Landscape Ecology vol. 9 no. 3 pp 175-190 (1994)
SPB Academic Publishing bv, The Hague

Coincidences between different landscape ecological zones and growth forms of Cembran pine (*Pinus cembra* L.) in subalpine habitats of the Central Alps

Anselm Kratochwil[1] and Angelika Schwabe[2]
[1]*Universität Osnabrück, FB Biologie/Chemie, Fachgebiet Ökologie, Barbarastr. 11, D-49069 Osnabrück, Germany;* [2]*Institut für Botanik der Technischen Hochschule/Geobotanik, Schnittspahnstr. 4, D-64287 Darmstadt, Germany*

Keywords: Cembran pine, Nutcracker, multiple trunk trees, intraspecific coexistence, area of glacier recession, timberline

Abstract

The 'forgotten' depots of the European Nutcracker (*Nucifraga* c. *caryocatactes*) often 'lead' to the development of tufts of *Pinus cembra*. In many cases the other individuals of such tufts are not suppressed by the fittest one, rather there is an intraspecific coexistence up to the senescent stage of the trees. There are fusions of separate trunks, and so frequently the individual history of older trees can only be reconstructed by studying sutures, crown structures or trunk cross sections. Different types of trunk fusions are worked out. By means of transect counting the occurrence of these 'multiple trunk trees' is documented quantitatively in different landscape ecological zones of the Engadin region (the Grisons, Switzerland). The data base is 3024 counted microsites of *Pinus cembra* individuals arising from seeds, including 5272 living individuals. These 'multiple trunk trees' significantly play an important role in the landscape ecological zones of recent glacier recession and at the alpine timberline. Their growth forms have a higher biomechanical stability.

1. Introduction

Taking as an example the growth forms of *Pinus cembra* we would like to point at the 'intraspecific co-existence' where positive interactions between individuals enhance the growth in extreme habitats. Mostly this coexistence depends on the intimate relationship between Cembran pine (*Pinus cembra*) and the Nutcracker (*Nucifraga* c. *caryocatactes*).

To our knowledge the growth forms of Cembran pine have not yet been treated synoptically as to also include their planting by the Nutcracker, and the degree of the fusion of the trunks. Also the work about *Pinus cembra* in the east Alps (Schiechtl and Stern 1975–1984) lacks this aspect. Schroeter (1908) mentions 7 different physiognomic Cembran pine types, and also Klein (1908) deals with the 'physiognomy' of the Cembran pine, particularly characterizing their bizarre shapes when growing close to the timberline. Rikli (1909) presents a compilation of different growth forms. Klein (l.c.) already recognized certain regularities in the growth form without, however, perceiving the connection to the "planting" by the Nutcracker. On the actual timberline the growth forms of young Cembran pine have been analyzed and classified as 'jay plantations' by Holtmeier (*e.g.* 1985), among other things taking into account damage through fungus attacks, long-time snowcover, or damage by blowing ice particles.

We asked the following questions:

- Is there a connection between the frequent occurrences of multiple trunk Cembran pine individuals and the ornithochorous dispersal?
- Are there different types of trunk fusions?
- Is it possible to demonstrate fusions of several

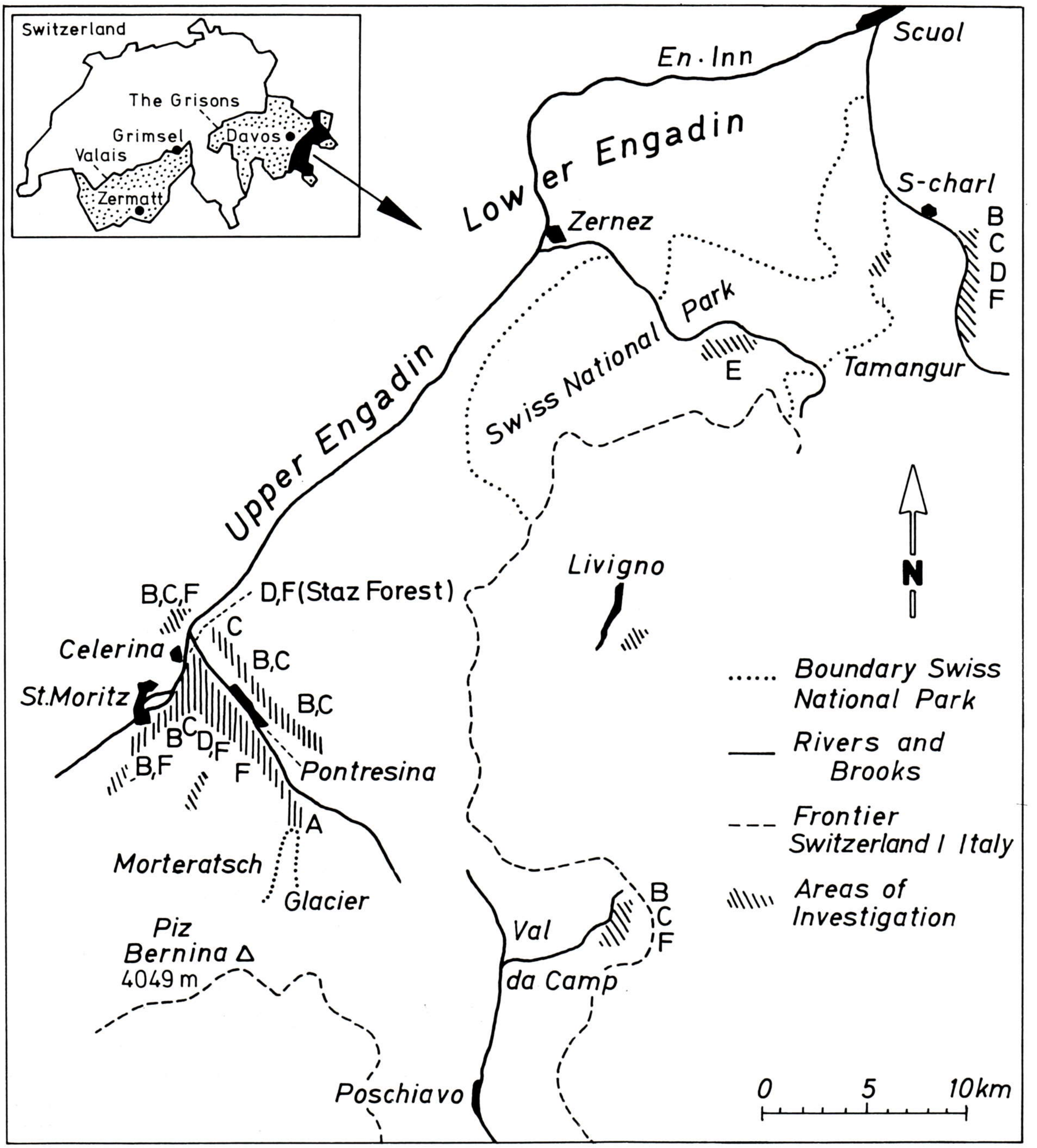

Fig. 1. Map of the area investigated in the Engadin, Poschiavo and in the high valley of Livigno (small map: further areas in The Grisons and Valais, location of the map section). Transects: A. Regions in front of the glacier; B. Actual timberline; C. Parklike tree stands; D. Juvenile growth; E. Mature woodland, non-managed; F. Mature woodland, managed extensively.

trunks when analyzing the trunk cross sections?

