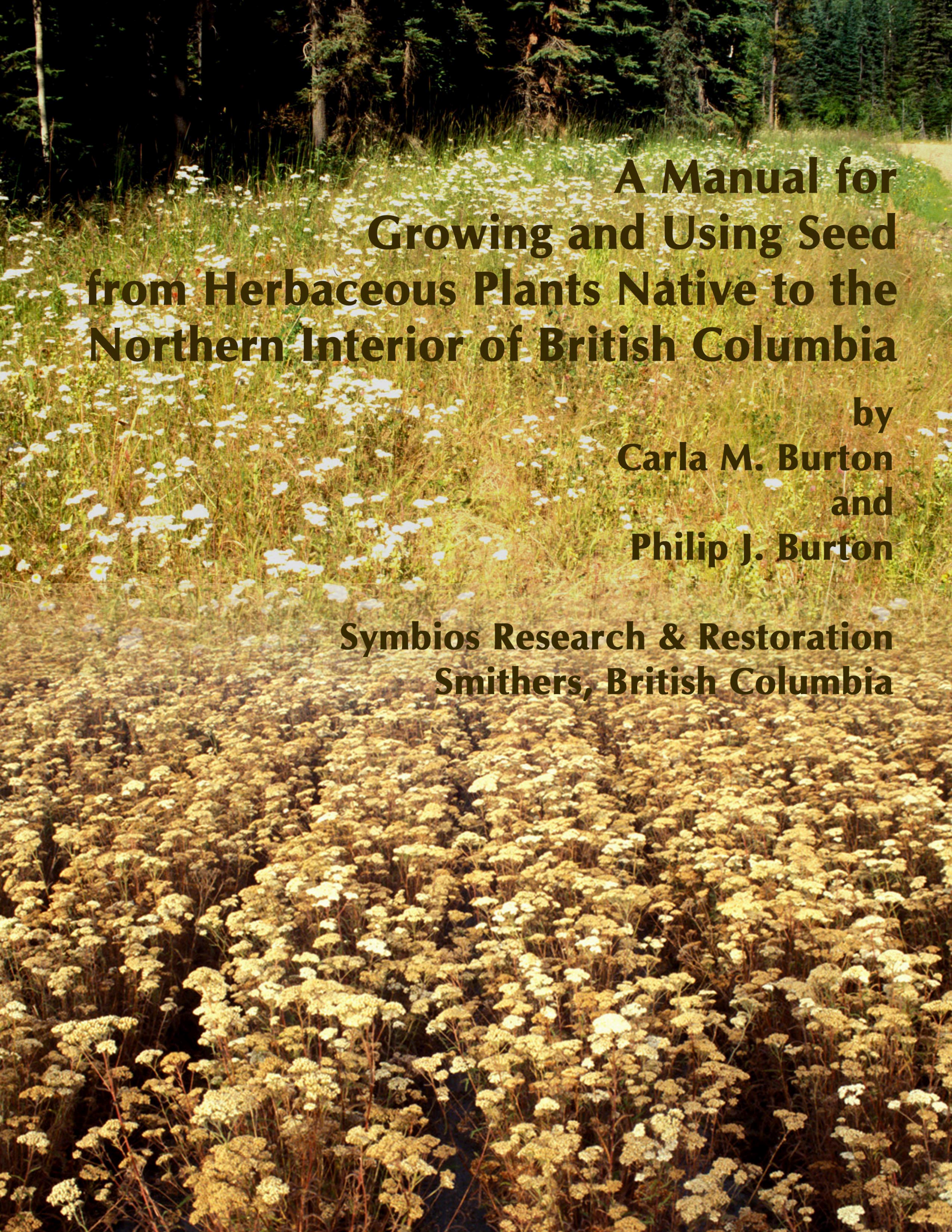

A Manual for Growing and Using Seed from Herbaceous Plants Native to the Northern Interior of British Columbia

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This document should be considered a work in progress. Readers applying this information for growing native plants or in using native plants for revegetation are invited to relate their own results and advice to the authors. It is hoped that future editions of this manual will fill in many of the gaps in our knowledge that still exist with regard to the biology and husbandry of these plant species.

Executive Summary

It is expected that native plant materials will see increasing use for revegetating disturbed and degraded lands in northern British Columbia and elsewhere. Mixtures of grasses and legumes (and sometimes other graminoid and forb species) are sown for roadside erosion control, the rehabilitation of compacted soils, the reclamation of minespoils, and the restoration of natural grasslands. To provide reliable supplies of herbaceous native plant seed for such applications, it is advisable to grow these plants under cultivation and to harvest the seed they produce. This manual provides instructions for this process, focusing on the biology and management of 31 species of herbaceous plants indigenous to the northern Interior of British Columbia. Information is also provided to guide the process of designing seed mixtures and selecting suitable application rates for using these plants in the revegetation of disturbed soils.

Native plant seed production follows many of the standard practices of agronomy and commercial seed growing. It is recommended that production plots or fields be established on loamy soils that have been kept free of weeds for the previous one or two years, and which can be irrigated (especially during the establishment phase). Stands can be established by starting containerized seedlings in a greenhouse and transplanting them into rows, directly seeding individual or paired rows by hand or with a single-row seeder, or (especially for larger fields) using a tractor-drawn seed drill. Most native plant seeds are relatively small, so sowing depths must be shallow. Inert carriers are sometimes needed to enhance seed flow and to dilute seed concentrations when used in standard agricultural machinery. Multiple applications of fertilizer are recommended each year to offset soil deficiencies, aid in stand establishment, maximize seed production, and prolong stand life. The biggest challenge and cost to native plant seed production is always weed control, which is imperative in order to guarantee a weed-free seed supply as well as to enhance crop seed production. Weed control in seed production plots and fields can be accomplished through a combination of cultivation, mulching, manual weeding, broadcast applications of selective herbicide, or spot application of broad-spectrum herbicide. Even if all weeds cannot be killed, weed shoots or seed heads should be manually removed prior to harvesting the seed crop.

The production of native plant seed in cultivation requires careful attention to the management of genetic diversity in each species being grown. Approaches can include seed increase of single local populations, or the development of broad, regionally adapted seed supplies. In all cases, it is important to retain the variability that is associated with features such as plant stature and the timing of reproduction. This means that several selective harvests are often preferable to a single harvest of seed production stands. Harvesting methods can include: manual picking, clipping and sickles; vacuuming; motorized seed stripping; swathing followed by threshing; or straight combine harvesting. The use of plastic mulch between rows of plants can facilitate the collection of dropped or scattered seeds (providing it is free of debris and weed seeds). Seeds of several species can complete their ripening process if dried in the sun or indoors. If not threshed as part of the harvesting process or if the threshing process is not complete, a stationary threshing machine, rethresher, or rotary flail can be used to extract seeds. The straw generated from the harvesting and threshing process can be baled and used as mulch for weed control in seed production plots, or for erosion control on exposed soils at disturbed sites. This manual provides recommended harvesting and threshing methods for each species, with preliminary specifications for machine settings, but a grower must adjust these guidelines as necessary for each crop.

Seed cleaning and testing is an important component of native plant seed production. Cleaning to remove inert plant debris and non-crop seeds is typically done using a combination of sieving and controlled air-flow separation methods. Recommendations for sieve sizes and shapes, and relative air flow settings, are provided for each plant species. As with threshing, cleaning procedures will have to be adjusted for each seed lot, with the requirement that all non-crop seeds must be excluded and the general guideline that less than 5% of crop seeds should be lost in the process. Once cleaned, seed should be stored in sealed containers under cool, dry conditions. Proper seed lot identification is essential. Each seed lot then needs to be tested for its purity (apparently viable seeds as a percentage of seed lot weight) and viability (the percentage of apparently viable seeds that will germinate). For these northern species, germination should normally be tested under conditions of 25^{o}C days and 15^{o}C nights, and tests may have to extend more than 30 days.

Procedures are described for the revegetation of disturbed or degraded soils, and for the design of suitable seed mixtures to be sown on such sites. Each seeding prescription must undertake a degree of matching species to the site and to other species in a proposed mixture. Consideration should be given to the natural distribution and site preferences of candidate plant species, and to site characteristics such as elevation, slope, soil texture, management objectives, and the composition of nearby natural vegetation. Most seed mixtures will consist of tall and short grass species, a rhizomatous species, a nitrogen-fixing species, and slow and fast germinators. Species proportions and seeding rates should be based on densities of pure live seeds (PLS). A general seeding rate of 1500 PLS/m^2 is suitable for many situations, providing that a balanced fertilizer is applied at the same time. Lower rates can be used for level sites where rapid green-up is not essential, while higher rates are needed for erosion-prone sites. Seed should be applied as soon as possible after soil disturbance, or will benefit from raking, harrowing or decompaction if the soil had settled for a prolonged period of time. Seed can be spread by hand, using a cyclone seeder, or using a seed drill, followed again by raking or harrowing. Hydroseeding can also be used, but because it typically requires much more seed, it is discouraged for use with native plant seed that is often expensive and in short supply.

