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On-site vegetation restoration techniques developed and applied in Denali National Park and Preserve, Alaska

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On-Site Vegetation Restoration Techniques
Developed and Applied in
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by

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INTRODUCTION

Denali National Park and Preserve is a six million acre preserve located in the Alaskan Interior and managed by the National Park Service. The land has been used by native people, miners, settlers, hunters, and is now toured, mostly by public bus, by hundreds of thousands of visitors each summer. Restoration of sites degraded by human activities such as trampling, road construction and gold mining has been a regular activity at Denali National Park since at least 1975. In the last twenty years the park's plant ecologist, Dr. Roseann Densmore, and other members of Denali's staff have studied the restoration of degraded ecosystems and developed many restoration techniques.

Although many of the studies mentioned above have been published, until now, no single document assembles their findings in a manner that future restorationists can use in the field. In addition, many innovative on-site techniques and observations are not recorded anywhere, except in memories and fieldnotes.

This professional paper attempts to fill that gap in the record by compiling and synthesizing knowledge related to on-site ecological restoration techniques gained through research and field experiences at Denali National Park. I believe it necessary to preserve this information for three reasons. First, growing visitor use has generated and will likely continue to generate road and facility construction and renovation--the very activities that cause disturbances in need of restoration. Thus, in the near future Denali National Park managers will need to plan and perform a large number of restoration projects. Large-scale restoration projects are already planned for several drainages disturbed by placer mining in the Kantishna Hills. Managers cannot afford to lose information and relearn skills. Second, the restoration of subarctic ecosystems is a relatively new and dynamic field; research and techniques originating in Denali are important contributions to the field of restoration ecology as a whole. Finally, this information needs to be recorded because it is vulnerable. Bureaucracies often lose information through high employee turnover rates or inadequate information management. This is especially true of the technical information--like the revegetation techniques described in this manual--gained through field experience.

This paper draws largely on the field experiences (in the forms of progress reports, field notes, personal communications and technique evaluations) of plant ecologist Dr. Roseann Densmore, revegetation specialist and crewleader Michael Pope, and myself, Pope's successor. I examined these documents and published studies, and I evaluated restoration projects on-site according to how well they achieved their planned goals and objectives. Finally, I drew together these sources in an attempt to record in an organized way what we know about restoration at Denali.

The final result is this document. Part I describes Denali National Park and introduces the biotic and abiotic template that characterizes the subarctic biome. It also includes information on disturbance ecology in the subarctic, with the idea that managers should make technical decisions based on a theoretical understanding of the area's ecology. Part II is a "how-to" section that describes eight successful on-site restoration techniques currently used at Denali National Park. Part III is a set of recommendations for improving restoration activities at Denali. Resource managers and administrators should review this section. Appendix A contains a case study of restoration successes and failures--an evaluation of the 1991 Federal Highways Road Renovation and Revegetation Project.

PART I

THE BIOLOGIC SETTING OF DENALI NATIONAL PARK

Climate

Denali National Park is located within the subarctic biome, which is characterized by seasonal temperature extremes driven chiefly by continental cooling influences and drastic variations in solar radiation. In North America, the subarctic covers a large geographic region that forms a continent-wide belt across central Alaska and Canada. The subarctic has short, warm summers and long, extremely cold winters. Temperature extremes in the Denali region of the Alaskan subarctic range from -57°C in the winter to 32°C in the summer. The January mean temperature is -24°C, while the mean temperature in July is 16°C. The frost-free period is typically 90 to 100 days (Love, 1970 and Oechel and Lawrence, 1985).

Most of Denali National Park lies within the rain shadow of the Alaska Range and receives approximately 30cm of precipitation annually. Winter snowfall is approximately 170cm, contributing about a third of the annual precipitation. The snowpack generally lasts from October to May (Kimmins and Wein, 1986). Though Denali receives a relatively modest amount of annual precipitation, it rains on about 50% of summer days (Heacox, 1990). Light snow and freezing rains can also occur in the summer.

Plant Communities

Although the region's biological diversity is low relative to temperate and tropical plant communities, the subarctic supports both coniferous forest of low to moderate productivity and regions of moist and dry tundra. Soil temperatures are generally cold. Plant communities vary significantly with slope and aspect due to the high latitude and the ensuing low solar angle (Kimmins and Wein, 1986). Treeline in the park is at about 610m, but can extend to 854m on protected slopes and valleys.

Denali National Park supports approximately 450 species of plants. Many variables influence the distribution of plant species throughout the park and thus shape vegetation community types. Factors that may produce variations in community structure and function include slope, aspect, elevation, microclimate, soil characteristics, permafrost (common but discontinuous), community dynamics, and natural disturbances such as flooding or fire (Heacox, 1990).

For the purposes of this paper, I identify four primary vegetation community types within the park--spruce forest,
moist tundra, dry tundra and riparian areas--but ecotonal variations are common.

Spruce forests (also known as "taiga") consist primarily of white and black spruce and the Denali-area hardwoods typically associated with disturbance--quaking aspen, paper birch, and balsam poplar. These forests commonly have a moss and sub-shrub understory. Wet tundra is characterized by meter-high thickets of willow, dwarf birch and blueberries. Dry tundra occupies cold and windy upslope regions and typically supports vegetation under 15cm in height (Heacox, 1990). Riparian vegetation is typified by thickets of willow, alder and poplar, 1m to 4m high.

Subarctic Succession and Disturbance Ecology

An understanding of succession and natural disturbance can guide the restoration of human-caused disturbances. For example, floods tend to deposit silt on gravel riverbars, which, in turn, host species like willows. A restorationist faced with a placer-mined gravel pile washed clean of fines should recognize that the site needs a "flood," i.e., the restorationist should add fines and encourage the establishment of willows. The information below should serve as a brief introduction to succession and disturbance in the subarctic.

Plant Succession

"Plant succession"--as defined by Barbour, Burk and Pitts (1987)--"is a directional, cumulative change in the species that occupy a given area, through time." There are two successional patterns: primary and secondary. Primary succession describes the establishment of plants on substrates that previously had not supported vegetation. Alluvial soil depositions from braided rivers and gravel outwash from glaciers are common in the Alaskan Interior, and often support primary succession plant communities (Viereck, 1966). Secondary succession is the re-establishment of vegetation on sites where it once existed, such as revegetation after wild fire or restoration after human trampling impacts. Restorationists at Denali National Park are primarily interested in early succession, the first stage of either primary or secondary succession.

Classic plant succession progresses from primary or secondary beginnings through intermediate seres until a climax community is established. Climax communities are described as self-replacing and in a state of "dynamic equilibrium" (Kimmins, 1987). However, Larson (1980) asserts that a traditional concept of succession does not apply to subarctic ecosystems because succession does not progress to a single regional climax, and because it results in decreased plant productivity over time. The primary factors responsible for decreasing plant productivity are soil cooling and nutrient deficiencies caused by the accumulation of organic material; the organic material insulates the soil (by preventing summer soil warming) and locks up the nutrient capital.

Although a typical "climax" community is difficult to define in the subarctic, other concepts are useful in describing succession in the subarctic. Connell and Slatyer (1977), for example, propose three pathways to describe the sequence and dynamics of successional processes: facilitation, inhibition and tolerance. These models (although not unique to the subarctic) are helpful in understanding natural succession and predicting the successional impacts of assisted restoration at Denali. Bear in mind that pathways can operate simultaneously in the same plant community. The pathways can be described as follows:

Facilitation Pathway Change occurs as early colonizers alter the abiotic environment and promote the establishment of other species and at the same time create conditions less acceptable for themselves.

Inhibition Pathway Initial colonizers inhibit the invasion of other species.

Tolerance Pathway Late successional species, if present in early successional stages, are too small and inherently slow growing to dominate. Growth of these species is typically not improved by the removal of the early successional plants, but they may dominate with time.

Although succession is complex and difficult to predict, Van Cleve et al. (1986), among others, have described basic successional trends. Succession after a taiga fire that has burned through the organic layer to mineral soil, for example, typically follows several successional stages. In the first stage, several things happen: light-seeded species such as fireweed, willow and poplar and legumes such as Eskimo potato arrive and get established. The legumes that arrive at this stage often facilitate present and future vegetation by adding nitrogen to the soil (Viereck, 1966). At the same time, many species already present on the site, like rose, willow or aspen, will either sprout from root and rhizomes or from buried seed, as in the case of pale corydalis. Slow-growing and inconspicuous spruce seedlings may follow the tolerance pathway at this initial stage.

During the second stage, the maturing shrubs and deciduous tree saplings may dominate, with spruce forming a low understory beneath them. Next, the deciduous hardwoods may form a dense canopy and shade the understory, leading to the invasion of shade-tolerant and soil-cooling moss. Heavy litter fall may temporarily inhibit moss invasion, but once shade-tolerant moss has established itself, conditions change drastically. The soil cools and moss inhibits hardwood regeneration and the establishment of shrubby species. The spruce established before the moss invasion continue to follow the tolerance pathway, growing slowly as the initial tree community dies out and fails to regenerate. During the third stage, after about 200 years, patches of hardwood remnants and a spruce forest are manifest. Eventually, white spruce may give way to black spruce, as the summer permafrost level encroaches towards the surface, creating a shallow active layer that favors black spruce. (Viereck et al. 1986).

Natural Disturbance

It is natural disturbance, such as fire in the example above, that sets succession in motion. Naturally disturbed areas can be characterized by high solar radiation inputs, warm soil temperatures and relatively high nutrient availability. Under these conditions certain plants will grow vigorously. Plant species that first dominate disturbed sites, termed pioneer species, typically have high potential growth rates, precocious and prolific reproduction, and the ability to expand by root or stump sprouts, rhizomes, and stolons. Examples of subarctic pioneer species include alder, soapberry, aspen, and many others. Later successional species, like black and white spruce, usually have inherently slow growth rates, and evergreen leaves to conserve nutrients (Grime and Anderson, 1986).

In the subarctic, natural disturbance to spruce forest, wet tundra or riparian areas typically induces relatively productive plant communities, such as primary and mid-successional forests on recently deposited flood plains (Viereck et al. 1986). Secondary succession often proceeds much faster than primary succession, as nutrients, organics and propagules may remain in the soil after the disturbance and increase recovery rates (Barbour et al. 1986).

The effects of natural disturbance, however, vary with the site. For example, disturbance in the high, dry tundra is less frequent than in the lowlands, and results in a much less productive revegetation response, as the majority of plant communities recover slowly and with difficulty. Low air and soil temperatures, higher evapotranspiration rates and generally thin, undeveloped soils contribute to slow plant recovery (Billings, 1973).

In nature, floods, fire, landslides, herbivory and other disruptive forces, along with slope, aspect, seed sources and chance help shape the pattern and rate of succession in the subarctic.

Human-Caused Disturbance

Human-caused disturbances, especially on a large scale, are relatively new to the Denali environment. Although native people travelled through the Denali region and used it as a hunting and gathering ground, they left few long-lasting traces of their use (Brown, 1991). In this century, however, humans have introduced new, widespread and dramatic disturbances to Denali. In the subarctic, human-caused disturbances--the types that most interest restorationists--can make plant establishment and growth more difficult in an environment already characterized by poor growing conditions. Restorationist at Denali are challenged to restore plant communities that result from five basic types of human-caused disturbance:

1) trampling impacts and social trails
2) road renovation and roadside stabilization problems
3) construction activities
4) abandoned roads and gravel pits
5) mining activities.

Each of these disturbance types changes the natural environment in different ways. Trampling impacts are usually not severe and can be restored relatively easily--by, for example, closing the area to further foot traffic. Roadside restoration projects, on the other hand, typically involve seeding and raking. Construction disturbances are usually relatively easy to restore--if restoration was part of the original plan and soils and plants were actively salvaged. Abandoned roads, gravel pits, and placer mining disturbances limit plant establishment and growth most, and often present the greatest challenge to revegetate.

HOW TO CHOOSE YOUR TECHNIQUE

Before work begins, a restorationist faced with a disturbed area needs to analyze the site's abiotic and biotic characteristics in light of the project's goals. Abiotic factors (substrate stability, soil texture, moisture, nutrients, topographic and micro-topographic influences) and biotic factors (disturbance severity, presence of propagules, plant life history characteristics, and facilitative and interference relationships) interact with the particular site's history of use to create a unique disturbance regime.

In addition, certain restoration goals take priority on each project. For example, in 1990, after the park's new visitor center (VAC) was constructed, a contractor salvaged and transplanted taiga mats to revegetate the area around the new building. The contractor chose to salvage, rather than rely on plants growing more slowly from seed, because immediately improving aesthetics was the project's primary goal. However, a similarly disturbed site near the park airstrip--out of view of visitors--was revegetated with a slower-growing, less expensive mix of legume and grass seeds. Different goals and site characteristics require different techniques, making the decision as to what technique to use difficult. Techniques also have multiple applications. Restorationists might use that *legume/grass technique* (described later in this manual) on a fresh construction site in order to prevent the invasion of exotics; the same technique could be used on severe trampling impacts to prevent erosion.

Nevertheless, it is possible to give some general guidelines about how to analyze a site, diagnose its needs, and prescribe a strategy to restore it based on its revegetation potential. Revegetation potential results from the combined effects of a site's biotic and abiotic characteristics acting in concert to make the site more or less productive for plant establishment and growth. For example, salvaged topsoil with abundant propagules placed on a southern exposure would have a much greater revegetation potential than regraded placer mine spoils in a shady ravine because the salvaged topsoil will have a more productive revegetative response.

The revegetation potential of a site may vary for specific plants and for specific stages in a plant's life, such as establishment or growth. For example, alder have difficulty establishing naturally on regraded placer mine tailings, but if seedlings are manually established, alders grow with vigor. Therefore, the revegetation potential of placer mine spoils is low for alder establishment but high for alder growth.

Four steps should be taken to choose the right technique for the specific site characteristics and goals:

1) assess the abiotic factors that help determine the revegetation potential of the site
2) assess the biotic factors that help determine the revegetation potential of the site
3) consider the goal of a proposed revegetation project
4) choose a technique.

Below I describe a process a restorationist could use to choose appropriate techniques for site restoration.

Step One: Assess Abiotic Site Characteristics

The most important skill a restorationist can possess is the ability to identify the factors that limit plant establishment and growth and determine the revegetation potential of a site. In this section I describe abiotic limiting factors and their secondary effects.

Soil Characteristics

Substrate Stability

The first matter to consider when assessing a site for revegetation is the stability of the soil. Erosion or mass wasting can occur on lightly, moderately or severely disturbed sites, but is most common on severely disturbed sites. Placer mine disturbances and sloped road-cut or fill slopes are especially vulnerable to substrate instability. Obviously, if the soil is eroding or moving, plants cannot take hold. Generally, five factors influence soil stability (Howell, 1987):

1) Degree of slope--slopes greater than 5% are more likely to cause problems and require stabilization.

2) Type of soil--organic soils are generally more stable than mineral soils.

3) Soil texture and drainage--gravelly and sandy textured soils drain well and are less erodible than silty or clayey soils.

4) Moisture--the greater the level of moisture in the soil, the more likely it is to erode.

5) Permafrost--the presence of permafrost causes drainage problems and increases soil erodability.

Soil Texture

Soil texture influences plant establishment and growth. In particular, particle size affects plant establishment. For example, severe disturbances like placer mining can leave behind coarse-textured and unweathered soils with low water- and nutrient-holding capacities. Such areas are frequently barren. The revegetation potential of a site like this would be enhanced by the presence of sub-sand sized soil particles, which retain moisture and nutrients better than coarse soil particles.

Soil texture also affects soil compaction, which occurs when vehicle or foot traffic reduces the air spaces between soil particles. The results of compaction are decreased soil oxygen and hardpans. Oxygen is essential for plant growth and microbial activity; hardpans create barriers to root penetration and water percolation. In general, coarse soils tend to compact less severely than fine soils.

Moisture

Soil moisture can be influenced by soil texture, precipitation, topography, micro-topography, snow pack and rates of evapotranspiration. Soil moisture is rarely limiting in the subarctic due to frequent precipitation and the low evapotranspiration rates typical of the region. Exceptions include sites with well-drained, coarse-textured soils, well-drained south-facing slopes and windy alpine areas, where quick drainage and/or desiccation can inhibit plant establishment and growth.

Nutrients

Nutrient availability is affected by parent material composition, soil texture, decomposition rates, soil temperature and the presence of nitrogen-fixing species. Nutrient levels are relatively low in the subarctic and may limit plant growth. Most plants in the subarctic, however, have adapted to nutrient deficiencies by maintaining inherently slow growth rates, evergreeness, and high root-to-shoot ratios. Disturbed sites frequently offer enhanced nutrient availability due to soil warming and faster nutrient cycling.

Topographic and Micro-topographic Influences

Topographic Influences

Elevation, slope and aspect influence plant productivity and soils. Plant productivity typically decreases with elevation as a result of decreased soil moisture, poorly developed soils, and abrasion from blowing snow and ice. Slope affects soil stability and moisture. Aspect influences soil temperature and moisture. For example, south-facing slopes receive more solar radiation during the growing season, and thus are warmer and drier than other aspects (Densmore, 1985).

Micro-topographic Influences

Restoration projects using seeds for plant initiation require microsites for seed catchment and germination. Microsites provide the basic requirements for seed germination: purchase, moisture and warmth. Severely disturbed areas such as roadsides and graded placer mine spoils are often barren due to a lack of microsites to catch and germinate seeds. Without proper microsites to host seeds, any effort to foster natural seeding or to assist seeding is wasted; creating mircosites may be one necessary precursor to revegetating a site.

Step Two: Assess Biotic Site Characteristics

By evaluating abiotic limiting factors, a restorationist develops a base-line portrait of the site's ability to establish and grow particular plants. The next step is to consider the biotic factors that should shape revegetation strategies: severity of disturbance, presence of propagules, plant life history characteristics and facilitative/ interference relationships.

