RECLAMATION OF SEVERELY DISTURBED ALPINE ECOSYSTEMS: NEW PERSPECTIVES[1]

by

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Abstract. Early research on revegetation of severely disturbed alpine ecosystems in the Beartooth Mountains of Montana focused on the use of high seeding densities of native colonizer graminoid species and high rates of fertilization. Results showed that these methods tended to competitively exclude the establishment of other species and lifeforms in the community. Initial high applications of nitrogen did not increase long-term nutrient retention capabilities of disturbed sites, and when applications were discontinued, sharp declines resulted in site productivity that further retarded establishment of forbs and other species. In recent years new perspectives of alpine revegetation have been adopted that concentrate on more basic approaches. Research suggests that seed mixtures for harsh disturbances should include species with low nutrient requirements or nitrogen fixing symbionts in addition to high nutrient requiring graminoids, that seeding densities should be reduced, and that moderate applications of balanced macronutrients will likely result in higher species richness and increased rates of succession. Species responses to revegetation treatments appear to be controlled by widely different physiological characteristics and life history traits.

Additional Key Words: revegetation, plant succession, disturbances, amendments, plant species selection,

Introduction

Alpine ecosystems of North America are vitally important watersheds for agricultural, industrial, and metropolitan development. Snow accumulation and water storage at high elevations provide the main sources of summer runoff for streams and rivers. The more gentle slopes and rolling plateaus of alpine regions also provide summer range for both livestock and wildlife, and these unique ecosystems offer stunning panoramas and remote wilderness solitude for recreationists. However, with the advent of modern technology many areas are being disturbed at an accelerated rate by human activities such as recreation, road construction, mineral exploration, mining, and other endeavors.

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Severe disturbances of alpine ecosystems threaten their important watershed, wildlife habitat, grazing, and recreational values. Revegetation is essential to minimize the consequences of erosion, loss of water quality, and to reestablish stable native plant communities. However, conventional techniques of revegetation developed for more moderate climatic zones at lower elevations have been largely unsuccessful for disturbed high mountain ecosystems. The rigorous climate of alpine ecosystems, coupled with the impacts of disturbance, dictate the use of revegetation techniques that have been designed for the unique conditions of this life zone. Short, cool growing seasons, strong winds, frequent frosts, and a limited pool of adapted plant species severely complicate revegetation efforts. These constraints are compounded by the effects of disturbance that often results in exposed acidic spoil material that is low in essential plant nutrients or that contains toxic concentrations of heavy metals or other unsuitable constituents. Erosion, acid-water runoff, and sedimentation frequently result in the destruction of offsite plant communities, streams, and aquatic habitats, and the general deterioration of water quality.

Early attempts to revegetate alpine disturbances were frustrated by a lack of knowledge about the complexities of the alpine environment, its interactions with the native flora, and the effects of disturbances. However, numerous promising techniques have been developed in recent years based on the results of basic research on the succession of alpine disturbances and some of the ecological and physiological characteristics of adapted native plant species. Specific techniques including surface shaping and contouring, application and incorporation of fertilizers, lime, and organic matter, methods of seeding and planting, and techniques for applying surface mulches for alpine disturbances have been discussed elsewhere (Brown et al. 1976, 1978, Brown and Johnston 1979, 1980). The purpose here is to discuss some of the primary factors limiting successful revegetation of alpine disturbances and to summarize some of the promising new techniques for revegetation emerging from this research.

Factors Limiting Revegetation

The climatic conditions of alpine ecosystems are often limiting to successful revegetation of disturbances. Generally, these ecosystems have low heat budgets that result in short, cool growing seasons that range from 45 to 90 days in length (Billings 1974). Summer temperatures average about 10°C, frequently falling below 0°C with frost occurring commonly throughout the growing season (Billings and Mooney 1968). Needle ice can uproot seedlings and contribute to surface soil erosion on disturbed sites where soil water status is maintained at or near saturation (Brink et al. 1967). Precipitation in the alpine zone occurs mainly as winter snow, but soil water availability is highly variable with season, location, and topography. For example, snow fields commonly accumulate on the lee sides of ridges while ridgelines may remain nearly snow-free throughout the year due to redistribution by wind. High winds are common in alpine ecosystems and can cause significant soil erosion and be physically and physiologically detrimental to plants. Solar radiation flux densities commonly exceed those at lower elevations.

