"Development and Testing of Native Grasses and Legumes for Seeding in the Northern B.C. Interior"

FINAL REPORT

SCBC Number: FR96/97-111
FRBC Number SB06031-RE

July 31, 2001

by Philip J. Burton and Carla M. Burton

Project Leader: Philip J. Burton, Ph.D., R.P. Bio.
Organization: Symbios Research and Restoration
P.O. Box 3398, Smithers, B.C. V0J 2N0
Tel. 250-847-0278 Fax. 250-847-0279
E-mail: symbios@bulkley.net

Other Team Members: Adam Hossack, Symbios Research and Restoration
Tom Duralia, University of British Columbia
Kermit Ritland, University of Brtitish Columbia
Brian Ie, University of British Columbia
Brian Holl, Lamorna Enterprises Ltd.
Tim Mullin, Genesis Forest Science Canada Inc.
Joe Wong, Woodmere Nursery
Canadian Forest Service

Project Start and End Dates: May 1st, 1996 to April 30th, 2001

Abstract

In northern British Columbia, large areas of land degraded by logging, mining, road construction and other industrial activities are currently revegetated with domesticated grass and legume species of European origin. While these species can 'green up' and stabilize an area after disturbance, they frequently grow so aggressively that succession to native species is delayed or prevented. Re-introducing native plants to degraded lands is thus an integral component of ecosystem restoration.

A five-year research project embarked on a program to collect, screen, and cultivate native grasses, sedges, legumes and other forbs in a manner that would maintain their genetic integrity and make seed available at reasonable prices. The seed produced as a result of this project, once increased to commercial quantities, will enhance Forest Renewal B.C.'s priority to rebuild and protect healthy streams, decommission logging roads and landings, and restore degraded terrestrial ecosystems so that they can once again support multiple resource values. The use of native seed for such activities represents a basic premise of ecological restoration, and supports Forest Practices Code biodiversity guidelines for the designation of a range of biodiversity emphasis options.

We collected over 1,000 accessions from more than 40 plant species for evaluation. Seeds were tested in several years of laboratory germination assays, propagated in a greenhouse, and installed in seed-increase plots. Borrowing from tree seed orchard design, seed-increase plots were established at two locations near Smithers, B.C., to produce easily harvested seed with broad genetic diversity. This multi-lineal seed is adapted to most locations between 52^{o} and 60^{o}N and between the Coast Mountains and the Rocky Mountains. Most species produced maximum seed yields in their third growing season. This seed can then be used to establish larger seed production fields, or directly for revegetation. This approach is a promising compromise between the use of locally collected native seeds and revegetation with cosmopolitan exotics.

Research based on wild- and plot-grown seed and the plants it produced has documented germination and growth requirements, seed yields, and establishment success. Genetic diversity (as expressed through morphometric characters and allozyme variability) in *Elymus glaucus* was studied as part of an M.Sc. thesis. Field trials at 22 operational revegetation sites across northern B.C. were used to compare native species with agronomic species, different seed densities, different combinations of species, season of sowing, the use of mulches, fertilizer and other treatments. We concluded that some native species can be just as successful as the agronomic species currently used for roadside seeding. Another component of these field trials (which is being written up as another M.Sc. thesis) has identified optimal densities of seed and fertilizer to achieve plant cover goals at minimal cost: we recommend application of our most promising 6-species mixture at rates of 2,000 pure live seeds (PLS) per m^2 along with approximately 300 kg/ha (30 g/m^2) of 18-18-18 fertilizer.

As the research components of this project were being wrapped up, a transition to commercial levels of seed production was encouraged. This involved the recruitment and encouragement of contract growers in the Bulkey Valley of northwestern B.C. to undertake seed production of some of these native plant species, and the regular delivery of oral presentations, posters, and written materials to communicate our results. This has culminated in a comprehensive extension document entitled "A Manual for Growing and Using Seed from Several Herbaceous Plants Native to the Northern Interior of British Columbia" being written for seed growers and revegetation specialists. This manual incorporates the results of our research and that of other specialists. We are now providing limited quantities of native seed, on a cost-recovery basis, to BC Parks and community groups for revegetating areas disturbed by logging, road construction, and other activities.

Table of Contents

Introduction

Background and Rationale

There is growing awareness among scientists, land managers, and the public at large that indigenous plant and animal species are being displaced by man's activities and by the domesticated and pest organisms associated with us. These concerns have been recognized in a number of provincial (e.g., 1995 Biodiversity Guidelines of the B.C. Forest Practices Code), national (1995 Canadian Biodiversity Strategy), and international (1992 United Nations Convention on Biodiversity) policy statements. The whole thrust of the Watershed Restoration Program and the Terrestrial Ecosystem Restoration Program of Forest Renewal B.C. is based on the recognition that logging activities have damaged the integrity of many B.C. ecosystems. Restoration activities are therefore being undertaken to rebuild and protect healthy streams, and to decommission logging roads, landings, and other degraded areas so that they can once again support timber and non-timber management goals. Areas in which forest and grassland composition and structure have been degraded by past land management practices are now the focus of ecological restoration efforts. Yet standard prescriptions for rapid revegetation (associated with many restoration projects) typically use domesticated forage mixtures of Eurasian origin, contrary to the principles of restoration ecology (Harker et al. 1993), especially where land management objectives encompass non-timber values. Like physical degradation, non-native plants (whether domesticated or weedy) can be disruptive to the healthy functioning of ecosystem (Vitousek 1986).

Numerous factors justify the timely development of commercially available sources of native plant seed for use on B.C. forest lands, in conjunction with improved awareness and expertise concerning its use. These factors include the following (Burton and Burton 1999):

1. Some sites are so stressful that no agronomic plants currently do well on them;
    - severely compacted soils or exposed parent material often support only a few specialized species, e.g., *Carex aenea* (M. Krannabetter, pers. obs. 1995);
    - sites at high altitudes and other locations with short growing seasons likewise support specialized species (e.g., *Poa alpina*, *Phleum alpinum*), some of which have recently been made commercially available through research efforts of the Univeristy of Alberta and the Alberta Environmental Centre (Pahl and Smreciu 1999);
    - some soils can be severely contaminated or so chemically inhospitable that specialized strains need to be derived from plants that have evolved with such stresses.

2. Agronomic species of grasses and legumes have been bred and selected for centuries to have high productivity and resilience, often resulting in the persistence and spread of these species in favourable habitats at the expense of indigenous plants of the same life form; it is suspected that forest soil biology (mycorrhizae and bacteria) can be seriously altered when dominated by aggressive grass species too.
    - example problem species include smooth brome (*Bromus inermis*), creeping red fescue (*Festuca rubra* var. *rubra*)

3. Even registered seed of commercially available forage species tends to be contaminated with noxious weeds (e.g., bull thistle, *Cirsium vulgare*, and cheatgrass, *Bromus tectorum*); extraordinary measures are needed to ensure seedlot purity.

4. Many agronomic forages are not compatible with other resource uses. For example, deer frequently become bloated on alfalfa (*Medicago sativa*), bears feeding on roadside plantings of clover (*Trifolium* spp.) are more likely to encounter humans, and creeping red fescue tends to form a dense sod in which it is difficult to establish conifers. Impacts on arthropod communities are not understood at all.

5. Even where ecosystem restoration and the protection of high biodiversity values are desired, obtaining seed of native plant species is difficult and expensive. As a result, their reintroduction currently depends on custom collection of wild seed (which often has unreliable germination), and on nursery production of transplant stock (followed by manual outplanting of individual plants).

6. Finally, revegetating roadsides with agronomic species (such as timothy and clovers) further serves to homogenize and domesticate our surroundings, a trend to which many recreationists and conservationists object.

It is important for silviculturists, range managers, agronomists, revegetation specialists and restoration practitioners to have a wide range of plant products available for use in land rehabilitation. Grass and legume seed mixtures are particularly useful, because they can be used in support of a number of land management objectives:

- To provide rapid erosion control and aesthetic improvement;
- To provide forage for livestock and/or wild ungulates;
- To rebuild soil structure, fertility and productivity after site degradation; and
- To purposely constrain the growth of highly competitive non-crop vegetation in conifer plantations.

In addition, grasses and legumes typically have good germinability, rapid growth, and easily handled seeds, making them suitable for blanket introduction through sowing (whether by drill, hydro-seeding, cyclone seeder, or by hand). This makes them suitable for revegetating large areas rapidly and inexpensively, and a preferred alternative to hand-planted nursery stock. Forage mixtures are now widely used on roadsides, abandoned excavations, deactivated roads and landings, degraded skidder trails, landslides, streamsides, after wildfire, and in some cutblocks.

Recommendations for forage seeding in the Prince Rupert Forest Region will serve as an example of current practices, typical of those in all Forest Regions in British Columbia. It is recommended that different combinations of species should be used to meet different objectives, and that forage mixtures consisting of two to five species be devised from a list of 7 legumes species and 12 grass species, all domesticated and of Eurasian origin (Drinkwater 1993). It could be argued that such prescriptions to purposely introduce exotic organisms into wilderness areas (internationally valued for their natural flora and fauna) are in contravention of biodiversity guidelines. The B.C. Ministry of Transportation and Highways has already grappled with some of these issues, resulting in a 1992 policy directive to promote the use of native plant materials in their roadside management program wherever possible (A. Planiden, pers. comm., 1995). B.C. provincial parks also have a clearly articulated policy for using only indigenous plant materials for revegetation activities (Anonymous 1999). But implementation of both policies is drastically constrained by the commercial availability of native seed.

The program of native plant research and development described in this report is intended to alleviate the shortage of plant material and expertise for using native grasses and legumes in northern B.C. There is already an established demand for native plant materials and for expertise in ecological restoration, and this can only increase, as suggested by the following indicators:

- insistence by the Canadian Wildlife Service that disturbance on federal wildlife reserves must be revegetated with native vegetation, 1993;
- initiation of the "Restoration of Natural Systems" program at the University of Victoria in 1994;
- initiation of the Watershed Restoration Program by Forest Renewal B.C., 1994-95;
- a successful and over-subscribed "Native Plant Forum" held in Vernon in 1995;
- initiation of the "Naturescape" program by B.C. Ministry of Environment, Lands and Parks, 1995;
- formation of the NPSBC Native Plant Society of BC in 1996
- a successful and over-subscribed "Helping the Land Heal" conference held in Victoria in 1998;
- formation of the B.C. Chapter of the Society for Ecological Restoration, 1999;
- initiation of the Terrestrial Ecosystem Restoration Program by Forest Renewal B.C., 1999;
- release of a "Guide to Ecological Restoration Resources" by the B.C. Environmental Network Educational Foundation, 2001; and
- numerous requests for native plant seed received by Symbios Research & Restoration, 1997-2001.

Within the realm of forest management specifically, the Forest Practices Code biodiversity guidelines explicitly call for the designation of a range of biodiversity emphasis options on different landscape units (Anonyomous 1995). In addition, Forest Ecosystem Networks and Special Management Areas are now being zoned in land use plans (both regional and local in scale). These areas will have greater biodiversity emphasis, by definition, and it has been suggested that all disturbances within them should be restored with only indigenous plant materials.

Objectives

The purpose of this project has been to develop reliable supplies of native grass and forb seed, and expertise for its production and use in rehabilitating damaged ecosystems in the northern interior forests of B.C. Our study area is loosely defined as being north of 52^{o} latitude (in order to encompass most of the Sub-Boreal Spruce biogeoclimatic zone), south of the Yukon border (60^{o} latitude), and between the Coast Mountain and Rocky Mountain ranges in B.C. (Figure 1). This large region is characterized by a predominantly continental climate with cordilleran modifications, having long cold winters with deep snow, and cool moist summers. This geographic area served as our focus, but the process described here could be repeated in the southern interior or coastal regions of British Columbia, or anywhere else.

Since research on the planted species being developed was scarce, a variety of activities with subsidiary objectives was required in order to achieve our goal. Specific intermediate objectives of this project were as follows:
1. The determination of suitable species for further work, based on ecological amplitude, ease of propagation, and growth properties (inferred by literature review, field observations, and germination screening);
2. The collection of seed samples of candidate species from widespread natural populations within the natural range of the species;
3. The establishment of breeding plots of each species, allowing diverse geographic accessions to exchange pollen in order to develop broadly adapted, general-purpose seed;
4. The testing of plot-produced seed, in single-species and mixed-species stands, in operational rehabilitation and restoration trials in northern B.C.;

5. Making plot-produced seed available to commercial growers for further increase and production; and
6. The development of recommendations for using combinations of native grass and legume species to meet different rehabilitation and restoration objectives.

Having met these objectives, this project was also successful in accomplishing its goal of delivering significant quantities of seed of several plant species, for future use and development. Along with the knowledge gained in this process, this accomplishment supports Forest Renewal B.C.'s investment priority (as stated in November 1995) "to restore and protect the forest environment."

Figure 1. Study area for collection, testing and application of native plant seed for use in ecological restoration in the northern interior of British Columbia.

Methods

Species Selection

A large component of this project consists of the screening of candidate species for use in large-scale seed production and revegetation activities. This process consists of successive filters using various methods and criteria. Literature review, range mapping, seed collecting, seed testing, plot testing, and field testing all contribute to the species selection process.

In general, we were looking for common and widespread species indigenous to all or most of our study area. It is not a goal of this program to restore or enhance populations of rare or endangered plant species. Suitable species for cultivation and seed production should have broad ecological amplitude, but must inhabit open areas and grow well on poor soils. Candidates for a seed production program must obviously exhibit good germinability, and species which are prolific and reliable seed producers are especially desirable. Ease of establishment in cultivated fields and on operational revegetation trials also constitute criteria for acceptance or rejection of a species from further research and development.

The initial list of species to evaluate included all native grasses and legumes known from numerous locations in northern Interior of B.C. While reducing this list to the most promising species, we also utilized field observations and recommendations from colleagues to consider non-grass and non-legume species. Ultimately, we found that our own observations on the prevalence of species found on roadsides and other disturbed areas across the forested zones of north central B.C. were more useful than the published literature (typically very sparse) in identifying species suitable for further work. Visiting a large number of sites characterized by compacted or skeletal soils that had been abandoned for 5 to 10 years, we took note of the most successful herbaceous plant species which had naturally established on such sites. These habitats included roadsides, abandoned landings, little used logging roads or skidder trails, gravel quarries, and the floodplains and gravel bars of creeks and rivers. We also talked to a number of plant ecologists, agronomists, plant breeders, and silviculturists active in northern B.C. for their suggestions regarding promising native plant species for use in restoration efforts. These observations and recommendations demonstrated that many herbaceous species found growing successfully on disturbed land are neither grasses nor legumes, so the scope of candidate species was widened to include other plant families (such as Cyperaceae and Rosaceae) as well.