Severity of Disturbance

Disturbance can be classified into three levels, light, moderate, and severe (Densmore, 1985):

Light Disturbance damages or destroys vegetation, but leaves the organic mat (the O layer) intact. Since the organic mat contains most of the nutrient capital, as well as roots and stems that may sprout and buried seed that may germinate, the revegetation potential of lightly disturbed sites is high, and they require little if any assistance to recover. However, most plant species in the subarctic are adapted to germinate in mineral soil, so the presence of the O-layer may inhibit the invasion of some plants.

Moderate Disturbance removes the organic mat and exposes mineral soil. Sites with exposed mineral topsoil (the rooting zone or active layer) have a high revegetation potential, especially from off-site seed sources or assisted revegetation.

Severe Disturbance exposes subsurface materials that are usually coarse, nutrient-poor and have a low ability to hold moisture and nutrients. The revegetation potential of severely disturbed sites is typically low.

Presence of Propagules

Revegetation or natural regeneration is impossible without a source of propagules--seeds, sprouting plant parts or whole plants. Propagules for regeneration or revegetation on disturbed sites can come from 3 sources: (1) buried in the soil on site (2) nearby undisturbed sites and (3) manually collected, dispersed or planted. A lack of propagules is a limiting factor on most types of disturbance. When assessing the biological limiting factors, consider whether and how well the species that occupied the site before the disturbance, and those species on adjacent sites, will be able to reestablish themselves.

Plant Life History Characteristics

The ecology and physiology of a plant species significantly influences the type of site it can tolerate, and the success or failure of specific revegetation techniques. For example, seeding fireweed and spreading fertilizer on re-graded placer mine tailings may seem intuitively accurate, but will probably fail because fireweed--a plant that seems to grow everywhere--requires a warm, nutrient-rich and consistently moist habitat that well-drained gravelly soil cannot provide. Thus, it is important to investigate the appropriateness of using a particular species by comparing the ecological and physiological characteristics of that species to the abiotic characteristics of the disturbed site. Also consider biotic factors, such as symbiot relationships, and, in particular, facilitative and interference interactions.

Facilitative and Interference Relationships

As restorationists we are usually interested in establishing vegetation as quickly as possible, typically to stabilize the soil or to promote aesthetics. To accomplish these tasks effectively we must understand how facilitation--in this sense, how one species can promote the establishment or growth of another--affects earlier and later successional stages. For example, if you want to revegetate a roadside area of sandy gravel, an understanding of facilitation will likely lead you to plant nitrogen-fixing legumes, since nitrogen-fixers can take on poor soils, and, equally importantly, ameliorate the soil for other species by adding nutrients.

(Chapin et al. 1994).

Facilitation is not the only interaction among species that affects plant community development. Interference--how one species can limit the growth and establishment of another--also plays a role. Indeed, facilitation and interference can happen simultaneously; the direction and character of community development depends on which of these processes is more influential in a given set of circumstances (Cargill and Chapin, 1987, and Walker and Chapin, 1986).

Grime (1977), for example, maintains that in productive, low-stress environments, interference has a stronger influence on community structure than facilitation. Walker and Chapin (1986) found that a productive floodplain on the Tanana River, alder had an inhibitory effect on spruce in all successional stages. However, according to Chapin et al. (1994), alder have primarily facilitating effects on spruce on a harsh, recently deglaciated site in Glacier Bay National Park. In 1994, I observed similar community dynamics on graded mine tailings on Glen Creek in the Kantishna Hills.

Restorationists need to consider these interactions as best as they can, given the available information. In some cases, luckily, facilitative/interference interactions are easy enough to predict. For example, if the goal of a restoration project includes quick soil stabilization and directing succession towards a spruce forest, then planting dense stands of alder will certainly stabilize the soil and facilitate spruce growth by providing nitrogen; however, it may also inhibit spruce seedling establishment with leaf litter and slow growth with shade. Similarly, establishing grass to stabilize a disturbed site may facilitate the establishment and growth of some species by introducing organics into the soil. It may also inhibit them by impeding further seedling establishment, causing competition for nutrients and moisture and preventing soil warming.

Step Three: Consider the Goals for Restoring the Site

To choose the proper technique or set of techniques to restore a disturbed site, the goal or goals of the project need to be considered. Goals are broad, general statements of purpose and vision. The goals of a specific project are usually obvious, and typically have the greatest influence over the choice of technique. In Denali National Park, four basic goals drive the demand for restoration activities:

(1) soil stabilization

(2) restoration of lost environmental values (aesthetics)

(3) restoration of ecosystem functions (i.e., nutrient cycling or facilitative relationships)

(4) prevention of exotic plant infestations.

To efficiently restore a disturbed site, choose the technique that involves the least effort and expense, yet adequately achieves the planned goals. For example, in the Kantishna Hills aesthetics and excluding exotic species are not usually priorities, but soil stabilization and restoring ecosystem functions are--so for a project there, choose the technique that will stabilize and ameliorate the soil, but don't fret over looks and exotics. Near the front entrance, however, soil stabilization, aesthetics, restoring ecosystems processes and excluding exotic plant species are all important, so the techniques you choose must contribute to all four goals.

Step Four: Choose a Technique

Restoration work at Denali requires contributions from ecologists, engineers, equipment operators, maintenance workers and restorationsts. The choice of a specific technique is based on the abiotic and biotic factors that limit plant establishment and growth, the primary goals set for a specific project, and on a set of revegetation options. Below, I list categories of revegetation strategies, describe them in detail, and recommend specific techniques from Part II of this manual.

Once a revegetation strategy has been selected for a specific disturbance, a set of techniques can be chosen and project objectives can be clarified. Project objectives, as opposed to goals, should be site-specific and detailed in order to quantify successful completion of the work. For example, an objective could be to "plant 350 alder in this area," or to "construct a brush bar from this stake to that stake."

Revegetation Options

Categories of revegetation options include:

1) natural regeneration

2) direct seeding

3) salvage and transplant

4) nursery propagated native plants

5) use of non-native plants.

Natural Regeneration usually requires that a site have few limitations to plant establishment and growth, and a high revegetation potential. A site with light to moderate trampling impacts on an area of low aesthetic value is an example of a place where employing the natural regeneration of native plants would be appropriate. Natural regeneration techniques are usually applied with little effort or expense.

Direct Seeding can be applied to sites with moderate limitations to plant establishment and a moderate to low revegetation potential. Direct seeding can be appropriate on a wide range of disturbance intensities, depending on the species to be seeded and the goal for a specific site. The amount of effort needed to direct seed depends on how difficult seeds are to collect and on the need to create proper micro-sites. The *legume/grass seeding* *technique,* the *seed trap technique* and the *autumn seed blitz technique* are appropriate for direct seeding situations, and are described in detail in Part II.

Salvage and Transplant strategies are useful on sites with moderate limitations to plant establishment and a moderate to low revegetation potential. Salvaged plants can be used on all severities of disturbance, but since salvaging and transplanting involves a significant effort, it is usually reserved for severely disturbed sites. Salvage strategies are often used when aesthetics are a priority. The *plant salvage* and *bioengineering techniques* described in Part II are useful on severely disturbed sites where soil stabilization is a priority.

Nursery propagated Native Plants can be used on severely disturbed sites where plant establishment is limited but plant growth is not, such as mine spoils. Coarse- textured, well-drained soils do not provide adequate moisture near the surface for seedling establishment but do provide enough moisture at root depth to allow seedling survival. Collecting seeds and cuttings for propagating nursery-grown native plants (such as containerized plants), then out-planting the seedlings, is typically an expensive and labor-intensive task.

Use of Non-native Plant Materials (mostly sterile annual rye) is used as a last resort, on sites where erosion is a problem. Though easy to apply, annual rye has been shown to be detrimental to the establishment of native vegetation, and as a result, seeding annual rye is less ecologically sound than other strategies. In addition, protecting the genetic integrity of native plant communities is a principal concern in all revegetation activities. Thus, the use of annual rye seeds may be risky, since they may be contaminated with other, non-sterile weedy species or else they may accidentally reseed themselves. Nonetheless, annual rye is sometimes used with the *legume/grass technique* and some *bioengineering techniques.*

Revegetation Potential and Technique Options

The following table provides a general guide for choosing restoration techniques. The table describes a site's revegetation potential based on site characteristics, and then matches the disturbance with specific techniques described in detail in Part II. The technique options are based on simplified goals common to many restoration projects at Denali National Park.

It must be emphasized that the following table is based on the broadest of generalities. The correlation between revegetation potential and degree of disturbance is often imprecise due to factors such as elevation or aspect; similarly, goals such as "aesthetics" can translate into anything from blending the disturbed area into off-site vegetation to creating a beautiful floral display for visitors on a bus to planting a wall of alder to hide C-Camp. To complicate matters, in my experience more than one technique should be used per site. For example, after seeding an area with legumes and grass, I might plant the same area with wildflowers, or, after planting thickets of alder, I may then put seed traps between alder clumps. Experience should dictate how to combine techniques.

Revegetation Potential and General Site Characteristics	Technique Options Based on Specific Goals
High Revegetation Potential * low to moderate disturbance * low elevation * organic layer intact or mineral topsoil with soil fines present * propagules present on site * no or minor erosion * good soil water- and nutrient-holding capacity	For aesthetics: * natural regeneration * autumn seed blitz * legume/grass seedings * seed traps * containerized plants * alder plantings For erosion: * legume/grass seedings * alder plantings * containerized plants * bioengineering techniques For ecosystem function: * natural regeneration * autumn seed blitz * legume/grass seedings For exotic weed control: * legume/grass seedings * alder plantings
Moderate Revegetation Potential * low to moderate disturbance * low to moderate elevation * exposed mineral soil with some soil fines * no or few propagules on-site * moderate erosion potential * moderate soil water- and nutrient-holding capacity	For aesthetics: * seed traps * legume/grass seedings * salvage and transplant * containerized plants * alder plantings For erosion: * legume/grass seedings with erosion blankets * bioengineering techniques * containerized plants * alder or willow plantings For ecosystem function: * legume/grass seedings * alder or willow plantings * salvage and transplant For exotic weed control: * legume/grass seedings * alder plantings

Revegetation Potential and General Site Characteristics	Technique Options Based on Specific Goals
Low Revegetation Potential * moderate to high disturbance * low to high elevation * mineral soils--coarse textured or unweathered * no on-site propagules * low to high erosion potential * poor soil water- and nutrient-holding capacity	For aesthetics: * seed traps * legume/grass seedings * salvage & transplant * containerized plants * alder plantings For erosion: * legume/grass seedings with erosion blankets * bioengineering techniques * alder or willow plantings * containerized plants For ecosystem function: * legume/grass seedings * alder plantings * seed traps * plant salvage * containerized plants For exotic weed control: * legume/grass seedings * alder plantings

Conclusion

It is tempting to consider disturbances in the abstract, but when assessing the site characteristics and noting limitations to plant establishment and growth, bear in mind that the degree of disturbance, and not the type of disturbance, often determines site characteristics and the site's revegetation potential. For example, foot traffic generally causes only minor disturbance to a site and leaves a high revegetation potential, while road construction, mining, or other work with heavy equipment usually tears it up severely, leaving a low revegetation potential.

However, this is not always true; for example, at Polychrome Pass--an area of high, dry tundra restored in 1989--years of human trampling caused only moderate damage, but resulted in a site with a low revegetation potential because of limitations imposed by elevation and wind. Conversely, severely disturbed road construction sites near the front entrance (revegetated in 1991) had areas with a high revegetation potential due to warm temperature and mild wind conditions particularly conducive to plant growth. Therefore, it is important to assess how the type of impact really affects the individual site, rather than rely on an abstract idea of how damaging the disturbance should be.

PART II

ON SITE RESTORATION TECHNIQUES

INTRODUCTION

This section contains a "how-to" guide to eight on-site restoration techniques I have found to be successful in the restoration of human-caused disturbance in Denali National Park. Each technique can be used in a variety of ways. For example, aesthetic goals can be met using the *legume/grass seed mix* on road sides, or, with slight changes in application, it can be used for erosion control. Therefore, consider the following directions as guidelines rather than prescriptions. Keep in mind that each restoration project is unique, and the techniques used to restore it should complement individual site characteristics and goals.

A completed restoration project is not really finished until it has been adequately protected from further disturbance; therefore, I have also included a section on project protection techniques.

LEGUME/GRASS SEEDING TECHNIQUE

Introduction

The *legume/grass seeding technique* involves direct seeding of several species of nitrogen fixing legumes and grass onto disturbed areas. The seed mix has worked well on sites characterized with few propagules and microsites, by providing an abundance of seed and holding the seeds in the soil through vigorous raking. In nature, most of the seeds from these species stay on the soil surface, and eventually get blown away or eaten. The key to this technique is holding the seeds in the soil--a moist place safe from herbivory--where seeds can germinate. Because seeds must be held in the soil, the *legume/grass seeding technique* is vulnerable to failure by erosion.

Three site-specific native plants comprise the legume/grass seed mix and plant community. These include the legumes Hedysarum and Oxytropis and several species of the grass Agropyron.

Using a legume/grass seed mix has several advantages. First, the legumes in the mix fix atmospheric nitrogen into a form useable to plants through an association with *Rhizobium* bacteria, thus adding a valuable nutrient to the soil. A second advantage is that by using a variety of species, the probability of wide spread mortality from disease is unlikely. Third, a diversity of species will grow in a variety of microsite conditions resulting in more complete cover. Once established, the vegetation will add organic matter to the soil through leaf drop and root throw, which will greatly enhance the nutrient and water holding capacity of the soil. And fourth, the *legume/grass seeding technique* is inexpensive to apply relative to other techniques because seeds are easy to obtain and labor costs are low.

There are several species of Hedysarum, Oxytropis and Agropyron found in the park, at a different elevations and various plant community types. The most common species of Hedysarum in the park is Hedysarum alpinum, though the showier H. mackinzii is also present and can be used. Oxytropis campestris is common throughout the park, and O. borealis is abundant on streams and rivers near the Toklat Road Camp. Seeds of less common legume species that invade disturbed sites such as O. deflexa, Astragalus alpinus, and A. eucosmus, can be used, and their seeds can be mixed with the more common seeds. Agropyron macrourum and A. violaceum are both common but difficult to distinguish, so seeds collected for plantings in the past are probably a mixture of both. In 1993 I observed--several miles east of Sable Pass--an unidentified species of Agropyron growing on an extremely steep and unstable road fill slope. If used in the restoration program, this plant may be important for erosion control projects on steep scree slopes.

Where to use the legume/grass seeding technique

The *legume/grass seeding technique* can be used anywhere that a seed source is available. The genetic integrity of the plants used in the revegetation effort must be maintained, so only site specific seed collections for site specific plantings are recommended. The legume/grass seedings have been successful on well drained, nutrient-poor soils with high gravel and sand contents. The seed mix is especially useful on roadsides as it is aesthetically pleasing and seldom reaches a meter in height, thus satisfying roadside safety concerns. The established legume/grass plant community can tolerate mowing and light scraping; when planted densely, it is extremely resistant to invading exotic plants such as dandelions.

Limitations

Patience is the key to growing native plants in the subarctic. The legume/grass growth will not be impressive for the first or even second growing season, and may leave some sites vulnerable to erosion. The third and forth seasons should yield striking results, and mature sites should provide an excellent seed source for future revegetation projects.

Seed Collecting and Handling

Where To Find Seeds

The seeds of Hedysarum, Oxytropis, and Agropyron are easily identified, harvested, and stored. They can be found along roadsides, riversides and gravel bars, and other places where disturbance is common. An example of a cultivated legume/grass plant community can be observed along mile one of the park road and should provide abundant seed for many years.

When To Collect Seeds

The seed harvesting season usually starts in late July and lasts until late August. Harvest only ripe seeds. Hedysarum seeds are brown and papery and easily striped off seed stalks when ripe. Oxytropis seeds are ripe when you can shake the seed stalk and hear the seeds rattle. The entire stalk should be harvested and kept in an upright position until placed in a bag, as the loose seeds will fall out of the open, vase-like pods. Agropyron seeds are ripe when they are light brown and scatter easily from the seed head when rubbed. The entire seed head can be harvested with scissors.

Drying Seeds

Dry the seeds and chaff thoroughly by placing them in a warm dry place for several weeks. Lay them out as flat as possible in trays. Adequate drying will prevent pathogens from damaging the seeds and reducing their viability. Inspect the drying seeds closely for evidence of insect damage. If a problem exists, place a no-pest insecticide strip on the drying seeds. The tiny and seemingly insignificant bugs that take up residence inside the Oxytropis seeds can consume a weighty portion of the harvest.

Cleaning Seeds

Separate the seeds from the chaff for Agropyron and Oxytropis by following these three steps: First, place the seeds and chaff in a large cloth bag and kick it around a bit. Or try placing the bag, along with several pairs of shoes, in a clothes dryer set on "no heat" and tumbling it for a time. Much of the seed will separate from the chaff and gravitate towards the bottom of the bag. Next, place the seed and chaff in a shaker box made of a milk crate lined with quarter inch mesh screen and shake the box over a garbage can. The seeds will fall through the screen, leaving the chaff behind. Further cleaning can be accomplished by winnowing (using a light breeze to blow the chaff away).

Hedysarum seeds need no cleaning.

Scarifying Seeds

Some seeds need to be scarified to ensure germination. Scarification involves breaking down the seed coat to allow water imbibition and gas exchange. In nature this can happen by abrasion with sand and gravel. In the legume/grass mix, only Oxytropis seeds need to be scarified to increase germination rates. Do this by soaking the seeds in a strong solution of sulfuric acid for 10 minutes, stirring occasionally and rinsing them thoroughly. Another method involves rubbing the seeds lightly between two sand paper blocks. Care must be taken to avoid rubbing too much of the seed coat off.

