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THE UNIVERSITY OF ALBERTA

REVEGETATION TRIALS ON A SIMULATED PIPELINE TRENCH USING SELECTED NATIVE PLANT SPECIES, FORT NORMAN, NWT

BY

© LYNN ANNE MASLEN

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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OF MASTER OF SCIENCE

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EDMONTON, ALBERTA
FALL, 1989

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled REVEGETATION TRIALS ON A SIMULATED PIPELINE TRENCH USING SELECTED NATIVE PLANT SPECIES, FORT NORMAN, NWT submitted by LYNN ANNE MASLEN in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

G.P. Kershaw

Supervisor

Date August 21, 1989

ABSTRACT

Revegetation experiments were initiated on a simulated pipeline trench, located in a Subarctic *Picea mariana* forest, to evaluate the potential of selected native plant materials for use in Subarctic revegetation programmes. The following treatments were applied separately to exposed mineral soils: locally-collected seed of two herbaceous species and five shrub species, locally-collected *Epilobium angustifolium* rhizome cuttings, seed of three commercially-available native herbaceous species, and a commercially-available native grass seed mix. Each treatment was applied with and without fertilizer.

First-year results indicated that, except for *Carex membranacea*, which did not germinate, all herbaceous species established well and appear to have potential for revegetation, but only Alyeska polargrass produced sufficient cover and phytomass to be useful for short-term erosion control. Two shrub species, *Betula glandulosa* and *Ledum groenlandicum*, germinated and established well, and may be useful for revegetation depending on long-term success. Fertilizer increased the cover of all herbaceous species that established, but except for Alyeska polargrass, did not increase phytomass. Fertilizer did not affect the rate of native vascular plant invasion. Bryophytes responded positively to fertilizer application. In the first year, the native cultivars produced in other northern regions performed as well as, or better than, locally-collected herbaceous species.

Stem cuttings from six shrub species were planted and monitored over two growing seasons. *Salix arbusculoides* and *S. glauca*, had the best survival rate (47% and 53%, respectively) and are suitable for revegetation. *Vaccinium uliginosum*, *Betula glandulosa*, *Alnus crispa* and *Potentilla fruticosa* did not successfully establish. Fluvial erosion significantly reduced survival of all six species. Of the two *Salix* species, *S. glauca*, survived better in the first year when planted under a variety of conditions. Fertilizer did not affect first-year survival or growth of *Salix* cuttings. At the end of one growing season, no adverse effects were noted for *Salix* cuttings planted with a relatively slowly-establishing native grass seed mix. Several of the other slowly-establishing trial species have potential for seeding in conjunction with shrub cuttings. *S. glauca* cuttings collected from a previously disturbed site survived better than those collected from an undisturbed site.

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As one component of the broader SEEDS project, this study was only made possible through the enthusiasm and diligence of many, over the course of several years. The study greatly benefitted from this enormous team effort. I wish, therefore, to express my appreciation to all past and present SEEDSTERS for their individual contributions. Special thanks go to Kevin Evans,

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1. INTRODUCTION

In Canada, Subarctic ecosystems cover approximately 760,000 km^2, or 7.6% of the country (Zoltai *et al.* 1987). Over the past 2 decades, Canada's Subarctic has been the location of numerous large and small-scale industrial developments, resulting in widespread and varied terrain disturbances. Many new developments, including roads, pipelines and parks have been proposed for this region. An essential component in the reclaiming of these disturbed sites is re-establishment of a plant cover to provide site stabilization and promote recovery (Viereck 1982; Elliot *et al.* 1987). Revegetation programmes are commonly implemented for this purpose. Although the design of any revegetation programme is ultimately determined by project-specific conditions and goals, the short-term goals of most northern revegetation programmes are to control fluvial, aerial, and thermokarst-induced erosion. The more variable long-term goals include establishment of a stable and self-maintaining plant community, reduction of the visual impact of disturbance, re-establishment of wildlife habitat, and, sometimes, restoration to pre-disturbance conditions (Zasada and Epps 1976; Johnson and Van Cleve 1976; Johnson *et al.* 1987).

The extreme climatic and edaphic conditions characteristic of most Subarctic sites require innovative, site-specific approaches to revegetation (Johnson 1987) and extensive field testing of selected species (Densmore and Holmes 1987). The design of Subarctic revegetation programmes has typically followed two broad approaches: 1) the agronomic approach, modifying methods and species proven successful in more temperate regions of North America; and 2) the ecological approach, emphasizing the use of indigenous northern plant species well-adapted to natural analogs of human-induced disturbances (Johnson 1978; Johnson *et al.* 1987).

Early research indicated that selected agronomic species provided better erosion control, in the short-term, than the most promising native species. For this reason, revegetation treatments on mineral soils have typically involved fertilizer application and seeding of agronomic species to stabilize the soil. This method was predominant in the reclamation of both the Norman Wells and the trans-Alaska pipelines (Interprovincial Pipelines Ltd. 1983; Alexander and Van Cleve 1983). However, several studies in Subarctic environments have indicated that agronomic species require repeated fertilizer application to sustain their initial high cover values and growth rates (Younkin 1976; Bliss 1979; Kubanis 1980; Shaver *et al.* 1983; Younkin and Martens 1985; Johnson *et al.* 1987), and that the presence of agronomic varieties often retards or prohibits the invasion of native species (Owens and Van Eyk 1975; Bliss 1979; Kubanis 1982; Younkin and Martens 1985; Hardy BBT Ltd. 1987). Clearly, the use of agronomics can at times conflict with long-term revegetation goals.

Therefore, depending on site conditions, the ecological approach is now widely recommended for the Subarctic, even for the initial stages of revegetation programmes (Kubanis 1980; Brown and Berg 1980; Shaver *et al.* 1983; McKendrick *et al.* 1984; Elliot *et al.* 1987; Johnson 1987). The use of native species is considered to be more consistent with long-term revegetation goals. Since they are well-adapted to the climate and conditions of the region they should be better able to establish a self-sustaining plant community (Shaver *et al.* 1983; McKendrick *et al.* 1984; Vaartnou 1988) while minimizing the potential for such ecological problems as the introduction of disease and weeds (Chapin and Chapin 1980; Johnson 1987). Native species are aesthetically more desirable (Johnson 1987; Mitchell 1982), and their use allows for re-establishment of wildlife habitat (Densmore *et al.* 1987; Johnson 1987).

The broad objective of this study was to evaluate the potential of selected native plant materials for use in Subarctic boreal forest revegetation programmes. First and second-year results of this long-term study are presented in the following two chapters:

Chapter 2. Trial seeding of selected native plant species on a simulated pipeline trench.

Chapter 3. First and second year results of revegetation trials using selected native shrub cuttings.

Chapter 2 includes a documentation of the short-term establishment rate of selected local and commercially-available herbaceous and shrub species when seeded on exposed mineral soil, and includes discussion of their suitability for various types of revegetation programmes. The first-year effects of applying fertilizer are also discussed. Chapter 3 includes an evaluation of the relative ability of six shrub species to establish from stem cuttings, provide erosion control, and compete with seeded native species. Optimal planting techniques and the importance of ecotypic variation to revegetation success are also discussed. Results of several preliminary, supporting studies are presented in Appendices A, B and C.

Study Area

This study was one component of the SEEDS (Studies of the Environmental Effects of Disturbances in the Subarctic) project, a broader ecosystematic study of the effects of installing a simulated transport corridor and pipeline trench, and the relative merits of selected mitigation and reclamation treatments. The SEEDS site, located 10 km north of Fort Norman, NWT, (64°58'N., 125°36'W.) (Figure 1.1), is within the discontinuous permafrost zone (Brown 1978). Mean predisturbance active layer thickness at the site was 48 cm (Evans *et al.* 1988). The terrain has been mapped as a flat to gently sloping (2% to 5%) glacio-lacustrine and morainal plain with local hummocky relief (Reid 1974; Interprovincial Pipelines 1980).

The site is within an homogeneous stand of open subarctic forest, dominated by mature to decadent (>200 year-old), stunted *Picea mariana*; *Larix laricina* is also a common canopy species. Understorey vegetation is characterized by *Ledum groenlandicum*, *Salix myrtillifolia*, *Vaccinium vitis-ideae*, *Arctostaphylos rubra*, *Vaccinium uliginosum*, and *Empetrum nigrum*. Dominant non-vascular species are *Hylocomnium splendens*, *Aulacomnium palustre*, *Tomenthypnum nitens* and *Dicranum undulatum* (Kershaw 1987).

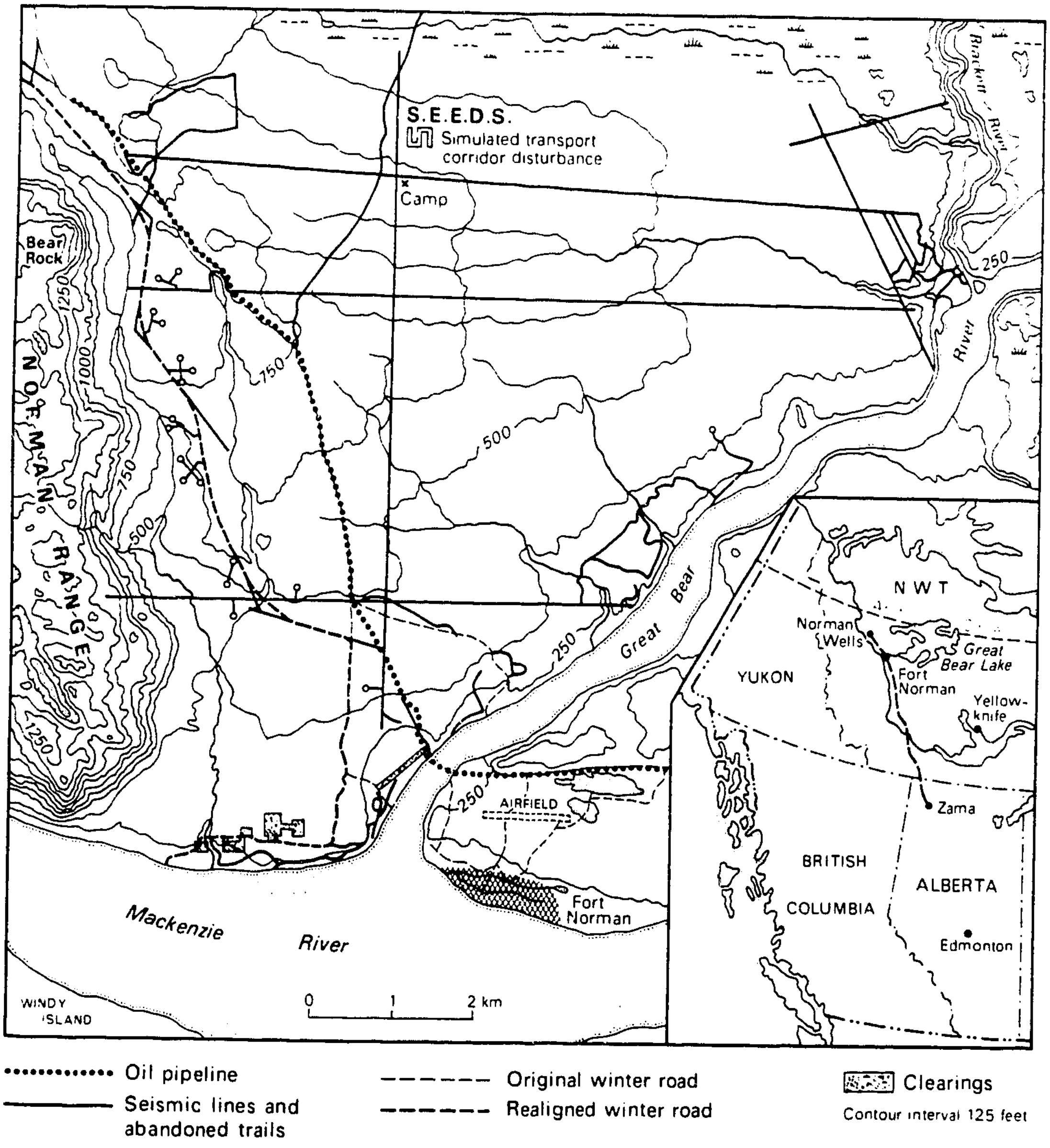

Figure 1.1 Location of the Studies of the Environmental Effects of Disturbances in the Subarctic (SEEDS) project Fort Norman, NWT.

Within this area, during the summers of 1985 and 1986, a 25 m-wide simulated pipeline right-of-way (ROW) was hand-cleared and a 2 m-wide simulated pipeline trench installed near the centre of the ROW (Figure 1.2). The trench was hand-excavated to an average depth of 50.7 cm and backfilled with the material that was originally excavated, resulting in complete alteration of the original soil profile, and random blending of the organic and mineral soils.

Prior to excavation, soil samples were taken every 5 m along the designated trench location. Soils were typically of a silt-loam texture and have been classified as Gleysolic Turbic Cryosols (Kershaw and Evans 1987). Five soil horizons were present: a fibric Of, a slightly decomposed Om, a discontinuous Bm, a gleyed and cryoturbated Cgy, and a perennially frozen Cz. Pre-disturbance soil conditions (moisture content, macro-nutrients and pH) were found to be highly variable throughout the site. The mean pH of each horizon increased with depth, ranging from 6.5 in the Of horizon to 7.2 in the Bmz horizon (Evans et al. 1988). Although post-excavation soil samples were not taken, the pre-excavation variability seen on the site was undoubtedly increased after excavation, due to mixing of the horizons.

Climatic records from the two nearest meteorological stations at Fort Norman and Norman Wells (80 km to the north) have identical mean annual temperatures of -6.3°C (Crowe 1970; Anon. 1982). At Norman Wells, mean annual precipitation is 321 mm, and the mean annual total growing degree days above 5.5°C is 890 (Burns 1973).

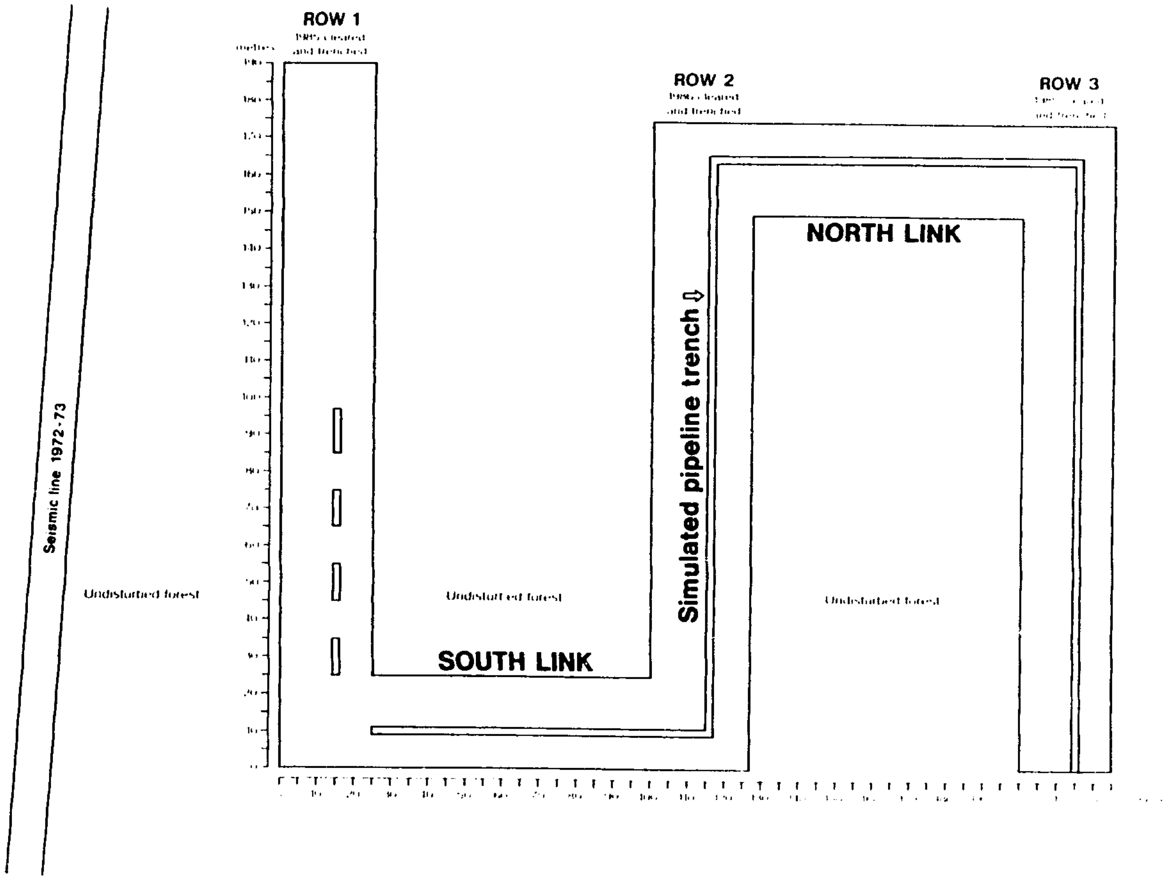

Figure 1.2 Simulated transport right-of-way (ROW), SEEDS, Fort Norman, NWT.

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2. TRIAL SEEDING OF SELECTED NATIVE PLANT SPECIES ON A SIMULATED PIPELINE TRENCH

INTRODUCTION

Depending on site characteristics and programme objectives, the use of native plant species in Subarctic revegetation programmes is often recommended (Berger 1977; Mitchell 1982; McKendrick *et al.* 1984; Elliot *et al.* 1987; Johnson 1987) but seldom implemented. Reasons cited for not using native species usually include the lack of commercially-available seed and the lack of species and techniques suitable for specific purposes (Bliss 1979; Brown *et al.* 1978; McKendrick *et al.* 1984; Elliot *et al.* 1987; Johnson 1987).

The problem of seed availability has been addressed by various experimental programmes, culminating in the release of several cultivars of northern plant species (Mitchell 1982; Miller *et al.* 1983; Wright 1989). However, these cultivars are limited in number and, for the present, must supply demands for use in areas characterized by Arctic, Subarctic, coastal and continental climates. Additional field testing is required to identify the range of conditions under which these cultivars will readily establish.

In the north, the most commonly used revegetation method is seeding and fertilizing. Although several plant species native to the Subarctic have been identified as suitable for seeding on disturbed soil (Younkin 1976; Chapin and Chapin 1980; Chapin and Shaver 1981; Mitchell 1987; Vaartnou 1988), the need to identify others remains because if native species are to be consistently used for revegetation in the Subarctic, species suitable for all types of revegetation requirements must be available. While several studies investigating the performance of seeded native species have been conducted in Canada's Western Subarctic (Bliss and Wein 1970; Hernandez 1973; Younkin 1973, 1976; Vaartnou 1982) most of these have focussed on pioneering herbaceous species to determine their ability to provide erosion control. The ability of shrubs to establish from seed on exposed mineral soil has received little attention, despite the fact that shrubs are an important component of northern communities. The inclusion of shrubs in revegetation seed mixes warrants further research.

