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Revegetation with Native Species

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Fort Lauderdale, Florida
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Abstract

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The seven papers in this proceedings address the current state of knowledge and application of ecological restoration in the Western United States. They provide an overview of: rangeland revegetation lessons as they apply to ecological restoration today; USDI National Park Service, USDA Natural Resources Conservation Service, and Forest Service restoration strategies and perspectives; biological factors for using native plant species; and the challenges of native seed collection, production, and marketing. These papers comprise the proceedings from a technical symposium at the 1997 Society for Ecological Restoration 9th Annual International Conference held in Fort Lauderdale, FL, November 12-15, 1997.

Keywords: restoration, seed production, seed conditioning, succession

Preface

There is increasing demand by the general public, environmental organizations, and public land managers to revegetate rangelands with indigenous native species. Revegetation objectives include restoration of natural ecosystems, native plant communities, biodiversity, gene flow, and sustainability. The Society for Ecological Restoration asked the Natural Resources Conservation Service to organize a symposium to educate and to share technical information about current approaches to ecological restoration. Specifically, this symposium was to address the practical application of revegetation and soil remediation experiences with actual case studies.

The symposium "Revegetation with Native Species" was developed by some of the prominent leaders in the field within the Natural Resources Conservation Service, the National Park Service, University systems, the U.S. Forest Service, and the Agricultural Research Service. Together, they met the goal of presenting the practical side of ecological restoration while complementing the Society for Ecological Restoration 9th Annual International Conference theme "Ecological Restoration and Regional Conservation Strategies." Our session provided an overview of rangeland revegetation lessons as they apply to ecological restoration today; reviewed USDI National Park Service, USDA Natural Resources Conservation Service and Forest Service restoration strategies and perspectives; presented biological factors for using native plant species; and discussed the challenges of native seed collection, production, and marketing. The discussions emphasized practical and technically sound restoration approaches, applications, and actual case studies of native plant revegetation projects including site assessment, plant community composition inventories, seed and plant collection, seed conditioning, storage, quality control, agronomic seed and plant production, planting, and monitoring.

This proceedings is a synthesis of knowledge and applications of ecological restoration in the Western United States. While we have reviewed and edited these papers for technical content, peer review has been the responsibility of the authors.

—Larry K. Holzworth and Ray W. Brown

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We are grateful to the Society of Ecological Restoration (Madison, WI) for providing the unique opportunity of bringing together the latest knowledge about revegetation and to present it to a diverse and enthusiastic audience of natural resource scientists, professionals, and managers. The conference organizers were committed to, and highly supportive of, our session and supported our intention of publishing this proceedings of our technical session. We are indebted to Andre Clewell, Society of Ecological Restoration President, for inviting our symposium and to George Gann, 1997 Conference Chairman, for including us in the conference. We thank the Publishing Services staff, Rocky Mountain Research Station, for assistance with editing, revisions, formats, and author guidance.

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Selecting Plant Species for Ecological Restoration: a Perspective for Land Managers

Ray W. Brown
Michael C. Amacher

Abstract—We recommend in this paper that land managers adopt a policy of mandatory use of native plant species for revegetation and restoration of severe disturbances on wildlands throughout the Interior West. A review of the relative advantages and disadvantages of using introduced and native species suggests that selection criteria based on ecological adaptability and suitability are more consistent with the objectives of ecosystem management than are criteria based on cost, availability, familiarity, or other nonecological considerations. We suggest that land managers initiate a policy requiring the collection and accumulation of native seral species throughout their respective regions and districts to be used in restoration activities. Further, we suggest that such a policy will foster closer ties between public land managers and public research scientists, and will enhance the implementation of science-based land management.

Recognition that ecosystem health has been in decline West-wide on public lands has motivated the adoption of ecosystem management by many public land management agencies in an effort to restore broad-scale ecosystem diversity and resiliency (Dombeck 1998; Thomas 1997). The urgency driving such measures stems, in part, from an accelerating public demand for more natural resources, a recognition that this demand cannot be met if ecosystem health continues to decline, and a realization that we may not possess the scientific or applied knowledge needed to implement appropriate solutions. Meeting the onerous challenges of an expanding public demand for natural resources while simultaneously preserving the sustainability of water quality and quantity and other renewable resources on Western wildlands should assist land managers in adopting a more science-based form of land management directed by ecological principles rather than just economic ones.

One of the direct consequences of this philosophical shift in policy is that land managers are being pressured to reexamine standard practices of reclamation and revegetation of disturbed lands. Concerns about restoration of ecosystem health center, in part, on the use of suitable plant species in revegetation that are consistent with overall ecosystem form and function. The "old saw" controversy over the relative advantages and disadvantages of using native versus exotic or introduced plant species has continued to fester for decades. The controversy is driven by strong emotions fostered by a spectrum of concerns ranging from economic issues to "environmental correctness" to physiological adaptability. In addition, the type of disturbance, its location and environmental limitations and conditions, and historic and potential future land uses also become entangled with the various arguments for or against the use of each group of species. The scientific objectives of the controversy are often lost or mixed with the passionate ones, and often are misrepresented or reformatted to fit predetermined points of view. Unfortunately, the debate has been tainted by both the political and public relations arenas. This has probably impaired progress toward adoption of a clear and unified policy favoring use of appropriate plant species by the major land management agencies.

This paper summarizes some of the concerns and constraints in selecting and using native and introduced or exotic plant species in reclamation and restoration of disturbed lands. We discuss some of the criteria used to select plant species for the active restoration of disturbed lands, including concerns about native and introduced species, and suggest alternative standards that may be useful in choosing plant species for restoration purposes. We offer principles, guidelines, and criteria for judging what plant species should be selected for restoring natural ecosystem form and function based on our more than 40 collective years of research experience in surface reclamation and restoration throughout the West.

The focus here is on the issue of selecting plant species for the restoration of severe disturbances on wildlands where the intent of management is to return the disturbed site to a self-sustaining condition supporting natural ecosystem processes. Not addressed in this paper is the issue of general reclamation techniques designed for specific land uses such as pasture development, enhancing productivity for livestock grazing, campground development and esthetics, and other uses that may differ from wildland ecosystem form and function. Where the intent of management is to sustain natural ecosystem processes with little or no continued inputs by land managers, it is our contention that management practices of reclamation and revegetation be implemented as tools to achieve full ecological restoration. Further, we support the hypothesis that use of successional native plant species is essential in order to achieve ecological restoration, that this practice is consistent with the goals of

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ecosystem management, and that the process of natural succession should be used as a guide in selecting native species. We contend that many conventional cultural practices (such as fertilizer use, organic matter incorporation, surface mulching, liming of acidic spoils), although important and ameliorative in many cases, are insufficient alone to achieve ecological restoration if suitable native species are not also included in the restoration process. Natural succession is a universal process that is ongoing throughout natural ecosystems, and should be identified, observed, and used as a guide in not only selecting species that are suited for specific sites, but in developing entire restoration plans.

We believe the interests of land managers would be advanced by developing strong ties with research entities that could assist with the identification, selection, and collection of native plant seeds suited for restoring disturbed habitats and communities throughout the West. If these agencies recognized the true value and need of additional research, and were willing to apply science-based management policies through cooperative interactions with such agencies as the Natural Resources Conservation Service and appropriate State and local offices and groups, collectively they could have the commanding privilege of finally settling the matter of restoring disturbed public wildlands to a near-natural state in the spirit of ecosystem management in virtually every Western ecosystem.

Although we contend that ecological restoration of severely disturbed wildlands should be accomplished with appropriate local native plant species, we do not support or agree with the argument that all exotic or introduced species are somehow "bad" or subversive elements to be exterminated. All plants, regardless of origin, have biological and ecological legitimacy, but not all of them are necessarily suited for restoring every habitat or ecosystem. We do not endorse emotional-based values such as political or ecological "correctness" to plants or other natural systems regardless of their origin or potential use, nor do we necessarily support the idea that human values deserve greater or less favor than natural systems. It is our contention that plants and all natural systems are intrinsic to the survival and well-being of society, but imperatively they function quite separately from human emotions, desires, and economic concerns. Therefore, we contend that in managing and using these systems we need to be careful in judging their values and functions on the basis of what they truly are, not how we would like them to be.

Definition of Terms

In order to expedite understanding of concepts, the following definitions are offered with the understanding that rarely is there universal agreement among users of just what a definition should include.

Native plant species, like any plant species, are composed of an array of ecotypes or populations whose individual genetic material is circumscribed by the forces of natural selection originating under the particular local environmental conditions of climate, agents of disturbance, and other factors that characterize the area in which they evolved. Thus, the genetic material of each ecotype within the species complex is individually imprinted with distinctive physiological or anatomical-morphological features specific to the environment in which they originated. As such, native species survived and repeatedly reproduced under the vagaries of unstable climates, predation, disease, herbivory, competition, and all the other limitations and stresses imposed by an environment over multiple generations of continuous genetic editing and sorting. We purposely avoid the contentious issue of defining scale in terms of "local" conditions, preferring to be vague here with deference to more elaborate intonations (such as "local-native" versus "indigenous native" versus other terms) in the rather extensive literature (minimally cited here: Anderson 1971; Bengson 1986; Benson 1957; Harper 1977, Society for Range Management 1974; Stebbins 1974, 1979).

Introduced or **exotic species** (we equate both terms) are considered to be species whose genetic material originally evolved and developed under different environmental conditions than those of the area in which it was introduced, often in geographically and ecologically distant locations (Bengson 1986; Society for Range Management 1974). The issue of quantifying the difference in environmental conditions between the place of origin and the current place of occurrence is always speculative, and is not pursued here. Similarly, we avoid the issue of "naturalization" by introduced species, opting to suggest that if the environment of origin of the genetic material differed from that in which it was introduced, the plant then probably remains "introduced" despite its residence time (usually measured in years or decades). Under this definition, individual plants or ecotypes of a "native species" that originated in other ecological, topographic, or climatic regimes (regardless of distance or political boundaries) are considered to be "exotic" or "introduced" relative to the local environment. Caution is warranted when working with plant populations or ecotypes bearing the same taxonomic name based on anatomical or morphological features; populations of the same species name but that originated in different environments probably do not possess identical or even similar genetic composition, physiological tolerances, or environmental requirements. Similarly, political and administrative boundaries are not barriers to the migration of plant genes, and are not considered here as legitimate separators among groups of biological entities.

Considerable confusion arises with these or any definitions in specific applications because they provide no guidelines for definitive separations among groups. Questions such as "How far away from the location of origin does a native plant fade into becoming an introduced plant?" arise, but little solace can be offered here. The fact that plants or other organisms are not sensitive to distance units is of no comfort to land managers faced with choosing one plant over another for specific sites. Alternative terms such as "near native" are often suggested to differentiate native plants originating in a given habitat from other native plants that originated in other, or different, habitats ("far natives"?). Other terms have occasionally been suggested, apparently with the intent of overcoming some of the limitations of language or historic bias, including "suitable species" or "naturalized species." Supposedly, a "suitable" species is one that is adapted (although not specifically defined so), but with desirable characteristics for a given application. This term would seem to confuse more than clarify the issue from the perspective of wildland restoration because agricultural crops may fit the definition as well as "native" or "introduced" wildland species. A "naturalized" species is apparently a formerly "introduced" species that has successfully competed with native species for numerous generations, and in recognition of its success is endowed with the estimable title of "naturalized." Although maybe such terms are conceptually more tidy and provide a more comfortable feeling among humans, they provide little guidance and have virtually no applicability to plants or other natural systems. In addition, a high degree of emotionalism has crept into these definitions, and somehow many people tend to attach anthropomorphic or teleological interpretations to them as if these terms were something more than just words to describe totally artificial entities. Contrary to some opinions, there is no actual biological entity definitively characterized by the definitions of "introduced" and "native" species. Perhaps the concepts and terminology of "native," "introduced," and other similar terms should be abandoned altogether in favor of something more precisely defined and understood, but there is little likelihood of that, and perhaps there is little benefit to be derived.

Ecological restoration is the practice of *re-establishing* natural ecosystem processes responsible for the development of ecosystem form and function, including all major biotic and abiotic components, on lands where these forces have been terminated, interrupted, or deflected as the result of disturbance. *Passive* restoration relies exclusively on management policy and other indirect options as a means of restoring the desired condition. *Active* restoration, or the "intentional intervention" by land managers to alter disturbed conditions in order to accommodate the *reinitiation* of natural processes that lead to the redevelopment of ecosystems, habitats, or communities is emphasized here. This usually involves such activities as altering management techniques combined with, on the most severe disturbances, a more operative approach that involves reclamation, revegetation, and other active options. In most cases, the primary objective of ecological restoration is the reinitiation of natural succession that will lead to the re-establishment of ecosystem form and function. Although ecosystem restoration has been the subject of numerous theoretical discussions recently (Cairns 1995; Everett 1994; Jackson and others 1995; MacMahon and Jordan 1994; Urbanska and others 1997), from a practical and applied land management posture the alleviation of limiting site conditions and the selection of ecologically fit plant species are crucial.

Reclamation is considered to be the process of mitigating physical or chemical environmental conditions perceived to be limiting to land management objectives. Reclamation is an attempt to alter or lessen the effect of environmental damage through whatever means are available. For example, reclamation may include revegetation, use of impoundments and diversion channels to control water movement, chemical treatment to improve soil and water quality, contour trenching, terracing, or other earth-shaping activities to minimize surface runoff and erosion, using chemicals or an array of surface fabrics and other treatments to stabilize steep slopes.

Revegetation is the process of establishing vegetation. The semantic issue of *re-establishment* of vegetation on sites that had previously supported vegetation versus establishment on soil materials, for the first time, is ignored.

Ecosystem management is the process of guiding and manipulating the development and use of natural resources required for society according to principles that enhance and perpetuate ecosystem diversity and sustainability. Under this definition, management options, reclamation, and revegetation are a few of the many tools employed in the implementation of ecological restoration.

Succession is defined in the broadest sense, and is intentionally not restricted to just the sequential development of vegetation or plant communities. Therefore, succession is intended to imply not only vegetation, faunal, and microorganism development, but also includes soil genesis, the establishment of hydrologic pathways both at and below the soil surface, the re-establishment of geomorphological and biogeochemical processes, and all the various natural mechanisms that are initiated following disturbance that ultimately lead to the development of ecosystem form and function. As a natural process guided by climatological, geological, and biological forces, succession is constrained by limiting factors in the environment. When these limits are exceeded, succession is retarded or repressed until they are ameliorated.

The Nature of Disturbance

Deterioration and loss of ecosystem health are often associated with the occurrences of disturbance, but it should be emphasized that not all disturbances negatively affect ecosystem health; in fact, it is widely recognized that many forms of disturbance are essential for the maintenance of natural ecosystem form and function (Kaufman and others 1994; McIntosh 1981; Rogers 1996; Vogl 1980). Ecosystems evolved under the influence of stochastic climatic conditions and variable biology and geologic activity. Forces of natural "disturbance" have been of paramount importance in the long-term development of ecosystems and include: (1) physical phenomena such as climatic change, seismic activity, landslides, and fire, and (2) biological agents such as humans, insects, diseases, grazing animals, invasion and competition from outside flora and fauna, and others. For example, some natural disturbances such as fire (Bartos and Campbell 1998), periodic insect and disease cycles (Mattson 1996; Vogl 1980), and climatic extremes (Vogl 1980) are integral components of natural systems that are responsible, in part, for healthy functioning ecosystems. Interference of such natural forces by human activities has led to significant consequences, often resulting in deterioration of ecosystem health and degeneration in the availability of natural resources and their sustainability. It is clear that such disturbances are just as compulsory for healthy ecosystem form and function as are the multitude of biotic and abiotic components and forces encompassing natural systems.

Other forms of disturbance can be detrimental to ecosystem health, and may result from either human or natural causes. In the relatively short span of only about 200 years, the impacts of an expanding human society have been introduced into the ecosystems of North America, imposing quite different forces and types of disturbance than those involved in their evolutionary development. With the encroachment of European-style society, and especially the large increases in population with accelerating economic and cultural growth in more recent decades in the West, the ranges and extent of human-caused disturbances on ecosystems are expanding as the result of two primary activities: (1) construction-development-extraction enterprises and (2) inappropriate wildland management policies and strategies. Each decade the impacts of these activities are growing in intensity and geographic extent at dramatic and sometimes accelerating rates. The traditional Western industries of logging, livestock grazing, and mining are being replaced by road and highway construction and their perpetual maintenance, recreation, development of destination resorts and associated recreational facilities, pipelines, powerlines, exploding urban expansion (compounded by changing natural resource opinions and land ethics), and associated activities as sources of pervasive disturbance in virtually every ecosystem at all elevations in the West. There are perhaps no comparative natural disturbances of the magnitudes, frequencies, and intensities of these anthropogenic activities. Even regional volcanism, seismic activity, or anomalous and extreme climatic events (such as microbursts, extreme drought, heavy precipitation events) that may have significant impacts on ecosystem form and function occur much less frequently and less pervasively than current human activity.

Disturbances are referred to as "severe" if they result in the complete loss of native soil and vegetation, if they disrupt or destroy natural surface and subsurface hydrologic pathways, and if they result in accelerated rates of erosion and sediment transport. Severe disturbances are normally most significant on the local or watershed scale, but may have far greater impacts on water quality and quantity, wildlife habitat, and other attributes than larger scale, less severe disturbances. In the context of the larger issues of "Disturbance Ecology" (Rogers 1996), understanding the distinctions between and the interactions of human-induced and natural disturbances is essential to clarifying and interpreting the significance of human impacts on natural ecosystem processes. These interactive effects can be of compounding importance over time as they relate to stream flow, erosion, vegetation, and the transport of nutrients and toxic chemicals. Although these effects are exacerbated by both human and natural disturbances, human activities are becoming increasingly commonplace throughout the West in harsh environments and steep watersheds predisposed to slope instability. Human activities have the most severe impacts when they occur in harsh environments where natural recovery occurs slowly over long periods (such as in arid regions or at high elevations), in the headwaters of drainages, near streams and rivers, or on steep unstable slopes. Under these conditions, the potential for erosion, sediment transport, and subsequent degradation of water quality are maximized. Generally, total precipitation is low in many Western ecosystems, and precipitation regimes are typified by episodic high-intensity storms that dramatically affect landscapes and streams. Intensive human activity tends to exacerbate many natural forms of disturbance because much of the mountainous terrain in the West is naturally susceptible to surface erosion and mass-wasting.

There are real dangers in altering natural ecosystems that extend well beyond concerns about aesthetic appeal or changing floristic composition. Severe disturbances can be so harsh and environmental conditions can be so austere that the reinitiation of natural succession under such conditions can be limited or even prevented altogether. As a result, succession may become deflected, suspended, or stalled (Allen 1988; Curtin 1995; Glen-Lewin and others 1992; McIntosh 1980; Schramm 1966). In such cases, severe disturbances may result in loss of the "evolutionary roadmap" that allows succession to guide a damaged ecosystem back toward restored functionality and recovery. Some of the consequences of severe disturbance include:

1. Loss of ecosystem resiliency to forces of climate change and recurring disturbance.
2. Replacement of natural floral compositions by invading weeds or other undesirable species, resulting in loss of biodiversity and sustainability.
3. Accelerated rates of erosion, loss of developed soil, altered soil development, and declines or loss of nutrient cycling.
4. Oxidation of acid-forming materials or altered weathering patterns that enhance the availability of toxic chemicals.
5. Adverse impacts on natural hydrologic pathways.
6. Sediment and chemical transport and deterioration of water quality and quantity in ecosystems.
7. Loss of fauna that may have far reaching impacts on vegetation development and vegetation-animal interactions.

Intact functioning ecosystems conserve matter and energy (Billings 1965; Whittaker 1975), hence there is little net loss of energy or components needed to sustain them. Because natural intact ecosystems are self-regulating systems, they are internally and naturally buffered against all but the most severe of outside forces. The adoption of ecosystem management by land management agencies suggests that intact ecosystem function is recognized as the primary level of natural resource management to be attained (Boyce and Haney 1997; Kohm and Franklin 1997; Perry 1994; Yaffee and others 1996). It seems clear that if ecosystem management is the goal, we need to comprehend how ecosystems function; but to achieve that, we need to also understand how ecosystems develop and form from genesis to maturity. Restoration following disturbance provides an opportunity to achieve that level of understanding. Aldo Leopold noted that "If we are serious about restoring or maintaining ecosystem health and ecological integrity, then we must first know what the land was like to begin with" (quote in Covington and Moore 1994).

Plant Species Selection: the Debate

The selection of plant species for use in the restoration of severely disturbed public wildlands in the West continues to be a controversial and encumbering issue (Bengson 1986; Brown 1980; Gutknecht 1992; Mills and others 1994; Roundy and others 1997; Shaw and Roundy 1997). The criteria used to select plant species are generally recognized as some of the most important judgments that can affect the relative success of active restoration. Concerns over adaptability, suitability, and compatibility of the selected plant species with the surrounding ecosystem often become confounded with land management objectives and even personal biases, and these often lead to species selection decisions that contradict scientific judgement and ecological concerns. Selection criteria for most wildland or rangeland applications are often based on various characteristics, including productivity, habitat attributes, palatability, cover, aesthetics, and long-term vigor in particular climatic regions. Some land managers even consider physiological adaptation and ecological compatibility with surrounding vegetation; but in selecting species for restoring wildland disturbances, the criteria most often used are ill-defined "seat-of-your-pants" concerns and should probably not be categorized as criteria at all.

The distinctions that separate native and introduced species often are not as obvious and clear cut as many would like to believe. We may even have become so enamored with the debate that we have lost sight of its substance. The true differences between native and introduced species are largely physiological, arising from entirely different evolutionary histories and genetic characteristics, but these appear to be no greater than those arising between two different native species originating in two different environments. It seems that we often forget that all natural vascular plants are (or were) native to some region and environment prior to human intervention regardless of political boundaries, and that all of them cope with the environment using surprisingly similar types of physiological mechanisms. Aside from anatomical and morphological differences of shape or size, what truly distinguishes vascular species is the efficiency with which they transfer energy and acquire resources within the range of environmental conditions that prevail. If a plant is efficient in coping with its environment, it survives; if it is not, it dies. Thus, we should probably differentiate among plants at the ecotype, population, or species level more on the basis of their adaptability and physiological tolerances than on artificial distinctions of taxonomic name alone. Too often we ascribe significance to artificial nonbiological entities, such as "native" and "introduced," and to artificial taxonomic units such as "species" (Anderson 1971; Harper 1977; Stebbins 1974, 1979).

The range of physiological tolerances of each individual plant are defined by its genetic material, and in natural plants (as opposed to taxa whose genetic material has been intentionally manipulated), genetic expression is the product of natural selection acting over long periods of evolutionary time. The total pool of genetic material among all individual plants of a population or species defines the "heritable" attributes, including the range of physiological tolerances, for that entire population or species. In its most succinct form, the term "adaptability" comes closer to defining what controls species performance and distributions than do terms like "native" or "introduced." "Adaptability" has been variously defined, but basically it is considered to include the genetically controlled process of modifying structures and physiology in response to environmental conditions (Conrad 1983). "Acclimation," however, describes the ability of plants to make physiological adjustment in response to changing or altered conditions in the environment (Conrad 1983; Nilsen and Orcutt 1996). As emphasized by Smith (1978), there is no adaptation or acclimation in response to environmental stress unless there is genetic control of physiological responses, and these are heritable.

Unfortunately, the concept of adaptability is arguably misapplied with reference to selection of plant species, frequently being confused with anthropomorphic measures of "goodness" and "badness" instead of ecological fitness and suitability. As used by land managers, the concept of adaptability probably most often includes both adaptation and acclimation, and encompasses concerns about the ability of a species to grow, survive, and reproduce in a given environment. When selecting plant species for revegetation and reclamation, the criteria used to determine adaptability are usually based on experience, and often include attributes that appear to indicate adaptability to local conditions. These may include: (1) survival over a number of generations in the same or similar areas; (2) ability of a species to reproduce and complete its entire life cycle; (3) apparent tolerance to water deficits, temperature extremes, and nutrient deficiencies; (4) relative vigor during germination and growth (often based on plant size); and (5) apparent palatability for livestock. Care should be practiced in how the concept of adaptability is applied, because to describe adaptability only in terms of competitiveness, aggressiveness, or potential above-ground productivity renders the concept meaningless for species selection. Adaptability is not a unit of measure (such as biomass, height, density, cover), nor is it a unit of forage production or quality. Adaptability is a term defined by the physiological range of tolerance of an organism as determined by its genetic material. If the environmental extremes of a habitat or ecosystem fall within the range of physiological tolerances of a species, that species can adjust to them and carry on vital physiological processes. If extreme environmental conditions ever exceed that range (just one time!), however, the plant dies.

