas of mountain pine (*Pinus mugo*) and Swiss stone pine (*Pinus cembra*) were felled for production of ethereal oils (Plesnik, 1976). This has undoubtedly led to the lowering of the upper forest boundary. Also in the Caucasus (Gadzhiev, 1962; Makhatadze and Urushadze, 1972; Gulisashvili et al. 1975) subpalpine forests were felled at a rapid rate.

After destruction of upland forests, meadows and wastelands are usually formed. Sometimes shrub thickets are also formed. In the Caucasus *Calamagrostis arundinacea, Brachypodium silvaticum,* and *Agrostis capillaris* predominate on sites of recent forest felling (Gadzhiev, 1962). Where the soil has been preserved, and also if the plots are no longer used as hay fields and pastures, forest vegetation is gradually reestablished. Restoration of the original type of vegetation frequently passes through the succession of forest-forming species. For instance, in the Carpathians on sites of massive fellings, beech reestablished itself through the stage of spruce (Kolishchuk, 1966).

Pyrogenic Type. This type is characteristic for regions where the forests were submitted to the action of fire at their upper boundary. The fires start most frequently in the forest belt and then, moving up the slopes, reach the upper boundary of the forest. In most cases, fires start through the fault of men (careless management of fire, burning of forest and shrubberies to enlarge pastures and honey collecting plots); considerably less frequently, by natural means (stroke of lightning).

Fire destroys the vegetation totally, or inflicts severe damage, causing lowering of the forest's upper boundary. Traces of fire (remnant of burnt trees, charcoal, dryness caused by it) remain for a long time. Thus, Billings (1969) had found in 1967 trees which were destroyed by fire in 1809, i.e., they stood for some 160 years. The degree of destruction of the vegetation cover under the effect of fire depends on many factors (type of fire, meteorological conditions, state of the vegetation, mass and height of the mountains). In a dense krummholz coniferous woodland, the ground fire usually transforms into a crown fire (Billings, 1969; Molozhnikov, 1975). The combustibility of subalpine and subgoltsian shrub forests depends particularly strongly on the degree of the climate's oceanic or continental character. In regions with moist and moderately continental climate (Carpathians, Urals, humid part of the Caucasus), fires at the forest upper boundary develop comparatively rarely, only during particularly dry years and in certain units of associations, for instance, in the pine forests of Caucasus (Leskov, 1932). In regions with strongly continental climate (Central and Eastern Siberia, Altai, Sayans), fires at the upper forest boundary are a regular feature (Sapozhnikov, 1901; Kuminova, 1960; Tyulina, 1962). Particularly often burned are the subgoltsian open larch woodlands, under whose canopy develops the shrub stratum of *Pinus pumila* (Tyulina, 1959, 1962; Man'ko, 1961; Molozhnikov, 1975). Here, the fires are the main factor of lowering the upper boundary of the forest. Frequent fires occur also in the mountains situated in desert or semidesert regions (Billings, 1969).

Under the effect of fire, there is a considerable change in the environmental conditions at the upper boundary of the forest: In the physical and chemical properties of the soil, in its thermal and hydrological cycles, the rate of erosion increases sharply, the microclimate of the surface layer of air, the wind and snow conditions are changed. Fire may very seriously reduce the level of the upper boundary of the forest, right down to the foot of the slope.

Reestablishment of the initial type of vegetation on burns takes place very slowly, over decades or even centuries. The reestablishment of forest vegetation on steep stony slopes takes a particularly long time. After the fire, erosion is here increased and entirely naked stony placers (rock streams) are formed, on which the forest reestablishes itself only 80-100, or more, years later (Molozhnikov, 1975). In the Medicine Bow (Wyoming, USA) mountains, postforestial dry meadows are replaced by young spruce and fir forests only after 100-200 years (Billings, 1969).