Storing Seeds

Store the seeds for long periods by freezing. Label bags of seeds with species name, date collected, and location of origin. Unlabeled bags are useless and merely take up space in the freezer.

Site Preparation

As mentioned above, the legume/grass mix can be seeded with success on well-drained, nutrient-poor sites. A stable substrate is often the most important site-preparation concern. Slopes prone to sliding soil and erosion should be stabilized before sowing seeds. Avoid slope angles that are greater than the natural angle of repose for the soil type. Work with the road maintenance crews to protect the toe of the slope from disturbance. Often, if the toe of the slope can be stabilized, the entire slope is held in position. Look for potential water erosion problems. Sites that catch run-off from a road are especially vulnerable to erosion and seed displacement. Use waterbars, terraces, and reinforced waterways where needed. Rubber-tired tractor tracks that function as contour furrows have provided erosion protection by catching water, seeds and soil.

Soil compaction is rarely a problem for the legume/grass mix, but under extreme conditions, such as an abandoned road or gravel pit, a compaction problem may exist. To increase water infiltration, aeration and seed to soil contact, and to decrease run-off, the soil can be scarified by ripping. Ripping can be accomplished using a tractor with ripper tines, a front end loader with a toothed bucket, or a back hoe. Ripping to a depth of .25m to .5m is usually sufficient.

Sowing the Seeds

When To Sow

The legume/grass seed mix can be sown anytime during the growing season, but sow in the late fall or early spring for the best results. Seeding in midsummer can decrease seed viability and seedling survival by herbivory and pathogens as well as precocious germination, which can lead to increased winter kill.

Seeding Rates

An average seeding rate is approximately 50 Hedysarum seeds per square meter, 50 Oxytropis seeds per square meter, and 100 Agropyron seeds per square meter (3.7kg/ha). These seeding rates should provide 100% cover on a stable substrate.

However, rates vary depending on the objective of the project. For example, more seeds should be sown on a steep slopes, and fewer be sown in an area where colonization by other plant species is desired.

Since the legume/grass community should not be perfectly homogenous over an entire project, an attempt should be made to vary the species composition over a site. Patches where the cream colored flowers of Oxytropis are dominant contrast nicely with stretches where the purple flowers of Hedysarum are in the majority.

How To Sow

Hedysarum seeds are most easily sown by hand, but Oxytropis seeds can be more difficult to handle because of their small size. A pepper shaker can be useful for broadcasting these seeds. Agropyron seeds can be broadcast using a hand-held seed spreader, although the slightest moisture will cause the seeds to stick together and render the spreader useless. Avoid seeding during windy periods.

Fertilizer

Fertilizer is useful but not necessary for the establishment of the legume/grass plant community. We have used with success, a slow release (14-14-14) osmocote fertilizer at a rate of 50g per square meter. Using a time-release fertilizer is important because it slowly releases nutrients nearer the rooting zone. In well drained soils, nutrients are often washed deep into the soil and made unavailable to the plants. High nitrogen fertilizer should be avoided because they can deter the formation of nitrogen-fixing root nodules. Fertilizer can be applied efficiently using a hand-held spreader.

Raking

The final step of the legume/grass technique is vigorous raking. Intensive raking helps to ensure seed germination and seedling survival by creating seed-to-soil contact. Raking has many other benefits: it holds seeds in place and protects them from wind, water displacement, and herbivory: it puts seeds in contact with the subsurface soil moisture essential for germination and seedling survival; and it may aid in scarifying the seeds, thereby increase germination rates.

The soil, seed and fertilizer should be raked to a depth of 1cm to 3cm. This process is sometimes difficult in gravely soils, but it is critical to the establishment of the legume/grass community.

After seeding and raking and on steep, unconsolidated slopes, such as a newly constructed road fills, it may be advisable to run a small D-3 caterpillar tractor equipped with wide tundra tracks up and down perpendicular to the contour. Using a small caterpillar has several advantages. The weight of the tractor with wide tracks should firm up the soil without causing excessive compaction, and tractor cleats will press the seeds firmly into the soil. In addition, the imprints from the tractor cleats create an enhanced microclimate, and those imprints running parallel to the contour of the slope will aid in erosion control.

Inoculation

Inoculating a revegetation site with the nitrogen-fixing Rhizobium bacteria is usually not necessary. However, if the site to be revegetated is unusually sterile--fresh mine spoils or mineral soils from deep under the surface--inoculation may be helpful. Make inoculant by digging up a nodulated legume and the soil that surrounds the legume roots. Chop up the roots, mix them with the soil obtained from the root ball and sprinkle the mixture over the site. The site can be inoculated before or after seeding. Legumes should be examined for root nodules after they have reached maturity.

Erosion Control

Annual Rye

As mentioned above, although the legume/grass mix is useful for erosion control, the plants may require an entire growing season or more to establish an adequate cover, leaving the site unprotected in the meantime. To ameliorate this problem, add a small amount of annual rye seed (7-8 Kg/ha) to the mix to provide prompt protection. Annual rye has not reseeded itself in the park and should not become an invasive weed. Fertilizer is often needed to stimulate fast growth for rapid erosion control. Again, a time release fertilizer is preferred; if a regular fertilizer is applied, an application rate of approximately 250-300 Kg/ha should be effective.

Care should be taken when using annual rye, as it can drastically delay or impede native plant establishment. A thick layer of dead and decaying annual rye can slow or prevent native vegetation establishment in several ways:

1) A vegetation blanket can insulate the soil causing low soil temperatures and delayed or decreased germination and growth rates.

2) Valuable nutrients can be tied up in the decomposition of the annual rye.

3) A vegetation layer can prevent colonizing native seeds from reaching mineral soil.

4) Native seeds having a light requirement may not germinate under the darkness of a vegetation mat.

A tactic that may be helpful in cases of extreme erosion potential involves sowing annual rye at a high rate (15 Kg/ha or approximately 200 seeds per square meter) along with the standard quantity of the native legume/grass mix. The mix should be sown near the end of the growing season, about mid August. By sowing late in the season, the annual rye germinates and reaches only a quarter to a third of its potential full height, then dies with the autumn frosts. The roots and stems from the rye will provide some erosion protection and will not severely impact spring germination and growth of the native species. Irrigation may be necessary to ensure that the majority of the annual rye germinates in the autumn. It is important that annual rye germinating in the spring with the native legume/grass community be kept to a minimum, to prevent stressful competition.

Erosion Control Mats

Erosion control mats are commonly used on revegetation projects. The mats are usually made of organic fibers (coconut fiber) held together with plastic or fabric netting, and are designed to be left in place and degrade naturally. In the Denali region, I have noticed that germination and growth rates of seeds under a mat may be inhibited, possibly because the mat insulates and keeps the soil cold. Mats also decompose very slowly in the subarctic, and when the mat degrades, the netting remnants may blow off the site and make an unsightly mess. There have also been cases of birds becoming caught in the netting. Although we have had problems with mats, a procedure for using mats with success includes:

1) Seed, fertilize and rake the slope using the standard rates of application. Seeding should be done in the late fall or early spring. As described earlier, annual rye may be added to the mix. Tracks, depressions and ridges should be removed to increase mat to soil contact.

2) Peg the mat securely to the ground. Thick mats work best on sites where running water is expected. Thin mats (old used mats) are recommended on other sites however, as they will insulate the ground less, and increase germination times and rates.

3) Remove the mats as soon as germination of the legumes is evident. It is important to remove the mat as early as possible to avoid damaging the seedlings that may protrude through the mat. Grass seedlings may

germinate before the legumes, but will slip easily through a lifting mat, while the dicotyledons and multiple stems of a legume may cause problems. Removing the mat early is imperative for the growth and survival of the legumes and grass; however, the small plants may not be of any erosion protection value and the site will be vulnerable to erosion until the plants are well established.

Seed Mix Additions for Landscaping

When aesthetics are a priority, the legume/grass mix can be seeded over an entire area, followed by plantings of colorful containerized or salvaged flowers and shrubs. In this way a site receives immediate visual amelioration and the bare ground between the planted flowers will fill in with the legume/grass plant community. Experience has shown that planted flowers and shrubs rarely colonize beyond their planting hole, leaving bare ground available for invading native and exotic weed species. If this technique is applied it is important to plant the flowers and shrubs either simultaneously with the legume/grass mix, or plant the flowers shortly after the area has been seeded with the mix (before the legumes and grass have germinated). Walking and working on seeds will not harm them, whereas walking on sensitive seedlings can be extremely damaging.

PLANT SALVAGE, STORAGE AND TRANSPLANT

Introduction

Plant salvage involves recovering clumps of living vegetation or soil with propagules from construction sites and roadsides, and using these plant materials to revegetate disturbed sites. Salvaged plants can be used to create barriers, stabilize slopes, add aesthetics and prevent the spread of exotic vegetation. Plant salvage can be expensive relative to other techniques due to labor costs and the use of heavy equipment.

Denali National Park is fortunate to have an abundance of salvageable plant material from construction sites, maintenance activities and roadside ditches. The first and most important task is to acquire the plants before they are destroyed. To identify and procure salvageable plants, the restorationist must communicate with the park engineer, the roads and trails foreman and the park's compliance officer. To prevent loss of salvageable plant material, plant salvage should become a standard practice during construction and maintenance activities, and a standard aspect of park planning. Establishing salvaged plant material storage facilities may be one way to encourage plant salvage on a routine basis. A prototype salvaged plant storage facility was installed at the Wonder Lake Campground in the summer of 1994. The storage facility consists of four railroad ties formed into a small box and filled with four inches of sand. Salvaged plant material can easily be planted in the box, then, when needed, easily removed and transplanted. The plant material for this test was salvaged from near-by drainage ditches along the park road. Renegade tundra clumps (sliding roadside vegetation) are common, and should be salvaged by park employees when observed since road maintenance activities may accidently destroy the clumps if not salvaged promptly. If the Wonder Lake salvaged plant storage facility proves successful, other small facilities could be constructed in places where plants are needed most, such as the Eilson Visitor Center or the Savage Campground. Keeping genetic integrity in mind, salvage protocols must be developed to record the origin of the plants.

Salvaged plants have several advantages over nursery stock or seeding in revegetation projects:

1) Mature plants provide immediate visual amelioration.

2) Large trees and shrubs provide effective screens and barriers.

3) Salvaged plants are usually inexpensive to procure.

4) Salvaged plants preserve the genetic constitution of the site when used correctly.

5) Using salvaged plants prevent waste.

What & How We Salvage

Tundra & Taiga Mats

Vegetation mats in the subarctic can host a great variety of species and growth forms, including moss carpets, grass clumps, berry bushes, willow bushes and small spruce trees. Mats can be used effectively for many restoration needs, such as: to fill in large areas of bare ground; to create a mound forming a barrier to pedestrian and vehicular traffic; to provide material to be used in bioengineering structures that stabilize a slope.

The following recommendations should aid in salvage, transportation, storage, and transplanting of vegetation mats:

1) With a pulaski, pre-cut the vegetation mat to the desired size which can be the size of a tractor loader bucket, or, if a tractor is not available, into smaller pieces that one or two workers can wrestle. Attempt to cut the mat in such a way that the roots on the most valued plants remain intact. Root systems on many plants in the subarctic spread horizontally, rather than delve into cold or frozen soil, so the mats can be surprisingly large.

2) Scoop the mat up with a tractor or undercut and peel the mat by hand.

Attempt to bring up as much of the root mass and active layer as possible. Effectively salvaging mats in the spring is sometimes difficult because a portion of the active layer may be frozen.

3) Transport the mats on a flatbed low-boy trailer or pickup truck. Before depositing any mats on the trailer, cover the bed with a single section of engineer's cloth. To off-load the mats, position the trailer where you want to store the plants, anchor the engineer's cloth in place by rolling the end of the cloth around a log or board. Chain the log to a solid anchor. Then, simply drive the trailer away, leaving the cloth and mats behind.

4) If properly salvaged and maintained, mats can be stored for several years. Eliminate gaps between stored mats by pushing them tightly together or filling in the spaces with soil. Keep the mats moist with a sprinkler or drip irrigation system. Mats with an intact active layer and only minor root damage may need little or no maintenance while in storage. Prevent exotic plant contamination by avoiding areas where exotics exist, such as the headquarters district.

5) To transplant a vegetation mat, excavate a depression deep enough to bring the mat to ground level. Scarify the soil in the depression to enhance

root penetration. Fertilize the hole with a time release fertilizer. Fit the mat into the depression. To ensure good mat to soil contact, leave no air pockets. On a steep slope use rebar pegs anchor the mat. Rebar pegs can also be used to anchor and secure any spruce trees that threaten to fall over within the mat. Fabricate L-shaped pegs about 50cm in length for this purpose. Treat transplanted mats with Vitamin B-1 to reduce shock and promote root growth.

Expected Results

Some vegetation mats drastically change species composition after transplanting. The species change is usually due to damaged root systems that lead to plant mortality within the mat. Mats may shift from a typical tundra or taiga community to a disturbance type community. This is not necessarily bad, as the disturbance oriented plants often establish quickly and provide adequate cover. Nor do aesthetic goals suffer--visitors rarely notice differences in species composition. Mat mortality and species composition change can be remedied by careful salvaging, thus preserving the integrity of the mat and the underlying active layer. The active layer may be somewhat unconsolidated, and can be lost through careless handling.

Spruce Trees

Spruce trees can be salvaged almost anytime the soil is thawed, except in the spring when the trees are producing terminal branch growth. If you observe new, light colored needles on branch tips, do not attempt to transplant.

I recommend pruning spruce roots a year before transplanting the trees. With a pulaski or sharp spade, slice a narrow trench around the spruce the size of the desired mat or root ball. The trench should be as deep as possible to ensure most of the roots are cut. Root pruning will induce the spruce to develop new roots near to the trunk and within the boundaries of the salvage mat or rootball. Leaving the tree in place after pruning allows the tree to adjust to shorter roots without the added shock of being moved. However, root pruning make trees susceptible to wind throw, or to falling over with a heavy snow load and to winter kill due to water stress. To moderate the physiological effects of root pruning, pruned trees can be watered, fertilized, and treated with vitamin B to reduce shock.

Black spruce (Picea mariana) and white spruce (Picea glauca) trees grow in various substrates which call for different salvage methods. White spruce have flexible rooting patterns and can develop a tap root in deep soil and a mat root system in shallow soil. Black spruce produce only shallow roots in deep or shallow soils.

White and black spruce growing in shallow soil are salvaged the same way as vegetation mats. A tractor is essential for this type of work. Typically, spruce roots spread horizontally well past the drip line of the canopy, so a rather large mat can be expected. For example, a tree 3m in height will need a mat approximately

3m wide. A salvaged tree 4m high is considered very large. Often several small spruce trees growing in a clump can be salvaged and transplanted together.

White spruce salvaged from deep soil must be excavated in such a fashion as to preserve the deeper roots. This is difficult to do with a tractor or loader, as the buckets on these machines are not made for excavating. As a result, these trees should be salvaged by hand with a pulaski, mattock and shovel. A spruce tree a meter high needs a root ball about 75cm wide and 20cm to 30cm deep. The soil surrounding the roots in deep rooted spruce can be very unconsolidated and easily lost.

Trees to be salvaged without the assistance of heavy equipment should not be over a meter tall. The mat or root ball on larger trees becomes too heavy for even the strongest workers to lift. An injured back and damage to the roots system are usually the results.

Transport deep-rooted spruce by placing them in large plant pots immediately after they are salvaged. The pots keep the soil and roots together and make moving them much easier. If the spruce are to be stored for a long time, care must be taken in the potting process. Soil should cover the roots completely, with no airspaces. Spruce can be stored in this manner for several years. While in storage, potted spruce will require more maintenance, such as watering and weeding, than matted spruce.

Transplant salvaged spruce by digging a hole or depression slightly wider and deeper than the mat or root ball. Sprinkle fertilizer in the bottom of the hole and on the soil to be used as back fill. Place the spruce in the hole so that it stands unassisted. Back fill the hole and tamp the soil around the roots to ensure root to soil contact. If a spruce is properly planted, little support is needed later in the way of guy wires or rebar pegs. Leave a shallow watering moat around the planted spruce and water it with vitamin B-1.

If an unstable tree requires support, rebar pegs driven through the mat into the subsoil work better than guy wires. Guy wires are unsightly, can cause caribou much trepidation, and do not provide the mat to soil contact that pegs can. Tree stakes are also an option, but tree stakes and guy wires tend to induce tall, thin, and weak, growth while rebar pegs do not effect a tree's growth form.

Willow Bushes

Willow bushes (Salix spp.) are extremely resilient and can be treated rather roughly compared to other plants, such as spruce. Small willows can be excavated by hand and transported in pots. Larger willow can be scooped with a tractor and moved like a mat. The root balls on willows tend to be very heavy, and sit well in planting holes. Transplant and fertilize willow in the same manner as spruce. Willows typically respond vigorously to fertilizer, and will not need vertical support.

A procedure for salvaging and transplanting willow quickly entails digging the plants out of the ground with heavy equipment, storing the plants and root wads in a pile, then transplanting them by burying the stems and root wads in trenches or holes. The outcome can be unsightly, but the results are usually favorable. Running a bulldozer over the plantings not only tidies up the site, but also ensures good soil to root contact. This technique is especially applicable on new fill slopes, and was employed on the mile-20 slump project.

Soil Salvage

Introduction

Soil, specifically the active layer, should be considered a collection of living flora and that can be salvaged, stored, and transplanted just like other plant materials. Salvaged soil can contain an abundance of propagules (roots, stems, rhizomes and seeds) that when applied correctly can vegetate a disturbed site. Organic matter incorporated into a mineral soil forms a productive substrate for seed germination and vegetative sprouting. I recommend the following steps for successful soil salvage, storage and application:

Remove Stems

Remove most of the living brush and stems from the area to be salvaged. Removing the live stems does several things: it increases the root to shoot ratio which promotes sprouting; it removes organic matter that may later tie up nutrients in the decomposition process; and it makes hauling and dumping the soil easier as the stems won't get stuck in the dumptruck gate.