Rationale for Selecting Introduced Species

Land managers are often pressured to select species on the basis of human-based and economic criteria, and these criteria almost always favor the selection of introduced plant species over natives because most introduced species possess attributes that more nearly favor preconceived human notions of what is "good" or ideal for achieving land management goals. These criteria encompass the ranges of tolerance of most introduced species in most environments of the West, and thus conveniently suggest that introduced species are at least equally adapted to local conditions as natives. Based on these criteria alone, and ignoring all others, it would be difficult to argue against introduced species given the geographic range over which many have been successfully used for erosion control and range improvement, and given the multiple generations that many of them (including invasive species) have endured in the West. Most of the common introduced plant species used in revegetation of Western rangelands and disturbances are the products of long-term research and "improvement" through breeding and selection. Many of these species were brought to North America from Europe and Asia decades ago because of certain beneficial traits deemed desirable at that time. It is little wonder that smooth brome (*Bromus inermis*), orchardgrass (*Dactylis glomerata*), timothy (*Phleum pratense*), crested wheatgrass (*Agropyron cristatum*), and others produce higher biomass than native species, are more favored by livestock, have higher seed production, higher seedling and mature plant vigor, green-up sooner and remain green longer, or grow to larger size than native species; they have the "advantage" of having been manipulated, selected, and sorted for specific predetermined uses and objectives over multiple generations.

Some of the reasons why introduced species may appear attractive for wildland revegetation and restoration include:

1. Familiarity: Many introduced species have been used extensively for many generations for highway revegetation, hay crops and pastures on farms and ranches, rangeland improvement by Federal and State agencies, and many other applications.
2. Availability and cost: Introduced species are more widely available commercially than natives at cheaper prices.
3. Growth and vigor: Introduced species tend to have higher germination and seedling vigor, growth and development rates, and flowering and seed productivity than most native species.
4. Plant size: For given life forms, introduced species tend to grow larger, have larger vegetative structures, and provide more cover and biomass per plant under favorable conditions than most native species.
5. Palatability: Introduced species are generally more preferred by livestock over longer periods during the growing season than natives.
6. Growth form diversity: Introduced species tend to have richer varieties of growth forms (such as rhizomatous versus bunch habit, larger spreading vegetative crowns, greater seed production) than natives.
7. Ranges of tolerance: Some introduced species tend to have broader physiological and ecological ranges of tolerance to limiting conditions, and may tolerate herbivory better than many natives.
8. Competitiveness: Introduced species tend to be more competitive for limited resources than many natives.

These features are often cited as reasons why introduced species are "better," or more advantageous, than native species (Bengson 1986; Gutknecht 1992; Thornburg 1982). Although there are no valid biological reasons to believe that one species is somehow "good" or "bad," it appears there is a surprisingly prevalent attitude that human values somehow apply to biological systems. Human measures of goodness or badness are normally based on economic and measurable quantities such as productivity, growth rate, palatability, or even availability of seed or plant stock, but rarely on biological factors such as physiological tolerance or adaptability.

The issue of seed acquisition cost is particularly bothersome because it is more often used as an excuse for substituting introduced species for native species than any other. Seed cost is almost always determined on the basis of cost per unit PLS (pure live seed) weight. Although cost concerns may be valid and are intentionally not trivialized here, there are at least two issues that tend to offset the real effects of cost:

1. Native species often have far more seeds per pound than most introduced species, and hence the cost per unit PLS seed (the potential number of live plants per unit area) may be far less than expected.
2. The "ecological cost" of *not* restoring a wildland disturbance to a self-sustaining condition by using introduced species may have "hidden" costs and negative impacts in perpetuity as has been the case in numerous documented instances throughout the West and other regions in recent history (Brown 1995; Hess 1995; Lesica and DeLuca 1996; Mills and others 1994; Roundy and others 1997; Seagrave 1976).

Another almost universal excuse for not using native species is the issue of availability of seed. There is no doubt that the *commercial* availability of native species for use in revegetation has been limiting and that real efforts to enhance that are arguably minimal and primarily local in scale (although this situation is changing rapidly). However, there is not now, nor has there ever been, a real shortage of collectible native seeds in virtually any ecosystem with which a public land management agency has been involved. The only real shortage has been in administrative imagination and commitment to implement serious steps toward ecological restoration as part of ecosystem management policy. Land managers need to be more sensitive to this need and either collect their own seed from key areas or contract with professional seed collectors or dealers as needed.

Another rationale used to legitimize the use of introduced plant species in revegetation and restoration of wildland disturbances suggests that when severe disturbances create such harsh environments that the successional "clock is reset to zero," the same successional trajectory that led to the predisturbance community may no longer be possible. This argument suggests that because climatic conditions have probably changed since the last time succession was initiated (perhaps hundreds or thousands of years ago), the identical pathway that led to the immediate predisturbance community is no longer possible or available (this argument is widely cited as a reason why the process of ecological restoration as implemented by humans is impossible). Because this pathway has been altered significantly, the native species that developed along with the community are likely no longer available or adapted. Therefore, this argument suggests, the use of new introduced genotypes may be justified.

Such reasoning also overlooks the fact that the prevailing climate, no matter how different from that of the past, is and has been the primary guide affecting succession and ecosystem form and function up to the present, and despite any recent severe surface disturbances, remains in place. The same species that were components of the predisturbance community were primarily influenced and sorted by those same variable climatic conditions. It is reasonable to extrapolate that restoration using these native species would continue to be primarily influenced by those same, albeit changing, climatic conditions. These native species have the benefit of sorting by natural selection under those variable conditions, even if of relatively recent origin, whereas introduced species do not.

Climatic and other environmental conditions are probably rarely static for significant periods of time in any ecosystem, and current conditions in most ecosystems are likely not representative of the highly variable environments that existed throughout their evolution (Covington and Moore 1994; Ellis and Galvin 1994; West and others 1994). Thus, it is almost certain that climatic instability over time has been a normal constituent of ecosystem evolution. Climatic instability or climate change in and of itself does not automatically mean that there will be measurable shifts in floral or faunal composition, soil development, nutrient cycling, or any other ecosystem attribute. We contend that it is entirely reasonable to suspect that environmental change is ubiquitous, but that it is unreasonable as an excuse to alter species compositions for the sake of economic and administrative convenience. Extending well beyond any moral or ethical considerations of public land management, such decisions require caution and far more knowledge than is currently available.

Another pretense suggests that European people have so grossly altered the original ecosystems of North America (Kay 1994) that these ecosystems no longer exist and, therefore, concerns about diversity are no longer valid. Yet another argument suggests that humans are now the prevailing force shaping ecosystem form and function and, therefore, humans should have the freedom to shape and form ecosystems in any manner deemed economically or aesthetically suitable. The latter pretense stems, in part, from archaic theological determinism based on biblical or religious belief and will not be discussed further.

Perhaps most disturbing of all is the apparently persuasive argument that if the natural soil has been destroyed through either human-caused or natural disturbances, natural ecosystem processes and function have been irreparably altered, and thus native species are no longer adapted. This argument ignores the numerous examples of natural succession on mine lands and along road cuts and fills (Brown and others 1979; Chambers and others 1984; Winterhalder 1995), on landslides and areas of volcanism (del Moral and Wood 1993; Nilsen and Orcutt 1996; White 1979), and other drastic and severe disturbances where natural soil was lost or destroyed. Many such disturbances expose raw disrupted geological materials at the surface, some of which harbor acidic constituents and high concentrations of toxic chemicals totally dissimilar to the predisturbance natural soil. Many studies have shown that natural succession occurs on such materials, and not always slowly and undramatically, composed of native seral species that are representative of adjacent undisturbed communities (Brown and others 1979; Chambers and others 1984; del Moral and Wood 1993; Munshower 1993; Winterhalder 1995). Obvious exceptions are noted on some severe disturbances where exotic annuals or perennials appear to overwhelm native species succession (cheatgrass [*Bromus tectorum*], Russian thistle [*Salsola kali*], bindweed [*Covolvulus arvensis*], dyer's woad [*Isatis tinctorum*], and other species) (Monsen and McArthur 1995; Sheley and others 1996; Young and Evans 1976).

The presence of invasive weeds, even at densities and concentrations that appear to exclude native seral species, is no indication that natives are no longer adapted; it merely suggests that the native species may be less competitive and have temporarily been suppressed. In some cases observations suggest that dominance by invasive weeds may be a temporary phenomenon lasting perhaps several years, and that eventually the perennial natives resume succession (personal observation), although notable exceptions are also common (Monsen 1994; Munshower 1993; Smith and others 1988). Unfortunately, in addition to being wrong, we believe the argument tethering species adaptability to natural soil is even more subtly dangerous than most misinterpretations of natural forces because it has implanted an unwarranted fear of failure for using native species in areas where highly competitive exotics may appear to dominate early succession. It is clear that despite infestations of aggressive introduced weeds in some areas, natural selection has sorted for highly adapted early seral native species that successfully and routinely colonize severely disturbed lands in virtually every ecosystem, and that the challenge for the land manager is to identify them and learn to capitalize on their adaptability.

Consequences of Using Introduced or Unadapted Plant Species

Historically, the most common form of reclamation or rehabilitation used by public land managers on disturbed areas has been revegetation. Typical revegetation and reclamation activities by public land managers have overwhelmingly relied upon the use of non-native plant species, and have largely been guided by the perception that such practices can improve natural conditions. Land managers revegetate and reclaim disturbances to minimize erosion and sediment movement, and to improve water quality, wildlife habitat, forage for livestock grazing, aesthetics, and other attributes, but give little thought to the long-term ecological restoration of the disturbance. It is generally accepted that re-establishing a plant cover on disturbed sites is the most effective means of achieving these goals, although engineering structures and other facilities are often utilized as well. In many cases, the land manager is less concerned about the origin or physiological tolerances of the selected species than for how quickly and inexpensively a plant cover can be established to provide forage, surface stability, and reduce erosion. By doing this, the conventional leap of faith instills the hope that surface stability will somehow allow "nature to take its course" and return the disturbed area to ecological recovery or some other desired state. This belief further extrapolates that the other attributes of wildlands, including wildlife habitat, aesthetics, and water quality, will eventually be enhanced as a result of these practices. This rests heavily on the assumption that the course of natural succession following revegetation will be directional and desirable regardless of what plant species are used, and that immediate stabilization of disturbed soil is far more important than other concerns about plant species composition of the newly created community (Hull and Holmgren 1964; Thornburg 1982; Thornburg and Fuchs 1978).

Although stabilizing the surface and minimizing surface erosion are beneficial and in some cases (such as following extensive fires) may be considered essential, we have learned in recent decades that revegetation and many other remedial land management activities are no guarantee that the course of nature and succession will progress as expected or as desired (Brown 1995; Lesica and DeLuca 1996; Mills and others 1994). Often the use of exotic plant species and various cultural treatments on severely disturbed wildland areas, although perhaps capable of providing short-term surface stability and protection from the immediate problems of surface erosion, lead to highly oversimplified and artificial plant community systems totally inconsistent with the form and function of the natural ecosystem, or with the objectives of ecosystem management. Vast areas of these unnatural systems have been created throughout the West as a result of unfortunate land management decisions and poor information, and not only have these areas not returned to a natural ecosystem state, but may in fact be retarding or delaying ecosystem re-establishment following disturbance. In many documented instances, some land management practices such as fire exclusion (Bartos and Campbell 1998) and spurious revegetation-reclamation activities (Allen 1988; Bradshaw 1995; Briggs 1996; Brown 1995; Lesica and DeLuca 1996; Mattson 1996; Monsen 1994; Munshower 1993) can result in apparently near-permanent losses in plant community biodiversity, deflected, arrested, or misdirected successional development (Glen-Lewin and others 1992), ecosystem dis-integrity (Regier 1993), and loss of ecosystem resiliency to climate change and the impacts of cyclic redisturbances caused by either natural or human agents (Briggs 1996; Mattson 1996; Rogers 1996; Williams and others 1997; Woodley and others 1993).

It has been firmly established that many introduced species are more aggressive and more competitive for limited resources such as water and nutrients than most native species. Hence, a loss of biodiversity over time (loss in species numbers; shifting proportions or loss of life forms such as grasses, forbs, shrubs, and trees; reduced pools of physiological traits; and so forth) is being widely observed. A primary consequence of loss of diversity is a concomitant loss in flexibility, resiliency, and recoverability under environmental stress (such as recurring drought, climate change, increasing levels of human influence, grazing). As emphasized by Mattson (1996), if diversity in ecosystems is in any way simplified, it likely may lead to more frequent and possibly more severe outbreaks of various insect pests. Analogous extrapolation would suggest similar responses for disease and other agents of disturbance.

For example, extensive National Forest lands impacted by phosphate mining in southeastern Idaho on and adjacent to the Caribou National Forest were revegetated with exotic species including alfalfa (*Medicago sativa*), smooth bromegrass, and orchardgrass over the last 25 to 30 years (Richardson and Farmer 1985). Most of those revegetated areas, including the oldest ones, still support extensive communities of these highly competitive high-resource-consuming plant species to the virtual exclusion of native species. As a result, vascular plant biodiversity has been depleted by more than an order of magnitude, natural succession has been arrested or deflected, soil development lags far behind expectations, insect and disease outbreaks have devastating impacts on the species-poor flora, and land managers are discovering that wildlife populations and domestic livestock congregate in these artificial communities to the detriment of soil stability, water quality, and community stability (Zufelt 1998). Other similar examples are common throughout the West, including Watersheds A and B on the Wasatch Plateau (Meeuwig 1960), some tall forb communities in the Wasatch Mountains (Monsen and McArthur 1995), and other revegetated mine lands (Zufelt 1998).

Similarly, thousands of acres of crested wheatgrass stands were established throughout the West in the name of rangeland improvement (Hull and Holmgren 1964; Johnson 1986; Vallentine 1989) over the last 60 to 80 years, and they continue to persist with analogous consequences (Lesica and DeLuca 1996). Countless miles of interstate highway seedings planted decades ago with crested wheatgrass (the so called "savior of the West") are still dominated by that species, as are numerous rangeland seedings throughout the West. In our opinion it has become clear that, relative to restoration of native communities in wildland areas, the concept that any plant cover is equally beneficial and "good" if it provides site protection and minimizes surface erosion, regardless of what species are involved, is not only misleading and dangerous, but is probably ecologically wrong as applied to Western ecosystem restoration and should be abandoned. Equally, the concept that any form of reclamation (including revegetation) will eventually allow nature to take its course in restoring disturbed ecosystems is naive and misleading. In recent decades, numerous documented cases describe where artificial revegetation with introduced or exotic species and other reclamation activities (under the best of intentions) have arrested successional development and altered the natural composition of significant portions of numerous ecosystems throughout the United States (Bartos and Campbell 1998; Brown 1995; Covington and Moore 1994; Detwyler 1971; Kaufmann and others 1994; Kay 1994; Lesica and DeLuca 1996; Mills and others 1994).

The Alternative: Ecological Restoration

The Role of Natural Selection

A strong and compelling argument can be made that species selection should be based on physiological adaptability and on the suitability and compatibility of the species with local flora or ecosystem conditions. The criteria commonly used in selecting introduced species do not usually encompass the physiological basis for, and the process of, adaptability to changing conditions over time. Given that our total experience with revegetation, natural resource management, and environmental science in the West only spans about 100 years, in terms of evolution and genetic flexibility we really know very little about the true adaptability of any species, native or introduced, or about the full range of environmental conditions that really characterize our Western regions. In fact, we have begun to gain quantitative knowledge about the physiological tolerance ranges and adaptability characteristics of native Western wildland plant species only in the last two decades or so, and thus our ability to select from them on the basis of hard facts is still a weak link in ecological restoration. If we knew as much about the physiology of many native species as we believe we do about some introduced species, perhaps a greater variety of native species would be selected for restoration and related other uses.

Native species have at least one enormous advantage over introduced species that is often overlooked by restorationists and land managers and that provides us with an encouraging advantage in selecting species: native species have a very long history of genetic sorting and natural selection by the local environment. Throughout evolutionary time, ubiquitous adjustments in climate and other conditions have altered environments significantly. Strong sorting forces or genetic editing are continuously refining the genetic programming in plants, and as a result native flora have developed broad ranges of physiological tolerances (Bazzaz 1979). In arid and semiarid regions, natural selection is particularly strong in eliminating many genotypes in response to overwhelming sorting pressures exerted by limiting environmental conditions (Smith 1978). Selection pressure usually results in a highly resilient biome over time in balance with resource availability and biodiversity, and large numbers of relatively low-resource-requiring species can be accommodated in resource-poor environments (Smith and Nowak 1990; Trimble 1989). The ranges of physiological tolerance of each species are thus continuously being stressed as environmental conditions swing from one extreme to another under the influence of climate change, fire, insects and disease cycles, seismic events, volcanism, and other stresses (Nilsen and Orcutt 1996).

Succession under such systems is highly dynamic, with natural selection continually sorting out marginal or unadapted species, populations, and ecotypes (Bazzaz 1979; MacMahon 1983). The overall trajectory of such a system points toward complete resource allocation and eventual stability (although probably never truly achieved) defined within the limits of that particular system. These pressures create a flora and fauna that are resilient to disturbance and yet compatible with available environmental resources. Examples abound, but include such adaptations as root system stratification and above-ground architectural attributes of cover and biomass that are compatible with the availability of water, nutrients, and other resources in balance with soil development, hydrologic pathways, and other natural characteristics of the ecosystem (Bazzaz 1979; Nilsen and Orcutt 1996). Resource extraction patterns by plants are thus in balance with climatic configurations of growing season length, precipitation, dormancy, snowfall and accumulation, temperature extremes, competition, reproduction and flowering of associated species, symbiotic associations, herbivory and predation pressures, fire recurrence patterns, insects and disease cycles, and other variables. This balance is achieved over long-term exposures in an ecosystem (such as adaptability), and is likely not equivalent to those developed by introduced species that originated in a geographically and ecologically distant environment, even though these introduced species may have successfully survived in the new environment for long periods of time in human terms. The introduction of new species into a system can cause imbalance by shifting resource allocation patterns and altering successional trajectories at the cost of diversity, resiliency, recoverability, and flexibility to stress and other forces (Brown 1995; Lesica and DeLuca 1996; Mattson 1996; Mills and others 1994). Although we may have limited knowledge about some aspects of native plant adaptability and the mechanisms that contribute to it, we do know that natural selection has provided a broad spectrum of genetic material in many native species that are very well suited and ecologically fit for the seemingly harshest conditions.

Grazing in the Interior West prior to European settlement was probably largely limited to wildlife, insects, and perhaps native peoples (Kay 1994). It is doubtful that the arid portions of this region ever supported massive herds of grazing animals on a permanent basis and that herbivory was ever a major natural selection or sorting force of plant evolution, especially in comparison with mesic regions like the Great Plains. Native plant species in the Great Basin and throughout the Interior West were more likely sorted by forces of extreme climatic events like water deficits and highly variable climatic swings characteristic of this largely arid and semiarid region. Therefore, native species in the Interior West are unable to withstand repeated and frequent foliage removal. When European peoples began to populate the West in large numbers on a permanent basis, they attempted to apply standards of land use and management that had been learned in more moderate climatic regions. The unfamiliar environmental extremes encountered throughout the West doomed many agrarian attempts to failure (Cottam 1947; Hidy and Klieforth 1990; Smith and Nowak 1990; Stewart 1941; Trimble 1989).

Selecting Adapted Native Species

An essential step in implementing ecological restoration of disturbed wildlands is recognizing the significance of the compatibility required among the biological, physical, and chemical components of an ecosystem with natural succession. Equally important is the realization that although native species have had the benefit of extended periods of natural selection to shape their heritable features of adaptability, not all native species are equally well suited for initiating the early processes of succession. One attribute of a highly variable and rich native flora in Western ecosystems is a broad array of adaptations in many different species for colonizing severe disturbances. Colonizers have physiological requirements and adaptations that allow aggressive invasion and establishment in openings or other niches created by disturbances within all ecosystems. Despite their essential function, many native colonizer species, like some annuals and perennials, are often mistakenly relegated to the lowly regarded role of “weeds” (Kricher 1980), but rarely do early seral natives resemble the common image of pesky annual garden plants. A surprisingly large proportion of the native species found to be aggressive colonizers on disturbances are also major components of mid- to late-successional communities in most Western ecosystems at virtually all elevations, such as arid desert lands as in Wallace and Romney (1980); mesic steppe ecosystems as in Daubenmire (1975) and Smith and others (1988); coniferous forests of *Pseudotsuga* and *Pinus* as described by Arno and others (1985), Franklin and Hemstrom (1981), and Perry (1994); *Thuja-Tsuga* forests of northern Idaho as in Mueggler (1965); alpine and subalpine ecosystems as in Baig (1992), Chambers and others (1984), and Churchill and Hanson (1958). These examples are quite unlike the classical models of succession in which early seral species are described as aggressive and persistent annuals and biennials, especially as developed from prairie and “old-field” sites in the Midwest (Clements 1916). However, where introduced species have escaped and spread in Western ecosystems, early seral plant development may be dominated by highly competitive and aggressive exotic annuals and biennials, which probably deserve the label “weeds” (Monsen 1994).

Typically, early seral native species play an extraordinarily important role in ecosystem development because they are instrumental in initiating the interactive phases of succession among the biological, physical, and chemical components of the environment. In some cases where extreme disturbance exposes toxic geologic material, physical and chemical forces of weathering or intensive human-induced reclamation may be required before active colonization can occur. However, once early seral species colonize and become established on a disturbance, the processes leading toward soil genesis and nutrient cycling are initiated (Glenn-Lewin and van der Maarel 1992; MacMahon 1983; McIntosh 1980, 1981).

The contrasts between early and late seral species is not always absolute, but a summary of their comparative attributes is listed in table 1 in broad terms to indicate their general characteristics. These are only general characteristics of the differences between the two groups of seral species because exceptions can always be found. This illustrates the generally higher aggressiveness and colonizing ability of early seral species over later seral species. The summary also illustrates that early seral species tend to have higher seed productivity, seed germination, seed dispersal, growth rate, and tolerance to stress than late seral species. Although early seral species tend to display broad ecological amplitude and nutrient requirements, they generally have lower competitiveness and root/shoot biomass ratios than later seral species.

The land manager responsible for selecting plant species to be used in restoration efforts can take advantage of a broad range of opportunities. Typically plant species are selected either on the basis of personal experience or after consultation with local county agents or other experienced workers. Another more productive opportunity rarely exercised is the observation of existing active successional areas on disturbances such as may be found along old roads, on road cuts and fills, at abandoned mine or building and construction sites, in areas of heavy rodent activity, along powerline and pipeline corridors, on landslides, in abused campground areas, at burned sites where succession remains in its earlier stages, and at similar disturbed sites. Careful observation of these sites often reveals valuable information about a range of plant species adapted to colonization and survival on disturbed lands in the area of concern. Perhaps more than any other source, succession displays those species that are obviously adapted to local conditions of disturbance. Depending on environmental conditions and the life zone in which the disturbance occurs, a range of seral species will likely be displayed. These may include an assortment of life forms composed of graminoids, broadleaf plants, and woody species.

It is recommended that land managers and restoration specialists identify the seral native species for each of the ecosystems within their area of responsibility, and that the distribution, growth, phenological and other ecological habits of these species be carefully observed and documented. It is these species that should be selected for whatever seed mixture or planting stock is designed for the restoration of disturbed wildlands. Ideally a range of disturbance ages and community types will provide a broader spectrum of seral species to include in the pool of potential available native species to be used for restoration. We recommend that careful notes of species locations, rates of phenological development including flowering habits and seed maturity dates, growth habit (such as bunch versus rhizomatous growth, prostrate versus erect form), and other habits be maintained over time. Not all native species produce high quantities of germinable seed every year, and in some areas seed production may be highly variable with climatic conditions.

Some examples of seral native species found to be useful for restoration of severely disturbed wildlands in the Interior West are listed in table 2. This species list is only intended to be used as an indication of some of the many appropriate seral native species that can be selected; there

Table 1—Some contrasting characteristics between early- and late-seral species.

Characteristics	Early seral	Late seral
Ecological amplitude	Broad	Narrow
Nutrient requirements	Broad	Narrow
Aggressiveness	High	Low
Colonizing ability	High	Low-medium
Seed production	High	Low-medium
Seed germination	High	Low
Seed dispersal	High	Low
Stress tolerance	High	Low
Growth rate	High	Low
Competitiveness	Low-moderate	High
Root/shoot ratio	Low	High
Succession stage	Low	High

Table 2—Examples of some native seral species useful for restoration of severe wildland disturbances by major ecosystem.

Species	Common name
Arid to semiarid (such as desert shrub and pinyon-juniper communities)	
Oryzopsis hymenoides	Indian ricegrass
Sitanion hystrix	Squirreltail bottlebrush
Stipa comata	Needle-and-threadgrass
Penstemon palmeri	Palmer penstemon
Sphaeralcea coccinea	Scarlet globemallow
Artemisia tridentata	Big sagebrush
Chrysothamnus nauseosus	Rubber rabbitbrush
Foothill lower montane	
Agropyron spicatum	Bluebunch wheatgrass
Agropyron trachycaulum	Slender wheatgrass
Bromus marginatus	Mountain brome
Festuca idahoensis	Idaho fescue
Festuca ovina	Sheep fescue
Achillea millefolium	Western yarrow
Artemisia tridentata	Big sagebrush
Chrysothamnus nauseosus	Rubber rabbitbrush
Subalpine to alpine	
Agropyron trachycaulum	Slender wheatgrass
Deschampsia caespitosa	Tufted hairgrass
Phleum alpinum	Alpine timothy
Poa alpina	Alpine bluegrass
Trisetum spicatum	Spike trisetum
Sibbaldia procumbens	Sibbaldia

are many more not listed here (Thornburg 1982 for more complete species lists by ecosystem).

