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PERFORMANCE OF HIGH ALTITUDE AFFORESTATIONS IN THE ALPS SINCE 1865: ANALYSES OF DAMAGES AND CHANCES OF SUCCESS

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ABSTRACT

This paper presents the preliminary results of field investigations, studies on natural succession at timberline, and discussions on practical experience aimed at identifying causes of success or failure in high altitude afforestations (30 and 80 years old) in Austria and Switzerland. The findings so far reveal the following implications for future projects:

Planning:

- long-term 'High Altitude Development Plans' on a local and regional basis are essential
- digital mapping and superimposition of natural site factors (altitude, exposure, inclination, plan communities, ground relief etc.) should shortly be possible

Preparation:

- autochthonous seed from (a few) locally growing individuals should be used
- plants should be raised without excessive or unbalanced fertilisation under climatic conditions corresponding as closely as possible to those of the prospective planting site
- planting sites should be carefully selected with regard to altitude, exposure, inclination, ground relief, soil type and depth, ground cover, plant communities, soil erosion and local natural tree vegetation
- planting holes should be prepared 2-5 years in advance

Execution:

- careful pit-planting in groups is necessary
- the young trees must be adequately protected against damage by cattle, wild animals, and skiers

Tending:
- all infected individuals should be consistently removed
- gaps should be filled (beating up)
- compact adult groups should be thinned to create stable units

It is recommended that a model afforestation be established to demonstrate and confirm the results of scientific studies and practical experience.

INTRODUCTION

The above-mentioned title represents in a simplified way the subject of a comprehensive research project at the Institute of Silviculture of the University of Soil Cultivation, Vienna. The aims are first to examine and verify the practical experience gained in successful and unsuccessful high altitude afforestations; and secondly to treat analysis of the phasic natural development along the alpine timberline, together with the latest scientific findings, in a comprehensive survey.

To date, analyses have been made of afforestation projects in the Mur, Ziller, Pitz and Paznaun Valleys in Austria and the Ulten Valley in Italy, all 25-30 years old, and an 80-year-old project in the Engadine in Switzerland; and of the natural renewed colonization by cembran pine in the Oetz Valley and Kühtai in the Tyrol.

Further analyses will include projects in the Great Walser and Lech Valleys (Austria), Pontresina, Bever (Switzerland), and Sonthofen (FRG). The natural development of spruce and larch in the southern, northern and eastern Tyrol will also be treated.

GENERAL BACKGROUND

Thirty years ago in Austria, the discussions on the problems were pervaded by an initial euphoria of success, but since then a feeling of deep resignation has become increasingly apparent. Without doubt this is due not only to professional setbacks but also, and most especially, to the circumstance that the time factor had been enormously underestimated. In our future work we will have to accept that projects will take much longer to realise than was originally thought. That successful reforestation of suitable high altitude sites is basically feasible - financial considerations aside - is demonstrated by numerous projects along the timerline in Switzerland. In the 1870s and 1880s afforestation rendered many an avalanche starting zone above the then existing forest belt more or less innocuous. However, the enormous success of those afforestation projects is now causing tremendous problems in forest tending.

The stands of cembran pine, with their high stem count and disorderly arrangement, are now 80-100 years old and 10-15 m high. They must be thinned at any price if their further stable development is to be ensured.

It can be done - of this there is no doubt. How it is to be done should be easily decided after so many years' experience. This is true even where expenditure has to be kept within reasonable limits, although the cost factor must take second place to success in evaluation and decision-making.

That afforestation is necessary remains undeniable. For one thing, various types of agriculture (forest pasture, forest litter utilisation) have lowered the actual forest line by as much as 300 m and created very unfavourable soil-hydrological conditions. For another, the once utilized areas above the actual timberline have now largely fallen into disuse, with the result that new avalanche starting zones have developed. Some two-thirds of all avalanches are released within the potential timberline zone. In the past few decades, over-aging aggravated by pollution and game damage has lead to an increasing destabilisation of the forests with a concomitant reduction of their protective ability. This development in particular demands the regeneration and restabilisation of the mountain forests, if only at their most vulnerable point, the upper timberline.

PRELIMINARY PARTIAL RESULTS

These are presented in terms of those factors influencing success which the practical forester can easily recognize in the field.

Height above sea-level: For the present, practical work has been restricted to medium high altitudes (1800-2000 m/1500-1700 m) because success at very high altitudes (2000-2200 m inner eastern Alps, 1600-1900 m edge of eastern Alps) has been extremely limited. Nevertheless, natural regeneration of cembran pine has been quantitatively and qualitatively adequate on sunny slopes up to 2330 m and shady slopes up to 2150 m in the inner Tyrolean Alps, at least where pressures of pasturing and game have not been too great (Obergurgl, Vent, Kühtai). In places, larch and spruce also grow successfully up to these altitudes. 60-100-year-old afforestations up to 2300 m in Switzerland have even achieved optimum results, and the methods of growing on are well worth imitating.