Literature Review

Literature review was conducted as a three phase process: a cursory review of floras, a broader search for relevant information on selected species, and a comprehensive written summary prepared for our two most promising species. The second and third phases of literature review and synthesis were conducted by Tom Duralia, a Ph.D. candidate in the Forest Sciences Department at the University of British Columbia.

A cursory review of regional floras and manuals (particularly Hultén 1968, Hitchock and Cronquist 1973, Coupé et al. 1982, McKinnon et al. 1992, Douglas et al. 1989-1994, and Cody 1996) was undertaken early in the project to draw up a large candidate list, emphasizing grasses (plant family Poaceae) and legumes (family Fabaceae). Emphasis was placed on geographic distribution, ecological amplitude and abundance or ubiquity in the study area, but no systematic notes or data were recorded in this phase.

A more detailed literature review was conducted for approximately 40 candidate species, using library databases and computer search tools. Emphasis was placed on autecology, propagation, and any previous experience with cultivation or seed production. Notes were recorded in a ProCite bibliographic database, and were used in preparation a manual for the cultivation and use of the final set of species.

A comprehensive literature review was prepared for two of our most promising species, one grass (*Elymus glaucus*) and one legume (*Lupinus arcticus*). Following a format similar to that employed by Haeussler et al. (1990), this review documented a large amount of the biological information known for these species, including growth and development, population genetics, reproduction, competitive ability and beneficial effects. While such detailed reviews were also planned for other species, unanticipated expenses in other components of this project (namely weed control) meant that this could not be completed.

Range Mapping

We prepared the most comprehensive range maps possible for the final set of 30 species being studied and developed for seed production. Known locations of these plants were compiled from herbarium collections (based in Smithers, Prince George, Vancouver, Victoria and Ottawa), the B.C. Ministry of Forests database of biogeoclimatic relevés, and Symbios seed collection sites. Only records with specified latitude and longitude were incorporated, with some other locations reconstructed if collection sites were described in a sufficiently detailed manner. Documented collection or observation sites are presented as dots on a standard base map, but were also overlain on a map of biogeoclimatic subzones. Every subzone in which a location was documented was then shaded as being within the likely range of the species under consideration. Being geographically distinct and covering a limited range of climatic and elevational variability, it was felt that biogeoclimatic subzones would provide a reasonable unit for inferring the likely range of plant species (A. Banner, pers. comm., 2001). A different colour was used to denote those subzones represented by Symbios collections, and hence with genetic contribution to the seed produced by this project. Though emphasizing our study area (as defined above), these maps show the distribution of each species for the northern three-quarters of British Columbia, and are presented with species descriptions in a manual. All map work was done using the Pamap GIS (geographic information system) by Dennis Rasmussen of Laing and McCulloch Forest Management Services.

The importance of reviewing the published literature and documenting herbarium collections has become apparent on two fronts. First, it assisted us with identifying the preferred habitats in which to search for these species (when seed collecting) and in prescribing their use. Secondly, it was important with respect to the geographical and elevational limits to the natural distribution of these species when they are prescribed for operational revegetation. For example, we learned that *Lupinus polyphyllus* should be used only at low to medium elevations in the southern and eastern portions of our study area, while *Lupinus arcticus* can be used at all elevations throughout the region. Likewise, *Calamagrostis rubescens* is restricted to the most southern portion of our study area and was eventually dropped from our seed-increase program.

Seed Collection

Seed collection and the evaluation of additional species was carried out during the first three years of the project, primarily in August, September, and early October. Seed from wild populations of candidate species was collected from widespread natural stands within the study area (Figure 1). Seed collection was guided by the goal of obtaining wide geographical and ecological representation; specifically, it was our nominal objective to obtain accessions representing an average of 30 different combinations of forest district and biogeoclimatic subzone.

Once a suitable population was located, seed from a large number of individual plants (preferably 30 or more) were collected by hand and placed in envelopes or paper bags and labelled. Seed was later extracted by hand and cleaned using hand seives. Air-dried seed was stored in a deep freeze or refrigerator for later use.

The exact geographic location of all seed collection sites was determined using a global positioning (GPS) receiver, or from a large-scale topographic map. Elevation was usually taken from a topographic map as well, as the GPS unit did not give reliable values. Biogeoclimatic subzone and variant were determine from published maps, the Forest District was recorded, and the general location described. Notes on site and soil conditions and dominant vegetation were also recorded. All of this information was then entered into a spreadsheet, allowing the data to be sorted by species, date, biogeoclimatic zone, etc.

Germination Testing

Germination testing of seed collected from the wild constituted a primary screening for species selection. It was also carried out on all plot-produced seed to determine seedlot viability, (needed for seed sales and to calculate pure live seed (PLS) for sowing and revegetation prescriptions), to optimize cultural and testing practices and to report on expected rates of emergence.

Tests of germination capacity (total % germination) and germination rates (time to 50% of potential germination) were conducted on all species under laboratory conditions. Such conditions include subjecting seeds to day and night of equal length in a programmable incubator. Each subsample consisted of 100 individually counted seeds, placed on filter paper or paper towels wetted with distilled water in plastic trays with tight fitting lids, and then placed in the incubator. Three or four subsamples were tested for each seedlot, depending on the amount of seed available and the scale of the germination testing program in a given year. Throughout the project, temperatures in the incubator were 30^{o}C (days) and 20^{o} C (night), with florescent lights on during the daytime period. Though these are the standard conditions for seed testing recommended by the Association of Official Seed Analysis (1985), we hypothesized that such temperatures were too warm for many of our northern species. So in the last year of the project we adjusted incubation temperatures to 25^{o}C days and 15^{o}C nights.

In an effort to determine true seed viability and to optimize subsequent propagation efforts, a number of pre-germination treatments were tested from time to time on selected species. These treatments included:

- stratification -- germination trays, with seeds on water soaked filter paper, were stored in a refrigerator (5^{o} to 8^{o}C) for 60 days before incubation and germination monitoring;
- scarification -- species of seed with hard coats (especially Fabaceae) were knicked with a razor blade before germination testing
- soaking -- seeds were soaked in distilled water for 24 hours before germination testing.

Germination monitoring consisted of weekly inspections of each germination tray. A seed was deemed "germinated" if the length of its emerging radicle (seedling root) exceeded the length of the seed. Monitoring was initially conducted for a standard four weeks, but we noticed that many of our species had delayed or prolonged germination behaviour. So for the last three years of the project, all germination tests were continued until two weeks had passed with no more emergence (after initial germination had begun), or for twelve weeks. Seed trays were remoistened if necessary during monitoring. After initial testing of our wild collections, plot-produced seed was tested annually. Intermittently, archived seed samples from previous years were tested for germination tests in order to document the longevity of seed viability and vigour.

Greenhouse Propagation

Given that an assured number of seedlings of different accessions was desired for our seed-increase program, and that the successful establishment of seed-increase plots in desired configurations was paramount, seedlings were first produced under nursery conditions for later transplanting outdoors. While doing so, we were also able to determine germination rates under more operational conditions, and hoped to lengthen the first growing season in seed-increase plots. Initially, this activity took up a high percentage of project resources but as our seed increase plots became established, we scaled down the greenhouse propagation activities and concentrated our efforts on plot maintenance.

Recycled 313B styroblocks (donated by Woodmere Nursery) were filled with wetted peat moss. Each cavity was then sown with 1 to 5 seeds, depending on the results of germination tests. Seeds were then covered with a light mulch or nursery gravel to reduce surface evaporation and prevent seeds from dislodging during watering. Blocks were then placed in an unheated plastic- or fibreglass covered greenhouse, watered daily, and monitored. Sowing was done in April or May. Throughout the project, more than 1500 styroblocks (with 240 cells per block) were sown: over 600 blocks with 270 accessions of 25 selected species in the second year; 561 styroblocks with 420 accessions of 28 species in the third year; 225 blocks of 118 accessions of 29 species in the fourth year; and 90 blocks with 79 wild accessions of 12 species in the fifth year.

We systematically monitored seedling emergence in Year 3 of the project. Every two days each styroblock was checked for germination. Individual cells in each block were tagged with a toothpick or wire loop when successful germination was noted, and the cumulative progress of germination in each styroblock was tallied on data sheets. We also kept track of maximum and minimum daily temperatures in the greenhouse, which allowed us to calculate heat sums in terms of growing degree-days (the sum of successive days' average temperatures, minus a 5^{o}C base). These data have allowed us to portray the germination speed of each species not only in terms of time but also in terms of temperature requirements. Prior to our research, many of the species with which we are working were untested for germination behaviour and temperature response.

Establishment and Maintenance of Seed-Increase Plots

Preparation and maintenance of our two seed-increase plots at Woodmere Nursery (near Telkwa, B.C.) and at the site of the Canadian Forest Service Field Station (near Smithers, B.C.) was time consuming. Land for the project was donated by our project partners, Woodmere Nursery and the Canadian Forest Service (CFS). Considerable preparation was necessary to make the donated land suitable for experimental crop production. The land at Woodmere had been unmanaged for approximately ten years and had a high density of noxious weeds, including Canada thistle, dandelion and hemp nettle. The land at the CFS field station had been a hay field in the recent past, but with a large component of quack grass (also a noxious weed), plus persistent creeping red fescue and an alsike clover seed bank. Prior to cultivating, large rocks were picked and removed from the plots. Both plots were cultivated two or three times with a 6-foot rototiller attached to a farm tractor, after first being sprayed with Roundup™ (CFS only). Prior to planting, each sub-plot was finely rototilled with a rear-tyned, hand operated rototiller.

Preparation, planting and maintenance of seed-increase plots was ongoing throughout the project as we tested new species and expanded the production of some. In Year 2 of the project (the first year of planting), we established 28 single-species subplots (one or two for each of 26 species) of varying sizes, for a total of 21,251 plants established. Most were transplanted seedlings, but some plots were seeded directly.

We retained the services of Tim Mullin, of Genesis Forest Science Canada Inc., to design a generic planting layout which would maximize the diversity of accessions found in the immediate neighbourhood of representatives from each individual accession, thereby optimizing the conditions for out-crossing. As used in the design of conifer tree seed orchards, a generic orchard design for 1200 plants from each of 30 accessions was prepared using a computer program for permutated neighbourhood design, named COOL (Bell and Fletcher 1978). The program assigned accession numbers to available planting positions at random, while ensuring that each plant was surrounded by an immediate neighbourhood of 20 unique accession numbers (Bell and Fletcher’s design type 3), and that accession numbers did not occur as immediate diagonal neighbours any more than 10 times. Maximizing the diversity of genetic neighbourhoods was considered an important aspect of this program, if we hope to produce seed that can be used across a wide geographical area and a wide range of site conditions. Even for species that are self-pollinating, production of a multi-lineal seed supply will ensure that such species will germinate in areas appropriate to their lineage.

The generic planting layout generated by Genesis Forest Science was modified for each species by substituting our unique accession numbers into the 30 positions allocated in each layout. As the number of accessions collected for each species varied, a number of blank positions were left in some subplots. These blanks were planted in subsequent years with appropriate accessions subsequently collected or later with our plot produced seed. Computer generated sub-plot layout maps were created for each species, then used in the field to determine the planting layout.

A wooden template with dowels spaced at 10, 20 or 30 cm was used to uniformly mark the positions in which to transplant seeds or seedlings. The 20 cm spacing was used for most species, while 30 cm was used for *Lupinus* spp., and 10 cm was used for *Dryas drummondii* plots. Each row in a subplot consists of 5 sub-rows (staggered so plants are arranged in a triangular or hexagonal array), with 80 cm alleys maintained between rows for access and weed control (Figure 2). Immediately following templating, labelled plastic horticultural pot markers (colour coded by accession number) were placed in the planting positions, following the planting layout pertinent to that species.

Seeds or seedlings were then planted in appropriately marked spaces. Thus each individual plant was labelled as to its origins to facilitate future monitoring of vegetative attributes, seed production and genetic properties. This proved to be a long and labour intensive process but it allowed evaluation of the performance and breeding value of individual plants, and maintains the site as a "common garden" experiment for population genetics studies, as well as maximizing the potential for outcrossing.

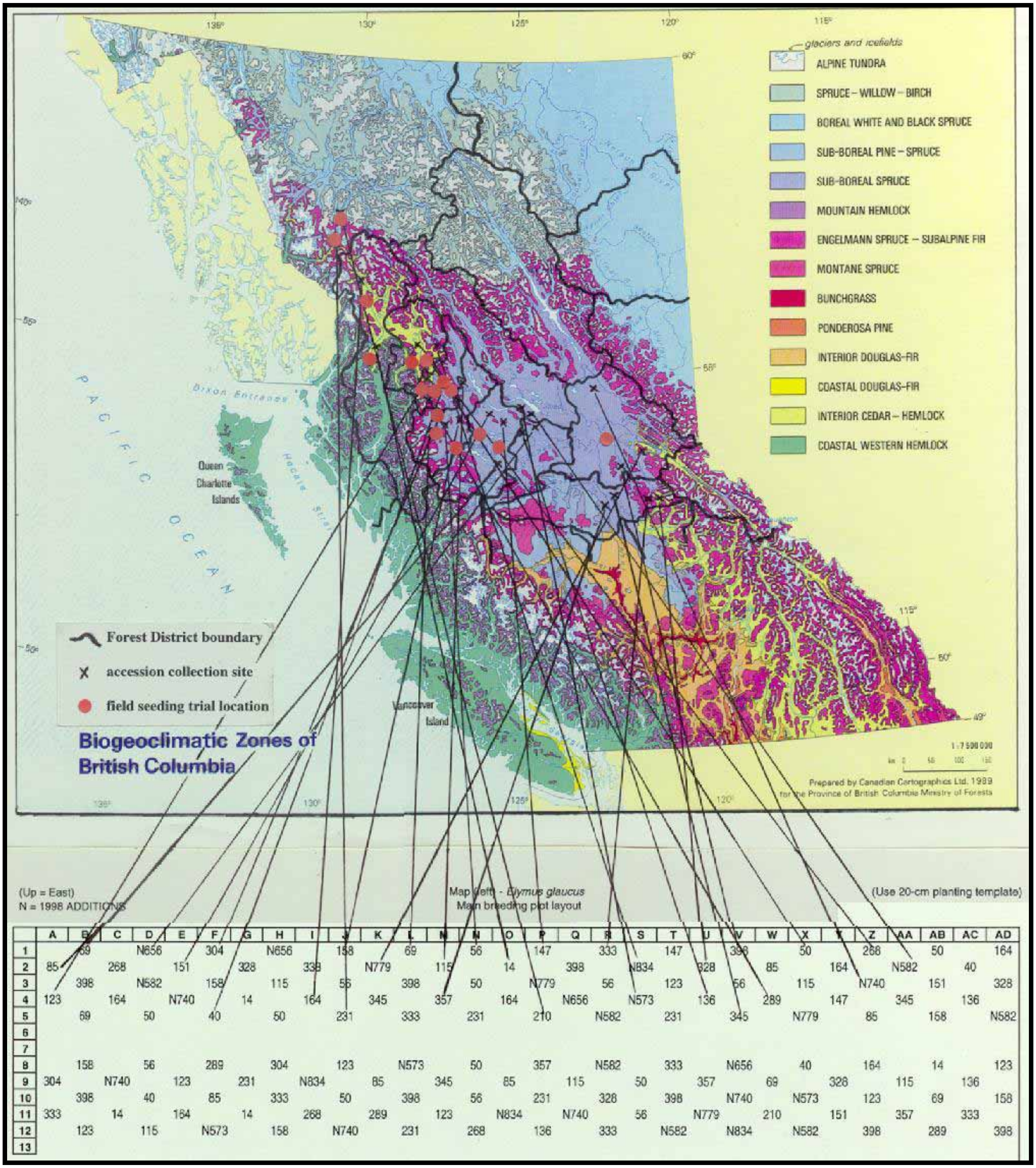

Figure 2. Wild seed from each species was collected from 52^{o} to 60^{o}N, between and Coast Range and the Rocky Mountains. Nursery-grown seedlings were then transplanted into computer-generated planting arrays in seed-increase plots designed to maximize the potential for outcrossing.