- Are there coincidences between certain growth forms and landscape ecological zones, and if this can be recognized: what is the reason?

2. Topographic situation of areas and methods

Our investigations were mainly carried out in the lower and upper Engadin and the Poschiavo. Main

Fig. 2. Pinus cembra "nest" (hiding place of the European Nutcracker) with 12 seedlings which were germinating at the highest points of *Sphagnum nemoreum*-bults (Taiswald above Pontresina 2200 m NN, 29.7.1989).

centers of research were the extended Larici-Pinetum cembrae of the Staz forest and the Tais forest near Celerina and Pontresina in the upper Engadin. Additional observations were made in the surroundings of Zermatt, Davos and the Grimsel area (Fig. 1).

The characterization and standardization of the growth forms were made according to intensity of fusion of the individual trunks and according to their number. Moreover, an actual comparison was made with the aim of reconstructing the ontogeny of the multiple trunk Cembran pine individuals from the juvenile to the senescent stages.

The distribution patterns of multiple trunk individuals in the landscape were analyzed by means of transect counting. For the selection of transects we mainly chose already existing paths (avoiding, however, broad tracks with changing light conditions). Here we noted the Cembran pine individuals standing in a 2–5 m wide strip on the path, divided into '1-, 2-fold trunks' etc. In closed forest stands we counted the older trees, and, in some cases, separately also the juvenile individuals up to 3 m high. In the area in front of the Morteratsch glacier a transect of ca. 200 m width was recorded.

When counting the juvenile trees in the closed stands and near the timberline we analyzed transects of about 10–50 m width (according to the density of the juvenile growth).

We found that in most cases it is possible to determine the number of individual trunks, when taking into account sutures in the stem region, and the 'sheaf structures' of the Cembran pine crowns. Heterogeneous Cembran pine-groups, which, without any question, originated from one or more 'nests', and trees of multiple or single trunk-growth of which could not be assessed clearly, were not taken into account. The quota of trees not being assessed in this way lies beneath 5% (locally beneath 10%). Though 'critical' cases were not recorded, a very small quota of wrong assessments in mature woodland cannot be excluded.

3. Results and discussion

3.1 Germination of Pinus cembra

It is mainly thanks to the researches of Mattes (1978, 1982) in the upper Engadin (mainly: Staz forest) that we know about the hiding places of *Pinus cembra* seeds by the Nutcracker. Ample references can be found in the results of the afore mentioned publications (see also Holtmeier 1965, 1966). Already in the older Swiss literature references are made with regard to the enormous performance of the Nutcracker and the seed dispersal (see *e.g.* Campell 1950; Furrer 1955).

Of great significance for the occurrence of Cembran pine juveniles is the fact that some hiding places were not rediscovered (according to Mattes l.c. only 20% of the total sum of hiding places), that a number of them were simply 'forgotten' or, that in years with rich seed supply, they were not exploited. Every individual bird can possess more than 10.000 hiding places; Mattes (l.c.) found a mean seed number of 3,5 per hiding place.

Quite often we found *Pinus cembra* tufts containing an exceptionally high number of juvenile trees (> 10) in the bogs, embedded in the Staz forest, or in the area of the shoulder of U-shaped valleys at the highest points of *Sphagnum nemoreum*- and *Sphagnum fuscum*-bults (Fig. 2). These are often preliminary, so-called 'in between' hiding places of the Nutcracker (Mattes 1978). Such 'nests' though have no chance to get established for a long time, however they show the germination capacity of the seeds if sufficient humidity and light

Fig. 3. Characteristic *Pinus cembra* tuft growing from an Nutcracker's hiding place on the actual timberline of Muottas Muragl above Pontresina (2200 m NN, 28.10.1990). In the background the main valley of the Upper Engadin.

Fig. 4. 4-trunck *Pinus cembra* individuals in the region in front of the Morteratsch glacier; till now no welding processes were found (1900 m NN, 30.10.1990).

is available and if there is no impact by *e.g.* ibexes (*Capra ibex*) in bog habitats. The maximal number per nest observed was 23 seeds (Sutter 1981).

Under natural conditions (little impact of ibexes and stags (*Cervus elaphus*); none or only a minor grazing impact) Cembran pine 'nests' with more than 10 juvenile plants per 'nest' should occur more frequently than is observed at present. Being a gymnosperm species *Pinus cembra* in the juvenile stage is not able to make basitone branches after the main shoot has died by browsing.

Kirchner *et al.* (1909) and Rikli (1909) mention that Cembran pine suffers a lot from goat browsing and that, contrary to the spruce (*Picea abies*), only few branches are replaced.

3.2 Tufts of Cembran pine

The 'nests' in Fig. 3 are dealing with ornithogenic 'planting into plant holes'. In one hiding place there may be Cembran pine seeds which often originate from different nature regions which become mixed in the sublingual pouch of the bird; this was confirmed by H. Mattes (pers. communication) and is based on many years of observation. The sublingual pouch of the Nutcracker can take more than 100 Cembran pine seeds (maximum number confirmed till today is 134, see Glutz von Blotzheim 1964).

When transporting the seeds to the hiding places the distances covered can be up to 15 km and the change of altitude up to 700 m (Mattes 1978). Hence, it follows that the Cembran pine tufts may

Fig. 5. 3-trunk *Pinus cembra* individuals showing strong welding processes in the lower parts, 2 trunks being completely welded with clearly visible sutures (above Findelbach/ Zermatt: Valais, 2020 m NN, 30.7.1987).

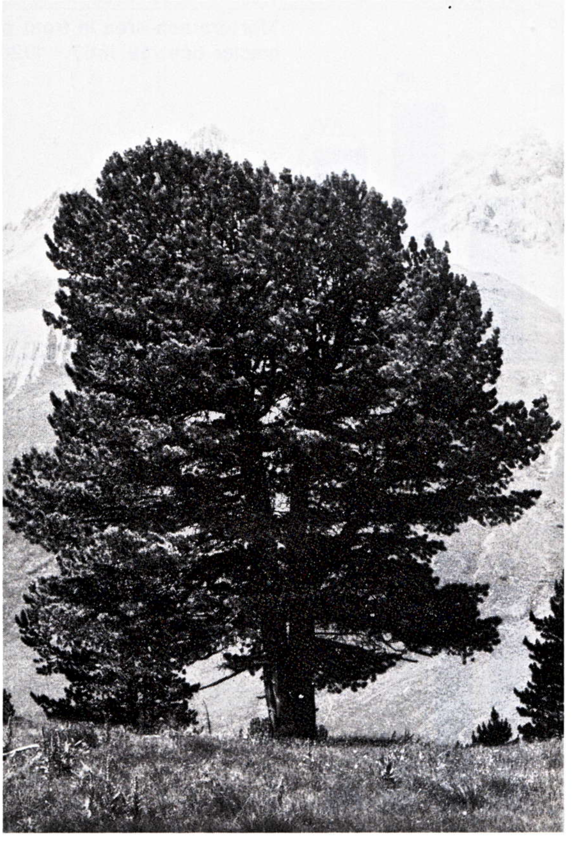

Fig. 6. Windshaped 2-trunk Cembran Pine, having fused at the basis, with the physiognomy of a monocorm (Tamangur near S-charl/ Lower Engadin, 2340 m NN, 5.8.1991).

consist of genetically different individuals. The conception 'kinship' for those tufts as it is used by Kuoch and Amiet (1970) does not seem quite suitable.

