High altitude revegetation research in Switzerland : problems and perspectives = Forschung über Wiederbegrünung in Hochgebirgslagen der Schweiz : Probleme und Aussichten

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by

Krystyna M. URBANSKA

1. INTRODUCTION

High altitude ecosystems in the Swiss Alps belong to the alpine tundra that occurs above timberline and corresponds respectively to alpine and subnival belts (LANDOLT 1983, Fig. 1). The environmental conditions there are amongst the most rigorous in the world; they also are notoriously unpredictable. The low-heat budget results in a growing season that in general does not exceed 90 days but in some years may be as short as six weeks. Temperature during the growing season may fall below $0^{\circ}C$ with the resulting restrictions in the availability of nutrients and water as well as the limited growth and development of plants.

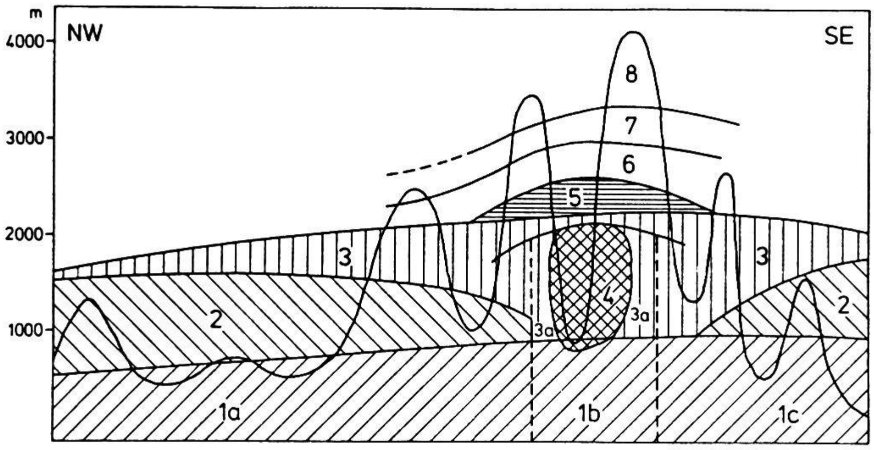

Fig. 1. Altitudinal belts in the Swiss Alps.
1: colline (1a: left to right: Jura, Swiss Midlands, northern Alps, 1b: central Alps, 1c: southern Alps). 2: montane. 3: subalpine (3a: central Alps). 4: continental mountain. 5: suprasubalpine. 6: alpine. 7: subnival. 8: nival. (After LANDOLT 1983).

Abb. 1. Höhenstufen in den Schweizeralpen.
1: colline Stufe; (1a, von links nach rechts: Jura, Mittelland, Nordalpen), 1b: Zentralalpen, 1c: Südalpen); 2: montane Stufe; 3: subalpine Stufe (3a: Zentralalpen); 4: kontinentale Bergstufe; 5: suprasubalpine Stufe; 6: alpine Stufe; 7: subnivale Stufe; 8: nivale Stufe. (Nach LANDOLT 1983).

Needle-ice formation and frost heaving represent very serious hazards in the life of alpine plants, especially at the establishment phase of seedlings and/or clonal modules (see e.g. BILLINGS 1974, BLISS 1971). Other important features of the alpine tundra environments are e.g. strong winds, high levels of biologically active UV-radiation and soil water stress. The high altitude soils are rather poorly developed, their nutrient capital and exchange capacities being low.

Plants occuring above timberline evolved complex adaptations specifically suited to a given ecosystem. Of a particular interest in this respect are regeneration strategies. The behaviour of alpine plants represents an argument in favour of the opinion expressed by some evolutionists (e.g. BAKER 1959, 1970, U. GRANT 1949, V. GRANT 1963, 1975,1981, STEBBINS 1951, 1970, 1971) that speciation is essentially related to adaptive changes in reproductive characteristics. Both the reproduction by seed or seed-like structures as well as the clonal growth and vegetative propagation represent the most important components to the regeneration of whole populations and individuals; it seems that the biological importance of a given structure is more relevant than its sexual or asexual origin (URBANSKA 1985).