Figure 2 shows how *Elymus glaucus* accessions from diverse locations were placed in a seed-increase plot. Rooted plants were then extracted from the styroblocks as "plugs," dipped in a solution of 4-10-10 fertilizer and IBA rooting hormone, planted using trowels, watered, and labelled with the appropriate accession number (Figure 3).

Figure 3. Planting crew establishing *Elymus glaucus* seed-increase plot at CFS Field Station in 1997.

Weed control proved to be a time-consuming and frustrating experience throughout the project, and was the primary reason for over-expenditures and delays. Most weeding was done by hand, employing local young people (some university students, some otherwise unemployed) during the summer months. Digging was often required to remove the rhizomes of perennial weeds; rhizomes and seed heads were removed from the plot to prevent further contamination of the site. Herbicide spraying could be done before planting at the CFS plot, but not at Woodmere. Once our crop plants had been introduced into subplots, they were protected with inverted plastic cups or buckets when spraying was conducted to control dense patches of weeds. A broad-spectrum, foliar active, biodegradeable herbicide (Roundup™, with glyphosate the active ingredient) was applied using a backback sprayer and protective clothing. Banvel™, a selective herbicide, was used in an attempt to control broadleaved plants through broadcast application to grass and sedge plots. Alleys and plot perimeters were kept weed-free by rototilling and the application of plastic and straw mulches. If non-crop plants were not fully controlled by the time plots were ready for harvest, rows were walked and "rogued" of seed heads belonging to all non-crop species before harvesting commenced.

Year 3 of the project (1998) marked the first substantial harvesting of viable seed crops from our seed-increase plots. Harvesting of seed from wild plant species presents a challenge, because they have not been selected for seed retention on the stalk, uniform stature or uniform maturation times. If plots are harvested too late, much of the seed ends up on the ground, while if harvested too early, much seed formation and maturation is incomplete. Harvesting for maximum seed collection therefore often has to be selective, and was largely done manually: most seed was picked by hand, with clippers or with hand sickles. Depending on the stage and uniformity of ripeness, seed stalks were then laid out in swaths to dry and ripen in the sun or in a dry warehouse, or were stored directly in labeled paper or woven plastic bags. Ripe seed was threshed on site or over winter in a warehouse (using a custom-made motorized rotary flail) and then cleaned during the winter. As seed production increased and we shifted attention to larger seed-production fields, we searched for an alternative to hand harvesting. Most species were too small or difficult to handle with a standard farm combine, so we settled on a hand-held motorized seed stripper, designed specifically for harvesting wild seed (Morgan and Collicutt 1994). This seed stripper (Figure 4) cut our harvesting time by two-third, but also scattered a lot of seed in the stripping process, so we are once again evaluating alternative technologies. For example, many of the small or fluffy seeded species can be collected with a vacuum cleaner (shop-vac or modified backpack leaf-blower).

Figure 4. Harvesting *Elymus glaucus* using a motorized seed stripper, August 1998.

Field Seeding Trials

Since native seed mixes have not been used extensively in revegetating degraded sites, we established seeding trials in operational rehabilitation and restoration trials at 22 different sites across the northern Interior of British Columbia. These plots were established in single species and mixed species stands to test seeding densities, seed mix, comparisons with agronomic species, optimal season for seeding, fertilization, sowing techniques and substrate preparation, as summarized in Table 1. Most treatment plots were 25 to 50 m^2 in area, were cleared of large rocks and woody debris prior to sowing, and were then manually raked (or in some cases rototilled) to expose fresh soil. Plots were hand sown with a pre-measured seed mix plus whatever fertilizer or other supplements might have been added to individual plots. Seed was mixed and measured to give pre-determined application rates calculated in terms of pure live seed (PLS) per m^2, based on seedlot purity and viability determinations.

Plots were monitored once a year (in late August or in September) for at least two growing seasons after they were sown. Randomly generated coordinates were used to select the location of three subsamples per treatment plot. A subsample consisted of a 1.0 m^2 circular quadrat, within which all plant stems were counted and their percent cover estimated by species. Plant density was determined in order to estimate the emergence rate or establishment percentage relative to the number of seeds spread; plant cover served as the basis for describing plant community composition and overall performance (especially with respect to erosion protection and green-up success). Data were collected for volunteer native and weedy invaders too. The surface area covered by rocks, wood, plant litter and erosional rills was also recorded. Data were analyzed by analysis of variance to test for species differences in seedling emergence, and for treatment differences in overall cover production and protection from weed invasion.

Table 1. Field trials established and monitored during the native plant seed project.

Location Description					Treatments Evaluated						
Place Name	Biogeo-climatic Subzone	Forest District	Date Sown	No. of Plots*	Native *vs.* Agro.	Spp. Mix	Seed Dens.	Spring *vs.* Fall Sowing	Mul-ches	Cover Crops	+/- fert-ilizer
Willow Creek FSR	BWBSdk1	Cassiar	Oct/98	10		x					
Telkwa Mtns.	ESSFmc	Morice	Oct/98	20	x	x					
McKendrick Pass	ESSFmc	Bulkley	Oct 4/99	12			x	x			x
McKendrick Pass	ESSFmc	Bulkley	June 8/00	12			x	x			x
Sam Green Rd.	ICHmc1	Kispiox	May/98	15		x	x				
Vetter Log Sort	ICHmc2	Kalum	May/98	10		x	x	x			
Vetter Log Sort	ICHmc2	Kalum	Sept./98	10		x	x	x			x
Vetter Log Sort	ICHmc2	Kalum	Oct 6/99	12			x	x			x
Vetter Log Sort	ICHmc2	Kalum	June 4/00	12			x	x			x
Date Creek	ICHmc2	Kispiox	May/98	7		x	x				
Tea Lake FSR	ICHmc2	Kispiox	July/97	13	x	x					
Meziadon Lake	ICHvc	Kalum	Oct/98	18	x	x	x		x		
Devil's Creek	ICHwc	Cassiar	Oct/98	5		x					
Old Babine Lake Rd.	SBSdk	Bulkley	May/98	11		x	x	x		x	
Old Babine Lake Rd.	SBSdk	Bulkley	Oct/98	6		x	x	x			
Ptarmigan Rd.	SBSdk	Bulkley	Oct 3/99	12			x	x			x
Ptarmigan Rd.	SBSdk	Bulkley	June 3/00	12			x	x			x
CFS Field Station	SBSdk	Bulkley	Oct 18/99	12			x	x			x
CFS Field Station	SBSdk	Bulkley	June 5/00	12			x	x			x
Francois Lake	SBSdk	Morice	Oct/98	15		x	x				
Francois Lake	SBSdk	Morice	Sept 9/99	12			x	x			x
Francois Lake	SBSdk	Morice	June 2/00	12			x	x			x
Canyon Creek	SBSmc2	Bulkley	May/98	6		x	x				
Driftwood Canyon	SBSmc2	Bulkley	Sept/98	11		x	x		x		
McDonnell Lake	SBSmc2	Bulkley	May/98	10		x					
Smithers Comm. For.	SBSmc2	Bulkley	July/97	7		x	x				
Cheslatta	SBSmc2	Lakes	May/98	10		x	x				
Little Andrews Bay	SBSmc2	Morice	Oct/98	16		x	x		x	x	x
Pimpernel Road	SBSmc2	Morice	Oct/98	10	x	x					
Chapman Road	SBSmc2	Morice	Oct 15/99	12			x	x			x
Chapman Road	SBSmc2	Morice	June 8/00	12			x	x			x
Aleza Lake	SBSwk1	Pr. Geor.	July/97	48	x	x					x
TOTALS:	9	7		402	5	20	25	16	3	2	15

* includes monitored control (unseeded) areas;
most plots measure 25 m^2, though sizes range from 6.25 to 50 m^2.

Results

General Literature Review

A broad review of available information on the ecology, germination, cultivation and use of 31 plant species is reported in our manual (Appendix I). Though a detailed review of the biology of these plants could only be completed for *Elymus glaucus* and *Lupinus arcticus* (Appendix II), similar reviews had already been published for some of our other species. Existing reviews, often emphasizing propagation requirements or potential for use in land reclamation, include the following publications on the species indicated:

Achillea millefolium --	Warwick and Black 1982, Rose et al. 1998, Pahl and Smreciu 1999, Small and Catling 2000
Anaphalis margaritacea --	Rose et al. 1998
Bromus ciliatus --	Pahl and Smreciu 1999
Calamagrostis canadensis--	Hardy BBT Limited 1989, Haeussler et al. 1990
Dryas drummondii --	Hardy BBT Limited 1989
Elymus glaucus --	Rose et al. 1998
Elymus trachycaulus --	Hardy BBT Limited 1989, Pahl and Smreciu 1999, Smith and Smith 2000
Festuca saximontana --	Pahl and Smreciu 1999
Lathyrus ochroleucus --	Hardy BBT Limited 1989
Leymus innovatus --	Hardy BBT Limited 1989
Poa alpina --	Hardy BBT Limited 1989, Pahl and Smreciu 1999, Smith and Smith 2000
Trisetum spicatum --	Hardy BBT Limited 1989
Vicia americana --	Hardy BBT Limited 1989, Rose et al. 1998, Pahl and Smreciu 1999

Prospects and Requirements for Commercialization

One of the ultimate objectives of this research program is to make large quantities of commercially grown (rather than wild-collected) native grass and legume seed available for use by foresters, agronomists and restorationists. Thus suitable mechanisms by which commercial quantities of seed could be distributed, grown, bought and sold need to be explored. Dr. F.B. Holl (Lamorna Enterprises Ltd., Vancouver) prepared a comprehensive analysis of the options for commercialization of native plant materials propagated by seed. The executive summary of his analysis is as follows:

1. Though practicing agronomists often state otherwise, there are no legal requirements for registration of seed sold for reclamation/revegetation applications.
2. "Ecovars" have no legal status, though the term could be used to describe the plant material we are developing. The concept has been developed as an *ad hoc* solution to the need to devise some standard for commercialized native plant materials in the pedigree seed system. An ecovar is defined as source-identified material with a prescribed (by the breeder) level of variation. [Note: Since this review was done by Dr. Holl, Native Plant Solutions Inc. (a division of Ducks Unlimited Canada) has registered the term ecovar as a proprietary trademark; B. Wark, pers. comm., May 2001].
3. For species with broad adaptability and a large, recurring market demand the ecovar or source-identified cultivated production route would justify the cost and effort. He estimates approximately 4-7 years to produce marketable seed. For species with specialized ecological adaptation and/or erratic market demand, the ecovar concept does not appear to be cost effective.
4. For all marketed seed stocks, a certificate of germination (performance) and purity (contamination with weeds or other crop kinds) should be an essential component of any commercialization, and provides an important marketing tool.
5. "Ownership" of seed stocks can be maintained by controlling seed supplies and the multiplication process. This control may be exercised directly or through an agent such as SeCan. He does not see a strong argument for any attempt to protect the material under Plant Breeders' Rights legislation even if that choice was available. Cost and the difficulties of identification of "uniqueness" make this an unattractive option.
6. For those species which are unlikely to prove economic to develop as ecovars, there may be alternative options to undertake short-term multiplication and marketing. In addition to control

of the seed supply, there may be some opportunities to market the material under a "brand name".

7. Development efforts should be concentrated on species with "commercial populations," and/or those with broad enough ecological adaptation to provide adequate markets for significant recurring returns.

This information can now be used by Symbios Research and Restoration (or any other plant material development agency or enterprise) to serve as the basis for further product development. It should also help interested parties devise a suitable policy for the eventual sale and distribution of plant material generated by this research project.

Accession Acquisition

A total of 1076 seed accessions of more than 50 different species from 12 forest districts and 22 biogeoclimatic subzones were collected over the course of the project. Table 2 summarizes the results of our collection efforts; this table does not include all species later rejected for various reasons. For the 31 species retained in our program of seed-increase research and analysis, we utilized a total of 881 wild accessions. An average of 19 different combinations of biogeoclimatic subzones and forest districts are represented in the population of accessions used for each species; this is somewhat less than the 30 combinations desired for each species (though that goal was an arbitrary one). Most of the more remote and unroaded portions of our study area are unrepresented in our program, because resources originally budgeted for seed collection had to be reallocated to weed control in the seed-increase plots.

Seed collections provided the basic stock for our seed increase program. In addition, associated observations on the abundance, dominance and vigour of native plants growing on disturbed sites constituted one of our primary sources of information for the identification and selection of candidate species. Documented collection sites also served to add data to the known distributional range of each species, as mapped in our manual (Appendix I).

A total of 18 species were rejected from further study. Some were rejected due to difficulty in collecting or seed handling. Others were rejected after primary screening to test germinability (at $30/20^{o}$ C, with and without stratification, and under greenhouse conditions) resulted in poor performance. Table 3 summarizes these rejected species, why they were originally considered, and why no further work was done with them.

