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WHAT DOES THE TERM "KRUMMHOLZ" REALLY MEAN? OBSERVATIONS WITH SPECIAL REFERENCE TO THE ALPS AND THE COLORADO FRONT RANGE

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ABSTRACT The term "Krummholz" is applied to the bush-like growth-forms of *Pinus mugo prostrata, Alnus viridis,* and some other species which are genetically determined. The term has also long been used by English-speaking botanists to refer to the climatically stunted and distorted trees in the forest-tundra ecotone. Thus, distinct ecological and plant-geographical differences are disguised which, in a more precise differentiation of the mountain plant cover, ought to be accentuated. The author tries to explain this by observation and field studies in the European high mountains and in the Rocky Mountains and suggests restricting the German term "Krummholz" to the genetically controlled shrub-like species; the timberline species shaped by climatic influences should be called cripple-trees. Thus, the elfin wood is nothing but a cripple facies of the upper montane forest.

RÉSUMÉ *Que veut vraiment dire le terme "Krummholz"? Observations avec reference particulaire aux Alpes et aux Montagnes Rocheuses du Colorado.* En allemand, on appelle "Krummholz" les espèces de bois comme *Pinus mugo prostrata* et *Alnus viridis* qui sont d'une pousse tordue par voie d'hérédité. En anglais, on appelle "Krummholz" depuis quelque temps aussi les formes des arbres à la limite forestière supérieure qui sont occasionées par le climat. Avec ce transfert, des différences importantes en vue de l'écologie et de la géographie floristique sont effacées qui devront être soulignées pour obtenir la différenciation la plus exacte de la végétation de haute montagne. Cela, l'auteur essaye de démontrer au moyen des observations comparatives dans les hautes montagnes européennes et dans les montagnes rochenses. Il suggère de réserver le terme "Krummholz" pour les espèces de pousse tordue fixée genetiquement et d'appeler arbres deformés les formes de pousse tordue forcées par les constraints du climat. Alors, le "elfin wood" n'est qu'une forme tordue de la forêt près de sa limite supérieure.

ZUSAMMENFASSUNG *Was bedeutet der Ausdruck "Krummholz" wirklich? Beobachtüngen die sich speziell auf die Alpen und die Rocky Mountains beziehen.* Als Krummholz werden im Deutschen die erblich krummwüchsigen Holzarten wie *Pinus mugo prostrata* und *Alnus viridis* bezeichnet. Im Englischen ist es seit geraumer Zeit üblich geworden, auch die klimatisch bedingten Wuchsformen im Waldgrenzbereich "Krummholz" zu nennen. Mit dieser Übertragung werden aber wesentliche ökologische und pflanzengeographische Unterschiede verwischt, die im Hinblick auf eine möglichst genaue Differenzierung der Hochgebirgsvegetation eigentlich hervorgehoben werden müßten. Dies versucht der Autor anhand vergleichender Beobachtungen und Studien in europäischen Hochgebirgen und in den Rocky Mountains zu begründen. Er schlägt vor, den Terminus "Krummholz" den Arten mit genetisch fixierter Krummwüchsigkeit vorzubehalten und die klimatisch induzierten Zwangswuchsformen als Krüppelwuchsformen oder Baumkrüppel zu bezeichnen.

INTRODUCTION

In the European Alps, the Carpathians, and some other European mountain areas, a nearly impenetrable scrub of *Pinus mugo prostrata* extends above the upper timberline which is formed by spruce (*Picea abies*) or beech (*Fagus silvatica*). This formation represents the most conspicuous feature within the altitudinal zonation of these mountains (Figure 1). The scrub-like contorted growth forms of *Pinus mugo prostrata,* and of the Green Alder (*Alnus viridis*) by which it is replaced under special conditions, comprise the "Krummholz-Gürtel" (Krummholz-belt) (Schröter, 1908; Hegi, 1958; Braun-Blanquet, 1964; Schmidt, 1969; Reisigl, 1970; Ellenberg, 1978; Franz, 1979; and others).

In the Colorado Front Range and some other ranges of the Rocky Mountains there is also a transitional belt of varying width formed of stunted and crooked tree species (*Picea engelmannii, Abies lasiocarpa, Pinus flexilis*) which lies

Figure 1. Krummholz (*Pinus mugo*) with solitary windshaped spruce (*Picea abies*) in the High Tatra near Stary Smokovec, Czechoslovakia. August 1970.