One would assume that through severe selection, caused mainly by the competition of the roots (Holtmeier 1989), the most competitive seedling would win in any case, and that out of the nest only one single individual would develop. This is surely quite often the case. Kuoch and Amiet (1970) mention that the surviving juvenile Cembran pine would be able to 'take over' the root system of the other dead juveniles at the age of 8 years (see also chapter 4). The authors proceed (page 273): 'During the growth period single or several plants, depending on the collective size, gain a decisive start on the remaining ones, which are more or less at a disadvantage, which lose the competition and finally die'.

Many tufts deviate from the a.m. type, and, as we will show, this depends on the respective landscape ecological zone where they are growing. Even in the senescent stage of the trees former tufts are found having grown together in the trunk part at different intensity levels.

In many cases several of the juvenile Cembran pine individuals originating from one nest grow up. At first the small stems have no contact at the basis (Fig. 3, 4); later they develop into multiple trunk Cembran pine individuals whose trunk bases touch each other in the process of growth, and finally they fuse (Fig. 5).

In the course of time also in the upper parts of the trunks fusions occur, so that, even though there are several individuals, multiple trunk *Pinus cembra* in-

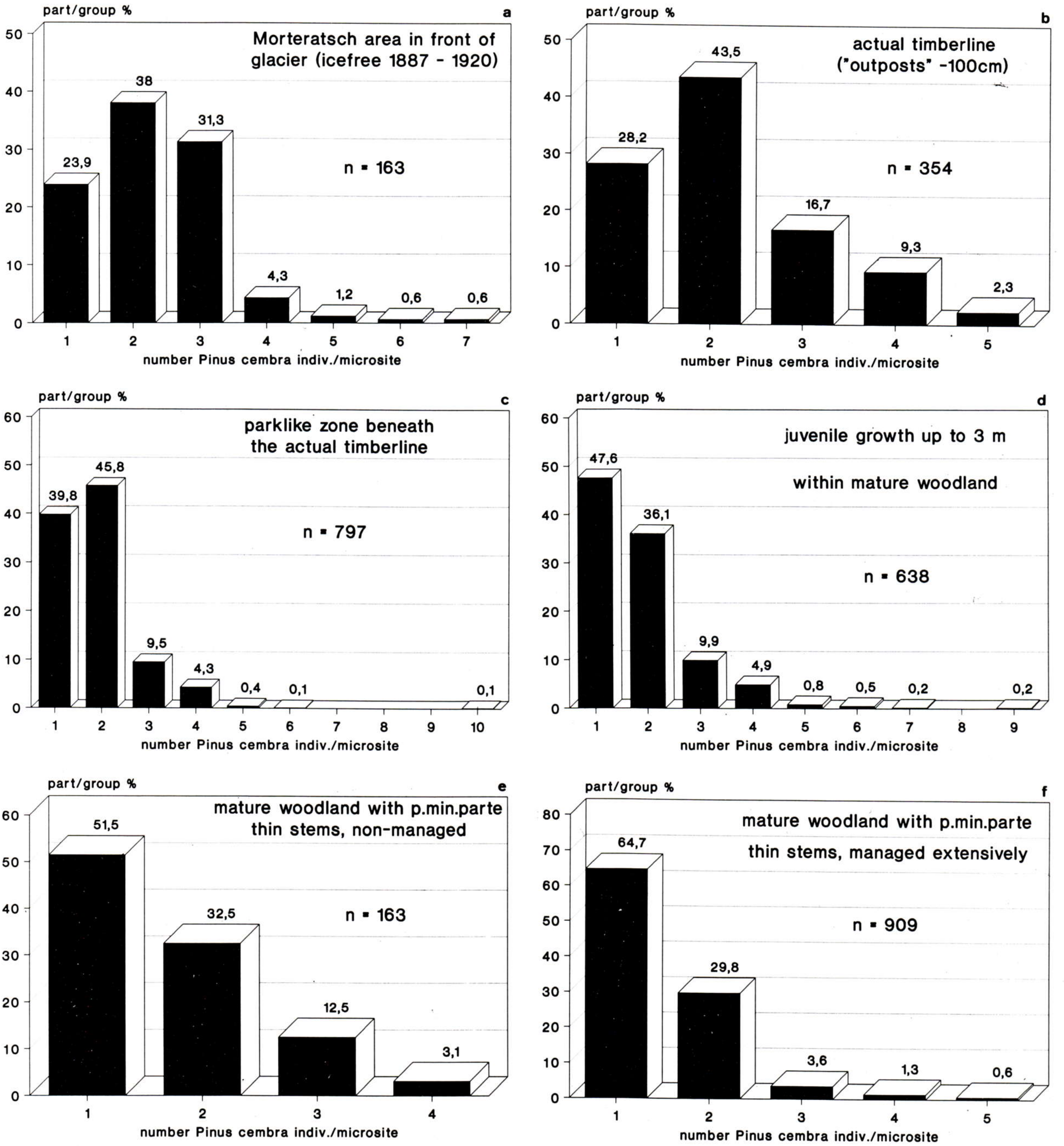

Fig. 7a–f. Distribution pattern of 1- and multiple trunk Cembran pine individuals in different landscape ecological zones in the Engadin and Poschiavo. Data were collected when counting transects in the years 1989–1991; n designates the number of tufts counted.

dividuals, giving the impression of one tree (Fig. 6). The sutures between the individuals are quite often clearly discernable. More than 10 trunks can be involved in the fusion, however, as a rule, there are less.

As we shall show, the multiple trunk individuals of *Pinus cembra* occur quite frequently on sparsely overgrown ecological border habitats (possibility of the root extending to the side), *e.g.* on moraines or on rocks; they are also not absent in extensively

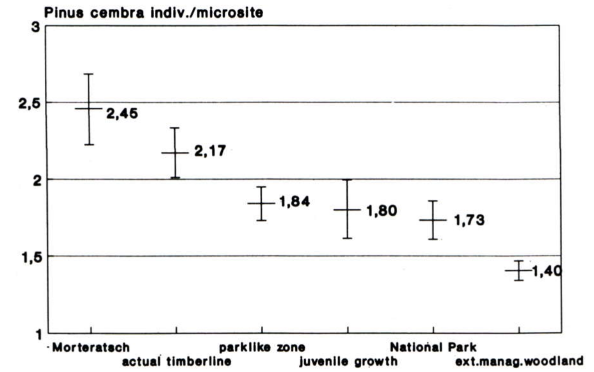

Fig. 8. Germinated/ growing *Pinus cembra* individuals per "nest": different landscape ecological zones and age groups. Mean values and standard deviations are given.

managed forests with a higher portion of fine ground. Whether here also it comes to intraspecific root intergrowths, is not yet known. However, judging by the results of other pine species, this could be expected (s. chapt. 4). A more efficacious 'selective thinning' will, as a rule, only enhance the growth of one individual per tuft. For this reason the multiple trunk type is underrepresented in such forests.