In the last year of our research program, 359 samples (consisting of at least 100 seeds each) of the remaining accessions were donated to a national germplasm depository, Plant Gene Resources Canada, based at the Agriculture and Agri-Food Canada Research Centre in Saskatoon, Saskatchewan. Species represented in this seed bank are limited to those considered to be of potential commercial interest, particularly members of the Fabaceae and Poaceae. Some of this seed is being grown for more detailed agricultural-botanical characterization by Agriculture and Agri-Food Canada staff, will be periodically refreshed by cultivation and harvesting, and will be made freely available for use by plant breeders.

Table 2. Seed accessions of major candidate species acquired in the northern Interior of B.C.

Plant Family	Species	Subzones Represented	Districts Represented	Subzone/Dist. Combinations*	Total No. Accessions	No. Donated to Seed Bank**
Asteraceae	*Achillea millefolium*	23	14	43	75	50
	Anaphalis margaritacea	18	13	39	68	0
	*Antennaria neglecta****	8	8	10	12	0
	Arnica chamissonis	1	1	1	1	0
	Arnica cordifolia	9	9	16	24	0
	Aster conspicuus	9	10	16	22	0
	Aster foliaceous	3	5	5	5	0
Cyperaceae	*Carex aenea*	12	11	25	29	19
	Carex macloviana	14	12	27	34	30
	Carex mertensii	18	10	31	47	43
Fabaceae	*Lathyrus nevadensis****	3	5	6	16	0
	Lathyrus ochroleucus	9	11	18	35	12
	Lupinus arcticus	13	9	22	41	8
	Lupinus polyphyllus	8	6	12	21	7
	Vicia americana	12	12	22	32	13
Juncaceae	*Luzula parviflora*	11	10	19	24	0
Liliaceae	*Allium cernuum*	3	3	3	3	1
Onagraceae	*Epilobium angustifolium****	14	9	22	28	0
	Epilobium latifolium	11	10	15	17	0
Poaceae	*Agrostis exarata*	11	8	17	19	12
	Bromus ciliatus	17	12	26	39	25
	Calamagrostis canadensis	15	11	26	42	20
	Calamagrostis rubescens	9	6	12	14	3
	*Danthonia intermedia****	6	5	7	7	0
	*Deschampsia caespitosa****	8	8	10	16	0
	Elymus glaucus	22	12	50	89	50
	Elymus trachycaulus	9	7	14	22	14
	Festuca occidentalis	16	10	34	56	27
	Festuca saximontana	10	5	11	14	8
	Leymus innovatus	5	4	5	9	5
	Poa alpina	9	7	11	13	7
	*Stipa richardsonii****	3	4	4	4	0
	Trisetum spicatum	11	9	21	28	5
Polemoniaceae	*Polemonium pulcherrimum*	4	4	6	6	0
Ranunculaceae	*Aquilegia formosa****	2	1	2	3	0
	*Thalictrum occidentale****	1	2	2	3	0
Rosaceae	*Dryas drummondii*	10	9	12	22	0
	Geum macrophyllum	17	11	23	28	0
Rubiaceae	*Galium boreale****	9	9	14	22	0
Scrophulariaceae	*Collinsia parviflora*	1	1	1	2	0
	*Rhinanthus minor****	5	4	7	10	0
All 41 Species:	MEAN:	9.73	7.73	16.27	24.44	8.76
	TOTAL:	399	317	667	1002	359
31 Tested Species:	MEAN:	10.97	8.45	18.81	28.42	11.58
	TOTAL:	340	262	583	881	359

* number of combinations divided by 30 expresses the success in achieving the arbitrary goal of representing 30 subzone and district combina
** archived with Plant Gene Resources Canada, a division of Agriculture and Agri-Food Canada (Saskatoon, Saskatchewan), for public use.
*** species eventually excluded from seed increase program and not included in the manual.

Table 3. Candidate species rejected from further consideration.

Species	Reason considered	Reason rejected
Antennaria neglecta	abundant on open sites with poor soils	seed handling difficult, poor competitor
Aquilegia formosa	aesthetic appeal, add for diversity & colour	germination poor
Danthonia intermedia	performs well on dry and gravelly sites	few accessions obtained, little cover
Deschampsia caespitosa	vigorous growth in open forests	few accessions obtained, some of questionable identity
Epilobium angustifolium	rhizomatous, invader of disturbed sites	seed is easily collected from wild stands
Galium boreale	common on roadsides, dry open habitats	could not germinate in lab or greenhouse
Hedysarum boreale	northern species, nitrogen fixing	few populations found
Heracleum lanatum	widespread species on semi-open sites	germination erratic, nutrient demanding
Lathyrus nevadensis	nitrogen fixing	poor establishment success in plots
Oxytropis campestris	nitrogen fixing	few populations found
Petasites palmatus	common on roadsides and semi-open sites	seed handling difficult
Phleum alpinum	hardy grass	few populations found
Rhinanthus minor	widespread on roadsides and in hayfields	could not germinate in lab or greenhouse
Scirpus microcarpus	robust growth in open, moist sites	(not tested; more of a wetland plant)
Solidago canadensis	widespread roadside invader	seed handling difficult
Stipa richardsonii	common on native grasslands	(acquired late in program; not tested)
Thalictrum occidentale	common in open forest and forest edges	poor germination results

Germination Testing

Table 4 summarizes five years of native seed germination test results. Note that tests conducted in 1996 and 1997 were done with individual subsamples (germination trays of 100 seeds each) each consisting of an accession collected from the wild. Tests conducted over the last three years primarily come from plot-produced seed, meaning that the seed arose from lines that have (at least once) been propagated through successful germination under greenhouse conditions. We might therefore expect that the seed-increase process may have selected for ease of germination, and perhaps inadvertently for other genetically linked characteristics as well. This may be the case for *Aster conspicuus*, *A. foliaceous*, *Elymus glaucus*, *Festuca saximontana*, *Geum macrophyllum*, *Lathyrus ocroleucus*, *Lupinus arcticus* and *Poa alpina* (Table 4), though some of these trends may be due to cooler test temperatures in the last year. Such a shift, if real, represents an enhancement of plant material that will make seed production and revegetation efforts more successful, but raises concerns about a loss of genetic diversity. On the other hand, there is also evidence that the seed-increase process has somehow resulted in reduced seed viability for some species: *Agrostis exarata*, *Allium cernuum*, *Calamagrostis canadensis*, *Luzula parviflora*, *Polemonium pulcherrimum*, and *Trisetum spicatum*. Again, these apparent differences may be due to the use of different germination temperatures, but may also indicate that recent weather differences, or seed production conditions under cultivation, have been less than optimal. Germination tests were conducted to test for differences between wild-collected and plot-produced seed, but there were so many confounding influences that no statistical analysis was conducted to test the hypotheses alluded to above.

Table 4. Summary of laboratory germination tests (% germination capacity), 30°C days, 20°C nights.*

	Source:	Wild Seed		Wild Seed		Plot Produced		Plot Produced		Plot Produced	
	Year Tested:	1996/97		1997/98		1998/99		1999/2000		2000/01*	
Species	Pre-Treatment	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Achillea millefolium	none	71.5	15.2	91.5	7.4	97.7	2.3	64.7	14.7	86.0	6.6
	stratified									86.3	7.2
	1998 seed							92.3	4.0	89.7	2.9
	1999 seed									92.3	4.9
Agrostis exarata	none			99.9	i.d.			4.7	1.5	75.0	3.6
	stratified									13.0	4.4
	1999 seed									81.0	7.9
Allium cernuum	none			74.0	i.d.			11.5	0.7	19.7	7.8
	stratified									26.0	4.4
	1998 seed									20.0	14.8
Anaphalis margaritacea	none	42.4	42.7	84.0	8.7	62.0	i.d.			75.3	3.2
	stratified									23.3	2.1
	1998 seed									93.3	2.1
	1999 seed									91.3	3.1
Antennaria neglecta	none			9.5	12.0						
Arnica chamissonis	none							23.3	3.5	41.3	5.9
	stratified									36.3	2.5
	1999 seed									33.0	7.2
Arnica cordifolia	none	2.3	4.5	19.0	8.6			5.0	1.7	12.0	1.0
	stratified									22.0	1.0
	1998 seed									28.3	2.5
	1999 seed									9.3	3.1
Aster conspicuus	none	6.0	4.0	30.8	12.9					33.7	7.2
	stratified									38.7	2.1
	1999 seed									63.3	2.5
Aster foliaceous	none			38.3	11.2					53.0	9.5
	stratified									73.7	6.1
	1999 seed									64.3	5.0
Bromus ciliatuus	none	64.8	13.7	80.3	15.9	56.7	21.1	83.7	2.1	25.0	8.7
	stratified									23.0	12.2
	1999 seed									86.0	2.0
Calamagrostis canadensis	none			42.5	14.4					7.0	2.6
	stratified									3.7	1.2
	1999 seed									24.0	6.6
Calamagrostis rubescens	none	42.0	50.2	5.5	6.1	11.7	2.1	7.0	2.6	21.0	5.3
Carex aenea	none	69.5	29.1	80.8	5.9	77.7	8.3	63.3	4.2	67.7	4.7
	stratified					87.8	3.0			47.7	16.7
	1998 seed							81.3	20.3		
	1999 seed									78.0	9.5
Carex macloviana	none	61.3	23.6	75.5	19.5	62.3	4.5	65.3	5.7	69.7	3.8
	stratified					49.8	2.2			70.0	6.2
	1998 seed									31.3	2.5
	1999 seed									39.0	3.5
Carex mertensii	none	87.5	12.0	93.3	6.4	37.0	5.0	56.3	15.0	32.3	5.0
	stratified									90.0	2.6
	1999 seed									87.0	11.8
Collinsia parviflora	none							3.3	5.8	49.0	1.7
	stratified									8.3	1.5
	1999 seed									22.3	8.4
	soaked 24 hrs at 5°C							21.7	8.4		
	scarified w/ razor blade							40.0	10.8		
Danthonia intermedia	none			11.5	7.0			0.3	0.6		
Deschampsia caespitosa	none			27.5	30.4						
Dryas drummondii	none	65.3	23.0	26.6	32.9	41.0	i.d.	9.0	4.6	58.3	5.5
	stratified									22.0	6.1
	1999 seed									39.3	8.1

sc.= scarified; st. = stratified; s.d.=standard deviation;

* tests in 2000/2001 were all conducted under 25°C days, 15°C nights.

Table 4. Summary of laboratory germination tests (% germination capacity), 30°C days, 20°C nights*, continued

Source:		Wild Seed 1996.0		Wild Seed 1997.0		Plot Produced 1998.0		Plot Produced 1999.0		Plot Produced 2000*	
Species / Source / Treatment		mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Elymus glaucus	none	75.0	29.4	51.8	10.7	81.0	3.6	88.7	3.5	75.0	6.6
	stratified									74.7	5.1
	1999 seed									93.3	3.1
Elymus trachycaulus	none	62.3	22.7	94.0	i.d.	59.0	10.4	73.7	15.3	76.7	0.6
	stratified									83.3	6.1
	1999 seed									82.3	2.3
Epilobium angustifolium	none									63.3	6.7
Epilobium latifolium	none	61.7	19.3	44.3	34.5					52.0	14.9
	stratified									39.0	3.5
	1999 seed									80.0	10.1
Festuca occidentalis	none	55.0	19.1	98.6	2.9	84.7	3.1	85.0	5.3	88.3	1.5
	stratified									78.0	3.0
	1998 seed							86.7	6.0		
	1999 seed									92.7	3.2
Festuca saximontana	none			28.5	9.2					34.7	6.0
	stratified									31.3	2.1
	1999 seed									96.3	1.5
Geum macrophyllum	none	69.0	17.0	62.8	35.4					94.7	5.0
	stratified									76.7	9.0
	1998 seed							76.7	2.5		
	1999 seed									90.7	7.1
Lathyrus nevadensis	scarified and stratified	2.0	2.3								
Lathyrus ochroleucus	none									21.0	3.6
	stratified									27.3	3.8
	scarified and stratified	13.8	11.1								
	soaked 24 hours at 5°C							48.0	5.2		
Leymus innovatus	none	9.5	10.8	7.0	i.d.					50.3	10.4
	stratified									53.0	5.6
	1999 seed									88.7	3.2
Lupinus arcticus	none			22.7	7.5	38.0	3.0	59.7	9.1	75.3	1.5
	stratified					46.0	0.0			87.3	2.1
	1999 seed									84.0	11.3
	ripe when harvested									81.3	3.8
	unripe when harvested									65.3	6.7
	scarified and stratified	95.2	3.3								
Lupinus polyphyllus	all plot-produced			81.0	i.d.	51.5	0.7	42.3	4.2	73.3	11.7
	stratified									91.0	4.6
	1998 seed							56.3	12.4		
	1999 seed									85.7	4.0
	ripe when harvested									82.7	5.8
	unripe when harvested									70.7	2.3
	scarified and stratified	72.8	15.5								
Luzula parviflora	none			96.6	0.5	53.0	i.d.			92.0	5.3
	stratified					58.0	17.0			79.0	5.3
Poa alpina	none	25.0	12.1			35.0	16.1			61.7	1.5
	stratified					50.6	11.7			62.7	1.2
	1998 seed							40.0	7.8		
Polemonium pulcherrimum	none			92.9	i.d.			65.0	5.3	88.0	5.3
	stratified									80.0	7.0
Trisetum spicatum	none			68.3	19.9			60.3	24.2	48.7	7.5
	stratified									44.7	12.6
	1999 seed									46.0	2.0
Vicia americana	none	85.0	8.2							87.3	2.5
	stratified									85.7	1.2
	1999 seed									74.0	8.5

sc.= scarified; st. = stratified; s.d.=standard deviation;

* tests in 2000/2001 were all conducted under 25°C days, 15°C nights.

Original germination tests were conducted under the standard conditions of 30^o C days/20^o C nights as recommended by the Association of Official Seed Analysis (1985). It occurred to us, however, that most of these northern plant species rarely experience 30^o C days, especially in the spring, so more recent testing employed temperatures of 25^{o}C days/ 15^o C nights. Unfortunately, our lab has only one incubator, so just one temperature regime can be utilized in a given year.

Species that appeared to have better germination at the lower temperatures include *Arnica chamissonis, Aster conspicuous, Aster foliaceous, Calamagrostic rubescens, Collinsia parviflora, Geum macrophyllum, Lupinus arcticus, and Poa alpina.* It is not surprising that *Lupinus arcticus* and *Poa alpina* have higher germination at lower temperatures since they are more prevalent at high elevations and higher latitudes. Species that appeared to prefer higher temperatures include *Agrostis exarata, Calamagrostis canadensis, and Trisetum spicatum.* Although it may appear that *Bromus ciliatus* and *Carex mertensii* respond negatively to the lower temperature (Table 4), the reason for the lower germination rate is likely related to seedlot differences in seed viability rather than temperature, since the one year old seed tested at lower temperatures showed germination comparable to that of previous years. This information on temperature preferences is useful in defining the optimal conditions for seed viability determination, and also has implications for the optimum time for sowing and for climate control settings in greenhouses.