Figure 2. Elfin wood formation (*Picea engelmannii, Abies lasiocarpa*) on the east slope of Mount Audubon (Colorado Front Range, U.S.A.) at about 3,400 m. The different growth forms are mainly due to the influence of the prevailing westerly winds (from the left). 10 August 1977.

between the upper montane forest and the alpine belt (Daubenmire, 1943; Griggs, 1946; Marr, 1961, 1977; Ives, 1973, 1978; Holtmeier, 1978; Höllermann, 1980). This appears quite similar to the "Krummholz-Gürtel" of the European high mountains (Figure 2). This formation is usually called "elfin-wood" or, with reference to the strong influence of wind, "wind-timber" (Löve *et al.*, 1970), but the German terms "Krummholz" or "Krummholz-Belt" have also long been used by American and English scientists to refer to these distorted trees and to this transitional belt ("forest-tundra ecotone") (Wardle, 1965, 1973, 1977; Clausen, 1963; Löve *et al.*, 1970; La Marche and Mooney, 1972; Ives, 1973, 1978; Baig and Tranquillini, 1976).

This transfer of the German term seems to be suitable with regard to the phenotypical similarity of the *Pinus mugo*-associations of the European high mountains and the stunted conifer formations above the upper timberline in the Rocky Mountains. However, it disguises distinct differences which ought to be highlighted in a more precise differentiation of the mountain plant cover. Because of this, such use of the term Krummholz is contested; a point of view which may be substantiated by comparing the European Alps and the Colorado Front Range.[1]

THE DIFFERENCES BETWEEN "KRUMMHOLZ" AND "ELFIN-WOOD" GROWTH FORMS—GENETICALLY CONTROLLED OR PHENOTYPICAL RESPONSE TO THE ENVIRONMENT?

The growth forms of *Pinus mugo prostrata* and of *Alnus viridis* are said to be genetically controlled, whereas those of elfin-wood seem to be a phenotypical response to harsh climatic influences (thus the terms "elfin-wood" and "cripple trees" are used synonymously). In addition, there are also problems with the European term "Krummholz" as applied to *Pinus mugo*. This species is usually divided into four subspecies (ssp. *uncinata rostrata,* ssp. *uncinata rotundata,* ssp. *pumilio,* ssp. *mughus*). However, this subdivision still seems to be unsubstantiated for botanists have not yet succeeded in finding a distinctive combination of characteristics which permits exact definition of the systematic position.

Thus, for the sake of simplicity in plant geography, only the arboreous mountain pine (*Pinus mugo arborea*) is separated from the bush-like (many-stemmed) *Pinus mugo prostrata*, the actual "Krummholz." The former is distributed throughout the Western Alps and the Pyrenees, the latter ranges over the Eastern Alps, the Dinaric Alps, and the Carpathians (Reisigl, 1970; Wraber, 1970; Kuoch and Schweingruber, 1975; Ellenberg, 1978). The distributions overlap in the Central Alps (Figure 3). Both

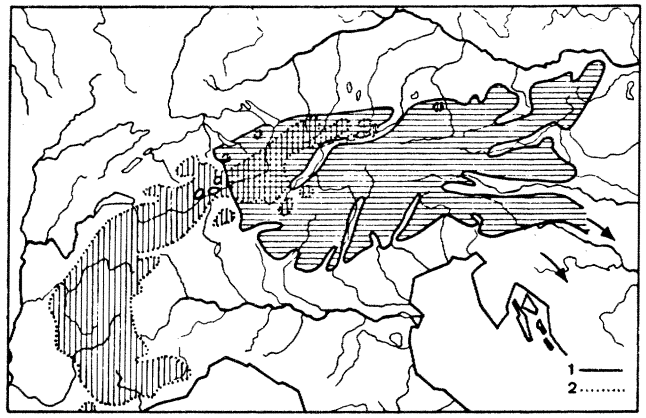

FIGURE 3. Distribution of *Pinus mugo* in the Alps. 1: *Pinus mugo prostrata* 2: *Pinus mugo arborea* (from Kuoch *et al.*, 1975).

kinds of pines are found even at the same site (at the fringe of bogs, for example, or on poor soils). Transitional growth forms between the arboreous and the prostrate form are abundant. It is impossible to determine whether this is due to hybridisation or to environmental influences (Däniker, 1952; Schweingruber, 1972). Schönenberger (1978) reports that in the northern Pre-Alps the arboreous type can easily assume prostrate growth within avalanche tracks if permanently influenced by avalanches (mechano-metamorphosis).