Machines to Use

Remove the soil with the appropriate machine. A front-end loader is useful on level or slightly hilly terrain. A track hoe can salvage soil from steep slopes. A bulldozer can remove soil from most sites but cannot load it into a truck. Small jobs, or projects in remote areas, can be done with a mattock and shovel.

What Soils to Salvage

The entire active layer should be salvaged. Many times the organic layer is deeper than the active layer, so close inspection is necessary. Look for viable roots.

Soil Storage

Store salvaged soil carefully. Transport the soil with a dumptruck and store it in a place safe from exotic plant infestation. Avoid compacting the salvaged soil with heavy equipment because many micro-organisms essential to ecosystem restoration are sensitive to the decrease in soil oxygen that results from compaction. Living soil cannot be stored for long and remain viable because buried propagules may decompose and lose their ability to germinate or sprout. Some seeds, however, can remain buried and viable for many years. To ensure maximum viability the soil should be used the same season it was salvaged. Soil should be applied in the fall so as to take advantage of every hour of sunlight and warm temperatures in the spring. A soil pile stored over the winter will freeze solid and remain frozen well into the spring growing season.

Site Preparation

Some site preparation may be necessary before spreading the soil. For example, shallow (10cm to 40cm) trenches, furrows or depressions can be excavated to hold salvaged root wads, or the site may be scarified to enhance soil mixing and root penetration.

Applying The Soil

Spread 10cm to 20cm of salvaged soil and propagules over the disturbed site. Root wads and willow stems should be pushed into trenches and buried. Mixing the highly organic salvaged soil with the mineral substrate is essential. Alone, an organic layer would quickly desiccate, and significantly decrease the chance of seedling and sprout survival. Abate soil compaction while spreading the soil by using a small bulldozer equipped with wide tundra tracks. Some compaction is beneficial to consolidate the soil, increase soil to propagule contact, and mix the salvaged soil with the underlying mineral soil.

Dressing The Site

After the soil has been dispersed and the propagules sufficiently mixed and buried, often no further action is needed. To hasten growth for erosion protection or aesthetics, however, the site can be treated with a time release fertilizer. The site can also be seeded with the appropriate grass, legume, shrub or tree seed. It may be helpful to fertilize and seed the site after the soil has been spread but before the tractor has finished dressing the site to ensure the fertilizer and seed are incorporated thoroughly into the soil.

Expected Results

The enhanced water holding capacity, increased nutrient capital, higher soil temperatures, and a lack of competition of the applied salvaged soil will facilitate seed germination, seedling survival and growth, and rooting and stem sprouts from vegetative propagules. A soil surface roughened with salvaged organics will function as a seed trap, and the species composition of the restored site will hinge upon the propagules present in the salvaged soil and on neighboring seed sources.

A soil salvage project completed before seed dispersal in the fall will experience an advantage over those completed in the spring or mid-summer because many aggressive pioneer species such as, alder, fire weed and most grasses seed in the fall. However, felt-leaf willow (Salix alaxensis) and balsam poplar (Populus balsamifera) seed in the late spring.

Sprouts from willow roots and stems in the salvaged soil should be evident within a few weeks after spreading, or the early spring. Tall fireweed (Epilobium angustifolium) and the grass Calamagrostis canadensis grow from roots, rhizomes or seeds, and favor disturbed, nutrient rich sites. Balsam poplar and quaking aspen sprout from root wads. Alder can also sprout from root wads, but with less vigor. Dwarf birch (Betula spp.) and blueberry (Vaccinium spp.) do not fare as well as the species mentioned above.

Buried seed in the salvaged soil may present a few interesting surprises. Little is known about the species composition and viability of buried seed in the subarctic; thus every project where salvaged soil has been used should be monitored regularly to assess the success of the *soil salvage technique*.

BIOENGINEERING TECHNIQUES

Introduction

Bioengineering is an approach to land stabilization that uses plants as engineering materials (Schiechtl, 1980). Bioengineering involves the construction of living structures such as brush bars, hedge layering and sodding, that can stabilize and protect streambeds, streambanks, flood plains, and steep slopes.

These techniques have played increasingly significant roles in the revegetation and restoration effort at Denali National Park. Recently, abandoned placer mines on Glen Creek in the Kantishna Hills region have provided an exceptional opportunity to conduct research on riparian area restoration. Together, research ecologists and engineers are solving problems that occur in the restoration of drastically disturbed riparian ecosystems in the subarctic. Many of the solutions are bioengineering techniques.

Bioengineering is not a new concept. It has been used extensively in Europe for many years, and is now becoming widely accepted in the United States. For agencies concerned with restoring for aesthetics, such as the National Park Service, it may become a preferred engineering tactic because it can replace structures such as retaining walls, terraces, rip-rap and rock gabions. By building a protective structure that lives and grows, we establish a natural-looking entity that is self-maintaining and aesthetically pleasing.

Denali is fortunate to have an abundance of materials, like willow and alder, from which bioengineering structures can be built. Felt-leaf willow (Salix alaxensis) will sprout from cuttings and buried branches. Alder (Alnus crispa) is more abundant, but does not sprout. Nonetheless it is used to add mass, strength and nutrients to a structure. Both species are often found conveniently near a restoration project. Road maintenance crews welcome their removal and if requested, they will often assist the revegetation crew in the harvest.

Brush Bars

Brush bars, sometimes called willow wattles or live facines, are the most common type of bioengineering technique used at Denali. Brush bars can be used to: stabilize stream banks and slopes; assist sediment deposition; control gully erosion and improve drainage. The steps to construct a brush bar are listed briefly here and described in detail below:

1) Dig a trench of the desired depth, length and width.

2) Lay anchoring ropes across the bottom of the trench; at right angles to the trench. Branches will be placed on top of the ropes.

3) Lay a sproutable species of willow like felt-leaf willow, in the trench along with some alder branches.

4) Back-fill the trench with soil and rocks. This will cover the willow and anchor the brush bar.

5) Fertilize the back-fill.

6) Weave alder and some willow into the bar until the desired height is reached.

7) Tie the bar together by squeezing the bundle of branches with the ropes laid down across the bottom of the trench.

8) Anchor the bundle with pegs.

The Trench

Digging the trench can be an arduous task, especially in compacted gravel and rock, or on a steep slope. The trench can vary in size and placement according to the planned objective and the engineer's specifications. Generally the trench is 30cm to 50cm wide and deep. If the trench is to be excavated by hand, a maddox and shovel are the tools of choice. A backhoe or bulldozer with a six-way blade can save a lot of time and effort.

The Anchoring Ropes

The ropes laid across the bottom of the trench should be spaced at about one-meter intervals. Tuck the ends of the ropes under a rock or around a bush, as the rope ends can be accidently buried in the construction process. The ropes should be made of a strong biodegradable natural fiber. Manila rope has been used in the past, but can lose strength after a year. The weakened rope should not cause major problems because the bar should be well rooted in a year's time, and the sprouting willow branches should hold the brush in place.

Placing the Brush

The two major objectives when placing brush into the trench are inducing the willow to sprout and building strength into the structure.

Willow branches should be used as soon as possible after cutting. Delays of less than one hour between cutting and planting are recommended. If a longer delay is unavoidable, the branches can be preserved by laying the cut ends in a stream. Use willow and alder with basal diameters of 2cm to 10cm. Branch lengths can vary, from shorter than the trench, or can be longer than the trench by about a meter.

Place the willow branches in the bottom of the trench to ensure good soil contact. The small ends and lateral branches should be allowed to protrude out of the trench. The willow will sprout from these branches protruding near the soil surface. Weave the branches together when placing them into the trench to give the bar strength. After the bottom layer of willows has been laid, weave in a mixture of willow and alder until the trench is full to ground level.

Live plants with intact root systems can also be incorporated into the brush bundle. Small willows, poplars and alders can be yanked easily from gravely soils and transplanted. These plants, even when transplanted so ungraciously, will often grow better than the sprouting willow. I have not tried planting nursery-grown containerized alder seedlings inside a brush bar, but it should be tested.

Back-filling the Trench

Back fill the trench to anchor the brush bar and to give the willow a growing medium. The trench should be back filled to 3/4 full, leave spaces for weaving in more brush. Shake the brush in the trench to fill air pockets and increase soil to brush contact. Water can be used for this purpose, and on drier sites a good watering is highly recommended. A slow release fertilizer should be added to the backfill at a rate of about 50 grams per meter of trench. Add the fertilizer slowly as you backfill the trench to ensure thorough mixing with the soil and brush. The back fill can also be amended with large rocks for stability and drainage, or with compost and topsoil to ensure that the willows sprout and grow with vigor.

Add More Brush

Weave more brush into the bar, usually the more common alder, until the desired height above ground level is reached. Alder contributes mass, strength and nutrients, while willow is saved for that part of the bar the needs to sprout.

Tie and Anchor the Brush Bar

Tie the brush bundles together with the ropes laid across the trench earlier in the construction process. The ropes should be tied as tightly as possible by using a trucker's hitch. The ropes should hold the bundle firmly in the trench, with the weight of the back-fill acting as an anchor.

Peg the Bundle

Some practitioners anchor brush bars using long sproutable pegs hammered through the bundle. However, wooden pegs are often ineffective in rocky soil while pegs made from rebar can penetrate rocky soil. The rebar peg can be shaped to form a hook that holds the brush snugly in the trench. Pegs 50cm to 75cm long should be sufficient.

Pegs should be driven into the soil as deeply as possible, at one-meter intervals. On extremely unstable slopes the spacing can be spaced closer. Pegging the brush bar is not always necessary, especially on flat areas such as flood plains. The weight of the back-fill and the quality of the branch weaving may be adequate to hold the bar in place.

Expected Succession and Maintenance

Do not expect horticultural miracles in the subarctic. Plant colonization and growth may be slow. Willow sprouts over a meter high after one year's growth are exceptional. However, nutrients from fertilizer and alder branches and an enhanced micro-climate within the bar will encourage a variety of pioneer species.

Little maintenance should be required. The bar should increase in strength each year as the willow sprouts hold the brush together and the roots consolidate the soil. In extreme conditions where quick growth is essential, fertilizer can be added each year.

Brush Bar Construction Guidelines for Specific Restoration Goals

Stream Bank and Flood Plain Stabilization

Experimental work on abandoned placer mines on Glen Creek has generated an assortment of techniques to stabilize streambeds, stream banks, flood plains and to restore pre-disturbance riparian vegetation. Brush bars have been used extensively and with favorable results in the stabilization and restoration of recontoured mine tailings and newly constructed flood plains on Glen Creek.

Brush bars are placed on the streambank, perpendicular to the stream flow. They are designed to control erosion and encourage sediment deposition; willow roots hold the soil together and the above ground alder branches slow the flood-water velocity. Slower water velocity allows sediment deposition within the bar and on the flood plain immediately downstream. Fine soil particles from sediment deposition are extremely important to vegetation colonization and growth.

Nutrients from the alder branches and the added fertilizer also improve plant growth.

Colonization by pioneer species should be expected within the bar as well as immediately downstream. The bar and area surrounding the bar, will only increase in plant diversity and stability as time goes by; floods however, can extremely forceful, so expect the loss of some structures.

When constructing brush bars for stream stabilization and restoration, consider these points:

Build to Specifications

Build the bars to the engineer's specifications. The engineer or hydrologist considers channel and flood plain design and flood frequency and intensity when deciding the length and placement of the brush bars.

Build Strong Brush Bars

The bar needs to be well built, as it will experience flooding and high velocity currents. Specifically, special attention should be given to digging a deep trench, anchoring with heavy rocks, weaving branches well.

Remove Large Rocks Upstream

Large rocks within a meter upstream of a brush bar should be removed, as flood water passing over these rocks will eddy and undermine the bar.

Shape the Bars to Your Needs

Brush bars need not be straight. They can be constructed to form V shapes, or built perpendicular to the stream, then extended downstream to wrap around a vulnerable streambank. Creativity is key in brush bar planning and construction.

Slope Stabilization and Drainage

Although restorationists at Denali have had limited experience using brush bars to stabilize steep slopes, projects completed thus far, like the bar built for the mile 20 slump project, demonstrate great promise for future slope stabilization projects.

Unstable cut and fill slopes along the road corridor present excellent opportunities to perfect the use of brush bars for slope stabilization.

Bare and unstable slopes in Denali National Park are extremely common and a part of the natural ecology, so consider carefully before attempting to restore the vegetation on a steep slope. Slope types that may require stabilization include:

1) Those caused by human disturbance that may degrade a park visitor's experience. Often the only close view of vegetation a visitor may have is just outside the bus window along the road corridor. Road scars are often evident, even from a great distance.

2) Those with sliding soil and rock, requiring constant maintenance to remove.

3) Unvegetated and unstable slopes that threaten the integrity of a road, structure, or trail.

4) Slopes that threatens water quality as a result of human disturbance. Unstable slopes with sliding soil and rock, or water erosion prevent plant establishment. By constructing a brush bar, the slope stops sliding temporarily, while the willow in the brush bar take root and stabilize the bar and the slope permanently. The bar and slope will be most vulnerable to failure between bar construction and willow rooting. Other temporary slope stabilization techniques--for example, sowing annual rye, or employment of an erosion blanket--may be necessary.

In many areas along the park road, slope instability and the accompanying lack of vegetation is caused by road grading, especially, grading away the toe of the cut slope. When the toe of a slope is removed, the substrate slides to seek its angle of repose and material above the grading cut moves to fill in the missing toe. Many slopes would be vegetated if grading methods could be modified, or if a band of vegetation existed just above the toe. Those slopes naturally stabilized by vegetation or large rocks near the toe are usually not affected by grading. Vegetation can be seen colonizing these slopes above the vegetation clump. Many times the vegetation clumps originated at the top of the slope and slid down to their present position. Brush bars can be constructed to provide this same kind of slope protection. The brush bar built near mile 20 on the park road in mid-August, 1994 is good example of this technique.

Slope stabilization brush bars can range in size according to the job at hand. The bar can be as small as four or five willow branches completely buried beneath the soil, to a full sized willow and alder bundle that protrudes half a meter above the soil. Such brush bars can be built on the contour to catch and hold moisture, or at a slight angle to direct water flow. In cases where drainage is a primary concern, the bar can be constructed perpendicular to the contour or down the middle of a ravine, although this technique has not been tested at Denali.

Gully Erosion Control

Gully erosion can present a serious threat to natural vegetation, roads, structures, trails and restoration projects. Wooden plank fences and terraces have been used for gully erosion control with mixed results. Brush bars can be applied to gully erosion problems with improved results, and are also much more aesthetically pleasing. Using branches instead of planks allows water to pass through the structure, leaving the soil drier and more stable. Proper drainage also minimizes the possibility of water undercutting the brush bar.

To build brush bars for gully erosion follow construction steps described above for slope stabilization and consider the following recommendations:

1) If the gully in question is an obvious waterway, it may be prudent to treat it as such, and take measures to construct a drain, or a rough, rock hardened surface.

2) A series of brush bars is usually necessary to do the job correctly.

3) Begin at the bottom and work up. The brush bar trench must be at least 25cm below the floor of the gully. This is will prevent water from undermining the bar.

4) The brush bar should be firmly keyed into the slope by extending the trench one meter on either side of the gully. The trench for this type of brush bar can sometimes be over a meter deep.

5) Back filling the gully behind the brush bar is recommended; however, the material to do so is usually far downslope and unavailable. Importing soil may be necessary. The bare soil up hill of the brush bar should be vegetated with seeds, salvaged plants, tundra mats or nursery grown plants.

6) Soil, seeds and dislodged plants should accumulate behind a properly constructed brush bar. Hasten plant establishment and growth by fertilizing

the accumulated soil and organic debris. As time passes the brush bar should increase in strength, and the soil uphill of the brush bar should support a host of pioneer plants.

Hedge Layering

A technique similar to brush bar construction, called "hedge layering," has not been tried at Denali, but may prove to be useful for slope stabilization. This technique requires only a small terrace (25cm wide) dug along the contour, and densely stocking it with rooted plants. Lay seedlings horizontally on the terrace, then backfill the terrace to the original slope angle, leaving the plant stems protruding. At Denali, containerized alder seedlings may be the shrub of choice. Site-specific alder seeds are easy to collect and nursery-grown seedlings are relatively economical to propagate. They could be planted as close as 15cm apart to create a stable strip of vegetation.

Sodding

Sodding is a bioengineering technique that uses vegetation mats for soil stabilization and erosion control. Tundra mats, taiga mats and turf grasses have been used with success (see the Plant Salvage, Storage and Transplanting section for more information).

As with brush bars, the major concern when using vegetation mats is anchoring them in place and inducing them to root. The following is a list of recommendations for using vegetation mats as bioengineering materials:

1) To anchor mats to a slope excavate a hole deep enough to bring the vegetation mat level to the ground. Then position the mat in the hole and drive L-shaped re-bar pegs through it into the soil beneath. Mats can be cut to form any shape desired. A shallow, narrow trench built along the contour of a slope and planted with a vegetation mat may become an effective terrace.

2) Round and stabilize the top of a road or trail cut excavating under the existing vegetation mat and allowing the mat to fold down and cover the slope. The mat should remained attached to stable vegetation, and thus be held in place from the top. The mat should also be pegged to prevent ripping and sliding. If this technique is used, it is important to stabilize the toe of the slope as well.

3) Vegetation mats can be used as building bricks. Slice the mats into rectangular pieces and use them to construct a very steep, living wall. The

bricks should be pegged to each other and to the underlying substrate. This technique may be useful around culverts or sunken walkways.

Summary

At Denali National Park bioengineering techniques have been successful in the past and are sure to increase in application and scope in the future. An abundant supply of building materials, 85 miles of road maintenance problems, and a profusion of abandoned placer mines will give us the opportunity to test new techniques and prefect old ones. The Resource Management and Maintenance Divisions will need to work together towards the development of innovative bioengineering ideas and methods.