Although many of these species are becoming available by commercial native plant seed dealers and collectors, some species may only be available in limited quantities in any given year (see Dunne, this publication) and may require the land manager to collect seeds of key species locally. Despite concerns about cost, available time, or personnel shortages, we strongly urge land managers and restoration specialists to consider collecting seral native plant seeds in their local areas to build up a supply of appropriate species, even during years when no restoration is planned. It is not uncommon for unusually abundant seed production to occur in years when no restoration or revegetation activity is implemented, but it is recommended that land managers take advantage of these periodic high seed production years by collecting and storing the seed properly until needed (see Shaw and Roundy 1997 and Young and Young 1986 for guidelines). Although in research we collect seeds of seral species either by hand or with seed collecting equipment to acquire small research plot seed mixtures, land managers may find it more cost effective to contract with native seed suppliers to collect, clean, and store larger quantities of seed until restoration is implemented. In addition, perhaps land users such as mining companies, ski area developers, and grazing permittees may be required to pay for developing sources of native plant seeds and appropriate storage facilities.

We recommend that each local office maintain a seed herbarium consisting of small samples of native seed of different important species. These samples should be stored individually in small labeled glass vials representative of the district to be used as a reference and for verifying seed composition of mixtures supplied by contractors. Also, land management agencies should streamline and standardize the permitting process for native seed collection on public lands to facilitate collection by private contractors. This will ease time constraints for obtaining adequate native seed. Although it may be inappropriate for land managers to conduct detailed observations and studies of germination requirements, physiological tolerances, successional processes, and soil chemical and physical properties, research personnel can assist in this effort and enhance understanding of the important interactions among the physical, chemical, and biological components of a particular ecosystem. Methods of collecting, cleaning, and storing seeds are discussed elsewhere (Young and Young 1986).

A pervasive concern regards the issue of how far from the disturbed site can plant seeds be collected to ensure they are still adapted and representative of the local population of that species. Although there are no definitive guidelines to ensure adaptability (distances in feet or meters are not sensitive measures), seed should be collected from those species observed as colonizers and found growing on disturbances within the same relative environmental zone as the disturbance to be treated. We find that seed collection is often more convenient on disturbances where seral species frequently occur in highest densities. However, we have also successfully collected seeds of seral species from adjacent undisturbed communities. Slope, aspect, and elevation are quantitative guides easy to follow, but are not necessarily indicative of adaptability. Similar species composition between adjacent undisturbed communities and disturbed areas serves as an excellent indicator of environmental congruity, and is probably the best guide for assuring that the collected seed is from an adapted population of the species (see Currans and others 1997 and Young and Young 1986 for additional guidelines).

Implementing Ecological Restoration on Severe Disturbances

Ecological restoration is viewed here as the process of “operative intervention” by land managers to intentionally interfere with the disturbed state in order to initiate, enhance, and accelerate succession. Restoration is envisioned in the context of an “active” process to re-establish a self-sustaining community of interdependent chemical, physical, and biological components on severely disturbed wildlands where natural succession has been deflected, suspended, or terminated. Active intervention may be required when the soil is exposed to erosion, or when the soil is lost, and alterations have occurred to the natural surface and subsurface hydrologic pathways on a local or watershed scale. In addition, when these forces impact water quality, intervention may become critical. To re-establish natural succession, and to ensure that it be consistent and congruent with successional processes of the surrounding ecosystem, we contend it is essential that indigenous native seral plant species be selected that are evolutionary products of the full range and extent of natural selection and other forces affecting genetic sorting in that environment. It is more likely that indigenous native seral species will be genetically and physiologically better suited to survive, grow, and reproduce under the environmental extremes and fluctuations of the local area than any introduced or exotic vascular plants that originated in other environments.

More passive approaches to restoration that rely on nonaggressive and nonoperative approaches, such as excluding grazing or recreational activity, are largely ineffective for restoring severe disturbances within acceptable timeframes. Active erosion, transport of toxic-laden sediments, and surface and subsurface hydrologic deterioration on such sites likely have already arrested succession and resulted in degraded water quality and other intrinsic resource values. Unless an active operative approach of intervention is adopted, whereby land managers take physical steps to reinitiate succession, deterioration of site characteristics will likely continue. In fact, in most cases of severe disturbance restoration, a combination of active and passive management strategies are required to achieve ecological restoration.

The undisturbed state is regarded here as a relative reference condition, recognizing that forces such as climate change, industrial and social pollution, and human interference in environmental conditions may have altered the overall forces responsible for creating the original community before it was disturbed. Like the original undisturbed community, the restored community would be considered to be self-sustaining, yet dynamically seral in response to successional forces, when it requires no continued long-term inputs of resources by land management to support soil genesis and nutrient cycling. Also, the restored community will minimize erosion and sediment transport commensurate with the natural ecosystem, and will ultimately lead to the re-establishment of natural surface and subsurface hydrologic pathways.

Limiting site conditions on disturbances can be ameliorated using various reclamation practices, including saving natural soil where possible or replacing the natural soil if soil is available. On many wildland disturbances, however, the natural soil has been lost and replacement soil is not available. In these cases, a complete soil analysis is justified to characterize the chemical and physical properties that may be limiting to plant establishment and growth. Various cultural amendments may be required, including:

1. Liming to adjust acidic pH upward.
2. Incorporating organic matter to improve nutrient and water-holding characteristics and to prevent contamination by heavy metals or other toxic chemicals.
3. Nutrient enhancement with various fertilizers to provide essential nutrients for plant growth.

Although some land managers may be hesitant to apply chemical fertilizers to wildland disturbances for fear of contamination of nearby waters or because of other concerns, we have found that nutrient enhancement is essential for plant emergence and early growth following germination, especially on barren inert or sterile geologic materials such as occur on mine spoils or road cuts and fills. Leaching and surface movement of fertilizers is retarded on such areas if organic matter is incorporated to assist in retention of the nutrients, and if normal precautions of application rates are followed.

Seeding of adapted native seral species collected in adjacent areas should be performed in the fall of the year to mimic natural phenological phases of seed dispersal. In most native Western environments, seed of native plants is dispersed in the late summer or fall and lays in place over the winter in or on the soil. In the spring following snowmelt and with the onset of optimum temperature and soil water conditions, germination is able to proceed at optimum rates. If seed is not distributed until spring, access to the site may be hampered or prevented due to unpredictable spring weather and other access problems, which will prevent the seed from being in place when optimum conditions occur.

It is recommended that high seeding rates be used, especially on harsh sites where conditions are particularly limiting to assure adequate seedling densities to minimize surface erosion and sediment movement. Seedling mortality tends to be very high in most Western wildland environments, and care should be taken to compensate. On severe disturbances, we usually recommend that seeding rates be adjusted to provide about 250 to 350 PLS seeds per ft^2 (2,700 to 3,800 seeds per m^2). Although these figures are higher than that recommended for normal rangeland reseedings, this seeding rate compensates for high seedling mortality and poor seed viability and germinability on severe disturbances. Mortality due to competition that might result from heavy seeding rates will compensate for mortality due to limiting environmental factors, and will provide site cover and protection at the optimum level that the environment can support. Alternatively, underseeding to avoid competition does nothing to minimize environmental mortality, and opens up bare soil to potential erosion. We also recommend that seeds be applied on the basis of "number of seeds per unit weight per unit area" rather than on the basis of a "unit weight per unit area" alone. This provides a quantitative means of assessing plant establishment by species in followup assessments and tends to equalize competition among all the species of a seed mixture.

Following seeding, a surface mulch should be applied to: (1) aid in retarding evaporative loss of soil water; (2) minimize wind redistribution of seed, fine soil particles, and other amendments; (3) moderate soil or spoil surface temperature extremes; (4) minimize chances of erosion; and (5) maximize seed trapping of native species from surrounding plant communities. Surface mulching can be applied with straw or hay, straw tacked down with commercial tackifying agents, straw crimped into the soil, or with commercial erosion blanket netting materials. We strongly favor erosion blanket materials, especially those constructed with cotton or other natural biodegradable twines and netting, due to their ease of application and efficiency in achieving the goals of surface mulching.

We recommend refertilization of restoration plant communities with N-P-K (nitrogen-phosphorus-potassium) granular fertilizers each year for three to five growing seasons following seed application to enhance growth and rooting activity and to hasten the initiation of nutrient cycling. Repeat fertilization favors the establishment of graminoid species (grasses and sedges) to the near exclusion of forbs and other life forms, but does build up a nutrient base in the rooting zone of the new community that also accelerates the re-establishment of nutrient cycling. Following the termination of repeat applications of fertilizer, graminoid dominance declines and gradually opens niches for invasion and colonization by other species and more diverse life forms. We have observed rapid increases in species and life-form richness following the termination of refertilization schedules, characterized by dramatic increases in species and life-form numbers during subsequent growing seasons. At this stage of community development, continued repeat applications of fertilizer are not warranted or required. In short, we advocate that succession be "pushed" to create an environment where nutrient cycling can sustain these early seral communities. In this manner, an attempt is made to harness succession as a restoration tool that also guides community development.

It is unreasonable to expect that restoration will ever lead to the absolute and exact replacement of each species and other components of the original community or habitat that existed prior to disturbance. This is an unnecessary and perhaps undesirable expectation from a land management perspective because: (1) there are rarely data available to guide such an objective, and (2) there are no guarantees that the current climate and other environmental factors are consistent with conditions as they may have existed when the original community was formed. Therefore, it seems more realistic to accept current successional trajectories, which are guided by prevailing environmental conditions, and to achieve a natural self-sustaining community appropriate with the overall form and function of the total ecosystem as it currently exists. Frequently, species composition, abundance, and diversity in the "restored" community vary, sometimes significantly, from that which was perceived to have characterized the original community before disturbance. This is less concerning than is the capability of the new system to function biotically and abiotically in equilibrium with the contemporary overall environment and ecosystem of the area. With the initiation of natural succession in “new” or “restored” communities or community systems, the ultimate commencement of such seral milestones as nutrient cycling and soil genesis will occur under the influence of current vegetation and climatic forces, with the end products being entirely compatible with the overall existing natural system.

The Challenge

One of our objectives in this paper is to challenge land managers to face the issue of restoring severe disturbances in wildland areas with ecologically appropriate techniques and methods, and to act on it. It is now clear that one of the most appropriate policies that should be adopted and implemented universally is to require the use of locally adapted seral native species for restoring disturbed natural communities. We recognize the many overused and cadaverous excuses for why this may be difficult to implement, but find continued reliance on them unconvincing. There are some highly significant concerns about the continued use of introduced species on wildlands that extend well beyond economics, commercial availability, livestock palatability, vigor, and other apparent attributes. These center around ecosystem health, sustainable natural resources, biodiversity, and resiliency to disturbance. In short, these concerns involve the very principles of ecosystem management.

No administrative entity has greater opportunity, means, or incentives to favor and influence the use of native species than public land management agencies. Certainly no other organizations have comparable networks of motivated and trained personnel and facilities located in such intimate contact with so wide a diversity of ecosystems and habitats as do agencies such as the Forest Service, Bureau of Land Management, National Park Service, various State and local agencies, and private organizations. In view of the commitment made by such agencies to ecosystem management, an excellent opportunity is waiting to influence the direction of future management of disturbed wildlands. By adopting an aggressive policy of requiring the production and use of native plant species and of restoring native communities, these agencies can have a tremendously positive influence on how disturbed lands are treated and restored by other government agencies, private individuals and businesses, and perhaps foreign governments.

The challenge is straightforward, simple, and consistent with ecosystem management policy: restore severely disturbed lands only with native species that originated in the same ecosystem in which the disturbance occurs. Managers should encourage their personnel to work cooperatively among themselves and with others to identify, collect, and store the various successional native species found colonizing disturbances, or contract with private firms to do so. They could encourage research to provide indepth scientific knowledge and information about native species to ensure that disturbed lands are restored to the sustainable and ecologically diverse systems they once were. With recent commitments to ecosystem management by most land managers and with the realization that concerns over biodiversity and sustainability stem in significant measure from the prevalence of introduced and exotic species now occurring within native ecosystems (due in part at least to aberrant historical revegetation practices and other ill-advised management policies), shifts in land management philosophies can finally begin favoring a more ecologically based approach to the restoration of ecosystem health.

Conclusions

It is our thesis throughout this paper that severely disturbed wildlands can be restored to a condition commensurate with the overall ecosystem of the area, and that this can be achieved by using adapted local native seral species. We advocate this position because the scientific evidence supports the hypothesis that native seral species are ecologically and physiologically adapted and acclimated to the local vagaries of climate and other environmental conditions by virtue of local natural selection over much longer time periods than species that evolved in other environments. It is clear that a major consequence of introducing exotic plant species into Western ecosystems has been a significant loss in ecosystem diversity, resiliency, and recoverability in the face of accelerating human demands for natural resources. Historically, revegetation and reclamation of disturbances by public land managers have overwhelmingly relied upon the use of non-native plant species, and have been influenced by the perception that such practices can “improve” natural conditions. This practice has been justified on the basis that any form of vegetative cover is better than none at all, and that by using introduced species to minimize erosion and stabilize disturbed sites, “nature will take its course” and return the site to some desirable state. In view of overwhelming scientific evidence, a considerably juvenile “leap of faith” is required to believe that using introduced species will accomplish erosion control, stabilize sediment, improve water quality, provide plant biomass and livestock palatability, and achieve ecosystem restoration. Not only is this position naive and misleading, it is almost certainly wrong. The evidence is now abundant that there are no guarantees that nature will take a desirable course following the use of introduced species, or that succession will progress in expected trajectories following their establishment.

Not all objections to using introduced (or unadapted) plant species are entirely justified. For example, following large devastating wildfires, enormous quantities of inexpensive and readily available seed of rapidly growing species are often required to at least temporarily stem the impacts of accelerated erosion. Given the immediacy of such problems, especially in highly populated areas, the relative unavailability and cost of most native seed in the large quantities required for such applications almost dictate that introduced species will likely continue to be used. Until recently, native species were virtually unavailable commercially, and even though many species are now readily available, their unit cost per unit weight tends to be more variable and much higher than that of most introduced species. When balanced against the goals of ecosystem health, ecological fitness, and public demands to protect sustainable wildlands, and with continued and increasing requirements that native seed be used, we are optimistic that near-parity will eventually be reached in the availability and cost of native and introduced species.

We also advocate the position that natural succession is the driving force of restoration, either human-implemented or natural, and that it should be used as a guide in designing restoration activities on disturbed public lands. Further, we suggest that land managers learn to use succession as a tool that can be "pushed" or accelerated once it has been initiated on severe disturbances through the use of such practices as revegetation and reclamation. Part of the process of implementing ecosystem management by public agencies must be upgraded to instilling in land managers an understanding of how ecosystems function under conditions of stability and under the influence of disturbance. Disturbance either by natural or human causes is a universal state in natural ecosystems. The processes of succession and ecosystem formation are foundation blocks in how these systems function, and they must be used as guides in making management decisions.

Native successional colonizer species on disturbances often are components of mid- or late-successional communities in Western ecosystems. Therefore, the most appropriate species for use in restoration are very often the same species commonly identified as the more desirable individuals for erosion control, grazing, wildlife habitat development, and other uses. Seral native species play an extraordinarily important role in ecosystem development because they are instrumental in initiating succession and all the interactive forces among the biological, physical, and chemical components of the environment that lead to ecosystem formation. Once these species colonize and become established on a disturbance, the processes of soil genesis and nutrient cycling are initiated.

As envisioned here, ecological restoration is the fairly straightforward operative and active approach to reinitiating natural succession. It is our position that active restoration is the most ecologically efficient and sound means of reestablishing natural communities that are structurally and functionally similar to the surrounding natural "undisturbed" ecosystem, especially on severe disturbances where succession has been arrested due to limiting conditions. The process of active restoration is best achieved through the direct application of various cultural treatments to ameliorate limiting site conditions, and may include revegetation and reclamation to facilitate invasion, colonization, and establishment of plants on severely disturbed sites. However, the integral upgrading step that differentiates ecological restoration from traditional revegetation and reclamation is the added caveat of utilizing natural succession as a guide, and of selecting adapted native seral species instead of more traditional introduced species. Obviously, this additional requirement involves the use of techniques and procedures that are ecologically compatible with the physiological requirements of the selected native species (such as seed collection timing and methods, seed cleaning and storage, seeding and planting methods, seedbed preparation).

Land managers can definitively set the standard for how disturbed natural ecosystems and communities can be restored to a self-sustaining, diverse, resilient condition. It is already known that healthy natural wildlands provide balance and stability, and are resilient to the long-term managed use of sustainable natural resources. In the face of accelerating public demands, ecological restoration of severe disturbances is an unavoidable necessity. No private or public entities have such unrestricted access to, and knowledge of, natural resources and the components of natural ecosystems as do public land management agencies. We urge land managers to advocate or require the use of native adapted seral plant species for revegetation, reclamation, and restoration of disturbed public lands. We suggest that stronger ties with natural resources research scientists to help identify, select, and collect seed banks of native plants suited for restoring disturbed habitats and communities throughout the West will help advance this effort. Collectively, land managers could have the commanding privilege of finally settling the matter of restoring disturbed wildlands to a near-natural state in virtually every Western ecosystem. Central to this concept is recognition of the role of natural succession as the primary driving force of ecological restoration, not only of biological components, but also of soil genesis, nutrient cycling, hydrologic patterns, and all other biotic and abiotic components of functioning ecosystems. This represents a major departure from traditional attitudes of restoration and reclamation in land management, and its significance is being substantiated and advanced by basic and applied research within some of the very agencies in which change is slowly, but finally, occurring.

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References

Allen, E. B., ed. 1988. The reconstruction of disturbed arid lands: an ecological approach. Boulder, CO: Westview Press. 261 p.

Anderson, E. 1971. Man as a maker of new plants and plant communities. In: Detwyler, T. R. Man's impact on environment. New York: McGraw Hill: 653-666.

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Baig, M. N. 1992. Natural revegetation of coal mine spoils in the Rocky Mountains of Alberta and its significance for species selection in land restoration. Mountain Research and Development. 12(3): 285-300.

Bartos, D. L.; Campbell, R. B. 1998. Decline of quaking aspen in the Interior West—examples from Utah. Rangelands. 20(1): 17-24.

Bazzaz, F. A. 1979. The physiological ecology of plant succession. Annual Review of Ecology and Systematics. 10: 351-371.

Bengson, S. A. 1986. "Native" vs. "Exotic"- the dilemma of ecological mine waste revegetation. Rangelands. 8(2): 65-67.

Benson, L. 1957. Plant classification. Boston: D. C. Heath and Co. 688 p.

Billings, W. D. 1965. Plants and the ecosystem. Belmont, CA: Wadsworth Publishing Co, Inc. 154 p.

Boyce, M. S.; Haney, A., eds. 1997. Ecosystem management: applications for sustainable forest and wildlife resources. New Haven: Yale University Press. 361 p.

Bradshaw, A. D. 1995. Alternative endpoints for reclamation. In: Cairns, J., ed. Rehabilitating damaged ecosystems. Boca Raton, FL: Lewis Publishers: 165-185.

Briggs, M. K. 1996. Riparian ecosystem recovery in arid lands: strategies and references. Tucson: University of Arizona Press. 159 p.

Brown, D. 1995. The impact of species introduced to control invasion on the vegetation of an electrical utility right-of-way. Canadian Journal of Botany. 73: 1217-1228.

Brown, R. W. 1980. Revegetation with native and introduced plant species. In: Twenty-sixth grass breeders work planning conference. June 18-20, 1980. Logan: Utah State University: 9-16.

Brown, R. W.; Johnston, R. S.; Johnson, D. A. 1979. Revegetation of disturbed alpine rangelands. In: Johnson, D. A., ed. Special management needs of alpine ecosystems. Range Science Series No. 5. Denver: Society for Range Management: 76-94.

Cairns, J., ed. 1995. Rehabilitating damaged ecosystems. Boca Raton, FL: Lewis Publishers.

Chambers, J. C.; Brown, R. W.; Johnston, R. S. 1984. Examination of plant successional stages in disturbed alpine ecosystems: a method of selecting revegetation species. In: Colbert, T. A.; Cuany, R. L., eds. Proceedings high altitude revegetation workshop No. 6. Information Series No. 53. Fort Collins: Colorado State University, Water Resources Research Institute: 215-224.

Churchill, E. D.; Hanson, H. C. 1958. The concept of climax in arctic and alpine vegetation. Botanical Review. 24: 127-191.

Clements, F. E. 1916. Plant succession: an analysis of the development of vegetation. Publ. 242. Washington, DC: Carnegie Institution of Washington. 512 p.

Conrad, M. 1983. Adaptability: the significance of variability from molecule to ecosystem. New York: Plenum Press. 383 p.

Cottam, W. P. 1947. Is Utah Sahara bound? Eleventh annual Fredrick William Reynolds lecture. Salt Lake City: University of Utah. 42 p.

Covington, W. W.; Moore, M. M. 1994. Southwestern ponderosa forest structure: changes since Euro-American settlement. Journal of Forestry. 92: 39-47.

Currans, S. P.; Kitchen, S. G.; Lambert, S. M. 1997. Ensuring identity and quality of native seeds. In: Shaw, N.; Roundy, B. A., eds. Proceedings: using seeds of native species on rangelands. Gen. Tech. Rep. INT-GTR-372. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 17-20.

Curtin, C. G. 1995. Can montane landscapes recover from human disturbance? Long-term evidence from disturbed subalpine communities. Biological Conservation. 74: 49-55.

Daubenmire, R. 1975. Plant succession on abandoned fields, and fire influences, in a steppe area in southeastern Washington. Northwest Science. 49: 36-48.

del Moral, R.; Wood, D. M. 1993. Early succession on barren volcanic plain at Mount St. Helens, Washington. American Journal of Botany. 80(9): 981-991.

Detwyler, T. R. 1971. Man's impact on environment. New York: McGraw Hill. 731 p.

Dombeck, M. P. 1998. Memorandum: Forest Service natural resource agenda. March 2, 1998. On file at: Washington, DC: U.S. Department of Agriculture, Forest Service.

Ellis, J.; Galvin, K. A. 1994. Climate patterns and land-use practices in the fry zones of Africa. BioScience. 44: 340-349.

Everett, R. L., comp. 1994. Volume IV: Restoration of stressed sites, and processes: Eastside forest ecosystem assessment. Gen. Tech. Rep. PNW-GTR-330. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 123 p.

Franklin, J. F.; Hemstrom, M. A. 1981. Aspects of succession in coniferous forests of the Pacific Northwest. In: West, D. C.; Shugart, H. H.; Botkin, D. B., eds. Forest succession: concepts and application. New York: Springer-Verlag: 212-245.

Glenn-Lewin, D. C.; van der Maarel, E. 1992. Patterns and processes of vegetation dynamics. In: Glenn-Lewin, D. C.; Peet, R. K.; Veblen, T. T., eds. Plant succession: theory and prediction. London: Chapman and Hall: 11-59

Glenn-Lewin, D. C.; Peet, R. K.; Veblen, T. T., eds. 1992. Plant succession: theory and prediction. London: Chapman and Hall. 352 p.

Gutknecht, K. W. 1992. Native vs introduced species: the new range war. Utah Science. 53(3): 69-78.

Harper, J. L. 1977. Population biology of plants. New York: Academic Press. 892 p.

Hess, K., Jr. 1995. A tale of the exotic. Utah State University Magazine. 1(3): 26-31.

Hidy, G. M.; Klieforth, H. E. 1990. Atmospheric processes affecting the climate of the Great Basin. In: Osmond, C. B.; Pitelka, L. F.; Hidy, G. M., eds. Plant biology of the basin and range. Berlin: Springer-Verlag: 17-45.

Hull, A. C.; Holmgren, R. C. 1964. Seeding southern Idaho rangelands. Res. Pap. INT-10. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 31 p.

Jackson, L. L.; Lopoukhine, N.; Hillyard, D. 1995. Commentary - ecological restoration: a definition and comments. Restoration Ecology. 3(2): 71-75.

Johnson, K. L. 1986. Crested wheatgrass: its values, problems and myths; symposium proceedings. 1983 October; Logan, UT: Utah State University. 348 p.

Kaufmann, M. R.; Graham, R. T.; Boyce, D. A., Jr.; Moir, W. H.; Perry, L.; Reynolds, R. T.; Bassett, R. L.; Mehlhop, P.; Edminster, C. B.; Block, W. M.; Corn, P. S. 1994. An ecological basis for ecosystem management. Gen. Tech. Rep. RM-246. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p.