East of this transitional zone only the prostrate form is found. In the peripheral ranges of the Eastern Alps, and also in the Carpathians, it forms a nearly continuous "Krummholz-belt," especially on limestone and dolomite slopes. On slopes subject to avalanches it extends downward into the montane forest (Figure 4). This is the real "Krummholz-belt" from which the term originates.

In the Central Alps the Krummholz formation is less conspicuous and is usually confined to avalanche tracks, dry and infertile boulder fans, or to local bogs (Pitschmann *et al.*, 1970, 1971, 1973). The other real "Krummholz," *Alnus viridis,* never grows like a tree. *Pinus mugo prostrata* and *Alnus viridis* normally have many stems (polycormic growth). On level sites they display a candelabrum-like form. Within avalanche tracks and on steep slopes, stems and branches are pressed down to the soil surface by the snow in winter and deflected downhill. Thus, in these stands the shape of both Krummholz-species have a marked tendency to be asymmetrical (Figure 5).

Elfin-wood shows a great variety of growth forms, depending on the local environmental influences. In the Colorado Front Range, for example, the scale of deformations ranges from slightly asymmetric canopies, to flagged trees with no branches or twigs on the windward side, to table trees and mat-growth forms which cannot grow higher than the surrounding dwarf shrub and grass vegetation. All the tree individuals display a more or less pronounced asymmetric growth, due to the permanent influ-

[1]Although having drawn attention to this problem earlier (Holtmeier, 1973), because of the great difficulties in replacing a well-introduced but misunderstood term by a better one, I myself have referred to the wind-shaped trees in the forest-tundra ecotone of the Colorado Front Range as "Krummholz" in some recent publications (Holtmeier, 1978, 1980, 1981).

Figure 4. *Pinus mugo* Krummholz replacing the tall spruce forest (*Picea abies*) within an avalanche track in the Mieminger Mountains, Austria. August 1970.

Figure 5. Green-alder Krummholz (*Alnus viridis*) within an avalanche track on the northerly slope of Birgitzköpfl, Axams Lizum, Austria. The stems are deflected downhill by snow pressure. 22 April 1981.

FIGURE 6. Wind-trimmed *Picea engelmannii* hedge along the shore of Lefthand Reservoir at 3,230 m in the Front Range, Colorado, U.S.A. The windward side (left) shows mat- and wedge-like growth forms overtopped by single-flagged stems. Toward the lee-side the hedge is higher and less deformed. In the foreground and around the hedge are willow species. 30 July 1977.

ence of strong westerly winds (Wardle, 1974; Marr, 1977; Holtmeier, 1978, 1981; cf. Figure 2).

Crippled trees are also characteristic phenomena within the forest-tundra ecotone of other high mountain areas and of the Subarctic, although the influence of wind normally is less conspicuous than in the Front Range.

In the subalpine belt of the Alps and the Carpathians both Krummholz (*Pinus mugo prostrata*) and elfin wood of other forest species (*Picea abies*) are found. During the early decades of their growth these outposts of spruce are protected by Krummholz thickets. As they grow higher these individual trees are gradually shaped by the strong climatic influences (Figure 1).

There is ongoing discussion as to whether or not the elfin wood growth forms (e.g., mat-growth, flagged, table-growth) are also genetically predetermined (Clausen, 1963; Löve *et al.*, 1970; Grant and Mitton, 1977). Löve *et al.* (1970) conclude that the stunted growth of trees within the forest-tundra ecotone is genetically influenced in so far as there are some tree species which are able to grow like "Krummholz" and others which do not have genes allowing this habit. The latter are usually not represented within the forest-tundra ecotone. That seems also to be true for the Colorado Front Range. Nevertheless, in a pilot study Grant and Mitton (1977) have found some evidence that even different growth types of one species (such as spire, flag, and krummholz) are characterized by different gene frequencies.

My own observations do not support this theory. Within extremely wind-trimmed "ribbons" and "hedges" (Holtmeier, 1978, 1980, 1981), which normally have originated from one individual tree seedling that propagated by layering, frequently all types of growth are represented, mat-growth at the windward side, flagged stems in the more sheltered middle section, and stems with fairly normal crowns on the leeside (Figure 6). This indicates that there has not been any control by different gene frequencies. In addition, if a crippled alpine fir or Engelmann spruce is transplanted from an exposed site to a more favourable habitat, it will develop like a normal tree. If *Pinus mugo prostrata* or *Alnus viridis* are transplanted similarly they will continue to grow in a bush-like form.