Pyrogenic successions in various mountainous regions run variously. In the regions with alpine tundra type of landscape, mosses (from genera *Polytrichum* and *Bryum* first settle on the burns, then lichens and undershrubs (Tikhomirov, 1933; Molozhnikov, 1975), and in regions

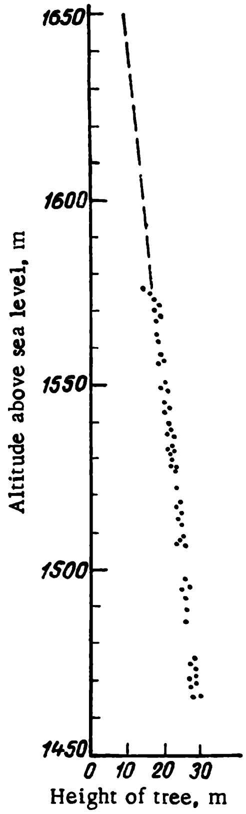

Fig. 1. Changes in the height of trees with increasing altitude of the locality in Tatra Mountains. The points indicate the results of actual measurements, the dotted line, the probable course of the change of that index above the current boundary of the forest. Proceeding from the fact that trees at the upper limit can reach the height of 10-12 m, the level of the potential upper boundary of forest is determined at 1650 m (after Plesnik, 1971).

with alpine type of landscape, mesophytic herbage and shrubs (Kuminova, 1960; Krylov, 1963; Billings, 1969; Douglas and Ballard, 1971). In the Caucasus the fir forests are replaced after a fire by pine forests with abundance of subalpine grasses (Leskov, 1932). At the early stages of renewal, microcomplexity and mosaic structure are characteristic for the vegetation.

Technogenic Type. This type occurs under the effect of air and soil pollution by industrial effluents (primarily from mining industry plants situated near or above the forest border line). In some places, as a result of extraction and crushing of ores, mud-streams are formed which also can entail lowering of the forest boundary.

Depending on the kind and intensity of pollution, destruction of trees may occur very rapidly or over a considerable time interval. On the site of forest communities, herbal phytocenoses are formed, consisting of species resistant to pollution. Many weedy plants appear. Trees growing in the zone of action of pollutants have a reduced vitality index (reduced growth, poor fertility, etc.), shrivelled tops, and traces of damage on foliage. Very characteristic is the absence or underdevelopment of lichens on tree barks. The boundaries of this type of forest are usually encountered in direct vicinity of the source of pollution.

Recreational Type. This type is connected with places of mass holiday, tourism and sport. Degradation of forest vegetation at its upper limit under the effect of recreational activities began only in the 20th century. The upper boundary of forest is lowered particularly sharply in places where skiing is practiced (Plesnik, 1976). Along the ski runs and tourist paths, young growth and young trees are destroyed. Woody plants die also around tourist bases and camping grounds; in the first place, regrowth and undergrowth are destroyed. Communities of herbage plants resistant to trampling are formed near the paths. The soil is enriched with nitrates; among the synanthropic plants, nitrophiles are abundant, including *Urtica dioica* (Lippert, 1972).

PHYTOINDICATION OF DEVIATIONS OF THE ACTUAL UPPER BOUNDARY OF FOREST FROM ITS POTENTIAL BOUNDARY

To estimate the ecological situation in some mountain regions, developed under the effect of anthropogenic factors, it is necessary to determine to what extent the actual upper boundary of the forest has descended in comparison with the potential boundary. The gap between these two boundaries can be determined on the basis of a number of biometric and phytochorological signs with due regard to historical evidence and toponymy.

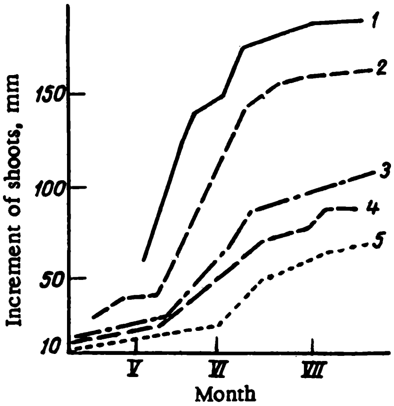

Fig. 2

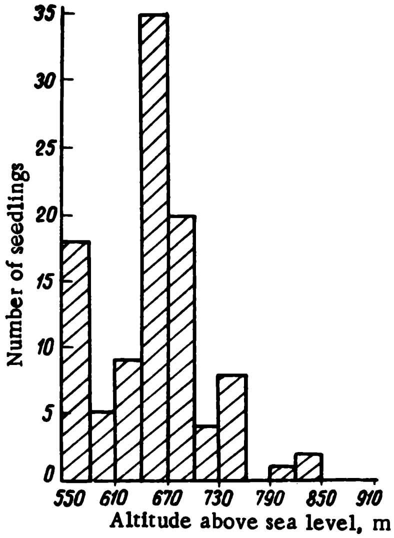

Fig. 3

Fig. 2. Seasonal growth of apical shoots of Crimean pine growing at various altitudes: 1) 1150 m; 2) 1300 m; 3) 1380 m; 4) 1480 m; 5) 1520 m above sea level (after Krylova, 1964).