The type of disturbance imposes various limitations on successful revegetation. Severe disturbances result in the removal of surface soil horizons and expose the underlying geological materials. Less severe disturbances leave the surface soil in place but may result in mixing of the surface and subsurface soil horizons (Chambers et al. 1988). Natural causes of severe disturbances include geomorphological processes such as landslides or avalanches, whereas human causes include such activities as road building and mining. Less severe disturbances result from processes such as freeze-thaw cycles (Johnson and Billings 1962), small mammal burrowing and tunneling (Thorn 1982), and some human recreational activities. The two types of disturbances result in significantly different revegetation environments. Severe disturbances that remove surface organic horizons and leave mineral soils in place are often characterized by lower water and nutrient holding capacities. Disturbance in general can result in the loss of finer soil particles due to wind erosion.

Severe disturbances in alpine ecosystems often leave exposed pyritic materials at the surface that initiate a cycle of sulphide oxidation (Johnston and Brown 1979). This can result in low soil pH and increased availability of potentially toxic metals such as lead, zinc, copper, iron, and aluminum. Plant establishment and growth, and thus natural successional processes, can be severely limited. Runoff from such areas frequently causes mortality to offsite plant communities and seriously degrades water quality and aquatic ecosystems downslope.

Many of the limiting factors associated with disturbances can be ameliorated by careful site preparation techniques. For example, severely disturbed sites should be shaped and contoured to minimize slope angles, sharp ridgelines, and water movement or accumulation. On disturbances where materials such as pyrites are exposed at the surface, the poorest growing media should be covered with soil or spoil using the best available materials on the site. If available, topsoil should be stored and respread over the site prior to revegetation. A complete soil analysis should be performed well before seeding and planting so that limiting physical and chemical properties and nutrient deficiences can be identified (Jurinak 1982, Chambers et al. 1987a). Fertilizer and other required amendments should then be incorporated into the upper 15 to 30 cm of soil or spoil to be available within the rooting zone of germinating seedlings and developing young plants (Brown and Johnston 1979). Lime may be required to improve nutrient availability and to minimize plant absorption of toxic metals and other chemicals where soil pH is lower than about 5.0. Organic matter such as manure or peat moss may be used to improve nutrient and water holding capacities of soil or spoil materials.

A major limitation to successful revegetation of alpine disturbances is a lack of knowledge about the selection and use of adapted plant species. The total flora of alpine ecosystems is relatively small compared with more moderate low elevation life zones, and the pool of adapted species suitable for revegetation is limited. Introduced plant species commonly used for revegetation of lower elevation disturbances are frequently unadapted and unsuccessful when used for revegetation in the alpine zone. Brown and Johnston (1979, 1980) found that such introduced species as Bromus inermis (smooth brome) and Agropyron intermedium (intermediate wheatgrass) were no longer present 4 years after planting on a subalpine-alpine site that had been mined in southwestern Montana. However, native adapted species from the area such as Deschampsia cespitosa (tufted hairgrass) and Poa alpina (alpine bluegrass) increased in density, cover, and biomass production over the same period. The most important criteria used in selecting adapted species for revegetation, including observations of natural succession on disturbed areas, are discussed by Chambers et al. (1984, 1988).

Selection of Adapted Plant Species

One of the most important aspects of successful reclamation is the selection of plant species that are suited to the limiting environmental factors characteristic of a disturbance. Adapted species are those capable of long-term survival and reproduction. One of the most productive field methods of identifying adapted species for revegetation of alpine disturbances is to examine natural successional processes on local old disturbances such as road cuts and fills and gravel pits (Brown and Johnston 1980, Chambers et al. 1984, 1988).