Objectives

This study was designed to assess the potential of selected locally-occurring and commercially-available native herb and shrub species for use in Subarctic revegetation programmes. The approach taken was to sow locally-collected, and commercially-available species on a simulated pipeline trench located in the Subarctic boreal forest, to evaluate their ability to establish during the first growing season. As the merits of fertilizing when using native species are currently in question (Walker *et al.* 1987), the first-year effects of fertilizer application on seeded species and on natural colonization were also assessed.

The study had the following four objectives:

Objective 1: To determine whether selected shrub and herb species, native to the Subarctic boreal forest, are suitable for revegetation of exposed mineral soils in the Subarctic.

species during the first post-treatment season. Cover by all the other invading species combined ranged from 0.2% to 3.8% (Table 2-6), and was not affected by fertilizer application.

Phytomass

Phytomass (above-ground production) was estimated for those treatments where trial species achieved mean cover >1%. Except for the fertilized Alyeska polargrass, which produced greater standing crop ($P<0.05$) than any other trial species, phytomass did not differ among treatments (Table 2-7). Applying fertilizer with Alyeska polargrass resulted in a mean phytomass increase of 663%, relative to the unfertilized treatment. This was the only treatment where fertilizer affected above-ground production by the trial species. There was a strong trend toward increased above-ground production in the fertilized *E. angustifolium* treatment, however, production within the fertilized treatment was highly variable (mean ± SE:12.59 ± 20.54). A larger sample size (>10) may have shown a significant difference. Variation in phytomass was high for each trial species (Table 2-7).

Only two treatments, the fertilized Alyeska polargrass and the fertilized Decora Mix, differed from the control in total above-ground production, indicating an insignificant phytomass contribution by the trial species for all other treatments.

The two most productive invading vascular taxa were *Equisetum* spp. and *Epilobium angustifolium*, although they contributed less to total phytomass, than they did to total cover.

Table 2-7: Mean total above-ground dry weight (g m^{-2}) and mean above-ground dry weight (g m^{-2}) of trial species, *Equisetum* spp., *Epilobium angustifolium*, and other species, in each treatment, at the end of the first growing season.

TREATMENT		n	TOTAL (SD)	TRIAL SPECIES (SD)	*Equisetum* spp. (SD)	*Epilobium angustifolium* (SD)	ALL OTHER SPECIES (SD)
Arctagrostis latifolia var. Alyeska polargrass	F[1]	10	72.23 a (44.88)	68.38 a (45.85)	1.06 bc (1.82)	2.60 a (3.91)	0.18 a (0.40)
	UF[2]	10	17.68 bc (7.67)	10.32 b (6.15)	7.06 abc (7.89)	0.02 a (0.03)	0.29 a (0.44)
Arctagrostis latifolia Local	F	10	16.73 bc (9.01)	14.72 b (8.96)	0.10 c (0.09)	1.70 a (2.47)	0.21 a (0.28)
	UF	10	8.83 bc (4.55)	1.00 b (1.31)	7.78 ab (4.47)	0 b (0)	0.06 a (0.05)
Artemisia Tilesii & *Calamagrostis canadensis*	F	10	12.63 bc (8.52)	AT[4]-8.00 b (6.40) Cc[5]-3.41 b (3.65)	0.53 c (0.74)	0.50 a (0.84)	0.20 a (0.44)
	UF[2]	10	15.81 bc (8.95)	AT-6.82 b (6.39) Cc-4.86 b (5.60)	3.60 abc (3.94)	* a (0.03)	0.53 a (0.65)
Decora Mix[3]	F[1]	10	24.07 b (15.86)	22.02 b (14.66)	0.31 c (0.35)	1.71 a (2.74)	0.03 a (0.04)
	UF	10	8.07 bc (7.54)	4.98 b (6.84)	3.04 abc (2.95)	* a (0.03)	0.05 a (0.08)
Epilobium angustifolium	F	10	15.18 bc (20.81)	12.59 b (20.54)	0.10 c (0.08)	12.59 a (20.54)	0.14 a (0.35)
	UF	10	10.52 bc (14.69)	0.74 b (1.60)	9.34 a (13.11)	0.74 a (1.60)	0.36 a (0.81)
Control	UF	14	1.81 c (2.39)	--	1.68 bc (2.32)	0.02 a (0.03)	0.09 a (0.12)

[1] F-Fertilized [2] UF-Unfertilized

[4] *AT-Artemisia Tilesii*, [5] Cc-*Calamagrostis canadensis*

Means in the same column, with the same letters are not significantly different (P>0.05) for TMR test.

Equisetum was more abundant. *E. arvense* and *E. scirpoides* were not distinguished when harvested, however, since cover of *E. scirpoides* never exceeded 3%, it was assumed that most production by this genus can be attributed to *E. arvense*. Fertilizer did not affect the production of *Equisetum*. Compared to the remaining invading species, *E. angustifolium* was dominant in most plots, although it was never more important than the trial species (Table 2-7).

The contribution of all other invading species to above-ground production was minimal in all treatments, including the control (Table 2-7), indicating that during the first growing season, neither competition from the trial species nor fertilizer affected above-ground production of invading vascular species.

Density and Frequency

Density and frequency were assessed for the two trial species, *B. glandulosa* and *L. groenlandicum*, that had some seedling establishment but achieved cover <1%. First-year emergence was high in all treatments using these species (Table 2-8). The difference between the two species was not significant and fertilizer did not affect seedling density of either species. High standard deviations indicate that seedling distribution of both species was clumped, particularly for *L. groenlandicum*. Even with such high densities, a frequency of <100% was recorded for *L. groenlandicum* in the fertilized treatment (Table 2-8).

Table 2-8: Mean seedling density (seedling m^{-2}) and frequency, of species that achieved seeded cover values of 0.1 -1%.

TREATMENT		n	DENSITY (SD)	FREQUENCY (%)
Betula glandulosa				
	F[1]	12	316 a (271.0)	100
	UF[2]	12	252 a (218.5)	100
	Combined	24	284 a (243)	
Ledum groenlandicum				
	F	12	207 a (326.7)	83
	UF	12	459 a (390.5)	100
	Combined	24	333 a (374.9)	

[1] F-Fertilized, [2] UF-Unfertilized,
Means with the same letter are not significantly different (P>0.05) for TMR test.

Species Frequency According to Substrate Type

Trial Species

If trial species were found only on the treatments in which they were applied, their maximum frequency would be 9% on undisturbed fertilized substrates and 8% on undisturbed unfertilized substrates. Each of the trial species that established in their own treatments had frequencies exceeding these values on both types of undisturbed substrates (Table 2-9). Due to low expected frequencies on some substrates, chi-squared contingency tables were only possible for two trial species: *A. latifolia* and *L. groenlandicum.* *A. latifolia* was not associated with any particular substrate ($P>0.05$), however, *L. groenlandicum* was found most frequently on undisturbed substrates ($P<0.05$) (Table 2-9), whether fertilized or not. *E. angustifolium* was the only trial species that was ubiquitous on fertilized undisturbed substrate and nearly ubiquitous (77%) on unfertilized undisturbed substrates.

Invading Species

Thirty-two vascular species (other than trial species) and 2 nonvascular taxa (bryophytes and *Marchantium* spp.) invaded the revegetation plots through natural means (Table 2-9). The nonvascular taxa had higher frequencies on most substrates than most invading vascular species and all trial species. Mosses were ubiquitous on 3 substrate types and nearly so on the fourth (fertilized disturbed). *Marchantium* spp. was found more frequently ($P<0.001$) on fertilized than on unfertilized substrates (Table 2-9).

Table 2-9: Frequency (%) of species found on undisturbed (U) and disturbed (D) substrates in fertilized and unfertilized revegetation plots.

SPECIES	FERTILIZED PLOTS U n=22	FERTILIZED PLOTS D n=13	UNFERTILIZED PLOTS U n=26	UNFERTILIZED PLOTS D n=16	Chi-squared Contingency Test Conducted (+)
Trial Species					
Agropyron violaceum *	23	31	8	6	
Arctagrostis latifolia *	68	23	42	38	+
Artemisia Tilesii *	36	15	23	31	
Betula glandulosa *	14	8	38	13	
*Calamagrostis canadensis**	36	15	15	19	
Epilobium angustifolium *	100	69	77	13	
Festuca ovina *	32	23	35	31	
Ledum groenlandicum *	59 a	0	69 a	19 b	+
Poa alpina *	32	31	19	13	
Poa glauca *	36	31	19	19	
Invading Species					
Nonvascular					
Mosses *	100	92	100	100	
Marchantium spp. *	100 a	46 c	27 b	6	+

n=number of plots

*Species with frequency >30% in any one category.

Statistical test: One 2x4 Chi-squared Contingency Table for each treatment where expected frequencies allowed.

Frequencies in the same row with different letters are significantly different (P<0.05).

Table 2-9: continued

SPECIES	FERTILIZED PLOTS U n=22	 D n=13	UNFERTILIZED PLOTS U n=26	 D n=16	Chi-squared Contingency Test Conducted (+)
Invading Species					
Vascular					
Agrostis scabra	9	0	0	0	
Arctostaphylos rubra	5	0	12	6	
Capsella bursa-pastoris	9	0	4	0	
Carex spp. *	86	46	65	56	+
Epilobium glandulosum *	41	0	0	0	
Epilobium palustre	5	0	0	0	
*Eriophorum brachyantherum**	41	8	31	25	
Equisetum arvense *	36 a	0 b	85 c	81 c	+
Equisetum scirpoides *	100	85	96	88	
Grass (unidentified)	27	8	38	38	
Larix laricina *	23	0	31	13	
Parnassia spp.	5	0	0	0	
Pedicularis labradorica	0	0	4	0	
Phleum pratense	5	0	0	0	
Picea spp.	0	8	4	0	

n=number of plots
*Species with frequency >30% in any one category.
Statistical test: One 2x4 Chi-squared Contingency Table for each treatment where expected frequencies allowed.
Frequencies in the same row with different letters are significantly different ($P<0.05$).

Table 2-9: continued

	FERTILIZED PLOTS		UNFERTILIZED PLOTS		Chi-squared
	U	D	U	D	Contingency
SPECIES	n=22	n=13	n=26	n=16	Test Conducted (+)
Invading Species cont.					
Potentilla fruticosa	14	8	0	0	
Potentilla norvegica	0	0	4	0	
Pyrola spp.	5	0	8	0	
Ribes hudsonianum	27	8	0	0	
Ribes triste	5	0	0	0	
Rosa acicularis *	46 a	8 b	46 a	13 a	+
Rubus chameamorus	5	0	4	0	
Rumex arcticus	0	0	0	6	
Salix cotyledon *	100	85	92	75	
Salix arbusculoides	0	0	14	21	
Salix glauca	9	0	0	21	
Salix myrtillifolia *	55 a	8 b	58 a	6	+
Saussurea angustifolia	14	0	12	0	
Stellaria longipes s.lat.	5	0	0	7	
Taraxacum officinali	9	0	0	0	
Vaccinium uliginosum *	41 a	8	50 a	13 b	+
Vaccinium vitis-idaea *	27	23	46	0	
Non-living					
Mineral Soil	100	100	100	100	
Organic soil	100	67	100	56	

n=number of plots

*Species with frequency >30% in any one category.

Statistical test: One 2x4 Chi-squared Contingency Table for each treatment where expected frequencies allowed.

Frequencies in the same row with different letters are significantly different ($P<0.05$).

Chi-squared contingency tables were only possible for five of the invading vascular species (Table 2-9). *Carex* species were common invaders, found in similar frequencies on all four substrates ($P>0.05$). *Equisetum arvense* was strongly associated with unfertilized substrate, both disturbed and undisturbed ($P<0.001$). The presence of *Rosa acicularis* differed significantly among substrates ($P<0.05$). Although subdividing the table was not possible due to low expected frequencies, *Rosa* was equally frequent on both undisturbed substrates (46%). Therefore the significant difference appeared to be due to lower frequencies on disturbed substrates. *Vaccinium uliginosum* and *Salix myrtillifolia* were also more frequently associated with undisturbed substrates regardless of fertilizer application ($P<0.05$). The presence of all three shrubs was primarily due to resprouting from buried shoots or rhizomes as opposed to seedling establishment.

Although not tested statistically, several other invading species were noteworthy. *Equisetum scirpoides* was the most frequent of all the vascular species (Table 2-9) and occurrence appeared to be independent of substrate type.

Salix spp. cotyledons, which were not identified to species due to their immature state, were second in frequency only to *E. scirpoides*. These cotyledons were found with similar frequency on all types of substrate, with a trend toward lower frequencies on disturbed substrates (Table 2-9).

Epilobium glandulosum was only found on undisturbed fertilized substrates. *Ribes hudsonianum* was also found exclusively on the fertilized plots, but on both substrate types.

As expected, mineral soil was ubiquitous on all four types of substrates. Organic soil was always present on the undisturbed substrates but was less common on disturbed substrate. This difference, which could not be tested statistically, could account for some of the differences noted above.

DISCUSSION

Treatment Performance

The performance of fertilized Alyeska polargrass was superior to any of the other treatments. *A. latifolia* has long been recognized as having potential for revegetation purposes because of its ability to colonize exposed mineral soil unassisted (Klebesdel 1969; Hernandez 1973; Younkin 1973, Chapin and Shaver 1981; Vaartnou 1988). In the early 1970's, several studies using locally-produced seed were initiated in the Mackenzie Valley (at Norman Wells, Inuvik and Tuktoyaktuk) to investigate this potential (Hernandez 1973). Each study had similar results: cover on fertilized exposed mineral soil, after one growing season, was sporadic or less than 3%, but increased significantly after two growing seasons to as high as 67%, depending on site conditions (Hernandez 1973). Similarly, studies in abandoned borrow pits, in the Richardson Mountains, Yukon, recorded slow emergence rates for *A. latifolia*, but after four growing seasons, surviving plants were vigourous and producing seed (Vaartnou 1988).

The low first-year cover produced by the local *A. latifolia* in this study is consistent with previous studies. The superior performance of Alyeska polargrass indicates that selection through cultivation programmes has enhanced this species' ability to establish rapidly on exposed mineral soil. Even without fertilizer, Alyeska polargrass performed as well as fertilized local *A. latifolia*. However, results from the above studies, suggest that long-term performance of both varieties of *A. latifolia* will be favourable.

Each of the other treatments using cultivated species (or varieties) performed as well as, or better than, the local *A. latifolia*. *A. Tilesii*, *C. canadensis*, and the Decora Mix all germinated and established well but compared to Alyeska polargrass were slow to develop and produce significant cover and phytomass. Cover produced by the *A. Tilesii/C. canadensis* mix on undisturbed substrate was primarily comprised of *A. Tilesii*. Although this species is currently produced at seed farms, few studies have documented its performance. It is, however, a pioneering arctic-subarctic forb that occurs naturally in sandy, dry areas (Porsild and Cody 1980) and therefore, may not be well-suited to persisting on fine-grained, poorly-drained, mineral soils. In northern Alaska, *A. Tilesii* is a frequent invader on abandoned drilling pads (typically mesic substrates, comprised of silt, sand and gravel) (McKendrick 1987). In contrast, in interior Alaska, seeding of cultivated *A. Tilesii* on silt-loam soils, resulted in vigourous seedlings and 75% to 100% cover in one and two growing seasons (Alaska Plant Materials Center 1986). This is significantly higher than cover produced in this study and is possibly a function of different seeding rates (the rates used in the Alaskan study were not indicated), different germination conditions, or, the use of different ecotypes. Preliminary data therefore indicate that *A. Tilesii* also thrives on moist mineral soils.

Calamagrostis canadensis was also recognized in earlier studies as potentially useful in revegetation despite its slow initial growth rate (Klebesedal 1969; Hernandez 1973; Mitchell and McKendrick 1975, Younkin and Friesen 1974). First-year cover produced by *C. canadensis* (Sourdough bluejoint) in this study is consistent with first-year results obtained using local varieties on mineral soils at Inuvik, Tuktoyaktuk and Norman Wells, NWT (Hernandez 1973), and on gravel substrate in the Richardson Mountains, Yukon (Vaartnou 1988). It appears that cultivation of the variety Sourdough bluejoint has not increased its ability to establish rapidly on exposed mineral soil. The low first-year production by *C. canadensis* in this study, may be partly due to the presence of *A. Tilesii* in the same plots. Sourdough bluejoint is known to have low seedling vigour and does not compete well when sown in mixes containing more aggressive species (Mitchell 1982). Earlier studies, however, suggest that long-term performance will be successful. At Prudhoe Bay, Alaska and in the Inuvik-Tuktoyaktuk region of NWT, *C. canadensis* produced biomass and cover equal to, or greater than that produced by seeded agronomics after three growing seasons (Younkin and Friesen 1974; Mitchell and McKendrick 1975).

In this study, relatively poor performance by the Decora Seed Mix appeared to be due to the slow growth rate of *Agropyron* *violaceum* and *Festuca ovina.* However, Vaartnou (1988) considers *A. violaceum* to be a rapidly-establishing native species. He evaluated the short and long-term performance of all four of the species comprising the Decora Mix when seeded individually and fertilized in abandoned borrow pits in the Richardson Mountains, Yukon. In the year of seeding, all four species had 100% emergence, and were rated as having average to strong vigour. After seven growing seasons, *A. violaceum* survival had decreased to 33%, and seedlings were of poor vigour. However, the other three species retained survival rates of 100% (partially due to natural reseeding) and were classified as vigourous. Based on this, and the apparently successful seedling establishment by all four species in this study, second-year cover is expected to be significantly higher for each of the species comprising this mix, but long-term performance may only be favourable for *P. alpina, P. glauca,* and *F. ovina.* It is possible, however, that the different test substrate and growing conditions found at the SEEDS site, will result in significantly different long-term performance for each species. For example, *A. violaceum* may initially develop slower on moist, mineral soils but may ultimately survive longer.

Mitchell (1981, 1982) has worked extensively with *Poa glauca* in Alaska cultivating a commercially-available variety, Tundra Glaucous bluegrass, from material collected in Alaska's Arctic. This variety is not well adapted to wet areas, and is not recommended for use south of the treeline (Mitchell 1981). The provenance of the Alaskan variety used in the Decora Mix is not known, but if from the same stock, long-term performance of this species will likely be poor.