Since the occurrence of multiple trunk Cembran pine individuals in the different landscape ecological zones is not uniform, we would like to show their distribution pattern in the landscape of the upper and lower Engadin as an example – before we start on a characterization of the different growth forms.

3.3 Distribution pattern of multiple trunk Cembran pine individuals in the landscape of the upper and lower Engadin

In 29 areas (listed below under A–F according to the designations of the 'Landeskarte der Schweiz 1:25.000'), trunk countings of altogether 5227 living individuals of Cembran pine and 3024 microsites (hiding places of the Nutcracker) of Cembran pine were carried out in the upper and lower Engadin and the Poschiavo.

The results are presented in Fig. 7a–f and 8 and are explained as follows. The areas belong to 6 types, characterizing definable landscape ecological zones (see Fig. 1).

A. Regions in front of the Morteratsch glacier, 1900 m NN, trees and small trees from (1.5) 2 m height, Fig. 4, 7a, 8

In the area in front of the glacier, which has been icefree since 1857–1920, *Pinus cembra* appears – like on the neighbouring Roseg glacier – as a pioneer and reaches at present a maximal height of 5 m. Whereas in the transect, which has been icefree since 70 years only, we discovered only two small trees.

Lüdi (1958) already mentions individuals of Cembran pine in the front of the Morteratsch glacier, which, at that time, had a height of less than 1 m. The portion of the 3-trunk individuals with 31,3% has the highest value of all types investigated. A low average age and less damage by ibexes combined with a favourable light climate are important ecological factors in this area.

B. 'Outposts' (Holtmeier 1985) in the area of the actual timberline, 2200–2350 m NN, trees and small trees from 1–2 m height; Fig. 2, 7b, 8

Regions: Above Alp Languard and Suot Paradis near Pontresina; Munt da la Bês-cha near Celerina; Val da Camp/Poschiavo; Tamangur near S-charl; Tavrü near S-charl.

In this landscape ecological zone the 2-trunk individuals of *Pinus cembra* predominate with 43,5%, however, also the 3-trunk type is well represented with 16,7% (often occurring on rock sites); the mean number of individuals per microsite is 2,2. The area in front of the glacier and the zone of the actual timberline differ by number of *Pinus cembra* individuals per microsite significantly from the following types (Fig. 8).

In the zone of 'outposts' the tufts of *Pinus cembra* display in their growth form a similarity to the polycorms of *e.g. Picea abies* as they have been described in the important publications of Kuoch and Amiet (1970) and Tranquillini (1979). Also in North America there are corresponding clone forming species near the timberline (*e.g. Picea engelmannii, Abies lasiocarpa*, see Holtmeier 1989). Already Campell (1950) points at the different origin of *Pinus cembra* groups due to the seed hiding places of the Nutcracker.

C. Parklike zone beneath the actual timberline (at times overlapping and without clear demarcation) 2000–2250 m NN, Fig. 7c, 8

Areas: near Alp Languard, Muottas Muragl and Schafberg near Pontresina (without considering Cembran pine-afforestations at Schafberg); beneath Muottas da Schlarigna; Spuondas da Staz ob St. Moritz-Bad; Munt da la Bês-cha near Celerina; Alp Clavadatsch near Cristolais (Samedan); Val da Camp/Poschiavo; Tamangur near S-charl.

Of this type 1-trunk and 2-trunk type occur frequently; the formerly strong grazing impact in this zone and the partially already limited light climate are surely playing a part here. In addition there may be seeds of non-ornithochorous origin. The mean number of *Pinus cembra* individuals per microsite is around 1,8.

D. Juvenile growth up to 3 m within closed mature woodland, 1800–1980 m NN; Fig. 7d, 8

Areas: Staz Forest near St. Moritz-Bad with the exception of areas rich in *Picea abies*, on the fringe of Alp da Staz and Plaun da Staz, on the fringe of Val S-chüra near Pontresina; Tamangur near S-charl.

Countings of 1–3 m high juvenile trees in the Staz Forest and boundaries and in the non-managed *Pinus cembra* forest 'Tamangur' reached mean values of 1,8 individuals per microsite. The values given by Mattes (1978), who investigated 1–20 year old juvenile trees in the Staz forest (also including dead individuals and areas strongly overshadowed by *Picea abies* trees: the number of counted microsites being 218) are slightly lower (1,5). Here also one has to reckon with juvenile growth originating from non-ornithochorous dispersal.

It is astonishing that a comparison with non-managed mature woodland shows that the basic distribution of the 1-trunk, 2-trunk, 3-trunk types does not change very much.

E. Mature woodland with p.min.parte thin stems, non-managed; Fig. 7e, 8

Areas: National park: beneath Alp la Schera, closed stand 1800–2100 NN; Tamangur near S-charl 1200–2200 NN.

The steep slope area beneath Munt la Schera mapped by Campell and Trepp (1968) as Rhododendro-Vaccinietum cembretosum contains, next to thick stemmed *Pinus cembra* individuals also many thin and even dead stems.

Though being part of the National Park, the envisioned virgin forest conditions are disturbed by too much deer (every young *Picea abies* has been bitten off).

In spite of worse light conditions (in comparison with Type A–C) and the more severe competition with other tree species still 32,5% microsites of *Pinus cembra* with 2 trunks could be found; the mean number of individuals per microsite is 1,7. The non-ornithochorous dispersal certainly plays a part in closed forest stands.

Park zone, non-managed stands and the juvenile growth type show a uniform behaviour concerning the mean number of *Pinus cembra* individuals/microsite (Fig. 8) and differ considerably from other types.

F. Mature woodland with p.min.parte thin stems, managed extensively, 1800–2000 NN; Fig. 7f, 8

Areas: Staz forest near Pontresina, Celerina and St. Moritz-Bad; Sur Plaun near Samedan; God Spuondas-Rosatsch near St. Moritz-Bad; Tais Giuven and Chalchagn between Surovas and Morteratsch; Val da Camp/Poschiavo.

Also in these closed mature woodland approximately 30% of all trees are 2-trunk *Pinus cembra* individuals which have already coexisted over decades. Here too, according to Mattes (1978), the non-ornithochorous dispersal is involved.

The mean number of individuals per microsite is 1,4 and differs quite a bit from the other types. The distribution of trunk types according to Fig. 7f also applies to woodland, which, according to Bisaz (1968) contain Cembran pine trunks of the 'ideal shape' (with solid wood and a continuous axis): the foot of the slope of Staz- and Tais forest near Pontresina exposed to the north.