Lathyrus ochroleucus, Lupinus arcticus, Lupinus polyphyllus, Arnica cordifolia and *Aster foliaceous* appear to respond positively to extended stratification, while *Aster conspicuous, Luzula parviflora* and *Agrostis exarata* have higher germination without stratification treatment. Since stratification prior to seed testing or sowing requires extra time and money, it is important to conduct this step only for species in which stratification strongly enhances germination success. Alternatively, one may be able to adjust unstratified germination results by the ratio of stratified to unstratified germination observed in our tests, though it would be good to confirm such ratios with more tests. For example, tests of unstratified *Lupinus arcticus* could just be multiplied by 87.3/75.3 (= 1.16) to estimate the viability of a given seedlot.

It is a challenge to harvest the seed of *Lupinus* species when they are mature enough to be viable but before the pods dehisce. We therefore compared germination of seed harvested when pods on a stalk were predominantly darkened (ripe) with seed harvested when pods on the stalk were predominantly green (unripe). Harvested seed stalks were placed in separate bags denoted "ripe" or "unripe," then stored and cleaned in an identical manner until the time of germination testing. Although the unripe seed pods did turn brown in the bag, results from our testing suggest their germination was considerably lower. However, it is difficult to conclude that harvesting the seeds heads when they are predominantly ripe is beneficial because the loss due to dehiscing may be as great or greater than the "loss" due to suboptimal germination. A clearly superior alternative is to pick seed pods individually as they ripen, but this is much more time consuming than the clipping of whole seed heads.

We conducted tests on the longevity of some of our archived seed a year or two after production. Based solely on mean germination values, it appears that most species germinate as well (or even better!) after one to two years of cool storage (Table 4). The following species showed some decline in unstratified germination of 1998 or 1999 seed when tested in 2000/2001: *Achillea millefolium*, *Carex macloviana*, and *Trisetum spicatum*. As mentioned above in the comparison of wild vs. plot-produced seed germination, these differences could also be due to germination being tested at lower temperatures in 2000/2001, so more work needs to be done without this confounding factor. Many of the wild accessions we collected in 1996 and 1997 have also been successfully germinated by Agriculture and Agri-food Canada staff at the Plant Gene Conservation Centre in Saskatoon, Saskatchewan, in 2001 (K. Richards, pers. comm., 2001). The hard-seeded *Lupinus* species are especially well known for being long-lived, with seeds of *L. arcticus* suspected to be thousands of years old (excavated from animal burrows in the Yukon) having been successfully germinated (Porsild et al. 1967).

Greenhouse Emergence

Propagation from seed under greenhouse conditions was very successful for most of these herbaceous species. Daily watering and inspection was necessary to make sure young seedlings didn't get too hot or dry. We always had more consistent emergence of crop plants in the greenhouse styroblocks than when seeds were directly sown into the soil of our seed-increase plots. Daily inspection of the progress of seedling emergence and records of daily minimum and maximum temperatures in the greenhouse allowed us to gain more information on the germination behaviour of these species. In particular, Table 4 reports on the average time taken for germination to start and to reach its halfway point, both in terms of calendar time and in terms of heat sums

Table 5. Rates of seedling emergence during 1999 greenhouse propogation, as related to heat sums.

	Mean Days			Mean GDD*	
Species	to Start	to 50% done**	to Finish	to Start	to 50% done**
Achillea millefolium	5.0	5.7	33.5	32.5	37.2
Agrostis exarata	7.3	9.9	33.3	50.6	68.6
Allium cernuum	14.5	48.6	60.0	120.0	483.1
Anaphalis margaritacea	13.3	26.2	97.0	80.2	181.6
Antennaria neglecta	6.0	10.1	45.0	41.5	68.1
Arnica chamissonis	16.0	39.9	58.0	114.1	235.7
Arnica cordifolia	13.1	21.9	76.1	84.0	164.3
Aster conspicuus	13.2	25.1	71.9	82.9	174.6
Bromus ciliatus	12.4	11.9	34.1	87.4	87.5
Calamagrostis canadensis	15.4	22.0	54.5	98.8	160.6
Calamagrostis rubescens	12.1	15.5	41.1	92.9	112.5
Carex aenea	37.7	47.0	61.7	297.1	417.3
Carex macloviana	25.0	41.5	59.0	170.4	362.0
Carex mertensii	22.9	37.5	58.8	148.5	301.4
Danthonia intermedia	15.5	22.1	58.5	88.2	139.3
Deschampsia caespitosa	14.3	19.0	42.7	86.5	122.6
Dryas drummondii	16.6	40.2	68.5	89.9	299.1
Elymus glaucus	9.5	8.9	39.0	63.4	68.6
Elymus innovatus	12.7	15.0	49.7	93.9	120.3
Elymus trachycaulus	11.4	15.9	39.0	85.1	120.2
Epilobium latifolium	10.8	19.3	53.0	86.4	160.0
Festuca occidentalis	9.0	6.7	26.2	54.2	93.9
Festuca saximontana	11.0	8.0	38.0	57.4	60.0
Geum macrophyllum	13.2	17.1	44.4	86.8	110.5
Lathyrus ochroleucus	18.0	18.0	60.0	118.6	118.6
Lupinus arcticus	6.5	14.2	51.7	48.4	107.5
Lupinus polyphyllus	7.9	21.5	52.5	60.8	180.7
Luzula parviflora	25.0	42.1	67.9	159.1	351.7
Poa alpina	11.2	12.9	50.9	70.6	83.0
Polemonium pulcherrimum	6.0	11.0	50.5	39.5	71.5
Stipa richardsonii	18.0	19.1	43.0	129.6	140.6
Trisetum spicatum	10.1	8.9	34.6	62.1	69.4
Vicia americana	14.3	29.9	55.2	109.7	283.9

* GDD = Growing Degree-Days, 5^{o}C; each day's average temperature has 5^{o}C subtracted from it, and is summed over the period from sowing until seedlings are observed emerging.

** 50% done means germination has reached one-half of final germination capacity.

measured as growing degree-days. There is tremendous variation in these species, with *Achillea millefolium* emergence starting in 5 days (32.5 degree-days>5°C), while *Carex aenea* doesn't start for 38 days (297 degree-days>5°C). *Festuca occidentalis* finished germination first (after 26 days), while the last *Anaphalis margaritacea* seedling emerged 97 days after sowing. These results help guide expectations for germination tests and establishment times under field or greenhouse conditions.

Seed Production

All seed-increase plots were measured and seed yields were recorded annually. Table 6 provides a summary of plot seed yields over the last three years of the project. Of course yield can be varied considerably depending on the configuration of planted rows and plant-free alleys, the level of stocking and survival within rows, etc. But these data provide a good basis for describing the seed yield potential of our plant species, differences among species, and trends from year to year.

The most productive plant species, measured in terms of pure seed produced per m^2, are *Achillea millefolium*, *Anaphalis margaritacea*, and *Festuca occidentalis*, all species with moderately small seeds. In terms of pure seed weight per unit land area (data not presented here), *Festuca occidentalis* is clearly the most productive species, making it one of the most promising species for cultivated seed production. Other high-yielding species (in terms of weight per unit area) are *Bromus ciliatus* and *Carex aenea*.

Some year -to-year trends in mean seed weight and yields suggest some needs related to crop establishment and management. Most species had the heaviest seeds (fewest seeds per gram) and the greatest yields in 1999, the third growing season after plot establishment. 1998 had a hot dry summer, and we note that *Allium cernuum* and *Calamagrostis rubescens*, species characteristic of the warmer drier ecosystems in our region, showed optimal seed production that year. *Allium cernuum*, *Calamagrostis rubescens*, *Dryas drummondii*, *Geum macrophyllum*, and *Lupinus arcticus* produced their largest seeds in 1998, suggesting that these species may be more sensitive to stand ingrowth, aging, or cooler weather. Several species with higher yields in 2000 were also in their third year of growth: *Arnica chamissonis*, *Festuca saximontana*, *Polemonium pulcherrimum*, and *Trisetum spicatum*. Many species showed a decline in 2000, which may be due to weather conditions or to stand deterioration. Other species (e.g., *Dryas drummondii*, *Epilobium latifolium*, and *Leymus innovatus*) showed a steady increase in yields over the three years due to a combination of slow establishment and gradual stand expansion or infilling. In general, we noted stands of *Agrostis exarata*, *Calamagrostis rubescens* and *Festuca occidentalis* were especially difficult to maintain as the plants tended to die back after a few years.

Other lessons learned from five years of cultivating these wild plants are not so easily supported with quantitative data, but are substantiated with observations and experience recorded in work journals. Some of these lessons and advice for future growers include the following:

- weed control is paramount; at least two years of black plastic mulching, repeated cultivation, and/or broad-spectrum herbicide application is recommended before plot establishment;
- though our hexagonal planting array was designed for breeding purposes, it resulted in much ground area that had to be hand weeded; for operational seed production, single rows of crop plants interspaced with alleys that can be rototilled or mulched are recommended;
- plots can be established either in the spring or fall;
- plants may need irrigation during establishment or periods of drought;

Table 6. Summary of seed production from seed-increase plots.

	Pure Seed Yields											
	1998				1999				2000			
Species	Harvest	Plot Area	Seed Size	Yield	Harvest	Plot Area	Seed Size	Yield	Harvest	Plot Area	Seed Size	Yield
	(g)	(m^2)	(seeds/g)	(seeds/m^2)	(g)	(m^2)	(seeds/g)	(seeds/m^2)	(g)	(m^2)	(seeds/g)	(seeds/m^2)
Achillea millefolium	5,736.4	323.7	8,065	142,922	8,616.7	324.0	6,073	161,510	1,244.6	323.7	8,865	34,086
Allium cernuum	72.1	1.4	313	16,115	4.9	1.4	363	1,282	2.4	2.3	381	399
Agrostis exarata	-	-	-	-	1,252.5	100.0	22,108	276,905	66.8	100.0	30,181	20,165
Anaphalis margaritacea	89.4	111.0	13,375	10,771	635.1	111.0	15,322	87,661	237.3	111.0	31,153	66,589
Arnica chamissonis	-	-	-	-	51.0	4.0	2,320	29,560	419.6	26.0	2,255	36,390
Arnica cordifolia	1.2	1.9	3,030	1,857	13.0	73.8	1,905	334	66.6	73.8	1,657	1,495
Aster conspicuus	-	-	-	-	336.5	97.9	2,144	7,370	133.8	97.9	2,708	3,701
Aster foliaceous	-	-	-	-	71.2	33.6	2,814	5,960	3.4	33.6	2,578	261
Bromus ciliatus	3,217.1	288.0	471	5,261	32,344.2	288.0	340	38,184	6,524.4	288.0	604	13,683
Calamagrostis canadensis	-	-	-	-	1,810.8	130.0	9,115	126,965	156.4	130.0	24,370	29,323
Calamagrostis rubescens	250.5	87.2	9,500	27,295	2.3	2.9	9,500	7,469	0.5	2.9	7,191	1,226
Carex aenea	3,754.7	170.0	1,853	40,926	10,400.9	170.0	1,192	72,929	5,306.3	170.0	1,415	44,167
Carex macloviana	721.8	160.0	2,137	9,641	5,820.3	160.0	1,424	51,801	2,900.0	160.0	1,889	34,239
Carex mertensii	189.8	200.0	1,833	1,740	3,594.9	200.0	1,551	27,878	3,346.6	200.0	2,019	33,784
Collinsia parviflora	12.4	15.0	1,449	1,203	9,385.1	150.0	904	56,561	45.0	3.0	1,189	17,823
Dryas drummondii	1.9	64.6	1,837	53	357.3	64.6	1,837	10,161	326.5	64.6	2,244	11,341
Elymus glaucus	3,810.8	952.0	237	949	50,923.2	1,052.0	206	9,972	19,044.6	1,052.0	243	4,399
Elymus trachycaulus	1,969.4	421.0	423	1,979	14,034.4	421.0	370	12,334	7,084.2	421.0	351	5,906
Epilobium latifolium	0.1	22.3	13,004	58	9.7	22.3	13,004	5,665	27.4	22.3	8,165	10,017
Festuca occidentalis	1,803.6	80.8	2,702	60,312	11,425.5	80.8	2,441	345,169	4,715.0	41.0	3,736	429,644
Festuca saximontana	-	-	-	-	936.0	100.0	531	4,970	2,830.5	100.0	2,130	60,290
Geum macrophyllum	214.4	53.9	1,879	7,476	381.8	53.9	4,229	29,953	2,339.6	83.0	2,576	72,613
Leymus innovatus	1.1	57.1	842	16	502.5	57.1	555	4,884	661.8	57.1	545	6,316
Lupinus arcticus	254.7	453.0	98	55	2,308.5	453.0	121	617	663.8	453.0	110	161
Lupinus polyphyllus	1,507.7	422.0	94	336	968.3	421.1	140	322	3,952.0	421.1	80	751
Luzula parviflora	8.6	67.1	8,591	1,100	4.2	67.1	4,254	267	36.9	67.1	5,879	3,235
Poa alpina	416.5	109.0	3,576	13,664	390.3	109.0	2,995	10,725	2,043.0	109.0	2,844	53,305
Polemonium pulcherrimum	-	-	-	-	40.6	60.0	1,144	775	586.3	60.0	1,123	10,973
Trisetum spicatum	-	-	-	-	379.7	100.0	6,352	24,122	911.6	100.0	5,514	50,268
Vicia americana	155.5	78.5	66	131	374.0	78.5	62	295	35.8	78.5	74	34

- plants benefit from a high nitrogen fertilizer in their establishment year (to promote growth), and a fertilizer with higher ratios of potassium and phosphorus in all subsequent years (to promote seed production);
- frequent inspection of plots is needed to identify and address weed problems, and to track crop progress in terms of health and maturation;
- working with high-diversity multi-lineal seed lines means that plants will often be of different statures or different ripening times, which can make harvesting difficult; frequent clipping or seed-stripping can address this issue, but growing multiple plots of different source-identified populations may be more feasible;
- species differ in their lifespan, with seed productivity in most species peaking in their second, third or fourth years (see Table 6), so a program of regular stand replacement and rotation is needed.