Transplanting and fertilizing *E. angustifolium* rhizomes was successful in accelerating the rate at which this species naturally colonized the trench. During subsequent years, *E. angustifolium* cover and phytomass, in the fertilized plots, is expected to continue to increase at a rate faster than in other plots because *E. angustifolium* establishes and develops faster by rhizomatous growth than by seed (Neiland 1978). Moreover, many of the new shoots produced by the rhizomes flowered during the first growing season providing another source of propagules in just one season. The unfertilized rhizomes were not successful, relative to other plots. Three explanations are possible: the rhizomes did not survive the transplant; they were eroded from the plot; or, the limited available nutrients were allocated primarily towards below-ground production, rather than production of new tillers. If the third explanation is correct, second-year production in these plots should be significantly better than in the untreated plots.

Although *B. glandulosa* and *L. groenlandicum* successfully established during the first growing season, seedling development of both species was slow. Both species germinated in growth chamber experiments (Appendix A), so some germination was expected. The high germination of *L. groenlandicum* conforms to results obtained in the growth chamber and in experiments conducted by Karlin and Bliss (1983). Conditions on the trench surface (moist soils and no shading) were ideal for *L. groenlandicum* seedling establishment, as described by Karlin and Bliss (1983). Germination rates of *B. glandulosa* on the trench was much higher than rates recorded in the growth chamber, however, it is common for germination and establishment rates observed in the field to differ from germination rates observed in laboratory tests (Harper *et al.* 1965; Gartner 1983).

The long-term success of *B. glandulosa* and *L. groenlandicum* is difficult to predict. Given the immature state of the seedlings, particularly for *L. groenlandicum*, high overwinter mortality is anticipated for both species. Due to their small size and slow development, *Ledum* seedlings growing in water-saturated substrates are highly susceptible to flooding and frost heave (Karlin and Bliss 1983); two phenomena characteristic of the trench surface. However, even if overwinter mortality is high, significant cover could still be achieved during subsequent growing seasons because of the high first-year densities of seedlings.

The inability of the other shrub species (*A. rubra*, *E. nigrum*, and *V. uliginosum)* to establish from seed appeared to be due to poor germination. Some seeds of each species were clearly visible on the plots in August, indicating that they had not all been lost to run-off. Germination rates in the field were consistent with the low rates obtained in growth chamber experiments (Appendix A). However, little or no germination in a lab does not indicate whether poor germinability is the result of seed dormancy or inviability. In Alaska, each of these species has been observed to naturally colonize exposed mineral soil from seed (Densmore 1979).

Furthermore, when applied untreated to mineral soil in the autumn, each species successfully germinated during the following first or second growing season (Densmore 1979). If the poor germination seen in this experiment was due to seed dormancy rather than inviability, it is possible that these species will germinate during the second growing season (Densmore 1979).

Although mature specimens of *Carex membranacea* were found on several plots, the *Carex* seeds used in this study did not germinate, either in the field or in the lab (Appendix A). Germination requirements for *C. membranacea* are not known.

Seed ripeness may also have affected the germination rates of all species. Although seed appeared to be ripe when harvested, some seeds may not have been. However, seed ripeness should have affected the performance of species in all plots equally because all seeds of one species were mixed together and seeds from each plot were randomly chosen from the homogenized samples.

Potential for Erosion Control

Species suitable for erosion control must be able to establish rapidly and root profusely during the first growing season. In permafrost-affected terrain, the amount of dry matter produced is important as it can contribute to the insulation of the soil surface (Viereck 1982), and so reduce soil heat flux (Rouse 1982). Vegetative cover will reduce the albedo of the exposed surface and eventually assist in stabilizing the permafrost table (Johnson 1978).

Roots are important as a means of physically stabilizing the substrate and reducing moisture content (Wishart 1988).

The poor performance of all trial species on disturbed substrate suggests that none of these species would be effective as initial stabilizing treatments in areas with high erosion potential. In such areas, (e.g. pipeline trenches or ice-rich slopes) engineering measures will likely be required for initial stabilization. Poor species performance was probably due to a combination of an inability to tolerate extreme conditions (such as standing water and shifting substrate) and loss of seed during spring run-off. Although it is impossible to determine which factor was more significant, the volume of surface run-off observed in the spring, suggests that seed loss was significant. If so, the performance of some species, such as Alyeska polargrass and Decora Seed Mix, may be improved by delaying seeding until after spring run-off. Surface flow was particularly heavy in some *Betula glandulosa* and *Ledum groenlandicum* plots. The high seedling densities recorded for these species suggest that reseeding after spring run-off successfully mitigated at least some seed loss. The mixture of *A. Tilesii/C. canadensis* is a promising candidate for use in these instances as it had the best performance on disturbed substrate.

Revegetation trials on the Norman Wells Pipeline right-of-way, indicated that a first-year cover of 18% was adequate for controlling erosion in most situations (Hardy BBT. Ltd. 1987). However, Younkin and Martens (1987) concluded that, where surface run-off is significant, in even gently sloping areas underlain by permafrost, 20% cover would often provide less than adequate erosion control; in many situations closer to 40% cover would likely be required. Using these criteria, fertilized Alyeska polargrass was the only one of the trial species (or varieties) that provided enough cover during the first growing season to adequately control erosion in areas with moderate to low erosion potential. Furthermore, the phytomass accumulated by this variety during the first year, will assist in reducing soil moisture content by transpiring water out of the soil column (Wishart 1988), and will contribute to stabilization of the soil thermal regime by increasing total plant cover, in the form of litter, the following year. Litter cover is an important criterion used to rate potential for erosion control (Younkin and Martens 1987). Phytomass produced by the other trial species was too low to contribute significantly to litter cover.

Alyeska polargrass has proven to be suitable for use in reclamation programmes in Alaska (Millar et al. 1983). First-year results from this study suggest that Alyeska is also suitable for use on permafrost-affected mineral soils in Canadian Subarctic forests.

The low above-ground production by all treatments except Alyeska polargrass may in part be due to phytomass sampling irrespective of substrate type. Standard deviations in above-ground production were high for each treatment indicating patchy distribution. The low cover recorded for all species on disturbed substrates, suggests that inclusion of disturbed substrate in phytomass sampling lowered the mean. The fertilized Alyeska polargrass was the only treatment where disturbed substrate was not present.

Revegetation Potential

True restoration (return of a site to its former undisturbed state) of a denuded area is probably an unattainable revegetation goal in the North, except perhaps in the long-term (>50 years) (Younkin and Martens 1987, Kershaw 1983). Revegetation programmes that work toward establishing a self-sustaining plant community comprised of native species or plant communities resembling those that establish naturally on disturbed soil, have more feasible long-term goals (Densmore and Holmes 1987). Species suitable for these purposes are not necessarily the same as those suitable for erosion control (Walker *et al.* 1987). Although suitable species must establish well, rapid development is not necessary. It is important that the seeded species either establish well and facilitate invasion of other native species, or that they comprise a long-term component of a relatively stable plant community (Cargill and Chapin 1987). If re-establishment of wildlife habitat is desired, the time required to establish cover and the amount and quality of forage produced are important considerations (Densmore *et al.* 1987).

Results here indicate that, providing their performance in subsequent years equals or surpasses performance during the first growing season, the following herbaceous species are suitable for use in revegetation of mineral soils with low erosion potential in the Subarctic boreal forest, because they will accelerate establishment of a native plant community: *A. latifolia* (local variety or Alyeska), species comprising the Decora Mix (particularly *Poa glauca* and *Poa alpina*), *C. canadensis*, and *A. Tilesii*. Cover could likely be improved during the first growing season for the Decora Mix, *C. canadensis* and *A. Tilesii*, by increasing seeding rates. Sourdough bluejoint, a proven revegetation candidate in Alaska (Miller *et al.* 1983), has maintained vigourous growth without fertilizer for up to 8 years (Mitchell 1981). However, mature stands of *C. canadensis* are highly resistant to invasion by other species, including trees and shrubs (McKendrick *et al.* 1984), and therefore may not be desirable for large scale restoration programmes unless grasses are the desired dominant component of the community.

Planting *E. angustifolium* rhizomes cuttings, in conjunction with fertilizer, has strong potential for accelerating the establishment of a species that would almost certainly colonize disturbed mineral soil naturally. This treatment achieved cover and phytomass equal to that of the fertilized *A. Tilesii/C. canadensis* and Decora Mix. Rhizome cuttings were easily collected and processed, and did not require any pre-treatment. However, on a large scale, using *Epilobium* rhizomes would be more labour intensive than seeding other species.

The ability of all these species to establish when applied with other native species should be investigated because first-year cover and phytomass (and therefore erosion control potential) might be increased by seeding the slower-establishing species as components of a seed mix.

The ability of *B. glandulosa* and *L. groenlandicum* to establish during the first growing season suggests that these species have potential for use in programmes where shrubs are a desired component of the long-term plant community. *B. glandulosa* appears to be especially promising due to its relatively rapid developmental rate.

The performance of *Betula* and *Ledum* when grown with other species should be investigated. Shade requirements of these seedlings and their ability to compete with other species will determine their suitability for inclusion in seed mixes. Seeds of both species are easily collected and require no pre-treatment beyond cold stratification (Densmore 1979), and *L. groenlandicum* may not require any pre-treatment (Karlin and Bliss 1983). The high densities achieved in the field suggest that using lower seeding rates (perhaps reduced by a third) may be possible for both species. Other shrubs tested are not suitable candidates for revegetation programmes due to pre-treatment requirements and unpredictable germination rates (Densmore 1979).

Effects of Fertilizer

Johnson's (1984) review of the effect of fertilizer on Alaskan tundra plants shows that, in general, fertilizing disturbed areas strongly affects species composition (increasing the abundance of high turn-over species and growth forms), but has little or no long-term effect on biomass. Therefore, applying fertilizer in these areas may be contrary to restoration goals. Revegetation recommendations for tundra terrain have included limiting or reducing the use of fertilizer whenever possible (Walker *et al.* 1987).

In this study, fertilizer had no effect on invading vascular species but seemed to stimulate growth of mosses on several plots. Since the presence of a dense moss mat can inhibit the establishment of some vascular plants (Walker *et al.* 1987), fertilizing could have an indirect negative effect on slowly-invading native species and may, therefore, be counterproductive to revegetation programmes (Johnson 1987). Although mosses did not exclude invading species during the first year of this study, competition may become apparent in later years. Therefore, when seeding native species, fertilizer should only be applied when it has a strong positive affect on the establishment rate of the seeded species, or when mosses are a desirable long-term component of the community. In Subarctic forests, re-establishment of moss cover can significantly minimize thaw depths and stabilize disturbed sites (Viereck 1982).

Although applying fertilizer resulted in increased cover for most germinating trial species, for many species, cover remained low in both fertilized and unfertilized treatments. With the exception of Alyeska polargrass fertilizer did not affect first-year production of any species. Since increased phytomass is an important criterion for erosion control potential, it was concluded that fertilizer was only significant to the revegetation abilities (in that it affected recommended uses) of Alyeska polargrass and *Epilobium angustifolium*. (While unfertilized Alyeska polargrass would still be useful for some programmes, planting *E. angustifolium* rhizomes would only be useful if fertilizer was also used.) The marginal effect of fertilizer on most species production may have been the result of the inability of slowly-establishing species to use the added nitrogen before it became unavailable due to leaching or volatization. Unless the positive effect that was recorded for the other trial species (Decora Mix, *A. Tilesii, C. canadensis, A. latifolia,* local) during the first year results in significantly accelerated growth rates during subsequent years, the application of fertilizer during the first growing season is not recommended when using these species. For these species, fertilizer may be more effective when applied during the second growing season. Or, it may simply not be necessary to revegetation success.

Fertilizer had no affect on seedling establishment or growth of *B. glandulosa* or *L. groenlandicum*. Once an extensive root system has been produced, fertilizer may positively affect production. Accelerated growth rates may be important to shrub seedlings to compete successfully with invading or seeded grasses. Further studies of the effects of delayed fertilizer application on shrub seedlings should be conducted.

In some cases, the effects of fluvial erosion confounded interpretation of the effects of fertilizer. The substrate survey conducted in August was thought to give an accurate measure of the disturbed substrate present at that time, however, it did not identify substrate that may have been disturbed immediately following snowmelt, and then restabilized. Plots that had been so affected would have lost some or all of the applied seeds or rhizomes. Therefore, the effects of fluvial erosion were likely underestimated, particularly on the unfertilized treatments which were aligned with the slope and subject to more surface run-off. However, the high densities recorded for the unfertilized *B. glandulosa* and *L. groenlandicum* suggest that reseeding these plots after spring run-off successfully mitigated seed erosion, in at least some cases. The low cover on the disturbed, fertilized substrates, may have been due in part to the loss of fertilizer as well as the loss of seed in these areas. Cover values for trial species on disturbed, fertilized treatments most closely approximated cover values on the undisturbed, unfertilized treatments (Table 2-3).

Natural Colonization

There were only two important invading vascular species on the trench: *Equisetum arvense* and *Epilobium angustifolium*. Colonization by *E. angustifolium* was primarily through seed establishment (Appendix C). Excavation of *E. arvense* in some plots revealed that establishment of this species was primarily by rhizomes (Appendix C). *E. arvense* is a widespread and common understory species in some parts of the SEEDS site (Kershaw 1988). The extension of rhizomes onto the trench from adjacent undisturbed areas would explain the inconsistent cover pattern exhibited by this species on unfertilized treatments because cover in any area of the trench would then be related to proximity of the trench to existing undisturbed *E. arvense* individuals. Depending on site conditions, where *E. arvense* is a common component of the surrounding undisturbed vegetation, the need for active revegetation may be diminished.

The following taxa were identified as frequent colonizers on mineral soil, and therefore significant to restoration programmes: mosses, *Marchantium* spp., *Carex* spp. *Equisetum arvense*, *E. scirpoides*, and *Salix* spp. Their performance should be monitored in the future.

Rosa acicularis, *Salix myrtillifolia*, *Vaccinium uliginosum* and *V. vitis-idaea* were also frequently found on the trench. However, these species were not important invaders on the mineral soil; they were more frequently found in clumps of organic soil where they had resprouted from buried stems or rhizomes. Therefore, these species may only be important in revegetation of areas where some or all of the organic soil remains intact. Organic soils have played a significant role in the revegetation of other northern disturbances (Chester and Shaver 1982; Gartner *et al.* 1983; Cargill and Chapin 1987).

CONCLUSIONS

The following species are deemed to be unsuitable for revegetation of exposed mineral soils in the Subarctic: *Carex membranacea*, *Arctostaphylos rubra*, *Vaccinium uliginosum* and *Empetrum nigrum*. The following species are considered suitable for revegetation purposes, providing that their long-term performance equals or surpasses their short-term performance: *A. latifolia* (local and Alyeska polargrass), Decora Seed Mix (*Agropyron violaceum, Festuca ovina, Poa glauca,* and *Poa alpina*), Sourdough bluejoint (*Calamagrostis canadensis*) *Artemisia Tilesii, Betula glandulosa* and *Ledum groenlandicum.* Alyeska polargrass is also considered suitable for erosion control purposes in areas with low to moderate erosion potential. Planting and fertilizing *Epilobium angustifolium* rhizomes has potential for accelerating the establishment of a plant community resembling that which would naturally establish on disturbed soil.

Although each of the native cultivars tested in this study (Alyeska polargrass, Sourdough bluejoint, *Artemisia Tilesii* and the Decora Seed Mix) were produced in other northern regions, they are deemed to be suitable for revegetation purposes in Subarctic boreal forests such as those occurring in the Fort Norman region. Cultivation of selections of *A. latifolia* has enhanced the ability of this species to establish rapidly and provide significant cover; however, the same is not true for *Calamagrostis canadensis.*

The addition of fertilizer did not affect first-year cover of *B. glandulosa, L. groenlandicum, V. uliginosum, E. nigrum, A. rubra and C. membranacea.* Fertilizer application positively affected first-year plant cover of Alyeska polargrass, local *A.latifolia,* Decora Mix, *A. Tilesii, and C. canadensis.* However, with the exception of Alyeska polargrass, fertilizer did not affect the above-ground production of any trial species. Fertilizer increased cover, but not above-ground production of transplanted *E. angustifolium* rhizomes.

On the basis of cover and above-ground production, fertilizer had no affect on the rate at which native vascular plant species naturally colonized exposed mineral soil during the first growing season, however, in some treatments, cover of mosses did increase in response to the addition of nutrients. *Marchantium* spp. was more frequently associated with fertilized substrates, but cover values were low in both fertilized and unfertilized treatments.

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Objective 2: To determine whether selected native cultivars, produced in other northern regions are suitable for revegetation of exposed mineral soils in Subarctic boreal forests.

Objective 3: To determine whether fertilizer positively affects first-year performance of seeded native plant species.

Objective 4: To determine whether fertilizer affects the rate at which native species naturally colonize exposed mineral soil during the first post-disturbance growing season.

Study Area

The experiments were conducted in ROW 2 and the South Link of the SEEDS site (Figure 1.2). These sections of the trench were installed during July and August, 1986 and remained untreated for the rest of that year. Natural revegetation during that growing season was negligible. The trench surface, though dominated by exposed mineral soil, appeared by visual estimates to be heterogeneous with respect to soil moisture, organic content and microtopography.

METHODS

Species Selection and Experimental Design

Three common herbaceous species and five shrub species that had successfully established on other disturbances near the study area, were selected for testing (Table 2-1). During the summer of 1986, seeds of each species were hand-collected from randomly-selected plants growing on local seismic lines. Seed ripeness was assessed visually and only seeds that appeared to be ripe were

Table 2-1: Species and varieties of seed selected for testing.[1]

SPECIES	GROWTH FORM	SEED PROVENANCE
Collected from study area		
Arctagrostis latifolia (R.Br.) Griseb. var. reed polargrass	graminoid	study area
Carex membranacea Hook.	graminoid	study area
Epilobium angustifolium L. s. *lat.*	forb	study area
Arctostaphylos rubra (Rehn. & Wils.)Fern.	shrub	study area
Betula glandulosa Michx.	shrub	study area
Empetrum nigrum L.	shrub	study area
Ledum groenlandicum Oeder	shrub	study area
Vaccinium uliginosum L. s. *lat.*	shrub	study area
Obtained from research centres		
Arctagrostis latifolia[2] var. Alyeska polargrass	graminoid	Alaska
Calamagrostis canadensis (Michk.) Beauv. var. Sourdough bluejoint[2]	graminoid	Alaska
Decora Seed Mix[3]:		
Agropyron violaceum (Hornem.) Lange-82%	graminoid	Northern Alberta
Festuca ovina L.-10%	graminoid	Northern Alberta
Poa alpina L.-5%,	graminoid	Alaska
Poa glauca M. Vahl -3%,	graminoid	Alaska
Artemisia Tilesii Ledeb.[2]	forb	Alaska

[1] Nomenclature follows Porsild and Cody (1980)
[2] Donated by the Plant Materials Centre, Palmer Alaska
[3] Donated by Decora Landscaping Ltd., Whitehorse, Yukon

collected. The seeds of each species were then pooled together, stored in paper bags and air dried. In September, the seeds were moved to the lab, placed in plastic bags and stored at -23°C. In May 1987, the seeds were removed from cold storage, cleaned and weighed. At that time, it was determined that the *Epilobium angustifolium* seeds were unsuitable for use due to their small size and the difficulty in separating the seed from the papus. Therefore, it was decided to plant rhizomes of this species, rather than seed.

