

**THE PROGRESSION OF NATIVE SPECIES ISLAND ESTABLISHMENT
AND MONITORING PRACTICES ON HIGH-ELEVATION WASTE ROCK DUMPS
AT QUINTETTE OPERATING CORPORATION**

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ABSTRACT

Few agronomic species are able to establish and persist on high-elevation disturbances. Consequently, a native species island establishment program was started at Quintette Operating Corporation to ensure that the short- and long-term reclamation objectives outlined in Quintette's reclamation permit were met. Islands have been established almost every year since the program began in 1991. The species established, the methods of establishment, and monitoring procedures employed have changed over the years. The objective of this paper is to describe the evolving native species island program and to discuss the results of the program to date.

INTRODUCTION

Quintette Operating Corporation's reclamation permit C-156 states "... native species islands in the Mesa/Wolverine area shall be established and the land revegetated to either a self-sustaining state or to a state where the ecological succession of native species islands will lead to achievement of the approved land-use capability within 20 years."

The native species island colonization model focuses on the establishment of islands or patches of native plants that provide seed that will disperse to adjacent areas thereby expanding the size of the original island and possibly creating new distant islands from the original islands (Smyth 1996, Bittman 1997). Similar programs have been proposed or developed at other mines in the world (Scherer and Everett 1998) but not for high-elevation mine disturbances.

The following text describes the evolving island establishment practices and the performance monitoring program.

ISLAND ESTABLISHMENT

As part of Quintette's reclamation program, production and transplanting of native species has been undertaken since 1991. The island establishment program has evolved since its beginnings, and these changes are documented below.

Species Selection

As a result of research since 1991, Quintette developed a list of approximately 80 candidate species for the native island program. These included grasses, sedges, forbs, shrubs, and trees. This list was reduced to 30 species in 2000 after a review of the native species list. Criteria for selections were based on ecosystem restoration functions such as addition of soil structure, organic matter, and nitrogen; wildlife forage value, and ease of seed collection and plant establishment. Table 1 shows the current native species list with ecosystem restoration functions.

NURSERY PRODUCTION

Seed Collection

Seed for native species is collected from areas adjacent to the minesite. This process begins in August and continues until October. Equipment such as gas powered vacuums and Seed Strippers™ is used where appropriate to shorten collection times. The seed collection process has been simplified with a reduction in the number of species required, but still takes considerable time.

Processing of seed takes place after drying. Mechanical preparation such as screening is used for most species, and some species require blending or crushing of the seed pods to liberate the seed. Berry species are blended with water to remove the pulp, then dried.

Table 1. Native species and ecosystem restoration functions.