ECOLOGICAL ASPECTS

One of the most striking differences between the European Krummholz and the elfin wood formation of the Colorado Front Range is the fact that the Krummholz is formed of separate species, the ecological requirements of which differ considerably from those of the forest tree species, while the elfin wood usually consists of the same species as those occurring in the upper montane forest.

In the course of the successional development of the plant cover this distinction has been of paramount importance. When the upper timberline reached its highest position during postglacial times, the Krummholz *Pinus mugo* was confined to relatively unfavourable sites such as

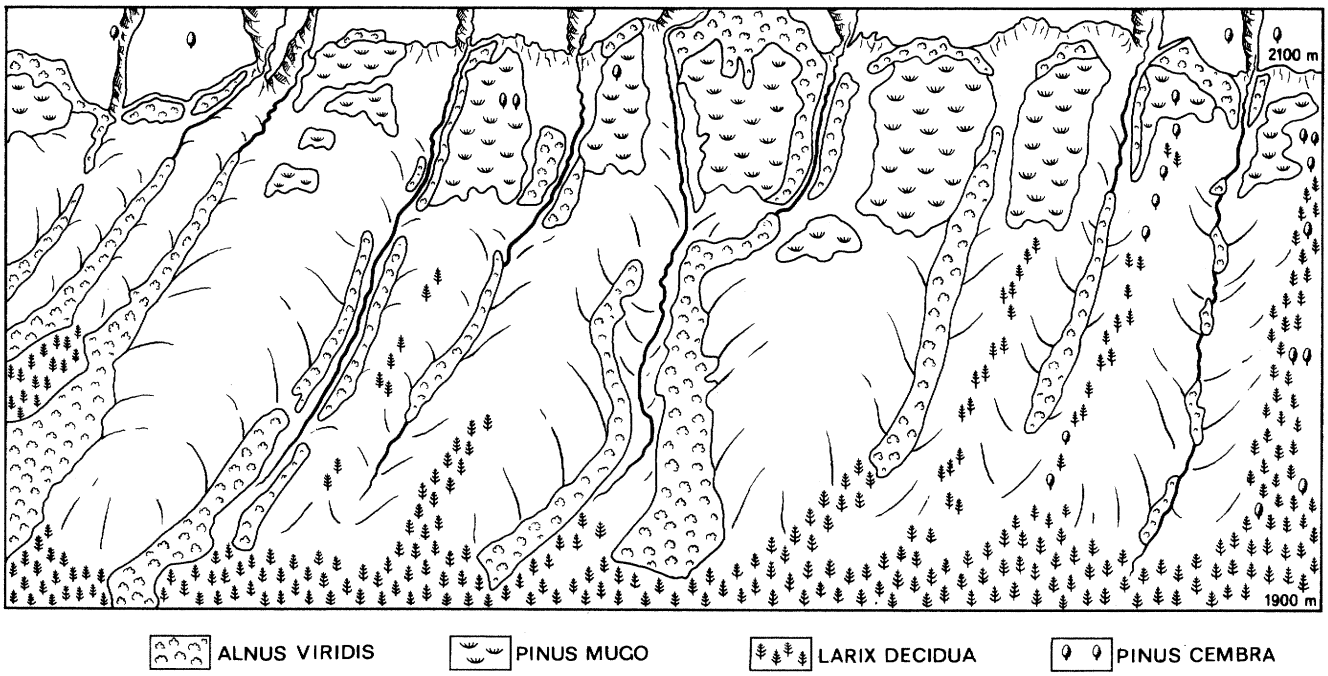

FIGURE 7. The northeast-facing slope (silicate subsoil) of the Bernina Valley, Upper Engadine, Switzerland. The area frequently overrun by avalanches is covered by Krummholz (*Pinus mugo* and *Alnus viridis*). *Pinus mugo* covers the small ridges which are relatively dry, whereas *Alnus viridis* grows along the streams and in marshland. Stone pines (*Pinus cembra*) and larches (*Larix decidua*) are confined to sites fairly sheltered from the influence of avalanches (from Holtmeier, 1967).

infertile boulder fans, rock walls, roches moutonnées, cold air depressions, bogs, and avalanche tracks (Figure 4). Subsequently, the upper timberline has been lowered due to the deterioration of climate after the Hypsithermal and to intensive human influences (mining, farming, and pasturing). During this time the light-demanding Krummholz was able to spread into the deforested area. Thus, it can be considered a substitute formation there (Grabherr, 1934, 1949; Mayer, 1965, 1966; Aichinger, 1967; Köstler and Mayer, 1970; Pitschmann *et al.*, 1970; Wraber, 1970; Kral, 1973; Wilmanns and Ebert, 1974). Within the actual timberline belt there is strong competition between the forest tree species (*Picea abies, Larix decidua, Pinus cembra*) including *Alnus viridis,* which was also able to spread into the former forest area (Surber, 1971; Schiechtl, 1972).