Kay, C. E. 1994. Aboriginal overkill: the role of native Americans in structuring Western ecosystems. Human Nature. 5(4): 359-398.

Kohm, K. A.; Franklin, J. F. 1997. Creating a forestry for the 21st Century: The science of ecosystem management. Washington, DC: Island Press. 475 p.

Kricher, J. C. 1980. Needs of weeds. Natural History. 89(12): 36-45.

Lesica, P.; DeLuca, T. H. 1996. Long-term harmful effects of crested wheatgrass on Great Plains grassland ecosystems. Journal of Soil and Water Conservation. 51: 408-409.

MacMahon, J. A. 1983. Nothing succeeds like succession: ecology and the human lot. 67th Faculty Honor Lecture. Logan: Utah State University Press. Logan. 31 p.

MacMahon, J. A.; Jordan, W. 1994. Ecological restoration. In: Meffe, G. K.; Carroll, C. R. Principles of conservation biology. Sunderland, MA: Sinauer Associates, Inc.: 409-438.

Mattson, W. J. 1996. Escalating anthropogenic stresses on forest ecosystems: forcing benign plant-insect interactions into new interaction trajectories. In: Korpilahti, E.; Mikkela, H.; Salonen, T., eds. Caring for the forest: research in a changing world. Congress Rep. Vol 2. Finn. IUFRO World Congress Organizing Committee: 338-342.

McIntosh, R. P. 1980. The relationship between succession and the recovery process in ecosystems. In: Cairns, J., Jr., ed. The recovery process in damaged ecosystems. Ann Arbor, MI: Ann Arbor Science Publishers: 11-62.

McIntosh, R. P. 1981. Succession and ecological theory. In: West, D. C.; Shugart, H. H.; Botkin, D. B., eds. Forest succession: concepts and application. New York: Springer-Verlag: 10-23.

Meeuwig, R. O. 1960. Watersheds A and B—a study of surface runoff and erosion in the subalpine zone of central Utah. Journal of Forestry. 58: 556-560.

Mills, E. L.; Leach, J. H.; Carlton, J. T.; Secor, C. L. 1994. Exotic species and the integrity of the Great Lakes. BioScience. 44(10): 666-676.

Monsen, S. B. 1994. The competitive influences of cheatgrass (*Bromus tectorum*) on site restoration. In: Monsen, S. B.; Kitchen, S. G., eds. Proceedings—ecology and management of annual rangelands. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-50.

Monsen, S. B.; McArthur, E. D. 1995. Implications of early Intermountain range and watershed restoration practices. In: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann, D. K. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station:16-25.

Mueggler, W. F. 1965. Ecology of seral shrub communities in the cedar-hemlock zone of northern Idaho. Ecological Monographs. 35: 165-185.

Munshower, F. F. 1993. Practical handbook of disturbed land revegetation. Boca Raton, FL: Lewis Publishers. 265 p.

Nilsen, E. T.; Orcutt, D. M. 1996. The physiology of plants under stress: abiotic factors. New York: John Wiley and Sons, Inc. 689 p.

Perry, D. A. 1994. Forest ecosystems. Baltimore, MD: The Johns Hopkins University Press. 649 p.

Regier, H. A. 1993. The notion of natural and cultural integrity. In: Woodley, S.; Kay, J.; Francis, G., eds. Ecological integrity and the management of ecosystems. St. Lucie Press: 3-18.

Richardson, B. Z.; Farmer, E. E. 1985. Revegetation of phosphate mined lands in the Intermountain West. In: Robertson, D. J., ed. Reclamation and the phosphate industry: proceedings of the symposium; 1983 January 26-28; Clearwater Beach, FL. Florida Institute of Phosphate Research: 374-389.

Rogers, P. 1996. Disturbance ecology and forest management: a review of the literature. Gen. Tech. Rep. INT-GTR-336. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 16 p.

Roundy, B. A., Shaw, N. L.; Booth, D. T. 1997. Using native seeds on rangelands. In: Shaw, N. L. and Roundy, B. A., eds. Proceedings: Using Seeds of Native Species on Rangelands. Gen. Tech. Rep. INT-GTR-372. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 1-8.

Schramm, J. R. 1966. Plant colonization studies on black wastes from anthracite mining in Pennsylvania. Philadelphia: Transactions of the American Philosophical Society. 56 Part 1: 1-194.

Seagrave, S. 1976. Scientists learn from wild plants. BioScience. 26: 153-155.

Shaw, N. L.; Roundy, B. A., eds. 1997. Proceedings: using seeds of native species on rangelands. Gen. Tech. Rep. INT-GTR-372. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 30 p.

Sheley, R. L.; Manoukian, M.; Marks, G. 1996. Preventing noxious weed invasion. Rangelands. 18: 100-101.

Society for Range Management. 1974. A glossary of terms used in range management. Denver, CO: Society for Range Management. 36 p.

Smith, J. M. 1978. Optimization theory in evolution. Annual Review of Ecology and Systematics. 9: 31-56.

Smith, P. W.; DePuit, E. J.; Richardson, B. Z. 1988. Plant community development on petroleum drill sites in northwestern Wyoming. Journal of Range Management. 41(5): 372-377.

Smith, S. D.; Nowak, R. S. 1990. Ecophysiology of plants in the Intermountain lowlands. In: Osmond, C. B.; Pitelka, L. F.; Hidy, G. M., eds. Plant biology of the basin and range. Berlin: Springer-Verlag: 179-241.

Stebbins, G. L. 1974. Flowering plants: evolution above the species level. Cambridge, MD: Harvard University Press. 399 p.

Stebbins, G. L. 1979. Fifty years of plant evolution. In: Solbrig, O. T.; Jain, S.; Johnson, G. B.; Raven, P. H., eds. Topics in plant population biology. New York: Columbia University Press: 18-41.

Stewart, G. 1941. Historic records bearing on agricultural and grazing ecology in Utah. Journal of Forestry. 39(4): 362-375.

Thomas, J. W. 1997. Foreward. In: Kohm, K. A.; Franklin, J. F. Creating a forestry for the 21st Century: the science of ecosystem management. Washington, DC: Island Press. 475 p.

Thornburg, A. A. 1982. Plant materials for use on surface-mined lands in arid and semiarid regions. SCS-TP-157. U.S. Department of Agriculture, Soil Conservation Service. 88 p.

Thornburg, A. A.; Fuchs, S. H. 1978. Plant materials and requirements for growth in dry regions. In: Schaller, F. W.; Sutton, P., eds. Reclamation of drastically disturbed lands. Madison, WI: American Society of Agronomy: 411-423.

Trimble, S. 1989. The sagebrush ocean: a natural history of the Great Basin. Reno: University of Nevada Press. 248 p.

Urbanska, M.; Webb, N. R.; Edwards, P. J., eds. 1997. Restoration ecology and sustainable development. Cambridge, MA: Cambridge University Press. 397 p.

Vallentine, J. F. 1989. Range development and improvement. San Diego, CA: Academic Press. 524 p.

Vogl, R. J. 1980. The ecological factors that produce perturbation-dependent ecosystems. In: Cairns, J., Jr., ed. The recovery process in damaged ecosystems. Ann Arbor, MI: Ann Arbor Science Publishers Inc.: 63-94.

Wallace, A.; Romney, E. M. 1980. The role of pioneer species in revegetation of disturbed desert areas. Great Basin Naturalist Memoirs No. 4. Provo, UT: Brigham Young University: 31-32.

West, N. E.; Stark, J. M.; Johnson, D. W.; Abrams, M. M.; Wight, J. R.; Heggem, D.; Peck, S. 1994. Effects of climatic change on the edaphic features of arid and semiarid lands of Western North America. Arid Soil Research and Rehabilitation. 8: 307-351.

White, P. S. 1979. Pattern, process, and natural disturbance in vegetation. Botanical Review. 45(3): 229-299.

Whittaker, R. H. 1975. Communities and ecosystems. New York: Macmillan Publishing Co., Inc. 385 p.

Williams, J. E.; Wood, C. A.; Dombeck, M. P., eds. 1997. Watershed restoration: principles and practices. Bethesda, MD: American Fisheries Society. 561 p.

Winterhalder, K. 1995. Natural recovery of vascular plant communities on the industrial barrens of the Sudbury area. In: Gunn, J. M., ed. Restoration and recovery of an industrial region: progress in restoring the smelter-damaged landscape near Sudbury, Canada. New York: Springer-Verlag: 93-102.

Woodley, S.; Kay, J.; Francis, G., eds. 1993. Ecological integrity and the management of ecosystems. St. Lucie Press. 220 p.

Yaffee, S. L.; Phillips, A. F.; Frentz, I. C.; Hardy, P. W.; Maleki, S. M.; Thorpe, B. E. 1996. Ecosystem management in the United States: an assessment of current experience. Washington, DC: Island Press. 352 p.

Young, J. A.; Evans, R. A. 1976. Responses of weed populations to human manipulations of the natural environment. Weed Science. 24: 186-190.

Young, J. A.; Young, C. G. 1986. Collecting, processing, and germinating seeds of wildland plants. Portland, OR: Timber Press. 236 p.

Zufelt, N. 1998. [Personal communication]. Regional Reclamation Specialist. Ogden, UT: U.S. Department of Agriculture, Forest Service, Region 4.

Collection and Production of Indigenous Plant Material for National Park Restoration

Mark Majerus

Abstract—The National Park Service is taking the "Restoration" approach to reestablishing native plant communities by salvaging topsoil and by seeding and planting native indigenous plant materials. In this way, they are making every effort to protect the genetic integrity of the often unique native plant resource. Since 1985, Yellowstone and Glacier National Parks have been working with the USDA Natural Resources Conservation Service, Plant Materials Center in Bridger, MT, to identify native plant species from which seed can be readily collected, propagated on a large scale, and successfully reestablished on disturbed roadsides. Early colonizers are utilized for initial protection and stabilization, but late seral dominant species are added to mixtures to add longevity to resulting plant communities.

Revegetation, reclamation, and restoration all imply the reestablishment of plant cover on a disturbed site, but if taken literally may imply three levels or intensities of site mitigation. "Revegetation" is simply the reestablishment of plant cover, often a monoculture of an introduced plant species. Although relatively inexpensive, revegetation may not offer permanence or ecological stability. "Reclamation" has been defined historically as the process of returning disturbed land to a condition that approximates the original site conditions and is habitable by the same or similar plants and animals that existed on the site before disturbance (Redente and others 1994). Restoration strives to emulate the structure, function, diversity, and dynamics of a specific ecosystem. Topsoil salvage can preserve the soil biota along with viable propagules in indigenous plant materials. By utilizing native indigenous materials (seed, cuttings, transplants), the genetic integrity and diversity of the native plant communities may be maintained. Even with soil salvage and the use of native indigenous plants, restoration must not be interpreted as a discrete event, but rather as an ongoing process involving the reestablishment of nutrient cycling, plant succession, and plant community dynamics.

The U.S. Department of the Interior, National Park Service has adopted a policy of restoration of all disturbed sites related to road construction, visitor impact, and facility maintenance. The National Park Service is committed to maintaining the genetic integrity of the unique native flora, with secondary goals of erosion control, competition with exotic and noxious invasive plants, and improving overall aesthetics of a disturbed site. In 1985, with the financial support of the Federal Highway Administration, both Yellowstone National Park (northwestern Wyoming) and Glacier National Park (northwestern Montana) initiated restoration programs that involved topsoil salvage and plant salvage, native indigenous seed collection and production, plant propagation from seed and cuttings, and extensive seeding and planting of disturbed sites. A nationwide cooperative agreement between the National Park Service and the U.S. Department of Agriculture's Natural Resources Conservation Service Plant Materials Centers was established in 1986 to assist in the determination of which native species could be readily collected, increased, and successfully reestablished on disturbed sites. The decision by the National Park Service to adopt a restoration policy has generated many unanswered questions and much controversy concerning the protection and preservation of the indigenous gene pools, such as:

- What plant species can be considered indigenous to an open disturbance in a forest community?
- What constitutes the limits of a genotype? How far away from the project area can plant propagules be collected and still be within these limits?
- What species can be readily collected and produced using standard agricultural techniques?
- By taking seed outside of the Parks to a dissimilar environment to increase seed or plants, is genetic drift or natural selection going to impact the genetic integrity of the plant material?
- What type of plant community is an acceptable restoration goal?

Species Selection

Once the National Park Service made the decision to use native indigenous plant materials in its restoration efforts, its next decision was to determine what species would naturally colonize on open disturbances within forest communities. In Yellowstone National Park, the first road project (Old Faithful to West Thumb) was through lodgepole pine (*Pinus contorta*) habitat types, whereas in Glacier National Park, the first project was along Lake McDonald through a cedar-hemlock (*Thuja plicata*/*Tsuga heterophylla*) habitat type. The open road corridors would not support the understory species of the forest communities. By examining abandoned roads, burns, old disturbance areas (both manmade and natural), and open parks and meadows it was possible to identify early colonizing species. Chambers and others (1984), working in the alpine zone of the Beartooth Mountains of south-central Montana, found early colonizing species to have characteristics most desirable for

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reclamation of alpine disturbances. These species exhibited an ability to establish and grow on harsh phytotoxic sites, frequently have larger ecological amplitudes, and are distributed over wide geographic areas. Harper (1977) stated that early colonizing species usually had abundant and consistent seed production, effective seed dissemination, higher germination percentages, and broad tolerance for establishment on disturbed sites. Late seral dominants, on the other hand, as defined by Johnson and Billings (1962), are found on older and less severely disturbed sites. These species are often included in seed mixtures to accelerate succession, but may not be completely successful because of competition from early colonizers, or simply may not be suited to the edaphic conditions of the disturbed site. Both Yellowstone and Glacier Parks are creating mixtures for each specific project that include both early colonizing and late seral dominant species (table 1). Mixtures are relatively simple, relying somewhat on existing propagules in the salvaged topsoil and seed rain from adjacent areas to compliment the seeded material.

Genotype Determination

The genetic variability within and among plant populations vary by species as a function of geographic range, reproduction mode, mating system, seed dispersal mechanism, and stage of succession (Hamrick 1983). Whether a species is self-pollinating or outcrossing makes a difference in genetic variability. The self-pollinating mode of reproduction limits the movement of alleles from one population to another, so these species are found in small disjunct populations with little variation within populations, but distinct variation among populations. Outbreeding plants have widely dispersed pollen and seed, and tend to exhibit significant variation among individuals but less variation among populations. Species with winged or plumose seeds have the greatest potential for gene movement and subsequently have less variability among populations.

To capture the genetic diversity of early successional stage (primarily selfed) plants, seed would have to be sampled from several populations within a project area. With late seral dominants (primarily outcrossed), however, the number of populations that would need to be harvested is significantly less. When a disturbed site is planted with seed from an adjacent or close-proximity site, there is a possibility that a distinct new genotype may develop. Jain and Bradshaw (1966) found that those species that evolve on a disturbed site may actually be genetically different from individuals of the same species on adjacent undisturbed sites. Antonovics (1968) found that on harsh sites characterized by low pH and heavy metals, grass species had the ability to change from an outcrossing to a self-pollinating mode of reproduction to prevent dilution of the gene pool by adjacent unadapted populations. This raises the question of the need to harvest from many sites if a new distinct genotype will evolve on disturbed sites as it is influenced by the harshness and edaphic conditions of the site.

Table 1—Native plant species found to reestablish naturally on disturbed sites in Yellowstone and Glacier National Parks.

Scientific name	Common name
Colonizers	
Short-lived perennial grasses	**Perennial forbs**
Elymus tracycaulus	Slender wheatgrass
Bromus marginatus	Mountain brome
Elymus elymoides	Bottlebrush squirreltail
Elymus glaucus	Blue wildrye
Achillea millefolium	Western yarrow
Anaphalis margaritacea	Pearlyeverlasting
Phacelia hastata	Silverleaf phacelia
Aster integrifolius	Thickstem aster
S*olidago elongata*	Goldenrod
Viguiera multiflora	Showy goldeneye
Late seral dominants	
Long-lived perennial grasses	**Perennial forbs**
Poa ampla	Big bluegrass
Deschampsia cespitosa	Tufted hairgrass
Pseudoroegneria spicata	Bluebunch wheatgrass
Festuca idahoensis	Idaho fescue
Poa alpina	Alpine bluegrass
Phleum alpinum	Alpine timothy
Agrostis scabra	Rough bentgrass
Lupinus argenteus	Silvery lupine
Eriogonum umbellatum	Sulfur eriogonum
Penstemon confertus	Yellow penstemon
Geranium viscosissimum	Sticky geranium
Potentilla gracilis	Cinquefoil

Seed Collection

Seed collection within National Park boundaries can only be done by hand or by using backpack vacuums. Collection outside of the Park is also done by hand because of the rough terrain or small plant communities that are harvested. Hand collection consists of hand stripping or cutting off seedheads—a time consuming task however it is performed. The National Park Service uses a variety of permanent and seasonal employees and volunteers to collect most of the seed. After drying the seed, they send the harvested material to the Bridger Plant Materials Center for cleaning and storage. The amount of seed that can be harvested per person-hour varies with species, density of the plant population, yearly climate, degree of seed set, and the individuals collecting the seed (table 2).

The easiest species to collect are the short-lived pioneer species such as mountain brome and slender wheatgrass. Collection of seed from forbs such as pussytoes (*Antennaria* sp.) and broadleaf arnica (*Arnica latifolia*) is very time consuming and often not worth the effort. Seeds of a majority of the composites (Asteraceae Family) are difficult to collect because there is usually poor fill, the plumose seed has a very short time period between maturity and shattering, and there is significant insect predation on the seedheads. Those species that are easiest to collect are generally the easiest to produce because of their seed production potential and generally high level of seed viability.

Since 1985, seed of 47 species of grasses and sedges, 75 species of forbs, and 33 species of trees and shrubs have been collected from 137 different sites in Yellowstone National Park. During the same period, seed of 42 species of grasses,

Table 2—Seed collection rates of the primary plant species being used for restoration projects in Yellowstone National Park.

Common name	Scientific name	Number of collections	Time ratio Range	Average
			grams per person-hour	
Grasses				
Mountain brome	*Bromus marginatus*	61	30 - 1008	269
Slender wheatgrass	*Elymus trachycaulus*	91	35 - 976	235
Bluegrasses	*Poa* spp.	17	8 - 514	149
Blue wildrye	*Elymus glaucus*	49	23 - 465	147
Bluebunch wheatgrass	*Pseudoroegneria spicata*	29	10 - 433	122
Rough bentgrass	*Agrostis scabra*	20	29 - 197	94
Tufted hairgrass	*Deschampsia cespitosa*	28	3 - 318	89
Bottlebrush squirreltail	*Elymus elymoides*	23	12 - 195	77
Richardson needlegrass	*Stipa richardsonii*	10	23 - 118	67
Idaho fescue	*Festuca idahoensis*	38	13 - 234	63
Subalpine needlegrass	*Stipa nelsonii*	28	9 - 96	43
Forbs				
Showy goldeneye	*Viguiera multiflora*	8	28 - 332	126
Penstemons	*Penstemon* spp.	48	14 - 1583	122
Helianthella	*Helianthella uniflora*	15	9 - 339	88
Western yarrow	*Achillea millefolium*	82	3 - 188	53
Thickstem aster	*Aster integrifolius*	34	3 - 136	52
Lupines	*Lupinus* spp.	39	5 - 222	49
Silverleaf phacelia	*Phacelia hastata*	25	4 - 300	46
Pearlyeverlasting	*Anaphalis margaritacea*	23	3 - 149	41
Goldenrod	*Solidago* spp.	22	2 - 78	41
Cinquefoils	*Potentilla* spp.	55	9 - 110	39
Hairy goldenaster	*Heterotheca villosa*	11	4 - 57	29
Sticky geranium	*Geranium viscosissimum*	19	5 - 62	16

sedges, and rushes, 84 species of forbs, and 37 species of trees and shrubs were collected from 104 sites in and around Glacier National Park. The cost of collection varies from about $40 per kg for large-seeded grasses to well over $200 per kg for some of the forbs.

Seed and Plant Production

The Bridger Plant Materials Center is located approximately 160 km northeast of Yellowstone National Park and 560 km southeast of Glacier National Park. The elevation at Bridger is 1,128 m and the average growing season is 130 days. Seed is collected from sites at 1,800 m to 2,400 m in Yellowstone and from elevations of 970 m to 2,050 m in Glacier—most sites have less than 100-day growing seasons. The most significant shortcoming at Bridger, for seed production of mountainous species, has been the hot dry spring weather. Species that mature early and set seed in August and September in the mountains will mature as early as late June or early July in Bridger. Hot weather during anthesis will significantly reduce pollination and subsequent seed set.

Seed production fields are established by seeding a 1 m spaced row at a rate of 90 pure-live-seeds per linear meter of row. Fields are furrow-irrigated, fall-fertilized (80 kg nitrogen and 30 kg phosphorus per ha), and cultivated and sprayed following standard procedures used by most commercial seed growers. Extensive hand-roguing is required to minimize weed and off-type invasion. Depending on the size of the seed increase field, seed is harvested by hand, head-harvested with a swather equipped with a canvas catch basin, or harvested with one of two small plot combines. All harvesting equipment is thoroughly cleaned between harvesting of each individual ecotype.

There is some question as to how much natural selection and genetic drift will occur when seed is grown at a site remote from the original source. Merrell (1981) stated that individuals developing at the same time, but under different environmental regimes, may develop different phenotypes, even though their genotype is essentially the same. Seed production at a site remote from and dissimilar to the original collection site has the potential for natural selection and genetic drift. There is a potential for a decrease in genetic diversity at several stages of production, for example: (1) The sizing nature of the cleaning process may exclude the largest and smallest seeds; (2) harsh conditions at the time of germination and emergence may limit the survival to only the most viable seeds; (3) as individual plants compete for space and nutrients in the seed production field, some individuals may succumb to others; and (4) during the harvesting process only the seeds that are mature at the time of harvest will be represented—early and late maturing individuals will be excluded.

Samples of three generations of mountain brome were evaluated both phenotypically and genotypically by Dr. Thomas Mitchell-Olds and Dianne Pavek at the University of Montana-Missoula. The original collection (G_0) was collected in the Dickie Creek drainage along the southern border of Glacier Park (1987), the second generation (G_1)

was produced at the Bridger Plant Materials Center (1990) in a field established with G_0 seed, and the third generation (G_2) was produced at the Bridger Plant Materials Center (1992) from a stand established with G_1 seed. Mitchell-Olds (1993) found the phenotype variation (comparing morphological characteristics at three common garden sites in Glacier National Park) and genotypic variation (isozyme electrophoretic analysis utilizing 25 scorable bands) was not significant among the three generations of mountain brome. The distance coefficients (after Johnson and Wischern 1982) and the similarity coefficients (after Gottlieb 1977) indicated that there was very little difference among the original mountain brome collection and the two subsequent generations grown at the Bridger Plant Materials Center. Although this data is for only one species, it supports the potential for producing native indigenous plant materials at sites remote from their source with minimal impact on the genetic integrity of the original gene pool.

If increased seed is to be used on restoration sites, the planning process must allow for at least 3 years—the first to collect and clean the seed, the second to plant and establish a seed production field, and the third year to make the first harvest. Three to four harvests can be taken from a field before production drops to an uneconomical level. The cost of producing seed under commercial conditions varies greatly with species, size of field, yearly environmental conditions, and the timing of harvest. However, seed production under cultivated conditions produces a more reliable quality and quantity of seed than under natural conditions.

To date, there are only a few private growers that are attempting to grow native indigenous ecotypes under contract with the National Park Service and the U.S. Forest Service (table 3). Contracts with private growers include stipulations to guarantee genetic purity and usually a set price as well as the maximum and minimum amount of seed that will be purchased.

Both Yellowstone and Glacier National Parks are using multiple sources of plant materials for their restoration projects: (1) salvaged plant material is either directly transplanted or potted for later use; (2) seed of native indigenous plants is collected for direct seeding, seeding of flats or containers, or for seed increase at the Bridger Plant Materials Center; (3) cuttings are propagated at each Park's own nursery facilities; and (4) containerized material is grown at their nurseries or contracted to commercial nurseries.

Table 3—Estimated cost of production of native ecotypes by commercial growers.

	Asking price[a]	
Scientific name	**Dollars per pound**	**Dollars per kilogram**
Bromus marginatus	3-10	6-22
Deschampsia cespitosa	10-30	22-66
Elymus glaucus	8-28	18-62
Agrostis idahoensis	9	20
Glyceria elata	8	18
Elymus elymoides	17	37
Stipa comata	75	165
Stipa columbiana	46	101

[a]Source: contracts between U.S. Forest Service and private seed growers in Oregon.

Planting and Monitoring

To maximize species diversity and compatibility, plant mixtures are designed to minimize competitive interactions. The goal of the restoration effort is to produce a plant community that is as stable as the adjacent undisturbed area, which can sustain itself as it progresses through successional stages. The nature of the disturbance may place constraints on both the ability to restore the site and the subsequent success that occurs on that site (Chambers and others 1990). To minimize competition, seed mixtures should not be too complex. With linear disturbances in particular, seed rain from adjacent areas will provide added species diversity to a seeded plant community.