These results clearly show that cultivation at very high altitudes is perfectly feasible as long as the necessary care is exercised and the latest technical knowledge is applied. Nevertheless, the effects of successful afforestation on the environment can only be assessed after longer periods than were initially assumed. Comprehensive, highly detailed plans are of supreme importance, especially for subsequent checking of success. Choice of tree species, suitable seed material, and micro-site as well as cultivation and planting methods and quality of work are also crucial.

The urgent necessity of re-stocking very high altitude sites arises, among other things, from the generally damaging effects of snow-slips on lower slopes (snow pressure, fungal infections), which are usually fairly flat and could easily be afforested.

Exposure: In almost all projects success was greatest on sites with (SE), S and W exposure. Long-term, stepwise afforestation should begin on just such sites. The less influential the warmth factor, the more important the careful selection of micro-site. For example, south-facing sites at 2000 m in the Ziller and Pitz Valleys clearly exhibit a wider amplitude of success in terms of micro-site than north-facing sites (hilltops only; see Figure 3). Schönenberger (in Turner,1983) demonstrates with his computerlayout of the Stillberg research area that greater exposure to solar slope irradiation promotes growth.

In the north of the eastern Alps there are a few warm, dry areas; in the southern Tyrol and the western Alps (in particular the Engadine and the Valais) such sites are more numerous and extensive. Where north-westerly weather prevails, sites with E-SE aspect are unfavourable because of the accumulation of snow and the formation of cornices. On basically favourable hilltop sites, snow deposition and snow superposition may occur with such negative results as concentrated infestations of *Phacidium* (Ziller Valley).

Inclination: Together with soil cover, inclination is the most important factor in damage by snow pressure. Sites can be classified without measurement of the absolute inclination according to the type of snow movement:

- snow slides off (movement over fairly large distances, little snow remains)
    + thin layers of snow slide up to 15 (20) cm
    + thicker layers of snow slides 20+ cm
- deposition of snow (sliding down from areas above)
- snow slides over small distances only
- snow creeps (fairly flat terrain, deep snow cover)
- no active snow movement (flat areas, rounded hilltops, thin snow cover).

In areas with natural regeneration and in afforestation zones it can clearly be seen that even a minor snow cover of only a few cm will slide from very steep slopes (45°+) with surfaces inducive to sliding (rocks, rock slabs etc). Consequently, plants beginning to grow on such sites are seldom or never exposed to snow pressure. Schönenberger (1981) found no deformation of trees on sites with inclinations above 40° and little snow. This provides the only possible explanation for the frequent occurrence of solitary trees and small tree groups on even the steepest sites at very high altitudes.

At the same time, although such steep sites (break-off zones) often extend over only small differences in height (3-15(20) m), snow sliding from them can initiate snow movement over 3-20 times that distance on less steep slopes directly below.

Because of the enourmous difficulties and the tremendous planting costs, such break-off zones have been excluded from our projects so far. Our present knowledge, however, indicates that they are in fact the most suitable sites for afforestation, first because they are generally favourable for the stablishment of trees and secondly because with increasing age of the trees they release smaller masses of snow.

Where natural growth occurs on such steep, rocky sites, successive regeneration often fails to occur on the slopes below. This is usually due to browsing by game and cattle interrupting the natural course of colonization (=regeneration) shown in Figure 1. Growth occurs first in the steep break-off zone and with increasing stabilization of the slope by the developing trees spreads uphill from the end of the snow blanket.

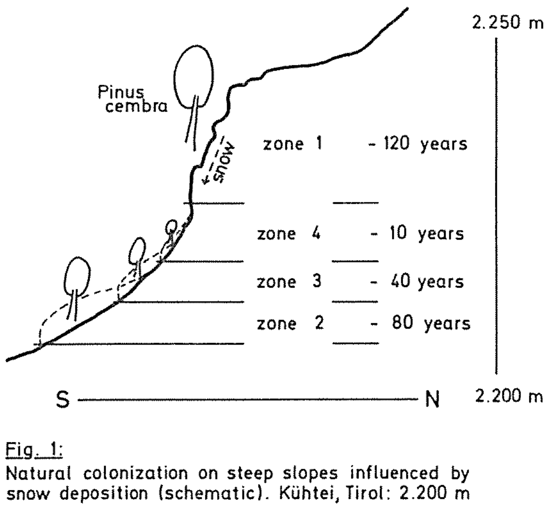


Fig. 1:
Natural colonization on steep slopes influenced by snow deposition (schematic). Kühtei, Tirol: 2.200 m

Slope inclination also influences soil and soil formation through its effect on the moisture and air content of the substratum, and consequently on its warmth. Plants will often grow successfully on unpastured, rocky, steep areas but fail to do so on adjacent pastured sites with no accumulation or sliding of snow and dense soils rich in fine earth. This may be explained by the better drainage and warmer conditions obtaining on the steep slopes in contrast to the cold, wet conditions unfavourable to growth on the flatter sites. Turner (1983) found such conditions to be hostile to root development.