Most of this manual consists of information on the biology, husbandry and use of 31 herbaceous plant species, including eleven grasses, four sedges and rushes, four legumes, six composites, and six representatives of other plant families. Almost all of these species are perennials, with individual plants expected to persist in fields and in the wild for three or more years. Maps of the range of each species in northern British Columbia are provided, as are photographs of their growth habits and seeds. Information is given on growth form, site preferences, seed size, germination behaviour, techniques for seed production, harvesting and seed processing, and considerations for use in revegetation. It is expected that this information will be relevant to the growth and use of these widespread species in regions beyond northern British Columbia, and that the principles and techniques will apply to other work with native herbaceous species as well.

Though based on several years of research and experience, as supplemented by the published literature, this manual must be considered a first approximation of the knowledge needed to grow and use these plant species. Growers and revegetation specialists who work with these plants are encouraged to try different techniques, to monitor their effectiveness, and to record the results.

Table of Contents

(Table of Contents, continued)

Introduction

Land management in the 21st century increasingly emphasizes the need to maintain ecosystem integrity, and to restore integrity where it has been lost. Even in the recent past, it was considered responsible and sufficient to revegetate degraded sites – it didn't really matter what was grown, so long as it was green and could control erosion. Now we realize that it is possible to accomplish these goals without introducing weedy exotics or domesticated species that may out-compete native vegetation, interfere with natural succession, and alter community structure and function. It has become important to pay attention to what was growing on sites before human disturbance, so that appropriate restoration can be carried out after disturbance. Hence the increased interest in using native plants for revegetation purposes, and in growing native plants to produce the seed needed for revegetation and restoration work.

Some government agencies in both Alberta and British Columbia now require the use of native species for restoring certain disturbed sites (Gerling et al. 1996). But because native plants were not routinely used in the past, little is known about their ecology, biology, propagation and husbandry. This manual provides information on these topics. Species documented in the manual are all native to the northern Interior of British Columbia and, as such, are recommended for use in that area. However, since some of the species are found in other parts of Canada and the adjoining U.S.A., much of the specific information and general advice contained in this manual is pertinent to the broader region.

This manual takes a species by species approach to meeting two objectives: (1) providing seed growers with useful information for establishing, growing, and harvesting seed of the designated native species; and (2) providing the ultimate users of these plant materials with guidance for their use in revegetation and ecological restoration projects. We draw primarily upon our own experience in providing these recommendations, as supplemented by reference to the literature where appropriate. This manual emphasizes the husbandry and use of individual species, and is not intended to be a comprehensive manual for plant propagation or revegetation procedures in general. For good background information on native plant propagation and seed production, the reader is referred to Rose et al. (1998), Pahl and Smreciu (1999), and the propagation protocols regularly updated at the website of the Native Plant Network (based at the University of Idaho) at www.nativeplantnetwork.org. For broader overviews of relevant considerations in revegetating disturbed and degraded land, the reader is referred to Greene et al. (1992), Morgan et al. (1995), Gerling et al. (1996), B.C.'s *Soil Rehabilitation Guidebook* (Anonymous 1997), and the *Native Plant Revegetation Guidelines for Alberta* (Anonymous 2001).

Background

This manual is a product of a five year long research project conducted by Symbios Research and Restoration, based in Smithers, B.C. Funding was provided primarily by Forest Renewal B.C., to develop and test native plants for seeding in the northern B.C. Interior. Other supporters of that research included Woodmere Nursery Ltd. (Telkwa, B.C.), and the Canadian Forest Service (Pacific Forestry Centre, Victoria, B.C.). Literature reviews were first conducted to collate existing information on candidate herbaceous species. These species were identified on the basis of their widespread distribution in the region, and their frequent occurrence on disturbed sites such as compacted landings, clearcuts, skidder trails and roadsides. Over 1,000 accessions of 45 different species were collected over three years from 22 biogeoclimatic subzones and 12 forest districts across northern B.C., from 52°N to 60°N and from the Coast Range to the Rocky Mountains. The area from which plant material was collected is broad, but seed was only collected at low to middle elevations (below alpine tree line), so these species and techniques described here are primarily applicable to the treed ecosystems of B.C.'s northern Interior. The climate is fairly homogenous in its boreal, sub-boreal, and subalpine character. Dominated by long snowy winters and short cool summers, this region approximates the zones described by the Canadian Committee on Ecological Land Classification (CCELC) as the boreal and subalpine sections of the Interior Cordilleran, Southern Cordilleran and Mid-Cordilleran ecoclimatic regions (CCELC 1989).

Some researchers and restoration practitioners advocate the use of only local plant materials when conducting ecological restoration. This approach is highly desirable and is especially important for ecological reserves, species at risk of extirpation, or for species that reproduce predominantly by selving. But such an approach ignores the potential benefits of high genetic diversity in populations exposed to a changing climate, and to the practicalities of being able to produce seed in cultivation so that it can be marketed on an economically feasible scale (for which moderately broad geographic applicability is required). Large revegetation programs, such as the roadside seeding of new logging roads and the reclamation of mine spoils, often manage dozens or hundreds of hectares of land every year, making the collection of local wild seed supplies and cuttings neither practical nor sustainable.

In the Symbios program, wild seed from diverse locations was collected in the summer and fall, dried at room temperature, manually cleaned, and stored over winter in refrigerators. Tests for germination capacity using a programmable incubator were conducted in late winter. Seed germination tests were initially conducted for 30 days at 30°C days and 20°C nights, but subsequent tests were done at 25°C days and 15°C nights, with tests often extended for many weeks until germination stopped. In early spring, all accessions were germinated in a greenhouse in peat-filled styroblocks to lengthen their first growing season and to shorten the time to seed production. Seedlings were then transplanted into outdoor seed increase plots. Each seedling was planted in a single-species plot in a computer-generated planting pattern designed to optimize the conditions for outcrossing and hence maximize the potential to produce seed with broad genetic diversity (Burton and Burton 2002). Seeds produced from these plots in the following years were also tested for germination capacity, then passed on to growers to initiate large-scale seed production. Over the course of the project, several species were eliminated due to poor germination, or harvesting and cleaning difficulties.

Field trials testing various species combinations, sowing densities, mulches, and the use of fertilizer were conducted over the course of four growing seasons, and were monitored for 2 or 3 years after seeding. Details of these and other tests and procedures in the development of native seed supplies are provided in the final report for the project (Burton and Burton 2001a), which is available from the authors. Information for the 31 species included in this manual was obtained from direct experience in cultivation and revegetation trials, supplemented by information from the literature and other researchers. These species are presented with their plant family affiliation in Table 1. Most of this manual consists of species by species accounts of growth form, site preferences, seed size, germination behaviour, techniques for seed production, harvesting and seed processing, and considerations for use in revegetation. Some general guidelines apply to all species, as presented in the next section, but much of this information is repeated in the individual species treatments so that those subsections can stand alone as well.

Table 1. The plant species covered in this manual, organized by plant family.

Family	Species	Family	Species
Asteraceae	*Achillea millefolium*	Polemoniaceae	*Polemonium pulcherrimum*
	Anaphalis margaritacea	Poaceae	*Agrostis exarata*
	Arnica chamissonis		*Bromus ciliatus*
	Arnica cordifolia		*Calamagrostis canadensis*
	Aster conspicuus		*Calamagrostis rubescens*
	Aster foliaceous		*Elymus glaucus*
Cyperaceae	*Carex aenea*		*Elymus trachycaulus*
	Carex macloviana		*Festuca occidentalis*
	Carex mertensii		*Leymus innovatus*
Fabaceae	*Lathyrus ochroleucus*		*Poa alpina*
	Lupinus arcticus		*Trisetum spicatum*
	Lupinus polyphyllus	Rosaceae	*Dryas drummondii*
	Vicia americana		*Geum macrophyllum*
Juncaceae	*Luzula parviflora*		*Festuca saximontana*
Liliaceae	*Allium cernuum*	Scrophulariaceae	*Collinsia parviflora*
Onagraceae	*Epilobium latifolium*		

General Considerations for Growing

Native plants are cultivated for seed production in order to concentrate the desired plants in a small convenient area, and to enhance their seed production through soil management and weed control. But there is always the danger that this process will result in the active or passive selection of plant genotypes well suited for growth in cultivation, but perhaps less suited for growth in the harsh and competitive environments of revegetation sites. Consequently, it is recommended that the entire program of native plant husbandry incorporate conscious efforts to protect genetic diversity:

plant material from diverse locations and habitats should be employed;

efforts should be made to encourage outcrossing ("cross-breeding" of populations within a species);

infusions of new wild stock should be added to producing fields;

every effort should be made to coax all plants into production; and

seed should be saved from even the smallest and apparently inferior genotypes.

Genes of plants that may not grow the tallest or produce the most seed are still important in the wild if they confer drought tolerance, disease resistance, and so on. In order to grow native plants on a long-term basis, and not just domesticate them, the grower must always have the maintenance of genetic diversity in mind.

Most of the species described in this manual are perennials. They typically require a year or two for establishment before they produce significant quantities of seed. After a slow start, they are generally quite persistent and will continue to produce seed for three years or more. During that time, weed control will be the biggest challenge to most seed growers. Perennial crops are not tilled under and re-established every year, so weeds aren't killed by cultivation on a regular basis like they might be when farming annual crops. One of the main purposes for using native plants in revegetation is to avoid the introduction of exotic species, so there is "zero tolerance" for the spread of noxious weeds with native plant seed. The presence of all non-crop species also inhibits the vigour and seed production of the desired species. Careful field selection and preparation, followed by vigilant weed control, are key to the success of any commercial seed growing effort.