Additional species, that are native to the North and that are currently being cultivated at research centres, were selected for field testing (Table 2-1). Selection was based on seed availability and the need for testing as determined through discussions with staff at the centres from which the seeds were obtained. All seeds were taken to the study site and stored at ambient temperature for 3 weeks. In May 1987, while the ground remained frozen, *Epilobium angustifolium* rhizomes were collected from local seismic lines and from a burned area 5 km from the study site. The rhizomes were placed in cold storage (buried under the snow), where they remained dormant until planting.

Using the above species, a total of 23 revegetation treatments were designed for field testing (Table 2-2). With the exception of the untreated control, each of the species was tested both with and without fertilizer. Unseeded and fertilized control plots were originally established on the trench, but throughout the course of the study circumstances on site rendered these plots unacceptable

Table 2-2: Revegetation treatments applied to trench surface, ROW 2.

TREATMENT	SOURCE	APPLICATION RATE (g m^{-2})
Arctagrostis latifolia seed (reed polargrass)	local	3.50
Arctagrostis latifolia var. Alyeska polargrass seed	Seed Farm Alaska	2.50
Carex membranacea seed (fragile sedge)	local	1.50
Artemisia Tilesii (mountain wormwood)-56% and *Calamagrostis canadensis* var. Sourdough bluejoint-44%, seed	Seed Farm Alaska	2.75
Decora grass seed mix: *Agropyron violaceum* (violet wheatgrass)-82%, *Poa alpina* (alpine bluegrass) -5%, *Poa glauca* (glaucous bluegrass) -3%, *Festuca ovina* (sheep fescue)-10%	Seed Farm Yukon	3.00
Epilobium angustifolium rhizomes (fireweed)	local	4 - 6 rhizomes m^{-2}
Arctostaphylos rubra seed (red fruit bearberry)	local	8.00
Betula glandulosa seed (glandular birch)	local	8.00
Empetrum nigrum seed (crowberry)	local	4.00
Ledum groenlandicum seed (Labrador tea)	local	0.50
Vaccinium uliginosum seed (bilberry)	local	6.50
Untreated Control		no seed

for comparative purposes. They were therefore not included in data analysis.

Most species were seeded in separate treatments to allow for accurate identification of seedlings and to control for the effects of interspecific competition. Easily distinguishable cultivated species were sown as mixes (Table 2-2). Seeding rates were determined based on seed weights, recommended seeding rates (Hernandez 1973; Johnson 1981; Kubanis 1982) and germination rates achieved in previously conducted growth chamber germination experiments (Appendix A). In some cases (e.g. *Arctagrostis latifolia* local) allowances were made for the per cent weight of chaff that was mixed in with some of the locally-collected seeds. Seed coats of the *Arctostaphylos rubra*, *E. nigrum* and *V. uliginosum* seeds were scarified with sandpaper; seeds from the other species were not treated in any way.

In May 1987, 48 revegetation plots (2 x 3 m each) were established on the trench in ROW 2 (Figure 2.1). The total number of plots established was determined by the length of trench available for experimentation. Between 21 and 30 May 1987, immediately following snowmelt on the trench, each of the 23 revegetation treatments was applied to duplicate 2 x 3 m plots. The control plot was replicated 3 times (n=4). Although it is recognized that to achieve true replication the entire trench design should have been replicated, this was not possible at the SEEDS site.

Treatments were assigned to plots at random, but to control

LEGEND

Test revegetation treatment types

1	*Arctostaphylos rubra seed*
2	*Arctagrostis latifolia* (Alyeska) seed
3	*Epilobium angustifolium* rhizomes
4	Untreated (control)
5	*Empetrum nigrum* seed
6	*Artemisia Tilesii* and *Calamagrostis canadensis* seed
7	*Carex membranacea* seed
8	*Betula glandulosa* seed
9	Decora grass seed mix
10	*Vaccinium uliginosum* seed
11	*Arctagrostis latifolia* (local) seed
12	*Ledum groenlandicum* seed

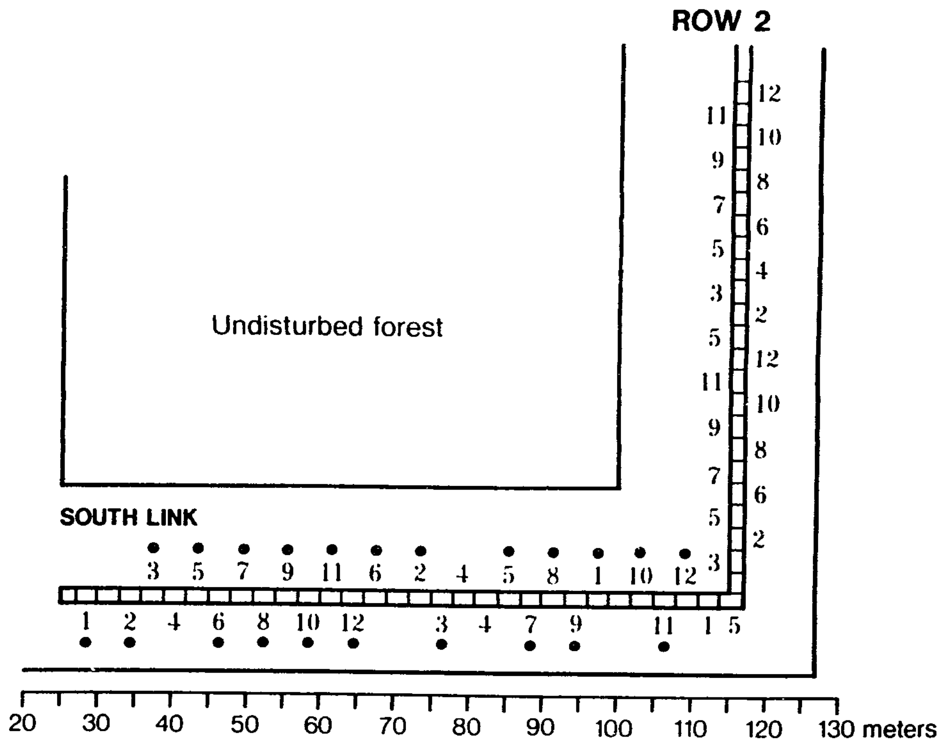

Figure 2.1 Revegetation treatments on SOUTH LINK and on ROW 2, SEEDS 1987.

for possible transportation of fertilizer to unfertilized plots, through fluvial erosion, all of the treatments that included fertilizer were grouped together on the South Link of the trench (Figure 2.1). One to 10 days prior to application of the treatments, $N-P_2O_5-K_2O$ (17:25:15; 42.5kg-N ha$^-$, 62.5 kg-P ha$^-$, 37.5 kg-K ha$^-$) fertilizer was hand broadcast onto the designated plots, at a rate of 25 g m^{-2} (250 kg ha^{-2}). The fertilizer and application rate were the same as those used on the Norman Wells pipeline (Interprovincial Pipelines Ltd. 1983). The source of nitrogen could not be ascertained.

Seeds were hand broadcast onto the plots. The *Epilobium angustifolium* rhizomes were cut to lengths of 25-60 cm, and all lateral roots and shoots were trimmed. Rhizomes were buried at a depth of approximately 5 cm, in rows located 10 cm apart beginning 5 cm from the trench edge. Planting density varied from 25 to 35 per plot. During the spring run-off (i.e. snow-melt in the surrounding forest) some plots lost much of their seed through fluvial erosion so some reseeding (at the original rate) took place in the highly disturbed locations after run-off had abated.

Assessment of Performance

In mid-August 1987, after one growing season, performance of the revegetation treatments was evaluated on the basis of per cent cover and phytomass. For those treatments where trial species achieved cover <1%, frequency and density, rather than phytomass, were estimated.

A buffer zone of 10 cm was established around the periphery of each 2 x 3 m revegetation plot to control for erosion of soil and seed that had occurred along the trench edges; this zone was exempt from sampling. Each 2 x 3 m revegetation plot was then divided into 4 subplots (each 0.9 m x 1.4 m), intended for use as cover sampling quadrats. However, by August 1987, it became apparent that fluvial erosion had significantly altered more than just the edges of some of the plots and had, in places, affected the trench surface throughout the growing season. It appeared that this disturbance had caused revegetation to be differentially successful so some sampling adjustment was needed to separate the effects of fluvial erosion from experimental factors and to reduce variability in the data. Therefore, the condition of the soil surface in each 0.9 m x 1.4 m subplot was visually assessed and assigned to 1 of 2 types: 1) undisturbed substrate - essentially unaltered since seeding (Figure 2.2); 2) disturbed substrate - evidence of post-seeding fluvial erosion or deposition (Figures 2.2, 2.3). The per cent cover of each substrate type was estimated and per cent plant cover assessed separately for each substrate type. Thus, although the entire area of each 0.9 m x 1.4 m subplot in each treatment was ultimately assessed for cover, the actual size of the cover quadrats varied according to the amount of disturbed or undisturbed substrate present within each subplot (Figure 2.3).

For each vascular plant species, per cent cover was estimated to the nearest 1%, for those species present at <5%, and to the nearest 5% for more abundant species. Species that were present at

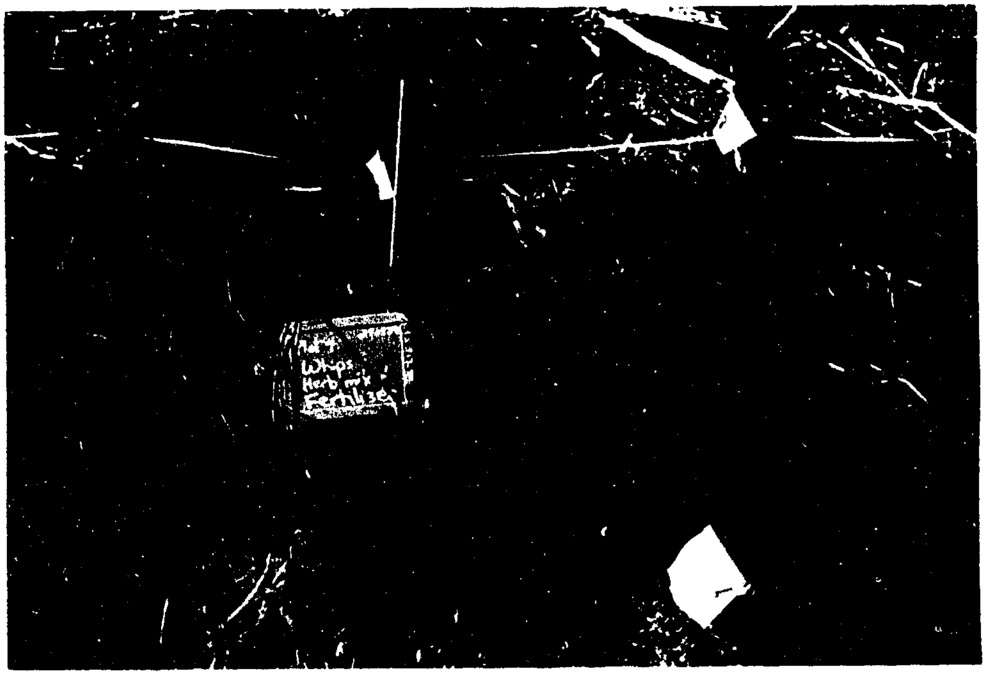

Figure 2.2: Treatment plot containing undisturbed and disturbed substrate. Undisturbed substrate is at the center of the plot with grasses established on it. Disturbed substrate, with standing water and silt deposits, is in the foreground.

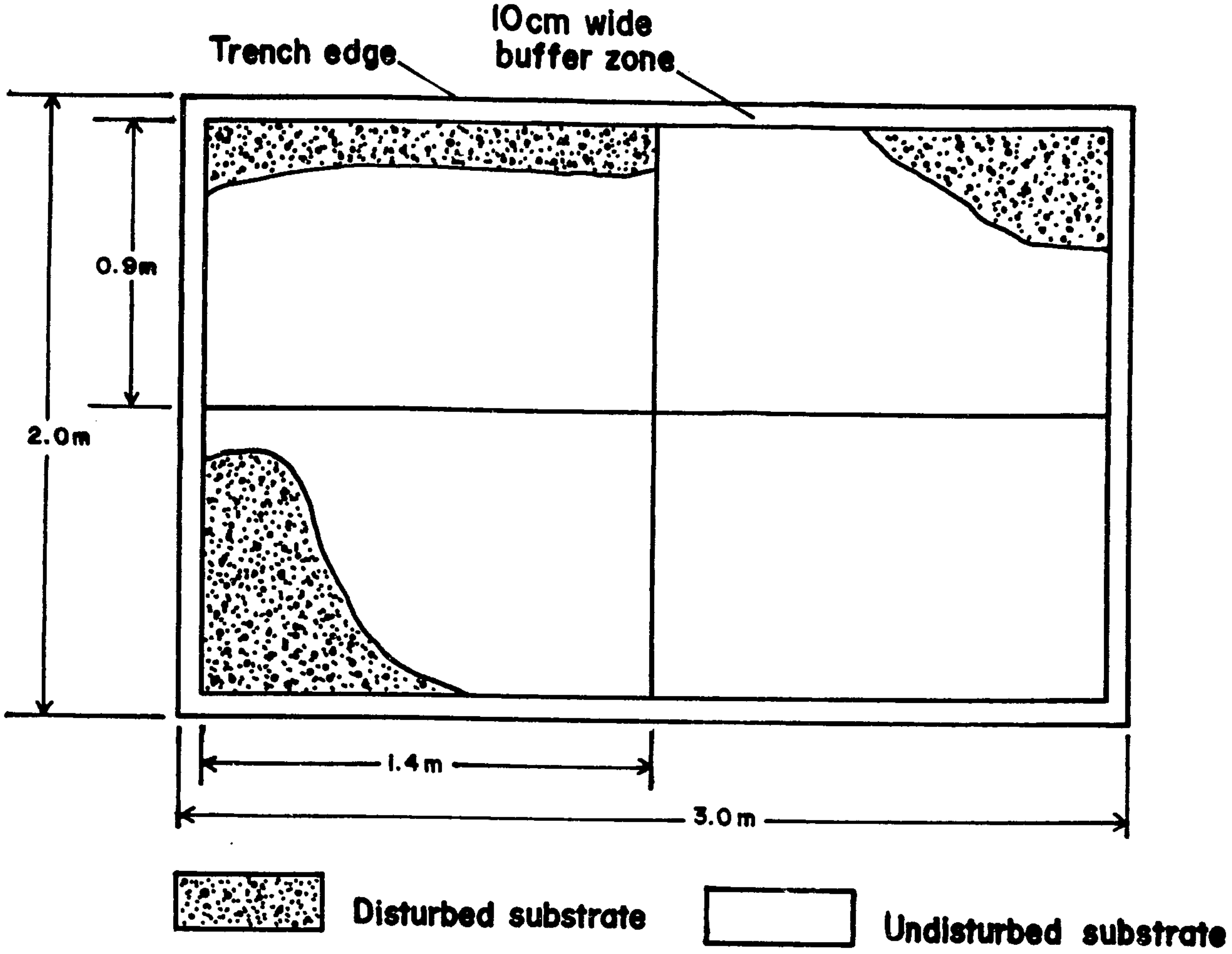

Figure 2.3: Schematic diagram of revegetation plot showing 4 subplots with disturbed and undisturbed substrate. Size of cover quadrats was determined by the area of disturbed and undisturbed substrate within each subplot.

<1% were assigned a value of 0.1%. Per cent cover of mosses and liverworts was also assessed.

Due to the varying quadrat size used to sample per cent cover on the treatments, the frequency of invading and trial species in each treatment could not be calculated using the cover quadrats. However, because the entire area of each 1.8 x 2.8 m plot (2 x 3 m plot less the 10 cm perimeter) was sampled, species presence or absence could be determined for each substrate type within each plot. Species frequency was therefore calculated for four substrate types: fertilized and undisturbed, fertilized and disturbed, unfertilized and undisturbed, and unfertilized and disturbed.

Phytomass was estimated for each of the treatments where the trial species achieved a plant cover >1%. Five 25 x 25 cm quadrats, were randomly located, using a table of random numbers, within each 1.8 m x 2.8 m revegetation plot, for a net total of 10 samples from each treatment. When placing the quadrats, no distinction was made between undisturbed and disturbed substrates because due to time constraints the substrates types had not been permanently delineated. All above-ground portions of vascular plants rooted within the quadrats were collected. Harvested material was sorted into 4 categories: trial species, *E. angustifolium*, *Equisetum* spp., and other species. Samples were stored in paper bags in the field and air dried. In September, samples were oven dried, at 38°C, for 24 hours and then weighed to the nearest 0.01 g.

Species density (number of seedlings in each sampling quadrat) and frequency (presence or absence in sampling quadrats) of *B. glandulosa* and *L. groenlandicum* were estimated using 5 randomly-located 25 x 25 cm quadrats in each 1.8 x 2.8 m revegetation plot, for a total of 10 samples from each treatment. Samples were not stratified by substrate type.

Data Analysis

All data were tested for normality using the Kolmogorov-Smirnov test for goodness-of-fit (Zar 1974; Statistical Graphics Corp. 1985). Appropriate transformations to normality were used when necessary. Analysis of variance (ANOVA) was used to test for differences among species and treatments, for data which were normally distributed. Homogeneity of variance was tested using Cochran's C test and Bartlett's test (Sokal and Rohlf 1981; Statistical Graphics Corp 1985). When the overall F-value in the ANOVA was significant, differences in means were tested using Tukey's Multiple Range (TMR) test (Sokal and Rohlf 1981; Statistical Graphics Corp. 1985). For non-normal data and data with heterogeneous variances, differences were tested using the Kruskal-Wallis test, and differences between mean ranks were identified by the Dunn test (Zar 1984).