High altitude sites in Switzerland are subject to a steadily increasing human impact mostly due to largely expanding recreational activities in summer and winter. The alterations of the alpine landscape are particularly drastic in machine-levelled ski runs where the original vegetation has been destroyed and the resulting bare surfaces are strongly endangered by erosion.

The need for revegetation of those areas has been recognized (see e.g. LESER et al. 1982). Unfortunately, the current revegetation practices carried out above timberline in the Swiss Alps lack the necessary understanding of adaptive patterns and processes operating in the alpine tundra, a commercially available material being used in the trials. It goes without saying that the ultimate success of revegetation at high altitudes is primarily influenced by adaptive traits of the plants used and only the taxa native to the Alps may succeed in a long run. The present paper, based upon results obtained in our long-term research on life history strategies of alpine plants and the high altitude revegetation, briefly outlines some aspects pertinent to the biological combat against erosion at high altitudes.

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2. BEHAVIOUR OF ALPINE PLANTS AND THE CHOICE OF MATERIALS FOR REVEGETATION

2.1. RACIAL DIFFERENTIATION

Plant species occuring in the Alps frequently manifest racial differentiation that can be considered as a first step of evolutionary divergence (GRANT 1981). Altitude-influenced formation of races was discussed e.g. by LANDOLT (1967, 1971, 1985). Another important factor in the racial differentiation above timberline is the influence of substratum observed e.g. within the Ranunculus montanus group (LANDOLT 1954, DICKENMANN 1982) or Biscutella levigata (GASSER 1983, GASSER, in preparation). The substratum-influenced racial differentiation at high altitudes may follow a small-scale pattern as exemplified by Lotus alpinus s.l. (URBANSKA 1982, 1984). Recent results (e.g. SCHÜTZ and URBANSKA 1984) suggest that edaphic races may be locally formed not only in sexual taxa but also in agamospermous ones.

The Swiss Alps are climatically differentiated, the central part being characterized by a more continental climate than are northern and southern parts (LANDOLT 1977, 1984, HESS et al. 1967). The distribution of numerous high-alpine taxa is clearly influenced by their climatic tolerances. As far as widely distributed species groups are concerned, formation of local races in climatically different parts of the Alpine chain is to be expected.

The few aspects mentioned point out the importance of genetical factors in the biological success of plants occurring at high altitudes. A possible racial differentiation should be taken into account when taxa for revegetation trials are being selected. The most promising are obviously the plants originating from the very area in which the surfaces to be revegetated occur; if the local material is not available, at least the climatic conditions as well as the substratum type should be considered as criteria determining the choice of plants from neighbouring alpine regions.

2.2. REGENERATION BY SEED

Regeneration in plants was sometimes defined as replacement of one mature individual by a new mature individual of next generation (GRUBB 1977). However, the sexual reproduction resulting in the appearance of new individuals i.e. genets does not represent the only aspect of regeneration; various forms of the asexual reproduction and the clonal growth as well as the actual ability to build up tissues and organs anew after damage also form part of the phenomenon. Our considerations here are

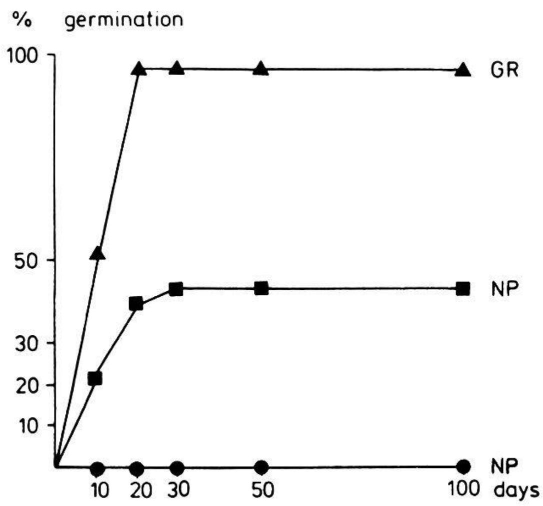

Fig. 2. Helictotrichon versicolor (Gramineae): germinating behaviour of seeds representing various age classes.
Black circles: two- month-old seeds; triangles and squares: six-year-old seeds from the same harvest. NP = no pretreatment; GR = glumes removed.
(Partly after FOSSATI 1980, unpubl. data of SCHÜTZ included).