Relief: The influence of micro-relief on growth conditions at high altitudes in the inner eastern Alps is described in detail by Aulitzky (1963). Our analysis of structure and age in different phases of natural regeneration on a divided, sunny slope with little snow (Kühtai)revealed the following sequence: luff upper slope, lee upper slope/ridge, rounded hilltop/middle slope/ (lower slope) (Figure 2).

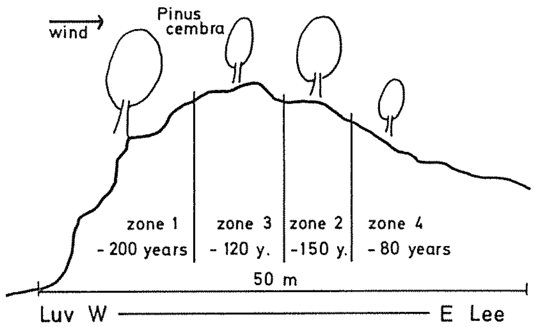


Fig. 2:
Natural colonization on steep slopes influenced by climatically favoured micro-stands and snow deposition (schematic). Kühtei, Tirol: 2.100 m

In those areas of the lower Ziller Valley rich in snow and not extremely windy, natural colonization by different species started directly on the rounded hilltops (ridges). Otherwise natural regeneration took place only gradually. Therefore the rounded hilltops and upper slopes can be regarded as favourable areas. Furthermore, the nutcracker tends to hide cembran pine seeds in such areas, because there is less snow cover (natural regeneration, Mattes, 1982). However, it must also be borne in mind that extended gullies in areas with much snow and smaller gullies in areas with little snow remain without vegetation for a long time because of snow deposition.

In all the afforestation areas, a progressive loss of trees was found, beginning in the gullies and spreading to the middle and lower slopes (Figure 3). How far the deaths extend towards the rounded hilltops depends on the amount of snow. Often there are only a few, isolated individuals of different tree species remaining.

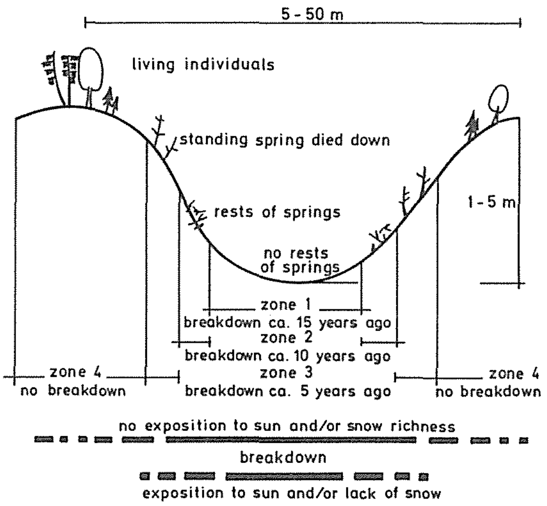


Fig. 3:
Breakdown of afforested plants, selected by micro-stand (schematic). Zillertal-Pitztal, Tirol: 1.800 - 2.100 m

In most cases the deaths were caused directly by the snow blight fungi *Phacidium* and *Herpotrichia* or indirectly by *Scleroderris* (cembran pine) and *Encoeliopsis* (larch) (Donaubauer, 1980), attacking trees with diminished vitality (Turner, 1983). In addition, all the types of damage caused by snow pressure were found. Deaths through wind and frost drought on rounded hilltops are only important in the inner eastern Alps and constitute only a small proportion of the losses. They are largely restricted to those areas affected by gradient winds. Nonetheless, entire slopes may be affected by severe wind and snow abrasion of bark and needles (Mur Valley). There is little hope of successful afforestation on such sites unless the plants are shielded by artifical constructions.

Geological substrate and provenance: The importance of provenance as a factor in the selection of suitable plants and seeds, especially for high altitude afforestation, had already been recognized in Switzerland 120 years ago. Old project documents contain many veried orders and worried remarks about it (1865-1910). As still happens today, however, short-sighted financial planning and lack of time often lead to the use of cheap material of uncertain origin. In many cases the lengthy preparations requisite for success were omitted. As often happens, it was necessary to begin work as soon as funds became available, without waiting to obtain the most suitable material for the project concerned (Schlatter, 1935). One of the most important conditions for the success of any long-term project (50-100 years) is that 5-10 years be spent on preparatory work, especially today. Simply acquiring suitable seed and raising 4-6-year-old trees for planting out requires that length of time.