A separate set of "seed-production plots" was established on land owned by the Canadian Forest Service and by private land owners who are acting as contract growers of the seed lines developed in this research project. These plots were set up to evaluate different depths and densities of seed, using different carriers to facilitate drill seeding using standard farm equipment. Though funding for monitoring these trials was not forthcoming, we have noted the importance of very shallow and very early (preferably late fall) sowing. By the end of research funding, we had 7 contract growers signed up, and a total of 728 m^2 producing a crop this year, another 8,954 m^2 sown, 16,200 m^2 scheduled for sowing this year, and another 12,100 m^2 undergoing weed control in preparation for sowing next year.

Population Genetics of *Elymus glaucus*

Bryan Ie completed his M.Sc. degree at U.B.C. in 2000, based (in part) upon his investigation of the population genetics of some of our collections. He evaluated morphological measurements on 18 populations of *Elymus glaucus* in our seed-increase plot, and correlated results with electrophoretic measurements from plant material of the same accessions. He detected significant population differences in the wild accessions, and concluded that most seed is produced through selfing, though there can be up to 50% outcrossing (Ie 2000).

> "Isozymes and morphological traits were used to study 40 *Elymus glaucus* populations located within British Columbia. F_{st} values, based upon 21 isozyme loci, were high (0.65) suggesting that species' diversity is predominantly distributed between rather than within populations. Q_{st} analysis, an index analogous to F_{st}, was used to describe population differentiation of the morphological traits measured. Continuous traits displayed an average Q_{st}^{c} of 0.80 while the discontinuous trait mean Q_{st}^{d} was 0.44. It seems that the distribution of diversity follows the same trend set by isozyme distributions in that morphological diversity of this native grass species is partitioned between rather than within populations. F_{is} and F_{it} estimates showed a deficiency of heterozygote individuals. This may be due to inbreeding, a colonization effect, or a recent evolutionary bottleneck. Mating system analysis of three Vancouver Island populations suggests that outcrossing does occur within *Elymus glaucus*. The distribution of *Elymus glaucus* populations seems characteristic of species undergoing metapopulation dynamics. This observation is supported by its high F_{st}, low geographic structuring (isolation by distance), and the patchiness of its environment."
>
> [from the Abstract of Bryan Ie's (2000) thesis]

Despite widespread promotion of the opportunity among plant geneticists and breeders across North America, we were not successful in recruiting additional researchers to study genetic variation in our common garden and among generations of plants. A "select" line of *Elymus glaucus* is being developed by our own staff, with a new plot grown from seed taken from plants meeting the following criteria:

- plants free of ergot, rust, and insect pests;
- seeds of uniform size and ripeness;
- greater than average size of seed head (measured in terms of length and overall robustness); and
- unbent, erect stalks of medium (1.2 to 1.5 m) height.

The seed produced by this plot will be further selected and grown out for one more generation, and then registration as cultivated variety will be sought. This seed will then be more uniform than our standard multi-lineal seed line for *Elymus glaucus*, and can be commercially grown and sold in response to interest from farmers and ranchers.

Seed Cleaning

Our final recommendations for seed cleaning procedures and specifications are given in Table 7. These specifications may be quite detailed and accurate for our particular equipment, but will not translate exactly to other machinery. As in all seed cleaning operations, operator acuity and discretion are needed to make suitable adjustments to keep as much seed and reject as much trash and non-crop seeds as possible. Most seed was run through a fanning mill (air and sieve machine) and a vacuum aspirator (Figure 5). We were generally successful in retaining >95% of crop seeds in the cleaning process, and had zero tolerance for weed seeds. Screenings containing a small amount of crop seed (and no weed seed) were also retained for donation to local restoration projects. Species not covered in Table 7 were generally harvested in very small quantities or did not require cleaning. We have not been successful in finding or devising suitable equipment for fully "de-bearding" or "de-fluffing" seeds with awns, achenes or other appendages. The tendency of these seeds to cling to each other and to hang up on machinery makes it more difficult to use mechanical methods for sowing and harvesting them.

Table 7. Methods and specifications for mechanized seed cleaning, 1999 crop.

	Threshing		Fanning Mill				Vacuum Separator	
Species	Concave Spacing	Speed	Top Screen		Bottom Screen		Air Flow	Comments/Finishing
	(mm)	(rpm)	(shape)	(size, mm)	(shape)	(size, mm)	(setting)	
Achillea millefolium	6.0	885	slot	1.8 x 12.7	slot	1.2 x 7.1	low	1.4 mm hand screen
Agrostis exarata	3.0	1850	slot	1.2 x 7.1	slot	1.8 x 12.7	not used	fanning mill in 2 steps
			square	1.5	slot	1.2 x 7.1		1 mm hand screen
Anaphalis margaritacea	1.0	1850	slot	1.2 x 7.1	slot	1.8 x 12.7	not used	2x thru mill; 0.5 mm hand screen
			square	0.5	slot	1.8 x 12.7		
Aster conspicuus	3.0	1241	slot	1.8 x 12.7	slot	2.5 x 19	not used	vacuum while rubbing top screen
Aster foliaceous	3.0	1241	slot	1.2 x 7.1	slot	2.5 x 19	not used	
Bromus ciliatus	6.0	1241	slot	2.5 x 19	slot	1.2 x 7.1	not used	2 times through fanning mill
Calamagrostis canadensis	1.0	1548	slot	4 x 19	round	4.89		fluff balls up, must rub apart
Carex aenea	6.0	1850	slot	1.8 x 12.7	slot	1.2 x 7.1	medium	2 times through fanning mill
Carex macloviana	4.0	1548	round	4.89	square	2.83	not used	fanning mill in 2 steps
			square	2.36	square	0.5		
Carex mertensii	just used rotary flail		slot	4 x 19	slot	2.5 x 19	low	fanning mill in 2 steps
			slot	2.5 x 19	slot	1.8 x 12.7		
Collinsia parviflora	1.0 - 2.0	1850	slot	1.8 x 12.7	square	1.2	medium	
Dryas drummondii	1.0 - 2.0	1850	slot	1.2 x 7.1	slot	1.8 x 12.7	not used	ran through thresher 12x to de-fluff
Elymus glaucus	10.0	1548	slot	2.5 x 19	slot	1.2 x 7.1	nr. high	2 times through fanning mill
Elymus trachycaulus	just used rotary flail		slot	1.8 x 12.7	slot	2.5 x 19	not used	much seed salvaged during curing
Festuca occidentalis	just used rotary flail		slot	2.5 x 19	slot	1.8 x 12.7	not used	fanning mill in 2 steps
			slot	1.2 x 7.1	slot	1.8 x 12.7		
Festuca saximontana	just used rotary flail		slot	1.2 x 7.1	slot	1.8 x 12.7	not used	
Elymus innovatus	just used rotary flail		slot	2.5 x 19	slot	4 x 19	not used	
Lupinus arcticus	4.0	1241	round	4.89	square	1.2	not used	4 mm square hand screen
Lupinus polyphyllus	5.5	885	round	4.89	square	1.2	not used	2 times through thresher
Poa alpina	6.0	1850	slot	2.1 x 25.4	slot	1.8 x 12.7	not used	
Polemonium pulcherrimum	3.0	1241	slot	1.2 x 7.1	square	1.5	high	
Trisetum spicatum	1.0 - 2.0	1850	slot	1.2 x 7.1	slot	1.8 x 12.7	not used	
Vicia americana	3.0	1241	slot	4 x 19	round	4.89	high	

Figure 5. Symbios employee, Adam Hossack, with seed cleaning equipment: a (above) fanning mill; b (right) vacuum aspirator.

Field Seeding Trials

As indicated in Table 1, a substantial program of field trials was established and monitored annually. In general, some native species can establish density and cover as effectively as agronomic species, though the native species are often slower to establish and grow. Comparisons of the density of seedlings with the nominal density sown in each subplot helps identify the most suitable species for use in operational revegetation activites. Table 8 shows our evaluation of seedling emergence (actually, the net density of seedlings to germinate, emerge, and survive their first one or two summers) in 1998 and 1999.

Table 8. Results of field trial monitoring interpreted in terms of emergence rates for each species.

	1998			1999			2-Year Average
	Plots	Emergence		Plots	Emergence		Emergence
Species	Sampled	Mean*	S.E.	Sampled	Mean*	S.E.	Mean
	n	%	%	n	%	%	%
Native Species							
Achillea millefolium	58	3.8	0.9	120	13.0	2.1	8.4
Anaphalis margaritacea	51	0.7	0.2	103	1.9	0.4	1.3
Arnica cordifolia	9	0.0	0.0	17	0.0	0.0	0.0
Bromus ciliatus	25	10.2	10.2	30	7.3	3.5	8.7
Calamagrostis rubescens	-	-	-	12	0.5	1.5	0.5
Carex aenea	49	0.5	0.2	96	1.4	0.4	0.9
Carex macloviana	-	-	-	18	0.8	0.4	0.8
Carex mertensii	39	1.4	0.8	96	1.9	0.7	1.6
Dryas drummondii	6	0.8	0.7	9	0.1	0.1	0.5
Elymus glaucus	61	16.7	4.3	110	25.1	8.6	20.9
Elymus trachycaulus	2	0.0	0.0	22	8.4	3.1	4.2
Festuca occidentalis	55	10.8	2.5	113	16.0	1.7	13.4
Geum macrophyllum	2	0.0	0.0	67	5.6	2.2	2.8
Lupinus arcticus	47	3.0	0.8	82	2.7	0.4	2.8
Lupinus polyphyllus	20	5.0	0.8	33	5.5	0.5	5.3
Luzula parviflora	8	0.0	0.0	10	2.0	2.0	1.0
Poa alpina	-	-	-	24	8.0	2.1	8.0
Vicia americana	8	0.0	0.0	30	0.0	0.0	0.0
Agronomic Species							
Lolium multiflorum	-	-	-	9	1.0	0.5	1.0
Phleum pratense	6	3.7	1.2	6	4.1	1.3	3.9
Trifolium hybridum	12	9.4	1.6	12	13.4	1.8	11.4

-- = insuffcient data PLS = pure live seed
* Mean seedling density divided by the approximate density of PLS sown.

Some strong species differences in species establishment under field conditions are evident. There was no (*Arnica cordifolia*, *Vicia americana*) or $\leq$1% (*Calamagrostis rubescens*, *Carex aenea*, *Carex macloviana*, *Dryas drummondii*, *Luzula parviflora*) average emergence for many of the species we tested (Table 8), despite the fact that they were successfully germinated under laboratory and greenhouse conditions. In contrast, several species had $\geq$8% average emergence: *Elymus glaucus* (20.9%), *Festuca occidentalis* (13.4%), *Bromus ciliatus* (8.7%), *Achillea millefolium* (8.4%), and *Poa alpina* (8.0%). Many of these species have emergence rates equal to or better than that of the three agronomic species (*Lolium multiflorum*, *Phleum pratense*, *Trifolium hybridum*) tested at the same time (Table 8).

Several of the treatment comparisons described in Table 1 were also evaluated for their effect on total sown plant cover after one and two years. Though treatments were often confounded or inadequately replicated among sites, some of the following conclusions were drawn:

- soil freshness, decompaction, or tillage is important in achieving revegetation success; surface raking (of road cuts, compacted landings or old running surfaces) alone is inadequate to loosen up the soil so it can serve as an effective seedbed;
- in particular, there is no point in sowing road cuts made into compacted glacial till unless suitable mulch and tackifier is used (i.e., usually by hydroseeding);
- higher seeding densities (up to several thousand PLS per m^2) seem to always be better in establishing as much shoot cover as possible; most of our early trials (established at 500 to 1000 total PLS/m^2) did not use enough seed;
- fall seeding (or actually "winter seeding," conducted in late September through October so that seeds don't germinate before snowfall) seems to promote better germination and seedling establishment than spring seeding, though this may be due to inability to get out on the land early enough in spring;
- the number of species in a mixture is not as important as the presence of some high-emergence species (Table 8) in assuring its rapid establishment and overall success;
- despite claims that native plants are typically low in their nutrient demands, fertilization of plots successfully promoted native plant cover, even in the presence of weeds;
- *Rhizobium* innoculation had no discernible effect on the cover or size of individual legumes, and most legumes appear to be naturally nodulated regardless; and
- mulches and cover crops seem ineffective in promoting native plant establishment or controlling weeds, though they may reduce erosional soil loss.

These results allowed a final set of three-factorial field trials to be designed with full geographical replication. In September of 1999, additional seeding density trials were established at five replicate industrial sites and one demonstration site (near our seed-increase plots) within our original seed collection area. These trials constitute the field component of Carla Burton's M.Sc. thesis currently under way at the University of Victoria. The purpose of these trials is to test different seeding densities and to compare the same densities with and without fertilizer. Identical treatments were installed adjacent to the first set of plots at the same sites in the spring of 2000, creating a three-factorial trial of 6 density x 2 fertilizer x 2 sowing time treatments.

At each site, a 75 m^2 area was divided into twelve 2.5 m x 2.5 m plots. A seed mix consisting of 20% *Elymus glaucus*, 20% *Achillea millefolium*, 20% *Festuca occidentalis* and 20% *Carex aeana*, 16% *Geum macrophyllum, and* 4% *Lupinus polyphyllus* (measured as pure live seed, PLS) was applied with and without fertilizer at six different densities. Seeding densities consisted of: control (0 PLS/m^2), 375 PLS/m^2, 750 PLS/m^2, 1500 PLS/m^s, 3000 PLS/m^2 and 6000 PLS/m^2. These densities were chosen based on literature suggesting that effective erosion control requires plant cover of more than 60% after the first growing season, at least three times greater than that observed in our preliminary field trials sown at an average rate of 561 PLS/ m^2. It is hypothesized that lower densities may be adequate if fertilization can coax more plant cover from a given density of seeds. Plots were rototilled to a depth of at least 10 cm before sowing. Fertilizer (18-18-18) was applied at a rate of 184.5 grams per plot, a rate consistent with agronomic applications and corresponding to 295 kg/ha or 53 kg N per ha. Plots were monitored for plant density and cover by species in August and September of 2000, and will be measured once again in 2001. Completed results of this three-factorial experiment will be useful in refining recommendations for sowing practices to be used in operational revegetation.

Preliminary results from the monitoring of this final set of field trials (those plots fall-seeded in 1999 only) clearly indicate that plant cover was greater where sown at higher densities, and this effect was more pronounced in the fertilized plots (Figure 6). In unfertilized plots, plant cover after approximately three months of growth remained relatively constant (12 ± 3%) across the range from 750 to 3000 PLS/m^2, and increased to an average of only 24% cover at the highest density tested (Figure 7). Fertilized plots, on the other hand, had 2.8 to 4.8 times the cover of unfertilized plots at all densities tested. Since commercial fertilizer is much less expensive to produce than large quantities of native plant seed, fertilizer application is strongly recommended at the time of sowing. We tentatively recommend sowing the tested seed mixture at 2000 PLS/m^2 with 18-18-18 fertilizer applied at 295 kg/ha in order to achieve 50% plant cover in the first season of growth.