Fig. 3. Determination of the position of the potential upper boundary of forest on the basis of distribution of the self-sown crop of Scots pine at various altitudes in the mountains of Scotland. The actual anthropogenic boundary of forest is at the altitude of 550 m, and the potential boundary, judging from the sharp reduction of quantity of the self-sown crop, is at the altitude of 700 m above sea level.

Correlation between the Height of Trees and the Locality's Altitude above Sea Level. According to the data of I. L. Krylova and N. D. Leskov (1959), there is a reciprocal, almost linear, connection between the average height of trees and the altitude of the locality above sea level. Plesnik (1956, 1971) proposes to determine only the height of the highest trees bearing no traces of damage. In this case, the effect of the tree's age is to a certain extent excluded.

There is no need to measure the height of all the encountered species of woody plants. It is better to select 1-2 species growing everywhere and reaching the upper boundary of the forest. To calculate the correlation ratios, measurement should be made on a large number of specimens. To elucidate the dependence between the height of trees and the altitude of the place above sea level, it is necessary to establish several profiles on those sections of the slopes where the boundary of the forest is due to natural factors, in particular, thermal ones. The obtained magnitudes of limiting values of indices serve as the basis for reconstruction of the possible potential boundary of the forest. Investigations have shown that at the natural climatic limit of forest in the Tatra, the height of trees reaches 10-12 m (Plesnik, 1971). Where the boundary has descended under the influence of man's activity, trees at the upper limit of the forest are of greater height. The potential level of the upper boundary of the forest can be determined graphically on the basis of the revealed correlational dependences (Fig. 1).

Magnitude of Yearly Increase of Tree's Height. Similarly as the height of the tree, so also the magnitude of yearly increment of their top (apical) shoots in height decreases with increasing altitude above sea level. On the mountains of Crimea, with ascent of 100 m of altitude above sea level, the magnitude of annual growth in Crimean pine (*Pinus pallasiana*) decreases approximately by 20%, and this decrease is statistically significant. At the climatically determined limit of the forest, a particularly sharp reduction of the magnitude of annual growth is observed (Krylova, 1960, 1971).

With the use of this index, particular attention should be paid to obtaining uniform and comparable data. Measurements should be conducted on trees of the same age class, on shoots belonging to the same order of branching. It is very important to maintain uniformity of soil-ground conditions.

On experimental plots established at various levels of altitude it is necessary to measure the magnitude of growth over several previous years at the axes of main orders on 25-30 specimens. Then, analytically or graphically, the dependence is determined between altitude above sea level and magnitude of yearly growth. The index of growth of the top shoots could be determined not for the entire growing season, but for a shorter time interval, e.g. a decade, a month (Krylova, 1964). This dependence is then used for determination of the potential upper boundary of the forest (Fig. 2).

Density of Foliage on Shoots. According to observations of I. L. Krylova (1964) on Crimean mountains at the level of the potential forest boundary, the density of foliage on the shoots of Crimean pine sharply increases (from 9.9 ± 26 to 10.6 ± 21). This trait can be also used for indication of the anthropogenic shift of the upper limit of forest.

Nature of Distribution and Vitality of Self-sown Crop of Woody Plants. Between the actual and the potential boundaries of the forest, reestablishment of woody plants is limited not by climatic conditions, but by human activity. if anthropogenic influence could be excluded, vigorous forest regeneration could start in that belt. According to the data of Pears (1968), in the mountains of Scotland a sharp reduction in the amount of self-sown pine is observed at the altitude of 700 m above sea level (Fig. 3). This indicates that the potential boundary of the forest passes precisely there. Besides, for indication of anthropogenic shift of the forest limit, the index of vitality of young plants can be used: At the level of the potential forest boundary the number of damaged, half-dried, and shrivelled seedlings increases sharply.

Occurrence of Live Trees and Remains of Dead Trees above the Actual Boundary of Forest. Individual trees and their clumps, as well as the remains of dead or felled trees (stumps, trunks) indicate the previous level of the upper boundary of the forest in the given mountainous region.