The acquisition of seed material is a major problem. The trees are not easily accessible at the best time of year for harvesting. Spruces produce many seeds and these are easily stored. Larches, on the other hand are more difficult to climb and seldom produce sufficient amounts of seed (high costs). In the case of cembran pine, besides coping with all these difficulties, the forester has to compete with the nutcracker for the seeds; it often happens that by the time the seeds are ready for harvesting the birds have collected them all. For this reason the nutcracker has been hunted in recent years, its importance for the natural regeneration of cembran pine not being realized (Winter, 1983). The recent success of E. Frehner, SFIFR, Birmensdorf, with premature harvesting and ripening in sorage could well provide the solution to this problem.

Provenance also seems to be a decisive factor in vulnerability to pests. Epidemic outbreaks normally only occur if:
- the provenance is attacked by a foreign parasite against which it has no effective defence mechanism (e.g. provenances from southern Tyrol)
- the vitality of the plants is generally reduced (e.g. death of sprouts in larch or cembran pine; loss of vitality due to faulty selection of site).

The importance of using plants of autochthonous provenance is demonstrated by the fact that spruces of local origin are flourishing in the afforestation at Taschach, Pitz Valley, 1900-2200 m, while almost all the larches and cembran pines of uncertain origin have died because of 'sprout decay' (parasitic fungi species of the genera *Encoeliopsis* and *Scleroderris*; see Donaubauer, 1980).

Type and depth of soil: This factor must also be considered in selecting afforestation sites. Long-term supply of nutrients, water, and air, together with the possibility of root anchorage from the purely mechanical viewpoint is very important for success. Where the soil is degraded and very dense, the planting holes should be prepared well in advance, or terraces should be constructed so as to break up the soil. Thick layers of humus on the surface should be thoroughly worked into the soil, preferably 2-5 years before planting. Soils with good drainage and ventilation are always preferable to dense, waterlogged ones.

Erodability of the site: The stability of the soil must remain undisturbed, particularly during the early growth of the plants. Where there is a tendency towards erosion, terraces should be constructed, but only as far as is absolutely necessary. Large terraces have proved unfavourable, especially when the trees are planted towards the front. Not only are the risks of freezing and frost drought higher, but snow pressure results in a slight lifting of the slopeward roots of older trees with inelastic stems (30-40 years old). Planting towards the back of flat or slightly inward sloping terraces is much more likely to succeed: it results not only in better moisture conditions, lower risks of freezing, and better mechanical protection during the early years but also in more stable mechanical support for the roots (Figure 4).

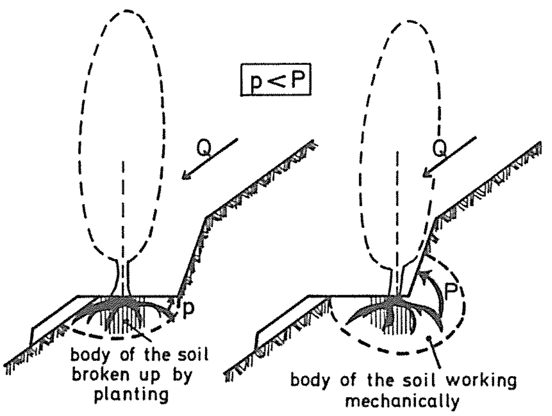


Fig. 4:
Stability of plants increased by planting slopewards in terraces

Soil surface (rocks, vegetation cover): The poor nutrient supply and apparent sterility of rocky surfaces - whether steep cliffs or flat slabs - are outweighed by their better retention of heat and moisture. In some areas of natural growth in the Tyrol, cembran pines growing in the vicinity of fairly large stone slabs displayed above-average survival and greater vitality. In Switzerland and the southern Tyrol, traditional planting methods included covering the holes with stone slabs. On the on hand the slabs accumulated and retained heat - hence their nickname, 'hot water bottle' - and on the other they held back the soil moisture, which was often minimal, to the benefit of the plants. In terms of heat and moisture, rocky surfaces create conditions favourable to root development and extremes are less marked. Furthermore, they lead to early snow melt with a correspondingly longer vegetation period (Figure 5).

Bare surfaces likely to overheat are usually rare and small in afforestation areas and should be left unplanted, at least at first.

Plant communities reflect the overall ecological conditions of the microsite and are thus important indicators for the practical forester. For the central region of the Eastern Alps, the 'wind-snow-ecogram' (Aulitzky 1963) may serve as a basic guide. The Institute of Silviculture is working on similar indicator comminities for the edge of the Alps.