CONTAINER PLANTS

Introduction

Containerized plants are propagated from seeds and cuttings collected from specific sites within the park. In the past the propagules have been sent to the Plant Materials Center in Palmer, or the State Forest Nursery, also in Palmer. In the future, the park may wish to consider a small nursery and plant propagation facility of its own. Containerized plants have been used extensively at Denali for the past six years and have proven valuable for revegetation projects that require immediate visual amelioration; projects on harsh sites where conditions limit seedling establishment, but not growth; and unstable sites where erosion is a major concern.

Containerized plants offer several advantages that should be considered during the planning of a restoration or revegetation project. Container plantings can be planted almost any time during the growing season, while seeding techniques should be limited to the spring and fall. Woody shrubs planted as seedlings provide subsurface soil protection and also resist washout, to which seeding is vulnerable. Containerized plants show less transplant shock than salvaged and transplanted plants or plants grown in beds, and they usually offer higher survival rates. Transporting and planting container stock is vastly easier than salvaging and transplanting.

Container stock gives the restorationist more control over diversity, density and spatial patterns during planting. This is a distinct advantage when the goal is to restore a site to pre-disturbance structure and function. Container plants are versatile and experiments in plant ecology often rely on container stock to test new restoration techniques or plant interactions. Container plants have also been effective as bioengineering materials, and show promise for the future.

Container plants also have several disadvantages: they can be expensive to propagate, and if propagation is contracted to an outside organization, the park risks genetic integrity and the introduction of exotic plants. In the past these problems have been substantial, especially the introduction of exotics. Also, container plantings usually cannot provide dense cover over a large area. The number of plants needed, the physical effort, and the inherent slow growth rates of plants in the subarctic make dense cover difficult and expensive to attain. Propagating and planting containerized stock is one of the more expensive and labor intensive techniques. Containerized plants must be adequately maintained while in storage. Watering containerized stock before planting is extremely important. Some plants, if allowed to wilt, may experience a severe set back in their ability to grow. Even if the plants regain turgor, the ability to take in carbon dioxide and convert it to plant tissue may be impaired for weeks. In the subarctic, where the growing season is short, inadequate watering may severely stress containerized plants.

Transportation and maintenance of container plants can also present a challenge, especially in remote areas. The resources required to care for stored containerized plants include a water source and a person to water. Simple as this may sound, imagine 10,000 containerized alders flown into a remote area in the Kantishna hills, awaiting planting and requiring care--the effort would be considerable.

The risk of introducing exotics always accompanies the use of container plants. Even if the plants arrive from the nursery in a clean condition, extreme care should be taken to avoid storing the plants anywhere near exotic species. The headquarters area, which hosts exotic plants and other pests, is especially unfit for plant storage.

Since propagating and planting containerized stock is expensive and labor intensive techniques, other options that meet the same goals should be considered first. Other options may include direct seeding or seed traps.

To use fewer containerized plants, the species used and the timing and spacing of the containerized plants should be planned to facilitate the establishment and growth of other species. Experience has shown that planting non-facilitating flowers and herbs on sites that limit seedling establishment, but not growth, will yield exactly what was planted minus mortality. Alder and soapberry, both nitrogen fixers, are good examples of plants that could be used to facilitate seedling establishment and growth of other species. In these situations, expect barren patches between plantings. Planting facilitating species may alleviate this problem.

One promising technique involves the merging of several tactics: planting facilitating or late successional containerized plants in clumps, and patches of soil between planted clumps could be amended or scarified to create a viable seedbed for seeding or natural regeneration. This technique was used to restore an abandoned gravel pit and parking lot just east of the intersection of the railroad tracks and the park road. (See Appendix A)

Planting Containerized Stock

To plant almost any containerized plant, the following guidelines should be helpful:

1) Excavate a planting hole deep enough to completely cover the roots and allow for a shallow watering moat. Examine the plants carefully before planting. Look for exotic plant species, insects and disease. Some plants may be root-bound. This condition is caused by too many roots in a small container. To remedy this situation it may be necessary to scratch the surface of the root ball, breaking the roots to stimulate lateral root growth. The seedling and roots should be planted straight up and down. Do not contort the roots to make them fit an inadequately sized hole. It is important to cover all of the roots, as moisture can be wicked away through

roots and potting soil exposed to the air. A mattock or hand pick are the preferred tools for planting.

2) Fertilize each plant with a time-release fertilizer, If a nitrogen fixing species is being planted, use a low nitrogen fertilizer. We have used the brand MagAmp successfully (7% N, 10% P and 5%K). High nitrogen fertilizers inhibit the nitrogen-fixing capabilities of actinomycetous. Mix the fertilizer thoroughly with the backfill.

3) Water each plant with one liter of vitamin B-1 solution. This will reduce transplant shock and stimulate root growth.

ALDER PLANTINGS

Introduction

While most inhabitants of the far north curse the alder, the restorationist can appreciate this remarkable shrub. Vigorous growth on harsh sites, the ability to fix nitrogen, easy seed collections and simple propagation all make alder the species of choice for many restoration projects. Alder are versatile; they can be used for streambank and flood plain stabilization, slope stabilization, erosion control, gravel pit revegetation, road obliteration, screening and barriers. Alder can also be used to initiate plant succession on barren sites, although a debate exists on the merit of alder as a pioneer species (Walker and Chapin, 1986). Planting and growing alder is easy, while understanding plant community dynamics is not. Alder plantings on recontoured placer mine tailings on Glen Creek have facilitated ecological succession (Densmore in press). There is no doubt that alder does inhibit the establishment and growth of plants on some sites, but it is a natural occurrence. If species diversity and hastened ecological succession are the objectives, the restorationist is challenged to establish a set of conditions that allow alder to stimulate successional processes rather than interfere.

Planting containerized seedlings is the most efficient way to establish alder for two reasons. First, when alders are established from seed on a disturbed site, they usually grow slowly for three to six years, and then more rapidly to mature height. Second, on some disturbed sites with very poor soils, alders have trouble getting started from seed, but grow well once established. In the past, seedlings have been grown under contract by the Alaska State Forest Nursery in Palmer.

Collecting Seeds

Collect alder cones in late August and early September. The cones are brown when ripe. Place the cones in a warm dry place for several weeks to ensure complete drying. Remove the seeds by placing the cones in a metal container, for example a #10 coffee can, and shaking vigorously. The seeds will separate from the cone and gravitate towards the bottom of the can. Strain off the cones with a kitchen noodle strainer. Package the seeds in properly labeled zip-lock bags and store the seeds in a secure freezer.

Every seed lot should be accompanied by a two gallon bucket of alder root nodules and soil from the collection site. Alders have a mutualistic association with the actinomycete Frankia sp. that allows the fixation of atmospheric nitrogen to a form useable to plants. The alder root nodules and soil surrounding the roots are used to inoculate the alder seedlings in the nursery. Label the inoculant and store it in a cool place. Do not forget this step. Soil inoculant is mighty hard to procure in January in Alaska.

Alder seeds and inoculant should be collected from the many places throughout the park where restoration work is likely to occur in the future, like Eureka and Caribou Creeks in the Kantishna Hills. By having seeds banked for an unpredictable future, the park will be prepared to produce alder seedlings in the winter for summer planting.

Nursery Propagation

Alder seed germination in the greenhouse is approximately 10% after 30 days at 22 degrees C. Cold stratification can increase germination rates to approximately 17%, but is seldom worth the effort. This means to produce one alder seedling, plant ten or more seeds.

Working with the Alaska State Forest Nursery, ecologists and restorationists from Denali have successfully grown large numbers of alder seedlings. The following description should give a basic illustration of the propagation process:

1) Mix a batch of soil to be used as a propagation medium. The medium contains one part peat to one part vermiculite with about one gallon of soil inoculant per cubic yard of mix.

2) Place the soil mix into growing tubes and plant 10 to 20 seeds per tube.

Thin the seedlings to one alder per container approximately six weeks after sowing. The alder take approximately three months to develop into plantable seedlings.

3) Harden off the seedlings by setting them outside of the greenhouse for approximately two weeks before planting. This will allow a time of adjustment between the cozy greenhouse and the harsh world.

4) Seedlings are transported in waxed boxes. Once in the park, the alder should be taken out of the boxes and stored in a place that receives partial sun, such as under a spruce forest canopy. Save the boxes for the State Forest Nursery to use again. Do not store seedlings anywhere near exotic plants. Containerized seedlings need lots of water, and should be monitored daily. If the seedlings need to be moved again, either re-box them for transport in the back of an open truck, or carry them internally un-boxed. Do not subject tender seedlings to wind in the rear of a truck.

Planting Alder

Planting methods and designs differ for various restoration goals, for example, erosion control, or hastening succession towards a future seral community. Planting strategies also differ according to site characteristics.

In general, researchers have found that planting alder moist fertile sites can have an inhibitory effect on successional process, while planting on well drained, nutrient deficient sites tend to have facilitating effect on succession (Cargill and Chapin, 1987). At Denali, alder has demonstrated a facilitating role towards willow, poplar and spruce in experimental plantings on recontoured placer mine tailings on Glen Creek. Thus, alder plantings should be limited to harsher sites where they can facilitate successional processes. Exceptions exist; for example, if the goals calls for a screen or barrier, planting alders on a fertile site will certainly attain this goal, but species diversity and succession potential will be diminished.

As in nature, alder grows best when planted in clumps. Clump sizes can range from 2 to 15 plants, with alders planted approximately 20cm to 30cm apart. For species diversity and aesthetics, clumps of other pioneer species can be planted amongst the alder. Felt-leaf willow, shrubby cinquefoil and fireweed are some possibilities.

Plants can be placed within alder clumps. White spruce seedlings planted inside four year old alder clumps have shown surprising vigor, while spruce planted outside the alder clumps appear stressed and unhealthy. Alder should be less than one meter tall at the time of spruce planting.

For goals such as stream-bank or slope stabilization, alder can be planted in thick bands along the contour. One way to accomplish this is to construct a small terrace along the contour and lay the alder seedlings horizontally on the terrace. Leaving alder stems in the horizontal position, fill in the terrace back to the original slope angle. For all of the ways alder can be used, actual planting is the same. The following directions for planting containerized alder seedlings should be helpful:

1) Excavate a planting hole deep enough to completely cover the roots and allow for a shallow watering moat. The seedling and roots should be planted straight up and down. Do not contort the roots to make them fit an inadequately sized hole. Cover all of the roots as moisture can be lost through roots exposed to the air. A mattock or hand pick are the preferred tools for planting.

2) Fertilize each alder with a time release, low nitrogen fertilizer; mix the fertilizer thoroughly with the backfill. The brand MagAmp has been used successfully (7% N, 10% P and 5%K). High nitrogen fertilizers can inhibit nitrogen-fixation.

3) Water each alder with one liter of vitamin B-1 solution. This will reduce transplant shock and stimulate root growth.

Expected Results

Generally alder seedlings have about a 95% survival rate for the first year, with very little mortality after that. Keep in mind that site characteristics change with changes in vegetation. Alder can modify a site by increasing soil nitrogen and moisture. Organics from leaf litter and root throw incorporated into well-drained soils will enhance the nutrient and water-holding capacity of the soil. Enhanced soil conditions can lead to productive immigration of other pioneer species such as felt-leaf willow and balsam poplar. Alder can also inhibit the establishment and growth of other species by competition for sunlight, and the litter layer can form a barrier to seedling establishment.

WILLOW CUTTINGS

Introduction

Using willow cuttings is a simple and inexpensive method for plant propagation and site revegetation. Cuttings are easily obtained at most locations where human disturbance is common. They can be used for slope or flood plain stabilization, erosion control, screens and barriers, and re-greening. Sprouts from willow can provide cover for most wildlife and browse for moose. Salix alaxensis (felt-leaf willow) is the species recommended for restoration activities. Populus balsamifera (balsam poplar) although not a willow, also sprouts from stem cuttings and can be used in similar ways.

Willows will establish themselves naturally from seed on all disturbed sites suitable for willow growth. In other words, where willows can grow they will revegetate naturally; where they do not establish themselves, planted cuttings usually won't grow well. On placer-mine tailings in Denali, Agriform time release fertilizer tablets have made it possible for cuttings to grow moderately well for six years on sites where willow does not revegetate naturally. However, these plants may die when the fertilizer is exhausted.

Therefore, planting willow cuttings has little value for long-term habitat restoration. Cuttings are best used to quickly stabilize, re-green, or screen sites where willow will can eventually revegetate naturally. For example, willow cuttings can be used to revegetate a site that may be disturbed again in the near future, such as a flood plain or a roadside fill-slope. On those sites they will provide soil protection and sprouting stems even after constant abuse. Other important uses for willow cuttings are described in the *Bioengineering* section.

Many restorationists use chilled dormant cuttings. This method will probably provide the best results, but is seldom practical because it takes planning and a cold-storage facility. Experience at Denali has demonstrated that fresh, promptly planted cuttings will yield satisfactory results. This is easily accomplished due to a great abundance of felt-leaf willow and its large geographic and elevational range in the park.

Collecting Willow Cuttings

1) Take advantage of ecotype adaptations and protect genetic integrity by collecting cuttings near the site to be planted. Cuttings should be about 30cm to 40cm in length and 1cm to 3cm in diameter. Select vigorously growing branches. Some practitioners have found that large diameter cuttings offer increased viability and growth, and recommend cutting sizes up to 10cm (Schiechtl, 1980). The practicality of using large cuttings is limited for most revegetation projects.

2) Each cutting must have at least one leaf node or bud. The node is the place where shoots originate, and without a node the cutting will not grow.

3) Do not take too many cuttings from a single plant, instead, spread the collections impact throughout the willow patch. Also, since willows are dieocious, selecting cuttings from a number of plants may prevent the cloning of a single sex.

4) Place the cuttings in a plastic bucket along with a few inches of water. Be sure to place the lower end of the cutting in the bottom of the bucket so planters will know which end goes up. Fresh cuttings should be planted soon after collecting, preferably the same day. If a delay is unavoidable, cuttings can be stored for approximately a week packed in moist moss, wrapped in plastic, and kept in a cool place.

Planting Willow Cuttings

Felt-leaf willow plantings have been successful on a variety of sites varying from well-drained, nutrient-poor mine spoils to sites rich in organics. As expected, cuttings are more successful on sites that have adequate soil moisture, and the ability to supply and hold nutrients. Soil temperature also has a significant influence on root and shoot development.

Steps taken to enhance soil moisture, soil temperature and soil nutrients will improve the establishment and growth of willow cuttings. For example, a handful of well composted and weed-free dog manure mixed thoroughly with the backfill will increase the soil water-holding capacity, provide nutrients, and increase soil temperatures by decreasing soil density. Snow fences can increase spring and early summer soil moisture on a site, but may shorten the growing season. Four-millimeter polyethylene sheeting has been used to cover cutting plantings. Good results were obtained by providing a warm, moist microclimate for one to two months after planting. In addition, willow establishment and growth will be improved if competition stress is avoided. Willows are sometimes stressed when planted with other water and nutrient loving plants like Calamagrostis canadensis.

The following list of steps for planting willow cuttings should lead their successful establishment and growth:

1) Plant willow cuttings in shallow holes at approximately a 45-degree angle. The planting hole should be deep enough to bury the cutting and allow two or three inches of the cutting to protrude above the soil surface. Leave a shallow watering moat around the cutting.

2) Arrange the plantings in clumps to create a natural looking setting. The

clumps can host 2 to 7 cuttings spaced about 20 to 30cm apart. The clumps can be arranged randomly about 1 to 2m apart. Clumps of other pioneer plants such as Alnus, Shepherdia, Oxytropis, or Hedysarum can be planted between the willow clumps to add diversity and nitrogen to the site.

3) As mentioned above, felt-leaf willow is responsive to nutrient availability, especially nitrogen. On well-drained, nutrient-poor sites, unfertilized cuttings will die or grow so slowly as to be of little value for revegetation. Willow cuttings should be fertilized with a time-release fertilizer such as Osmocote or Agriform tablets. Regular fertilizer will leach into the water table before the root systems can utilize it.

4) Each planted cutting should be watered with a B-1 vitamin solution to promote root growth and increase soil to cutting contact.

5) Protect the site from pedestrians, motorists, and maintenance and construction activities. Herbivory from moose and snowshoe hare may occur, but is seldom a problem.

Chilled Dormant Cuttings

Chilled dormant cuttings can be used for any project, but are most useful for large projects that need many cuttings, or a site where a high survival rate and vigorous growth is essential. As mentioned above, dormant cuttings require cold storage, planning, and a project that is on schedule.

Cuttings can be collected any time willow is dormant. It is best to scout collection sites while identifying leaves persist so that cuttings are taken from the correct species. Collect cuttings as described earlier, pack them in moist moss and wrap them tightly in plastic, before storing the cuttings in a freezer. Cuttings collected in the fall should be viable for planting in the spring.

To receive the added benefits of chilled dormant cuttings on short notice, non-dormant cuttings can be collected and packed as described, then chilled for three to four weeks in a refrigerator set just above freezing. The leaves will drop in the cooler, but new ones will grow when planted. This technique is useful for plantings in late July and August.

Expected Results

Willow establishment and growth varies with site conditions. On flood plains with well-drained nutrient- deficient soils, growth can be extremely slow.

Many plants in the subarctic have high root to shoot ratios, especially when under stress. As a result some revegetation goals, like flood plain stabilization, may be attained even though there is little evidence of growth visible above the soil surface. On improved sites willow can grow quickly. Soil nitrogen--even more than moisture--is probably the best predictor of willow growth (Densmore in press). Stem growth of one meter after one year in the ground is considered exceptional.