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Scientific Name	Common Name	Ecosystem Restoration Function								
		Below Ground Function			Above Ground Function					
		Soil Structure	Soil Organic Matter	Soil Nitrogen	Structural Diversity	Wildlife Forage				
Roots	Foliage					Flowers	Fruit	Seeds		
Grasses										
<i>Agropyron caninum</i>	Violet Wheatgrass	✓	✓				✓			
<i>Carex haydeniana</i>	Hayden's Sedge	✓	✓				✓			
<i>Carex mertensii</i>	Merten's Sedge	✓	✓				✓			
<i>Festuca brachyphylla</i>	Alpine Fescue	✓	✓				✓			
<i>Festuca saximontana</i>	Mountain Fescue	✓	✓				✓			
<i>Poa alpina</i>	Alpine Bluegrass	✓	✓				✓			
<i>Poa arctica</i>	Arctic Bluegrass	✓	✓				✓			
<i>Poa glauca (pattersonii)</i>	Glaucous Bluegrass	✓	✓				✓			
Forbs										
<i>Achillea millefolium</i>	Yarrow	✓					✓		✓	
<i>Artemesia norvegica</i>	Northern Wormwood	✓					✓			
<i>Astragalus alpinus</i>	Alpine Milkvetch			✓				✓		
<i>Epilobium angustifolium</i>	Fireweed	✓					✓		✓	
<i>Hedysarum alpinum</i>	Alpine Sweetvetch	✓		✓		✓		✓		
<i>Heracleum lanatum</i>	Cow Parsnip	✓					✓			
<i>Oxytropis podocarpa</i>	Stalked-pod Crazyweed	✓		✓				✓		✓
<i>Oxytropis sericea</i>	Silky Locoweed	✓		✓				✓		✓
<i>Oxytropis splendens</i>	Showy Locoweed	✓		✓				✓		✓
Shrubs										
<i>Alnus incana (sinuata)</i>	Mountain Alder	✓		✓	✓					
<i>Arctostaphylos uva ursi*</i>	Kinnikinnick	✓			✓				✓	
<i>Betula nana (glandulosa)</i>	Scrub (Bog) Birch	✓			✓			✓		
<i>Dryas integrifolia</i>	Entire-leaved Avens			✓						
<i>Eleagnus commutata</i>	Wolf Willow	✓		✓	✓		✓			
<i>Ribes hudsonianum</i>	Northern Black Current	✓			✓				✓	
<i>Ribes lacustre*</i>	Swamp Currant	✓			✓				✓	
<i>Rosa acicularis*</i>	Prickly Rose	✓			✓				✓	
<i>Rubus idaeus*</i>	Red Raspberry	✓			✓				✓	
<i>Salix arctica</i>	Arctic Willow	✓			✓			✓		
<i>Salix planifolia</i>	Tea-leaved Willow	✓			✓		✓			
<i>Vaccinium membranaceum*</i>	Black Huckleberry	✓			✓				✓	
Trees										
<i>Larix laricina</i>	Tamarack				✓					
<i>Picea engelmannii</i>	Engelmann Spruce				✓		✓			
<i>Pinus contorta</i>	Lodgepole Pine				✓		✓			
<i>Populus balsamifera</i>	Balsam Poplar				✓		✓			
<i>Populus tremuloides</i>	Trembling Aspen				✓		✓			

Pretreatment of Seed

Many of the species require pretreatment of the seed prior to sowing. This includes mechanical scarification, warm and/or cold stratification, and acid scarification for some of the berry species. After a literature review of pretreatments, trials were run to find the optimum method for each species. These treatments are tested on each seed lot before the seed is used in the nursery, to minimize germination problems.

Nursery Techniques

The native species program began with research at the mine's greenhouse facilities. The mine's facilities were used until the mid-1990's when staff reductions necessitated a switch to a local contract nursery. The techniques developed at Quintette are used at the contract nursery, with fine tuning over the years. Quintette personnel work closely with the contractor to ensure that the objectives are met.

Containers and Growing Medium

Spencer-Lemaire Hillson Roottrainers™ are used as the standard containers. These containers have a 170 ml capacity, and are arranged in "books" of 4 cells. The book can be opened up to inspect the root development. The basic growing medium is standardized at: peat based planting mix (Pro-mix™) 50%, perlite 25%, and vermiculite 25%. Once this basic formulation has been mixed, additions are made depending on the species. The most important addition is native soil, which serves as a source of symbionts such as mycorrhizal fungi and nitrogen fixing bacteria. This is collected from locations near the mine and added at 10% to 15% of the blend. Since this native soil contains unknown quantities of symbionts, its effectiveness varies. A study of nursery plants in 2001 indicated that using the native soil inoculum produced plants with 30% to 70% colonization of roots by mycorrhizal fungi. To improve the colonization rate, a commercial mycorrhizal product has also been used in the blend starting in 2002, to ensure that all plants would become colonized.

The pH of the planting mix is adjusted using dolomite lime at roughly 4% of the blend. The target pH ranges from 5 for acid-loving species such as *Vaccinium* to 8 for *Dryas*. The mix is tested during blending to ensure that the target pH is achieved.

A slow release coated fertilizer (Nutricote™ 14-14-14) is added at 3% of the blend. This supplies a steady nutrient feed to the plants. Release of this fertilizer occurs over 100 days at 25° C, so that at ambient temperatures, it provides a portion of the plant's nutrients for the entire growing season.

Sowing, Fertilizing, and Growth

After pretreatment, seeds are sown into the container cells. The number of seeds sown per cell is governed by the germination rate found during testing of that lot, and is typically 5 to 10. Some species with comparatively lower germination rates, such as the berries, are started in germination flats and the germinants are transplanted to containers. This avoids the problem of too many empty cells.