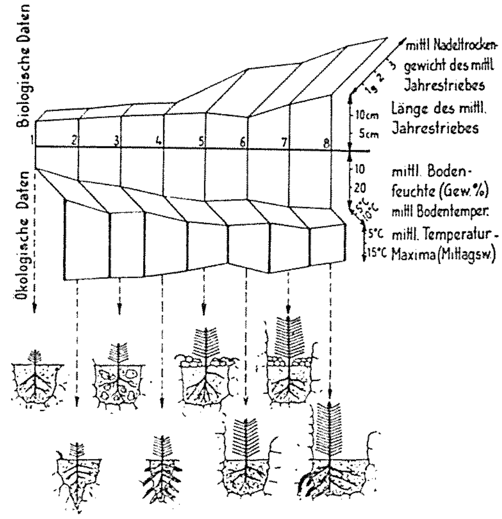


Fig. 5.: soil humidity influenced by covering the planting-hole with stones (Barner, 1978)

'Silent witnesses': The solitary trees and the tree groups of various species occurring on exposed high altitudes sites are not, as is often asserted, relics of a time before felling in these areas. The age of those so far examined ranges between 50 and 200 (250) years and almost always coincides with periods of exclusively agricultural utilization. So far the occurrence of these 'pioneers' on extreme sites has generally been assumed to be due to the absence of browsing by game and cattle because of the difficult terrain. However, in the light of the poor results often obtained in afforestations on relatively lower, more favourable, fenced sites, this explanation seems somewhat inadequate, because:

- since these steep areas have never been planted, the existing trees must be the autochthonous descendents of a population which has now largely died out;
- the high degree of success on these extreme sites selected by nature, as compared to the poor results in better, fenced, afforestation areas, indicates that either provenance or site conditions - probably both - were more favourable for growth.

Thus these 'pioneers' bear silent witness to the fact realized over a century ago that provenance is of crucial importance. They also indicate that too little attention has been paid in the past to the careful selection of seed material, presumably because of lack of funds and time. Successful afforestation at high altitudes will require a consistent method of harvesting extending beyond the present legal provisions.

Plant cultivation: The short-term, financially oriented approach has often resulted in cultivation methods using excessive fertilization and long vegetation periods (low altitudes) to produce large plants within the shortest possible time (3-5 years). While such plants may be suitable for normal afforestation, they are practically guaranteed to fail at high altitudes. The difference in altitude of the nursery and the planting site should not exceed 300 (max. 500) m. In Switzerland this condition has generally been observed. Unbalanced fertilization, particularly excessive nitrogen, should be avoided (sprout damage by frost).

Barner (1978: 97-98) published data given by Tranquillini (1963: 553-554) which indicate that young cembran pine plants raised at high altitudes are much more resistant to frost than fertilized plants from nurseries (Table 1). Furthermore, comparison of plants raised with and without snow cover at high altitudes shows that the uncovered plants are subject to stronger selection against partial frost damage and are hardier (Table 2).

Tabulation 1: analysis of frost damages to young cembran-pine plants growing in high altitudes and nurseries Barner, 1978

	young cembran-pine plants	
	grown in high altitudes	grown in the nursery
partial damages	-29°C	-17°C
damages of medium extent	-33°C	-24°C
total damages	-39°C	-30°C

Tabulation 2: analysis of frost damages to young cembran-pine plants growing in high altitudes covered with snow/ covered with no snow and in nurseries Barner, 1978

	young cembran-pine plants		
	plants grown in high altitudes covered with no snow	plants grown in high altitudes covered with snow	plants grown in the nursery
partial damages possible	-41°C	-31°C	-17°C
partial damages certain	-41°C	-35°C	-26°C
total damages certain and possible	-47°C	-47°C	-31°C

In recent observations in Austria, potted plants failed to meet expectations. In many cases the plants were unable to root in the surrounding substrate sufficiently, or the roots became fused. This may be an indication of the effects of an over-fertilized substrate on the direction of root growth.
Vaccination with mycorrhiza is equally important (Göbl, 1980).

Spruce regeneration 'under shelter' has been shown to result in the advantages of higher attainable physiological age and dense juvenile wood affording better resistance to rot. In view of this, young plants with broad annual rings should neither be raised nor used for high altitude afforestation.

Planting method: Angle-notch planting often results in an asymmetrical root system oriented towards the slope (Sauer, 1983). A heavy burden of snow (=Q) can easily uproot a 20-40-year-old tree without normal supporting roots (Figure 6). To ensure the greatest mechanical stability of the tree, methods resulting in an evenly distributed root system should be used (e.g. pit planting).