3.4 Growth forms of Pinus cembra multiple trunk individuals (coexisting types)

The following growth forms of *Pinus cembra* are found; in each case several individuals are involved:

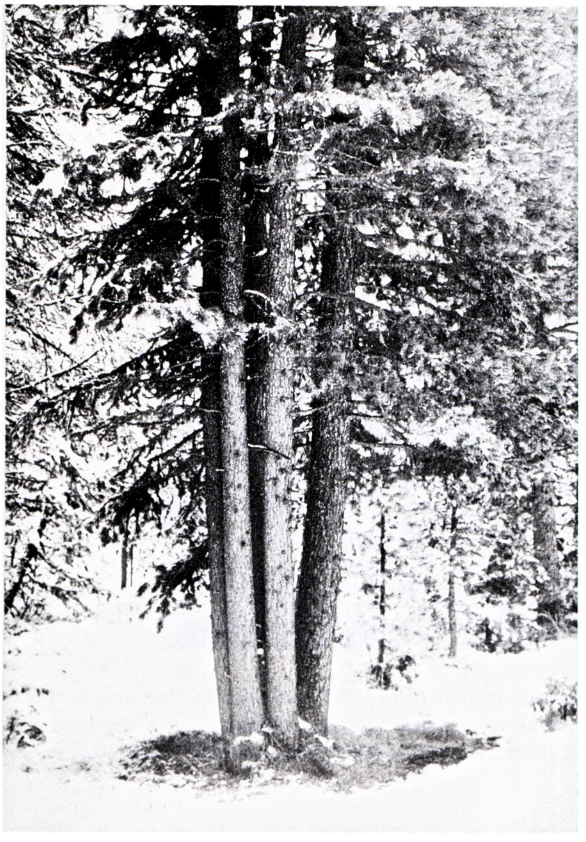

Fig. 9. 5-trunk Cembran pine without welding tendencies in the Staz forest (1800 m NN, 1.11.1991).

A. Multiple trunk Pinus cembra without or with slight welding processes

There are *Pinus cembra* individuals originating from seed nests which do not reveal a tendency of welding. Already closed to the ground they tend to grow apart in a funnel-like shape (Fig. 9). It is not quite clear whether this happens:

1) because the trunks have no contact with one another during the early stage of growth when they grow apart in a fountain-like manner;
2) because several hiding places of the Nutcracker are only slightly separated from one another within one locality;
3) because of the distinct genetical differences of the individuals.

In the area of the actual timberline one can often observe that, due to the minor growth the small trunks have no contact, and that the 'sabre shaped' basis – which came about through heavy snow pressure – helps to counteract welding. According to Holtmeier (1965) *Pinus cembra* tends to grow in a 'sabre-shaped' way close to the ground, especially when exposed northwards.

B. Multiple trunk Pinus cembra individuals with welding processes

This type demonstrates several different intensities of welding:

B. 1 Individuals with welding processes on the basis, often with physiognomically clearly definable tops:

Quite often there are examples of two surviving *Pinus cembra* individuals having grown together at their basis. This is confirmed by countings in different landscape ecological zones (Fig. 7, 8). The sutures at the points of welding are, as a rule, easily recognizable. This not yet completed welding becomes even more distinct when one of the trunks looses its stability, *e.g.* by lightening stroke or storm impact, which leads to the appearance of a split exactly on the suture.

B. 2 Individuals of intensive welding processes, sometimes up to 10–20 m height and the formation of a complete tree top made up of several individual tops:

Very impressive are multiple trunk individuals with various welding points in the trunk region, when their individuals form a complete crown with their tops, which, however, are still discernable as single 'sheaves'. It occurs, however, more often locally, especially in parklike zones beneath the actual timberline. When dying, *e.g.* as a result of immission damage, the individual tops of *Pinus cembra* are clearly distinguishable.

B. 3 Individuals whose multiple-trunk growth of intensive welding processes could mainly be seen on transections of trunks (see below) and only vaguely on sutures on the surface of trunks. In the area of the tree top the individual trunks can mainly be recognized by their 'sheaf structure'.

Under special circumstances (close togetherness of individual trunks, assumingly also close genetical

Fig. 10. Candelabra-shaped *Pinus cembra* photographed by L. Klein already in 1897 (Klein 1905, table 8). (a) The circonference at breast height in the year 1897 was 4.10 m, in 1989 5.05 m. In 1989 the trunk sutures clearly suggest a multiple trunk Cembran pine; (b) wide angle photograph, as the tree is now growing within the forest stand; Muottas da Schlarigna/ above Celerina, 2120 m NN, 7.8.1989).

relationship), extensive welding processes occur. This genesis can mainly be reconstructed when analysing the trunk transects (see below).

B. 4 Special types

– Double multiple trunk Pinus cembra individuals, same age

Co-existing types of multiple trunk *Pinus cembra* were found conglomerated with other multiple trunk individuals. At a certain moment of growth they had come into contact with each other and from then one started growing together at the basis. The formation of such double multiple trunk Cembran pines could possibly have developed from a 'double nest', which was deposited in an 'attractive' place by the Nutcracker.

– Double multiple trunk Pinus cembra individuals, different age groups

A special type was found which consisted of several multiple trunk *Pinus cembra* conglomerates (2-fold, *e.g.* 50 and 20 years old). One 'tuft' grows up under the shelter of another one; the earlier planted one serving as orientation for the Nutcracker.

←

Fig. 10b.

– Candelabra-shapes (Fig. 10a, b)

Candelabra-shapes develop above all when the main stem of a tree has been destroyed by lightening or storm ('break candelabra' according to Klein, 1913/14), and when earlier lateral branches compete for 'dominance' (Mattheck 1991). Particularly bizzare is the appearance of *Pinus cembra* candelabras, when they have developed to the multiple trunk type and when several main trunks have been destroyed (Fig. 10a, b).

The candelabra type of *Pinus cembra* shown in Fig. 10a was photographed by Klein on 20th August 1987 (Klein 1905, Table 8B) and was rediscovered by us in 1989 (Fig. 10b). Klein describes this as 'the most beautiful Cembran pine (candelabra tree with dominant main trunk) of the Muottas da Celerina (2120 m) . . . height 15–16 m'. Klein (l.c.) records a circumference at breast height of 4,10 m; 1989 we measured 5,05 m. The increase of the trunk circumference by 95 cm in 92 years is considerable (which is an approximate increase of 30 cm in diameter), this can only be explained by the accumulated increment of secondary growth in the thickness of several single trunks and the accumulation of reaction wood.

According to calculations made on the yearly increment of single trunk *Pinus cembra* in the same habitat Klein (l.c.) concluded that the age of this individual corresponds to its five-fold diameter. The candelabra tree photographed by him (Fig. 10a) was, according to his calculation method in 1897, 650 years old. When using this calculation method today, 92 years later, one would arrive at an age of 800 years. This proves that this calculation method cannot be applied to welded multiple trunk individuals, and that other multiple trunk individuals as well are much younger than assumed. Such connections were also not considered by other authors (*e.g.* Kirchner *et al.* 1909; Rikli 1909).

Formerly, this tree was standing completely free – as can be seen on the photograph by Klein (l.c.) – and it had far more branches and needles; today it is growing in the parklike zone beneath the actual timberline.