Fertilizing typically begins at the 2 leaf stage. The standard fertilizer regime is 20-20-20 soluble fertilizer at 500 mg/l, applied twice weekly. Low concentrations of fertilizer are used because of the possibility of inhibiting mycorrhizal fungi colonization (excess P) and nitrogen fixing bacteria colonization (excess N). This fertilizer regime is used until mid August when the plants are hardened off. Watering without fertilizer is done daily as required.

Hardening Off

The plants are hardened off in August. Fertilizing is tapered off, ending in mid-August. Watering is reduced to every second day. In the past, significant mortality was experienced during hardening off, and is thought to be a result of under-watering. Close monitoring of the moisture in the containers is important.

Determination of "Plantability"

The most important factor governing survival of the nursery plant after outplanting is adequate root development. After hardening off at the nursery, roots are checked, and only those with a well developed root mass are selected for transplanting. Stock with poor root development are overwintered and allowed to grow for another season. Since overwintering adds to the final cost of the plant, the focus of the nursery program is to produce as much stock as possible that is plantable after one growing season. Some shrub species normally take two growing seasons to reach plantable size.

TRANSPLANTING

Island Location Selection and Size

Determining locations for the native islands starts with consideration of the size and shape of the disturbed area. Areas nearer to the center of the disturbance are optimum locations for the islands, since natural invasion by native plants progresses inwards from the edges. Island locations are chosen with wildlife habitat re-creation in mind. Moisture distribution is perhaps the most important factor in siting islands. Areas subject to drying winds are particularly difficult to establish islands on, although subsequent expansion of the islands into these areas is possible.

The native islands planted in the early 1990's were relatively small. The success of these islands led to an expansion of the program. Table 2 lists the native species transplanted by year. The challenge was to increase both the number of islands as well as the size of each island. It was thought that planting large numbers of individuals on a grid, such as in conifer reforestation, would be successful in covering a larger area than planting in clusters. This proved not to be the case. It was found that pollination efficiency was increased by clustering the plants. Current practice is to plant in islands of several hundred individuals, with the species mix tailored to the site. Individuals of each species are clustered, and native legumes are included in each island for their nitrogen fixing capability.

Table 2. High Elevation Native Transplants By Year

Year	Number of Transplants
1992	3346
1993	4568
1994	11,473
1995	9213
1996	14,581
1997	18,588
1998	18,000
1999	24,704
2000	8,716
2001	0 *
Total	113,189

*switch from fall to spring planting

Site Preparation and Transplant Timing

Initial practice was to plant the islands into areas where agronomic vegetation had been established for at least two years. This approach made sense from the standpoint of the "conditioning" that the waste rock material receives from the agronomic grasses, but competition proved detrimental to island establishment. The solution was to rip closely spaced trenches with a dozer or grader. This discourages agronomic competition, loosens compacted material, and provides a microsite for the plant that is somewhat sheltered from the wind.

Initial large scale plantings were done in the fall after the plants had become dormant. It was noted that after the winter, some of the plugs were "frost-popped", with high mortality. To guard against the frost-popping concerns, it was decided to switch to planting in the spring. The plant then has the first growing season to anchor itself into the medium.

Diagnosis of Transplant Mortality

Due to the harsh climate and generally nutrient-poor soils of the minesite, a certain amount of mortality is expected. Mortality in the smaller islands was reasonable, but as the program increased in size, some survival problems were encountered. High mortality in the large scale plantings was difficult to diagnose, since it could have been a result of improper hardening off, insufficiently developed nursery stock, and/or planting techniques.

Hardening off techniques were changed from limiting water to giving the plants adequate water, reducing the risk of overdrying the plants. An overwintering site at roughly the same elevation as the plants' destination was selected to more closely imitate natural conditions. Only plants with adequate root development are selected for planting; the remainder are grown for another season.

The early small scale islands were planted by mine staff who had raised the nursery stock. The larger programs employed tree planting contractors. Use of contractors is thought to have contributed to planting quality problems, since the contractor was paid on a per plant basis, and even a native plant with well developed roots is much more fragile than a forestry seedling. In addition, inadequate site preparation at some islands made quality planting difficult. The current preference is to use salaried staff who understand the unique requirements of native plants.