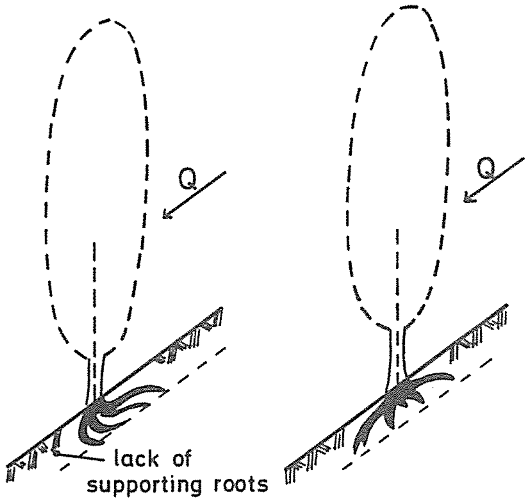
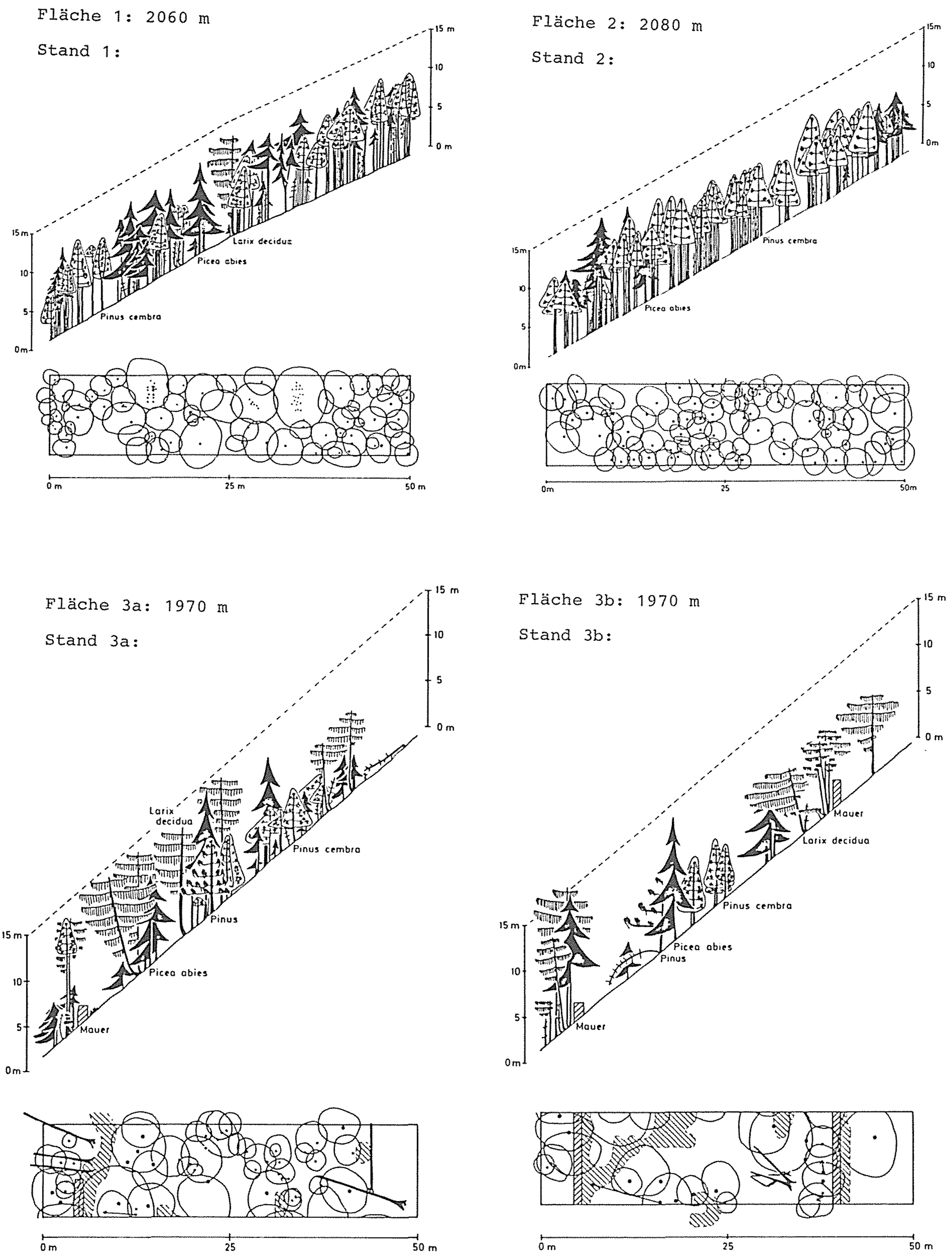


Fig. 6:
Stability of plants, increased by a regular-spread root system

On basically favourable micro-sites, planting in small groups (0.3-0.5 m spacing) is usually successful, as nature demonstrates. In the early decades of growth the trees protect each other from extremes of mechanical and climatic conditions. In terms of further development and stand tending, group planting produces separate, independently stable stands, as can be seen in Switzerland.