Abb. 2. Helictotrichon versicolor (Gramineae): Keimverhalten von Samen verschiedener Altersklassen.
Schwarze Punkte: zwei Monate alte Samen; Dreiecke und Quadrate: sechs Jahre alte Samen der gleichen Ernte. NP = keine Vorbehandlung. GR = Spelze entfernt.
(Teilweise nach FOSSATI 1980 und unveröff. Angaben von SCHÜTZ).

limited to the regeneration by seed, but it should be kept in mind that all the processes mentioned above play an important role in the population biology of plants inhabiting high altitude ecosystems.

Sexual and asexual reproduction by seed represents a high-risk strategy in life history of plants. As far as alpine plants are concerned, exceedingly large fluctuations in seed output, seed longevity and germinability occur quite frequently, no coherent pattern emerging from the data gathered to date (see e.g. FOSSATI 1976, 1980). This variability is at least partially influenced by environmental conditions; for instance, virtually no seeds were found in alpine and subnival belt near Davos (Grisons, E Switzerland) in 1984, but the harvest within the same area proved to be exceptionally good in 1985 (URBANSKA unpubl.). Variation in seed longevity is generally pronounced int the material from high altitudes, but seeds mostly remain viable for at least few years; in some taxa, germinability may even increase with the increasing age of seeds (WEILENMANN 1980, 1981, SCHÜTZ unpubl., Fig. 2).

Seed dormancy in alpine plants from Switzerland is characterized by diverse patterns and mechanisms. Some taxa have no dormancy, others only a partial dormancy, whereas in numerous groups no germination at all occurs without a special seed pretreatment or a substitution for a post-ripening period (Figs 3-6).

The results obtained by our research group indicate that seed dormancy in numerous Alpine taxa from high altitude sites is influenced by seed coat and/or pericarp (FOSSATI 1976, 1980, SCHÜTZ 1983, SCHÜTZ unpubl., URBANSKA et al. 1979, WEILENMANN 1980, 1981, ZUUR-ISLER 1981, 1982). In some cases, the inhibitory effect seems to be localized and the seed scarification must similarly be precise to break dormancy (e.g. FOSSATI 1980, Fig. 6).

The germinating behaviour of high altitude taxa from the Swiss Alps is similar in its diversity to that reported from other alpine ecosystems (AMEN 1962, 1965, 1966, BONDE 1965, PELTON 1956). Seed dormancy is known to be due to a variety of causes (see e.g. BILLINGS 1957); more data on germinating behaviour of high-alpine species are urgently needed for a better comprehension of ecological significance of dormancy as well as proper handling of materials for revegetation trials.

Production and dispersal of seeds result in the formation of seed banks. Some taxa occuring at high altitudes possess transient seed banks during autumn and winter; it seems that this type of seed bank, influenced by an enforced dormancy, may represent a specific adaptation delaying germination until the following season. Numerous species inhabiting high altitude belts are, on the other hand, capable of forming persistent seed bank with virtually no germination immediately after seed dispersal, even in favourable conditions. Further data are needed, but it seems that at least in some taxa there will be variation from site to site and from year to year in the proportion of the seed output that contributes to a given bank of buried seeds. High-alpine legumes e.g. <u>Oxytropis jacquinii</u>, <u>O. campestris</u> or <u>Anthyllis alpestris</u> that are representative of this category, have rather large seeds and their dormancy is pronounced.

A successful regeneration by seed depends essentially on seed population dynamics. In extreme ecosystems of high altitudes, 'safe sites' (HARPER 1977) suitable for germination and establishment of seedlings are often scarce. Also this aspect should be taken into consideration in revegetation research (URBANSKA and SCHÜTZ, in press).