SEED TRAPS

<u>Introduction</u>

Seed traps can be used on almost any site, and are especially useful on well-drained and nutrient-poor soils, like those found in abandoned gravel pits or mine tailings (see Appendix A). The basic theme behind the *seed-trap technique* is to alleviate several factors that limit plant establishment and growth by providing a place where seed can find purchase, a warm, windless microclimate favorable for seed germination, and soil conditions with high moisture and nutrient holding abilities.

Seed traps are simple, inexpensive, and have benefits that ensue for years. This technique is best used in concert with other techniques such as alder and willow plantings or the *autumn seed blitz technique* (described elsewhere in this manual). Seed traps should be constructed in early spring or late fall. Follow these instructions for optimal effectiveness:

<u>Instructions</u>

1) Collect seeds to disperse over the disturbed site. Use seeds that are naturally dispersed by the wind. Tall fireweed (<u>Epilobium angustifolium</u>),

for example, has been successful, and seeds of this species can be collected efficiently in large quantities.

Other species should be tested such as dwarf fireweed (Epilobium latifolium), and the wildflowers Arnica frigida, Aster sibericus, Senecio lugens, and Solidago multiradiata. Grass species should also be tested.

Use several species per site to gain diversity and insure against unforeseen, species specific disasters such as insects and disease. In the past, willow and poplar direct seedings have produced poor results. To improve establishment of these species, let them seed themselves by timing the construction of the seed traps to take advantage of naturally dispersed seeds.

2) Dig holes approximately 30cm long, 10cm wide and 15cm deep. Each trap should be backfilled with a mixture of on-site soil and a liter of well-composted, sterile dog manure for a finished depth of 10cm. The traps should be arranged in clumps of 2 to 12 traps, spaced about 30cm apart. The distance between clumps is generally one to two meters. Slope and aspect effects on soil temperature are amplified in the subarctic, so the traps should be positioned to take advantage of the summer sun and solar angle. Do this by orienting the traps lengthwise, east to west.

Fertilizer can be added to the backfill. Use approximately 15 grams of a time-release fertilizer. The addition of fertilizer to compost amended soil will have long lasting benefits, as the increased moisture and nutrient holding capacity of the soil will decrease nutrients lost through leaching.

3) Disperse seed over the site. A wet, and slightly windy day is best for seed dispersal. Ideally, a light breeze will push the seeds across the site and drop them neatly into the traps, where the damp soil and compost in the traps will hold the seed firmly. Naturally dispersing seed from nearby vegetation will also take advantage of the seed traps and add diversity to the site.

Expected Results

Providing a warm, moist and nutrient-rich environment for seed germination and plant growth will allow pioneer species to get established on inhospitable sites. After plants have been established, accumulating leaf liter and the warm protected environment of the trap will favor decomposition and hasten nutrient cycling. Species such as tall fireweed or the grass Calamagrostis canadensis will extend their range from the seed traps, spreading via rhizomes. In this way, seed traps act as centers of nutrient and moisture availability for plants distant to the traps. In addition, biodiversity is added to the site as the traps continue to catch seeds.

THE AUTUMN SEED BLITZ TECHNIQUE

Introduction

During the fall, conditions become suitable to use seeds to revegetate certain areas with minor effort. The *autumn seed blitz technique* is especially useful for impacts such as social trails and other disturbances related to human trampling. It can also be used on larger disturbances such as construction projects, and possibly placer mine tailings. This technique is quick, easy, and doesn't require any special talents except the ability to recognize a ripe seed and a strong back for raking.

Methods

The basic concept behind this tactic involves harvesting a variety of seeds near the disturbed site and sowing them immediately. The following guidelines should be helpful:

Site Assessment

If a quick site assessment reveals bare ground caused by a lack of propagules and microsites, then use this technique. The soil must have the ability to germinate and grow seedlings--look for a large percentage of silt and clay, and some organics. Throughout the summer, construct a written inventory of disturbed sites that could be revegetated using this method.

Timing

On a cool, dry day in early September, with a crew of four to six workers, travel to each site listed on the revegetation inventory. Windows of opportunity for this type of work can be quite small, so the job must be done quickly and efficiently. The actual work does not take much time.

Collecting Seeds

At each site collect seeds from a variety of plants. It is not necessary to know what species are collected, only that the seeds be ripe. During early September most seeds are ready, or past ready and dispersed. Seeds must be dry on the plant. Dry seeds can be coaxed from a seed head or pod, while moist seeds cannot. Species that are disturbance oriented are especially useful, and are found easily along roadsides and streams. Harvest whole seed heads and stalks with scissors or clippers and place them in a large bag. Species can be mixed together in the same bag. One lightly packed grocery sack should cover about 100 square meters.

Seeding the Site

Seed the area to be revegetated by briskly rubbing the seed heads and stalks between your hands and letting the seeds and chaff disperse over the site. Often, the heavy seeds gravitate towards the bottom of the bag. These seeds should be dispersed properly over the site.

Fertilizer

Fertilize the site with a slow release fertilizer. Osmocote 13-13-13 works well, and is easily dispersed with a hand spreader.

Raking

Vigorously rake the seeds and fertilizer into the soil. The importance of this step cannot be over emphasized. Raking holds the seeds on site, and creates conditions that greatly enhance seed germination. On a windy day, it is necessary to rake the site before and after the seeds are sown. Raking before seed dispersal vastly increases the amount of seed that lands and stays on the site. On sites that are well compacted, it may be prudent to break the soil up with a mattock or tractor. A toothed tractor bucket can often be used in leu of rear-mounted ripper tines.

Expected Results

By swamping a site with seeds from a variety of endemic species, we allow site conditions to determine which species will survive. This technique usually provides good cover and high species diversity. The revegetation project on the west side of the Eilson Visitor Center is a successful example of this technique. Typically these sites are vulnerable to human disturbance and must be adequately protected with signs and barriers.

PROJECT PROTECTION TECHNIQUES

Introduction

It takes surprisingly little foot or vehicle traffic to destroy a revegetation site. For this reason, all projects must be protected from further disturbance. This requires that the restorationist find the middle ground between adequate site protection and overly conspicuous and offensive barriers. Project protection is often a frustrating task because it so often fails. Persistence, patience and self-control are essential when visitors trample a restoration project.

Methods

Signs

Signs should be a part of all project protection tactics. Currently the park has three basic signs that are used to restrict foot and vehicular traffic. These signs include:

1) **"AREA CLOSED - REVEGETATION PROJECT"**
2) **"STAY ON TRAIL - REVEGETATION PROJECT"**
3) **"SENSITIVE AREA - PLEASE KEEP OFF"**

When used, signs should be mounted on a standardized sign posts. In the past the revegetation crew has shared posts with the bear technicians. When posting a sign it is usually necessary to dig a hole with a mattock, ensuring that the sign stays in the ground.

Signs can be used without barriers, but this has proven only somewhat effective. Interpretive displays describing the need for revegetation and the fragile nature of the vegetation, are also an option, and have been used at the Eielson Visitor Center and the Polychrome Reststop.

Rope Barriers

Past projects have been barricaded with a single manila rope on two foot rebar posts. This method, along with appropriate signs, will work. Unfortunately, rebar can present a hazard to park visitors, and wildlife can be ensnared in the rope. A low rope barrier, perhaps six inches above the ground and mounted on wood or fiberglass stakes, may be preferred. If wooden stakes are to be used, they should be made of two by two inch lumber. One inch lumber has been used in the past, but it cracks easily when hammered. Drill holes through each stake to hold the rope.

Manila rope is a natural fiber, and is appropriate for the natural environment; however, its fibers will relax and contract with weather conditions, often leaving the rope lying sloppily on the ground. To remedy this, include several feet of shock cord anywhere along the length of rope. This will keep the rope taut by creating constant tension. This works only if the rope is free to move through holes in the stakes.

Rock Barriers

Large rocks can be used to border a restoration project. Rocks protect against vehicular intrusion but do little to dissuade foot traffic. If a project needs long term protection it may be necessary to include large rocks in the landscape design. These rocks can be partially buried to give the site a more natural appearance.

Vegetation Barriers

Vegetation barriers have been very successful, especially at helping to eliminate social trails. Spruce trees over a meter high are particularly useful. Once a tree is planted at the head of a revegetated social trail or road, few visitors will venture past. Spruce, willow and alder have been used to hide sites such as abandoned roads and gravel pits. Hiding a project is often a successful protection technique.

Education

The Interpretation Division can assist the revegetation effort by explaining past and ongoing projects. Campfire programs offer a good opportunity to impart information about projects near the campground. Roving interpreters on shuttle busses could be asked to point out restoration projects along the road corridor. An auditorium program could be dedicated to explaining the restoration effort in the Kantishna Hills.

Design

It is essential that information on people's travel habits is incorporated into the restoration project design. When pedestrians are provided with sensible travel routes, they generally use them without disturbing the revegetation project.

Mulch

Mulch, though not very effective for growing plants in the subarctic, can be used effectively to send the message that a revegetation project is ongoing. Strips of coconut fiber mat strategically placed can direct traffic towards a less destructive route.

Part III

Recommendations

In this section I make recommendations towards improving the planning, implementation and monitoring of restoration activities in Denali National Park. The recommendations are addressed to specific divisions and to individual positions within those divisions.

To: Research and Resource Protection Division--division administrators and the restoration specialist.

Topic: Seed Banks

To prepare for future restoration activities and to preserve the genetic integrity of Denali's plant communities I, recommend collecting and storing seeds from a variety of species and locations throughout the park, especially those locations where restoration activities are likely (Kantishna Hills, Toklat or the Park Hotel area). The effort involved is small if seeds are collected each year. I would particularly recommend collecting seeds included in the *legume/grass mix* (see techniques section) and alder and spruce seeds.

I also suggest that guidelines for seed collecting be instituted. Thus far we have been conservative in our seed collection activities--using seeds collected in near to a restoration project--but standardization is necessary to ensure adequate protection of the gene pool. To properly bank seeds, store each lot (labeled by species, date, and location) in a secure freezer. Improperly labeled seeds or seeds that have been tampered with are worthless.

Topic: Restoration Project Documenting & Monitoring

Project documentation is essential for the continued success of the restoration program. We have learned valuable lessons by carefully scrutinizing past restoration projects and recording our observations. Documentation of the procedures and techniques used for each project should be continued. Fieldnotes taken during the implementation of a projects have proven to be valuable sources of information. In addition, to ascertain if the planned goals and objectives for a project were met, monitoring is essential. Therefore, I recommend standard monitoring guidelines be instituted for past and future restoration projects. Monitoring guidelines can be basic and still remain adequate; simpler monitoring strategies (such as evaluations based on the success or failure of meeting the planned goals) would be best for our program. Photo documentation, annual survival data, and colonization data can also be useful. Designate a "restoration library"--a secure permanent place to keep this type of information, and where future restorationist can find it.

Topic: Useful Literature For Restoration Activities

While researching this paper, I have come across several pieces of literature that I believe would be of special value and interest to resource managers, particularly the restoration specialist. The documents cited below contain information about on-site restoration techniques, general policy guidelines, national directives, and planning and monitoring procedures:

Densmore, R.V. 1985. Denali National Park Road Revegetation Study, 1985 Progress Report. Denali National Park and Preserve, P.O. Box 9, Denali Park, Alaska.

Hanbey, R.D. 1992. On-Site Restoration Methods for Mountainous Areas of the West. Intermountain Research Station, USDA Forest Service. Missoula, Montana.

National Park Service. 1993. Western Regional Directive #WR-094 and 1993 Guidelines for Revegetation in Disturbed Areas. National Park Service, Western Region.

Rochefort, R.M. 1990. Mount Rainier National Park Restoration Handbook. U.S. Department of the Interior, National Park Service, Mount Rainier National Park.

Viereck, L.A., C.T. Dryness, A.R. Batten, and K.J. Wenzlick. 1992. The Alaska Vegetation Classification. Gen. Tech. Rep. PNW-GTR-286. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Topic: Investments In the Restoration Program

Since restoration activities will likely increase within the boundaries of Denali National Park--in the Kantishna Hills for example--and from construction of new facilities and roads. I recommend the following list of tools, equipment, and facilities be acquired or constructed:

* A set of hand held seed sorting screens
* Soil testing apparatus (particle size and nutrient tests)
* Growth chambers
* A small greenhouse and weed-free nursery
* A Kubota 4X4 tractor with a front end loader, rear end grader, a drag, a set of ripper tines, a backhoe, and a 150 foot cable yarder
* A flatbed trailer to haul the tractor and salvaged plants
* Sprayers and herbicide
* A locking seed refrigerator and freezer
* A mobile sprinkler and drip irrigation system
* A truck that we could use each year
* A shed and storage area where we could consolidate the present 4 or 5 storage areas
* A subscription to Arctic and Alpine Research
* A subscription to Restoration Ecology
* A set of tools for a four to six person crew:
    * 4 rakes
    * 4 shovels (pointed)
    * 2 shovels (flat)

* 2 spades
* 2 shovels (tree planter's)
* 4 maddox
* 2 picks (big)
* 2 loppers
* 2 hand pruners

To: The Research and Resource Protection Division--division administrators and the park's restoration specialist. Also to the Maintenance Division--the chief of maintenance, the roads and trails foreman and the park engineer.

Topic: Plant Salvage

Plant and soil salvage should become a standard step in planning processes and on-site practice during construction and maintenance activities. Providing plant storage facilities may be one way to encourage routine plant salvage. A prototype salvaged plant storage facility was installed at the Wonder Lake campground in the summer of 1994. The storage facility was constructed with four railroad ties formed into a six by eight foot box, and filled with four inches of sand. Salvaged plant materials can easily be planted in the box, then, when needed, removed and transplanted. The plant materials for this test were salvaged from nearby drainage ditches along the park road. Renegade tundra clumps (sliding pieces of roadside vegetation) are common, and park employees should salvage them when observed since road maintenance activities may destroy these plants if they are not salvaged promptly. The clumps are usually small-- often single plants. If the Wonder Lake salvaged plant storage facility proves successful, other small facilities could be constructed in places where plants are needed most, such as the Eilson Visitor Center or the Savage Campground. Keeping genetic integrity in mind, salvage protocols--similar to those developed for seed collecting--must be developed to restrict the use of salvaged plants.

Topic: Plant and Soil Salvage Planning

When planning construction or maintenance projects that may destroy plant communities and salvageable plants, I recommend involving the park's restoration specialist from the beginning of the planning process. In the past, valuable opportunities and plant materials have been lost because resource managers were not informed of planned or ongoing construction activities. Examples of such lost opportunities occurred during the construction of the new storage shed near the headquarters auto shop, and the new airplane parking lot on the McKinley Airstrip.

Topic: Expanding the Use of Bioengineering Techniques

Bioengineering techniques show potential for use beyond revegetation and moderate soil stabilization (see Part II). I recommend the use of *bioengineering* *techniques* be expanded to ameliorate some standard engineering problems such as mass wasting, severe erosion and poor drainage. The park engineer, the chief of Maintenance, the Roads & Trails foreman, and members of the Roads and Trails crew, for example, could become familiar with bioengineering techniques presented in this manual and routinely apply them.

Topic: The Role of the Maintenance Division in Restoration Activities

In general, I recommend the Maintenance Division become more involved in restoration activities. In the past, cooperation between the Maintenance Division and the Research and Resource and Protection Division has been good, especially on the laborer level. Maintenance workers have frequently assisted in restoration projects, contributing innovative ideas, and exceptional skill and enthusiasm. Long-time maintenance employees have furnished historical information regarding roadside plant community dynamics and invasive exotic weeds. I would encourage even more cooperation in the future.

Crew leaders and laborers within the Maintenance Division should expect the park restoration specialist to provide training in restoration techniques, on-site consulting, and supplying plant materials such as seeds for the legume/grass mix or containerized plants.

CONCLUSION

Over the years, restoration techniques have evolved greatly and currently are producing good results at Denali National Park. Many successful techniques have been developed and applied in recent years. For example, since 1991, brush bars have been stabilizing flood plains on Glen Creek and legume/grass seedings have been beautifying and stabilizing an area along mile one of the park road.

However, evidence of past mistakes also lingers. Remnant stands of non-native brome grass--planted many years ago for revegetation purposes--visible throughout the park serve to remind us how our understanding of appropriate restoration techniques has changed through the years. Although revegetation goals in the past--stabilizing soils and providing aesthetics--are similar to restoration goals today, now we work with additional directives to protect the genetic integrity of native plant communities and to restore ecosystem structure and function.

New directives demand new approaches and techniques, and we find ourselves learning as we go. Recent unsuccessful projects--such as the Calmagrostis/fireweed seedings near the front entrance--usually failed to achieve these goals due to poor planning, failure to consider site characteristics and a limited knowledge of native plant ecology and physiology. These weaknesses in the restoration program are the very topics this manual is designed to address. Hopefully, this manual will help restorationists meet future goals by providing an introduction to the region's ecology, guidelines for decision making, step-by-step directions for on-site restoration techniques and general and specific recommendations for improving the restoration program as a whole.

With the lessons learned through solid research and trial and error behind us, restoration at Denali National Park continues to test our abilities to revegetate disturbed sites under the combined burdens of high environmental stress and severe human disturbance. Future restorationists will be challenged to pursue issues such as the facilitating affect of alder on spruce, or refine techniques like the use of bioengineering structures on scree slopes. The restoration program at Denali can look forward to continued success by building upon lessons learned in the past and competently answering questions that will arise in the future.

APPENDIX A

A CASE STUDY: THE 1991 PARK ROAD RENOVATION REVEGETATION PROJECT

INTRODUCTION

This case study of the Federal Highways Road Renovation and Revegetation Project provides an excellent opportunity to evaluate Denali National Park's approaches to vegetation restoration. Managers can apply its findings to future projects through out Denali National Park and the subarctic. The reader is encouraged to walk the areas and projects discussed in this case study to experience them first hand.