When calculated expected frequencies would allow, species frequency on each substrate type was compared using chi-squared contingency tables. When significant associations were detected, contingency tables were subdivided to identify the significant association(s) (Zar 1974). Although analysis by a multi-dimensional table would have been a superior test, as it would also test for interactions between substrate types, the necessary software was not available.

RESULTS

Fluvial Erosion

In mid-August of 1987, 62% of the revegetation plots had been disturbed by fluvial erosion. Twenty-eight per cent of the substrate surface in the north-south oriented section was disturbed, compared to only 15% of the South Link.

Cover of Trial Species on Disturbed Substrates

Cover of trial species on disturbed substrates was generally low (<5%) (Table 2-3). An ANOVA conducted for those treatments with samples greater than three indicated no difference ($P>0.05$) in cover of trial species on disturbed substrate among treatments (Table 2-3). Therefore, on disturbed substrates, fertilizer had no affect on plant cover.

Cover of Trial Species on Undisturbed Substrates

By the end of the first growing season, cover of trial species on undisturbed substrates varied significantly among the treatments ($P<0.001$) (Table 2-3). Fertilizer positively affected all of the trial species that achieved cover >1% on undisturbed substrate. Cover of those species was higher ($P<0.05$), by at least a factor of four, when fertilized. When unfertilized, there was no difference in

Table 2-3: Mean cover (%) of trial species, on disturbed and undisturbed substrates, after one growing season.

TREATMENT		DISTURBED SUBSTRATE		UNDISTURBED SUBSTRATE	
		n	% COVER ±SE	n	% COVER ±SE
Arctagrostis latifolia var.					
Alyeska	F[1]	0	-	8	33.8 ± 3.98 a
	UF[2]	5	0.3 ± 0.18 a[+]	8	6.0 ± 0.89 cde[+]
Arctagrostis latifolia					
Local	F	1	0.1 ± 0	8	5.9 ± 0.93 cd
	UF	6	0.2 ± 0.08 a	6	0.3 ± 0.15 e
Artemisia Tilesii & *Calamagrostis canadensis*					
	F	2	4.0 ± 2.0	8	15.6 ± 3.29 b
	UF	7	4.5 ± 1.07 a	8	3.2 ± 0.68 cde
Decora Mix	F	4	0.9 ± 0.59 a[+]	8	8.3 ± 0.64 bc[+]
	UF	4	0.2 ± 0.09 a	8	2.0 ± 0.71 e
Epilobium angustifolium					
	F	7	0.6 ± 0.42 a[+]	8	9.3 ± 2.67 bc[+]
	UF	6	* ± 0.17 a	8	0.4 ± 0.26 e
Carex membranacea	F	1	0 ± 0	8	0.1 ± * e
	UF	4	0 ± 0 a	8	0.2 ± 0.11 e
Arctostaphylos rubra					
	F	3	0 ± 0	5	0 ± 0 e
	UF	1	0 ± 0	6	* ± 0.02 e
Betula glandulosa	F	2	0.1 ± 0.05	8	0.1 ± 0 e
	UF	1	0.1 ± 0	8	0.1 ± 0 e
Empetrum nigrum	F	2	0 ± 0	6	0 ± 0 e
	UF	0	-	5	0 ± 0 e
Ledum groenlandicum					
	F	0	-	8	0.1 ± 0 e
	UF	0	-	7	0.5 ± 0.28 e
Vaccinium uliginosum					
	F	3	0 ± 0	7	0 ± 0 e
	UF	2	0 ± 0	5	0 ± 0 e
Control	UF	2	-	14	-

[1] F - Fertilized [2] UF - Unfertilized

[3] AT- *Artemisia Tilesii* [4] Cc- *Calamagrostis canadensis*

Means in the same column with the same letter(s) are not significantly different (P>0.05) for TMR test.

[+] Means in the same row are significantly different (P<0.05) for TMR test.

Means with no letters could not be tested due to small sample sizes.

mean per cent cover among any of the trial species (Table 2-3).

Alyeska polargrass was the most successful of all the trial species (Figure 2.4). The fertilized Alyeska polargrass produced a higher cover (34%,) than all other treatments and although cover produced by the unfertilized Alyeska polargrass was much lower, it was still at least equal to all other treatments except the fertilized *Artemisia Tilesii/Calamagrostis canadensis*.

Cover of the fertilized *A. Tilesii/C. canadensis* (Figure 2.5), was second only to the fertilized Alyeska polargrass, and equalled cover of the fertilized *E. angustifolium* rhizomes, and the fertilized Decora Mix (Figure 2.6); each of these produced similar cover (Table 2-3). The unfertilized *A. Tilesii/ C. canadensis* produced cover similar to the following fertilized treatments: Decora Mix, *E. angustifolium* and local *A. latifolia*. The success of the *A. Tilesii/C. canadensis* mix was primarily due to the cover produced by the former, rather than the latter, species (Table 2-4).

The Decora Mix, the *E. angustifolium*, and the local *A. latifolia* (Figure 2.7) all performed equally well when fertilized (Table 2-3). The success of the Decora mix was due primarily to the success of the two *Poa* species (Table 2-4). When fertilized, *P. alpina* and *P. glauca* produced higher cover than the other two species, despite comprising a smaller percentage of the mix. Neither *Agropyron violaceum* nor *Festuca ovina* produced cover >1%, even when fertilized (Table 2-4).

None of the *Carex membranacea*, *Arctostaphylos rubra*, *Empetrum nigrum*, or *Vaccinium uliginosum* seeds established on

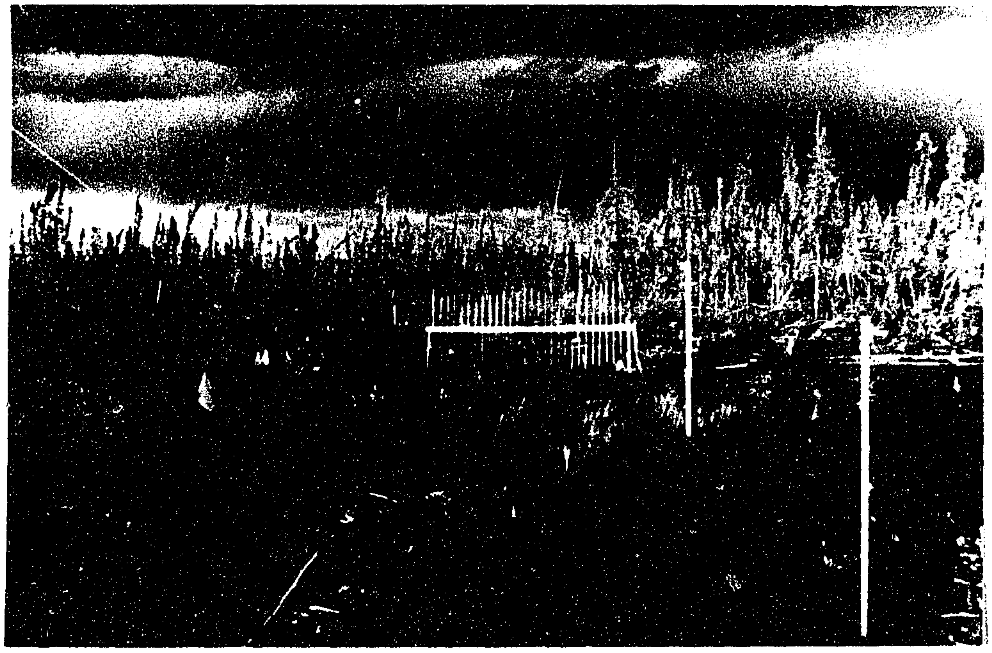

Figure 2.4: Eastward view of revegetation treatment plots on South Link. Plots are marked with blue flagging tape. Fertilized Alyeska polargrass is in the third plot to the east. Note the relative abundance. Adjacent and to the west, is fertilized Decora Mix.

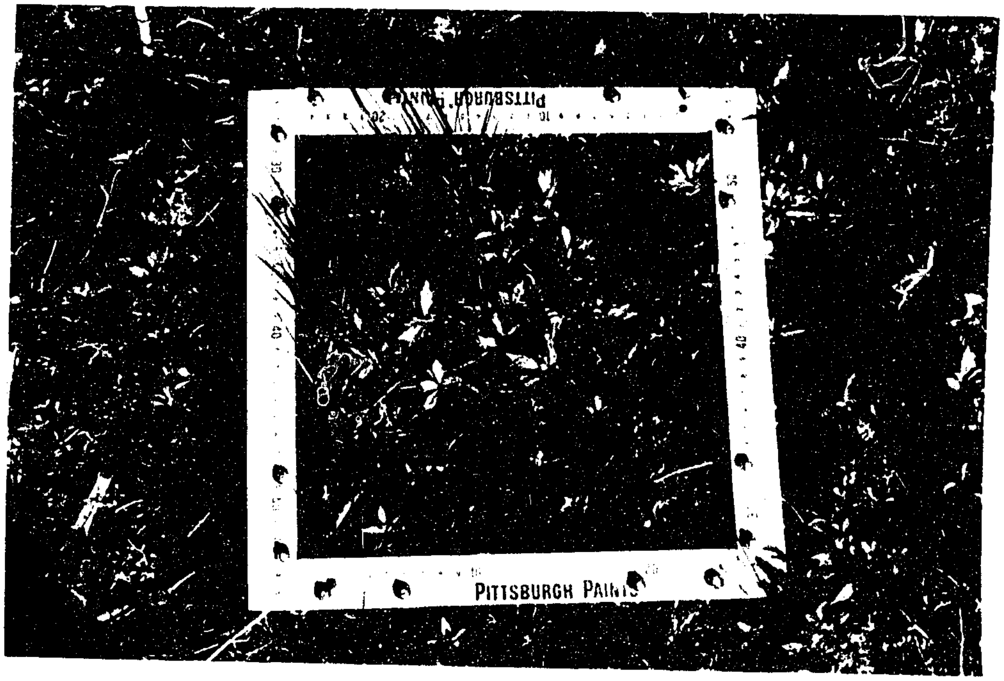

Figure 2.5: Cover of fertilized *Artemisia Tilesii/Calamagrostis canadensis* at the end of the first growing season. Note the state of *Artemisia* seedlings.

Figure 2.6: Cover of fertilized Decora Mix, at the end of the first growing season. *Salix glauca* cutting is to the left of the ruler.

Table 2-4: Mean cover (%) of *Artemisia Tilesii*, *Calamagrostis canadensis* and species comprising the Decora Seed Mix, in fertilized and unfertilized treatments, on undisturbed substrates after one growing season.

SPECIES	COVER (%) ± SE	
	Fertilized	Unfertilized
A. Tilesii	10.5 ± 2.25 a	2.9 ± 0.55 b
C. canadensis	5.1 ± 1.11 a	0.3 ± 0.15 b
Agropyron violaceum*	0.6 ± 0.17 a	0.3 ± 0.15 a
Festuca ovina	0.8 ± 0.15 a	0.2 ± 0.11 a
Poa alpina	3.0 ± 0.38 b	0.5 ± 0.25 a
Poa glauca	4.0 ± 0.27 b	1.1 ± 0.45 a

*Kruskal-Wallis test used for this species only (P>0.05).

Means in the same row, with the same letter, are not significantly different (P>0.05) for TMR test.

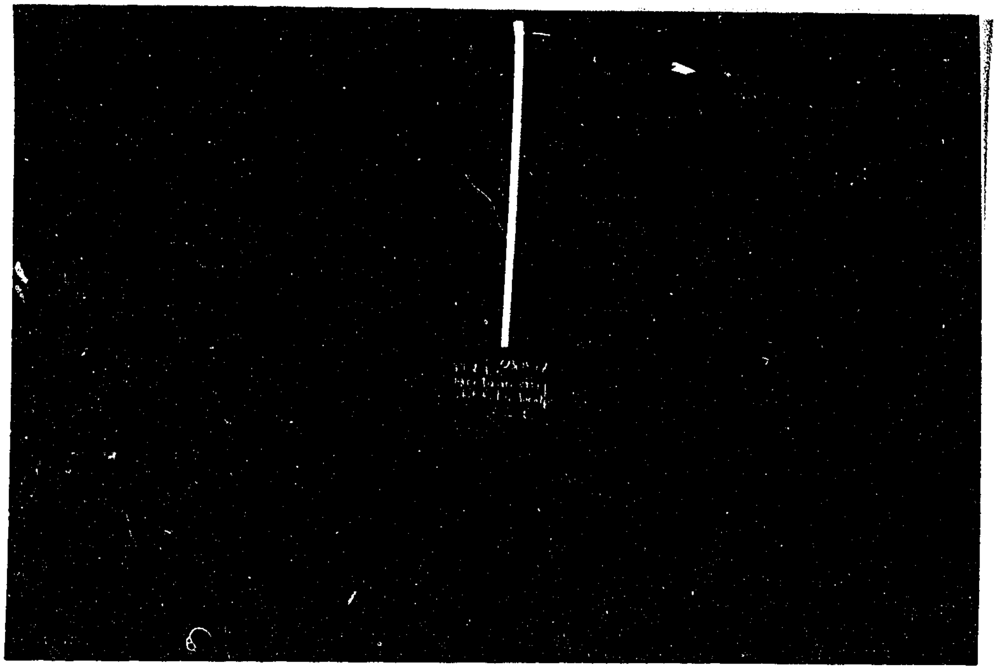

Figure 2.7: Cover of local *Arctagrostis latifolia* at the end of the first growing season.

either the fertilized or unfertilized treatments (Table 2-3). The minimal cover recorded for *C. membranacea* and *A. rubra* was the result of vegetative regeneration from buried material rather than seedling establishment.

In contrast to the other shrub species, *Betula glandulosa* and *Ledum groenlandicum* established well, producing a mean seedling density of 284 m^{-2} and 333 m^{-2}, respectively. Due to slow seedling growth, cover at the end of the season was <1% for both species, in both fertilized and unfertilized plots (Figure 2.8). Some of the cover recorded for the unfertilized *L. groenlandicum* was due to resprouting from buried shoots rather than seedling development. *B. glandulosa* seedlings generally appeared to be more mature than *L. groenlandicum* seedlings, most of which did not progress beyond the cotyledon stage.

In general, performance of trial species on disturbed substrate was poorer than on undisturbed substrate, particularly on those treatments where trial species cover was >1% (Table 2-3). Of the two fertilized treatments for which an ANOVA was done (*E. angustifolium* and Decora Mix) (Table 2-3), trial species cover was lower ($P<0.05$) on the disturbed substrates. Differences were less evident on the unfertilized treatments where cover was generally low on both substrate types. Of the six unfertilized treatments that were tested (Table 2-3), trial species cover differed ($P<0.05$) only for Alyeska polargrass.

Since each of the trial species was native to the area and, at least in theory, capable of establishing on the trench through

Figure 2.8: Cover of *Betula glandulosa* at the end of the first growing season. *Betula* seedlings are small and red (prominent one is on the left, near the 40 cm mark of the quadrat frame).

natural means, the presence of these species on the trench was not necessarily attributable to treatment. Plants establishing from active treatment would be indistinguishable from plants establishing by natural means. Therefore, cover resulting from treatment was measured by comparing the cover of the trial species in their respective treatments to the cover achieved by the same species in other treatments (Table 2-5).

All of the trial species that achieved cover >1% in their own treatments, were also found in at least some of the other treatments (Table 2-5). However, in all cases, cover by the trial species was higher ($P<0.05$) in their own fertilized treatments than in the other treatments. Cover of the two locally-collected species, *A. latifolia* and *E. angustifolium*, in the unfertilized treatments, was no different ($P>0.05$) from cover in treatments where they were not directly applied (Table 2-5). Either seeds and rhizomes had been transported from treatment plots to other plots, or these species had established on other plots through natural colonization. If the latter is true, then treatment without fertilizer had no positive affect on revegetation. In the case of *A. latifolia*, it is likely that establishment in other plots was at least partially due to dispersal of seed from the treatment plots. In the case of *E. angustifolium*, presence in treatments where it was not planted was more likely due to natural colonization rather than to transfer and reburial of rhizomes.

In contrast, the cultivated varieties (Alyeska polargrass, Decora Mix and *A. Tilesii/C. canadensis*) established sufficiently

Table 2-5: Mean cover (%) of trial species that achieved cover >1% in their own treatments, compared to cover achieved by the same species in other treatments at the end of the first growing season.

	TREATMENT									
	Arctagrostis latifolia Alyeska Seed (SD)		*Arctagrostis* latifolia Local Seed (SD)		*Artemisia Tilesii* and *Calamagrostis canadensis* Alaskan Seed (SD)		*Epilobium angustifolium* Rhizomes (SD)		Decora Seed Mix (SD)	
	F[1]	U[2]	F	U	F	U	F	U	F	U
SPECIES n=	8	8	8	6	8	8	8	8	8	8
Arctagrostis latifolia (Alyeska)	33.8a (3.98)	6.0b (0.89)	-[3]	-	-	-	-	-	-	-
Arctagrostis latifolia (Local)	-	-	5.9b (0.93)	0.3c (0.15)	*c (0.01)	*c (0.01)	0.9c (0.39)	*c (0.16)	*c (0.01)	0c (0)
Artemisia Tilesii	0.1 c (0.02)	*c (0.02)	0.1c (0.02)	0d (0)	10.5a (2.25)	2.9b (0.55)	0d (0)	0d (0)	0d (0)	0d (0)
Calamagrostis canadensis	0b (0)	0b (0)	0b (0)	0b (0)	5.1a (1.11)	0.3b (0.15)	* b (0.02)	0b (0)	0b (0)	0b (0)
Epilobium angustifolium	1.3bc (0.17)	0.1bc (0.02)	1.2bc (0.12)	*c (0.02)	0.6bc (0.26)	*c (0.02)	9.3a (2.67)	0.4bc (0.26)	2.0bc (0.41)	0.1c (0.02)
Decora Mix	*c (0.02)	0.1c (0.02)	*c (0.01)	*c (0.02)	*c (0.02)	0.1c (0.06)	0c (0)	0c (0)	8.3a (0.64)	2.0b (0.71)

[1] F -Fertilized, [2] U - Unfertilized, [3] *A. latifolia* was recorded as local.
* Species present at <0.1%
Means in the same row, with the same letters are not significantly different (P>0.05) for TMR test.

well in the unfertilized treatments to achieve cover greater ($P<0.05$) than in the treatments where they were not applied.

Several factors relating to experimental design may have affected species performances. Several species with different growth forms (e.g. graminoids, shrubs and forbs) were included in the same ANOVAS, introducing an additional source of error. Different seeding rates were used and some reseeding of plots was also done, but was not standardized. These factors likely account for some of the more subtle differences seen among species performance, and may also account for the fact that, for some species, differences were seen in cover but not phytomass. However, for others the difference in cover and phytomass values may be the result of species growth form. For example, for some species, treatments may have resulted in larger but not heavier leaves.