Direct Seeding of Islands

Most of the species selected for the native island program can be established by direct seeding. While this method requires more seed and takes longer to produce adult plants, it complements the transplant program. Grass species are particularly suited to this method of establishment, and numerous suitable native species are available commercially. Currently both grass and forb direct seed islands have been established, and their role has increased with the larger number of native islands needed since mine closure. A pot trial of native forb species growing in mine waste rock in 2001 confirmed that adequate populations of *Rhizobium* bacteria are present in waste rock to allow natural inoculation of legumes.

Site preparation for the direct seed islands includes ripping to discourage agronomic competition and loosen the compacted areas. The seed is broadcast and lightly raked to cover it, and 6-8-6 organic fertilizer is applied. Most direct seeding is done in the fall.

PROGRAM PERFORMANCE - MONITORING

Monitoring of native plant translocation and establishment programs is essential (Hyder et al. 1995, Elzinga et al. 1998) and is implicit in the C-156 permit regarding native species islands. The general objectives of the performance monitoring program are to monitor the persistence and expansion of established islands and to record the establishment of new natural islands. The following text describes the assessment results of the first year of the island monitoring program.

A subset of the islands that have been established were monitored in 2001. The selection criteria included slope, slope position, aspect, elevation, landform, parent material, management treatments, establishment age and proximity to undisturbed areas. In the future, islands, in addition to those monitored in 2001 will be selected from an updated list of island locations. Reconnaissance observations of native species establishment along the margins of the mining disturbance footprint will be recorded as well.

Sampling Procedures

Microplots located systematically along transects and reconnaissance macroplots were established and permanently marked with rebar. The vegetation data collected at each island included species percent over, vigor, reproductive activity (flowers and seed heads) and wildlife utilization. Plant density data at

each island was obtained by counting or estimating the total number of individuals in the microplots and then determining the extent of the area in which plants were represented. The extent of the area was determined by locating the centre of each island and then systematically walking the surrounding area to estimate visually the extent of the plants. For the reconnaissance plots, the entire island was used as a macroplot to estimate species cover and to describe the habitat while Daubenmire microplots were used to estimate plant density.

Environmental (habitat) data was recorded for each island. Numeric functional status codes were assigned as well as alphabetic non-functional descriptors. Coding for species distribution, recruitment abundance, island status/function and non-functioning descriptions are provided in Tables 3 to 6.

Data Analysis and Summarization

Data collected was entered into a Microsoft Excel spreadsheet for graphing and analysis. The assessment of the monitoring data focused on exploratory data analysis using graphs to describe trends or patterns in the data.

Table 3. Plant distribution code.

Code	Number of Plants	Description
1	1	Rare individual, single occurrence
2	2-5	A few sporadically occurring individuals
3	1 patch (<25% of plot)	A single patch or clump of a species
4	>6	Several sporadically occurring individuals
5	2-5 patches	A few patches or clumps of a species
6	> 6 patches, each <25% of plot	Several well-spaced patches or clumps
7	Many	Continuous uniform occurrence of well-spaced individuals
8	Many	Continuous occurrence of a species with few gaps in the distribution of well-spaced individuals
9	Many	Continuous dense occurrence of a species

Monitoring Results and Discussion

A total of 57 islands were selected based on the criteria described in the methods section. Four of the long-term (>5 years old) islands on the Wolverine South 1850m, Wolverine North 1765m, PI 1630m and the P2 1765m dumps were selected for the establishment of transect sampling. Reconnaissance-level samples were established for the remaining 53 islands. Islands representing a range of establishment years were selected. Islands established in 1994 and 1998 were omitted because location coordinates were not available. Islands from 1994 and 1998 will be sampled once the locations of these islands have

been determined. Data describing the status/functioning and expansion of the islands were collected and is presented and described in the following text and figures.

Table 4. Island / patch functional status.

Code	Description
1	Excellent
2	Good
3	Fair
4	Poor
5	Non-functional

Table 5. Non-functional island / patch coding description.

Code	Description
a	poor species selection
b	poor transplant establishment
c	low population density
d	low species diversity
e	nutrient stress
f	agronomic competition
g	lack of pollinators
h	low reproductive activity (vegetative and sexual)
i	no or low recruitment
j	diseased plants
k	insect damage
l	excessive browsing
m	coarse-textured soil
n	exposed habitat
o	soil compaction
p	soil erosion
q	deflation
r	corrasion
s	root exposure
t	dense litter mat

Table 6. Seedling recruitment abundance.