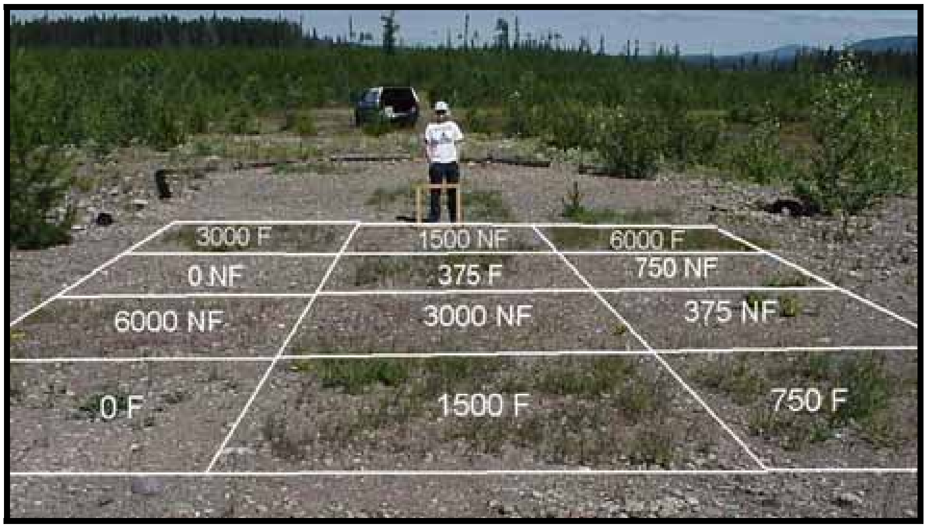

Figure 6. Seeding density x fertilization plots established by fall seeding at one of five locations in northwestern British Columbia, as seen in early August, 2000. The number shown for each 2.5m x 2.5m plot denotes the total seeding density in pure live seed (PLS) per m^2, while 'F' denotes fertilized (18-18-18 at 295 kg/ha) and 'NF' indicates non-fertilized plots.

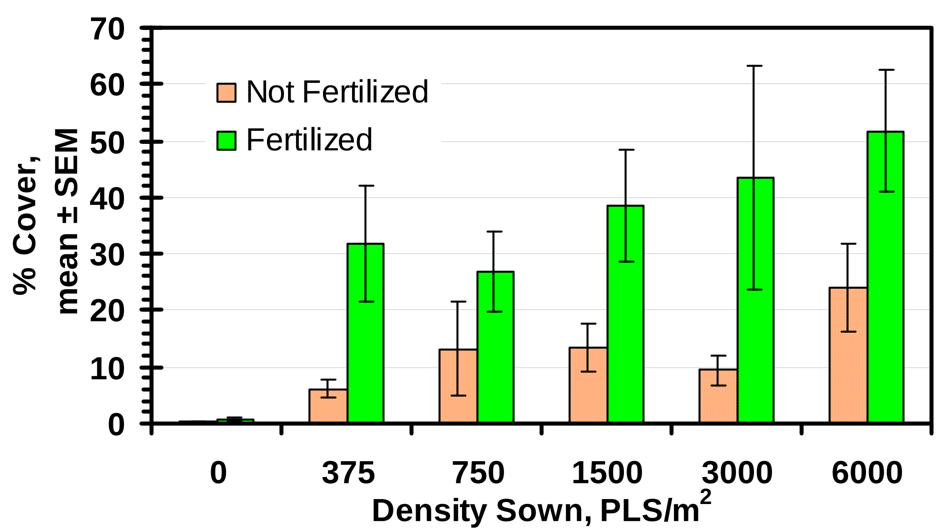

Figure 7. Early effects (mid-summer, 2000) of fertilizer on cover production at different fall-sown seed densities.

Extension Activities

We have been promoting this project and its applications regularly and broadly every year. These extension activities have included the following tangible deliverables and participatory activities:

- presentation and leading a field presciption exercise in a Workshop on Rehabilitation and Restoration sponsored by the Clearwater Forest District, 1996
- participation in problem analysis on degraded forest land, C. Bulmer and M Kranabetter (MoF), 1996
- large (80 x 60 cm) laminated information signs maintained at seed-increase plots, 1997-1999
- small (30 x 23 cm) laminated information signs maintained at field seeding trial plots, 1998-2000
- open house / field days hosted, with tours of seed-increase plots, field seeding trials and contract grower seed-production field, Sept. 1997, Sept. 1998 and Aug. 1999
- project was featured by the Skeena-Bulkley Region of FRBC in a news release, subsequently picked up and published as "Reclaiming the Soil With Native Plants" in Business Logger magazine (Nov. 1997), Business Farmer magazine (Dec. 1997) and Northwest Forest Digest (March 1998); see Appendix IIIB and IIIC
- "Making native plant seed available for mainstream land management" was published in the Spring 1998 (Vol. 3, No. 1) issue of Menziesia, the newsletter of the Native Plant Society of B.C.; see Appendix IIIA
- Presentation made to ER328, "Forest Restoration," class in the Restoration of Natural Systems Program at the University of Victoria, Feb. 1998
- Presentation made as part of the Natural Resources Research and Management Seminar Series, Northwest Community College, April 1998
- Presentation made at a workshop entitled "More Than Just Trees," Prince Rupert, Sept. 1998
- Poster displayed at the "Helping the Land Heal" conference in Victoria (Nov., 1998), and then again at the 1999 Interior Forest Site Rehabilitation Workshop in Kamloops (April, 1999), at a "Community Development Through Agroforestry Workshop" in Creston (April 1999), at the international meeting of the Society for Ecological Restoration (San Francisco, Sept., 1999), at a non-timber forest products workshop in Creston (May, 2000), an agroforestry workshop in Burns Lake (June 2000), and at Botany BC (July 2001);
- Article entitled "Native Plants for Restoration" published in British Columbia Environmental Report, Vol. 10, No. 1 (Spring 1999); see Appendix IIID
- Material from that poster display can also be viewed at our web site, http://www.bulkey.net/~symbios/native.html which has been up since late 1999
- Project featured in Synapse, newsletter of the Science Council of B.C. (Nov., 1999; Vol 5, No. 6)
- Byan Ie's M.Sc. thesis, "Reclaiming Disturbed Habitats Using Native Grasses: The Genetic Story of Elymus glaucus (Blue Wildrye)" was defended and deposited at the Unviversity of British Columbia (Feb. 2000)
- Preliminary results from the field testing of seed density x fertilization were presented as a poster at the annual meeting of the Society for Ecological Restoration, Liverpool, England (Sept. 2000)
- A condensed version of that poster has been published as a short article entitled "Fertilization can reduce the amount of seed needed to revegetate degraded soils (British Columbia)" in Ecological Restoration, Vol. 19, No. 1 (2001); see Appendix IIIE
- Presentations were made to the Bulkley Valley Farmer's Market Association and to the Bulkley Valley Farmer's Institute (Jan. and Feb., 2001)

- Sample packets of seeds with colour photographs and sowing instructions have been prepared for some of our more attractive wildflower species, and are being distributed as promotional items

In addition, we have distributed numerous handouts and species lists to a wide range of interested professional, technical, environmental and public groups in northern B.C. Most recently, we have conducted a market survey with more than 150 faxed questionnaires that also described our research program and the fact that native seed was now available for revegetation purposes.

Additional extension activities are in progress and will soon be complete. These include our manual for growing and using seeds from these native plants (Appendix I), Carla Burton's M.Sc. thesis at the University of Victoria (which is on the field density x fertilization x sowing-season trials), and two papers that are being prepared for publication in the refereed literature.

Discussion

Suitability of This Approach

The production of high-diversity seed from multi-lineal seed-increase plots modelled on conifer tree seed orchards has not, to our knowledge, been attempted for herbaceous species before. Based on the large number of accessions represented in our gardens (Table 2), and the good representation from a large geographical area (Appendix I), we believe we were successful in developing seed lines of high diversity and broad adaptability. We have not been able to test this using eletrophoretic or molecular genetics methods, and still intend to find grant funding to do so. Tests need to be done to identify the level of genetic variation within and among populations, within and among forest districts and biogeoclimatic zones, and between wild populations and our multi-lineal seed. Despite the great efforts made to protect and enhance genetic diversity in seed lines of these species, we must also recognize that these lines have still been subject to inadvertent selection. For example, all plants growing in seed-increase plots have been able to germinate from seeds with little or no pretreatment in a greenhouse environment. After two or three years of growing under the weather conditions prevailing in the Bulkley Valley, there may also have been some differential survival of plants derived from different locations, so the net diversity of the seeds now being produced is likely less than the diversity of accessions first planted.

We also have to question whether the great amount of work and meticulous record-keeping associated with our seed-increase plots was worth undertaking. In retrospect, it would have been easier, and perhaps just as effective to plant separate mini-plots of accessions from different locations. Plants therefore would have grown and matured more uniformly, and retained more population-based or ecotypic identity. Seed could have been harvested more easily as a result, and seed also could be cleaned and stored separately for eventual use in revegetation projects near the place of origin of the seed. On the other hand, seed from different accessions could still be mixed in preparation of a multi-lineal seed population (though it would not be the product of as much cross-breeding among populations). Such an approach might also address the concerns of purists who insist on only using "local" seed sources in restoration projects, though Burton et al. (1988) have argued that historic and impending climate fluctuations make local adaptation less important than a broad genetic base.

Efforts to maintain or generate high diversity seed also have to be weighed against the demand and alternatives currently, and potentially, existing within the operational revegetation committee. Even where native plants are desired (e.g., in B.C. provincial parks), there often seems to be little concern about the genetic origins of the plant material. While we might think such concerns should be taken more seriously, the fact is that off-the-shelf agronomic mixes will still be used if local or diverse seed is not available. In this context, the selection of native plant species to the degree that they can at least be grown efficiently in cultivation would seem to be appropriate. We have started to pursue this option in addition to the maintenance and increase of our high-diversity seed lines.

Species Suitability

As expected, most of the 31 species with which we were working are widely distributed over much of northern British Columbia (see range maps in the manual, Appendix I). Climatically and ecologically, it is therefore likely that our plants could be successfully used for revegetation activities anywhere in our study area. If concerned about artificially extending the range of a species, a restoration prescription for a given site might only include species known to occur in that vicinity or biogeoclimatic subzone. Even more restrictions could be placed on the use and distribution of the seed lines developed in this project so that they would be used only in the subzones from which they were originally derived.

Though we tested and grew more than 41 native plant species, and report on 31 species in our manual, future work will have to concentrate on only a subset of these. Based on germinability, ease of cultivation and seed handling, and effectiveness in revegetation trials, and alternative availability in stands from which seed could be collected from the wild, we think the following species are worth studying further for developing seed sources in cultivation: *Achillea millefolium*, *Arnica chamissonis*, *Aster conspicuus*, *Bromus ciliatus*, *Carex aenea*, *C. macloviana*, *C. mertensii*, *Elymus glaucus*, *E. trachycaulus*, *Festuca occidentalis*, *F. saximontana*, *Geum macrophyllum*, *Lupinus arcticus*, *L. polyphyllus*, *Poa alpina*, *Polemonium pulcherrimum*, and *Trisetum spicatum*. This means that another 14 species would be dropped from the seed production program (though existing seed will be kept refrigerated and available for interested researchers and growers) in an attempt to increase the yields and efficiencies associated with the remaining species.

Seed Growing Opportunities

The above set of 17 species can serve as the foundation for a productive and lucrative mini-industry in growing native plant seed for use in northern British Columbia. Unfortunately, there is no recent history or expertise in registered seed production in the Bulkley Valley, so growers will have to be guided through the standard procedures for stand establishment and weed control needed in all seed growing businesses. Several local farmers, vegetable growers, hobbyists and biologists have expressed interest in such an enterprise and are in various stages of growing some of these plants, or preparing sites to grow them in the near future. The importance of weed control cannot be over-emphasized: as many as two or three years extirpating weeds or other non-crop plants before trying to establish a seed-production field would save a lot of headaches. Some of the grasses may lend themselves to large-scale mechanical field sowing, harvesting and weed control, while most non-graminoid species will probably have to be grown, weeded and harvested by hand. Grasses and sedges can therefore be promoted within the farming community having appropriate machinery, while the asters, arnicas, lupines and other wildflower (non-graminoid) species lend themselves to production by hobbyists and market gardeners who are used to working gardens manually. If working on a small scale, it may still be more efficient for growers to establish stock in a greenhouse and then transplant seedlings out into rows. We now recommend single-row layouts to minimize the amount of land open to weed invasion and to facilitated regular tillage or mulching around the crop plants.

Symbios Research and Restoration is currently not able to fulfill most demands for native seed, demonstrating our effectiveness in conveying the knowledge that native plants are desirable and that we have been growing such seed in cultivation. We give priority to projects in parks and ecological reserves, as they have a mandate for which biological conservation is a greater priority than on most of the land base. Even in an area as unpopulated and wild as northern B.C., there is still great demand for and awareness of the desirability to use native plants for revegetation where circumstances will allow. For the foreseeable future, emphasis needs to be placed on boosting production to meet this demand and to maintain the wave of interest generated by this project and other efforts at promoting conservation biology and ecosystem restoration.

Using Native Plant Seed in the Field

Most lessons learned regarding the use of herbacous plant seed in revegetation activities also apply to agronomic seeding, but become doubly important because of the scarcity and expense of native seed. As noted in the Results, freshly exposed soil and fertilizer need to be recognized as important conditions for the successful establishment of a vigorous stand of grass and forb vegetation. Seed mixtures should consist of a "backbone" of large- and small-statured grasses, some species that will germinate very rapidly, at least one that will persist for many years, and some growthform diversity in the form of a legume or other non-graminoid species. Nitrogen-fixing species plants such as *Dryas*, *Lathyrus*, or *Lupinus* are especially valuable in building up soil nutrients, which may be desired to support tree growth. Disturbed areas can vary considerably in site conditions, so it is prudent to stretch seed supplies by prescribing only the most suitable sites for particular situations. For example, *Dryas drummondii*, *Epilobium latifolium* and *Lupinus arcticus* are all suitable for gravelly or cobbly sites, so long as water is available at depth. Moist sites that have better soils could support stands of *Elymus glaucus*, *Carex mertensii* and *Geum macrophllum*. *Lupinus polyphyllus* can do very well on fine textured soils. So every site requires its own revegetation prescription to most efficiently match species with the prevailing environmental conditions. Other land use concerns must also be considered. For example, there is much demand for native plants as an alternative to the use of timothy and clovers that attract bears to roadsides in the spring. Lupines should be used cautiously where cattle may be grazing, as there is still concern that some lupines may prove toxic to livestock.