Cover by Invading Species

Total cover also varied among the treatments ($P<0.001$), although relative total cover values did not always reflect cover contributed by the trial species (Table 2-6) because in some cases, invading species contributed more to total cover than treatment species. For example, the fertilized treatments of *A. rubra* and *V. uliginosum* were among the treatments with the highest mean total cover ($P<0.05$) despite the low cover achieved by the seeded species. In these cases, bryophytes were responsible for most of the cover.

Table 2-6: Mean per cent total plant cover (±SE), mean per cent cover (±SE) of trial species, *Equisetum arvense*, Bryophyta, *Epilobium angustifolium* (*E.ang.*) and other species, on undisturbed substrates, at the end of one growing season.

TREATMENT		n	TOTAL COVER	COVER BY TRIAL SPECIES	COVER BY *Equisetum arvense*	COVER BY BRYOPHYTA	COVER BY *E.ang.*	COVER BY OTHER SPECIES
Arctagrostis latifolia var. Alyeska	F[1]	8	41.2 a (5.10)	33.8 a (3.98)	0.1 f (0.02)	5.4 cd (1.44)	1.3 bc (0.17)	0.6
	UF[2]	8	11.8 bcd (1.14)	6.0 cde (0.89)	4.3 bcde (1.41)	0.7 d (0.17)	0.1 bc (0.02)	0.7
Arctagrostis latifolia Local	F	8	14.9 bc (1.82)	5.9 cd (0.93)	* f (0.02)	7.2 bcd (1.63)	1.2 bc (0.12)	0.6
	UF	6	15.2 bcd (6.29)	0.3 e (0.15)	11.0 abcd (3.16)	0.1 d (0.02)	* c (0.02)	3.8
Artemisia Tilesii and *Calamagrostis canadensis*	F	8	23.0 ab (3.38)	15.6 b (3.29)	* f (0.01)	6.1 cd (1.34)	0.6 bc (0.26)	0.7
	[2]UF	8	10.9 bcd (2.65)	3.2 cde (0.68)	5.9 d (3.10)	0.5 d (0.17)	* c (0.02)	1.3
Carex membranacea	[1]F	8	11.9 bcd (2.15)	0 e (0)	0 f (0)	7.3 bcd (1.25)	4.0 bc (1.13)	0.5
	UF	8	6.9 cde (1.03)	0 e (0)	4.8 abcde (1.21)	0.5 d (0.25)	0.1 c (0.02)	1.3
Decora Mix[5]	F	8	19.4 bc (2.34)	8.3 bc (0.64)	* f (0.01)	8.1 abcd (1.76)	2.0 bc (0.41)	1.0
	UF	8	7.3 cde (0.67)	2.0 e (0.71)	3.8 bcde (1.09)	0.6 d (0.36)	0.1 c (0.02)	0.8
Epilobium angustifolium	[1]F	8	25.1 ab (5.48)	9.3 bc (2.67)	* f (0.01)	13.5 abc (2.98)	9.3 a (2.67)	2.3
	[2]UF	8	10.9 bcd (4.08)	0.4 e (0.26)	8.9 abcde (4.05)	0.6 d (0.36)	0.4 bc (0.26)	0.6
Arctostaphylos rubra	F	5	22.1 abc (8.21)	0 e (0)	0 f (0)	17.7 a (8.27)	2.84 bc (1.70)	1.6
	UF	6	5.0 de (1.39)	* e (0.1)	2.5 ef (1.59)	1.3 d (0.78)	0.1 bc (0.02)	1.1
Betula glandulosa	F	8	8.3 bcde (1.0)	0.1 e (0)	* f (0.01)	6.0 cd (1.80)	2.0 bc (0.41)	0.2
	UF	8	3.3 de (0.63)	0.1e (0)	2.0 ef (0.53)	0.3 d (0.12)	0.1 bc (0.02)	0.8
Empetrum nigrum	F	6	13.0 bc (1.87)	0 e (0)	0 f (0)	8.4 abcd (1.77)	3.7 bc (0.60)	0.9
	UF	5	6.6 cde (3.66)	0 e (0)	5.6 cde (3.69)	0.2 d (0)	* c (0.02)	0.8
Ledum groenlandicum	[1]F	8	18.4 bc (3.03)	0.1 e (0)	* f (0.01)	13.3 abc (1.68)	3.9 bc (1.73)	1.1
	[2]UF	7	16.3 bc (2.5)	0.5e (0.28)	14.1 a (2.63)	0.5 d (0.27)	* c (0.02)	1.2
Vaccinium uliginosum	F	7	21.2 abc (3.71)	0 e (0)	0 f (0)	15.2 ab (2.31)	3.9 bc (1.35)	2.1
	UF	5	6.6 cde (2.67)	0 e (0)	4.6 abcde (1.57)	0.2 d (0.02)	* c (0.02)	1.8
Control	UF	14	2.4 e (0.59)	-	0.2 f (0.21)	1.1 d (0.36)	0.1 bc (0.01)	1.0

[1]F-Fertilized [2]UF-Unfertilized * Species present at <0.1% cover.
Means in the same column, denoted by the same letters are not significantly different (P>0.05) for TMR test.

The three most important invaders were bryophytes, *Equisetum arvense*, and *Epilobium angustifolium*. Bryophytes were dominant (i.e they produced more cover than each of the other species, including the trial species) in three of 10 treatments where the trial species produced cover >1%. (Table 2-6). Although there was an overall trend toward increased bryophyte cover as a result of fertilizer application, this increase was only significant ($P<0.05$) in 4 treatments (Table 2-6).

Equisetum arvense was the dominant species in all of the unfertilized treatments ($P<0.05$) (Table 2-6), but was not dominant in any of the fertilized treatments. With the exception of the unfertilized *A. rubra* and *B. glandulosa* treatments, cover produced by *E. arvense* was lower ($P<0.05$) on the fertilized treatments, than on the unfertilized treatments. However, cover by *E. arvense* was also lower on the control treatments suggesting that the cover achieved by this species in any one treatment was a function of plot characteristics, such as soil moisture, rather than a negative response to added nutrients.

Although not a dominant invader compared to *E. arvense* or the mosses, *E. angustifolium* was an important invading species occurring in all but one plot, and, excluding *E. arvense*, providing more cover than all other invading vascular species combined (Table 2-6). The application of fertilizer did not significantly increase ($P>0.05$) the cover of *E. angustifolium*, with the exception of the treatment in which it was planted.

As measured by cover, there were no other important invading

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3. FIRST AND SECOND YEAR RESULTS OF REVEGETATION TRIALS USING SELECTED NATIVE SHRUB CUTTINGS

INTRODUCTION

Shrubs are a dominant component of many northern plant communities and are often recommended for inclusion in northern revegetation programmes (Zasada and Epps 1976; Younkin and Martens 1985; Densmore *et al.* 1987), particularly those with restoration as a desired end result. Shrubs provide food and cover for wildlife and can aesthetically enhance a disturbed area (Zasada and Epps 1976). Due to their spreading growth form and deeply penetrating roots, shrubs have potential for minimizing fluvial-thermal erosion, and also for providing additional soil stabilization in highly erodible areas (Younkin and Martens 1985).

The preferred method of establishing shrubs is, in many cases, to plant stem cuttings. Although selected shrubs have been successfully propagated from cuttings in numerous Subarctic and Boreal environments (Younkin 1976; Holloway and Zasada 1979; Brown and Berg 1980; Johnson 1981; Johnson *et al.* 1981; IPL 1986), species suitability for revegetation, and optimal planting techniques remain poorly defined. For example, Densmore and Zasada (1978) had demonstrated poor rooting success for several of the willows (*Salix scouleriana*, *S. bebbiana* and *S. glauca*) that were ultimately chosen for use in the revegetation of the Interprovincial (IPL) Norman Wells Pipeline. However, the rooting ability of some of those species has been shown to vary with the season of cutting collection and the age of the stem section (Holloway and Zadasa

1979). Johnson and others (1981) concluded that simultaneously planting grasses and shrub cuttings significantly reduced the growth and survival of the cuttings. They recommended delaying seeding until the shrubs were established.

Several authors (Van Epps and McKell 1978; Slauson and Ward 1982; Good *et al.* 1985) have suggested that revegetation success may be enhanced by taking advantage of the ecotypic variation exhibited by certain shrub species. Ecotypes may be differentially successful at establishing in areas with harsh growing conditions, or may have growth forms that are better suited to minimizing soil thermal erosion. This suggestion, a logical extension of the ecological approach to revegetation, merits further research.

Objectives

The general objectives of this study were to evaluate the potential of selected Subarctic shrub species for use in Subarctic revegetation programmes and to address some outstanding questions concerning the use of shrub cuttings for revegetation purposes. Toward this end, two experiments were designed; each with two specific objectives:

EXPERIMENT 1

Objective 1: To evaluate the ability of selected Subarctic shrub species to successfully establish from stem cuttings when planted in exposed mineral soil, in a Subarctic environment.

Objective 2: To determine whether cuttings taken from plants established in a recently disturbed area perform differently from cuttings taken from plants of the same species, established in an undisturbed area.

EXPERIMENT 2

Objective 1: To determine whether fertilizer positively affects the performance of selected shrub cuttings during the first growing season following planting.

Objective 2: To determine whether simultaneously planting selected shrub cuttings with a native grass seed mix, negatively affects cutting performance during the first growing season.

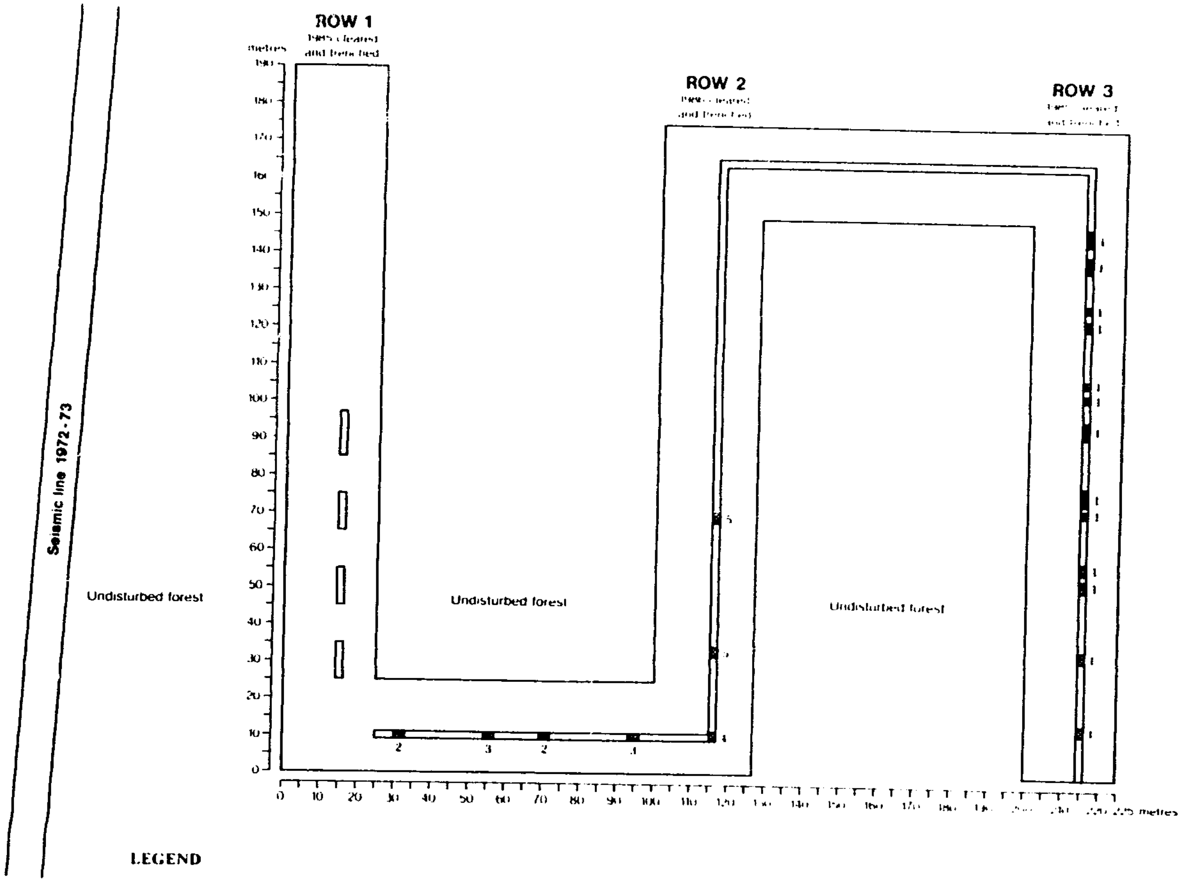
Study Area

The trench located within ROWs 3 and 2, and the South Link, served as the revegetation test substrates for Experiments 1 and 2 (Figure 3.1). The trench in ROW 3 was excavated in the summer of 1985, the trench in ROW 2 and the South Link were excavated in the summer of 1986. The trench surface, though dominated by exposed mineral soil, was heterogeneous with respect to moisture, organic content, and microtopography. Visual assessment suggested that soil moisture, within the plant rooting zone, appeared to vary throughout the growing season, depending on precipitation levels. Prior to the experiments, these sections of the trench were not treated in any way.

METHODS

EXPERIMENT 1 - Species and Population Performance

Six species of native shrubs commonly found in Subarctic forests and proven to be successful colonizers of local seismic lines



LEGEND

Species planted:

1 *Salix arbusculoides*, *Salix glauca*, *Vaccinium uliginosum*, *Betula glandulosa*, *Alnus crispa* and *Potentilla fruticosa* shrub cuttings
2 *Salix arbusculoides* and *Salix glauca* shrub cuttings and fertilizer
3 *Salix arbusculoides*, *Salix glauca* shrub cuttings, Decora Seed Mix and fertilizer
4 *Salix arbusculoides* and *Salix glauca* shrub cuttings
5 *Salix arbusculoides* and *Salix glauca* shrub cuttings and Decora Seed Mix

Figure 3.1 **Shrub cutting revegetation treatments on ROW 2, and ROW 3, SEEDS 1986 and 1987.**

were selected for use in the experiment: *Salix arbusculoides* Anderss. (little tree willow), *Salix glauca* L. *s.lat. (blue-green willow), Vaccinium uliginosum* L. *s.lat* (bilberry), *Betula glandulosa* Michx. (dwarf birch), *Alnus crispa* (Ait.) Pursh (green alder), and *Potentilla fruticosa* L.(shrubby cinquefoil) (nomenclature follows Porsild and Cody 1980). In May 1986, hardwood cuttings were collected from shrubs found in the vicinity of the study area. Two separate populations were sampled: plants established on a 14-year-old seismic line (disturbed site); and plants established in a *Picea mariana* stand that had remained unburned for over 200 years (undisturbed site). In early May, prior to bud-break, branches were clipped from at least 20 randomly-selected shrubs of each species, in each of the two sites. While shrubs were randomly-selected, individual branches were selected based on apparent health. The branches were placed in cold storage, to preserve their dormant state, until the time of planting.

Planting took place over the course of five days, in mid-June. Only those branches that had remained dormant and that appeared healthy, (i.e. had the growing tip intact) were selected for use. Suitable branches were clipped with pruning shears at an oblique angle, and trimmed to 10-cm-long cuttings. All lateral branches were clipped from the cutting, but leaf buds that had formed the previous fall were left intact (cutting design was modified from Dabbs *et al.* 1974; Kubanis 1982; Hardy and Associates (1978) Ltd. 1985).

Thirteen revegetation plots were established on the trench located in ROW 3 (Figure 3.1). Each plot spanned the width of the trench (2 m). Plot lengths varied from 2-5 m because their locations were determined by availability of previously untreated sections of the trench. In each of the 13 plots, cuttings were planted in rows, with a row and cutting interval of 25 cm. The rows began 25 cm in from the edge of the trench to reduce effects created by the trench walls. Each row contained only one species, but all six species were planted in each plot to minimize any bias resulting from the heterogeneous nature of the trench surface. For this same reason, cuttings from the two populations (disturbed and undisturbed sites) were distributed in a number of plots along the full length of the trench. Cuttings were planted so that approximately three cm of the stem was above the soil surface, leaving seven cm buried. A total of nine-hundred and five cuttings were planted (146 to 153 of each species). One-half of the cuttings of each species were from the disturbed site and one-half were from the undisturbed site.

Species and population (disturbed and undisturbed sites) performance were monitored during the first two growing seasons. Assessment of cutting performance was based on survival, vigour, rooting success, above-ground production and cover.

Assessment of Survival and Vigour

On 7 August 1986, approximately eight weeks after planting, per cent survival and vigour of all cuttings were assessed. Each cutting was classified as either 1) dead, 2) alive but stressed (leaves chlorotic or <50% fully expanded), or 3) alive and vigourous (leaves a healthy green and >50% of the leaves fully expanded). In June 1987, per cent survival overwinter was determined for all cuttings. At this time, it became apparent that some cuttings had been uprooted during the heavy pring run-off. The number and location of cuttings which had disappeared, were noted. On 2 August 1987, a second assessment of vigour was made, following the methods described above.

Assessment of Rooting Success and Above-Ground Production

In mid-August 1986, 40 cuttings of each species were harvested. Approximately equal numbers of cuttings were randomly-selected from each plot, and of each population. Cuttings were excavated by hand leaving enough surrounding soil to ensure that all roots remained attached. The soil was removed by washing; then the number and length (to the nearest mm) of first order roots (roots originating at the stem) were recorded. Rooting success was evaluated by the per cent of the cuttings that were rooted, the mean number of first order roots produced, and the mean cumulative length of first order roots. Cuttings were stored intact, in paper bags and air-dried. In September, the cuttings were oven-dried at 100°C and separated into: roots, leaves, stem growth produced that season, and original stem. The dry weight of each component part was recorded to the nearest 0.01 g. Above-ground production was measured by the number and dry weight of leaves and stems produced during the first growing season.

On 8 August 1987, a sample of the cuttings that had survived a second growing season was harvested. Sampling was limited to the two species, *S. arbusculoides* and *S. glauca*, with high survival rates (>20%),because the number of surviving cuttings of the other species was too small to allow for meaningful sampling. The small number of surviving *Salix* cuttings necessitated reducing the sample to 12 for each species. Cuttings were randomly-selected for harvest irrespective of population (due to low survival), but sampling was stratified among the plots. Cuttings were harvested as previously described. Rooting success and above-ground production were assessed as described above, except that a distinction was made between stems produced in 1987 and stems produced in 1986. Unlike the previous year, stem length was also measured.