– Individuals showing welding processes which begin at a minor height, appearing to be 'stilted' in the lower part; in the top area it comes partly to a 'disentanglement'

All these observations indicate that the rarely occurring stilted forms consist of 2 individual trees, originating from seeds which were deposited far enough apart by the Nutcracker, so that the growing trees had no contact at their bases; neither were they dispersed ornithochorously. Only on a higher level do the trunks come into contact and start growing together. In the crown part the two single tops 'disentangle' and can be easily distinguished again from one another.

3.5 Analyses of trunk cross-sections of multiple trunk Pinus cembra individuals

Multiple trunk individuals of *Pinus cembra* possess several cores, which again represent the cores of several individual trunks and do not derive from ramification of branches; this is shown by comparing trunk cross-sections in different heights.

In most cases we were able to analyze welded double trunk individuals, however, also examples with 3 cores could be documented.

– Double trunk Pinus cembra with 2 cores, individual trunks of the same age (Fig. 11a, b)

In the Staz forest we found a trunk cross-section of a double trunk *Pinus cembra*, of which the 2 cores were clearly distinguishable. After analysis of the annual tree rings it was found that the two individual trunks being of the same age came into contact with one another when 14 years old after which they fused. This double-trunk individuals, which reached a diameter of 19 cm, were cut when about 44 years old.

The increment up to the time of contact of the two individual trunks, was 1,5 mm/year; thereafter, for correction purposes, reacting wood developed in order to obtain an homogeneous tension-state of the trunk surfaces (increment 2,3 mm/year) (Mattheck 1990a). This reacting wood balances the tension (Mattheck 1991, 1992). Since coniferes can only store compression wood, this increment is re-

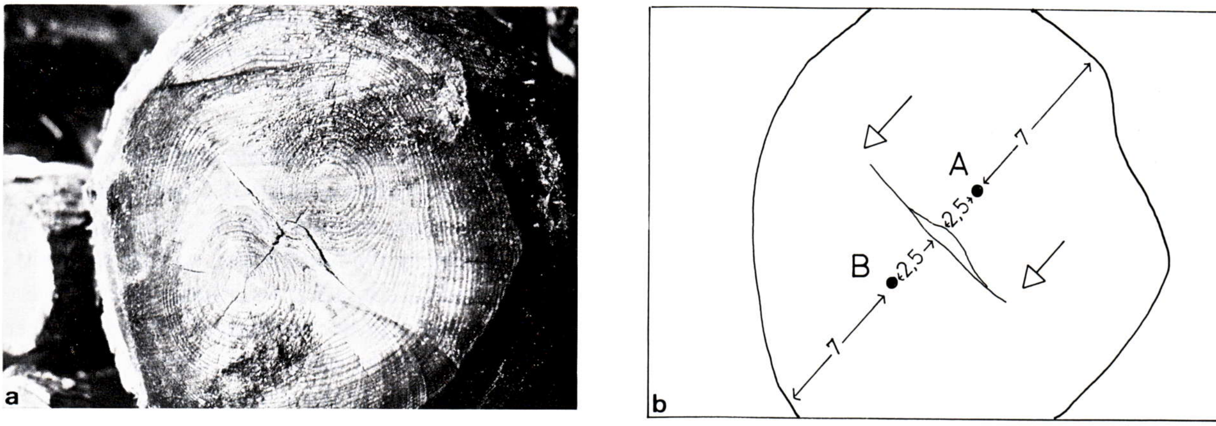

Fig. 11. Cross section of the trunk of a double-trunk Cembran pine; the outside of the trunk and the core A/ intergrowth suture/ core B; the outside is measured in cm. The arrows designate the vertical position of the annual rings on the contact area after the fusion of the individual trunks (Staz forest, 3.8.1988).

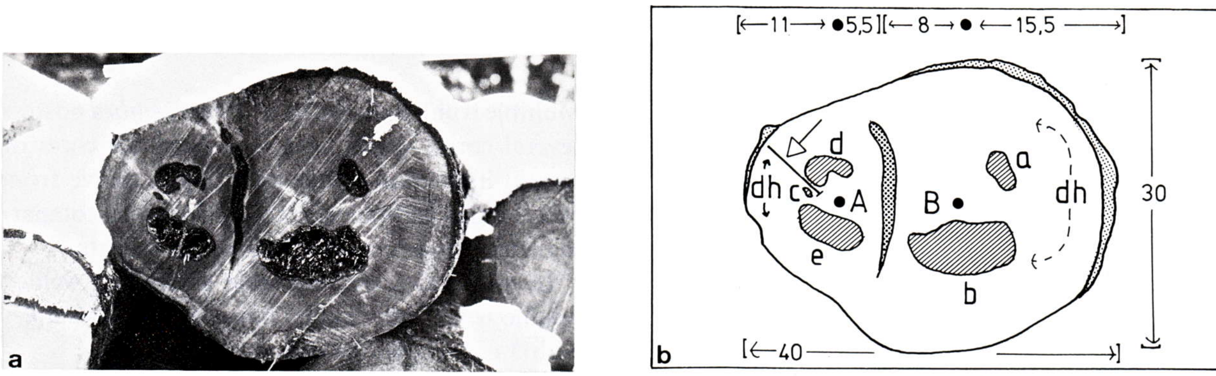

Fig. 12a,b. Double-trunk *Pinus cembra* with partial trunks of different ages (A = ca. 65 years, B = ca. 90 years); A and B = cores of the partial trunks, contact area between the partial trunks screened; a-d (hatched line) = rotten parts; arrow = welded suture, there vertical positions of annual rings; dh = compression wood area; distances in cm (above Pontresina, 2.11.1990).

stricted to the point of contact on the opposite side (s. *e.g.* Münch 1937; Bosshard 1974).

Remains of the outer bark are only recognizable as very thin strips.

The cross section of the trunk shows furthermore that 8 years after the contact the first common annula rings were formed. Such vertical position of the annual rings on the points of contact (see arrows in Fig. 11b) of two trunks being welded together are described by Mattheck (1990a). The vertical position enables steady process without any kinks of the all-connecting annual rings. On some examples concerning a number of finite-element calculations the author proves that there is quite an agreement of the position and orientation of the annual rings with the main tension trajectories, often also called force flow (Mattheck 1990a, b).

– Double-trunk Pinus cembra with 2 cores, individual trunks of different age (Fig. 12a, b)

We found individuals of this type near Pontresina. Assumingly they developed from two different Nutcracker nests out of which only one individual seed was successful. Analyses of annual tree rings gave an age of 90 years for trunk A and 65 years for trunk B. Also well distinguishable is the formation of compression wood on both opposite the contacts points. The two individual trunks are separated in the center by a thick strip of bark.