We note that our recommended seeding rates are somewhat higher than often recommended in various manuals for roadside seeding and minespoil reclamation, though they agree well with operational practices. The basis for the determination of recommended seeding densities needs to be reviewed and tested in a more systematic manner. We seem to be hanging on to advice that has been handed down by word of mouth but comes from pasture or rangeland experience and is not so relevant to most forest disturbances in northern B.C.

The futility of dry-seeding road cuts became painfully obvious after several attempts. We have yet to test the application of our native seeds using hydroseeding technology, but hope to do so in the near future. Unfortunately, hydroseeding uses two to three times as much seed as is required with dry seeding, but the mulch and tackifiers that can only be applied in a slurry are essential to hold seed on a compacted sloping surface. It would therefore be appropriate to limit the use of hydroseeding only to sites where it is really needed. And because such sites are often few and small, it also would be desirable to devise a very small-scale hydroseeder, perhaps based on a gasoline-powered pressure washer fed from a 200 L drum in which the slurry is mixed.

Options for the more conscientious repair of industrial damage in B.C.'s forests will help us protect and restore the natural ecosystems that make our landscapes so productive, diverse and distinctive. The importance of proper ecosystem restoration, not just reforestation or revegetation (Burton 1999), is evident from a number of initiatives that have taken place in British Columbia during the course of this timely project:

- a conference was held in Victoria in 1998 entitled, "Helping the Land Heal: Ecological Restoration in British Columbia," with more than 400 participants;
- the NPSBC Native Plant Society of B.C. and the B.C. Chapter of the Society for Ecological Restoration were incorporated, with more than 150 members between them; and
- Forest Renewal B.C. initiated a Terrestrial Ecosystem Restoration Program (TERP) with the mandate to fund on-the-ground projects for the repair of terrestrial ecosystems damaged by forestry

The use of native plants for purposes of ecological restoration is central to all of these initiatives. Though native plant seed may still be expensive, the wheels are now turning for growing these plants on a commercial basis. High prices for native plant materials and ecosystem restoration also convey the real cost of callous and excessive disturbance. An emphasis on using native plants and restoring indigenous plant communities are important considerations in forest certification initiatives (especially that of the Forest Stewardship Council) and in global perceptions of B.C. forest management policies and practices. This project will help provide the materials, expertise and awareness needed to minimize and repair some of the ecological damage caused by industrial forestry. In addition, it provides some modest opportunities for agricultural diversification in northern British Columbia, a region where a creative economic opportunities need to be explored.

Summary and Conclusions

This project has successfully brought 31 herbaceous species from the northern Interior of British Columbia into cultivation, with preliminary information collected on another 10 species. Though only 10 to 20 of these species may lend themselves to further work for development of commercial seed supplies, samples of all species have been archived for future use. Working with multi-lineal, high diversity seed lines has proven very challenging because of record keeping requirements, and the difficulties in growing and harvesting crops having different statures and maturation times in a single field. Given that the species with which we have been working are all common pioneers of disturbed habitats, we suggest that the heroic efforts undertaken to conserve genetic diversity in these plants is probably not warranted at this time. More important is the development of mechanized agricultural techniques for successfully growing large quantities of seed in order to meet the demand for its use in northern B.C., especially for seeding the right-of-way of new logging roads. Work should continue on a wide number of species in order to provide revegetation options for a range of site types. Some of the more adaptable and easily grown species may lend themselves to selection and cultivar development.

Species evaluation was conducted through several years of germination testing, greenhouse propagation, seed production in seed-increase plots, and field testing in operational revegetation settings. Even without active selection for specific traits, species (or populations within species) that exhibit reliable germination in laboratory, greenhouse and field settings were more likely to have been retained in our program of research and development. Species which produce a large number of viable seeds, and with stands that remain productive for several years are also desirable, as are species with seeds that are easily harvested, cleaned and handled. Seedling emergence, growth and survival in the field also provided information on species potential for use in revegetating and restoring sites that are often devoid of topsoil. Based on these criteria, we heartily recommend the following species for follow-up research, commercial-scale seed production, and breeding for cultivar development:

Grasses:	*Bromus ciliatus*, *Elymus glaucus*, *Elymus trachycaulus*, *Festuca occidentalis*, *Festuca saximontana*, *Poa alpina*, *Trisetum spicatum*
Sedges:	*Carex aenea*, *Carex macloviana*, *Carex mertensii*
Legumes:	*Lupinus arcticus*, *Lupinus polyphyllus*
Other Forbs:	*Achillea millefolium*, *Arnica chamissonis*, *Aster conspicuus*, *Geum macrophyllum*, *Polemonium pulcherrimum*

The other 14 species on which we have compiled information can also produce seed in cultivation, and would be desirable for providing diversity in the plant materials employed for revegetation purposes. But these other species are difficult to grow or seeds are difficult to handle, so it might be more appropriate for them to be grown on a small scale by hobbyists, or seeds might just be collected from wild populations.

The biggest challenge in growing wild plants for their seed revolves around the control of weeds and the need to guarantee the origin and purity of any seed being sold. All growers and collectors of native plant seed need to be diligent in their exclusion of weeds and other non-crop contaminants. Practitioners using native plant seed must recognize that supplies will be rather limited for several years. As a result, native plant seed should be used efficiently (e.g., only on freshly disturbed soil, with fertilizer to generate more plant cover per plant) and where it is most needed (e.g., in parks and ecological reserves, critical habitats, etc.). In addition, a large education and extension campaign is needed to reduce excessive forest disturbance, and to point out that the purposeful spread of exotic plants into wild landscapes is an element of ecological degradation that need not continue.

Acknowledgements

This project could not have been successfully completed without a small army of supporters and staff. The financial support of Forest Renewal B.C. and the administrative services of the Science Council of B.C. are gratefully acknowledged. In particular, we would like to thank Teri Chanyungco, Brian Rehwald, Angus Mackay, and Nana Zolbrod for their flexibility and understanding as we did our best to jump through the hoops. The free use of land offered by our major partners was critical to this project getting off the ground: we thank Joe Wong (Woodmere Nursery Ltd.) and Rod Garbutt, Allison LaFortune and Elaine Teske of the Canadian Forest Service (Pacific Forestry Centre) for their generosity. Tom Duralia did yeoman service in pulling together a mass of literature and in compiling the herbarium records at the University of British Columbia (UBC). Other herbarium data were gathered with assistance from Al Mattes, Shawn Reed, Alan Ladd, Tashi Newman, Carmel Jorgensen, Emma Dooley, and Janet Marsh; we also thank the curatorial staff at the Museum of Nature, Agriculture and Agri-Food Canada, UBC, University of Victoria, the Royal B.C. Museum, the University of Northern British Columbia, and the Prince Rupert Forest Region for their assistance. We thank Tim Mullins, Brian Holl, Kermit Ritland and Bryan Ie for their assistance in evaluating genetic diversity and providing guidelines for plant breeding. Seed collecting was conducted with assistance from Paul Sanborn, Marty Kranabetter, David Coates, Elaine Wright, Sybille Haeussler, Peter Hellenius, Denise McGowan, Andrew Ellis, and Rod Negrave. Hours and hours, days and days, and weeks and weeks of plot maintenance and weed control were conducted with dedication and perseverance by Norm Aasland, Adam Hossack and Geoff Littler, with assistance from Shawn Reed, Sarah Sacharoff, Tashi Newman, Jessica Hall, Gabe Newman, John L'Orsa, James Hay, Taisa Jenne, Nicole L'Orsa, Kyle Peterson, Darren John, Tlell Glover, Rhiana Rasmussen, Blaine Estby, Julie McCord, Mora Cunningham, Shannon O'Neill, Mary-Ellen Tucker, Sam Skinner, Kate Butterfield, Bart Newman, Dave Percy, and Kevin Litke (and probably others we have missed!). Seed cleaning was mostly done by Adam Hossack. Laboratory measurements and testing was conducted by Shawn Reed, Gabe Newman and Adam Hossack. We appreciate the involvement of our first contract growers, Irene Ronalds, Leroy Taylor, and Allen Banner. Thanks to Ed Hinchliffe and Tim Toman for the use of agricultural machinery, Harry Oevering for tractor work, and to Dave Riendeau for agronomic advice. We also thank Russell Klassen for assistance in compiling biogeoclimatic relevé data and Dennis Rasmussen for preparing the range maps provided in the manual. We also thank the many supporters and volunteers who have demonstrated their support for this concept, for this project, and for the expanded use of native plants in management of B.C. forests.

References Cited

Anonymous. 1995. Biodiversity Guidebook (Forest Practices Code of British Columbia). B.C. Ministry of Forests and B.C Environment, Victoria, B.C. 99 p.

Anonymous. 1999. Vegetation management. B.C. Parks Conservation Management, Part One: Conservation Program Policies. Viewed September 12, 1999, at http://www.env.gov.bc.ca/bcparks/protect/epp_pl/vegman.htm

Association of Official Seed Analysis. 1985. Rules for testing seeds. Journal of Seed Technology 6: 1-118.

Bell, G.D., and A.M. Fletcher. 1978. Computer organised orchard layouts (COOL) based on the permutated neighbourhood design concept. Silvae Genetica 27: 223-225.

Burton, P.J. 1999. An assessment of silvicultural practices and forest policy in British Columbia from the perspective of restoration ecology. Pages 173 to 178 in B. Egan, editor. Helping the Land Heal: Ecological Restoration in British Columbia -- Conference Proceedings. B.C. Environmental Network Educational Foundation. Vancouver, B.C.

Burton, P., and C. Burton. 1999. Native plants for restoration. British Columbia Environmental Report 10(1):31.

Burton, P.J., K.R. Robertson, L.R. Iverson, and P.G. Risser. 1988. Use of resource partitioning and disturbance regimes in the design and management of restored prairies. Pages 46 to 86 in E.B. Allen, editor. The Reconstruction of Disturbed Arid Lands: An Ecological Approach. Westview Press, Boulder, Colorado, U.S.A.

Cody, W.J. 1996. Flora of the Yukon Territory. NRC Research Press, Ottawa. 643 p.

Coupé, R., C.A. Ray, A. Comeau, M.V. Ketcheson, and R.M. Annas. 1982. A Guide to Some Common Plants of the Skeena Area, British Columbia. Land Management Handbook Number 4, B.C. Ministry of Forests, Victoria, B.C. 215 p.

Douglas, G.W., G.B. Straley, and D. Meidinger. 1989-1994. The Vascular Plants of British Columbia, 4 volumes. Special Report Series 1-4, B.C. Ministry of Forests, Victoria.

Drinkwater, B. 1993. Grass and legume seeding. Pages 7-80 to 7-87 in A. Banner, W. Mackenzie, S. Haeussler, S. Thomson, J. Pojar, and R. Trowbridge. A Field Guide to Site Identification and Interpretation for the Prince Rupert Forest Region. Land Management Handbook Number 26, B.C. Ministry of Forests, Victoria, B.C.

Haeussler, S., D. Coates, and J. Mather. 1990. Autecology of Common Plants in British Columbia: A Literature Review. FRDA Report 158. Forestry Canada and B.C. Ministry of Forests, Victoria, B.C. 272 p.

Harker, D., S. Evans, M. Evans, and K. Harker. 1993. Landscape Restoration Handbook. Lewis Publishers, Ann Arbor, Michigan, USA. 98 p.

Hitchock, C.L., and A. Cronquist. 1973. Flora of the Pacific Northwest: An Illustrated Manual. University of Washington Press, Seattle, Washington, U.S.A. 730 p.

Hultén, E. 1968. Flora of Alaska and Neighboring Territories: A Manual of the Vascular Plants. Stanford University Press, Stanford, California, U.S.A. 1008 p.

Ie, B. 2000. Reclaiming Disturbed Habitats Using Native Grasses: The Genetic Story of *Elymus glaucus* (Blue Wildrye). University of British Columbia, Vancouver, B.C. 102 p.

McKinnon, A., J. Pojar, and R. Coupé, editors. 1992. Plants of Northern British Columbia. Lone Pine Publishing, Edmonton, Alberta. 352 p.

Morgan, J.P., and D.R. Collicutt. 1994. Seed stripper harvesters: efficient tools for prairie restoration. Restoration and Management Notes 12(1): 51-54.

Small, E., and P.M. Catling. 2000. Canadian Medicinal Crops. NRC Press, Ottawa, Ontario.

Pahl, M.D., and A. Smreciu. 1999. Growing Native Plants of Western Canada: Common Grasses and Wildflowers. Alberta Agriculture, Food and Rural Development and Alberta Research Council. Edmonton, Alberta. 118 p.

Porsild, A.E., C.R. Harington, and G.A. Mulligan. 1967. Lupinus arcticus Wats. grown from seeds of Pleistocene Age. Science 158: 113-114.

Rose, R., C.E.C. Chachulski, and D.L. Haase. 1998. Propagation of Pacific Northwest Native Plants. Oregon State University Press, Corvallis, Oregon, U.S.A. 248 p.

Smith, S.R. and S. Smith. 2000. Native Grass Seed Production Manual (Including Selected Forbs). Ducks Unlimited Canada, Oak Hammock Marsh, Manitoba 155 p.

Vitousek, P.M. Biological invasions and ecosystem properties: can species make a difference? Pages 163 to 176 in H.A. Mooney and J.A. Drake, editors. Ecology of Biological Invasions of North America and Hawaii. Springer-Verlag, New York, USA.

Warwick, S.I., and L. Black. 1982. The biology of Canadian weeds. 52. *Achillea millefolium* L. s.l. Canadian Journal of Plant Science 62: 163-182.

Appendices

Appendix I. A Manual for Growing and Using Seed from Several Herbaceous Plants Native to the Northern Interior of British Columbia [extracts]

Appendix II. Complete Literature Reviews of the Biology of *Elymus glaucus* and *Lupinus arcticus*

Appendix III. Some extension products:

Appendix IIIA. "Making native plant seed available..." (Menziesia)

Appendix IIIB. "Native plants for soil reclamation" (Business Farmer)

Appendix IIIC. "Reclaiming the soil with native plants" (Northwest Forest Digest)

Appendix IIID. "Native Plants for Restoration" (British Columbia Environmental Report)

Appendix IIIE. "Fertilization can reduce the amount of seed needed..."(Ecological Restoration)