Though native plant seed is usually applied in mixtures when used for revegetation, reclamation, and ecosystem restoration purposes, that seed is best grown in single-species stands. This makes "weeding" and monitoring of the crop easier, and harvesting more efficient. Seed from several species can then be combined later in the precise proportions desired for particular land uses or microsites (as described in later sections).

Site Selection and Preparation

There are two schools of thought when it comes to the selection of a location for establishing seed production fields of native plants species: (1) to use rich fertile soils as one would any other crop; or (2) to use marginal soils that more closely match the sites that are intended for revegetation using the seed being grown there. If seed production is the goal, and if concerted efforts are made to maintain genetic diversity, it quickly becomes apparent, however, that good cropland is preferable. Soils should be loamy, or sandy if irrigation and fertilization are options. Deep soil free from topographic variation and stones will make mechanical operations much easier and the crop more uniform in its development.

5More important than soils are the weed populations and history of a field being considered for native plant seed production. Ideally, a field would be completely free of non-native species before being employed in native plant seed production, but this is rarely an option (perhaps only on recently broken land). Consequently, it is strongly recommended that fields be fallowed for two years and subject to rigorous weed control prior to stand establishment. Locations infested with noxious weeds such as quackgrass (*Elymus repens*, also known as *Agropyron repens*) or Canada thistle (*Cirsium arvense*) must be especially avoided. These perennial weeds tend to be abundant in former hay fields and pastures, so land that was previously used for cereals or other annual crops is generally preferable.

Pre-planting weed control is best achieved through a series of repeated control operations conducted throughout the growing season. When dealing with annuals and non-rhizomatous species, repeated cultivation (to uproot plants, and expose a fresh batch of weed seeds to surface conditions that prompt them to sprout) seems to work best. For example, a field might be disked or cultivated early in the season as winter annuals start to green up and flower; after they are turned under, it might be another two or three weeks before the fallow greens up again from a new crop of annuals. It is then time to cultivate the field again, killing those seedlings by exposure or burial, and prompting a new bunch of seeds to germinate; this should continue until the soil's bank of weed seeds is depleted. Perennial rhizomatous species are not so easily dislodged, and generally must be treated with systemic herbicides such as Roundup^{TM} or other product containing glyphosate. One problem with the chemical approach, however, is that it only works on green plants, and does not address the seed bank or dormant rhizome fragments inevitably found beneath the surface. Another alternative is to use large sheets of black plastic as a ground cover, heating the ground and cooking any weeds growing on the surface; furthermore, it prompts a number of weed seeds to germinate, after which they die in the darkness under the black plastic. Experience has shown that black plastic treatments, like other control efforts, generally have to be applied for two growing seasons (especially on former hay or pasture lands) in order to bring weeds under control. Whether by mechanical or chemical means, it is important to kill all weeds before they produce another crop of seeds or another generation of underground rhizomes.

It is generally considered that a well prepared but firm soil is best for growing any crop. Seeds of many of the species described in this manual are very small and as such have low food reserves. This means that the seedbed should be finely cultivated and smooth, and that sowing should not be too deep if establishing these species from seed. A recommended procedure is to disk or cultivate the field first, followed by repeated harrowing; alternatively, repeated rototilling can prepare a fine uniform seedbed. A firm seedbed conserves soil moisture, and enables the seed to make good contact with the soil, thereby enhancing the likelihood of successful germination (Pahl and Smreciu 1999).

Stand Establishment

Seed increase plots and seed production fields can be established in three main ways: transplanting greenhouse-started plants; manually sowing single rows; or mechanically sowing multiple (usually closely-spaced) rows. In all cases, provisions should be made for convenient weed control and harvesting. The first option, usually employed when starter seed is in short supply or its germination unreliable, is to start seedlings in a greenhouse and then transplant individual seedlings out into garden plots, usually arranged in rows for ease of weed control and harvesting (Figure 1). Seedlings can be started in open flats, or in containers; containers such as Styroblocks^{TM} have the advantage of keeping root systems of neighbouring plants separate, and the root system forms a "plug" that is easily transplanted. Seed can be started in any sterile greenhouse rooting or potting medium, consisting of some combination of peat moss and vermiculite, perlite, or sand. Seeds and seedlings are typically watered one or more times per day, fertilized once or twice a week with an all-purpose (high N-P-K plus S and micronutrients) plant food, and temperatures are monitored and venting adjusted accordingly to make sure that seeds and seedlings aren't heat-stressed.

Figure 1. Transplanting greenhouse-grown grass seedlings into a seed-increase plot.

Seed production plots or fields can also be started from seed, either in single or closely paired rows (Figure 2), or in tight stands (usually on a larger scale, Figure 3). Seed generally needs to be well cleaned and detached from any appendages (fluff and awns) or mixed with an inert carrier (such as cracked wheat, cat litter, or fertilizer) so it will "flow" well in the seeding machinery. A manual single-row seeder (Figure 2) does the job for most small-scale production areas. Sowing depth and density are easily adjusted, and peat moss, sawdust or loose soil can be manually scattered over surface-sown seeds. Rows are typically spaced 80 to 100 cm apart in order to allow room for weed control (e.g., rototilling) and maintenance access, and will also promote more vigorous growth than in dense stands. Rolls of plastic or paper mulch between rows can be an effective weed deterrent, but manual weeding within the rows will usually still be required.

Figure 2. Fall-sowing a native forb using a single-row (Planet Junior™) push seeder for establishment of a small seed production field. Row spacing here is approximately 80 cm, with strips of old vinyl flooring later rolled out between rows for weed control.

Mechanical sowing (Figure 3) is also an option for most species. Specialized precision equipment suitable for small-scale plot production is manufactured by companies such as Kubota™, Almaco™, and Wintersteiger™, but older small farm equipment for sowing, cultivating, and harvesting will often be adequate. Seed drills should be equipped with press wheels or the ground should be packed after seeding, except on heavy clay soils. The depth of seeding should never be greater than twice the longest diameter of the seed being sown; this means the small-seeded species are just spread on the surface and then lightly pressed into the loose soil. The use of a carrier to bulk up volumes and to improve seed flow in seed drills may be necessary (especially with the chaffy and hairy species). Seed carriers include cracked or roasted grain, vermiculite, and cat litter (Pahl and Smreciu 1999). Commercial fertilizer has also been used as a carrier, but questions remain about the advisability of having high concentrations of fertilizers (and their salts) immediately adjacent to germinating seeds. Fertilizers can also be highly corrosive to machinery if its dust is not carefully removed from the equipment (typically using a vacuum cleaner or compressed air stream) after use.

Figure 3. Spring-sowing a native grass using a small (Brillion™) seed drill pulled by a tractor for establishment of a small seed production field. Row spacing here is approximately 12 cm.

Where feasible, irrigation during the crop establishment phase is a good idea. Most developing seedlings will not tolerate drying, and this is the most vulnerable stage in seed crop stand management. Irrigation can continue until the flowers are ready for pollination; Pahl and Smreciu (1999) recommend that irrigation be stopped then and during seed ripening, although irrigation may resume temporarily during early seed development. In our experience, *Rhizobium* innoculant to stimulate the formation of nitrogen-fixing nodules in legumes is unnecessary on agricultural soils.

Stand Maintenance

Weeding is usually the main stand maintenance activity. Manual weeding by pulling or hoeing is the norm, with mulching or rototilling between rows. Once plants are well established and are mature in size, careful placement of deep straw or other mulches can greatly the need for weeding, which is very labour-intensive. Sometimes selective herbicides can be used: for example, dicotyledon weeds can be killed by broadleaf herbicides such as 2,4-D or Banvel™ (active ingredient dicamba) if the crop is a grass. But even though grasses and sedges are not killed by these chemicals, they can sometimes inhibit seed production, and these chemicals are all somewhat toxic to animals and humans. Spot-spraying with glyphosate (e.g., Roundup™) is another option, utilizing a backpack sprayer or spray bottle. A shrouded nozzle or a sheet of rigid plastic or plywood can serve as a baffle to protect adjacent crop plants. If a young stand is being over-run with weeds, one can sometimes "cup" all crop plants with upside-down plastic containers, and then broadcast-spray all weeds with glyphosate or other broad-spectrum systemic herbicide. Even large fields of native plants should still be walked to remove non-crop species, especially the exotic and noxious species that produce seed that would contaminate the seed crop.

To promote stand vigour and seed production, it is generally recommended that seed production plots and fields be fertilized. The appropriate fertilizer formulation and its rate of application will need to be adjusted depending on the species and the condition of the soil; soil testing should be conducted to determine deficiencies. For example, forb plots should be fertilized with a balanced fertilizer when plots are first established and annually thereafter. Grasses do not need excessive nitrogen (N) as this will encourage vegetative growth and lower seed yield. Nitrogen-fixing plants may not need nitrogen but will need other nutrients (Pahl and Smreciu 1999). Though high N supplements may be called for in the soil test results, this should only be done while the plants are in an early vegetative phase; higher ratios of phosphorus (P) and potassium (K) to N should be utilized in early to middle summer to promote seed set and filling.