The rotten parts a, b, c, e, d do not, according to

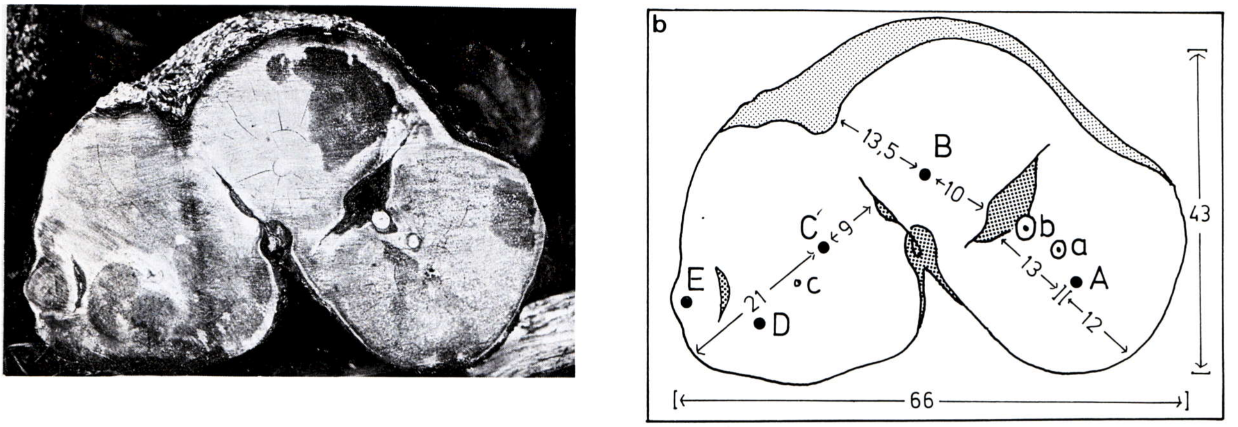

Fig. 13a,b. Multiple trunk Cembran pine with 3 cores (a-c) and branch enclosures (a-e). The contact area between the individual intergrown trunks are still very screened, the sutures on the trunk clear. Distances in cm (Staz forest/Pontresina, 2.8.1988).

the analysis of the annual rings, represent further cores.

It is remarkable that core B shows a welded suture on the left hand side. It starts on the point where the individual trunk has reached the age of 15 years. The cause of this welding processes cannot be found anymore as the rotting has already progressed too far.

Like in the above mentioned example the welded suture shows from a certain point again a vertical positioning of the annual rings.

– *Multiple trunk Pinus cembra individuals with 3 cores (Fig. 13a, b)*

We found a trunk cross section containing 3 cores of individual trunks (A–C) and furthermore enclosed branches (a–e). The more pronounced enclosed branches have a characteristic dark red-brown colour. The individual trunks with cores A, B and C are of the same age (approximately 90 years). They enclose in parts sections of bark.

3.6 Viewpoints of biomechanics

The analysis of the distribution of multiple trunk *Pinus cembra* individuals in different habitats clearly proves their frequent occurrence in extreme landscape ecological zones exposed to wind, ice, and where snow is being blown about. Though there is a tension in the trunk region according to Kübler (1959), which relieves the pressure tension caused by bending; however, here too there are stress limits (Mattheck 1990a, 1991).

Already during the early tuft growth there is a certain amount of friction between the branches, *e.g.* caused by wind. Through this friction a very effective, and above all, quick correction of the tension is obtained, thereby removing the extreme pressure- and tension-forces which the individual trunks would otherwise have to bear.

Though, in an early stage of the ontogenesis the trunks are still highly elastic, with secondary growth of the thickness, however, this elasticity decreases.

Already the first contacts through friction can be compared with the 'framework-principle' where a pull and pressure balance is possible with a minimum of material use. The next step is the 'permanent framework', arising from the friction effect, when the single individuals are entangled to such a degree that the single individual can only be assigned to with difficulty. After fusion of the individual trunks the framework is stabilized, and the tension is reduced considerably once the shape reaches its maximum. Computer models showing the framework principle of trees have been developed by Mattheck and his working team and give evidence of the above mentioned connections also quantitatively (CAO-Method = Computer Aided Optimization on the basis of biological growth; Mattheck and Moldenhauer 1990; Mattheck 1990b, 1992).

Fig. 14. "Framework principle" of a Cembran pine group with friction contact and intertwining of the smaller branches (above Lagh da Viola, Poschiavo, 2170 m NN, 19.7.1991).

Seen under biomechanical aspects the tuft growth leads to a higher degree of stiffness that the solitary growth, which is caused by the 'social' condition of the growth.

The tuft growth permits a convergent growth form *e.g.* to *Pinus mugo* with basitonic ramification. The elasticity of the young trunks of *Pinus pumila* in Japan and *Pinus mugo* s.str. in Europe have been analyzed by Wilmanns *et al.* (1985).

4. Concluding remarks

It appears that especially on the actual timberline and in the areas in front of glaciers tuft and multiple trunk growth of *Pinus cembra* is dominant. The parts above ground profit from this coexistence in such a way that it leads to a biomechanically stabilized 'compound'. But also below the ground such growth forms could be advantageous. One has to ask oneself whether the roots, in order to avoid competition, 'disentangle' or whether they also arrive at a kind of intraspecific coexistence. We were not able to examine the root conditions in this rather rock covered area.

According to tests made at random Fischer *et al.* (1960) assume that regular intraspecific root intergrowths do occur, the same as with other conifers (*e.g. Pinus strobus*, see Bormann and Graham 1959). According to Fischer *et al.* (l.c.) such root fusions can even be expected at regular intervals, when the mean tuft growth goes beyond 2,5 cm; its fusion into a larger compound root system should actually be an enormous help to survive on extreme sites. Junovilov (1952, cited in Graham and Bormann 1966) proved the occurrence of intraspecific root-intergrowth of *Pinus cembra* var. *sibirica*, and even the development of further annual rings on stumps still being supplied with nutrients by increasing intergrowth of the roots. Also recent literature describes that not much is yet known about the importance of intraspecific root-intergrowth (*e.g.* Vogt and Blomfield 1991). The fused multiple trunk *Pinus cembra* individuals have presumably also fused root systems.

The Nutcracker, as has been demonstrated by

Campell (1950), Furrer (1955), Holtmeier (*e.g.* 1965), and Mattes (*e.g.* 1978), is the most effective 'planter' of *Pinus cembra*, particularly on the timberline. He chooses 'safe sites' for his plantings (not too much snow, not too exposed to wind, and not too much ground frost) complying perfectly with the ecological requirements of the tree species (Aulitzky *et al.* 1982). The most preferred depots are rocky tops and slopes with markedly structured reliefs (Mattes 1978).

His 'tuft plantings' could serve as models which are biomechanically very well suited to withstand snow- and windpressure conditions. This 'ideal' is also being dealt with in recent literature which recommends the planting of tufts (*e.g.* Aulitzky *et al.* 1982 and Schönenberger *et al.* 1990). Forests, serving as protection against avalanches, should be structured in such a way that groups of trees which are confined to small areas should be the dominating feature (Gand 1983).

Pinus cembra tufts and their special growth forms play an important role for the sensitive landscape ecological zones in the subalpine area. A more exact analysis of the growth forms allows the reconstruction of the individual history which owes its specific genesis to the planting by the Nutcracker: a coexistence the roots of which are to be found in the close connection between plant and animal.

Acknowledgements

We heartily thank our colleague PD Dr. C. Mattheck (Kernforschungsinstitut Karlsruhe/Germany) who drew our attention to the realization of the 'framework principle' and who gave us important hints regarding the problems of biomechanics. Prof. Dr. H. Mattes (Münster/Germany) kindly answered questions concerning the seed collection by the Nutcracker. Many thanks to Prof. Dr. H. Zoller (Basel/Switzerland) and our colleagues from the Botanical Society Basel for a number of stimulating ideas for this work.