Restoration within Yellowstone and Glacier National Parks begins with the salvage of topsoil. The topsoil is carefully stripped and stored in windrows along the upper edge of the road project and redistributed on the prepared cuts and fills during the same growing season. The surface is left rough, and downfall logs and rocks are strategically placed to create micro-niches. Most of the seeding is done by hand broadcasting, followed by mulching with wood chips, extruded aspen fiber, or straw to protect against surface soil erosion and reduce soil surface drying during germination and emergence. Seed mixtures are a combination of short-lived perennials (colonizers) and long-lived perennials (late seral dominants). The seed mixtures are relatively simple, consisting of four to six grasses and three to five forbs (table 4). Shrubs and some forbs are planted as transplants, containerized material, or as bareroot stock.

Monitoring is an integral part of the restoration process—providing information on the success of establishment and survival, species compatibility, and long-range stability of the established plant communities. Glacier National Park's monitoring program is loosely based on the U.S. Forest Service ECODATA (Jensen and others 1992) ocular plot methodology. This technique uses both microplot and ocular surveys of ground cover, species cover, species composition, erosion status, plant mortality, plant growth, and invasion of exotics. Both Parks utilize varying intensities of monitoring:

Level I is basic documentation of ground cover and the presence of exotics (often used to document conditions on small backcountry projects).

Level II is general evaluation of surface status and total vegetation cover including species lists, mortality, plant density, and overall plant vigor (most commonly used along road shoulders).

Level III involves microplots and shrub transects to collect data suitable for statistical analysis (utilized on large obliterated turnouts and larger cut-and-fill slopes).

Level IV uses replicated plot designs to evaluate the effectiveness of various combinations of restoration treatments (seeded versus unseeded, mulched versus unmulched, fertilized versus unfertilized, chemical weed control treatments of weeds and exotics, and nurse and cover crop alternatives).

The restoration attempts in Yellowstone and Glacier National Parks have made every effort to maintain the genetic integrity of the plant material, to salvage and protect the viability of the soil biota (micro-organisms, mycorrhizae, and plant propagules), and to create stable self-sustaining plant communities on disturbed sites. These new plant communities continue to change as some of the colonizer species give way to the late seral species and as additional species appear as a result of seed rain from adjacent sites and soil-borne plant propagules. Research results indicate that seeding and associated mulching practices provide erosion control, but do not totally restrict the encroachment of exotics without additional weed control measures.

Table 4—Basic seed mixtures developed for different vegetation types in Glacier and Yellowstone National Parks (other species are used as available).

Glacier National Park	Yellowstone National Park
Alpine	**Lodgepole pine forest**
Poa alpina[a]	*Bromus marginatus*[a]
Phleum alpinum[a]	*Elymus trachycaulus*[a]
Poa gracilima[a]	*Elymus elymoides*[a]
Deschampsia atropurpurea[a]	*Agrostis scabra*[a]
Carex haydeniana	*Poa ampla*[a]
Aster laevis	*Achillea millefolium*[a]
Sibbaldia procumbens	*Lupinus sericeus*[a]
Senecio triangularis	*Phacelia hastata*[a]
Epilobium alpinum	*Potentilla gracilis*
Hypericum formosum	*Eriogonum umbellatum*
	Viguiera multiflora[a]
Fescue grassland	
Bromus marginatus[a]	**Northern grasslands**
Pseudoroegneria spicata[a]	*Stipa comata*[a]
Festuca idahoensis[a]	*Pascopyrum smithii*[a]
Festuca compestris[a]	*Leymus cinereus*[a]
Koeleria macrantha[a]	*Nassella viridula*[a]
Elymus elymoides	*Bromus anomalus*[a]
Gaillardia aristata[a]	*Achillea millefolium*[a]
Hedysarum boreale[a]	*Linum lewisii*[a]
Geranium viscosissimum	*Potentilla fruticosa*
Huechera cylindrica[a]	
Potentilla gracilis[a]	**Wetlands**
	Deschampsia cespitosa[a]
Cedar Hemlock	*Agrostis scabra*[a]
Bromus marginatus[a]	*Elymus trachycaulus*[a]
Elymus glaucus[a]	*Pedicularis groenlandica*
Deschampsia cespitosa[a]	*Gentiana dentosa*
Calamagrostis rubescens	
Achillea millefolium[a]	
Penstemon confertus[a]	
Penstemon albertinus	
Aster laevis	
Antennaria neglecta	

[a]Species of seeds or plants that have been successfully produced at the Bridger Plant Materials Center.

Both Parks are satisfied that the seeding and planting of native indigenous plant material on major disturbances, rather than letting nature take its course, is the proper procedure for the preservation and protection of native gene pools.

References

Antonovics, J. 1968. Evolution in closely adjacent plant populations. V. Evolution of self-fertility. Heredity. 23: 219-238.

Chambers, J. C.; Brown, R. W.; Johnston, R. S. 1984. Examination of plant successional stages in disturbed alpine ecosystems: a method of selecting revegetation species. In: Colbert, T. A.; Cuany, R. L., eds. Proceedings: high altitude revegetation workshop, No. 6. Information Series No. 53. Colorado State University. Water Resources Research Institute: 215-224.

Chambers, J. C.; McMahon, J. A.; Wade, G. L. 1990. Difference in successional processes among biomes: importance in obtaining and evaluating reclamation success. In: Chambers, J. C.; Wade, G. L., eds. Evaluating reclamation success: the ecological consideration—proceedings of a symposium; April 23-26; Charleston, WV: Gen. Tech. Rep. NE-164. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Gottlieb, L. 1977. Electrophoretic evidence and applied systematics. Annals of the Missouri Botanical Garden. 64: 161-180.

Hamrick, J. L. 1983. The distribution of genetic variation within and among natural plant populations. In: Schonewald-Cox, C. M.; Chambers, S. M.; MacBryde, G.; Thomas, L., eds. Genetics and conservation—a reference for managing wild animals and plant populations. Menlo Park, CA: Benjamin Cummings Publishing Co., Inc.: 335-348.

Harper, J. L. 1977. Population biology of plants. New York: Academic Press.

Jain, S. K.; Bradshaw, A. D. 1966. Evolutionary divergence among adjacent plant populations. I. The evidence and its theoretical analysis. Heredity. 21: 407-441.

Jensen, M. E.; Hann, W.; Keane, R. E. 1992. Ecosystem inventory and analysis guide. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

Johnson, P. L.; Billings, W. D. 1962. The alpine vegetation of the Beartooth Plateau in relation to cryopedogenic processes and patterns. Ecological Monographs. 32: 105-135.

Johnson, R. A.; Wischern, D. W. 1982. Applied multivariate statistical analysis. Englewood Cliffs, NJ: Prentice Hall, Inc.

Mitchell-Olds, T. 1993. Genetic diversity of plant species in Glacier National Park: implications in management. Annual report—National Park Service Contract No. CA-1463-5-0001.

Merrell, D. 1981. Ecological genetics. Minneapolis: University of Minnesota.

Redente, E.; Cotts, N.; Schuller, R. 1994. Abandoned road restoration methods tested at Grand Teton National Park. Park Service. Vol. 14, No. 2. U.S. Department of the Interior, National Park Service.

Native Plant Restoration on the Going-to-the-Sun Road, Glacier National Park

David E. Lange
Joyce Lapp

Abstract—Since 1991, 53 acres of roadside vegetation and soil were removed along sections of the historic Going-to-the-Sun Road during road rehabilitation activities. Restoration strategies used indigenous plant material to re-establish plant cover, prevent erosion, compete with exotics, and improve aesthetics. From several hundred collections, simple seed mixes were created that included early colonizers and late seral species. Native forbs, shrubs, and trees were propagated as bareroot and containerized material. Grass was grown as seed and increased to larger quantities with off-site seed production plantings. Revegetation incorporated a combination of plant and soil salvage, seeding, inplanting, and natural regeneration. Our monitoring program was used to assess results and to help make decisions about species selection, seeding rates, successional strategies, and realistic objectives for restoration.

Glacier National Park is one of the world's most significant natural areas containing spectacular topography, active glaciers, and unique biotic diversity. It is located in the Northern Rocky Mountains of Montana at the center of an extensive ecosystem stretching from Banff and Jasper National Parks in Canada south to Yellowstone and Grand Teton National Parks. This is an internationally significant location from the standpoint of scientific, aesthetic, and conservation values.

The Going-to-the-Sun Road is the primary way visitors see Glacier National Park. It is renowned for its scenic beauty, historic value, and unparalleled driving experience. Nearly two million visitors travel the road annually. The historic qualities of the road, combined with the vegetation, rock, and scenery, are key parts of the experience for visitors to Glacier National Park. The National Park Service manages this Road to preserve its cultural and natural values as well as to maintain the unique visitor experience.

The Going-to-the-Sun Road was constructed in 1932 as the only road linking the Park's east and west sides across the Continental Divide. Construction, which carved a road out of the mountainside, was truly an engineering feat. This unique road was designated a National Historical Landmark in 1997 because of its design significance. It was the first park road built in this country in cooperation with the Federal Highway Administration. With passage of the National Surface Transportation Assistance Act of 1982, Congress recognized a nationwide need for rehabilitating and upgrading roads in the National Parks. The National Park Service, in partnership with the Federal Highway Administration, established a road improvement program. Glacier National Park became a participant in 1984. Since then, there have been seven road projects funded for Glacier at a total cost of $25 million.

Restoration Program

When native vegetation was removed as part of the construction process, the consequences included erosion, invasion by exotic plants, displacement of animals, loss of screening or buffers, and reduced aesthetic value. Our restoration strategies sought to emulate structure, function, diversity, and dynamics of the adjacent plant community. Indigenous plant material was used to maintain genetic integrity and diversity. Soil and plants were salvaged and stored for replanting after construction. Native seed and cuttings were collected annually and propagated in the Park's native plant nursery and greenhouse. Seed was sent to the Natural Resources Conservation Service Plant Materials Center in Bridger, MT, for storage or for increased production, or sent to private contractors for propagation. A resource crew implemented revegetation plans and monitored results.

Goal

The goal for restoration is that within 5 years following construction, a vegetation cover of native plants is established that blends with the adjacent plant communities, is ecologically compatible with the surrounding community, and is consistent with functional maintenance and safety requirements.

Objectives

The project-specific, goal-oriented, and measurable objectives are to:

- Preserve genetic integrity of native floral populations
- Provide for optimum survival and vigor of plant material by using species collected at or near the disturbed site
- Quickly provide plant cover to stabilize soil and prevent erosion

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- Keep coverage of exotic plants low in cut-and-fill slopes and prevent invasion into undisturbed site
- Restore species composition and structure that blends in aesthetically and ecologically with adjacent, undisturbed plant communities
- Use roadside vegetation that will not be a long-term food attraction to wildlife
- Select vegetation that is low maintenance, durable, safe, and able to stand up under heavy foot and automobile traffic
- Provide opportunity for research and technology transfer

Partnerships

Since 1986, Glacier National Park has used partnerships in planning, designing and constructing seven road projects within Glacier National Park. Nearly 53 acres of roadside disturbance have been revegetated through varied habitats along the Going-to-the-Sun Road. Revegetation costs range from 4 to 8 percent of construction project costs. Budgets have included 3 percent for administration, 40 percent for plant production, 32 percent for revegetation, 14 percent for monitoring, and 11 percent for planning and design. Engineering and construction specifications were modified to reflect a high degree of consideration for the existing flora and fauna.

Planning efforts began with an interagency core team to define long-term goals and measurable objectives for revegetation. Strategies were tested on the local Coram Experimental Forest and Biosphere Reserve on road cuts similar to those on the Going-to-the-Sun Road. Interagency Agreements were completed with the U.S. Forest Service and the Natural Resource Conservation Service for technical assistance. Revegetation strategies were evaluated through a peer review process with the National Park Service Denver Service Center. Implementation of revegetation was accomplished through partnering strategies with the Federal Highway Administration and the National Park Service. A cooperative greenhouse at the local high school was constructed to grow additional plant materials while involving students and their parents in the Park revegetation program.

Lake McDonald Section, 1991

This was the first Federal Lands Highway Program in Glacier National Park. The project involved 10 miles of roadside along Lake McDonald within a cedar-hemlock forest. Through partnering and teamwork we formulated strategies that were tested at the Coram Experimental Forest. During the revegetation of 12 acres of roadside, we learned to integrate restoration activities with the planning, designing, and construction activities of a road project. We refined our methods to collect, propagate, plant, and protect indigenous species.

St. Mary to Rising Sun, 1993

This project was located within aspen parklands and fescue grasslands for 9 miles along St. Mary Lake. The Park staff learned to work with large machinery on steep slopes to salvage and replace topsoil. They saw the advantage of taking steep slopes down to 2:1 slope if possible for long-term retention of plant material. Clearing limits were designed to avoid straight lines. The combination of salvage, regeneration, seeding, and inplanting worked together for best results. Within grassland communities we met the challenge of integrating noxious weed control and herbicides with reseeding strategies. We saw advantages to enlarging cut slopes to smooth out the transition of berms in old backslopes. Although labor intensive, we saw positive results with hand seeding and hydromulching. Slopes were left in a roughened condition with an uneven transition to the undisturbed area.

Logan Pass, 1995

The Logan Pass project is located on the crest of the Continental Divide at an elevation of 6,600 ft. The area is snow-covered, frigid, and wind-blasted for up to 9 months of the year, with an extremely limited growing season. Visitation to this fragile subalpine environment was estimated at 1.5 million visitors each season. This project used all the experience, partnerships, and teamwork accumulated from past projects. Three acres of disturbance was treated to reestablish soil and vegetation to roadside subalpine areas. Comprehensive site analysis, planning, seed collection, and plant production were needed, and over 55,000 containerized plants were prescribed. Restoration strategies included soil and plant salvage, imported soil pasteurization, mycorrhizal production and plant inoculation, planting, seeding, mulching, irrigation, monitoring, and protection.

Site Conditions

Site analysis was a procedure that was designated to collect information on revegetation sites prior to the disturbance. Through this process, strategies were developed in the revegetation plan that were designed to overcome factors of site conditions in order to achieve the goal and objectives.

Topography

The Going-to-the-Sun Road was built through rugged mountainous terrain with elevations that ranged from 3,100 ft at Lake McDonald to 6,600 ft at Logan Pass and down to 4,500 ft at St. Mary. The road travels through the forested Lake McDonald valley for 20 miles to the base of the upper mountains. At this point, the road was carved out of the mountainside and traversed steep cliffs for 10 miles up to the Continental Divide at Logan Pass. From here the road travels down the east side into the St. Mary valley, along St. Mary Lake to prairie grasslands at the base of the eastern Rocky Mountain front.

Soils

Soils are typically gravelly fine sands and silts from sedimentary bedrocks of argillites and limestones. Volcanic ash and loess deposits had a major influence on surface soil development, with resultant fertility and moisture-holding characteristics. The degree of weathering influenced the amount of clay in the soil profile, the thickness of the soil profile, the amount of organic matter, and water-holding capacity. For example, the soils at Logan Pass were very shallow, but in the fescue grasslands they were deep and well developed. Soils were classified along the Going-to-the-Sun Road based on a field inventory of landforms. Landforms were structural configurations of the topography that resulted from past and present geological activity. The soil component was interrelated with vegetation, drainage, and climate to determine the land-type designation.

Weather and Climate

The mountainous character of the area has marked effects on its climate, which varied widely within short distances. Average annual precipitation ranges from 28 inches at the lower elevations to 100 inches on the Continental Divide. At the lower elevations, snow was on the ground typically until May, with an average 90 day growing season. At Logan Pass, there were 60 snow-free days when planting could occur. Harsh weather and persistent snow did not allow access to this project site until late June or July. Even then, stormy weather often altered work schedules.

Diverse Plant Communities

The Going-to-the-Sun Road passes through four distinct ecoregions: montane forest, subalpine meadow and forest, aspen parkland, and fescue grassland. Species lists for restoration included over 100 species made up of several hundred collections. Seed mixes needed to not only provide revegetation species for the ecoregions, but provide for site variability within each project area. For example, the subalpine plant community had a very shallow soil with varying ranges of hydric to xeric conditions. Within the Logan Pass project area, there were seven microsites of mostly herbaceous plants. This complex arrangement of plants, with variable growing requirements, created challenges for nursery and greenhouse operations.

The plant communities along the Going-to-the-Sun Road included exotic plants and five noxious weed species. In 1991, an Exotic Vegetation Management Plan was implemented that used Integrated Pest Management to devise strategies to control exotic plants. These strategies included inventory, monitoring, education, prevention, research, and control. Herbicides were used along this Road to contain and reduce populations of noxious weeds. Monitoring results indicated optimism in reducing exotics while still retaining species diversity of native plants.

Wildlife

The wide diversity of habitat types was reflected in a similar diversity of fauna, including several endangered or threatened birds and mammals and many rare species. People stopped along roadsides to watch and follow wildlife, which resulted in trampling of natural vegetation and loss of soil. Work schedules were modified when grizzly bears passed through the project to prevent undesired encounters. Some project areas were closed for periods during the season to protect wildlife, such as nesting bald eagles.

Visitor Use

The Going-to-the-Sun Road was the primary route of travel for two million people visiting Glacier National Park, and this was concentrated during a 3 month period in the summer. The road was open during construction, with flag persons directing traffic. Overflow roadside parking, congestion, and social trails were evidence of visitor use that was greater than the developed areas could handle. The challenge was not only to restore vegetation to the areas disturbed by construction, but to protect it from very high levels of visitor use.

Past Construction

Unresolved problems of past construction continued to worsen each year, such as erosion and slumping soil on over-steepened slopes. Some of these were corrected during the new road work if they were within the project area. Examples included taking steep slopes down to a gentler grade to retain vegetation, smoothing out lips of cuts, and weaving clearing lines to blend in with natural openings.

Construction Specifications

The construction zone had tight limits for work to confine impacts to within the project area. Often construction limits were immediately adjacent to pristine meadows and watercourses. Because the road was open during construction, there was congestion with visitor traffic, which made access to the project areas difficult. Coordination between the contractor and restoration crews was critical to site preparation and planting.

Seed Collection

Large quantities of native seeds and plants were required for the revegetation of each segment of disturbance on the Going-to-the-Sun Road. Collection and propagation of this material required several years of advance planning prior to construction. In 1992, Glacier National Park established genetic guidelines for restoration projects to minimize the possibility of genetic contamination to the existing native vegetation adjacent to a disturbed site. Genetic guidelines required collections to be within the same habitat type, elevation, aspect, and drainage as the species removed during construction. Large numbers of individuals were collected among separate populations within similar community types. Over the last 12 years, the staff of Glacier National Park has made several hundred collections of over 100 different native plant species for restoration work.

Species selection was based on the predisturbance site analysis and the projections of what site conditions would be like after construction. Species lists and planting palettes emphasized colonizer species and included mid- and late-seral species to provide a better blending of the disturbance with the adjacent undisturbed vegetation. The Logan Pass project required a mix of 10 grass or carex species, 26 forb species, and five shrub and tree species. Seven distinct planting prescriptions were developed to address the extreme variables in soils, moisture, topography, and plant communities throughout the 3 acre project.

Seed collection was extremely time consuming and expensive because conditions varied from project to project and from year to year. Collection sites were located, maturity of seed was monitored, and all seed was collected by hand. The taller grasses and forbs were harvested with a small sickle, while the lower growing species were harvested with scissors. Yearly fluctuations in weather affected seed ripeness, and during some years there were complete crop failures when seeds did not mature.

An Interagency Agreement with the Natural Resources Conservation Service was initiated in 1987 to assist us with seed management. After our seed was collected in the Park, it was accessioned, dried, and sent to the Plant Materials Center in Bridger, MT. The Bridger staff provided seed cleaning, testing, and storage as well as technical expertise in species selection and collection. Some seed was returned to the Park for direct seeding or propagation into containerized plant material. The remaining seed was stored or sent to private contractors for propagation or planted for seed production.

We estimated that collection costs ranged from $25 per lb to $500 per lb for Glacier's native seed, depending on the species. The Logan Pass project required a total of 18 lb of grass, carex, and forb seeds for seeding and another 16 lb of seed for plant production. Our seeding rates for grasses were 70 seeds per ft^2, which translated to an average of 20 to 25 lb of seed per acre. Seeding rates for Logan Pass were considerably higher at 120 seeds per ft^2.

Salvage of Plants and Soil

On each project we salvaged as much plant material and soil as possible prior to disturbance. Plants were salvaged in clumps, as whole shrubs and small trees, and as sod mats in prairie or subalpine meadow situations. This plant material was either 'heeled-in' onsite in a protected environment or held in our native plant nursery until construction was completed. We stored several thousand square feet of salvaged subalpine sod in planter boxes onsite for periods of 1 to 3 years with no measurable mortality.

We salvaged topsoil prior to construction to capture the native seed and propagule bank present in the soil. In some instances, this topsoil was moved to the top of the cut and pulled back down after construction was completed. If this was not possible, soil was stored in windrows of no more than 4 ft in depth, and replaced the same season to ensure the viability of the soil and seed once it was replaced.

Where there were not sufficient quantities of salvaged topsoil available, we considered soil importation. Inspections were made of soil sources to determine seed bank species and to prevent occurrence of invasive weed seeds. Laboratory analyses were made to determine texture and chemical compatibility with native soils. In the pristine subalpine environment at Logan Pass, the soil was very shallow, and we had a deficit of soil available for revegetation following construction. In this case, imported soil was pasteurized to prevent the introduction of any exotic plant material. It was necessary to import 450 cubic yards of pasteurized soil media for the Logan Pass project. This material consisted of 25 percent well-rotted sawdust, 25 percent sphagnum peat moss, 10 percent sand, and 40 percent loam soil. This media was heated to 180 degrees for 30 minutes to ensure pasteurization.

Production of Plant Material

Plant Material Center

Some of the seed that was sent to the Bridger Plant Materials Center was planted for seed production and harvested to provide increased quantities of pure, live seeds for each construction project. Shrubs were grown in production beds as bareroot planting stock. Propagation methods were tested on species that were difficult to grow to improve production.

Native Plant Nursery

A small native plant nursery was constructed at the Park Headquarters area in 1987 to develop propagation procedures for native plant species that were not commercially available at that time. The purpose of this facility was to develop propagation techniques, produce plant material from seed and cuttings, serve as a staging area for revegetation efforts, and provide educational opportunities for staff, public, and cooperators. With a new road project scheduled every 2 years, we managed a number of projects at the same time in various stages of planning, design, and construction. We needed the nursery for coordination of plant material demands on multiple projects over 20 years. We improved efficiency with shared resources, responded quickly to changing revegetation needs, and produced small quantities of species that met strict genetic specificity requirements.

By the end of the 1997 season, we provided a wide variety of plant species and size classes for individual road projects. The transplants had exceptionally high survival, with an average of 80 percent survivorship in our monitoring plots. In 1996, we were holding over 50,000 plants in our nursery facility in preparation for the Logan Pass restoration project. We produced an average of 25,000 plants per year for revegetation needs on the Going-to-the-Sun Road.

The planting plan prescribed approximately 55,000 plants for the Logan Pass project. These plants were propagated by the Bridger Plant Materials Center, the Park's native plant nursery, and private growers. In addition, a private grower was contracted to propagate plant-specific mycorrhizal fungi and to inoculate 30,000 containerized plants prior to delivery to Glacier National Park. The Bridger Plant Materials Center supplied an average of 2,000 bareroot shrubs annually and also grew some of the more difficult species to propagate in their greenhouse.

Greenhouses

In 1993, we received a grant that served as seed money for the construction of a small greenhouse at a local high school and for development of an educational outreach program for 5th- through 12th-grade biology students. The facility was completed with additional moneys and supplies donated by community members and local businesses. Each year approximately 6,000 plants were produced in the greenhouse. Students collected seed at the Park in the fall, propagated containerized plants throughout the winter, and planted the material in the spring. Over 60 classes and nearly 1,000 students have participated in this innovative program. Additionally, our facility provided resource education to many visitors and students who toured and volunteered to work in the nursery.

Construction operations were initiated for two other greenhouse facilities in 1997. A hoophouse was located at the native plant nursery specifically designed as a weed-free enclosed growing environment for production of subalpine and alpine species. There were needs identified during the Logan Pass project to produce pallets of sod for projects in sensitive environments where it was critical to exclude exotic plants from the planting media. Also, funding was secured for a cooperative greenhouse at the Blackfeet Community College as a joint venture to produce plant material for revegetation projects on Blackfeet Tribal Lands and Glacier National Park.

Planting Strategies

The revegetation crew consisted of four crew members and a crew supervisor. They worked 10 hour days, 4 days a week from early May through October. Although they often faced difficult work conditions, these people were extremely motivated, hard working, and believed in the importance of their work. Leadership of the crew leader was critically important to achieve the restoration objectives. During the Logan Pass project, this crew was assisted in their work by a six-person crew from AmeriCorps Montana Conservation Corp. The short planting window at Logan Pass of mid July to early September, and the large number of plants to be installed, necessitated a larger planting crew.