Assessment of Cover

In mid-August 1986, cover was visually assessed, by one observer only, for 40 cuttings of each species. Sampling was stratified over all 13 plots and cuttings were randomly-selected irrespective of vigour. A 25 x 25 cm quadrat was centered over each cutting and plot locations were permanently marked. Per cent cover of the cutting was recorded to the nearest 1% (fine resolution was possible because all cuttings were small and cover values ranged between 0 and 2%). Cuttings with cover <1% were assigned a value of 0.1%, to indicate presence. Cover assessment was repeated by the same observer, for the same cuttings, in mid-August 1987.

EXPERIMENT 2 - Effects of Fertilizer and Planting with a Seed Mix

The two species from Experiment 1 that were the most vigourous at the end of the 1986 growing season, *S. arbusculoides* and *S. glauca*, were selected for use in Experiment 2. In May 1987, hardwood branches of both *Salix* species were collected following the methods used the previous year. However, to eliminate the potential influence of differential population performance, sampling was restricted to plants found on the seismic line, since preliminary data analysis indicated the best performance by that population. Branches were put in cold storage until snowmelt.

The experiment consisted of four revegetation treatments: 1) cuttings only; 2) cuttings and fertilizer; 3) cuttings and grass seed mix; 4) cuttings, grass seed mix and fertilizer. The grass seed mix, comprised of 4 native grasses, was obtained from an experimental seed farm (Table 3-1).

Eight revegetation plots (2 x 3 m) were established on the trench located in ROW 2 (Figure 3.1). Four plots were located on the South Link, and four on the north-south section. The two treatments that contained fertilizer were randomly-assigned to plots in the South Link (Figure 3.1), and replicated once; the two treatments that were not fertilized were randomly assigned to the plots in the north-south section, and replicated once.

Cuttings were planted during 25-27 May, 1987. Branches were selected and trimmed following the same methods used in Experiment 1, with the following exception: in an attempt to minimize losses to erosion, cuttings were trimmed to approximately

Table 3-1: Composition of native grass seed mix* applied with shrub cuttings.

SPECIES	PER CENT OF MIX BY WEIGHT	ORIGIN OF SEED
Agropyron violaceum (Hornem.) Lange	82	Northern Alberta
Festuca ovina L.	10	Northern Alberta
Poa alpina L.	5	Alaska
Poa glauca M. Vahl	3	Alaska

* Provided by Decora Landscaping Ltd., Whitehorse, Yukon

15 cm long, rather than 10 cm. Within each plot, 42 to 56 cuttings were planted in rows, with 25 cm between rows, and 50 cm between cuttings. Cuttings from each species were planted alternately in each row, beginning 25 cm from the trench edge. Each cutting was planted to a depth of approximately 10 cm.

Five days before the cuttings were planted, a complete fertilizer (17-25-15) (N-P_2O_5-K_2O) was applied to the designated plots at a rate of 25 g m^{-2} (250 kg ha^{-1}). After the cuttings were planted, the seed mix was sown at a rate of 3.0 g m^{-2} (30 kg ha^{-1}).

Cutting performance was monitored during the first growing season. The effects of the 4 treatments were assessed on the basis of cutting survival, vigour, rooting success, above-ground production, and cover.

Assessment of Survival, Vigour and Cover

To minimize the influence of fluvial erosion, a 10 cm buffer zone, which was exempt from all sampling, was established around the perimeter of each 3 x 2 m revegetation plot, resulting in a 2.8 x 1.8 m plot. Each plot was then divided into 4 subplots, each 1.4 x 0.9 m, which served as sampling quadrats for assessment of survival, vigour and cover. The net result was 8 quadrats (1.4 x 0.9 m) per treatment.

On 3 August 1987, cutting vigour and per cent survival were assessed for all cuttings in each quadrat. In mid-August, per cent cover of the cuttings, of the seeded grass mix, and of all invading species, was estimated to the nearest 1% if cover was <5%, and to the nearest 5% for more abundant species, in each quadrat. Species present at <1% were assigned a value of 0.1%.

Assessment of Rooting Success and Above-Ground Production

During 11-15 August 1987, eight randomly-selected cuttings of each *Salix* species were harvested from each plot. Rooting success and above-ground production were assessed following the methods used in Experiment 1 during the second growing season.

Data Analysis

All data were tested for normality using the Kolmogorov-Smirnov test for goodness-of-fit (Zar 1974, Statistical Graphics Corp. 1985). Appropriate transformations to normalize the data were used when necessary. Analysis of variance (ANOVA) was used to test for differences among species and treatments, for data which were normally distributed. Homogeneity of variance was tested using Cochran's C test and Bartlett's test (Sokal and Rolhf 1981, Statistical Graphics Corp 1985). When the overall F-value in the ANOVA was significant, differences between means were tested using the Least Significant Difference (LSD) method and Tukey's Multiple Range Test (Sokal and Rohlf 1981, Statistical Graphics Corp 1985). For data that were not normally distributed, differences in variances were tested using the Kruskal-Wallis test. Differences between mean ranks were identified using the Dunn test (Zar 1984). Chi-squared contingency tables were used to test for differences in survival between populations (Zar 1974).

RESULTS

EXPERIMENT 1 - Species and Population Performance

Survival and Vigour

Although mean per cent survival of cuttings (averaged over all revegetation plots) at the end of the first growing season, ranged from 87% for *Vaccinium uliginosum* to 64% for *Betula glandulosa* and *Potentilla fruticosa* (Table 3-2), the differences among the 6 species were not significant ($P>0.05$). Survival of each species varied greatly among the revegetation plots. For example, survival of *S. arbusculoides* cuttings ranged from 24% in plot 6 to 100% in plot 2.

Vigour of the cuttings at the end of the first growing season, also varied widely, both within and among the species (Figure 3.2). Most *P. fruticosa* (62%), *A. crispa* (52%) and *B. glandulosa* (45%) cuttings were classified as stressed, whereas most of the *V. uliginosum (48%)* and *Salix* cuttings (49% and 51%) were classified as vigourous. However, most of these differences were not significant: only *P. fruticosa* cuttings had a lower vigour ($P<0.05$) than the other 5 species.

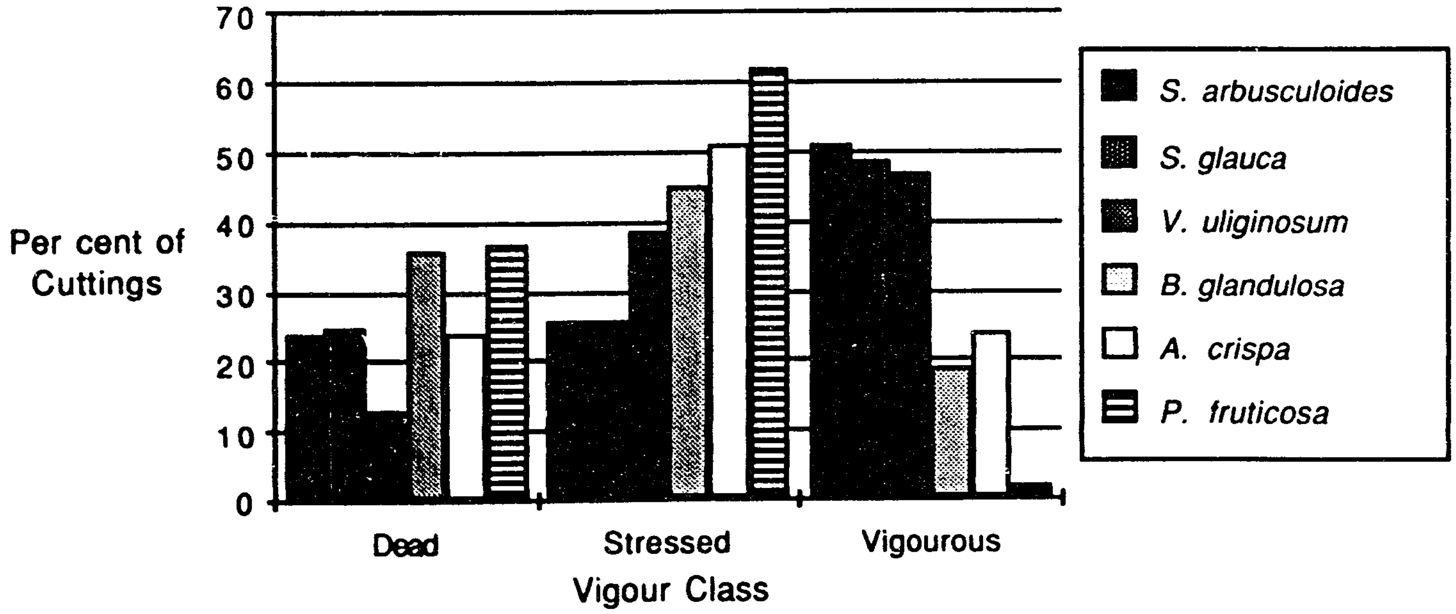
High overwinter losses were recorded for all 6 species. Over the winter, the survival rate of all species, except *S. glauca*, decreased ($P<0.01$) (Table 3-2). Differences among species survival also became apparent. *S. arbusculoides*, *S. glauca* and *V. uliginosum*, had a higher survival rate ($P<0.05$) than the other 3

Table 3-2: Mean per cent cutting survival of each species at the end of the first growing season, after one winter, and after 2 growing seasons, and mean per cent of cuttings lost to erosion after one winter.

SPECIES	n	MEAN % ALIVE, END OF FIRST GROWING SEASON (SD)	MEAN % ALIVE, BEGINNING OF SECOND GROWING SEASON (SD)	MEAN % LOST TO EROSION DURING FIRST SPRING (SD)	MEAN % ALIVE, END OF SECOND GROWING SEASON (SD)
Salix arbusculoides	11	75 a (21.9)	50 b (23.5)	11 d (12.4)	47 b (23.8)
Salix glauca	11	75 a (18.3)	53 ab (24.0)	21 d (17.4)	53 ab (24.0)
Vaccinium uliginosum	12	87 a (12.8)	17 b (13.1)	24 d (13.3)	15 b (12.5)
*Betula glandulosa**	11	64 a (24.2)	1 c (1.7)	24 d (21.1)	1 c (1.7)
*Alnus crispa**	13	76 a (21.0)	0 c (0)	20 d (16.8)	0 c --
*Potentilla fruticosa**	11	64 a (24.8)	8 c (9.8)	14 d (13.5)	6 c (9.8)

n = number of plots for which per cent survival was calculated
Means in the same column with different letters are significantly different (P<0.05) for One Way ANOVA and TMR test.
Means in the same row with different letters are significantly different (P<0.05) for One Way ANOVA and TMR test (% lost to erosion was not included in the row ANOVAS).
For those with * Kruskal-Wallis and Dunn tests were used.

Fig. 3.2: Mean vigour of cuttings of six species after one growing seasons, SEEDS-1986.



Note: Class means for one species do not total 100% due to averaging within each class.

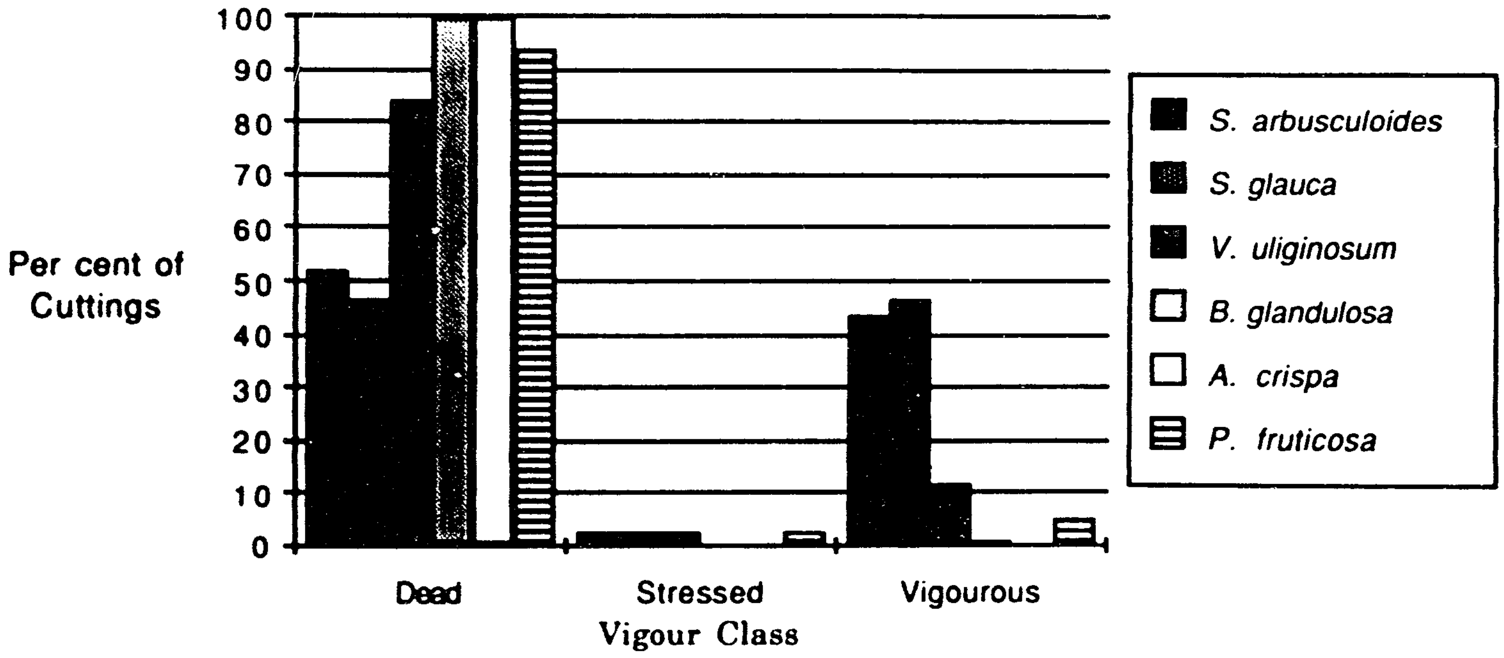
species. None of the *A. crispa* cuttings, and few of the *B. glandulosa* and *P. fruticosa* cuttings survived the winter.

Low survival rates were the result of both overwinter mortality and fluvial erosion during spring run-off. Fluvial erosion was an equally significant factor for all 6 species (Table 3-2).

A vigour assessment done at the end of the second growing season, indicated that those cuttings that had survived the winter also survived the second growing season (Table 3-2) and, in contrast to the first year, few of the cuttings that survived to that point appeared to be under stress (Figure 3.3). The 2 *Salix* species and *V. uliginosum* were equally vigourous after 2 growing seasons and were more vigourous ($P<0.05$) than the other 3 species (Figure 3.3).

Although ANOVAS indicated that, at the end of the first and second growing seasons, survival of *V. uliginosum*, *S. arbusculoides*, and *S. glauca* cuttings was not significantly different, the survival values used in these tests were averages of the per cent survival recorded for each species in each revegetation plot. The averages were highly variable among the plots and therefore differences between species were not significant. Larger sample sizes may have given different results. When mean per cent survival after two growing seasons was calculated for the total populations, survival of *S.arbusculoides* (n=152), *S. glauca (n=146)*, and *V. uliginosum* (n=153) was 45%, 52% and 16%, respectively. Therefore, for practical considerations, the two *Salix* species were considered to have demonstrated higher survival rates than *V. uliginosum*.

Fig. 3.3: Mean vigour of cuttings of six species after two growing seasons, SEEDS-1987.



Note: Class means for one species do not total 100% due to averaging within each class.

Rooting Success and Above-Ground Production

At the end of the first growing season, rooting success was poor ($<20\%$) for all species except the two *Salix* (Table 3-3). The few *V. uliginosum*, *B. glandulosa*, and *A. crispa* cuttings that rooted, produced only thin, short root hairs rather than roots. The roots produced by *P. fruticosa* cuttings were more substantial but all originated from the base of the cutting, and were thick, inflexible and contorted (Figure 3.4), rendering accurate measurement of root length impossible. *S. arbusculoides* and *S. glauca* cuttings produced a similar mean number of roots, however, *S. glauca* had a higher ($P<0.05$) mean cumulative root length (Table 3-3). Roots produced by both *Salix* species originated along the full length of the buried stem (Figures 3.5 and 3.6). All of the sampled cuttings that produced roots survived to the end of the first growing season.

At the end of the second growing season, rooting success of live *Salix* cuttings had remained constant for both species (Table 3-4). Although the mean number of roots produced by *S. arbusculoides* cuttings had not increased, the mean cumulative root length had increased by approximately 60% (Table 3-4). The surviving *S. glauca* cuttings had more and longer roots ($P<0.01$) than first-year cuttings (Table 3-4).

After two growing seasons there was no longer any difference in cumulative root length between the 2 *Salix* species, although *S. glauca* produced a higher ($P<0.05$) number of roots than *S. arbusculoides*.

The number of leaves produced by *S. arbusculoides* cuttings

Table 3-3: Rooting success of each species, after one growing season.

SPECIES	n	SURVIVAL* (%)	ROOTED* (%)	MEAN ** NUMBER OF ROOTS ± SD	MEAN ** CUMULATIVE ROOT LENGTH (mm) ± SD
Salix arbusculoides	33	76	70	4.9 ± 3.0 a	130.1 ± 80.7 a
Salix glauca	32	81	81	6.5 ± 2.8 a	183.7 ± 104.3 b
Vaccinium uliginosum	32	97	9	0.2 ± 0.6	--
Betula glandulosa	32	81	13	0.1 ± 0.3	--
Alnus crispa	32	72	3	0.2 ± 0.5	--
Potentilla fruticosa	32	56	19	1.1 ± 3.2	--

n=number of cuttings harvested
Means in the same column with different letters are significantly different ($P<0.05$) for One Way ANOVA and TMR test.
* Mean of harvested samples only.
**Mean was calculated for live cuttings only.