In 1985 the Federal Highway Administration and the National Park Service initiated a study to investigate roadside revegetation approaches and techniques (Densmore, 1985). The findings were used to plan and implement revegetation activities for the 1989 and 1990 Federal Highways Road Renovation Project. In 1990 and 1991 the revegetation part of the project was performed. The Park Service planned the revegetation project in accord with current policy. This policy emphasizes minimum interference with plant communities and ecosystem processes, and strives to protect the genetic integrity of the park's natural vegetation by using site specific native plant materials. The park road was renovated from its intersection with Alaska Highway 3 to the Savage River Bridge at mile 14. The project removed some roadway and structures; it also destroyed roadside vegetation on both sides of the road from the highway intersection to mile 1.2 on the park road. The up-grade did relatively little damage past that point. The aim of this study is to evaluate the success of the techniques used on the road up-grade project and to provide recommendations for future revegetation projects.

The primary goal of the roadside revegetation project was to establish site-specific native vegetation as fast as possible to provide visual amelioration, erosion protection and to reduce the spread of exotic vegetation. In 1994, after four growing seasons, Dr. Densmore and I evaluated the effectiveness of the six techniques used to revegetate the area:

1) taiga mat salvage and transplant
2) fireweed and grass seeding under a coconut fiber mat
3) containerized nursery grown plantings
4) legume/grass seeding
5) nursery bed grown (non-containerized) wildflowers
6) spruce tree salvage and transplant

I also cover alder and willow plantings--and a host of experimental techniques--under the heading, Railroad Crossing Project.

TAIGA MAT SALVAGE AND TRANSPLANT

Goal

The goals of most mat salvage and transplant work were aesthetics and exotic plant control. Aesthetics in this case meant an attempt to visually match the disturbed site to surrounding undisturbed vegetation. Most of the revegetation work around the VAC was done by a private company under contract, elsewhere, it was performed by Park Service personnel.

Technique Description

Vegetation mats comprised mostly of dwarf birch, blueberry and Labrador tea were salvaged by cutting them into workable pieces with a pulaski. The pieces were scooped with a tractor and transplanted immediately, or placed in a truck and stored in the headquarters area. If stored, the mats were periodically watered.

The mats were transplanted in shallow depressions of approximately the same size and shape as the mats. The soil beneath the mats was scarified by hand and fertilized with 14-14-14 osmocote at a rate of about 50g per square meter. If spruce trees were part of the mat's vegetation, the trees were supported by guy wires with duck bill anchors.

Location

The island of vegetation between the park road and the Denali National Park entrance sign (known as Carwisle Isle), and the vegetation on the south side of the road on either side of the VAC cross-walk host salvaged and transplanted taiga mats. Many areas around the VAC were also revegetated with salvaged taiga mats.

Technique Evaluation

In most instances the transplanted mats met the stated goals, at least initially. The mat transplants provided immediate, visually pleasing cover over the areas applied, blending well with surrounding undisturbed vegetation. However, soon after being transplanted, large revegetated areas around the VAC displayed signs of severe stress. Early in the growing season of 1991, many of the mats died. The taiga mats' original species were naturally and quickly replaced that same growing season by disturbance oriented plants sprouting from wind blown or buried seed. Fireweed and several species of grass now dominate these sites. Approximately 40% of the spruce and aspen trees included in the transplanted mats also died. Nonetheless, the shift in species composition on these sites does not detract from visual quality.

The primary reason for a species composition shift and high mortality among trees is probably damage to roots caused by careless handling.

Many social trails developed among the mat transplants near the VAC. Visitors often disregarded posted signs and rope barriers because the *shortest routes* from the park road to the VAC pass through the revegetated areas. Many social trails are a result of shortcomings in planning and design.

The success of taiga mats on Carwisle Isle, shows that vegetation mats can be salvaged and transplanted without tree mortality and the associated shift in species composition. In this instance, large vegetation mats and spruce trees were moved with minimal stress to the vegetation and no mortality. Healthy transplants result from carefully retaining and moving as much of the roots and active layer as possible.

Recommendations

Although mat transplants were mostly successful, the density of spruce within the mats may be less than desired. If a spruce forest is desired, spruce densities could be increased by planting containerized seedlings in the mineral soil between transplanted mats. Expect slow growth due to low soil temperatures. Planting nursery grown spruce may be worth the effort as spruce need mineral soil to establish seedlings, have difficulty establishing naturally on vegetation mats.

Social trails can be effectively hidden and foot traffic dissuaded by planting a meter high spruce tree at the head of developing trails. Containerized alder seedlings may also be effective if used to create a screen or provide a barrier to direct foot traffic. Consider developing heavily used social trails into proper walkways.

SPRUCE: SALVAGED, POTTED AND TRANSPLANTED

Goal

Potted spruce trees were used to provide aesthetics by introducing vegetation that blends into the surrounding forests.

Technique Description

Spruce were salvaged in 1988 by digging up trees less than one meter high and transplanting the trees into four-gallon pots. The spruce were stored and maintained for approximately two years, until they were outplanted.

The spruce were planted in well-drained sandy gravel and fertilized with 25 to 30 grams of osmocote 14-14-14, and watered with Peter's solution.

Location

Examples of salvaged, potted, transplanted spruce trees can be seen on the old Riley Creek Information Center road--now known as Pope's Forest--which lies on the south side of the park road opposite the sewage lagoon road. Potted spruce were also planted on the old utility corridor opposite the Jonesville Cut-Off Trail, and on the north side of the road at the hotel/depot crosswalk.

Technique Evaluation

Spruce plantings were partially successful in meeting planned goals. Nearly 100% of the outplanted spruce survived four growing seasons, but growth of these trees is very slow, possibly due to an imbalance in root to shoot ratios. Many pioneer plants such as fireweed and grass took advantage of the enhanced soil conditions that accompanied each spruce root ball. Fireweed sprouting from this soil often grew taller than the spruce.

Outplanting meter high spruce into compacted sandy gravel proved to be very labor intensive, also, the spruce were arranged in a regular pattern over the site, producing a somewhat unnatural looking landscape. Bare ground between the planted spruce was very conspicuous for the first three growing seasons. Native and exotic weedy species are slowly filling in the bare areas. Exotics such as dandelion also infest these soils. The spruce were probably contaminated by dandelion seeds while in storage in the headquarters area.

Although the major goal of this project was visual amelioration and road obliteration, an unstated goal of every restoration or revegetation project is an attempt to restore plant community ecological functions, such as nutrient cycling. These spruce plantings did poorly in this regard as the plant community is slow to provide cover and has a low species diversity with few plants species to ameliorate soil conditions, like legumes.

Recommendations

An alternative strategy to planting meter-high spruce might be to establish a diversity of pioneer species such as Hedysarum, Oxytropis, alder, willow, poplar, and aspen, then plant containerized spruce seedlings in irregular but dense patches throughout the site. The faster growing pioneer species will provide nitrogen capital, facilitating plant growth for many years. The pioneer species will also provide needed shade for spruce in the summer and in the winter enhance snow accumulation for wind and thermal protection.

Epilobium/Calamagrostis Seedings Under A Coconut Fiber Mulch

Goals

The primary goals of this technique were aesthetics, erosion control and inhibition of exotics. Both Epilobium and Calamagrostis can reproduce through rhizomes, which should produce a thick cover of flowers and grass.

Technique Description

First, grass seed was hand spread over an area the size of a coconut fiber mat. Fireweed seed was then dispersed over the same area by either letting the seed float to the ground or, on windy days, by "painting" the area with handfuls of seed as the mat was being rolled out. The rate of seeding for Calamagrostis was approximately 3 grams per square meter. Fireweed was seeded thickly in random patches covering approximately 60% of the matted area. Osmocote 14-14-14 fertilizer was applied at a rate of 50 grams per square meter. The areas were seeded, matted and pegged down in late May of 1991. The mats were removed after the fireweed had germinated in early July of that growing season.

Location

The fireweed/grass and coconut mat mulch seeding technique was used extensively along both sides of the park road from the highway intersection to mile 1.2 and along the sides of the VAC entrance road. Since these plantings were a complete failure they were over-seeded later with a legume/grass mix, and thus, cannot be examined today.

Technique Evaluation

As mentioned above, this technique failed. Since the soil type was a well-drained, nutrient-poor sandy gravel, the reason for failure seems simple: The roadside substrate not have the moisture and nutrient holding capacity needed to support the seeded species. The fireweed germinated well under the coconut fiber mat, but did not survive as the surface layer of soil dried out. The Calamagrostis did not germinate well, and the small amount of grass that did germinate also succumbed to inadequate moisture.

This technique was used successfully, however, on the Wonder Lake Camp Ground Project. The soils there are much higher in organics, with a high moisture and nutrient-holding capacity.

Recommendations

The fireweed/Calamagrostis mix should only be used on soils high in sub-sand sized soil particles and organics that can provide adequate soil moisture and nutrients. If roadside cover is desired on a well drained substrate, the legume grass mix containing Hedysarum, Oxytropis, and Agropyron is much more suitable.

CONTAINERIZED NURSERY GROWN PLANTINGS

Goal

Containerized flowers, shrubs, and grasses were planted for aesthetics, erosion control, and to restore ecosystem function through increased species diversity.

Technique Description

Containerized plants were propagated from seeds and cuttings collected near the disturbed area. The species chosen for propagation were selected according to the following criteria: (1) relatively high density, cover, and/or visual appeal on near by natural or human caused disturbances, particularly those having harsh site conditions, or (2) evidence that the density of these species on disturbed sites has been limited by propagule presence or seedling establishment and (3) ease of field identification and seed collection (Densmore et al. 1988). The plants were grown at the State Plant Materials Center, Palmer Alaska.

Containerized plants were used in a variety or locations to meet a number of objectives, but the basic technique for planting all the containerized stock was the same. Each plant was put into the ground in densities and groupings that mimic natural populations; for example, asters were planted in clumps of two to five flowers, while northern goldenrod was planted singularly. Each plant received approximately 10 grams of 14-14-14 osmocote mixed with the backfill and was watered with one liter of Peter's solution. Each plant was fertilized a second time in September, 1993.

Location

An example of Potentilla fruticosa and Artemisia tilesii used for slope stabilization can be viewed in back of the Denali Park entrance sign and on the steep slope on the backside of the entrance sign parking lot. The steep slope between the entrance sign parking lot and the entrance sign was also stabilized with Potentilla. These species, along with the grass Elymus innovatus, were used on the three cutbanks on the south side of the park road between the Riley Creek

Campground entrance and the VAC crosswalk.

Wildflowers planted for aesthetics can be viewed on the south side of the road between the Riley Creek Camp Ground entrance and the VAC crosswalk. More flowers were planted on the flat areas on the north side of the road on either side of the VAC crosswalk. The flat area between the lagoon road and the Jonesville cut-off trail was seeded with the legume/grass mix first, then planted with mixed wildflowers and Artemisia. The wildflower species planted in these locations include: Arnica frigida, Aster sibericus, Senecio lugens, Solidago multirada, and a small amount of Myosotis alpestris.

Species diversity was added to Pope's Forest by planting Mertensia paniculata and Solidago multiradiata around the margins of the spruce plantings. Containerized grass plugs (Elymus inovatus and Calamagrostis purpurascens) were planted among the spruce trees. A mixture of wildflowers and grass was planted on the site of the old Riley Creek Information Center, located across from the current Riley Creek Campground bus stop. In addition, mixed wildflowers and grass seedlings were planted along the dump station spur road.

Mixed wildflowers were also planted around all the pull-outs between headquarters and mile 13 of the park road.

Technique Evaluation

Containerized plantings used for erosion control were very effective and visually pleasing. Survival rates were high, approximately 95%, although in several places the grade was too steep for the soil type used, and severe gully erosion developed. These situations were often intensified by excessive road run-off.

All of the planted containerized wildflowers along the park road had survival rates of approximately 95%. The greatest source of mortality was off-road vehicles and snow plows. The growth and visual merit of the wildflowers was excellent; however, the actual cover gained from the plantings is very low, less than 15%. The flowers failed to range beyond their planting holes even after four growing seasons. Weedy species, both native and exotic, are slowly invading the bare soil between the plantings.

The combination of techniques used on the flat area on the north side of the road between the sewage lagoon road and the Jonesville Cutoff trail proved to be very successful. Here grass and legumes were seeded first, and then flowers. The result was an immediate pleasing floral display and an increase in cover over time.

Grass and flower plantings in Pope's forest added needed diversity, but, like the roadside flowers, also failed to extend beyond their planting holes.

Recommendations

The most serious problem with using containerized plantings is the lack of cover provided on harsh sites. This situation can probably be corrected by employing a combination of techniques like those used between the lagoon road and the Jonesville cutoff. However, if this combination of techniques is used, the flowers will soon be covered by legumes and grass.

In 1994, small patches of the legume/grass mix were sown between the roadside flower plantings. The patches were irregularly shaped and approximately .5 square meters to 1.5 square meters in size. The effects of these seedings should be monitored, especially for any competition effects with the flower plantings.

In summary, for the cover gained, the cost and effort of planting containerized wildflowers for visual amelioration is probably not worth undertaking. Planting a few wildflowers among a legume/grass seeding is probably the most efficient technique for immediate visual amelioration and long term cover. For slope stabilization, planting containerized flowers, shrubs and grasses is practical. Containerized plants are especially useful on slopes too steep to hold seed.

LEGUME/GRASS SEEDING

Goals

The primary goals of the legume/grass seedings were erosion control, visual amelioration, restricting the spread of exotic species, and restoring ecosystem functions by enhancing soil nutrients.

Technique Description

The legume/grass seed mix contained the legumes Hedysarum alpinum and Oxytropis campestris and the grass Agropyron macrourum. A small amount of annual rye was also added to the mix to provide quick cover. Oxytropis was applied at a rate of 50 seeds per square meter, Hedysarum at 50 seeds per square meter, Agropyron at 1.5g per square meter (approximately 375 seeds) and the annual rye at .5g per square meter (approximately 175 seeds). Annual rye was seeded at 1g per square meter on steep slopes, such as around culverts. The seedings were fertilized with slow-release osmocote 14-14-14.

The seed was broadcast by hand, so the rates stated above are approximations at best. Most areas were seeded twice to ensure adequate cover, once in the spring, and once in the fall. After seeding and fertilizing, the areas were vigorously raked to a depth of approximately 1cm to 3cm. Some areas were matted with a coconut fiber erosion protection blanket.

Location

The legume/grass mix was used on many roadside areas between park road/Highway 3 and the base of Government Hill. Thick patches of the legume/grass plant community are conspicuous and easily viewed. Some locations of note include the north side of the park road between a point approximately 10 meters west of the front entrance sign and the sewage lagoon road. This section was seeded and matted using coconut fiber mats. The south side of the road was also seeded and matted from the stop sign west for approximately 100 yards. These areas were matted from the shoulder break downslope one mat width (8 feet). These areas were seeded and matted in early May of 1991, and the mats were lifted in early July of 1991, after of germination was evident.

The non-matted, sparsely vegetated section from the front entrance sign and 10m to the west demonstrates the value of the erosion blankets. After four growing seasons this section is still sparse in vegetation and has developed erosion problems, probably due to seeds washing out. In this situation the slope of the road directed water onto the seedings and amplified the erosion problem.

The steep, vegetated slope on the north side of the park road between the

VAC entrance and west to the railroad crossing is an excellent example of the slope stabilizing capabilities of the legume/grass mix. Mats were not used on this section, but seed washout was not a problem because the slope of the road directed run-off away from these seedings.

Erosion problems on the south side of the park road from the base of Government Hill and several hundred yards up the hill were seeded, fertilized and raked in September of 1994. The legume/grass mix was also used in June of 1994 to fill in the bare spots between flower plantings along the park road.

Technique Evaluation

The legume/grass seedings can be considered an outstanding success. The seed mix was slow to establish, but after four growing seasons the resulting vegetation met all of the stated goals, and in most instances surpassed expectations.

In 1991, the first growing season, the seed mix provided almost no cover. Annual rye was the only plant identifiable. In 1992, the cover was sparse. The legumes were small--less than 5cm--and weak in appearance, and the Agropyron attained a height of about 20cm. In 1993 the vegetation finally established with vigor and provided thick cover. The agropyron reached maturity and seeded. The legumes flowered weakly and produce some seed. In 1994 the legumes and grass cover was 100% on most sites. The legumes and the grass flowered and produced a profusion of seed.

I examined these areas in 1994, and found no exotic invading plants in the legume/grass plant community, but saw dandelions were slowly invading the nearby wildflower plantings.

Root inspection of the legumes revealed they were heavily nodulated with Rhizobium bacteria. The legume/grass plant community has a low stature that does not obstruct views, and plants can be mowed in the fall without determent. The plant community will provide an excellent seed source for future restoration projects.

The long time it takes to establish adequate cover can be a disadvantage. Erosion problems still exist on steep slopes where seeds are washed out before seedlings could establish. Annual rye seeded densely along with the legume/grass mix, interfered with the establishment of the legume/grass plant community. This may be due to cool soil temperatures underneath a persistent mat of dead and slowly decaying annual rye stalks.

Recommendations

The most serious problem with the legume/grass mix has been a lack of establishment due to seed wash out on steep slopes. Learn to identify sites that may have a high risk to erosion and seed wash out, then protect these areas. Some indicators used to predict erosion problems include: steep slopes, coarse textured soils, and low soil percolation rates. The principal cause of erosion along the park road is road run-off sloped towards vulnerable unvegetated areas. This problem can be remedied in several ways:

1) Engineer gradual slopes.

2) Direct run off away from high risk slopes.

3) Seed, then mat the high risk areas with erosion blankets.

4) Plant annual rye for quick stabilization. The mulch layer resulting from annual rye seedings could be removed by prescribed fire.

5) Incorporate containerized plantings or bioengineering techniques to stabilize the slope.

6) Terrace slopes vulnerable to erosion. Terracing need not be an elaborate process. Simply driving a large rubber tired tractor along the contour of the slope may do the job. The tire tracks create seed and silt traps and enhance the microclimate for seed germination and seedling survival. This works especially well in wet weather as the tire tracks created in moist soil are significantly deeper.