Successful implementation of restoration work required careful coordination between planning, design, construction, and supervisory personnel. Comprehensive revegetation plans and planting designs were developed based on years of extensive site analysis and evaluation. These revegetation plans specified the needed plant materials by planting unit, supplies and equipment, soil strategies, personnel requirements, and sequencing of work activities. Considerations of visitor use, natural and cultural resource values, and historical record of construction along the road corridor was significant to revegetation planning.

One of the biggest coordination challenges was the tracking and moving of the large quantities of plant materials to the project sites. Plants were trucked daily from the nursery to the project sites to avoid mortality from desiccation and unpredictable weather conditions. Since the Going-to-the-Sun Road was kept open to visitor traffic during construction, the highly congested nature of the work site made access difficult. Thousands of plants had to be moved by hand or in wheelbarrows along busy roadways to reach individual planting units. Crew safety was always of greatest concern because of the need to work in proximity to large construction equipment and because of vehicle traffic on the extremely narrow road.

Revegetation efforts began immediately after the contractor finished final grading. Salvaged topsoil was pulled down over the new grade at an average depth of 2 inches. In cases where imported soil was needed, the salvaged native soil was spread thinly over this imported material and mixed to make a more homogenous planting media and to inoculate the pasteurized material with indigenous soil microbes. At Logan Pass, a low-analysis (6:1:3) slow-release organic fertilizer was applied at a rate of 500 lb per acre over the site. A fertilizer was used in this instance because it was believed that this product would facilitate the recolonization of soil biota and enhance seedling establishment.

Seed was sown by hand prior to the installation of a biodegradable agronomy blanket composed of straw and coconut fiber woven with cotton string. Because of the high winds and extreme runoff from snowmelt the agronomy cloth was used to hold the seed and soil in place and to retain moisture. An overseeding of forb and carex species requiring light for germination was completed prior to the installation of containerized plant materials.

Landscape design was incorporated into the revegetation plan with written descriptions and drawings of how vegetation would be selected and arranged. Selections of species needed to be durable to vehicle and foot traffic, compatible with adjacent plants, and diverse in terms of texture of close-up and distant views. Plant material placement followed design guidelines, and wire flags were used to define locations of clumps of five to seven individual species. Despite the large quantity of plant material and variety of species, the adherence to planting plans was achieved.

Since we were dealing with cold-climate species, most revegetation was scheduled in the early fall or spring and discontinued between June 15 and September 1. Seeded areas were usually not irrigated, but relied on climatological patterns. At Logan Pass, irrigation was used the first 2 years to enhance establishment, vigor, and survivorship of planted materials. A low-tech passive irrigation system was developed in order to plant in July and August. An intake valve and over 1,000 ft of 2 inch plastic pipe were used to draw water out of two perennial streams with steep waterfalls. Simple valves and lengths of sprinkler hose delivered up to 8 gallons per minute of water to all planting units.

With completion of the planting, a significant challenge was to protect the newly established vegetation from being trampled by the nearly two million visitors traveling on the Going-to-the-Sun Road. Signs were placed at the sites to inform visitors of the restoration efforts. Within the concentrated Logan Pass Area we installed an unobtrusive and easily maintained chain barrier around all planted areas. Uniformed staff monitored and enforced the posted areas.

Monitoring Strategies

Assessment of Results

The Revegetation Monitoring Program was established in 1991 to provide baseline data for revegetation planning and assessment of results. The program helped evaluate completed revegetation work and helped determine whether objectives for restoration were met. Monitoring has been applied to seven road projects at Glacier National Park. This data was used to determine future strategies, to project trends over time, and to improve our revegetation methodologies. Monitoring results led us to conclude that our revegetation methods were appropriate to achieve most of our goals and objectives. Results of monitoring data were documented in annual reports.

Monitoring strategies included establishing permanent transacts on each plot that were used for line-intercept cover measurements of shrubs and trees. Canopy cover of all native and exotic plants and ground cover were measured in microplots along each transect (Asebrook and others 1996). Life form canopy cover estimates for each microplot were recorded as well. Ocular estimates were done in conjunction with microplot monitoring. Nested frequency monitoring was done where appropriate. The objective of each monitoring technique was to obtain sufficient data to provide for robust statistical comparisons.

Lake McDonald Section

The trend on these plots has shown that seeding native grasses and forbs resulted in higher native cover and lower exotic cover. Seeded plots had significantly higher native grass cover and significantly lower exotic forb cover than unseeded plots since monitoring began in 1992. Shrub survival remains high at 85 percent. This data suggested that revegetation should continue on these roadside areas, instead of relying on natural regeneration, for restoration of native communities (Asebrook and others 1996).

St. Mary to Rising Sun Section

Seeding native species along the roadcut resulted in a significant native component. On steep slopes, native grasses dominated the sites, and there was little erosion evident. Planted material had better survival and vigor when planted in spring rather than in the fall. Overall plant mortality increased on the revegetation plots over time, but there was still 60 to 70 percent survival of planted shrub species. Native grasses and shrubs showed the most success at controlling the dominance of exotic plants, but exotic species continued to be long-term components of the roadside communities (Asebrook and others 1997). Although exotic forb cover decreased, exotic grass cover dominated some roadcuts. It appeared seeding was necessary to introduce a native grass component to roadsides with salvaged soil to compete with exotic grass and forbs.

Logan Pass Section

Data collected the first year suggested that the survival of grasses was greater than 90 percent and survival of forbs and shrubs was greater than 80 percent. Of the live plants evaluated, greater than 90 percent had a vigor rating of good/fair (Asebrook and others 1997). Initial data supported the use of fertilizer treatments because the treated areas showed greater cover of seeded material, particularly grass germinants. Additional evaluations helped us determine if our seeding rates were appropriate, and if only seeding would have been as effective at reestablishing vegetation over time as the more costly and time-consuming planting and seeding.

Conclusions

The restoration of native plant communities removed during new construction was part of the Federal Lands Highway Program to rehabilitate the Going-to-the-Sun Road. The methods that were used included the preconstruction inventories, extensive planning, collection of seed and cuttings, propagation of containerized and bareroot material, increase of seed, and planting of grass, forb, shrub, and tree species. The success of these strategies depended on people with diverse disciplines working together and learning from their experiences. Although costly, results have shown we can achieve quality park roads, quality park experiences for visitors, and preservation of cultural and natural resources. Over the years we have developed a working relationship through partnerships and teamwork to assure that the Going-to-the-Sun Road will continue to provide access to the Park consistent with sustaining the world class quality of the natural and cultural resources of Glacier National Park.

References

Asebrook, J. M.; Lamb, B. E.; Funk, T. 1996. Revegetation monitoring report: Glacier National Park. Unpublished report on file at: Glacier National Park, MT.

Asebrook, J. M.; Lamb, B. E.; Kurth, L. 1995. Revegetation monitoring report: Glacier National Park. Unpublished report on file at: Glacier National Park, MT.

Asebrook, J. M.; Lamb, B. E. 1997. Revegetation monitoring report summary. Unpublished report on file at: Glacier National Park, MT.

Glacier National Park. 1992. Interim genetics guidelines for restoration projects. Unpublished paper on file at: Glacier National Park, MT.

Lange, D. 1991. Exotic vegetation management plan. February 1991. Unpublished report on file at: Glacier National Park, MT.

Lange, D.; [and others]. 1990. Vegetation management plan, Going-to-the-Sun Road (Lake McDonald section). Unpublished report on file at: Glacier National Park, MT.

Lange, D.; [and others]. 1992. Roadside maintenance guideline. Unpublished report on file at: Glacier National Park, West Glacier, MT.

Lapp, J. A.; Resource Staff. 1992-1997. Annual report, Going-to-the-Sun Road Revegetation, Glacier National Park. Unpublished reports on file at: Glacier National Park, MT.

Lapp, J. A.; Resource Staff. 1992-1997. Annual centralized resource management project system (CRMPS) reports. Unpublished reports on file at: Glacier National Park, MT.

Majerus, Mark E. 1991. Native, indigenous plants for Park Service revegetation. Durango, CO: American Society for Surface Mining and Reclamation.

Majerus, Mark E. 1997. Restoration of disturbances in Yellowstone and Glacier National Parks. Journal of Soil and Water Conservation. July/Aug 97: 232-238.

Natural Resources Conservation Service, Bridger Plant Materials Center. 1991-1997. Annual progress reports to NPS, Glacier National Park. Unpublished reports on file at: Bridger Plant Materials Center, Bridger, MT.

Potter, Rachel; Resource Staff. 1988-1991. Annual report for the Going-to-the-Sun Road revegetation, Glacier National Park. Unpublished reports on file at: Glacier National Park, MT.

Vanderbilt, K.; Potter, R. W. 1993. Logan Pass revegetation recommendations. Unpublished report on file at: Glacier National Park, MT.

Wick, Dale; Resource Staff. 1995-1997. Annual reports, Glacier native plant nursery. Unpublished reports on file at: Glacier National Park, MT.

Common Difficulties Encountered in Collecting Native Seed

Richard Dunne

Abstract—The increased demand for native seed has surpassed our ability to provide high quality range-collected seed. This paper discusses some of the hazards and common mistakes associated with the collection of wildland native seed. Among the common difficulties in collecting native seed are: (1) native species do not produce seed often in the arid West; (2) there is a scarcity of large homogeneous accessible stands of native plants; (3) a widespread occurrence of noxious weeds lowers the percent of seed purity; and (4) fire has reduced the availability of native shrubs. Environmental factors that may be hazardous to native seed collection include late frosts, hail, competitive grazing, and wind. Collection practices that can improve changes of success include: (1) management of moisture content of collected seed; (2) proper bagging of seed and protection from the elements; and (3) proper seed cleaning with minimal damage.

The increased demand for native seed has surpassed our ability to provide high quality range-collected seed. Frequently, the demand for seed arises in an atmosphere insulated from the realities and risks inherent in wildland collecting. Current Conservation Reserve Program seeding specifications, which recommend or require the use of species not available in the market, indicate a need for better understanding of the processes by which native seeds become available. Successful collecting of native seed requires favorable environmental conditions, some expertise, patience, and much luck. This paper discusses some of the hazards and common mistakes associated with the collection and conditioning of wildland native seeds.

In the arid West, the first and foremost cause of collection difficulty is that most native species do not produce seed very often. Many desert species produce good seed only once every 10 to 20 years. This is not only due to absence of rainfall but also because soils frequently lack the necessary nutrients to promote seed production. Therefore, much of the seed available on the market represents rare, opportunistic collections that cannot be anticipated or duplicated with any regularity. Where demand for certain seeds is stable and substantial, field cultivation of species is beginning to meet market demands. It takes approximately a decade of trials before field production of natives to become economically feasible.

The second factor limiting collection is the scarcity of large, homogeneous, flat, accessible stands of natives. Western reclamation customers demand high-purity, high-germination seed of individual species with very little weed or other crop species present. It is common for collectors from several states to converge on a good patch of seed.

An increasingly important hazard to native collecting is the widespread occurrence of noxious weeds. Many former collecting areas are avoided by conscientious collectors because the risk of noxious weed contamination is too high. Particularly, riparian plants such as snowberry (*Symphoricarpos albus*) are rapidly becoming intermingled with knapweed species that produce seed borne on parachutes that float in the air until they "hang-up" in neighboring foliage. Even general proximity of noxious weeds creates large risks.

Fire has taken its toll on the availability of native shrubs in the West. Due to the association between fire and cheatgrass *(Bromus tectorum)*, millions of acres have become cheatgrass deserts with few forbs or shrubs remaining. This trend appears to be accelerating, especially on the Snake River Plain and in the Great Basin.

Other environmental factors that make native seed collecting risky include late frosts, hail, competitive grazing, and wind. Many natives have physiological characteristics that increase harvest difficulty or reduce yields. Seed shattering in species such as needle grasses (*Stipa* sp.) reduces the harvest window to only 2 or 3 days before the seed falls to the ground. Timing and good weather become crucial for success, and the temptation to harvest immature seed before it drops is great. Indeterminance is another factor that can greatly reduce yield or quality. For many species, only a small percent of seed may ripen at a given time—often as little as 5 to 10 percent of the potential seed on a plant. Usually, wind carries away the ripened seed before more seed can mature; only a small percent of potential seed is harvested, and much of what is harvested is immature.

Collection practices can significantly enhance chances of success. The most common pitfall for both novice and experienced collectors is the management of moisture content in collected seed. Excess moisture can cause seed to heat up and die within 24 hours if not properly treated. In general, the vegetative material containing seed must be dried before damage occurs. Frequently this entails laying seed out on tarps to dry at the collection site, and constantly guarding the seed against damage from rainfall or from feathered and four-footed opportunists. Care should be made to avoid windy sites and land features that could flood in a thunderstorm. Tarps should be free from holes and secured quickly when weather threatens. Because tarps cause heat build-up very quickly, they should be rolled back soon after a storm passes. The greatest drawback to using tarps on the range is puddling. No matter how careful you are, some water will penetrate your defenses, and then tarps must be checked to remove puddles from beneath the drying seed pile.

Proper bagging and protection from the elements become the major concerns once seed is dry enough to transport. The

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need to move to other jobs quickly rarely allows for full seed-drying in the field. This leads to a very common mistake among collectors who drop off bags of partially dried seed in warehouses for storage until time can be made to further dry or clean the seed. A moisture content above 15 percent, but below the moisture necessary for heating, can seriously injure seed if left in that condition for months or even just weeks.

Assuming the successful completion of all these steps, the last major hurdle awaiting the unwary is seed cleaning damage. Many seeds are delicate and can be damaged by the improper application of horsepower and steel. Grinders and hammermills are especially efficient at destroying seed quickly and must be either mastered or avoided. Proper seed cleaning machinery such as fanning mills, aspirators and gravity separators are essential for successful seed cleaning. Frequently, seed characteristics obstruct our attempts to achieve high purity. Many shrubs, such as rabbitbrush (*Chrysothamnus* sp.), are cleaned only to about 20 percent purity due to size or flowability characteristics that cleaning machinery cannot address. Native seeds tend to vary in size and shape more than common grains, for which most cleaning machine are built. Frequently, homemade solutions are better than off-the-shelf technology.

Only when a seed lab analysis is completed at the end of cleaning do you know if you have a saleable lot of seed. It is unconscionable to sell or trade untested seed. The eye cannot tell if seed is alive or dead; also, the untrained eye can easily overlook the presence of noxious weed seeds. A certified third-party seed lab can give both buyer and seller reasonable assurance of seed quality.

But the risks don't end at this point. All seeds eventually die, and some seeds, such as Wyoming big sagebrush, (*Artemisia tridentata wyomingensis*), can die within weeks or months of collection. Seed collected during poor seed years tends to be lighter, more insect damaged, and lower in viability and longevity than seed collected during good years. Because of dropping germination in certain seed lots, we take $5,000 to $10,000 worth of seed a year to the dump.

With an understanding of the seed harvesting chain of events, its limitations and risks, buyers and regulators can better understand the difference between what is possible and what is not possible. We can improve restoration success when expectations are consistent with reality. Any divergence between the two can lead to confusion and dissatisfaction.

It is important for buyers and regulators to understand that it may take many years of wishing before some native species become available. Projects requiring unusual seed should be planned far enough in advance to assure availability. Seed suppliers should be consulted regularly during planning stages. Even regularly available seeds can become exceedingly expensive if large and unexpected demand arises. Finally, if wildland collected seed seems expensive or erratically available, buyers should understand the risk, luck, and skill required to collect a high quality product.

Regional Native Plant Strategies

Wendell G. Hassell

Abstract—Because of increasing public interest in native plants, regional groups have been cooperating to develop native species. The Federal Native Plants Initiative was formed in 1994 to coordinate and encourage the development and use of native plants. The program they developed includes public involvement, organizational structure, technical work groups, implementation plans, and followup. The implementation plan addresses native seed development by private industry, grower contracts, and agency cooperation. Public and private agencies can work together during the planning stages and provide the technical information necessary for development of native plant materials for a given region.

Public agencies were directed by Presidential Executive Memorandum in 1994 to use more regional native plants and to implement landscape practices that conserve water and prevent pollution on Federal projects. The agencies have developed or are developing policies and procedures to encourage the use of native plants.

Programs should serve the wide range of expectations of land managers and provide a variety of native plant species and ecotypes for reseeding and restoration projects. The Northern Great Plains Native Plant Committee, which has been functioning for 4 years, includes members from North and South Dakota and parts of Montana, Wyoming, Nebraska, and Canada. The Northern Great Plains Committee meets semiannually, conducts surveys, and publishes newsletters, brochures, and technical information.

Over the past 10 years the Natural Resource Conservation Service and the National Park Service have been cooperating on a plant materials program for development, testing, and establishment of native species on disturbed sites in National Park Service units. The materials tested and technology developed will apply to areas beyond the Parks. Over 700 new indigenous ecotypes have been collected and are now being tested or reproduced.

Other Federal land management and conservation agencies and private industry are interested in the development of technologies and are seeking sources of local native plant species. The Natural Resource Conservation Service plant materials program selection criteria include establishment, vigor, growth, production, broad adaptation, and commercial potential. The National Park Service plant increase program emphasizes local gene pool considerations, practical technology, adaptation, and cost effectiveness. Preservation of native plant genetics in natural ecosystems is a high priority in the National Park Service along with the restoration of native vegetation to areas that have been disturbed. Where disturbance is severe, restoration may have to begin at a lower successional stage, and pioneer species may have to be considered.

The Forest Service and the Bureau of Land Management have begun programs to develop native plants and technology for their use on public land. The military and Federal Highways Administration are contributing resources to the effort. Cooperation among agencies and private industry will be beneficial to the development of native plants and will allow their use to become more cost effective.

Issues

Scale and Magnitude

The National Park Service average seeding is 3 to 60 acres, but forest fires increase the demand for commercial native plant seeds each year. Forest fires in New Mexico and Arizona during the last 10 years have ranged from 58,600 acres in 1991 to 642,800 acres in 1994. The Bureau of Land Management is cooperating on a project in the Snake River plains to reseed 3 to 8 million acres of deteriorated rangeland. The Conservation Reserve Program and associated government programs reseeded millions of acres during the last 10 years. Each year, United States Army training maneuvers disturb thousands of acres that require revegetation.

Resources and Funding

The cost of restoration with native plants can be limiting. Project cost can vary from less than $300 per acre to several thousands of dollars per acre, depending of the restoration requirements and gene pool restrictions. Funds can be concentrated on a precise job in a small area, or the same amount can be spent on a less intensive effort over a larger area. What are the impacts of these decisions on the overall ecosystem of a region?

Diversity

Revegetation should include as much natural diversity as possible, but cost, technology, and time constraints must be considered. The size of the area to be revegetated is also a major factor.

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Gene Pool Considerations

Some species and ecotypes are easily adaptable, while others require specific site conditions. Availability of seed is usually more restricted, and seeds are more costly when the size and location of a particular ecotype is limited. Disturbance can alter site characteristics, but natural selection is an ongoing process. It may be possible to improve diversity and natural selection with a species on a new site.

Time Restraints

Native species often do not produce good seed every year. The season for native seed ripening and collecting varies from year to year. It takes at least 3 years to produce seed from most native collections. Annual funding and budgeting are not conducive to long-term contracting for seed production.

Proposal

The Federal Native Plants Initiative was established by a Memorandum of Understanding in 1994. It was organized to coordinate and encourage the development and use of regional native plants and now includes nine Federal agencies and approximately 70 non-Federal cooperating organizations. The Initiative Committee identifies priority conservation needs for native plants and their habitats and coordinates programs to address these needs. The Federal Native Plants Initiative Committee identified the following goals:

1. Establish common priorities and direction.
2. Share agency expertise and resources.
3. Support cooperative efforts.
4. Develop consistent scientific methodology.
5. Encourage collaborative training programs.
6. Coordinate public education and outreach efforts.
7. Support ecosystem management initiatives.

A draft proposal was put together by the Federal Native Plants Initiative Committee to aid Federal agencies in the development of regional native plant sources. The proposal outlines a way in which the Committee, working with agencies, could facilitate a cost-effective program to develop native plants for restoration and revegetation projects in a bioregion.

Outline for Regional Native Plant Development

The Federal Native Plant Initiative Committee would:

1. Provide general overall direction, coordination, and support through respective agencies and organizations.
2. Identify and select one or more bioregions for pilot projects for implementation. The projects should be significant (1,000 or more acres per year) and have a long-term (4 to 5 years) commitment by one or more agencies.
3. Identify and contact interest groups in the proposed project area.
4. Facilitate the selection of a lead agency to initiate and coordinate activities at the bioregional level.
5. Select a meeting facilitator to lead general planning meetings, maintain the group focus, resolve conflicts, and ensure consensus.

The lead agency (agency, task force, or formal group) would:

1. Organize an initial informational meeting and identify the objectives for the bioregion-region.
2. Form a general committee from a group of the interested participants to assist the lead agency in realizing the specific objectives of the bioregion.
3. Organize a technical work group (specialists in the field) to assemble technical information and make recommendations to the general committee.
4. With the help of the general committee, develop specific arrangements, agreements, contracts, letters of intent, and memoranda of understanding with group involvement. Agreements should cover seed collection or source, development or increase, storage, and nursery production, and should establish target amounts.

The technical work groups would:

1. Assemble specific information for the general committee, including:
   a. resources available (technology, plant species, facilities, commercial resources),
   b. agency projects and funding sources, and
   c. plant materials needs and estimated amounts by species.
2. Assemble species adaptation information by hardness zones, precipitation zones, vegetation, or bioregions (also information specific to the bioregion, such as species elevational range by ecotype).
3. Develop specific plans and logistics for making plant materials available, considering collection sites, reproduction technology, diversity, gene pool, processing, and storage characteristics; consider the advantages and disadvantages of self-regeneration, salvage, an increase program, and commercially available seeds.
4. Develop a species list and make recommendations on methods for developing seeds and plants (species by species).

Implementation:

1. Assemble project species list, estimate revegetation acreage, and propose schedule by vegetation zones or other grouping.
2. Develop technology for seed and plant production.
3. Use Association of Seed Certifying Agencies Guidelines for Wild Land Collected Seed program to maintain uniform quality control.
4. Develop cultural and management technology for successful establishment.
5. Review technical recommendations and the list of plant species to select the best methods and option(s) for allocation of resources to meet project objectives.
6. Maintain followup with informational and organizational meetings and evaluate long-term cost effectiveness relative to ecological values and objectives.
7. Ensure technical oversight of seed and plant production operations to maintain quality standards.
8. Coordinate with private companies and supporting agencies and groups on progress (this responsibility could be shared by agencies).

Summary

Regional groups can effectively develop local native plant sources. Several regional groups are already cooperating in the development of native plant species. A regional approach has the advantage of bringing agency and private industry resources together to provide funding, support, and direction. Through an exchange of information and a cooperative approach, the availability of a wide variety of native plants can be increased in a cost-effective manner.

Lessons from Historical Rangeland Revegetation for Today's Restoration

Bruce A. Roundy

Abstract—Rangeland revegetation in the Western United States historically was applied at a large scale for soil conservation and forage production purposes. Principles of revegetation that have developed over years of research include matching site potential and plant materials adaption, use of appropriate seedbed preparation and sowing techniques, and development of large supplies of seed of adapted plants. Although many of these large-scale projects were extremely successful in terms of their original objectives, they often lacked native plant diversity. Increased use of native species for revegetation of these lands, in the face of exotic weed spread, will require a more detailed knowledge of disturbance effects relative to site potential and of native plant requirements for establishment and persistence in mixed communities.

The purpose of this paper is to briefly review rangeland history for the Western United States, discuss some of the lessons learned as large-scale revegetation was developed, and raise some of the challenges and opportunities for using native species for restoration in the semiarid West.

Ecologists are appreciating much better these days the importance of disturbance in plant succession (Mooney and Gordon 1983). A number of factors combined to change the disturbance regime of Western rangeland plant communities. Except for parts of the Southwest and California that had been settled by the Spanish in the 1700's, most of the Western United States was colonized after the mid 1800's. The Donner party crossed the Great Basin on their ill-fated journey to California in 1846, the Mormons settled in the Salt Lake Valley in 1847, and the discovery of gold at Sutter's Mill and subsequent expansion of mining after 1849 all were the beginnings of a great Western migration. The end of the Civil War and the completion of the railroad in 1869 brought many more to the West.

West of the plains grasslands, plant communities were distributed across elevational gradients associated with high mountains and plateaus and relatively high valleys. Variations in temperature, precipitation, and soil conditions were associated with geological and elevational differences. Natural and Native American-ignited fire was an important regular disturbance, occurring every 10 to 30 or more years and providing for diversity of many communities that would otherwise have been dominated by woody species such as sagebrush (*Artemisia* spp.), juniper (*Juniperus* spp.), and mesquite (*Prosopis* spp.) (West in press; Wright and Bailey 1982).

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As the Native Americans were controlled by the Army, and mining and the railroads created a market and transportation for meat, stock raising went from the subsistence economy of the early pioneers to a market economy with wealth-generating incentives. Post Civil War soldiers, like John Sparks in Nevada, drove cattle from Texas to stock the Western ranges (Young and Sparks 1985).