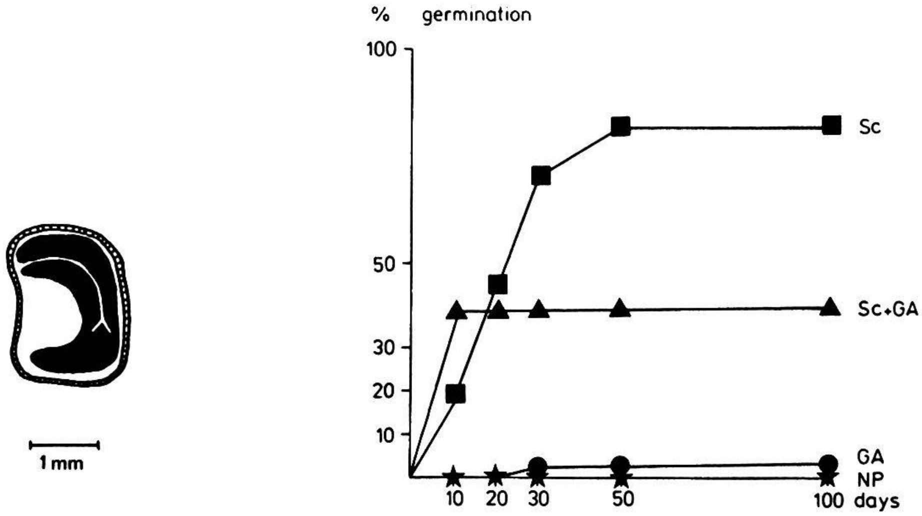

Fig. 3. Cerastium latifolium (Caryophyllaceae): germinating behaviour.
Left: seed anatomy. NP = no seed pretreatment; Sc = scarification; GA = pretreatment with giberellic acid.
(After ZUUR-ISLER 1982).

Abb. 3. Keimverhalten von Cerastium latifolium (Caryophyllaceae).
Links: Samenanatomie. NP = keine Vorbehandlung. Sc = Skarifikation. GA = Behandlung mit Gibberellinsäure.
(Nach ZUUR-ISLER 1982).

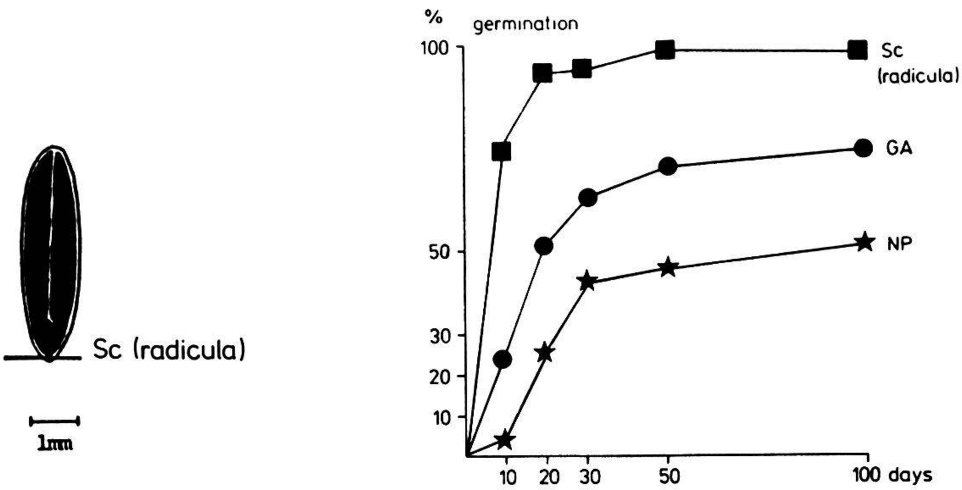

Fig. 4. Homogyne alpina (Compositae): germinating behaviour.
Left: achene anatomy: scarification marked with a line. NP = no pretreatment; Sc = scarification with a razor blade.
(After WEILENMANN 1981).

Abb. 4. Keimverhalten von Hymogyne alpine (Compositae).
Links: Anatomie der Achäne und Skarifikationsstelle. NP = keine Vorbehandlung. Sc = Skarifikation mit Rasierklinge.
(Nach WEILENMANN 1981).