With the exception of *Collinsia parviflora*, the plants listed in this manual are all perennials. It appears that some species (e.g., *Arnica* and *Aster* spp.) may be long lived, but others (e.g., *Festuca occidentalis*, and *Achillea millefolium*) have a relatively short life span (under 3 years) as seed producers, but the productive life span of most species still remains unknown. Weed control, fertilization, and stand rejuvenation through clipping and thatch removal can prolong stand life, but not indefinitely.

Mowing grass plots immediately after harvest and removing any post-harvest residue from forb plots are recommended to help reduce disease and insect problems. This procedure increases light and heat to the plant root crowns at the beginning of the next growing season. Remove weeds routinely before they go to seed in order to keep plots weed free, and the reservoir of weed seeds in the soil will eventually be depleted.

Where specific information is available for particular species, variations to these stand management recommendations are presented below in the individual species accounts. Much still needs to be learned about stand maintenance and the optimal timing for stand replacement. Growers are urged to try various management regimes (especially related to fertilization routines) and to keep records of stand maintenance practices, so this information can provide improved guidance for producers in the future.

Harvesting

Wild plants, by definition, have not been selected for uniformity of ripening time, which has been one of the first steps in the domestication of many of man's crop plants. As a result, the seed in stands with broad genetic diversity typically ripens over a long period of time, with some seed heads over-ripe and losing their seeds to the ground before seed on other plants is ripe yet. So the careful timing of harvest, and approaches to repeatedly and selectively harvesting a stand, are important elements of the successful production of native plant seed. Given the threat that seed stocks might be contaminated with exotic species, it is also a good idea to rogue out all undesired seed heads (of weeds and other non-crop species, and those that might be diseased) from the stand prior to harvest to avoid seedlot contamination.

Depending on the species, harvesting may entail the stripping of seeds from seed stalks in the field, or the entire removal of those seed stalks and heads for threshing. In both approaches, the challenge is to glean ripe seeds efficiently from the plants without scattering the valuable seed to the ground and losing it. The harvesting methods detailed in this publication are primarily manual and small-scale mechanical approaches. Sharp hand sickles are very effective for harvesting most grasses and sedges (Figure 4), while sharp clippers work well for other species. A scythe may also be appropriate for some grasses, but we have no experience from which to draw in that regard. Seeds can be harvested selectively as they ripen but this is time-consuming and eliminates any possibility of mechanical harvest. Placing plastic between rows early in the season will not only help to control weeds but also permits harvest of the seed crop when the bulk of it is ripe. Seeds that ripen early will drop onto the plastic and can be later vacuumed up, so long as they are not contaminated with weed seeds. So it is a good idea to sweep or vacuum the plastic to remove dirt, debris and other contaminants just before the crop starts ripening.

Figure 4. Harvesting *Calamagrostis canadensis* seed from a seed increase plot using hand sickles.

Small seed increase plots do not warrant the expense of combine harvesters, though seed production fields much greater than 0.2 ha might be harvested with such equipment if available. Recommended settings for the rotation speed of the combine cylinder head in rotations per minute (rpm) and concave spacing (in mm) are therefore provided with the individual species descriptions. Mechanical harvesting is especially suitable for most of the large-seeded grass and sedge species, and where large quantities of seed are being harvested on a regular basis. For plots intermediate in size, a hand-held seed stripper (Figure 5) can be used (Morgan and Collicutt 1994; see also www.prairiehabitats.com). While this method is especially useful for harvesting some seed from wild stands, we found it was not efficient for salvaging all the seed being grown in plots, because much of the seed was scattered by the stripper strings rather than being scooped into the hopper. Therefore, if using a seed stripper, make sure there is cleanly swept plastic between the rows so that scattered seed can be salvaged with a vacuum or broom.

Figure 5. Harvesting *Elymus glaucus* seed from a seed increase plot using a motorized seed stripper.

If one has access to electricity or a generator, a shop vacuum works extremely well for harvesting the species with fluffy seeds. A modified gas leaf blower is also available at a reasonable price, but its suction is not as good as that of a shop vacuum. There are also industrial vacuums and sweepers (such as various Toro™ Flay-O-Vac and Rake-O-Vac models) that can be pulled behind a tractor, but these are expensive. Modifications that combine sweeping and vacuuming action (also expensive; e.g., the Woodward Flail-Vac™ system; see www.ag-renewal.com) may represent the ideal compromise for harvesting field-grown wild seed. Flail-Vac heads range in width from 1.2 m to 3.6 m, and are mounted on front-end loader arms fitted to all-terrain vehicles (ATVs) or tractors. Technology that combines sweeper and vacuum action is generally flexible enough to be applied to a variety of species, and can be used repeatedly on the same stand for selective harvesting as seed ripens.

As mentioned above, seeds of wild and genetically diverse cultivated plants typically do not ripen uniformly, so this must be taken into account when harvesting. When using manual and vacuum harvesting methods, repeated passes of the seed production area every few days will allow most seed to be collected rather than lost. For seeds that are held more tightly to seed heads, it is often most practical to cut the entire crop at one time, and to then dry or cure it under warm dry conditions, thereby allowing much of the green or soft seed to fully ripen before threshing. Hand-clipping, sicklebar mowing, or swathing should be done before a significant amount of ripe seed falls and while some seed is still green or soft. Seeds can be efficiently dried in the sun if the weather co-operates. This step essentially allows the younger seeds to “catch up” in their process of maturation without losing all of the more mature seed. On a large scale, this is done by swathing the stand before threshing or combining it (Figure 6); on a smaller scale, sheaves (bundles) of seed stalks can be spread to cure on large tarpaulins or plastic sheets, or on clean concrete floors in the shelter of a warehouse or shed (Figure 7). Losses to mice and voles can be a problem, so mouse traps may need to be set, and drying times should be kept to a minimum (generally a few days to a couple weeks). Once dried, seed should be threshed immediately. If immediate threshing is not possible, seed heads or seed stalks should be stored as sheaves, or loosely in paper or breathable seed sacks, so that any remaining moisture can escape and the seed won't mold.

Figure 6. Swaths of *Elymus trachycaulus*, curing on the ground prior to threshing.

Threshing and Cleaning

Like harvesting, threshing and cleaning can be done by a range of manual and mechanized approaches. Old farm machinery can provide an economical means of harvesting, threshing and cleaning native plant seed, though modifications and relatively large quantities of seed are typically required. Seed is usually somewhat threshed (removed from seed stalks and seed heads) in the harvesting process, and more seed usually falls off during handling. It is important to salvage this seed, which is made easier by working on clean, sweepable concrete surfaces. Further seed removal can be done by hand-stripping, or by a variety of mechanical beaters or flails. For very small quantities, placing seed heads in a closed container with a hard rubber ball and shaking vigorously can serve to dislodge seeds; this can also be done in conjunction with small-scale seed cleaning conducted with soil sieves.

Figure 7. Grass seed stalks spread out for drying and curing (ripening) in a warehouse.

Symbios Research & Restoration uses two machines for mechanized threshing, both mounted on stationary stands and powered by 373 to 736 watt (½ to 1.0 hp) electric motors. One is a custom-made rotary flail, consisting of 10-cm lengths of bolted pipes between four steel disks (12 cm radius) mounted on an axle and housed in a cowling that directs seed downwards (Figure 8). Seed stalks are held by hand in large clusters, with the seed heads inserted into the flail until all or most seeds are removed by the beating action. Care must be taken that heads are never inserted so far that they get wrapped around the axle, and that hands are not drawn into the machine (wearing strong, loose work gloves and eye protection is essential).

If the resulting seed stock still contains a number of full or partial seed heads with seeds attached (as often happens for some grass species), seed may be run through a second machine called a rethresher. A rethresher is like a miniature combine harvester, consisting of concave-grooved bars attached to a heavy flywheel that can be run at different rotations per minute (rpm); the one we utilize was salvaged from an old Massey Harris™ combine. Seed is removed from stems when the machine lines up the stems and seeds longitudinally, and abrades them against small plates protruding perpendicularly from the housing. As with primary combine settings, seed species differ in the optimal width of the space between the rotating bars and the fixed plates ("concave spacing"), and in the optimal rpm at which to operate the machine. Where known, these recommended specifications are provided for individual species, and these settings are assumed to be good preliminary estimates for full-scale combine harvesters as well. The seed heads and stalks left after threshing can be bundled or baled to serve as a straw mulch for weed control in seed production plots of the same species, or for erosion control on bare soils at revegetation sites.