Code	Density Class
0	0
1	1 - 5
2	6 - 10
3	11 - 25
4	26 - 50
5	51 - 75
6	76 - 100
7	101 - 250
8	251 - 500
9	501 - 750
10	751 - 1000
11	1001 - 1500
12	> 1500

Total cover by island was collected and then aggregated by year (Figure 1). The mean total cover values are highest for the islands established in 1997 and lowest for those established in 2000. Mean cover within years is relatively constant except for 1999. The variability in cover recorded for the islands established in this year is attributed to the heterogeneity of the sites in which the islands were established in 1999. The high cover value recorded in 1997 is attributed to the fact that the islands were situated in areas of high agronomic cover.

The mean number of species versus establishment year is illustrated in Figure 2. The number of surviving species declined from 1992 to 1999 but increased in 2000. The decline is attributed to a decrease in the number of species used in the islands and nursery stock quality and transplant establishment problems during this time period. The higher species richness values recorded in 2000 illustrate that corrections to these problems have already been made.

Grasses are the primary contributors to species richness for the majority of the establishment years although the proportion of forbs is higher in 1996 and 2000. Shrubs typically comprise a small, but very important, component of the islands.

The mean number of individuals is highest for the islands established in 1992 and 2000 and lowest for the islands established in 1999 (Figure 3). The variability in the number of individuals present in the 1992 islands is attributed to site heterogeneity primarily and to the size of the island established secondarily. The mean for the 1992 islands was 155 while that of the 1999 islands was 8. Interpretation of the data is confounded by the fact that the size of the islands was greater in 1992 than in 1999.

Figure 1. Total cover.

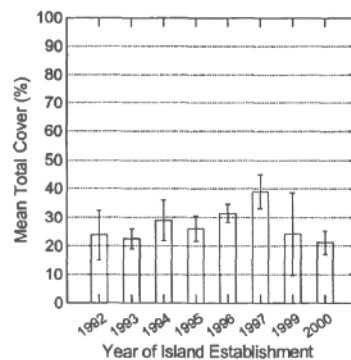


Figure 2. Species richness.

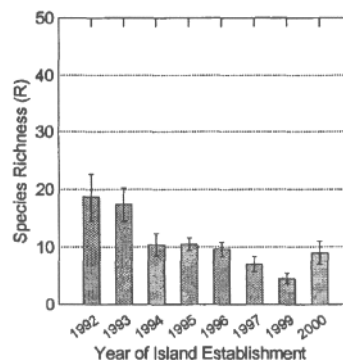


Figure 3. Number of individuals.

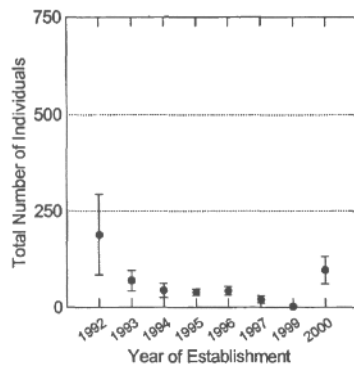
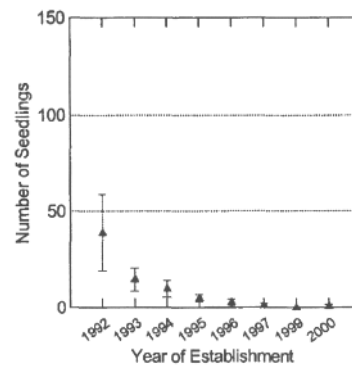


Figure 4. Seedling recruitment.



Seedling recruitment is highest in the islands established in 1992 and lowest in the islands established between 1996 and 2000 (Figure 4). This observation was expected since it typically takes a number of years for the plants to establish reproductive activity leading to seedling recruitment.

In 2001, the percentage of individuals producing seeds was greater than or equal to 60 percent in each of the establishment years except for the islands established in 1997. The lower values in 1997 are attributed to the type of species planted and the habitats in which these islands are located.