Degree of Contraction of the Actual Belt of the Highland Shrub Forest in Comparison with Its Potential Width. In any mountainous country, in regions unaffected by man's activity, the altitudinal range of the belt of highland (subgoltsian, subalpine) shrub forest is approximately the same. Knowing that altitudinal range, the position of the potential forest boundary in regions disturbed by anthropogenic influence can be determined from the remains of the shrub forest belt.

Lower Limit of Shrub Communities Bordering from Above onto the Potential Upper Boundary of Forest. In many mountainous countries, the belt of shrub communities is situated above the upper boundary of forest. After felling, the belt of shrubs is often preserved and serves as an indicator of the position of the potential upper boundary of the forest. This index was used by Pears (1968) in Scotland.

Microgrouping of Forest Grasses and Undershrub above the Actual Forest Boundary. Some forest plants growing previously under the canopy of the forest, exist as isolated microgroups also after felling of the tree stratum. The line which connnects the topmost sites of such plants indicates the position of the potential boundary of the forest.

Correlation between Indexes of Thermal Conditions of the Growing Season and Position of the Upper Boundary of Forest. It was found that within the zonal ranges of temperate and cool climates, the altitudinal position of the upper boundary of the forest is determined by thermal conditions of the growing season. A correlation was found between the absolute altitude of the forest boundary and such indexes as: average temperature of the warmest month (10°C), average temperature of air for the period June-August (6-8°C), the sum of effective (above 10°C) temperatures (200-300°C), and duration of the growing period. With increasing altitude, thermal conditions are gradually deteriorating. The vertical gradient of temperature is more or less constant in various mountainous countries. It is almost unchanged through the yearly seasons, and on average amounts to 0.5°C per 100 m of altitude (Rubinshtein, 1926; Gol'tsberg, 1936). It is, however, necessary to make reference to the available meteorological stations which may be situated above or below the upper forest boundary. Knowing the thermal limit of the timberline and the vertical gradient of temperature, the level of the potential thermal boundary of forest can be determined.

Such calculations were conducted by Pears (1968) in the mountains of Scotland. The vertical gradient of temperature in that region amounts approximately to 0.6°C for every 76 m of elevation (or 0.8°C per 100 m). It was found that shrub forests can exist at the altitude of 760 m above sea level, where from June to August during the growing season the average temperature of air rises above 10°C.

In regions where meteorological stations are absent, the magnitude of the vertical gradient can be determined by means of conducting special meteorological observations at various altitudes.

Historical Evidence and Toponymics. In individual cases, valuable information on the past position of the upper limit of forest vegetation can be drawn from ancient maps of agricultural lands and from literary sources (accounts of travellers, works of botanists and geographers). Besides, material of interest for this purpose can be obtained on the basis of studying the names of settlements and natural boundaries, as Pears (1968) has demonstrated convincingly for the mountains of Scotland.

CONCLUSIONS

1. The upper boundary of the forest is an important botanical and geographical borderline which quickly reacts to changes in environmental conditions in high mountain areas. In many mountainous regions, lowering of that borderline takes place under the influence of human activity, and natural forest boundaries are transformed into anthropogenic boundaries.

2. Depending on the factors which decisively affect the position of the upper limit of forest vegetation, several types of anthropogenic degradation of the upper forest boundary should be recognized: pasture type, hay mowing, forest clearing, pyrogenic, technogenic, and recreational.

3. The position of the actual forest boundary in relation to the potential forest boundary serves as an index of the degree of disturbance of the ecosystem and of the biotypes in the uplands under pressure of anthropogenic factors.

4. Discovery ofthe potential upper boundary of forest, in relation to the actual one is necessary for estimating the general ecological position in the uplands, and for substantiating the measures taken for reestablishment of highland forests to their possible level, in order to control water erosion of soils, torrents, and snow avalanches.

5. Phytoindication of the potential boundary of forest is possible on the basis of several biometrical and phytochorological indexes (correlation between height of trees and altitude of the site above sea level, magnitude of annual increments of the trees' height, density of foliage on shoots, character of distribution and vitality of self-seeded woody plants, occurrence of living and dead trees, as well as microgroups of forest grasses and undershrubs above the actual boundary of the forest, etc.).

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