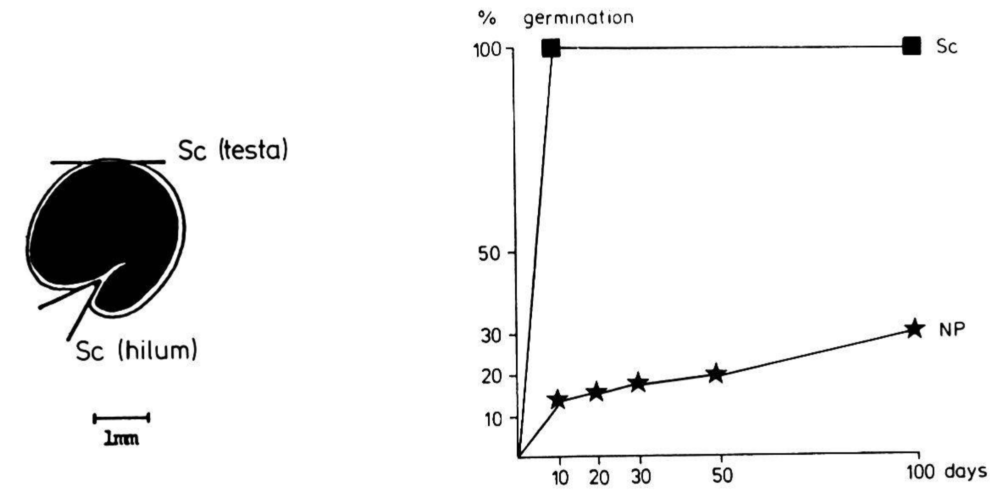

Fig. 5. Trifolium alpinum (Leguminosae): germinating behaviour.
Left: seed anatomy. Scarification marked with lines. NP = no seed pretreatment; Sc = scarification with a razor blade. (After WEILENMANN 1981).

Abb. 5. Keimverhalten von Trifolium alpinum (Leguminosae).
Links: Samenanatomie und Skarifikationsstellen. NP = keine Vorbehandlung.
Sc = Skarifikation mit Rasierklinge. (Nach WEILENMANN 1981).

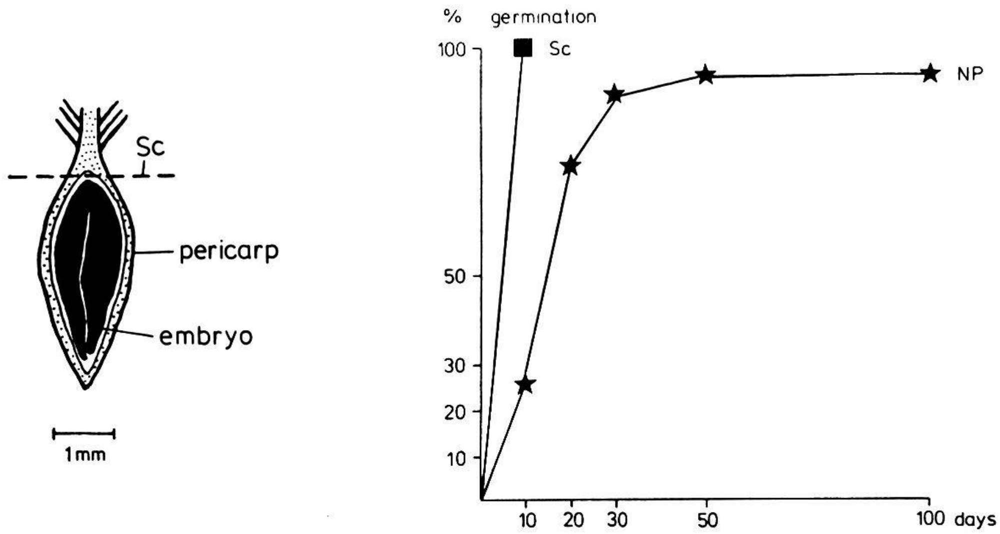

Fig. 6. Dryas octopetala (Rosaceae): germinating behaviour.
Left: fruit anatomy; scarification marked with a line. NP = no pretreatment; Sc = scarification with a razor blade. (After FOSSATI 1980).

Abb. 6. Keimverhalten von Dryas octopetala (Rosaceae).
Links Fruchtanatomie und Skarifikationsstelle. NP = keine Vorbehandlung. Sc = Skarifikation mit Rasierklinge.
(Nach FOSSATI 1980).

Fig. 7. Ski run in the area of Strela, about 2350 m a.s.l.; revegetation by seeding upon dolomite. Trial surface after one year: well-developed young plants and seedlings protected by a biologically degradable CURLEX blanket. Swiss National Science Foundation grant 3.480-0.83. Photograph taken by the author in July 1985.