Fig. 7: Motta d'Alp



Ha--figures of item numbers and supply according to different diameters, mortality and taking in % of the living total ressources

<u>Tabulation 3:</u>

Motta d'Alp: Fläche 1 Stand 1:

BA		1-4	%	5-8	%	9-12	%	13-16	%	17-20	%	21-24	%	25-28	%	29-32	%	33-36	%	Σ leb	%	%	Σ tot	%	N in Rotten	%	durch schnittl.
Zi	N	-	-	20	2	80	9	200	22	260	28	140	15	140	15	80	9	-	-	920	100	29	100	12	420	46	1,9
	Vfm	-	-	0,40	-	3,30	2	13,94	10	28,86	21	24,12	18	40,22	29	28,04	20	-	-	138,88	100	39	-	-	220	33	
Fi	N	120	5	260	12	420	20	480	22	360	17	260	12	140	7	80	4	20	1	2.140	100	69	660	79	1940	91	4,6
	Vfm	-	-	4,85	2	19,36	9	31,34	15	42,48	20	47,10	22	36,06	17	25,20	12	6,72	3	213,11	100	59	-	-	420	64	
Lä	N	-	-	20	33	20	33	-	-	-	-	-	-	20	34	-	-	-	-	60	100	2	80	9	40	67	2,0
	Vfm	-	-	0,35	4	0,81	10	-	-	-	-	-	-	6,92	86	-	-	-	-	8,08	100	2	-	-	20	3	
Σ	N	120	4	300	10	520	16	680	22	620	20	400	13	300	9	160	5	20	1	3.120	100	100	840	100	2400	77	3,5
	Vfm	-	-	5,60	1	23,47	6	45,28	13	71,34	20	71,22	20	83,20	23	53,24	15	6,72	2	360,07	100	100	-	-	660	100	

	OS	%	MS	%	US	%	Σ	%
leb N	1820	58	100	32	300	10	3.120	100
tot N	20	1	160	4	660	16	840	27
ges N	1840	-	1140	-	960	-	3.960	-
Entnahme N	240	6	300	8	180	5	720	23

<u>Tabulation 4:</u>

Motta d'Alp: Fläche 2 Stand 2:

BA		1-4	%	5-8	%	9-12	%	13-16	%	17-20	%	21-24	%	25-28	%	29-32	%	33-36	%	Σ leb	%	%	Σ tot	%	N in Rotten	%	durch schnittl.
Zi	N	20	1	120	6	160	9	380	20	400	22	400	22	240	12	140	8	-	-	1860	100	71	220	55	920	49	2,0
	Vfm	-	-	1,86	1	5,64	2	26,14	9	49,98	19	73,56	28	57,1	22	48,12	19	-	-	262,40	100	79	-	-	460	70	
Fi	N	20	3	100	13	100	13	220	29	180	23	80	11	60	8	-	-	-	-	760	100	89	180	45	680	89	3,5
	Vfm	-	-	1,87	3	2,25	4	14,82	22	23,20	33	11,24	16	15,30	22	-	-	-	-	68,68	100	21	-	-	200	30	
Σ	N	40	2	220	9	260	10	600	23	580	22	480	18	300	11	140	5	-	-	2620	100	100	400	100	1600	61	2,4
	Vfm	-	-	3,73	1	7,89	2	40,96	12	73,18	22	84,80	26	72,40	22	48,12	15	-	-	331,08	100	100	-	-	660	100	

	OS	%	MS	%	US	%	Σ	%
leb N	2020	77	440	17	160	6	2.620	100
tot N	-	-	160	6	240	9	400	15
ges N	2020	-	600	-	400	-	3.020	-
Entnahme N	440	17	300	11	120	5	860	33

legend: Zi= Pinus cembra
Fi= Picea abies
Lä= Larix decidua

OS= upper layer
MS= middle layer
US= under layer

leb= individuals alive
tot= individuals died
ges= individuals total

in Rotten= in groups
durchschnittl.= in average
Entnahme= taking out

In the afforestation Motta d'Alp, Tschlin (Engadin), completed at the beginning of the century, and in many other projects of that time, group planting (1-3 m^2) lead to real success (Figure 7). At an altitude of 2000-2100 m some 60-80 % of all indivuduals are gathered in groups. The stem count within each group is generally twice as high for spruce as for cembran pine (Tables 3,4).

Quality of work: Experience shows that optimum success can only be guaranteed by employing skilled workers who are paid by the hour and consequently work carefully. In Switzerland the importance of the quality of work was already recognized a hundred years ago, and experts were employed to supervise planting.