Under *Pinus mugo* a thick raw humus layer builds up and consequently the soil acidity increases. For that reason, only highly specialized plant species are able to obtain sufficient nutrients (Kuoch and Schweingruber, 1975). Furthermore, natural regeneration of forest trees within the Krummholz is strongly hampered by low light intensity under the dense Krummholz canopies. Therefore a readvance of trees into the Krummholz belt should not be expected until after the decay of the Krummholz thickets (Margl, 1973).

Thus the present distribution of Krummholz can be attributed largely to the different ecological responses of Krummholz and tree species to the natural and human environmental influences. Due to these conditions *Pinus mugo prostrata* appears in different successional stages: as pioneer vegetation on moraine fields or similar bare soils, as climax formation within, or at the fringes of, avalanche tracks, and as a substitute formation on deforested slopes.

Although *Pinus mugo* and *Alnus viridis* inhabit quite similar sites, the Mountain Pine prevails on limestone and dolomite while the Green Alder is more common on silicate subsoil. On account of this distribution *Pinus mugo* and *Alnus viridis* are said to be vicarious plants. In fact, this distribution does not primarily depend on the acidity of the soil, but on the different requirements of soil moisture. Where sufficient soil moisture supply and fresh soils are guaranteed, the Green Alder will grow on dolomite or limestone nearly as well as on silicate substratum. Conversely, *Pinus mugo* will successfully compete with *Alnus viridis* on granite or gneiss, provided that the sites are relatively dry and poor in nutrients (Figure 7).

In contrast to these ecological and phyto-sociological determinants of the European Krummholz, the elfin wood is nothing but a cripple facies of the upper montane forest, shaped by the more or less successful struggle for existence under severe environmental conditions. With increasingly favourable local climatic conditions, the elfin wood changes more or less gradually into high-stemmed forest. The cripple-growth is primarily caused by desiccation and mechanical damages (such as iceblast) in

winter and by reduced growth rates due to these injuries and to the low temperatures of the growing season (Holtmeier, 1978, 1980, 1981). However, there is no competition between elfin wood and forest as has been described above between the European Krummholz and forest. On the other hand, there are differences between the ecological requirements of the various tree species. They influence the natural regeneration and propagation processes and the distribution pattern (Peet, 1981). Thus *Pinus flexilis* is more common in dry and wind-exposed localities than in more sheltered sites. But, in general, the tree species are equally well adapted to the unfavourable environmental conditions and they all are able to inhabit the most extreme sites.

There are, nevertheless, some differences between the growth forms of spruce and fir on the one hand and limber pine on the other. While the wind-trimmed growth forms of *Picea engelmannii* and *Abies lasiocarpa* look quite similar, those of *Pinus flexilis* are somewhat different because of its manner of ramification. Furthermore limber pine usually grow as solitary trees whereas the other conifers, which in the forest-tundra ecotone predominantly regenerate and propagate by layering, frequently form tree-islands.

CONCLUSIONS

The preceding comments should be sufficient to support the argument that in plant geography more precise differentiation is required between Krummholz and elfin wood formations. From the terminological point of view it certainly does not even seem necessary for English-speaking botanists and plant geographers to borrow the term "Krummholz" from German for all shrub-like woody vegetation above timberline, since the words "scrub," "shrub," or "shrubland" are perfectly adequate. When referring in particular to the climatically stunted and distorted trees in the forest-tundra ecotone it would be the best to use the word "cripple" (Schröter, 1908; Däniker, 1923; Walter, 1968; Ellenberg, 1978). In this manner cripple-tree, used as synonymous to elfin wood, should facilitate explanation of the essential ecological differences. Such a process is not only important from an academic-scientific point of view. With rapidly increasing use of the upper timberline belt and alpine meadows for recreation, an increasing pressure is being placed upon all of these tree-forms. In the Rocky Mountains especially, destruction of cripple-trees for camp fires results in an irreversible process of deforestation since reproduction in the uppermost belt of tree growth depends upon layering.

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