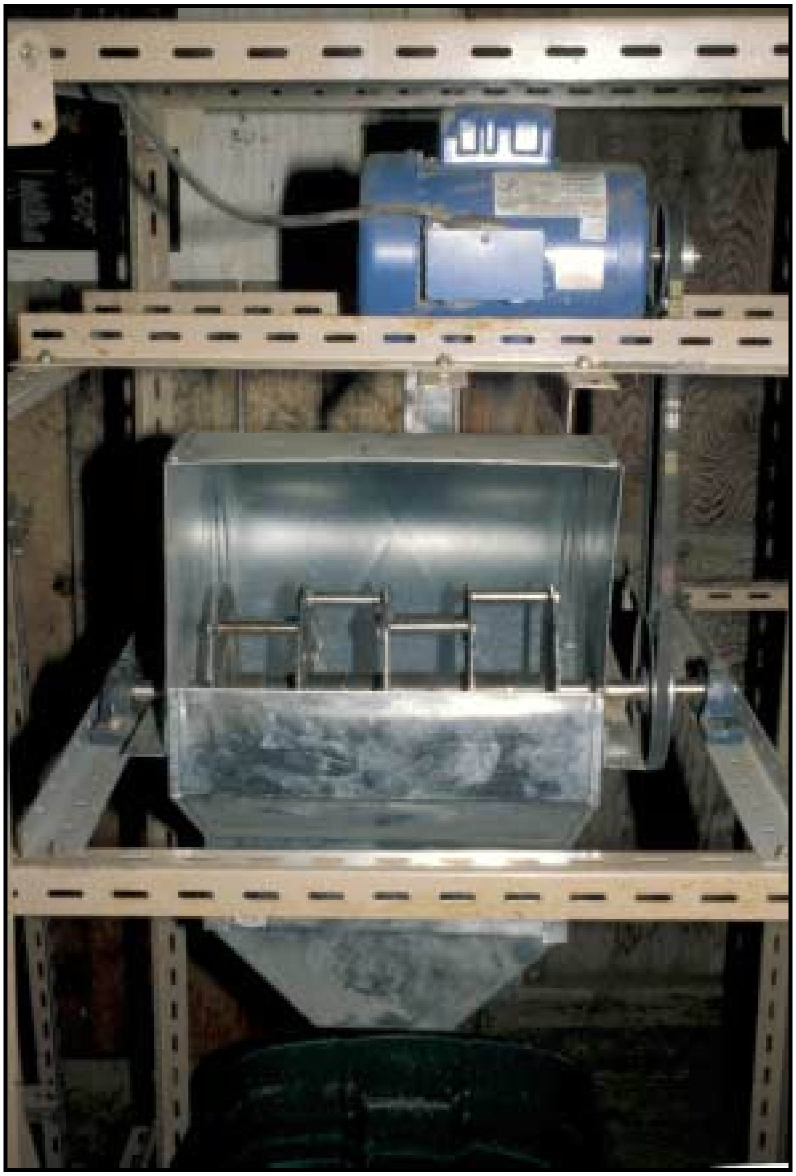

Figure 8. Custom-made rotary flail, mounted with housing and electric motor. Heads of long seed stalks are held into the unit, with the seeds knocked out of seed heads by the rotating bolts mounted horizontally between the vertical discs.

The objectives of seed cleaning are to separate pure seed from chaff and other vegetative debris, to remove the seed of any contaminating species, and (sometimes) to remove most of the small unfilled seed that is unlikely to germinate. While vegetative debris does not functionally inhibit the use of the seed in revegetation, this debris often makes seed lots more bulky and difficult to handle because the seed supply won't flow easily through machinery. Seed cleaning is generally done by one or a combination of methods: sieving by size and shape, and/or separating by buoyancy in an air stream.

We utilize a variety of brass soil sieves for manual cleaning of small quantities of seed, and for the final "finishing" step of cleaning some large seed lots. The primary cleaning operation can be done by a small fanning mill, consisting of two or more large flat shaker screens, and an adjustable stream of air generated by a large fan, all powered by an electric motor (Figure 9). As with hand sieving, screens are carefully selected by matching the size and shape of their apertures to match the upper and lower sizes of viable seeds of the crop species. Consequently, this manual reports, for each species, seed dimensions and recommended specifications for the “top screen” (which excludes seeds and debris larger than the crop seed) and for the “bottom screen” (which lets seeds and debris smaller than the crop seed fall through). Sometimes a preliminary screen is utilized too, in order to exclude larger stems, leaves, and other debris. The air stream of a fanning mill is adjusted by setting the rotation of the fan at different speeds, and/or by adjusting a baffle to damp down the wind created by the fan. Trial and error for each individual seed lot is required in order for the air stream to remove chaff and dust but not crop seed. A general guideline is that all non-crop seeds and as much debris as possible should be removed by the cleaning process, without losing more than 5% of the crop species.

Figure 9. A small fanning mill or “air-sieve machine” used for seed cleaning.

A custom-made vacuum airflow cleaner was used for some seed lots as the final cleaning step in the Symbios program (Figure 10). Many versions of such machines exist, generally connected to a commercially available vacuum cleaner that is controlled by an adjustable rheostat (a “dimmer switch”). Seed is gradually released from a hopper, and passed over an upward-flowing air stream and over one or more baffles so that heavy contaminants fall straight down, the desired seed is pushed or pulled over the first baffle, and dust and chaff continues on over a second baffle. Each machine will vary in its power, distances, baffle configuration, and the adjustments possible, so settings generally have to be made on a trial and error basis with each seed lot. As with all seed cleaning procedures, the operator has to carefully monitor that the crop is properly separated from both small and large contaminants, without losing too much of the valuable seed to the “reject” stream. The rejected material from all cleaning processes is commonly referred to as “screenings,” and can be useful as a mulch for revegetation projects, so long as it is sure to be free of weed seeds.

Figure 10. A vacuum aspirator used for final separation of filled seeds from dust, chaff, and unfilled seed, based on differential buoyancy in an air stream.

Clean seed can be stored in sacks, bags, or plastic buckets and tubs (Figure 11). It is important that seed be protected from insects and rodents that might consume or contaminate it. If well cured, dry, and stored in cool dry conditions, seed from most of the species reported in this manual has proven to remain viable in storage for at least five years. Each container should be clearly labeled according to a unique seedlot identifier, denoting the species, grower or field, year of production, and any other particulars. The weight or volume of seed should be recorded, and an inventory database maintained to record additions and withdrawals of seed stocks.

In order to prepare precise seeding prescriptions, it is important to know the viability and purity of each seed lot being used. Seed lot purity simply denotes what proportion of the bulk weight consists of pure mature seeds, as determined from weight measurements of several random samples. Seed viability is usually determined from germination tests on several samples of those mature seeds, generally under standard moist warm conditions in a laboratory. These determinations can be made by the seed grower, or (more often) by specialized testing labs or seed brokerage houses. The results of seed lot tests conducted by licensed testing labs are reported in "certificates of analysis." The product of purity and viability percentages give the "pure live seed"

(PLS) content of a seed lot, important for the accurate calculation of seeding rates (see next section). Purity analysis of several samples is also important in order to check for the presence of seeds of any non-crop species. Seeds of some domesticated and weed species subsequently can be separated by recleaning the seed lot, or else the seed lot can be used for establishing agricultural pastures or hay fields. Under no circumstances should seed lots known to contain noxious weeds be used for ecosystem restoration purposes or introduced into largely wild, uncontaminated landscapes.

There is currently no requirement under the Canada Seed Act to use certified seed for purposes of revegetation or ecological restoration. There is some progress in establishing standards of germinability and purity for official certification of native plant seeds, but the many species, difficult cleaning procedures, and little trade involved means that progress in this area is slow. Once such standards are in place, hopefully they will support rather than inhibit the wider production and use of native plant seed.

Figure 11. Cleaned seed in sealed containers labeled by species, year and seedlot, and arranged alphabetically for storage in a cool dry warehouse.

General Considerations for Use in Revegetation

Regionally adapted native plant seed is likely to remain a valuable commodity in northern British Columbia for the foreseeable future, whether collected from the wild or grown in cultivation. Consequently, every effort must be made to optimize its use and to maximize its effectiveness for revegetation and restoration. While revegetation procedures will vary with local site conditions and project goals, some generalizations can be made. Foremost among these general rules are to:

- introduce seed to freshly loosened soil;
- match the species selected to local soil and site conditions;
- avoid or minimize the effects of weeds;
- remember that stand establishment will often take two growing seasons; and
- employ an adaptive management approach (testing different techniques and monitoring their effectiveness on an operational basis).

Site Preparation

It is important to prepare a receptive seedbed that will have good mineral soil exposure, good soil-seed contact, and will support unimpeded root growth. Many sites degraded by industrial activities such as road building, log loading, or overgrazing have very compacted soil. This first must be alleviated by deep cultivation, disking, or ripping. The rooting zone should be loosened (cultivated) to 10 or 15 cm if possible, and heavily compacted sites (such as former roads and landings) may need to be ripped or treated with a winged subsoiler to depths of 40 cm (Bulmer 1998). Simple raking or harrowing of the surface is insufficient to provide an optimal growing medium in most cases, but is better than no treatment at all. The removal or rearrangement of logs, brush, and stones is not necessary or desirable on most revegetation sites, as these features contribute to microsite diversity.

If the remnants of the pre-existing native plant community are already found on the site, one may not want to disrupt the vegetation, no matter how depauperate or degraded it might be. The existing vegetation can be directly "over-seeded," but provisions for inserting the seed into or onto the soil must be considered, and some degree of site preparation is still desirable. This may consist of mowing the existing vegetation to a short stubble, or raking/harrowing the soil surface to expose some bare soil. Manual removal of weeds or spot-spraying of weeds and other exotic plants with a broad-spectrum herbicide may be desirable. If the weeds are annuals, mowing or clipping them at the time of flowering (i.e., before they go to seed) can help shorten their hold on the site. When digging up perennial weeds such as bull thistle (*Cirsium vulgare*), the filled-in shovel holes left behind then consist of loose, bare soil that is well suited for immediate seeding with native plants.