Many viewed the free grass of the West as a great economic opportunity for grazing. Initially, a Spanish style form of stock raising was used with stock left on the range year-round and rounded up mainly for shipping to market (Young and Sparks 1985). By the end of the 19th century, excessive grazing associated with open range had depleted the grasses and palatable shrubs and forbs near water, and major droughts in the Southwest and winters in the North had temporarily devastated livestock herds. Reports to Congress from ranchers and from Bureau of Plant Industry officials, like David Griffiths, on the condition of the Western range, eventually led to grazing management legislation and practice (Roundy and Call 1988).

What came out of all of this?

1. Overuse, especially of grasses, as well as the need to put up hay for winter or drought, led to the development of guidelines for carrying capacity and proper stocking.

2. Grazing-sensitive bunchgrasses on many ranges were replaced by unpalatable woody shrubs and trees. Overgrazing reduced fine fuels and fire frequency, allowing woody plants to invade or dominate sites where herbaceous plants had been dominant.

3. Heavy summer rainstorms on mountain slopes that had been excessively grazed resulted in debris flows to the towns below. This prompted research by Arthur Sampson and others on the effects of grazing on watershed response, as well as on methods to rehabilitate damaged watersheds (Keck 1972).

4. Exotic weeds brought in with grain, and otherwise transported from the Old World, began spreading onto depleted rangelands (Mack 1986; Monsen and Kitchen 1994).

5. All of these factors led to the development of range management as a profession with a focus on learning to manage grazing for production and sustainability. In addition, methods of undesirable plant control and re-establishment of grasses for soil conservation and forage production were developed (Vallentine 1989).

As well as the Western United States, the best-reported example of large-scale and long-term rangeland revegetation research is from the deserts of Central Asia (Nechaeva 1985). Revegetation goals there were to establish mainly adapted shrubs to meet the year-round dietary requirements of sheep and to control wind erosion. Success of the work involved years of research to understand the biology of the candidate species, the potential and constraints of different sites, and appropriate seedbed preparation and sowing methods. The revegetation research in the Western United States and in former Soviet Central Asia are generally parallel in approach, although grasses were the focus in the United States, while shrubs were the focus in Central Asia. The point is that conducting large-scale revegetation in semiarid and arid areas required a major commitment in long-term research to be successful.

A major break-through in revegetation success in the Western United States occurred when it was found that certain introduced grasses were successful in establishing and persisting under extreme environmental conditions. For example, crested wheatgrass (*Agropyron desertorum*) was highly adapted to big sagebrush (*Artemisia tridentata*) rangelands and was seeded extensively as an early growing, grazing-tolerant forage on thousands of acres (Johnson 1986), while smooth brome (*Bromus inermis*) was seeded extensively to rehabilitate mountain watersheds (Monsen and McArthur 1995). An exception to this emphasis on exotic grasses was the work of A. Perry Plummer who pioneered in the use of native grasses, shrubs, and forbs for revegetating mule deer winter ranges in Utah (Plummer and others 1968). Much later in the 1960's, mineland reclamation in the West borrowed many of its approaches and methods from range revegetation technology. The approach was more agronomic than ecological, emphasizing the use of large machines to prepare the land and seed easily sown, widely adapted, vigorous grass species (Jackson 1992).

With our current emphasis on diversity rather than production, some have looked critically at these past efforts to revegetate rangelands. But remember, the goals are different today—we are the Supermarket Generation. In 1995, there were 1.4 million farm operators and managers and 3.5 million total individuals (less than 2 percent of the total population) employed in agriculture and related occupations in the United States (U.S. Bureau of the Census 1996). Past goals of the land reflected a much larger percentage of the population that lived directly from production agriculture, as well as reflecting the demands for shortages of agricultural products through two world wars.

Lessons from Rangeland Revegetation

There are some lessons—good and bad—that can be learned from Western rangeland revegetation development. These efforts resulted in some of the largest scale revegetation projects on semiarid lands in the world.

The Lesson of Scale

It is one thing to create small-scale ecological gardens as a restoration goal. It is quite another to revegetate or restore thousands of acres of rangeland in poor ecological and hydrological condition. The United States Park Service has been able to establish shrubs in the dry Mojave Desert by bypassing the vulnerable seedling stage. They grow deep-rooted shrubs in plastic tubes before transplanting and deep-watering them through a smaller tube. This allows them to restore roads to native shrubland. However, if large areas need to be restored, direct seeding is usually necessary.

The need to revegetate large areas affected much of the historical approach to rangeland revegetation and still affects large-scale fire rehabilitation on Western rangelands today. Big machines (such as the brushland plow and the rangeland drill) were developed to control competing plants and to seed large acreages of topographically diverse rangelands. The anchor chain was employed to control large areas dominated by trees, such as pinyon (*Pinus* spp.) and juniper, and to cover seeds broadcast from the air. Widely adapted, easily established species were selected that had high germination and that were easily seeded through a drill.

The lesson for today—don't expect small-scale methods to fix large areas. Large-scale methods and machines can be used, however, to create more floristic and structural diversity across the landscape than was done in the past. For example, anchor chaining and other mechanical methods can be used to create diverse patterns of woodland for cover and shrublands for forage to support wildlife (Fulbright and Guthery 1996; Roundy 1996). Special trashy seed drills and other machines are being developed to allow sowing of native seeds across large areas.

The Lesson of Site Potential

Historical rangeland revegetation was generally successful at and above the big sagebrush (*Artemisia tridentata*) zone in the Intermountain West. In the lower elevational, drier, and more saline shadscale (*Atriplex confertifolia*) zone, seedings failed (Bleak and others 1965). Vegetation restoration must be site-specific and requires an understanding of soils, climate, and species adaptation. Rangeland revegetation guidebooks have categorized site potential and adapted species (Roundy and Call 1988); however, the emphasis has been on forage species, predominately grasses. Many perennial species do not establish every year on semiarid areas; their establishment may be episodic on unusually wet years. Some species may establish on a wet year, but do not persist under the long-term climate of the site (Roundy 1995).

The Natural Resource Conservation Service has developed a system of Major Land Resource Areas, Subareas, and specific range sites that characterizes site potential (Shiflet and McLauchlan 1986). Range site descriptions list the species that are considered to have been present in the natural plant community. A Plant Materials Handbook (OSMRE 1988) lists recommended species for revegetating disturbed range sites. The best recommendations for matching species to sites have come from years of field plot research. Because abiotic and biotic changes such as soil erosion and weed invasion have occurred on many sites, historical potential may no longer exist. On those sites, current potential should be realistically assessed, based on existing plant community and soil conditions.

The Lesson of Plant Materials Selection

Historically, range revegetation practitioners selected a few, high-performing and widely adapted species. These were often introduced grasses with exceptional establishment ability and vigor. Plummer and others (1968) found out early on that if you are going to use native species, you need to understand the range of adaptability of specific ecotypes. Meyer and others (1995), Meyer and Monsen (1990), and Meyer and Pendleton (1990) found that many native ecotypes have germination characteristics that are tied to the environments of the collection population. Past and continuing research has shown the ecotypic nature and wide genetic diversity of many wildland plants (McArthur and Tausch 1995).

Some concerns about plant materials selection are that high genetic diversity may be necessary to maintain adaptation in dynamic environments, that nonlocal seed sources will not necessarily have adapted genomes, or that nonlocal sources may result in genetic pollution and loss of local genomes (Linhart 1995; Rhymer and Simberloff 1996). These concerns led to changes in plant source identification, selection, and improvement approaches for wildlands (Meyer and others 1995; Pyke 1996; Young and others 1995). An understanding of the genetics and reproductive biology and ecology of many wildland species appears to be lacking, and is necessary to speak intelligently about these issues in particular situations. Using highly specific ecotypes requires a more intensive and longer term research effort than planting widely adapted species.

The agronomic approach to plant improvement has been to select or breed for plants with specific desirable characteristics. In so doing, genetic diversity is often reduced. The Natural Resources Conservation Service, Plant Materials Centers, and other plant materials researchers in the past have taken this agronomic approach of collecting from many populations, evaluating the segregated collections in common environments, and increasing and releasing the best performers for similar environments (Englert and White 1997; Shiflet and McLauchlan 1986). Developing improved plants based on ecological principles involves discovery and characterization of plant materials from native populations followed by possible selection or genetic manipulation for specific management needs (McArthur 1988). Some Plant Materials Centers are now developing nonsegregating methods such as convergent-divergent schemes to increase, rather than narrow, the genetic diversity of plant materials (Munda and Smith 1995). Researchers are continuing to try to determine the ecophysiological and morphological basis of adaptation to more easily evaluate plant materials as an alternative to lengthy field trials (Criddle and others 1994; Johnson and Asay 1993; Monaco and others 1996; Smith and others 1996).

An appreciation for the ecotypic nature of wildland plants has led to the concept and certification of source-identified plant materials (Currans and others, in press; Vankus 1996; Young 1995; Young and others 1995). The Forest Service has implemented the approach of seed collection zones for commercial tree species, but not for grasses, shrubs, and noncommercial trees. However, the Pacific Northwest Region of the Forest Service is developing techniques for increasing use of native species as evidenced by a native seed collection guide for the Wallowa-Whitman National Forest (Huber and Brooks 1993), a native plant project summary for the Mt. Hood National Forest (Cray and others 1995), and a native plant notebook for the Mt. Baker-Snoqualmie National Forest (Potash and others 1994).

The Sowing Lesson

The need to match the seedbed preparation and sowing method to the site and seeded species is well illustrated by two stories from rangeland revegetation history (Roundy and Biedenbender 1995). Pelleted seeding studies, conducted from the 1940's to the 1960's, sought an easy and inexpensive way to reseed degraded Western rangelands. The idea of broadcasting pelleted seeds was conceived by Lytle Adams, a retired dentist, who first thought of the idea in southern California when he noticed small cactus plants emerging from rabbit droppings. In 1945 he interested Congress in the idea of aerially distributing pelleted seed. The idea was that seed could be compressed into earthen pellets with fertilizers, fungicides, and insect and rodent repellents. The weight of the pellets would promote their even distribution and penetration into the soil. This idea was inexpensive and appealing, especially when compared with the alternative methods of broadcasting seeds alone, in which success was usually limited by lack of soil coverage, and mechanical seedbed preparation and sowing on the ground, which was slow and expensive over a large area. Dr. and Mrs. Adams actively promoted the pelleted seeding program at the local and national levels. Mrs. Adams made hats from Lehmann lovegrass (*Eragrostis lehmanniana*) and devil's claw (*Proboscidea* spp.) and presented them to such prominent ladies as Mrs. Morris Udall and Jacqueline Kennedy.

Jordan's (1967) findings on a Chihuahuan desertscrub site were similar to the results of other studies: pelleted seeds established to a similar or lesser extent than aerially broadcast nonpelleted seed. Mechanical seedbed preparation and sowing on the ground produced successful stands of grass when pelleted seeding did not, even in years with favorable precipitation. Pelleted seeding failed primarily because of inadequate soil coverage but also partly because the pelleting process reduced germination (Jordan 1967). When Adams's advocate in Congress, Representative Ben F. Jensen of Iowa, learned that pelleted seed research money had been used to make comparisons with other methods, he accused the University of Arizona of sabotaging the program. This story illustrates the need to do careful comparative research to test apparently easy solutions.

The land imprinter developed by R. M. Dixon (1978) is a heavy water-filled cylinder with metal ridges that modifies seedbeds by imprinting rain-catching furrows in the soil (Dixon and Simanton 1980). Theoretically, imprinting enhances soil surface roughness and promotes infiltration by allowing water to replace air in macropores that are open to the soil surface (Dixon 1978). The imprinter has been highly promoted as a tool to greatly improve revegetation of semiarid rangelands in the Southwest and throughout the world. Imprinting helps bury seeds (Winkel and others 1991), firms seedbeds, reduces wind erosion, increases seed contact with the soil, and increases seedling emergence on some soils (Clary 1989; Haferkamp and others 1987), but it is not effective for controlling sprouting brush (Cox and others 1986; Larson 1980). Imprinted furrows on sandy soils may slough and bury broadcast seeds too deep for emergence.

In comparative studies conducted in southern Arizona on a sandy loam soil, imprinting and other methods of soil disturbance increased seedling emergence of broadcast-seeded grasses in a moderately wet summer, but did not make a difference on a wet year or prevent failure on a dry year (Winkel and Roundy 1991). Seedbed preparation and sowing methods should be evaluated for different sites and species over a number of years in relation to where the seeds end up in the seedbed. The location of seeds and seedling roots should be determined in relation to the location of needed resources in time and space, such as available soil water and adequate temperatures for germination and growth (Roundy 1994; Roundy and others 1997).

The lesson from all this is that a knowledge of species establishment requirements and effects of seedbed preparation and sowing methods is needed to maximize success. For example, small seeded sagebrush and rabbitbrush (*Chrysothamnus*) have been successfully established by broadcasting them between successive pinyon and juniper chainings (McArthur and others 1995). Aerial seeding of species requiring very shallow burial has been successful when chaining or when some other mechanical treatment just barely covers them—the soil disturbance and burial depends on the method, as well as the soil water content and soil texture. Many larger seeded species, such as bitterbrush (*Purshia tridentata*), are most successful when seeded by a drill or from a seed dribbler off the tracks of a bulldozer to help bury them.

Seeding failures with native species can result from a lack of understanding establishment requirements. Scientists are working on developing seedling establishment models driven by soil moisture and temperature to better predict both weed and desirable species establishment (Christensen and others 1996). These efforts will increase our ability to use native species.

The Seed Availability Lesson

A major reason that some exotic species have been used preferentially over natives in the past is that these exotics were chosen not only for their wide adaptability, but also because their seeds are easily grown, harvested, cleaned, and sown. They are, therefore, less expensive than native seeds. The resulting lack of demand for native seeds historically restrained development of a native seed production industry, which in turn limits seed availability (Roundy and others 1997). Quality standards for produced and collected wildland seeds are being developed as the demand for native seeds increases.

The Surface Mining Control and Reclamation Act of 1977 greatly helped to promote the demand for native seeds by requiring the preferential use of native species for coal mine land reclamation. The way out of the seed availability bottleneck is to create a demand for native seeds and the resulting industry by developing seed warehouses. Existing warehouses have been essential for providing native seeds for fire rehabilitation projects in the West, but they are inadequate for current demands. Invasion of Western rangelands by cheatgrass (*Bromus tectorum*) and other annual weeds has caused a fire feedback loop that favors continual weed dominance. Fire rehabilitation is the major effort in revegetation on Western rangelands today (Roundy and others 1997).

To illustrate the magnitude of the problem, consider the 2 million acres of Western rangelands under Bureau of Land Management stewardship that burned after an unusually wet spring produced abnormally high fine fuels in 1995. Failure to seed these lands with perennial species would result in a return to weed dominance. In Utah alone, over 65 tons of seed were ordered for revegetation. Because of the relatively limited supply and high cost of native seeds, mainly introduced grasses were used.

The Lesson or Dilemma of Resource Protection Versus Diversity

In the past, as well as now, aggressively establishing introduced grasses have been used after fire for mountain slope watershed protection and also for site recapture from weeds. The fear has been that native species do not establish dependably or vigorously enough to protect the resource. Some of the vigorous exotic grasses then dominate the site and limit subsequent diversity (Pyke 1996). Land managers are still reluctant to seed expensive native species when it looks like the site could be lost to weeds or erosion.

The Maple Mountain burn of 1994 illustrates this dilemma. After an August fire burned the steep slopes of Maple Mountain above Mapleton, Utah, residents feared that thundershowers would produce damaging debris flows in town, just as happened 100 years earlier when Wasatch Mountain slopes were heavily grazed (Ellison 1960). The Forest Service was under pressure to seed immediately to establish plant cover and control runoff. The hydrologist was reluctant to trust native species alone, so smooth brome, intermediate wheatgrass (*Agropyron intermedium*), and orchardgrass (*Dactylis glomerata*) were the dominant species seeded. The Utah Division of Wildlife was able to contribute native species seed from their warehouse, but soil stabilization was considered to be dependent primarily on the exotic grasses.

Some managers have learned to increase diversity by reducing the rate of introduced species in the seed mix and by encouraging native species success with specific seeding techniques. For example, in Idaho the Bureau of Land Management has had success aerial seeding sagebrush into snow; the seed germinates just as the snow melts in the spring. They still seed crested wheatgrass on these areas, but at the rate of 1 kg pure live seed per ha rather than the usual 6 kg per ha. This allows sagebrush and the native bluebunch wheatgrass a much better chance of establishing.

The solution to this dilemma for some sites is difficult—possibly requiring initial resource protection of some sites with exotics, followed by retreatment to control the exotics and establish natives. Native plant material developed for greater vigor might help, but may also limit diversity.

In the past, we have learned that only partial control of some highly competitive species results in their rapid return to dominance. Yet other species are compatible with each other. For example, the two-layered root system of big sagebrush makes it much more competitive with associated bunchgrasses than does the tap root system of rubber rabbitbrush (*Chrysothamnus nauseosus*) (Frischknecht 1963). We need to better understand competitive and facilitory relationships among different species in our wildland plant communities (Pyke and Archer 1991) and which species can be most compatible by partitioning of resources in time and space.

The Lesson of Management

Rangeland managers in the Western United States learned fairly quickly that revegetation does not necessarily solve grazing management problems. If overstocking or heavy seasonal use resulted in deterioration of the plant community in the first place, appropriate grazing management had to be implemented to maintain the subsequent revegetation community. Management and control of both domestic and wild graziers is necessary. Normally, grazing is deferred for 2 years after revegetation of semiarid rangelands. Although this length of deferment may not be necessary for introduced grasses that evolved under herbivory, it is well recommended for many native plants, especially shrubs. Wild ungulates are harder to restrict from a revegetated area than are domestic livestock, and require special fences (Carson and Edgerton 1989). Management of revegetated grass and shrublands may also require the use of fire to control tree invasion. Restoration of a site to "near historic" conditions must also involve restoration of the historic disturbance regime.

Conclusions

The relatively new goal of restoring native, diverse plant communities is a challenging one, especially on a large scale. It requires us to understand much better the vegetation dynamics and disturbance ecology of our sites, the characteristics of native plant ecotypes and populations, and the ecology of species relationships. Hopefully the lessons from the past can guide us rather than limit our thinking in the future.

References

Bleak, A. T.; Frischknecht, N. C.; Plummer, A. P.; Eckert, R. E., Jr. 1965. Problems in artificial and natural revegetation of the arid shadscale vegetation zone of Utah and Nevada. Journal of Range Management. 18: 59-65.

Carson, S. G.; Edgerton, P. J. 1989. Creating riparian wildlife habitat along a Columbia River impoundment in North-Central Washington. In: Wallace, A.; McArthur, E. D.; Hafercamp, M. R., comps. Proceedings—symposium on shrub ecophysiology and biotechnology; 1987 June 30- July 2; Logan, UT. Gen. Tech. Rep. INT-256. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 64-69.

Christensen, M.; Meyer, S. E.; Allen, P. 1996. A hydrothermal time model of seed after-ripening in *Bromus tectorum* L. Seed Science Research. 6: 1-9.

Clary, W. P. 1989. Revegetation by land imprinter and rangeland drill. Res. Pap. INT-397. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 6 p.

Cox, J. R.; Martin-R., M. H.; Ibarra-F., F. A.; Morton, H. L. 1986. Establishment of range grasses on various seedbeds at creosotebush (*Larrea tridentata*) sites in Arizona, U.S.A., and Chihuahua, Mexico. Journal of Range Management. 39(6): 540-546.

Cray, C.; Horvath, C.; York, S. 1995. Go native! A summary of native plant projects on the Mt. Hood National Forest. Gresham, OR: U.S. Department of Agriculture, Forest Service, Mt. Hood National Forest. 25 p.

Criddle, R. S.; Hopkin, M. S.; McArthur, E. D.; Hansen, L. D. 1994. Plant distribution and the temperature coefficient of metabolism. Plant Cell and Environment. 17: 233-243.

Currans, S. P.; Kitchen, S. G.; Lambert, S. M. 1997. Insuring identity and quality of native seeds. In: Roundy, B. A.; Shaw, N. L., comps. Proceedings: using seeds of native species on rangelands; 1997 February 18; Rapid City, SD. Gen. Tech. Rep. INT-GTR-372. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Dixon, R. M. 1978. Water infiltration and control on rangelands: principles and practices. In: Hyder, D. N., ed. Proceedings of the first international rangeland congress. Denver, CO: Society for Range Management: 322-325.

Dixon, R. M.; Simanton, J. R. 1980. Land imprinting for better watershed management. In: Symposium on watershed management. Vol 2. Boise, ID: American Society of Civil Engineers: 809-826.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Botanical Review. 26: 2-78.

Englert, J. M.; White, R. S. 1997. Improved conservation plant materials released by NRCS and cooperators through December 1996. List of conservation plant releases. Beltsville, MD: U.S. Department of Agriculture, Natural Resources Conservation Service, National Plant Materials Center. 44 p.

Frischknecht, N. E. 1963. Contrasting effects of big sagebrush and rubber rabbitbrush on production of crested wheatgrass. Journal of Range Management. 16: 70-74.

Fulbright, T. E.; Guthery, F. S. 1996. Mechanical manipulation of plants. In: Krausman, P. R., ed. Rangeland wildlife. Denver, CO: Society for Range Management: 339-354.

Hafercamp, M. R.; Ganskopp, R. F.; Miller, R. F.; Sneva, F. A. 1987. Drilling versus imprinting for establishing crested wheatgrass in the sagebrush steppe. Journal of Range Management. 40: 524-530.

Huber, L. S.; Brooks, P. J. 1993. Native seed collection guide for ecosystem restoration. Baker City, OR: U.S. Department of Agriculture, Forest Service, Wallowa-Whitman National Forest. 64 p.

Jackson, L. L. 1992. The role of ecological restoration in conservation biology. In: Fiedler, P. L.; Jain, S. K., eds. Conservation biology. New York: Chapman and Hall: 433-451.

Johnson, D. A.; Asay, K. H. 1993. Viewpoint: selection for improved drought response in cool-season grasses. Journal of Range Management. 46: 194-202.

Johnson, K. L., ed. 1986. Crested wheatgrass: its values, problems and myths; symposium proceedings; 1983 October 3-7. Logan, UT: Utah State University. 348 p.

Jordan, G. L. 1967. An evaluation of pelleted seeds for seeding Arizona rangelands. Tech. Bull. 183. Tucson, AZ: University of Arizona Agricultural experiment Station. 32 p.

Keck, W. M. 1972. Great Basin Station—sixty years of progress in range and watershed research. Res. Pap. INT-118. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p.

Larson, J. E. 1980. Revegetation equipment catalog. Missoula, MT: U.S. Department of Agriculture, Forest Service, Equipment Development Center. 198 p.

Linhart, Y. B. 1995. Restoration, revegetation, and the importance of genetic and evolutionary perspectives. In: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann., D. K., comps. 1995. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 271-287.

Mack, R. N. 1986. Alien plant invasion in the Intermountain West: a case history. In: Mooney, H. A.; Drake, J. A., eds. Ecology of biological invasions of North America and Hawaii. New York: Springer-Verlag: 191-213.

McArthur, E. D. 1988. New plant development in range management. In: Tueller, P. T., ed. Vegetation science applications to rangeland analysis and management. Boston: Kluwer Academic Publishers: 81-112.

McArthur, E. D.; Stevens, R.; Monsen, S. B. 1995. Adaptation and success of big sagebrush and rubber rabbitbrush on disturbed sites. In: Schuman, G. R.; Vance, G. F., eds. Decades later: a time for reassessment, proceedings of the 12th annual national meeting of the American Society for Surface Mining and Reclamation; 1995 June 3-8; Gillette, WY. Princeton, WV: American Society for Surface Mining and Reclamation: 811-823.

McArthur, E. D.; Tausch, R. J. 1995. Genetic aspects of the biodiversity of rangeland plants. In: West, N. E., ed. Biodiversity on rangelands. Natural Resources and Environmental Issues Volume IV. Logan, UT: Utah State University, College of Natural Resources: 5-20.

Meyer, S. E.; Monsen, S. B. 1990. Seed source differences in initial establishment for big sagebrush and rubber rabbitbrush. In: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tueller, P. T., comps. Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 200-208.

Meyer, S. E.; Pendleton, R. L. 1990. Seed germination biology of spineless hopsage: between population differences in dormancy and response to temperature. In: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tueller, P. T., comps. Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 187-192.

Meyer, S. E.; Kitchen, S. G.; Carlson, S. L. 1995. Seed germination timing patterns in Intermountain Penstemon (Scrophulariaceae). American Journal of Botany. 82: 377-389.

Monaco, T. A.; Smith, B. N.; Hemming, D. J. B.; Hansen, L. B.; Monsen, S. B.; Carlson, S. L. 1996. Dark respiration comparisons of forbs and grasses from common gardens. In: Barrow, J. R.; McArthur, E. D.; Sosebee, R. E.; Tausch, R. J., comps. 1995 May 23-25; Las Cruces, NM. Gen. Tech. Rep. INT-GTR-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 210-213.