References

Aulitzky, H. and Turner, H. 1982. Bioklimatische Grundlagen einer standortsgemäßen Bewirtschaftung des subalpinen Lärchen-Arvenwaldes. Mitt. Eidg. Anst. forstl. Versuchswesen 58: 325–577. Birmensdorf.

Bisaz, O. 1968. Die forstlichen Verhältnisse der Gemeinde Pontresina. Bündnerwald 21: 188–200. Chur.

Bormann, F.H. and Graham, B.F. 1959. The occurence of natural root grafting in Eastern white pine, Pinus strobus L., and its ecological implications. Ecology 40: 677–691. Durham, NC.

Bosshard, H.H. 1974. Holzkunde. Bd. 2. Basel, 312 pp.

Campell, E. 1950. Der Tannen- oder Nußhäher und die Arvenverbreitung. Bündnerwald 4: 3–7. Chur.

Campell, E. and Trepp, W. 1968. Vegetationskarte des Schweizerischen Nationalparks mit einer Beschreibung der Pflanzengesellschaften von W. Trepp. Ergebnisse der wissenschaftlichen Untersuchungen im schweizerischen Nationalpark 11: 19–42. Liestal.

Fischer, F. *et al.* 1960. Künstlich hergestellte Wurzelverwachsungen. Mitt. Schweiz. Inst. forstl. Versuchswesen 36: 15–32. Zürich.

Furrer, E. 1955. Probleme und Rückgang der Arve (Pinus cembra) in den Schweizer Alpen. Mitt. Schweiz. Inst. forstl. Versuchswesen 31: 667–705. Zürich.

Gand, H. i.d. 1983. Schnee- und lawinenkundliche Grundlagen für Lawinenschutzwälder. Bündnerwald 36: 99–113. Chur.

Glutz v. Blotzheim, U. 1964. Die Brutvögel der Schweiz. 3. edit. Aarau, 648 pp.

Graham, B.F. and Bormann, F.H. 1966. Natural root grafts. Bot. Rev. 32: 255–292. New York, NY.

Holtmeier, F.K. 1965. Die Waldgrenze im Oberengadin in ihrer physiognomischen und ökologischen Differenzierung. Diss. Bonn, 163 pp.

Holtmeier, F.K. 1966. Die ökologische Funktion des Tannenhähers im Zirben-Lärchenwald und an der Waldgrenze des Oberengadins. J. Ornith. 107: 337–345. Berlin.

Holtmeier, F.K. 1985. Climatic stress influencing the physiognomy of trees at the polar and mountain timberline. In: Turner, H. and Tranquillini, W. (Eds.): Establishment and tending of subalpine forest: research and management. Proc. 3rd. INFRO workshop. Ber. Eidg. Anst. forstl. Versuchswesen Ber. 270: 31–40. Birmensdorf.

Holtmeier, F.K. 1989. Ökologie und Geographie der oberen Waldgrenze. Ber. d. Reinh. Tüxen-Ges. 1: 15–45. Göttingen.

Kirchner, O. v., Loew, E. and Schröter, C. 1909. Lebensgeschichte der Blütenpflanzen Mitteleuropas. Bd. 1, Abt. 1: Pinus cembra: 241–272. Stuttgart.

Klein, L. 1905. Charakterbilder mitteleuropäischer Waldbäume I. Vegetationsbilder 2 (1–3, 5–7), Jena.

Klein, L. 1908. Bemerkenswerte Bäume im Großherzogtum Baden. Heidelberg, 372 pp.

Klein, L. 1913/14. Ästhetik der Baumgestalt. (Festrede zur Feier der Großherzogl. Techn. Hochschule Fridericiana bei Übergabe des Rektorates) Karlsruhe, 59 pp.

Kübler, H. 1959. Die Ursache der Wachstumsspannungen und die Spannungen quer zur Faserrichtung. Holz als Roh- und Werkstoff 7: 1–9.

Kuoch, R. and Amiet, R. 1970. Die Verjüngung im oberen

Bereich der Waldgrenze der Alpen. Mitt. Schweiz. Anst. forstl. Versuchswesen 46: 159–328. Birmensdorf.

Lüdi, W. 1958. Beobachtungen über die Besiedlung von Gletschervorfeldern in den Schweizeralpen. Flora 146: 386–407. Jena.

Mattes, H. 1978. Der Tannenhäher im Engadin. Münstersche Geographische Arbeiten 2, Münster/Westf. 87 pp.

Mattes, H. 1982. Die Lebensgemeinschaft von Tannenhäher und Arve. Ber. Eidg. Anst. forstl. Versuchswesen, Birmensdorf, 74 pp.

Mattheck, C. 1990a. Why they grow, how they grow – the mechanics of trees. Arboricultural Journal 14: 1–17. Berkhamsted.

Mattheck, C. 1990b. Engineering components grow like trees. Materialwissenschaft und Werkstofftechnick 21: 143–168.

Mattheck, C. 1991. Trees. The mechanical design. Berlin a.o. 119 pp.

Mattheck, C. and Moldenhauer, H. 1990. Intelligent CAO-method based on biological growth. Fatigue & Fracture of Engineering Mat. & Struct. 13: 41–51.

Mattheck, C. 1992. Design in der Natur. Freiburg i. Br. 242 pp.

Münch, E. 1937. Entstehungsursachen und Wirkung des Zug- und Druckholzes der Bäume. Forstl. Wochenschrift Silva 45: 345–352.

Rikli, M. 1909. Die Arve in der Schweiz. Ein Beitrag zur Waldgeschichte und Waldwirtschaft der Schweizer Alpen. Neue Denkschrift der Schweizer Naturforschenden Gesellschaft 44. Teil 1 u. 2.; Basel, 455 S., 28 Tafeln, 1 Karte.

Schiechtl, H.M. and Stern, R. 1975–1984. Die Zirbe (Pinus cembra L.) in den Ostalpen. Teil I–IV. Angewandte Pfl. soz. 2, 24, 27, 28. Wien.

Schönenberger, W. *et al.* 1990. Ökologie und Technik der Aufforstung im Gebirge. Ber. Eidg. Anst. forstl. Versuchswesen 325, Birmensdorf, 58 pp.

Schroeter, R. 1908. Das Pflanzenleben der Alpen. Zürich, 806 pp.

Sutter, J. 1981. Der Tannenhäher (Nucifraga caryocatactes/Cratschla). Bündnerwald 34: 566–571. Chur.

Tranquillini, W. 1979. Physiological ecology of the alpine timberline. Ecol. Studies 31. Berlin u.a., 131 pp.

Vogt, K.A. and Bloomfield, J. 1991. Tree root turnover and senescence. In: Waisel, Y. *et al.* Plant roots. The hidden half: 287–306. New York.

Wilmanns, O., Bogenrieder, A. and Nakamura, Y. 1985. Vergleichende Studien des Pinus-Krummholzes in den Japanischen und europäischen Alpen. Tuexenia 5: 335–358. Göttingen.