NURSERY BED GROWN (NON-CONTAINERIZED) WILDFLOWERS

Goal

The primary goal for planting large clumps of wildflowers was visual amelioration, particularly near high visitor use areas.

Technique Description

In 1989 wildflower nursery beds were constructed in the area of the permanent-employee housing's leachfield. Wildflower seeds were collected in the park, propagated at the State Plant Materials Center in Palmer, then transplanted to the park's nursery beds. The main species planted in the nursery beds include: Arnica frigida, Aster sibericus, Senecio lugens, Solidago multirada, and a small amount of Myosotis sylvatica. The soil used in the nursery beds was a potting mix high in sand and peat.

The wildflowers were maintained in the nursery beds until the summer of 1991, when they were cut from the beds using a sharp spade, transported to the revegetation site, and planted. Flowers were typically outplanted onto very harsh sites with nutrient-poor, well-drained soils. The flowers were planted in plugs that had two or more individuals ranging in size from 15 by 15cm pieces to 30 by

30cm pieces. The flowers were planted by excavating a hole big enough to hold the plug and allow for a watering moat. Each plug received approximately 25g of osmocote 14-14-14 fertilizer and was watered with a liter of Peter's solution.

Location

Nursery-bed-grown wildflower plantings can be viewed near the front entrance sign at the intersection of the park road and highway 3. The flowers were planted along the top of the slope along the parking lot, on either side of the walkway leading to the sign, and in the area between the sign viewing zone and the park road. They are also present on the north side of the road on either side of the crosswalk between the hotel and the train depot.

Technique Evaluation

Initial outplantings of the nursery grown non-containerized wildflowers yielded superior results for immediate visual amelioration, and so met the stated goals. However, the entire process--from construction and maintenance of the nursery beds to out-planting--proved very labor intensive for the amount of vegetative cover attained. In addition, the plantings experienced severe transplanting shock that resulted in wilted plants. The flowers regained turgor in approximately one week. The thick and lush vegetation produced when native species are planted in potting soils has also caused some problems--for example, a higher than normal insect population, (mostly aphids) and a higher incidence of fungi and disease.

Several problems have also arisen with this revegetation technique since the time of planting that should be considered before using this technique again. The introduction of the wildflowers and the accompanying large pieces of friable soil into regions of harsher soils has invited a population of weedy species. Native and exotic invaders occupy approximately 50% of the total plant cover. Exotic species in these plantings have been eradicated on a regular basis, and currently do not comprise a significant portion of the plant cover. Approximately 10 hours of maintenance are required each growing season to keep these plantings free of exotics.

The visual attractiveness of these plantings has degraded over time. The flower plugs are extremely sensitive to trampling, and do not extend beyond the fertile soil they were planted with; as a result, many bare spots exist between plantings. Invasive weedy species, like the grasses Hordeum and Agrostis, are aesthetically inappropriate in showcase settings such as the front entrance sign area.

Recommendations

As mentioned above, the effort this technique requires is probably not worth the vegetative cover gained. For showcase areas such as around the front entrance sign, using a variety of techniques and patience may be the best tactic. Employing a healthy dose of hindsight, the following is a sample plan for the front-entrance sign area, or any showcase revegetation project on a harsh site:

1) Rip compacted soils with a tractor. Rough and uneven surfaces provide microsites for seed germination and seedling survival and dissuades pedestrian traffic.

2) Sow Hedysarum and Oxytropis seeds at the recommended rates. These legumes will eventually provide the majority of the vegetation cover and add vital nutrients to the soil.

3) Plant the seeded area with nursery-grown, containerized mixed wildflowers at a rate of approximately three flowers per square meter. For the best results plant the following wildflower species: Arnica frigida, Aster sibericus, Senecio lugens, Solidago multirada, and Potentilla fruticosa.

4) Excavate seed traps in clumps of two to seven traps at densities of three traps per square meter. Seed the traps with Epilobium angustifolium.

5) Protect the project from vehicles straying off the road and snowplows by using boulders (marked with poles in the winter). Neatly sign and barricade the project to direct foot traffic. Low (20cm high) unobtrusive rope fences will work.

6) Allow at least three growing seasons to obtain a high density, biologically diverse, self-sustaining cover that is visually pleasing and resistant to exotic plant invasion, pedestrian traffic and snowplows.

THE RAILROAD CROSSING PROJECT

Introduction

The Railroad Crossing Revegetation project demonstrates the value of innovative techniques and trial-and error to successfully restore native plant communities on a harsh site. Here, I had opportunities to test new ideas and learn about growing plants in nutrient poor, and compacted soils. The project is located just east of the railroad/park road intersection mile 1.2. The project has two sections, one west and east of the Airstrip Road. The total area covers approximately one acre.

Disturbance History

The site was first and abandoned gravel pit, then later used as a heavy equipment parking lot during the construction of the VAC and the Park Road Renovation Project in 1989-1990. At the beginning of the revegetation work the soil was found to be an extremely compacted sandy gravel with very little silt, clay or organic matter. The factors limiting plant establishment and growth included low soil moisture and nutrient holding capacity and a lack of microsites for seed purchase and germination.

Goals

The primary goal of this project was visual amelioration of a highly visible site and the restoration of ecosystem structure and function. This goal was reached through testing a variety of techniques over several years. The methods applied include: Willow plantings, alder plantings, seed traps, direct seeding, fireweed rhizome plantings, soil amendment tests, white spruce transplants and aspen transplants. The following evaluation follows a chronological order from 1990 to 1994, which describes techniques and results.

Revegetation Activities, 1991

Willow Plantings

In late May of 1991, 300 willow cuttings (Salix alaxensis) were planted over the site in clumps ranging from two to seven cuttings, with approximately .3m between cuttings. Each clump ranged from .3m to 1m in diameter. Each cutting was fertilized with approximately 25g of Osmocote 14-14-14, and watered with one liter of Peter's solution.

Alder Plantings

During early June of 1991, 800 containerized alder (Alnus crispa) seedlings were planted in clumps ranging from two to seven plants about .3m apart, with the clumps ranging in size from .3m to 1m in diameter. The alders were fertilized with 30 grams of Mag Amp fertilizer 7-40-6. Each alder was also watered with one liter of Peter's fertilizer solution.

The spacing between clumps of willow and alder was approximately 1m to 2m, which left a significant portion of the project unplanted.

The area was barricaded with a low rope and rebar fence (25cm high), and signs were posted. Throughout the summer of 1991 the project on the west side of the airstrip road suffered alder and willow mortality as several visitors ignored the ropes and signs and parked RV's in the project. Alaska Railroad employees also caused significant damage, as part of the project is located on the railroad right-of-way.

Revegetation Activities, 1992

Site Evaluation

A site assessment in early June of 1992, showed the revegetation site to be in fair condition. Of the plantings that survived vehicular mortality, 100% of the alders and approximately 50% percent of the willow survived the winter. The alder was growing with expected vigor, but the willow was growing slowly. Much of the area was still bare, as the soil between plants and between clumps supported no vegetation.

Seed Traps

Construction

On June 13, 1992, approximately 700 seed traps were dug between clumps of alder and willow to catch naturally dispersing willow seeds. Each trap was a hole about 30cm long and 20cm deep. The traps were arranged in clumps ranging from 2 to 12 holes and partially backfilled with a mixture of two-thirds sand and gravel, and one-third composted dog manure. Approximately 15 grams of slow release Osmocote 13-13-13 was also added. The finished traps were about 15cm deep. The purpose of the seed traps was threefold: to provide a microsite where a wind blown seed could find purchase, to increase the moisture and nutrient holding capacity of the soil, and to add nutrients through fertilization.

Results

The immediate results were excellent. Even as the seed traps were being excavated, dispersing willow seeds blown across the gravel fell neatly into the traps. The compost held the willow seed with great tenacity, and rains later in the day added moisture. Germination of the willow seeds took about a week. Approximately 60% of the seed traps supported willows seedlings.

The traps were monitored closely for about three weeks. Observations showed that the number of willow seedlings present in the traps decreased daily.

Closer observations revealed tiny grasshoppers consuming the seedlings. No willow seedlings survived. Several weeks later both the willow and the grasshoppers were gone, and in their place were lambsquarters seedlings, a species exotic to the park. One hundred percent of the seed traps held lambsquarters.

Apparently, the composted dog manure was abundantly infested with lambsquarters seeds, and when the seeds were exposed to light, they germinated. Purging the site of the exotic proved to be a simple task. The lambsquarters was allowed to attain a height of approximately 15cm, thus ensuring adequate time for all seeds that could germinate to do so. Then, each trap was carefully weeded by placing a finger on each side of the plant and slipping it from the loose soil. Disturbance was kept to a minimum to decrease the chance that more lambsquarters seeds would be exposed to sunlight and germinate. This technique worked, and the site is currently free of lambsquarters--though viable seed probably still exists, buried in each seed trap.

Fireweed Seeding

On June 15, 1992, tall fireweed (Epilobium angustifolium) seeds collected in the fall of 1991 were dispersed on the site. On a drizzly day with a light wind, three grocery sacks of seeds were scattered. Like the naturally dispersing willow, the seeds blew across the gravel and dropped into the traps. One hundred percent of the seed traps held seed.

Late in the growing season of 1992, small fireweed seedlings were observed in the seed traps. Approximately 85% of the traps supported fireweed.

Fireweed Rhizome Plantings

On June 9, 1992, rhizomes from tall fireweed were planted in two small test plots. Of 18 rhizomes planted, only three gave rise to leaves only to die shortly after. No fireweed has been observed in the test patches since that time. A lack of soil moisture and nutrients probably accounts for this test's failure.

Soil Amendment Patches

On July 2, 1992, 40 patches of composted dog manure were scattered throughout the alder and willow clumps and seed trap clumps. The patches varied in size from .5m to 1.5m in diameter. Approximately two centimeters of compost was raked into approximately two centimeters of sand and gravel. Lambsquarters germinated in the patches, but appeared slow growing and unhealthy relative to the lambsquarters that had grown in the seed traps. The lambsquarters in the patch tests eventually died, probably from a lack of moisture.

This test proved to be of great value, lending understanding to the difference in moisture-holding abilities between the seed traps and soil-amended compost patches raked into the surface gravel. In this case, lambsquarters was used as an indicator of soil moisture.

Spruce and Aspen Transplants

During early July, eight white spruce and six small clumps of aspen were salvaged and transplanted onto the project. Most of the spruce died, and the aspen was very unproductive. Invading pioneer species and buried seed took advantage of the transplanted soil and successfully invaded these sites. The spruce probably died due to three reasons: (1) transplanting during terminal bud elongation, and resultant excessive shock (2) transplanting large trees without the aid of machines, causing the loss of the rhizosphere and (3) a lack of on-site soil moisture and nutrients. The aspen, though unproductive, were surviving.

Revegetation Activities, 1993

Site Evaluation

A site assessment revealed the willows and alder plantings again survived the winter and grew favorably during the 1993 summer. A few small spruce persisted on the site, and the aspen remained alive but did not grow much.

The fireweed that had sprouted late in the growing season of 1992 survived the winter and grew vigorously throughout the 1993 growing season, producing mature, flowering plants in August. The warm, moist, and nutrient rich environment of the seed traps seemed to greatly enhanced fireweed growth. In contrast, fireweed seeded on a similar substrate, but under coconut fiber matting and fertilized with 13-13-13 osmocote, germinated but did not survive beyond the cotyledon stage.

The seed traps also caught and germinated seeds from other native pioneer species, mostly grasses.

The soil amendment patches could not be identified and did not seem to support any vegetation. It is possible that strong winds sorted the compost from the gravel and blew it away.

Chaff and Seed Spreading

In early June of 1993 the chaff from the 1992 seed collections was scattered over the entire site. The chaff added surface organics and a small amount of seed. Oxytropis and Agropyron constituted the majority of the chaff and seeds.

Revegetation Activities, 1994

Site Evaluation

The willow and alder continued to grow satisfactorily. The spruce and aspen plantings grew little but continued to support an increasing number of pioneer species in their organic rich rooting zones. Dandelions also took advantage of the fertile spruce plantings' soil. First year Oxytropis and Agropyron seedlings were observed throughout the site, possibly as a result of seeds sown in the chaff spreading test. The fireweed grew vigorously and established itself outside the seed traps through spreading rhizomes. Some rhizomes extended as far as .5m from the traps. The seed traps continued to catch seeds from a variety of native pioneer species, thus expanding the site's plant species diversity. During the late fall, dead fireweed stalks caught and held alder and willow leaf litter, allowing the litter to decompose and cycle nutrients in the seed traps.

Hedysarum and Agropyron Seeding

In midsummer of 1994, a swath of the western portion of the Railroad Crossing Project was destroyed for the construction of an underground telephone cable. An area about 5m by 10m near the telephone junction box was seeded with the legume Hedysarum and the grass Agropyron. After seeding, the soil was vigorously raked. Legume/grass seedings have been very successful on similar sites, and should provide interesting results here.

Summary

Identifying the factors that limit plant establishment and growth and manipulating site characteristics are the basis for successful revegetation on the Railroad Crossing Project. An approach, using a variety of methods and species, is also critical on harsh sites.

On infertile, well-drained sites, alder plantings are successful because site conditions limit seedling establishment, but not growth. Willow plantings are marginally successful and should not be relied upon as a primary source of vegetation cover. Planting spruce trees and fireweed rhizomes is not recommended for infertile, well-drained sites. However, tests on Glen Creek demonstrate that spruce may be successful on harsh sites if planted as small seedlings under a light canopy of alder. This may hasten succession towards a spruce forest.

Amending surface soils with organics does little good as the gravel and organics desiccate quickly and provide poor conditions for seedling establishment. In comparison seed traps amended with organics are very successful, as the organic/gravel and sand mixture is much deeper and thus protected from the wind. The use of seed traps in combination with soil amended with compost can restore nutrients, and more importantly, the moisture and nutrient holding ability of the soil. The technique requires little cost and labor, and has benefits that ensue for years. The use of more than one seed type adds diversity and can insure against unknown conditions and circumstances. After plants have been established in the seed traps, the accumulating leaf liter and the warm, protected environment in the trap favors decomposition and hastens nutrient cycling.

Recommendations

Although the Railroad Crossing Project is considered a success, the following sample plan might be used to revegetate the same or similar area more efficiently. (More information regarding on-site methods is available in Part II).

1) Alder Plantings: Plant 800 alders in clumps ranging from two to nine plants. The seedlings should be about .5m to .75m apart. The clumps should be arranged about 1m to 2m apart. Fertilize and water as per directions in Part II.

2) Willow Cuttings: Plant 200 willow cuttings about .5m to .75m apart. The clumps should be arranged about 1 to 2m apart. Amend each planting hole with a liter of well composted and sterile dog manure.

3) Seed Traps: Dig 1000 seed traps, 30cm long, 10cm wide, and 15cm deep. Each trap should be backfilled with a mixture of on-site soil and a liter of well-composted and sterile dog manure for a finished depth of 10cm. The traps should be arranged in clumps and spacings like the alder and willow and should be dug to take advantage of the summer sun and solar angle by orienting the traps lengthwise east to west. Disperse fireweed seed over the site. A wet and slightly windy day is best for fireweed dispersal.

4) Spruce Plantings: Spruce can be planted in the alder clumps, after the alder has reached a height of approximately .75m. The alder may need to grow several years before the spruce are planted.

APPENDIX B

Species Commonly Used for Vegetation Restoration

at Denali National Park

Scientific Names	Common Names
Trees	
Picea glauca	white spruce
Picea mariana	black spruce
Populus tremuloides	quacking aspen
Populus balsamifera	balsam poplar or cottonwood
Shrubs	
Alnus crispa	American green alder
Betual glandulosa	bog birch, resin birch
Betula nana	dwarf birch
Ledum palustre	Labrador tea
Potentilla fruticosa	shrubby cinquefoil or tundra rose
Salix alaxensis	felt-leaf willow or Alaska willow
Shepherdia canadensis	soapberry
Vaccinium spp	blueberry
Herbs	
Arnica frigida	frigid arnica
Artemisia tilesii	tall wormwood
Aster sibericus	Siberian aster
Epilobium angustifolium	tall fireweed
Epilobium latifolium	dwarf fireweed
Mertensia paniculata	bluebells
Myosotis alpestris	forget-me-not
Senecio lugens	black-tipped groundsel
Solidago multiradiata	northern goldenrod
Legumes	
Astragalus spp	milk vetch
Hedysarum alpinum	eskimo potato
Lupinus articus	arctic lupine
Oxytropis campestris	field oxytrope
Oxytropis deflexa	pendant pod oxytrope

<u>Grasses</u>

Agropyron macrourum . . . . wheatgrass
Agropyron violaceum . . . . wheatgrass
Arctagrostis latifolia . . . . polargrass
*Calamagrostis purpurascens*purple reed grass
Calamagrostis canadensis . . . . bluejoint
Elymus innovatus . . . . downy ryegrass
Festuca altaica . . . . fescue grass
Festuca rubra . . . . red fescue
Poa alpina . . . . bluegrass

APPENDIX C

Factors That Limit Plant Establishment and Growth

The following table illustrates some of the factors that can influence the revegetation potential of a disturbed site. Many of these factors are influenced--either directly or indirectly--by others, creating a complex web of interrelationships.

Climatic	Edaphic (soils)	Biotic
Precipitation	Stability	Presence of Propagules
Temperature	Texture	Plant Ecology
Season Length	Moisture	* Life History Traits
Day Length	Nutrients	* Reproductive Ecology
Wind	Microsites	Physiological Traits Microorganisms
Solar Angle	Temperature	* Symbionts
Snow Pack	Aeration	* Decomposers
	pH	Plant Interactions
	Toxicity	* Facilitative
	Permafrost	* Interference
		Herbivores
		Pathogens
		Pollinators

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