When tillage or harrowing is conducted on sloping terrain, it is essential that furrows run parallel to the contours (perpendicular to the direction of slope) in order to minimize erosion. Very steep road cuts are difficult to revegetate unless they are terraced or re-sloped to the natural angle of repose for loose, unconsolidated material. A more common solution, employed for both agronomic and native species, is to use hydroseeding techniques in which commercial "tackifiers" can be added to a slurry of water, seed, fertilizer and mulch that is then applied to the site using a specialized pump and nozzle. The tackifier essentially glues the seed to steep slopes, so some seed will be in place to germinate and establish if weather conditions cooperate.

Optimal conditions for seeding disturbed lands exist immediately after soil disturbance or site preparation. If disturbed soil is left too long, weeds will have a chance to invade and establish. Weathering results in soil settling over time, and silt and clay particles will fill most soil cracks, resulting in a gradual recompaction of the soil.

Soil Amendments and Mulches

Sites degraded by industrial activities often consist of compacted soils, stripped of topsoil and plant nutrients. Consequently, some degree of soil improvement is often needed in order to support more than sparse plant growth, and to restore healthy ecosystem functioning. When the area to be revegetated is dominated by subsoil, bare parent material, or shattered lithic material, one challenge is to accelerate soil development. In addition to decompacting this material (as described above), it can also be useful to incorporate organic matter into the substrate to improve soil structure and to provide cation-exchange sites for the retention of nutrients and soil water (Bulmer 1998). Suitable amendments can include wood chips, sawdust, peat moss, straw, manure, or various waste treatment sludges (e.g., from pulp mills, fish farms, or municipal sewage treatment plants). Care must be taken to manage the carbon to nitrogen (C to N) ratio of these amendments. If material with a high cellulose content (e.g., wood chips, sawdust, or straw) is added to the soil, it will be decomposed by soil fungi and bacteria, but those fungi and bacteria will gobble up most of the available nitrogen in the soil, thereby depriving plants of adequate resources for growth. So any time amendments with high C:N ratios are used, supplemental fertilization with nitrogen-rich or low C:N materials must also be done. This fertilizer can be from commercial sources (e.g., ammonium nitrate formulations), or from organic sources (such as manures, or municipal sewage).

Soil amendments should be well incorporated into the rooting zone of the substrate, typically the top 10 to 20 cm, before seeding. This will usually require the use of farm machinery such as a disker, plow or cultivator, as part of site preparation procedures. If applied as a surface dressing or mulch, amendments are not as effective for soil improvement, but can be important for erosion control, especially on sloping sites. Surface mulches are generally applied after seeding, rather than before. Mulch should not be applied too thickly (generally less than 1-2 cm) or densely, (<70% cover), so that seedling emergence is not inhibited. Suitable mulches for revegetation and restoration activities include straw from annual cereal crops (i.e., wheat, oats, barley, rye), or the straw and screenings from native plant seed production fields. Care must be taken not to introduce weed seeds or other contaminants with the mulch. For example, hay bales from fields of domesticated smooth brome (*Bromus inermis*), timothy (*Phleum pratense*) and clover (*Trifolium* sp.) might contain viable seeds of those exotic agronomic species. So use of hay mulch is not recommended, as the exotic seeds might defeat the purpose and expense of introducing native plants in the seeding process.

Fertilizer is often applied when sowing a revegetation site, even if organic matter is not incorporated into the soil. This is because most degraded sites are nutritionally barren, with substrates often consisting of unmodified glacial till. Furthermore, the enhanced plant growth achieved through the use of fertilizer can stretch sparse supplies of native seed by generating more plant cover per plant and greater probability of seedling survival (Burton and Burton 2001a). Where no intact topsoil remains, a balanced, high-concentration fertilizer (e.g., 18-18-18 or 13-16-10 NPK) applied at a rate of 200 to 300 kg/ha is generally sufficient to promote vigorous plant growth. Supplemental fertilization may be beneficial in another three years or so, depending on the chemistry of the site, the effectiveness of plant establishment and the initiation of nutrient cycling above and below ground, and on the success of nitrogen-fixing species. Natural fertilizers such as manure, fish farm waste, or municipal sludge can be beneficial substitutes, since they also include organic matter. If possible, soil testing should be conducted to document the precise nutrient limitations, so that fertilizer prescriptions can be optimized. The heterogeneity of soil conditions on many revegetation and restoration sites often precludes accurate diagnostic soil testing. It is safe to generalize, however, that N will usually be more limiting than P, K, or other nutrients on degraded soils in northern B.C. Contrary to some recommendations, our research has shown that fertilization even benefits native plant establishment on sites dominated by agricultural weeds (Burton 2003).

The Seeding Prescription

Designing the mixture of species and the density at which they should be applied to a site constitute the fundamental elements of a revegetation prescription. To optimize the use of scarce seed, it is strongly recommended that sites be roughly mapped and categorized according to soil texture, topographic position, and/or vegetation goals, so that customized seed mixtures can be assigned to each site class. Gravelly soils in low-lying sites should receive a different mixture of species than gravelly sites on upper slopes and ridge crests, while fine-textured or loamy soils require yet a different suite of species. Site preferences and tolerances, where known, are provided below in the individual species accounts.

In formulating a seed mix, it is useful to employ a combination of 5 to 10 species, consisting of some graminoids (grasses, sedges, and rushes) of low and high stature, some species with rhizomes, some (usually legumes) with nitrogen-fixing ability, and some fast germinators. Care should be taken to ensure that the mix will not be dominated by a single aggressive species, and the mature stature of each species should be considered when deriving the ratio of seeds to use. That is, only a few individuals of large-statured species (e.g., *Lupinus polyphyllus*) are needed, while many individuals of smaller plants (e.g., *Festuca occidentalis*) are required to achieve the same proportional crown cover per unit area. Other considerations, such as the decision to include or exclude species highly palatable to livestock or wildlife, or the decision to include species resistant to trampling, will enter into the design of a mixture according to the land use goals for the land being revegetated. The soil texture, site drainage, and soil fertility of the site to be revegetated must also be considered and matched to the most suitable species. For example, many of the species covered in this manual can establish and grow well on gravelly soils, but *Dryas drummondii* and *Epilobium latifolium* are more demanding of coarse soils than other species, but still need good access to soil water, so are usually limited to lower slope positions. *Geum macrophyllum*, in contrast, is most suited to loamy soils with high nutrient levels.

It is worth considering the inclusion of a fast-germinating and fast-growing "cover crop" on steep bare sites where heavy precipitation or spring runoff is expected to generate a risk of soil erosion. Most native plants (with some exceptions) are relatively slow to establish and achieve full stature, so some non-native species would need to be used. The challenge is to find species that will quickly generate cover, but will not persist and compete with the native plants as they establish and grow. Suitable cover crops include fall rye (*Secale cereale*), Italian ryegrass (*Lolium multiflorum*), and sterile hybrids of slender wheatgrass and wheat (*Elymus trachycaulus* x *Triticum aestivum*, sometimes marketed under the trade name of Regreen™). When added to a native plant seed mixture, such cover crops should be added on top of the desired native plant seeding rate, and should not constitute more than 10 to 20% of the total seed mixture applied to the site.

All seeding ratios and densities should be formulated on the basis of the amount of pure live seed (PLS) per unit area, not the weight of seed or seed stocks. This is because plant species vary greatly in seed size and consequently in the number of seeds per kg, and individual seed lots also tend to vary in the number of viable seeds per unit weight (relative to other contaminants like dust and plant debris). Adjustments for PLS are required in order to refine the amount of seed to be weighed out and applied to a site. For example, if your seedlot is 90% pure mature seed (by weight), and those seeds exhibit 90% viability, then every 25 kg bag of seed only contains 0.9 x 0.9 x 25 = 20.25 kg or pure live seed. Combined with knowledge of the number of seeds per gram for a particular seedlot or species (as provided for each species below), this determination allows the inter-conversion of seeding densities in PLS/m^2 and in kg/ha. Prescriptions should be developed in PLS/m^2, but those prescriptions are usually implemented in the field in terms of kg/ha. Individual species treatments (below) include the mean and range of the number of seeds per gram, and the mean and range in germination capacity encountered in the Symbios research program; seed lot purity varies with every crop and every seed cleaning operation, however. Table 2 provides a sample worksheet for the preparation of a seeding prescription. Such a table can be easily transcribed to a computer spreadsheet program, in which the amount of seed of each species to be weighed out and the total application rate can then be calculated.

Table 2. Sample worksheet and worked example for preparing a seeding prescription and calculating the amount of seed (of each species) to be mixed and sown over a given area.