Abb. 7. Skipiste im Gebiet von Strela, ca. 2350 m ü.M.; Wiederbegrünung durch Ansaat auf Dolomit. Versuchsfläche nach einem Jahr: gut entwickelte Jungpflanzen und Keimlinge, geschützt durch biologisch abbaubare CURLEX-Decke. Schweiz. Nationalfondsprojekt 3.480-0.83. Photographiert durch den Autor im Juli 1985.

A good understanding of germinating behaviour and requirements for seedling establishment in high altitude plants are indispensable for a proper revegetation by seeding above timberline. In the ski runs, where the A-horizon has been removed and the vegetation discarded, neither a balanced seed bank nor safe sites occur; a most careful planning is therefore necessary. Rather promising results recently obtained in our preliminary revegetation trials carried out with purposefully selected alpine seeds, a partial seed pretreatment as well as providing of safe site conditions (SCHÜTZ unpubl., Fig. 7), clearly indicate that the work dealing with the prevention of erosion in the alpine tundra should be based on solid scientific data.

3. CONCLUDING REMARKS

Primary aim of high altitude revegetation is to restore surface stability and the aesthetic appeal of a given site, the full rehabilitation being a long-term objective. To deal with this complex problem, an integrated programme of research in plant genetics and ecology is required, both field and laboratory investigations being indispensable before a satisfactory treatment is devised. We propose now to consider some points important for future studies in the subject.

Plants occuring in low-resource environments manifest high efficiency in use of limiting resources (CHAPIN 1985). Long-term survival is based upon strategies that proved successful in the process of natural selection; studies in alpine plants considered as a possible material for revegetation at high altitudes should therefore deal with e.g. drought resistance, nutrient requirements and/or growth capacity.

Revegetation by seeding and revegetation by planting represent not only complementary but also alternative aspects. For that reason, data on growth form, reproduction by seed, formation and establishment of propagules and regeneration by tillers, represent criteria essential for choice of a suitable material and technique for revegetation trials.

It should be kept in mind that some man-made disturbances in the alpine tundra represent entirely new ecological niches. Re-establishment of native plant communities **identical** with those which occurred before the vegetation has been destroyed may therefore be impossible (BROWN et al. 1978). Some recent field observations (e.g. MEISTERHANS, in prep., URBANSKA unpubl.) reveal that plants spontaneously appearing as first colonizers in machine-levelled alpine ski runs not always represent the actual pioneer taxa; the plant succession may apparently follow there a course different from that observed in natural alpine disturbances. Further studies in high altitude revegetation should thus include, in addition to taxa naturally occurring in pioneer niches, also those appearing in other successional phases.

To the author's best knowledge, high altitude revegetation trials in which native plants were used both for seeding and transplanting, have been carried out for the very first time nearly fifty years ago in the Rocky Mountains (see HARRINGTON 1946). However, the knowledge of the subject is still fragmentary, not only more data on behaviour of alpine plants but also the information on reliable techniques being needed (see e.g. BURNS 1980). The largely unexplored research field offers truly exciting perspectives.

LANDOLT (1983a) argued: "It is the arrogance of a modern man to except that the landscape should be adapted to his skiing requirements". The human impact has partially destroyed the alpine vegetation in Switzerland, the human effort will be required if the revegetation of high altitude sites is to succeed. Our study is in progress.

SUMMARY

Some aspects of behaviour of alpine plants from Switzerland are discussed in relation to the problem of revegetation at high altitudes, criteria relevant to a proper choice and treatment of suitable materials being defined. The author suggests as well main topics for future research in the subject.

ZUSAMMENFASSUNG

Aspekte des Verhaltens von hochalpinen Pflanzen aus den Schweizer Alpen werden in Zusammenhang mit Begrünungsprojekten in höheren Lagen diskutiert. Die für Auswahl und Behandlung von geeignetem Material entscheidenden Kriterien werden definiert. Der Autor schlägt ausserdem Schwerpunkte für künftige Forschung in diesem Bereich vor.

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Address of the author: Prof. Dr. Krystyna M. Urbanska
Geobotanisches Institut ETH
Stiftung Rübel
Zürichbergstrasse 38
CH-8044 Zürich