Monsen, S. B.; Kitchen, S. G., comps. 1994. Proceedings—ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 416 p.

Monsen, S. B.; McArthur, E. D. 1995. Implications of early Intermountain range and watershed restoration practices. In: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann., D. K., comps. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 16-25.

Mooney, H. A.; Gordon, M., eds. 1983. Disturbance and ecosystems. New York: Springer-Verlag. 292 p.

Munda, B. D.; Smith, S. E. 1995. Genetic variation and revegetation strategies for desert rangeland ecosystems. In: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann., D. K., comps. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 288-295.

Nechaeva, N. T., ed. 1985. Improvement of desert ranges in Soviet Central Asia. New York: Harwood Academic Publishers. 327 p.

Office of Surface Mining Reclamation and Enforcement. 1988. Plant materials handbook. Submitted by: U.S. Department of Agriculture, Soil Conservation Service, unnumbered. Soil Conservation Service Plant Materials Centers, Washington, DC.

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. 1968. Restoring big game range in Utah. Utah Division Fish and Game Publication 68-3. Salt Lake City, UT. 183 p.

Potash, L.; Aubry, C.; Busse, B.; Hamilton, W.; Ketcheson, G.; Henderson, J.; Mace, R. 1994. Native plant notebook. Mountlake Terrace, WA: U.S. Department of Agriculture, Forest Service, Mt. Baker-Snoqualmie National Forest.

Pyke, D. A. 1996. Rangeland seedings and plantings: exotics or natives? In: Edge, W. D.; Olson-Edge, S. L., eds. Proceedings: sustaining rangeland ecosystems symposium; 1994 August 29-31; La Grande, OR. Eastern Oregon State College SR 953. Corvallis, OR: Oregon State University: 32-44.

Pyke, D. A.; Archer, S. 1991. Plant-plant interactions affecting plant establishment and persistence on revegetated rangeland. Journal of Range Management. 44: 550-557.

Rhymer, J. M.; Simberloff, D. 1996. Extinction by hybridization and introgression. Annual Review Ecology and Systematics. 27: 83-109.

Roundy, B. A. 1994. Relating seedbed environmental conditions to seedling establishment. In: Monsen, S. B.; Kitchen, S. G., comps. Proceedings—ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 295-299.

Roundy, B. A. 1995. Lessons from the past—Gilbert L. Jordan's revegetation research in the Chihuahuan and Sonoran deserts. In: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann., D. K., comps. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 107-112.

Roundy, B. A. 1996. Revegetation of rangelands for wildlife. In: Krausman, P. R., ed. Rangeland wildlife. Denver, CO: Society for Range Management: 355-368.

Roundy, B. A.; Abbott, L. B.; Livingston, M. 1997. Surface soil water loss after summer rainfall in a semidesert grassland. Arid Soil Research and Rehabilitation. 11: 49-62.

Roundy, B. A.; Biedenbender, S. H. 1995. Revegetation in the desert grassland. In: McClaran, M. P.; Van Devender, T. R., eds. Desert grasslands. Tucson, AZ: University of Arizona Press: 265-303.

Roundy, B. A.; Call, C. A. 1988. Revegetation of arid and semiarid rangelands. In: Tueller, P. T., ed. Vegetation science applications to rangeland analysis and management. Boston: Kluwer Academic Publishers: 607-635.

Roundy, B. A.; Shaw, N. L.; Booth, D. T. 1997. Using native seeds on rangeland. In: Roundy, B. A.; Shaw, N. L., comps. Proceedings: using seeds of native species on rangelands; 1997 February 16-21; Rapid City, SD. Gen. Tech. Rep. INT-GTR-372. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 1-8.

Shiflet, T. N.; McLauchlan, R. S. 1986. Selecting plants for revegetation of rangelands in the United States. In: Joss, P. J.; Lynch, P. W.; Williams, O. B., eds. Rangelands: a resource under siege. Proceedings 2nd International Rangeland Congress; 1984 May 13-18; Adelaide, South Australia; New York, NY: Cambridge University Press: Australian Academy of Sciences: 295-296.

Smith, B. N.; Monaco, T. A.; Hemming, D. J. B.; Hansen, L. D.; Criddle, R. S. 1996. The relation between respiration and growth rates of accessions of plants of the Great Basin, United States. Russian Journal of Plant Physiology. 43: 821-825.

U.S. Bureau of the Census. 1996. Statistical abstract of the United States: 1996. Washington, DC.

Vallentine, J. F. 1989. Range development and improvements. San Diego, CA: Academic press, Inc. 524 p.

Vankus, V. 1996. Current issues and the future of seed certification of trees, shrubs, and native plants. In: Landis, T. D.; South, D. B., tech. coords. National proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. PNW-GTR-389. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 102-105.

West, N. E. [In press]. Juniper-piñon savannahs and woodlands of western North America. In: Anderson, R. C., ed. Vegetation of savannahs and barrens of North America. New York: Oxford University Press.

Winkel, V. K.; Roundy, B. A. 1991. Effects of cattle trampling and mechanical seedbed preparation on grass seedling emergence. Journal of Range Management. 44: 171-175.

Winkel, V. K.; Roundy, B. A.; Blough, D. K. 1991. Effects of seedbed preparation and cattle trampling on burial of grass seeds. Journal of Range Management. 44: 176-180.

Wright, H. A.; Bailey, A. W. 1982. Fire ecology. New York: John Wiley and Sons. 501 p.

Young, J. A.; Sparks, B. A. 1985. Cattle in the cold desert. Logan, UT: Utah State University Press. 255 p.

Young, S. A. 1995. Verification of germplasm origin and genetic status by seed certification agencies. In: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann., D. K., comps. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 293-295.

Young, S.; Kitchen, S.; Armstrong, J.; Watson, V. 1995. AOSCA approves certification guidelines for wild land collected seed. Seed World. 133: 20-21.

Important Biological Factors for Utilizing Native Plant Species

Loren E. Wiesner

Abstract—Native plant species are valuable resources for revegetation of disturbed ecosystems. The success of these plantings is dependent on the native species selected, quality of seed used, condition of the soil, environmental conditions before and after planting, planting equipment used, time of planting, and other factors. Most native species contain dormant seed. Dormancy in domesticated and wild species can make it difficult to establish stands; however, in wild species seed dormancy is one method of perpetuating the species. Temperature, moisture, and light requirements for germination of each species are important factors to know before planting. Each species has an optimum temperature range in which it will germinate. Successful stand establishment begins in the seed production field or collection area with proper nutrient balance, moisture, weed control, time of harvest, seed drying, seed handling, seed conditioning, and storage. Improper harvesting and storage can quickly reduce seed quality. All of these factors must be considered when using native species for revegetation.

Native plant species that are well adapted to the local environment of a particular area generally are more difficult to establish than introduced species. This is especially true of a bunchgrass species like blue grama (*Bouteloua gracilis*), which possesses generally good germination, but poor seedling survival (Hyder and others 1971). Native species such as green needlegrass (*Stipa viridula*) show high dormancy, a survival mechanism, but make stand establishment difficult from seed. The use of grasses appears to offer the best means of stabilization of disturbed lands, but shrub, forb, and legume plantings are desirable to increase vegetative diversity and improve winter grazing value. For shrubs, as with grasses, drought is a deterrent to stand establishment and maintenance. However, native shrubs offer better tolerances to low precipitation environments than introduced shrubs (Bleak and others 1965). In general, native species are the most desirable for reclamation use because of their adaptation to local environments and especially because of their ability to withstand drought, but they are usually the most difficult to establish. Native species are more difficult to establish compared to introduced species due to: (1) mechanical seed quality, (2) presence of seed dormancy, (3) use in mixtures of species, and (4) lack of seedling vigor. In addition to species characteristics, revegetation plantings are usually made on disturbed or poor soils that may contain heavy metals and have high clay contents, and usually are alkaline or acid (Lohmiller and others 1990). The objective of this presentation is to explain why native plants are difficult to establish during revegetation of disturbed lands and that they require the use of proper cultural practice.

Discussion

The selection of appropriate species for use on a particular site is very important, and these species should be selected based on adaptation to the area and future use of the land. In addition, these other requirements should be considered: (1) ability to rapidly establish a stand, (2) ability to reproduce and sustain adequate cover, (3) ability to stabilize the soil to prevent wind and water erosion, and (4) the ability to withstand harsh extremes of the local climate (Lohmiller and others 1990). If the reclaimed area is to be used for grazing, the species should tolerate grazing pressure, fit forage balance, and provide sufficient high quality forage to make grazing the reclaimed land economical. Based on these needs and the need for a diverse plant community, complex mixtures of grasses, shrubs, forbs, and legumes are used.

The use of complex mixtures creates many problems relating to seed biology. For example, selecting the proper planting date and planting equipment is difficult when a complex mixture contains dormant seed species, cool season grasses, warm season grasses, shrubs, and forbs. Spring or fall planting dates are usually chosen to accomodate the majority of the species within a mix. Dormant seed species are best planted in late fall so they will not germinate until the seed has been exposed to a cool moist period to reduce or overcome seed dormancy. However, late fall is not a good time to plant the warm season grasses or the shrubs and forbs. Planting twice may solve the problem—late fall for the dormant species and early spring or late spring for the other species. Even then problems may exist because the cool season species with nondormant seed should be planted in early spring and the warm season species in late spring (Lohmiller and others 1990). Date of planting can be determined by knowing the optimum temperature for germination of each species. Table 1 gives a few examples of optimum temperature for germination testing of seed as recommended by the Rules for Testing Seeds (Association of Official Seed Analysts 1996). Based on these optimum germination temperatures, it is evident that providing the optimum temperature for maximum germination of each species in a mixture is almost impossible. However, by knowing the biological characteristic of the seed and the compatibililty of each species with companion species a more appropriate planting date can be determined (Brown and Wiesner 1984).

In: Holzworth, Larry K.; Brown, Ray W., comps. 1999. Revegetation with native species: proceedings, 1997 Society for Ecological Restoration annual meeting; 1997 November 12–15; Ft. Lauderdale, FL. Proc. RMRS-P-8. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Table 1—Optimum temperatures for laboratory germination of various species.

Plant species	Temperature for germination	Days of germination
	- - °C - -	
Western wheatgrass (*Pascopyrum smithii*)	15-25 dark	28
Sheep fescue (*Festuca ovina*)	15-25 dark	21
Slender wheatgrass (*Elymus trachycaulus*)	20-30 light	14
Blue grama (*Bouteloua gracilis*)	20-30 light	14
Big bluestem (*Andropogon gerardii*)	20-30 light	14
Buffalograss (*Buchloe dactyloides*)	20-35 light	14
Rubber rabbitbrush (*Chrysothamnus nauseosus*)	20-30 dark	28
Skunkbush sumac (*Rhus trilobata*)	20-30 dark	40
Serviceberry (*Amelanchier alnifolia*)	20-30 dark	60

Equipment and Methods

Selection of the proper type of planting equipment is also difficult. It is recommended that the seed be broadcast onto the surface or drill seeded into the disturbed soil. A primary consideration when either broadcasting or drill seeding is depth; small seeds are planted at ¼ inch, medium seed at ½ inch, and large seed at 1 inch (Lohmiller and others 1990). Drill seeding is usually the most successful method of seeding if seeding depth can be controlled. Seeding depth can be controlled for drill seeding by having a very firm seedbed. Use depth bands on the disc openers and packer wheels following the discs (Holzworth and Wiesner 1990). However, if light is required for germination or if you are planting into a soft seedbed, then broadcast seeding is best. If broadcast seeding is used, the seed should be compacted into the soil surface with a corrugated roller to provide good seed-soil contact. Broadcast seeding is used on uniformly rough surfaces and when a large number of species are being planted. Drill seeding is used on seedbeds that are well prepared and when only a few species are used in the mixture (Lohmiller and others 1990). Multiple box drills are availiable and can be used to seed complex mixtures by placing seed with different characteristics into different seed boxes and obtaining more uniform distribution.

Seed Dormancy

Most native species contain dormant seed. There are many definitions of seed dormancy and many different types. A dormancy seed is a viable seed that will not germinate even though it is exposed to the proper environment for germination—proper temperature, moisture, air composition, and light. Dormant seed has a block that will not allow it to germinate until the block has been removed. There are many blocks that are known to prevent germination of dormant seeds (Bewley and Black 1982), such as: (1) immature embryos, (2) impermeable seed coats to water, (3) impermeable seed coats to gases, (4) physical restriction of the seed coat, (5) water soluble inhibitors in the seed coat or fruit, (6) metabolic inhibitors, (7) light sensitivity, and (8) combination of several of these blocks

Dormancy is a means for optimizing the distribution of germination in time or space, and it has great significance in an ecological context (Bewley and Black 1982). Distribution in time can be achieved by spreading germination over an extended period. This happens because seeds of many species show variability in degree of dormancy; the population consequently exhibits sporadic release from dormancy and results in irregular germination. This spreading of germination in time and space is advantageous for perpetuating established plant communities, but creates a problem when trying to re-establish a similar plant community from seed.

Seed Quality

Another factor affecting native species stand establishment is the actual quality of the seed for both purity and germination. Usually native species seed is of poorer quality than seed from introduced species that was harvested from cultivated fields rather than obtained from collections of native stands. Many of the warm season species, such as the grama grasses and the bluestems, have appendages that make them difficult to condition without damaging the seed. A study to evaluate seed quality was conducted using seed collected from plants growing on rangeland and reclaimed spoils in the Colstrip area of southeastern Montana. All seed was collected in the same year from this location. Pure live seed of the native species was less than the seed of species that were readily available in commercial channels (table 2).

Seed Vigor

Seed vigor affects the establishment of native species from seed. Seed vigor is defined in the Association of Official Seed Analysts Seed Vigor Testing Handbook (1983) as "Those properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions." Seed vigor is a measure of seed quality that indicates the ability of the seedling to grow rapidly under a wide range of field conditions. Comparative vigor tests were conducted using seed of native and introduced species collected, during the same year, from rangeland and from a reclaimed area near Colstrip, MT. These species were evaluated for vigor using speed of germination and speed of elongation tests. Results are shown in table 3. The average speed of germination index for the introduced species was 15.0 and for the native species 7.1. The average speed of elongation index for introduced species was 6.9 and for native species 4.6. These data suggest that native species are less vigorous and require better soil preparation and environmental conditions for establishment.

Table 2—Pure live seed of species collected from rangeland and from a reclaimed area near Colstrip, MT.

Plant species	Available in commercial channels	Pure live seed
		Percent
Thickspike wheatgrass (*Elymus lanceolatus*)	Yes	82
Western, and slender wheatgrasses (*Pascopyrum smithii* and *Elymus trachycaulus*)	Yes	88
Hard fescue (*Festuca brevipila*)	Yes	88
Switchgrass (*Panicum virgatum*)	Limited	68
Little bluestem (*Andropogon gerardii*)	Limited	67
Green needlegrass (*Stipa viridula*)	Limited	15
Prairie sandreed (*Calamovilfa longifolia*)	Limited	79
Fourwing saltbush (*Atriplex canescens*)	No	13
White prairie clover (*Dalea* sp.)	No	44

Table 3—Seed vigor test results of native and introduced species collected in the same year from rangeland and from a reclaimed area near Colstrip, MT.

Species	Type	Speed of germination index[a]	Speed of elongation index[a]
Crested wheatgrass (*Agropyron cristatum*)	Introduced	11.4b	4.6b
Smooth bromegrass (*Bromus inermis*)	Introduced	18.6a	9.2a
Slender wheatgrass (*Elymus trachycaulus*)	Native	16.3a	8.4a
Bluebunch wheatgrass (*Agropyron spicatum*)	Native	9.3bc	3.4cd
Blue grama (*Bouteloua gracilis*)	Native	1.3d	5.5b
Little bluestem (*Andropogon gerardii*)	Native	.2d	3.9c
Prairie junegrass (*Koeleria cristata*)	Native	8.2c	1.6d

[a]Means in columns followed by letters in common are not significantly different.

Seed Selection

The native species selected for use in a mixture can make a difference in the establishment of the individual species. A study was conducted to evaluate the establishment of seven species when planted in a pure stand, in combination with a wheatgrass base mixture, and in an all species mixture (table 4). All seed in this study was planted based on the number of pure live seed per square meter. The seeding rates for each treatment were as follows: pure stand = 215 pure live seed per m^2, one species with wheatgrass base mixture = 215 pure live seed per m^2, and all species mixture = 86 pure live seed per m^2 of each species, and all 10 species were included in the treatment.

The base mixture species of slender, thickspike, and western wheatgrass were selected because they were excellent native grasses for southeastern Montana, and each species had different establishment characteristics. By using three different treatments we could evaluate establishment of each species with and without competition.

Little bluestem established better with the base mixture than in a pure stand (table 5), but only 3 percent of the pure live seed established in the all species mixture. These data suggest that little bluestem performed well in the base mixture and that competition within the all species mixture was detrimental to its establishment. White prairie clover established well in the all species mixture as compared to other species, but did not compete well with weeds in pure stand (table 5). The poorest stand of white prairie clover was obtained with the base mixture. The base mixture wheatgrass species are well adapted to the area where these studies were conducted, and considering that two are sod-forming grasses and one a bunchgrass, these species at the seeding rate utilized were competitive with white prairie clover.

Fourwing saltbush did not establish well with competition from other species; it did best in pure stand (22 percent of pure live seed established) (table 5). After 3 years, most of the fourwing saltbush was eliminated from the base mixture and all species mixture treatments (unpublished data). Fourwing saltbush in pure stand had 45 percent of the pure live seed emerge, but after 1 year the percentage of pure live seed established was reduced to 22 percent.

Switchgrass established best in pure stand with 11 percent establishment of the pure live seed planted. Competition in the base mixture and the all species mixture reduced the percentage of pure live seed of switchgrass that established in those treatments.

Green needlegrass had good emergence in pure stand and with the base mixture. The pure stand had the same percentage of establishment as emergence (56 percent of the pure live seed). Emergence of green needlegrass in the all species mixture was low. Once the grass plants grew beyond the seedling stage, it was difficult to distinguish between the base mixture species and green needlegrass; therefore, no data was obtained for establishment of green needlegrass in the base mixture and the all species mixture.

Table 4—Species used in the establishment study presented in table 5.

Common name	Abbreviated common name	Scientific name
Little bluestem	LB	(*Andropogon gerardii*)
White prairie clover	WPC	(*Dale*a sp.)
Fourwing saltbush	FWSB	(*Atriplex canescens*)
Switchgrass	SG	(*Panicum virgatum*)
Green needlegrass	GN	(*Stipa viridula*)
Prairie sandreed	PS	(*Calamovilfa longifolia*)
Hard fescue	HF	(*Festuca brevipil*a)
Wheatgrass base mix:		
Slender wheatgrass	BM	(*Elymus trachycaulus*)
Thickspike wheatgrass	BM	(*Elymus lanceolatus*)
Western wheatgrass	BM	(*Pascopyrum smithii*)

Prairie sandreed and hard fescue established similarly in pure stand, base mixture, and all species mixture, indicating that the competition from the other species did not affect their establishment. Prairie sandreed had a higher percentage establishment of pure live seed than did hard fescue (table 5).

The base mixture of slender, thickspike, and western wheatgrass had the highest percentage of pure live seed establishment (30 percent) (table 5). Establishment of base mixture species was generally not affected by the addition of a single species to the mixture; the average percentage of pure live seed that established over all species was 26 percent compared to 30 percent for the base mixture species alone. The addition of one species of either little bluestem, fourwing saltbush, switchgrass, green needlegrass, or prairie sandreed to the base mixture increased percentage establishment over the base mixture alone. The addition of either white prairie clover or hard fescue to the base mixture did not improve percentage of establishment compared to the establishment of the base mixture alone.

The all species mixture (containing 10 species with equal amounts of pure live seed) had only 16 percent of the pure live seed established, and hard fescue was not represented in the established stand. Best stand establishment is usually obtained with simple mixtures that reduce species competition and control weed infestations.

Summary

Native species are difficult to establish due to reduced physiological and mechanical seed quality caused by specific seed characteristics. Most native seed has dormancy that is good for longevity of the species, but makes it difficult to establish a stand. Most native seed has reduced seed vigor, which results in poor seedling growth after germination. Revegetation with native species usually requires the planting of several species together in a mixture. The use of a simple mixture is desirable. Species establishment characteristics should be considered when selecting species to be planted together in a mixture. Most revegetation plantings do not require that a perfect stand be obtained the first or second year after seeding, which allows plants from late germinating seeds an opportunity to establish.

References

Association of Official Seed Analysts. 1983. Seed vigor testing handbook. AOSA Handb. 32.

Association of Official Seed Analysts. 1996. Rules for Testing Seeds. Journal of Seed Technology. 16(3): 53-85.

Bewley, J. D.; Black, M. 1982. Physiology and biochemistry of seed. Vol. 2. New York: Springer-Verlag. 375 p.

Bleak, A. T.; Frischknecht, N. C.; Plummer, A. P.; Echert, R. E., Jr. 1965. Problems in artificial and natural revegetation of the arid shadscale vegetation zone of Utah and Nevada. Journal of Range Management. 18(2): 59-65.

Brown, G. A.; Wiesner, L. E. 1984. Selecting species for revgetation—a guide for disturbed land in the western region. Montana Agricultural Experiment Station. Special Rep. 3.

Holzworth, L. K.; Wiesner, L. E. 1990. Principles of establishment and seedling year management. In: Baldridge, D. E.; Lohmiller, R. G., eds. Montana Interagency Plant Materials Handbook. EB 69. Montana State University Extension Service: 170-186.

Hyder, S. N.; Everson, N. C.; Bement, R. E. 1971. Seedling morphology and seeding failures with blue grama. Journal of Range Management. 24(4): 287-292.

Lohmiller, R. G.; Dollhopf, D. J.; Martinson, A. H. 1990. Disturbed land rehabilitation. In: Baldridge, D. E.; Lohmiller, R. G., eds. Montana Interagency Plant Materials Handbook. EB 69. Montana State University Extension Service: 248-255.

Table 5—Pure live seed planted in April 1976, the percentage emerged in July 1976 and the percentage established in July 1977.

Common name[a] and treatment	Abbreviated common name[a]	Pure live seed	Number pure live seed per m^2	Pure live seed emerged 1976	Pure live seed established 1977
		Percent		- - - - - - - *Percent*	- - - - - -
Little bluestem pure seed	LB	67.1	215.1	5.9	8.6
Little bluestem with base mix[b]	LB	67.1	215.1	7.1	11.5
	BM	81.7	645.2	32.9	26.2
Little bluestem in all species mix[c]	LB	67.1	86.0	6.9	3.1
White prairie clover pure seed	WPC	44.3	215.1	11.2	8.3
White prairie clover with base mix[b]	WPC	44.3	215.1	5.2	6.5
	BM	81.7	645.2	34.3	21.7
White prairie clover in all species mix[c]	WPC	44.3	86.0	6.9	10.1
Fourwing saltbrush pure seed	FWSB	13.5	215.1	45.9	22.3
Fourwing saltbush with base mix[b]	FWSB	13.5	215.1	45.9	22.3
	BM	81.7	645.2	49.8	31.8
Fourwing saltbush in all species mix[c]	FWSB	13.5	86.0	41.0	4.7
Switchgrass pure seed	SG	67.7	215.1	25.0	11.5
Switchgrass with base mix[b]	SG	67.7	215.1	18.6	8.6
	BM	81.7	645.2	50.8	24.9
Switchgrass in all species mix[c]	SG	67.7	86.0	8.5	5.5
Green needlegrass pure seed	GN	15.3	215.1	56.4	56.1
Green needlegrass with base mix[b]	GN	15.3	215.1	32.5	—[d]
	BM	81.7	645.2	44.5	—[d]
Green needlegrass in all species mix[c]	GN	15.3	86.0	3.1	—[d]
Prairie sandreed pure seed	PS	79.2	215.1	11.2	14.9
Prairie sandreed with base mix[b]	PS	79.2	215.1	2.8	12.7
	BM	81.7	645.2	36.1	25.3
Prairie sandreed in all species mix[c]	PS	79.2	86.0	0.0	14.8
Hard fescue pure seed	HF	87.6	215.1	5.3	5.0
Hard fescue with base mix[b]	HF	87.6	215.1	12.1	3.1
	BM	81.7	645.2	34.6	26.5
Hard fescue in all species mix[c]	HF	87.6	86.0	10.8	0.0
Base mix only	BM	81.7	645.2	47.5	30.4
BM in all species mix[c]	BM	81.7	258.0	43.1	41.6[d]
All species mix	ASM[c]	57.0	860.2	20.3	16.3

[a]Refer to table 4 for complete listing of abbreviated common names and scientific names.
[b]Base mix composed of equal parts pure live seed of thickspike wheatgrass, slender wheatgrass, and western wheatgrass.
[c]All species mix (includes all species in equal pure live seed proportions).
[d]Seedling condition made distinction between green needlegrass and base mix impractical.

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