Area to seed: __12,000_m^2 Plant Species	Plant Material Origins		Seeds per gram	Seedlot		Application Rate		Notes
	Location Or Vendor	Year or Seedlot		Purity, % of wt.	Viability, % germ.	desired PLS/m^2	Total g or kg	
A.	B.	B.	C.	D.	D.	E.	F.	G.
1. *Elymus glaucus*	Symbios	ET2001	228	93	80	300	2112g	
2. *Festuca occidentalis*	Symbios	WM2001	2995	84	91	650	3407g	
3. *Achillea millefolium*	Symbios	CFS2000	7560	71	90	500	1242g	
4. *Lupinus polyphyllus*	wild:P.G.	2000	117	95	77	50	7010g	add Rhizobium B
5.								
6.								
7.								
8.								
9.								
10.								
H. TOTAL:						1500	13771g	=11.48 kg/ha

Instructions: A. Select species based on site attributes, management objectives, and seed availability.
B. Record plant material origins, making sure they are suitable for your location.
C. Insert seeds per gram from published averages (e.g., means reported as part of individual species treatments, below), or based on seedlot analysis.
D. Insert seedlot purity and viability on the basis of seedlot tests or certificates of analysis.
E. Specify the desired PLS/m^2, based on the stature and aggressiveness of each species, speed of germination, site attributes, and desired plant community structure, so that all individual species sum to the total PLS/m^2 desired.
F. Calculate the total number of grams of seedlot needed for each species as:

= area to seed (in m^2) x desired PLS/m^2 / (seeds/g x % purity x % viability);

record % purity and % viability as proportions (0 to 1) for use in this calculation; divide result by 1,000 to express large values in kg, if desired.
G. Record additional information as needed, such as price, checking off each species as weighed, etc.
H. sum individual species application rates to derive total seed mix application; divide total application rate in g by area to seed (in m^2) and multiple by 10 to give application rate in kg/ha, or divide total application rate in kg by area to seed in m^2 and multiply by 10,000 to give application rate in kg/ha.

The amount of PLS applied to a site will not result in an equivalent density of plants. Though all PLS should theoretically germinate, our experience indicates that only 10% to 20% of those seeds will successfully germinate, emerge, and establish as seedlings on degraded sites. This low success rate is due to a variety of suboptimal practices (e.g., surface sowing instead of drill seeding), harsh site conditions (e.g., infertile or compacted soil), and accidents of weather and herbivory (e.g., frost, drought, grazing by insects or small mammals). Recent research with plants native to northern B.C. indicates that adequate amounts of cover can be achieved across a broad range of sowing densities (375 to 6000 PLS/m^2), but full cover is attained faster at densities ranging from 750 to 1500 PLS/m^2 (Burton 2003). A broadly applicable and generally acceptable recommendation is for 1500 PLS/m^2 when broadcast-sown as a dry seed mix, with higher rates recommended on erosion-prone sites, where rapid green-up is desired, or where weeds populations are high. Lower densities are acceptable if seed is in short supply, if weeds are not a threat, and if establishing cover quickly is not a priority.

Sowing and Monitoring

Seed can be introduced to a site by drilling it into the soil using standard or modified agricultural machinery, broadcast using cyclone spreaders (mounted on a helicopter sling, on the back of a tractor, an ATV, or operated by hand), spread directly by hand, or as part of a slurry by hydroseeder. Drill seeding is most efficient in terms of ensuring that a large proportion of the seeds will have good contact with the soil and will successfully germinate and emerge; unfortunately, it is not suitable for rough or steep terrain, and is not currently the norm for most roadside seeding. Next efficient is dry broadcast seeding (Figure 12), so long as it is conducted quickly after soil disturbance or after soil loosening by raking or harrowing, and then is followed up by more raking or harrowing. Small areas can be sown by hand if care is taken to distribute seed evenly. Hydroseeding is least efficient in terms of the use of seed, but the presence of tackifier (an organic soil binder) can greatly enhance its effectiveness on steep slopes. Typically mounted on the back of a large truck along with a big mixing tank, hydroseeders can also be small enough to fit on a pickup truck. Simple substitutes can be built using some water pumps, so long as the pumping mechanism does not damage seeds and nozzle apertures are big enough for the seeds being applied. Hydroseeding is not currently recommended for most native plant seed application purposes (except for steep sites), because it uses approximately three times the amount of seed that is used in dry broadcast seeding applications. A large amount of hydroseeded seed ends up being applied to unsuitable microsites and obstacles, and much of the seed is found in the upper layers of the mulch where it dries out, rather than under the mulch where it is protected. So a recommendation of 1500 PLS/m^2 for dry seeding should be adjusted to 4500 PLS/m^2 when hydroseeding is used.

Domesticated legumes are routinely treated with bacterial inoculum before being sown. This may not be necessary for native legumes, for which natural inoculum seems to be widespread in the forest environment. However, for very sterile and isolated locations such as large mines, it may be prudent to coat legume seeds with commercial inoculum before sowing. Different strains of *Rhizobium* are needed for each legume genus, with each vendor using different names or labels for the strains applicable to *Lathyrus*, *Lupinus*, or *Vicia*. Inoculum can be mixed in a powdered milk slurry so it lightly coats the legume seeds before they are added to the seed mix.

Figure 12. Dry broadcast seeding along a newly built logging road, spreading a grass-legume seed mix using a cyclone seeder mounted on an all-terrain vehicle (ATV).

It is generally recommended that one weigh out and mix the different species in a seed mixture ahead of time (i.e., in the warehouse). When dry seeding, fertilizer and mulch (if used) are generally applied to the site in separate steps from the seed. It helps to weigh out bags or tubs of seed for each discrete stratum (e.g., moist sites, ridge crests, gravel patches, etc.) or fixed areas of uniform land (e.g., in 100 m^2, 900 m^2, or 2500 m^2 units). Then flag out the boundaries or corners of each unit of land on the revegetation site, so that the rate of seeding can be adjusted to make sure it uniformly covers the designated area. Until experience is acquired at judging the rate of application, it is better to seed sparsely at first and then do a supplemental application, rather than to run short of seed because original application rates were too generous. The site should be raked or harrowed to expose fresh, loose soil immediately before seeding (as mentioned above), and then raked, harrowed or dragged to cover the seeds somewhat after sowing too (Figure 13). In northern B.C., seeding can be done in the spring (any time before July) or in late summer, but late fall seeding is often best.

Figure 13. Raking or harrowing after broadcast seeding is recommended to promote seed germination and seedling establishment.

All revegetation and restoration prescriptions and subsequent seeding operations using native species should be considered experimental in nature. That is, they may represent your best effort at designing an appropriate mixture and density of seeds and associated amendments, but there is no *a priori* reason to expect this design to be the optimal solution to local site management challenges. It is therefore prudent to incorporate assorted modifications to the restoration prescription, apply them at multiple locations, keep careful records of what treatment was employed where and when, and to monitor the results. Monitoring might be as simple as the installation of permanent photo points, with photographs taken of each treatment area at the same time of year over a number of years. Or it might be as quantitative as a rigorous program utilizing line transects or randomly located quadrats to sample plant cover and density (Figure 14). A template for recording plant density and cover observations in three quadrats per treatment stratum is provided in Table 2. Note that it is usually worthwhile to record weed cover and evidence of soil erosion and the accumulation of organic matter as well as the abundance of each plant species. A more rapid form of monitoring can consist of recording plant cover in four broad groups: sown species, other native plants, agronomic grasses and legumes, and weeds. Whatever the nature and intensity of monitoring undertaken, it is important to adopt a philosophy of structured adaptive management, constantly improving one's expertise in restoring native vegetation.

Figure 14. Sampling the density and cover of native plants sown on an old log sort yard.

Revegetation success ultimately depends on the establishment of an adequate amount and composition of plant cover. Depending on the goals of the project, the vegetation may be expected to be a faithful re-creation of a natural plant community, and to dominate the site indefinitely. In other situations, it will be sufficient for the vegetation to reduce erosion, and to cover the soil for only a few years until tree and shrub species dominate the site. Mowing or weeding of exotic plants may be desired in some cases, and supplemental fertilization in two or three years may be appropriate, depending on the land use goals. But areas revegetated to native plants are generally expected to be self-maintaining.

The value of creating a plant assemblage that is pleasing to the eye (Figure 15) should not be underestimated, as public support for the wider use of native plants still needs to be nurtured. Coupled with a desire to promote biodiversity and to mimic the composition of natural meadows, such aesthetic considerations provide another incentive for including non-leguminous wildflowers in native plant seed mixtures.

Table 3. Sample data collection form for monitoring plant community development after revegetation. This form records plant count and cover observations from three quadrats (remember to record quadrat area, e.g., 0.25 m^2 or 1.0 m^2); x and y values denote random rectangular coordinates for each sample.