Research results suggest that reclamation success of alpine disturbances may be improved when mixtures of species are planted that represent different life histories and physiological traits. Typically, grasses are the most widely used group of plants in revegetation, yet heavily fertilized swards of high-nutrient adapted grasses often tend to form closed stands that exclude or inhibit the invasion of other species. For example, Brown et al. (1984) found that high seeding rates with a mixture of native grasses and repeated applications of fertilizer on acidic spoil material tended to produce closed plant communities that resisted further successional development and enrichment of species diversity. Their data showed that the use of grasses alone in a revegetation species mixture, together with repeated fertilization for several consecutive years, resulted in no significant changes in species diversity of the revegetation community 8 years following seeding.

Research on plant succession of alpine disturbances suggests that inclusion of different life forms in seeding and planting mixtures, together with appropriate amendments, may increase species and structural diversity of revegetation communities and enhance rates of successional development (Chambers et al. 1988). In addition, use of seed mixtures consisting of species with many different physiological and ecological characteristics improves the chances of stand survival in the event of catastrophic events such as insect infestations, disease, or drought (Brown and Johnston 1980).

In alpine environments many plant species adapted for revegetation of disturbances can be classified according to their frequency of occurrence in different successional stages (Chambers et al. 1984, 1988). Initial colonizers of disturbed sites often exhibit broad ecological amplitudes and are usually widely distributed in geographic area. At low elevations early colonizers tend to include a large complement of annual "weeds" whereas at higher elevations more desirable perennial species predominate. Early colonizers often have large and consistent seed production capabilities, effective seed dispersal mechanisms, high seed longevity, and high rates of growth and development. They may also be able to tolerate high concentrations of heavy metals, low pH, and other adverse disturbance conditions. Late seral species often have slower growth rates, lower seed production and longevity, and lower rates of seed dispersal than early seral species (Chambers et al. 1988). For example, frequent colonizers such as tufted hairgrass typically produce large quantities of small seeds with high seed longevity, high seed dispersal capability, high plant growth rates, and low root to plant biomass ratios (Chambers et al. 1988). In contrast, species typical of late seral communities such as _Geum rossii_ (alpine avens), an alpine forb, produce small quantities of larger sized seeds with relatively short seed longevity, low seed dispersal capability, low growth rates, and high root to plant biomass ratio (Chambers et al. 1988). Also, tufted hairgrass tends to have shallower less extensive root systems and higher nutrient requirements than alpine avens (Chambers et al. 1987_c_). Species adapted to low-nutrient sites, such as alpine avens, can ensure long-term stability on disturbances, but lower rates of production are to be expected (Chambers et al. 1988).

Native alpine species that have successfully been established on disturbed sites from seeds (noted below with an asterisk *), together with others that have favorable characteristics for revegetation include (Brown et al. 1978, 1988, Chambers 1987, 1989_a_, Chambers et al. 1984, 1988):

Grasses and Grasslike Plants:

- *_Agropyron trachycaulum_ (slender wheatgrass)
- *_A. scribneri_ (Scribner wheatgrass)
- *_Carex paysonis_ (Payson sedge)
- *_Deschampsia cespitosa_ (tufted hairgrass)
- *_Phleum alpinum_ (alpine timothy)
- *_Poa alpina_ (alpine bluegrass)
- _P. epilis_ (skyline bluegrass)
- _P. rupicola_ (timberline bluegrass)
- *_Trisetum spicatum_ (spike trisetum)

Forbs:

- *_Achillea millifolium_ (western yarrow)
- _Agoseris glauca_ (pale agoseris)
- _Arenaria obtusiloba_ (alpine sandwort)
- _Artemisia campestris_ (wormwood sagewort)
- *_A. scopulorum_ (alpine sagebrush)
- _Cerastium arvense_ (mouse-ear chickweed)
- _C. beeringianum_ (alpine chickweed)
- *_Geum rossii_ (alpine avens)
- _Lupinus argenteus_ (silvery lupine)
- *_Potentilla diversifolia_ (varileaf cinquefoil)
- _Senecio fremontii_ (Fremont groundsel)
- *_Sibbaldia procumbens_ (prostrate sibbaldia)
- _Smelowskia calycina_ (alpine smelowskia)
- _Solidago multiradiata_ (mountain goldenrod)
- _Trifolium dasyphyllum_ (whiproot clover)
- _T. parryi_ (Parry clover)

Many of the species listed above have broad ecological amplitudes and occur as frequent colonizers on alpine disturbances. Also, many have high reproductive rates and easily collected seeds.

Seed Collection

Unfortunately, the seeds of most native alpine plant species suited for revegetation are not commercially available and must be hand-collected. Seed collection tends to be expensive, but use of locally adapted populations greatly enhances the chances for successful revegetation (Brown et al. 1988).

Seed collection of adapted native species requires a knowledge of the phenology of plant development and the complex interactions with environment. Seed maturity and production are highly variable from year to year, and collection must be opportunistic to take advantage of good seed production years for different species. Chambers (1989b) found significant differences among years and species in seed fill for grasses and viability between grasses and forbs for seeds collected successively between 1983 and 1986 on the Beartooth Plateau in Montana. These differences were attributed to variability in climatic factors such as dates of snowmelt, timing and amount of precipitation, and ambient air and soil temperatures. Large differences among species in seed viability were found, usually with the grasses having lower and more variable seed viability than forbs. Seed longevity of species with life history and physiological traits typical of late seral species was shorter than that of species with traits typical of early colonizer species.

Several years may be required to collect sufficient seed of all species desired for a given revegetation project. Usually, seeds mature on the plant in the late summer or fall and should be collected just prior to natural dispersal. Grass seeds can usually be hand-stripped from the inflorescence directly in the field, although clipping entire culms followed by thrashing has been used successfully. Seeds of most forbs are usually more difficult to collect and clean because seeds are often enclosed within fruiting bodies that must be thrashed and separated following drying. The seeds are normally stored in dry porous containers such as paper or cloth bags and kept in a cool dry environment maintained near 0°C. Storage conditions and seed longevity during storage must be monitored carefully (Chambers 1989b, Chambers et al. 1987a). There is some evidence that seed longevity of high elevation species is improved if stored at -18°C at low moisture content (Billings and Mooney 1968).

Successful revegetation of alpine disturbances is determined to a large extent upon how well techniques emulate natural conditions and modify limiting environments. Fall seed dispersal is typical of alpine plants in the northern hemisphere, indicating that seeds normally lay in the soil over the winter prior to germination and emerge in the spring following snowmelt. Our research indicates that seeding late in the fall mimics natural seed dispersal and enhances seedling establishment on disturbances. Also, fall seeding exposes the seeds to cold dormancy over the winter and permits stratification for those species requiring it (Chambers et al. 1988). Because fall timing of revegetation appears to be critical, both seed collection and seeding and planting may not always be possible in the same year if seed collection and planting times overlap.

Seed Mixtures and Planting Concerns

Seeding rates based on the number of viable seeds per unit area for each species used instead of the more typical method of weight per unit area allows seeding rates to be determined on an individual species seed viability basis. This ensures that potential competition among species will be uniform over the area, provides optimum opportunity for survival of seedlings, and permits success or failure of each species in the mixture to be correctly assessed. The amount of seed applied for each species in a mixture may need to be adjusted for different seed lots collected from different locations and times because seed viability varies widely from year to year (Chambers 1989b).

Seed application rates usually range from about 200 to 500 total viable seeds per m^2, depending on the species used and site conditions (e.g., Chambers 1989a). On particularly harsh sites seeding rates should be adjusted toward the latter figure, whereas more favorable sites should be seeded nearer the former figure. Our experience on alpine disturbances indicates that only about 25 to 80% of the viable seeds applied will germinate and emerge (e.g., Chambers 1987).