Stand tending and consistency: With afforestation projects requiring much work and money, the omission of appropriate stand tending means inconsistency and greatly endangers success. This is clearly demonstrated by the present labile state of the old afforestation areas in Switzerland (Figure 7, Tables 3,4). At Motta d'Alp the 2600-3200 living trees of 10-15 m height per hectare indicate that tending for stability (= thinning) has been neglected. This is confirmed by the decrease in stratification and the mortality rates of 15-30 % which are already beginning to affect the upper layer. It is extremely difficult to decide what method and intensity to use here in thinning operations, which, coming so belatedly, can at best produce only suboptimum conditions of stability.

Where high altitude afforestation is concerned, realistic, long-term planning is much more important than for production forest. Such planning should include:
- protection against browsing by game and cattle and against damage by skiers
- 'negative selection' of infected individuals (infectious clusters, cutting out and burning)
- beating up
- 'positive selection' of the best plants to free them from competition; creation of 'micro-collectives' as independently stable cells
- permanent, careful treatment of these corresponding to the particular conditions obtaining and the degree of endangerment.

These measures are absolutely essential for the success of high altitude afforestations and should be regarded not as expenditure but as investment. Their neglect has already cost a great deal of money.

PRELIMINARY ASSESSMENT OF DAMAGE SO FAR

Additional specific analysis of damage to determine the probable main causes of the failures in Austria points to two factors in particular:
1. Failure to take the different ecological conditions of the various microsites into account (schematic, regular planting; infection by fungi).
2. Choice of species and provenances not optimally corresponding to the site (altitude, climatic damage, infection by fungi).

PROSPECTS

Planning: High altitude afforestations not only take 50-100 years to develop fully but also require consistent treatment throughout this period (5-7 professional generations). Consequently a 'High Altitude Development Plan' will be indispensable for future work.

As a valuable supplement to the 'Danger Zone Index' and the 'Forest Development Plan', such a plan offers the following advantages:
- regional spatial representation of the high altitude areas in which forests have so far been destroyed, the areas in which afforestation is possible, and the consequences of such afforestation for land use planning and landscape management;
- local spatial and temporal representation of favourable zones and accompanying measures in the short-, middle- and long-term view;
- certainty of fixed aims and consistency over long periods;
- exact determination of areas, of material and man power requirements as well as of costs by means of previous and subsequent calculations;
- easy and clear recognition of the causes of failure to provide a basis for further findings (Barner, 1978).

So far, high costs have prohibited the production of such long-term, comprehensive, and detailed planning documents. Joint work with the Institute of Photogrammetry at the University of Soil Cultivation, Vienna, has shown that digital, fully automatic development of aerial photographs (one, in special cases repeated, photogrammetric flights; use of existing aerical photographs) will permit economic and efficient production of fuch maps in future.

This will mean that all the conditions so far recognized as essential can be fulfilled. With only one aerial photograph it will be possible not only to superimpose altitude, exposure, wind-direction, inclination and micro-relief on one map, but also to identify the major plant communities automatically (mapping of snow-melt will require an additional photograph; in some cases satellite pictures may also be used). Zones of soil with extreme surface temperature or high water content could be registered at the same time. Furthermore, it will be possible to construct simulation models of how locally occurring tree vegetation affects ecological conditions on the remaining, unplanted areas (changes in snow deposition, shading etc., and the effects on the following phase of afforestation).

For further, practical confirmation of there findings and for exact determination of costs, it would be advisable to set up a model afforestation (5-10 ha) on suitable terrain in accordance with the points mentioned above. Only thus can certain measures and their relation to each other be properly tested. All future projects should include carefully chosen, permanently marked observation areas.

Preparation: The accurate selction of favourable sites occurring in nature (empirically about one third of the area) would reduce the costs of group planting by 30-50 % and increase success. Further, vulnerability to epidemic outbreaks of parasites could be reduced by leaving zones with high risk of infection (with much snow) unplanted. The choice and preparation of the planting positions remain major conditions for success.

Supplies of seeds known to be autochthonous could be ensured by setting up 'cone picking groups' (training courses are offered).

Plants which have been well provided with nutrients but not subjected to unbalanced or excessive fertilization should be raised in sufficient quantity and at the correct time (the longer the plants remain in the nursery, the more space is needed). New nurseries should be set up at climatically appropriate high altitude locations, and the existing ones maintained and extended. Their long-term productivity cannot be compared with that of low altitude nurseries with mechanical equipment.

Realization and tending: Unless sufficient trained field staff are available, it will not be possible to deal with the problem of high altitude afforestation satisfactorily.

CONCLUDING REMARKS

This paper is not intended to give the impression that all the answers to the problems of high altitude afforestation have been found. Nonetheless, with consistent planning and careful site selection, the knowledge gained so far should make it possible to reduce costs and increase success.

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