Assessment of native plant species performance is based on frequency of occurrence and density, vigor, flowering, seedling recruitment and range expansion. In general, shrubs typically have good vigor but have not produced seedlings. The best performing shrub is scrub birch (*Betula nana*). The size or stature of the shrubs will need to increase before the individual plants will begin seed production. Most of the grasses have produced viable seed, as indicated by the presence of numerous seedlings. The best performing grass species are alpine bluegrass (*Poa alpina*), alpine fescue (*Festuca brachyphylla*), and timberline bluegrass (*Poa glauca*). Several forbs are performing well consistently, the most notable of which are alpine milkvetch (*Astragalus alpinus*), Bering's chickweed (*Cerastium beringianum*), boreal sandwort (*Minuartia rubella*), Indian milkvetch (*Astragalus aboriginum*), showy locoweed (*Oxytropis splendens*), purple milkvetch (*Astragalus agrestis*) and yarrow (*Achillea millefolium*).

Island expansion is greatest at the islands established in 1992. The maximum expansion distance is 500 metres.

The functional status of islands established in 1992 and 1993 is excellent or fair while those established in 1995, 1996 and 1997 are classified as fair to poor. The islands established in 1999 are classified as poor or non-functional while those established in 2000 are classified as fair. The major reasons for a less than optimal functional status are low population density, agronomic competition, and low species diversity. Poor transplant establishment is a common reason in islands established in recent years while several of the older islands have been subjected to heavy grazing pressure by marmots (*Marmota caligatd*). Grazing pressure has reduced their reproductive capacity and, therefore, functional status. Several of the islands are inserted within dense swards of agronomic grasses. The agronomic species are excluding competitively the native species at present, and the thick thatches of litter are preventing native species seedling recruitment.

SUMMARY

Island Establishment

The list of native species used at Quintette has been trimmed from a selection of approximately 80 candidates to the current list of 30 species. Criteria for selections were based on ecosystem restoration functions such as addition of soil building, wildlife forage value, and ease of seed collection and plant establishment.

Nursery production of transplants has evolved from research and small scale production to larger programs. Techniques have been standardized and refined over the years to yield quality stock. The biggest factor in determining whether the stock will have good survival after outplanting is root development.

The strategy of planting timing has changed from the former method of placing islands into areas where agronomic vegetation has been established two or more years. Currently, islands are placed into areas that have recently been seeded with agronomics, and the areas are ripped with a dozer or grader to discourage agronomic competition and provide planting microsites. Fall planting has largely been replaced by spring planting.

Most of the species selected for the native island program can be established by direct seeding. Both grass and forb direct seed islands have been established. Grass species are particularly suited to this method of establishment, and numerous suitable native species are available commercially.

Island Monitoring

Several questions were posed as part of the objectives of the monitoring program.

(1) Are the islands expanding in size, and are the species established initially still present? The answer to this question is conditional in that several of the islands are expanding currently while a number of them are not. The islands that are expanding at greater rates are doing so because of the good initial establishment and subsequent recruitment of species with high expansion capacity. The rate of island expansion is also related to site conditions such as exposure and mineral soil quality as well as biotic-controlled conditions such as the availability of biological space for seedling recruitment. Typically, if the seedlings are able to survive the initial transplant shock, they will persist. Poor survivorship (persistence), where present, appears to be related to nursery stock quality, i.e., poor root development, soil compaction that results in frost heaving, and inappropriate transplant establishment timing.

(2) Are all of the species established initially persisting and expanding their range? If not, which species are the most effective in expansion? How far have the perimeters of the islands expanded? Most of the species established are persisting, but some are more efficient at expanding their ranges. Island expansion ranges from 1 to 500 metres, but the average range expansion distance is only 25 metres. However, a number of the islands have not expanded, and the mean value of 25 metres is derived from a skewed distribution influenced by a few islands with high expansion distances. Although difficult to predict, many of the islands rated as good, but which have not expanded to date, should begin to expand within 5 years.

(3) Are the native species showing signs of nutrient stress? Are the plants producing viable seeds? If there are problems, what are the appropriate management practices to implement? The answer to the first question is no; only the accompanying agronomic species appear to be showing signs of nutrient stress. The answer to the second question is that the evidence of range expansion by many of the species indicates that the established plants are producing viable seeds.

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