Location:____________________________ Monitored by:_______________ Date: __________

Stratum/Treatment:____

	Sample 1		Sample 2		Sample 3	
Species or attribute	x=_____m	y=_____m	x=_____m	y=_____m	x=_____m	y=_____m
Seeded species	density	Cover	density	cover	density	Cover
Achillea millefolium						
Carex aenea						
Elymus glaucus						
Festuca occidentalis						
Geum macrophylum						
Lupinus polyphyllus						
Native invaders						
Agrostis scabra						
Aster sp.						
Betula papyifera						
Calamagrostis canadensis						
Collinsia parviflora						
Epilobium angustifolium						
Epilobium ciliatum						
Equisetum arvense						
Hieracium albiflorum						
Picea glauca x engelmanii						
Populus trichocarpa						
Rosa acicularis						
Salix sp.						
Exotic Agronomics						
Agrostis stolonifera						
Dactylis glomerata						
Festuca rubra						
Phleum pratense						
Poa pratensis						
Trifolium sp.						
Exotic Weeds						
Agropyron repens						
Cerastium fontanum						
Chrysanthemum leucocephalum						
Cirsium vulgare						
Galeopsis tetrahit						
Sonchus arvensis						
Taraxacum officinale						
Ground Cover / Physical features						
moss						
stones/wood						
erosional rills						
litter (leaves, etc)						

Figure 15. A successfully established stand dominated by *Elymus glaucus*, *Festuca occidentalis*, and *Achillea millefolium*, with scattered *Bromus ciliatus*, *Lupinus arcticus*, *Geum* macrophyllum, *Carex* species and *Aster* species. This mixture was sown along recent ski trail improvements and along a forest access road in the Smithers Community Forest, with seeding done by volunteers from the local cross-country ski club. This photograph was taken two growing season after sowing.

Some Examples of Native Plant Seeding Prescriptions

As indicated above, it is desirable to devise a seed mixture and seeding rate to match the site conditions and objectives of every revegetation project undertaken. We here provide some examples of species mixtures designed to meet certain revegetation goals and site conditions, not to serve as a fixed set of "off the shelf" mixtures, so much as examples of the decision process by which species and seeding densities are chosen.

The first example describes a **general-purpose mixture** for seeding newly constructed roadsides and ditches where the glacial till substrate consists of bare, gravelly clay loam:

Festuca saximontana	23%
Festuca occidentalis	26%
Elymus glaucus	18%
Achillea millefolium	25%
Lupinus arcticus	8%

Because erosion control and rapid cover production are priorities, the recommended application rate for this scenario is fairly high, approximately 2500 PLS/m^2. A short-lived, fast-growing cover crop of fall rye, Italian ryegrass, or Regreen™ could be added at rates of approximately 200 PLS/m^2. This mixture is dominated by three grass species: a tall one of medium longevity (*Elymus glaucus*);

a long-lived one of medium stature (*Festuca saximontana*); and a short-lived one with very rapid germination and short stature (*Festuca occidentalis*). The grasses are supplemented by a large amount of *Achillea millefolium*, which germinates rapidly, generates rosettes of low-lying foliage, and is rhizomatous, so provides valuable erosion control. Note that more *Festuca occidentalis* and *Achillea millefolium* seeds per m^2 are prescribed than *Elymus glaucus* and *Lupinus arcticus* seeds, because the latter two species are much larger when mature. *Lupinus arcticus* is included as a native nitrogen-fixer, but 300 kg/ha of 19-18-18 fertilizer is recommended for spreading at the time of seeding as well. Other native legumes, such as *Vicia americana*, could substitute for *Lupinus arcticus*, depending on seed availability and site conditions: if soils are “heavy” or clayey rather than gravelly, sandy or loamy, *Lupinus polyphyllus* would be a better choice. A variety of composites or other “wildflower” species could be added to the mixture to add a little colour and diversity, but these species should not constitute more than 10-15% of the total mix.

A second example describes a seed mixture recommended for a **lower slope position** that is either moisture-receiving, adjacent to a wetland or riparian area, or is characterized by seepage. Such sites might require revegetation in support of riparian restoration plantings of cottonwoods and willows, or they might be on the fringe of a reservoir subject to variable water levels, or in roadside ditches that tend to remain moist. Suggested species and proportions are:

Calamagrostis canadensis	23%
Carex mertensii	15%
Carex macloviana	12%
Collinsia parviflora	12%
Elymus glaucus	10%
Achillea millefolium	7%
Bromus ciliatus	6%
Geum macrophyllum	5%
Dryas drummondii	5%
Arnica chamissonis	3%
Lupinus polyphyllus	2%

This mixture of 10 species includes a variety of moisture-loving species and some that are more tolerant of upland conditions. *Calamagrostis canadensis*, *Carex mertensii*, *Elymus glaucus*, and *Geum macrophyllum* are naturally abundant on moist sites, though all can tolerate upland conditions to a degree. *Carex macloviana* and *Bromus ciliatus* are included as short-statured and tall-statured upland graminoids, respectively. *Arnica chamissonis* and *Geum macrophyllum* are both known to prefer rich sites, and should provide good cover and contribute to vegetation diversity. *Achillea* is once again included as a fast germinator, and *Lupinus polyphyllus* as a nitrogen-fixer. *Dryas drummondii* should be included only if the substrate is sandy or gravelly, with water flowing through the site but not standing. It was recommended that this prescription could be sown at 1200 PLS/m^2, or at higher application rates on slopes of bare soil where erosion is a concern. Fertilizer is again recommended, though the rate of application does not need to be high (perhaps 150 to 200 kg/ha of 18-18-18) if some topsoil or subsoil is found on the site.

A third example describes the sort of seed mixture designed for a **high-elevation or high-latitude area** (such as the Engelmann Spruce – Subalpine Fir or Spruce-Willow-Birch biogeoclimatic zones) with rocky soils and a short growing season. Such a site might need to be reclaimed after mining or mineral exploration, or might consist of the sides of a new road, or disturbances associated with the expansion of a ski resort. A recommended mixture for this scenario is:

Festuca saximontana	25%
Trisetum spicatum	18%
Poa alpina	18%
Achillea millefolium	14%
Luzula parviflora	10%
Epilobium latifolium	10%
Lupinus arcticus	5%

The backbone of this mixture consists of two medium-statured grasses, *Festuca saximontana* and *Trisetum spicatum*, supplemented by the shorter *Poa alpina*, all well-adapted northern, alpine and subalpine species. *Achillea millefolim* is again included for rapid germination and cover production, especially on steep sites where rapid erosion control is desired. *Luzula parviflora* is a graminoid that may provide low-lying ground cover too. *Lupinus arcticus* is included as a nitrogen-fixing legume, while *Epilobium latifolium* is a natural invader and useful cover-producer on well-drained (rocky) sites so long as moisture is available below the surface. Seeding of such sites is often best in fall, so that seeds will be in place well before access can be regained to such places in the spring. Light fertilization would be beneficial (50 to 150 kg/ha of 18-18-18), for such sites are nutrient-poor but plant growth tends to be more temperature-limited than nutrient-limited.

A final example describes the restoration of spot disturbances in a new nature reserve that includes a **sloping grassland** in the dry cool subzone of the Sub-Boreal Spruce biogeoclimatic zone (SBSdk) in the Bulkley Valley. These threatened ecosystems are classified as “Site Series 81, Saskatoon – Slender Wheatgrass Scrub/Steppe” (Banner et al. 1993). The natural vegetation of the site is largely intact around the disturbed areas, and is dominated by slender wheatgrass (*Elymus trachycaulus*) and Rocky Mountain juniper (*Juniperus scopularum*). Because this is a nature reserve, and the goal is **ecosystem restoration** (not just revegetation), priority is placed on the use of species documented to already occur in the project area; locally collected seed is used as much as possible. Soils are largely intact, fairly rich in level spots (which also had weed problems), but are shallow and dry on sloping areas. Existing plant cover makes erosion control a lower priority. Rather than digging up or herbiciding the exotic plants (especially *Chenopodium album* and *Cirsium arvense*) found on the site, these are manually cut or mulched with plastic ahead of time, and are then overseeded. The soil is manually raked before and after sowing. No fertilizer is used on the weedy areas; elsewhere, a light sprinkling of 13-10-10 fertilizer is applied at approximately 150 kg/ha. A light mulch consisting mostly of native *Elymus glaucus* straw and screenings is spread on areas with bare soil in order to partially shade new seedlings and help conserve moisture. The seed mixture and proportions (of PLS) devised for this project are as follows:

Elymus trachycaulus	45%
Achillea millefolium	18%
Collinsia parviflora	13%
Bromus ciliatus	7%
Elymus glaucus	7%
Anaphalis margaritacea	4%
Aster conspicuus	2%
Polemonium pulcherrimum	2%
Vicia americana	2%

This mixture is to be applied at 1550 PLS/m^2 in early spring, soon after snow is gone from the site. All eight species are naturally found in the nature reserve. To restore the grassland, heavy emphasis is placed on introducing the dominant *Elymus trachycaulus*, with lesser amounts of *Bromus ciliatus* and *Elymus glaucus*, so that grasses (all tall in stature) should constitute 59% of the seedlings. Though few short-statured or rhizomatous native grasses are found in the local vegetation (at least none for which seed was available), *Achillea millefolium* was found on site. So *Achillea* is included at a fairly high density in order to provide a fast-germinating and low-lying ground cover. *Collinsia parviflora* is a native annual and may also provide rapid cover if germination conditions are favourable, but it can also persist in the seed bank and may be a useful contributor to the native plant community in the future. *Vicia americana* is included as a native nitrogen-fixer, and more would have been used if seed supplies had been available. The other three species in the mixture (*Anaphalis margaritacea*, *Aster conspicuus*, and *Polemonium pulcherrimum*) can be considered enriching elements of biodiversity, wildflower species found on the site which may be important for certain insects, for aesthetics, and to contribute diversity and resilience to the vegetation.

Individual species treatment (PDF 2.6MB)