Knowledge of seed germination requirements of species is essential to determine seeding methods and other revegetation techniques. Many species have small seeds that cannot emerge from the soil if planted too deeply, whereas species with larger seeds may require deep planting to avoid desiccation during dormancy and seedling development. Also, some species must be planted at or near the soil surface because of a requirement for light during germination (Chambers et al. 1987b, Haggas et al. 1987). Chambers et al. (1987b) found that many alpine forbs require light for germination whereas grasses have less specific requirements. These species should be seeded on the soil surface separately following the planting and incorporation of other seeds on the site (Haggas et al. 1987). Chambers et al. (1987b) found that wet cold stratification during the winter following fall seeding results in fewer days for germination and, consequently, an increased likelihood of seedling establishment the following spring.

In most areas surface mulching with straw or other similar material is essential following seeding (Brown and Johnston 1979, 1980). A surface mulch tends to minimize the redistribution of seed and soil fines by wind, reduces the incidence of frost, and minimizes evaporation at the soil surface. This practice is also important in cases where photoblastic seeds (light requiring) are applied to the soil surface to reduce seed loss due to wind.

Nutrient Requirements for Plant Growth

Use of fertilizer is a common practice in revegetation (Brown and Johnston 1979), yet little is known about the growth responses of native alpine plant species to specific nutrient levels or nutrient requirements (Chambers et al. 1988). Although highly site specific, nitrogen and phosphorus are usually the most limiting nutrients on disturbances, but individual species responses to these nutrients vary widely. The availability of these and other nutrients, and the nutrient retention capacity of a soil are often determined by the severity of the disturbance (Tilman 1982). Chambers et al. (1988) found that tufted hairgrass, a frequent early colonizer on alpine disturbances, responded more to N inputs, and that the typical late successional species, alpine avens, respond more to P. They also show that tufted hairgrass had greater rates of growth at all levels of N and P than does alpine avens. This suggests that tufted hairgrass may have competitive superiority over alpine avens on disturbances and over broad ranges of available N and P.

Factors other than fertility and growth rate may affect the interactions among species in a revegetation mixture. Low growth rates and high root:shoot ratios are important attributes of species adapted to low nutrient environments. Including low nutrient-adapted and low growth rate-adapted species in a seed mixture with those that are high nutrient-adapted and high growth rate-adapted can help ensure long-term stability on nonintensively managed reclaimed disturbances. It may be necessary to use moderate seeding and fertilizer rates and to seed low growth rate species in equal amounts as high growth rate species with such mixtures. High application rates of fertilizer and seeds may favor the high growth rate-adapted and high nutrient-adapted species and result in reduced rates of colonization and succession (Brown et al. 1984).

Research Needs

Although the general techniques developed for revegetation of alpine disturbances appear to be successful, additional research is needed as this life zone comes under increasing pressure from a wide variety of uses. Identification of adapted native species and an understanding of their physiological tolerances and ecological characteristics remain as some of the most urgent needs. We need a better understanding of successional processes on disturbances, including the effects of competition and of nutrient and water relations requirements and interactions. In addition, we need to understand the characteristics and long-term interactions that mycorrhizal and nitrogen-fixing symbionts have with other adapted species on disturbances.

Further research is needed on the long-term effects of various reclamation methods, including soil amendments and the effects they have on species performance and interactions and on soil nutrient retention and cycling. Studies are needed on soil weathering and development and on the dynamics of heavy metals and other toxic materials as they interact with plants. Present methods appear to be inadequate for successfully revegetating the most extreme acidic mine spoils in the alpine zone. Thousands of hectares of abandoned pyritic mine dumps and tailing piles throughout the mountainous West are in the headwaters of watersheds of which increasing demands are being made as metropolitan areas expand. These, together with new mines and other disturbances, are degrading water quality of streams, rivers, and reservoirs throughout the West. Clearly, reclamation research of alpine disturbances needs to be expanded and intensified.

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