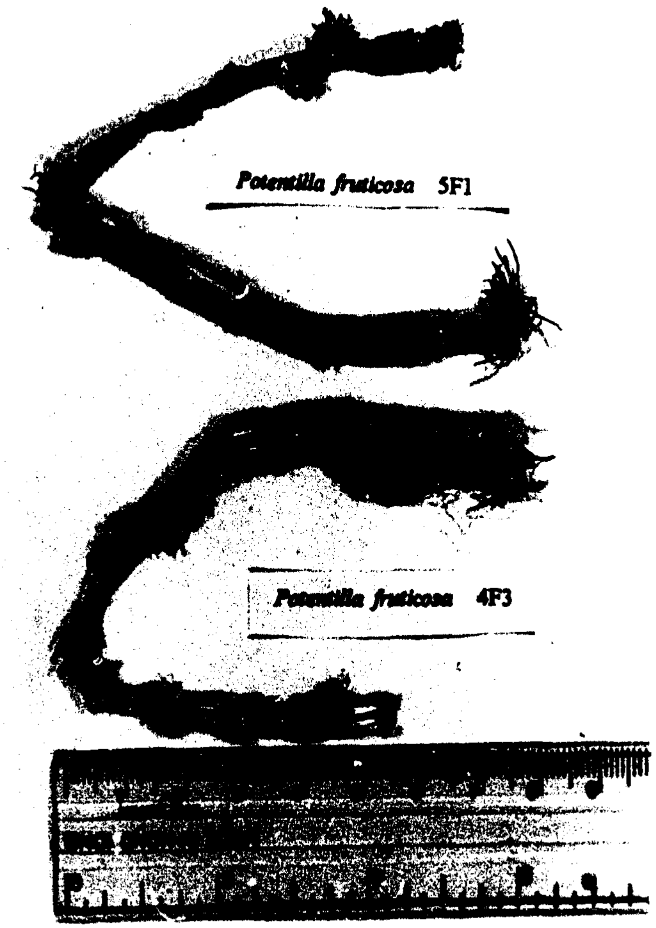


Figure 3.4: Roots produced by *Potentilla fruticosa* cuttings during the first growing season.

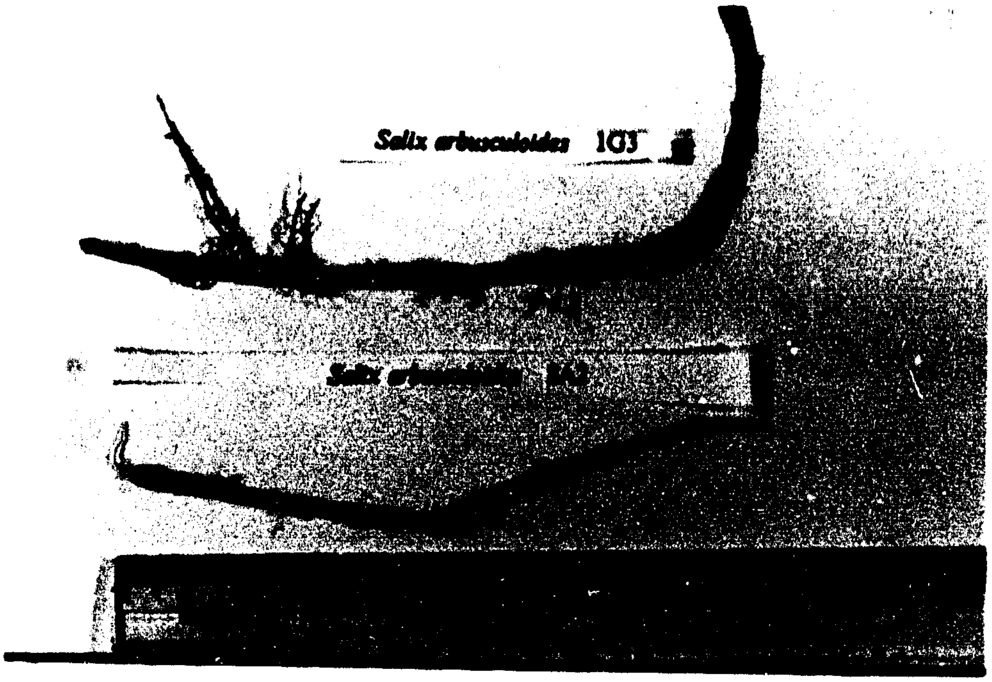


Figure 3.5: Roots produced by *Salix arbusculoides* cuttings during the first growing season.

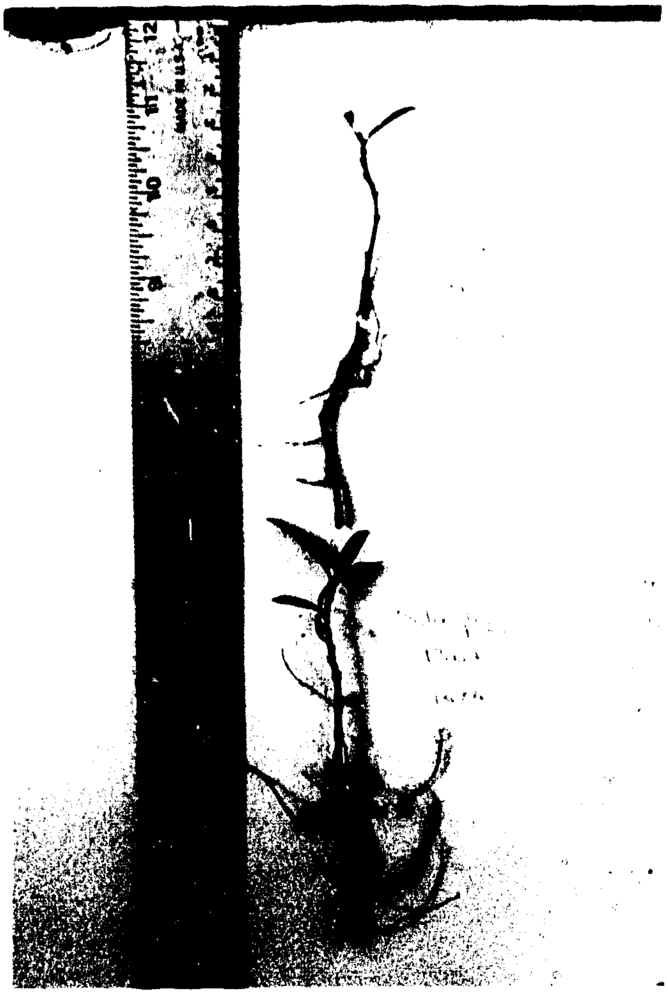


Figure 3.6: Roots produced by *Salix glauca* cuttings during the first growing season.

Table 3-4: Rooting success of live *Salix arbusculoides* and *Salix glauca* cuttings after one and two growing seasons.

SPECIES		n	ROOTED (%)	MEAN NUMBER OF ROOTS ± SD	MEAN CUMULATIVE ROOT LENGTH (mm) ± SD
Salix arbusculoides					
	1986	25	92	4.9 ± 3.0 a	130.1 ± 80.7 a
	1987	11	91	6.8 ± 3.3 ab	206.2 ± 92.8 b
Salix glauca					
	1986	26	100	6.5 ± 2.8 a	183.7 ± 104.3 c
	1987	11	100	10.5 ± 4.0 c	326.4 ± 201.1 b

n=number of cuttings harvested.
Means in the same column, with different letters are significantly different ($P<0.05$) for Two Way ANOVA and TMR test.

did not increase significantly during the second growing season, although a trend toward increased production was evident (Table 3-5). Leaf dry weight increased ($P<0.01$) in the second season relative to the first. The number of stems, cumulative length of stems produced in one season, and new stem dry weight (mean ± SD: 0.01g ± 0.01), did not increase over the two growing seasons. There was, however, an increase in the total stem length and there was a trend toward an increased rate of stem production.

The number of leaves produced by *S. glauca* was higher ($P<0.05$) in the second season, however, the mean dry weight of the leaves produced remained the same (Table 3-5). Although the number of new stems produced during the second season was higher ($P<0.05$), the mean annual cumulative length of stems produced did not increase in the second season. This could be a reflection of the smaller sample size used in the second year, because a trend toward increased production was present. Dry weight of the stems produced in one year (mean ± SD: 0.01 ± 0.06) remained constant over the 2 years.

Cover

Although the increments in growth were small for both species, at the end of the second growing season, there was an increase ($P<0.005$) in mean per cent cover of the surviving cuttings (Table 3-6). There was no difference in cover between the two species at the end of either growing season.

Table 3-5: Mean above-ground biomass production and growth by live *Salix arbusculoides* and *Salix glauca* cuttings, during the first and second growing seasons.

SPECIES		n	MEAN NO. OF LEAVES (SD)	MEAN DRY WEIGHTS(g) OF LEAVES (SD)	MEAN NO.* SHOOTS (SD)	MEAN * CUMULATIVE STEM LENGTH(mm) (SD)
Salix arbusculoides						
	1986	25	9.1 a (3.4)	0.02 a (0.01)	1.4 a (0.7)	13.0 a (11.2)
	1987	11	14.0 a (9.0)	0.07 b (0.06)	2.4 a (1.4)	26.7 a (21.1)
Salix glauca						
	1986	26	5.6 a (2.3)	0.03 a (0.02)	1.0 a (0.6)	11.0 a (6.7)
	1987	11	8.4 b (4.7)	0.04 a (0.03)	2.0 b (1.1)	19.2 a (24.8)

Means in the same column with different letters are significantly different ($P<0.05$) for Two Way ANOVA and TMR test.
*Refers to the stems produced in that season.

Table 3-6: Mean per cent cover of live *Salix arbusculoides* and *Salix glauca* cuttings after the first and second growing seasons.

SPECIES	FIRST GROWING SEASON		SECOND GROWING SEASON	
	n	% Cover ± SE	n	% Cover ± SE
Salix arbusculoides	26	0.5 ± 0.90 a	14	1.0 ± 0.10 b
Salix glauca	32	0.3 ± 0.06 a	21	0.9 ± 0.07 b

Means in the same row, with different letters, are significantly different (P<0.005) for One Way ANOVA and TMR test.

Means in the same column, with the same letter, are not significantly different (P>0.05) for TMR test.

Performance of the Two Populations

At the end of the first growing season, survival and vigour of the cuttings from the disturbed and undisturbed sites, differed for three species (Table 3-7). *S. arbusculoides* cuttings from the disturbed site survived better and were more vigourous than cuttings from the undisturbed site. However, for *B. glandulosa* and *A. crispa,* cuttings from the undisturbed site survived better than cuttings from the disturbed site. *A.crispa* cuttings from the undisturbed site were also more vigourous. Although survival did not differ for *S. glauca,* cuttings from the disturbed site were more vigourous than cuttings from the undisturbed site. By the end of the second growing season, the differences recorded for *S. arbusculoides, B. glandulosa, and A. crispa* cuttings were no longer apparent. However, the difference observed for the *S. glauca* cuttings was even more pronounced. Not only were cuttings from the disturbed site more vigourous ($P<0.025$) than cuttings from the undisturbed site, they also had a higher ($P<0.025$) survival rate (Table 3-7) (Figure 3.7).

There was no difference in the rooting success of the 2 populations of any species after one growing season. Rooting success was not analyzed by population for the second growing season due to insufficient sample sizes for the populations from the undisturbed site (n=2 and 3).

EXPERIMENT 2

The ability of *S. arbusculoides* and *S. glauca* cuttings to

Table 3-7: Survival and vigour of cuttings from the disturbed and undisturbed sites, after one and two growing seasons.

SPECIES	POPULATION	FIRST GROWING SEASON			SECOND GROWING SEASON		
		n	% Alive	% Vigourous	n[1]	% Alive	% Vigourou
Salix arbusculoides							
	D[2]	76	83*	66***	60	42	40
	UD[3]	76	67*	33***	59	47	44
Salix glauca	D	77	77	59**	62	63**	63**
	UD	69	70	35**	55	38**	33**
Vaccinium uliginosum							
	D	77	91	51	61	16	16
	UD	76	83	45	60	13	9
Betula glandulosa	D	76	54**	14	56	0	0
	UD	75	76**	20	65	2	2
Alnus crispa	D	75	67*	5***	60	0	0
	UD	76	86*	32***	61	0	0
Potentilla fruticosa							
	D	76	58	1	60	7	5
	UD	76	66	1	60	3	3

Statistical tests: 2x2 Chi-Squared Contingency Tables

[1] Smaller sample size is due to cuttings lost to erosion.

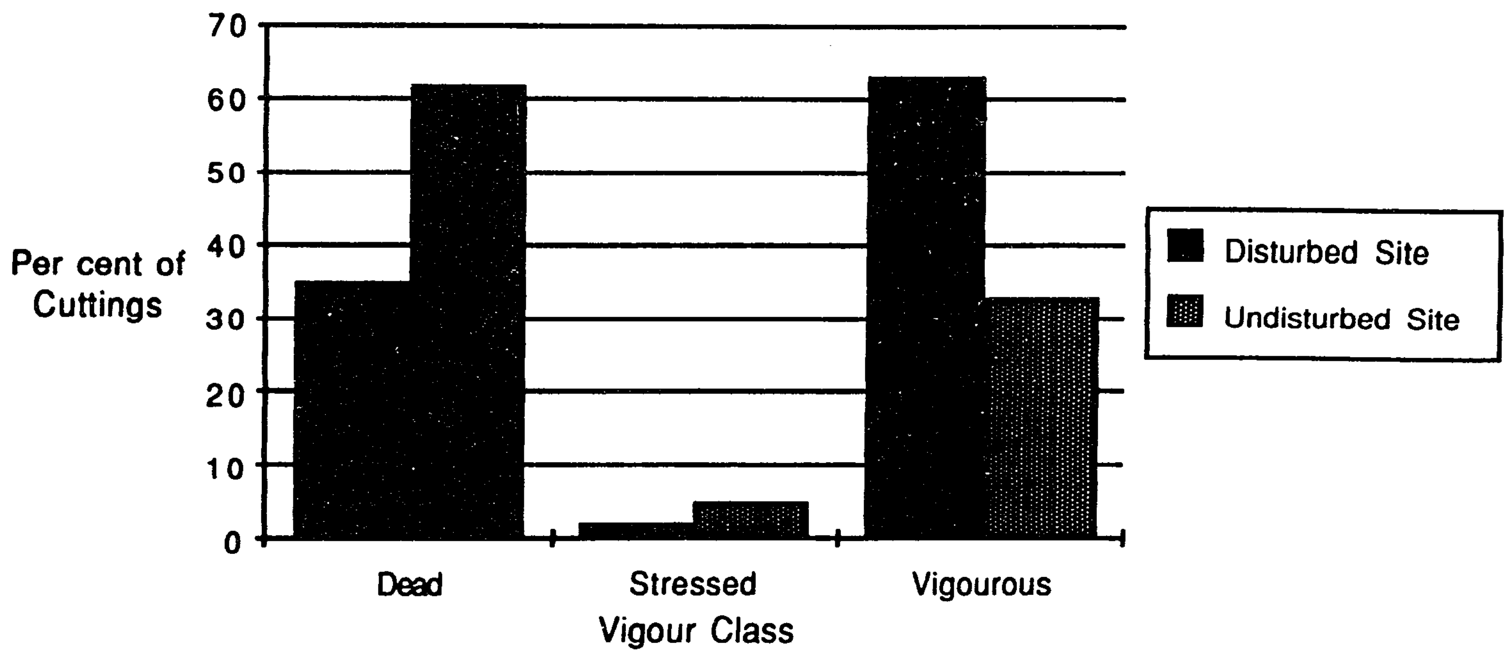
[2] D - Disturbed [3] UD- Undisturbed

*significant difference($P<0.05$) between populations of that species

**significant difference($P<0.01$) between populations of that species

***significant difference($P<0.001$) between populations of that species

Fig. 3.7: Vigour of cuttings of *Salix glauca* populations after two growing seasons, SEEDS-1987.



establish on mineral soil, was confirmed by Experiment 2. At the end of the first growing season, mean per cent survival of both species was high in each treatment, and survival rates were comparable to rates obtained in Experiment 1 (Table 3-8). Survival on all treatments combined was significantly higher ($P<0.05$) for *Salix glauca* than for *S. arbusculoides* (Table 3-8). *S. glauca* also had a higher ($P<0.025$) percentage of vigourous cuttings (mean ± S 79% ± 15.9) than *S. arbusculoides* (63% ± 23.2).

Survival of *S. glauca* cuttings was not affected by any of the treatments. Differences among the treatments were apparent for *S. arbusculoides*: cuttings planted alone, and cuttings planted with fertilizer and seed mix, had a higher survival rate ($P<0.05$) than cuttings planted with just fertilizer, and cuttings planted with just seed mix (Table 3-8). This differential survival cannot be attributed directly to either fertilizer application or to the application of seed mix because cutting survival was not consistently higher or lower for the 2 variations of either treatment.

Although mean per cent total plant cover varied among the treatments ($P<0.05$), cutting survival did not vary consistently with either total cover, or with cover by invading vascular or non-vascular species (Table 3-9). Cover of the cuttings, of both species, did not vary (0.01%) among treatments.

There were no differences in any aspect of rooting success (Table 3-10) or above-ground production (Table 3-11), among the treatments, for either species. When all treatments were

Table 3-8: Mean per cent survival of *Salix arbusculoides* and *Salix glauca* cuttings, in each treatment, after one growing season.

	Salix arbusculoides		*Salix glauca*	
TREATMENT	n	% Alive (SD)	n	% Alive (SD)
Cuttings only	8	88 a (14.8)	8	89 b (15.2)
Cuttings and Fertilizer	8	69 b (21.3)	8	81 b (15.3)
Cuttings and Seed Mix	8	62 b (18.9)	8	83 b (12.2)
Cuttings, Fertilizer and Seed Mix	8	85 a (13.3)	8	86 b (19.7)
All Treatments Combined	32	76 * (19.9)	32	85 * (15.3)

Means in the same column, with different letters are significantly different ($P<0.05$) for Two Way ANOVA and LSD test.

*Significantly different ($P<0.05$) for Two Way ANOVA and LSD test.

Table 3-9: Mean per cent total cover and mean per cent cover by native grass seed mix, invading non-vascula species and invading vascular species, in each treatment (n=8).

TREATMENT	TOTAL COVER (±SE)	NATIVE GRASS SEED MIX (±SE)	NONVASCULAR SPECIES (±SE)	VASCULAR SPECIES
CUTTINGS ONLY	9.2 ± 3.59 a	0	0.2 ± 0.02	9.0
CUTTINGS & FERTILIZER	28.6 ± 4.31 b	0	18.0 ± 8.01	10.6
CUTTINGS & SEED MIX	7.3 ± 0.67 a	2.0 ± 0.71	0.6 ± 0.36	6.7
CUTTINGS, SEED MIX & FERTILIZER	19.4 ± 2.34 b	8.3 ± 0.64	8.2 ± 1.76	11.2

Means with different letters are significantly different ($P<0.05$) One Way ANOVA and LSD test.
Means without letters were not tested.

Table 3-10: Rooting success of *Salix arbusculoides* and *Salix glauca* cuttings in each treatment.

TREATMENT	MEAN (n=2) PER CENT ROOTED (SD) Total	Living	n	MEAN NUMBER* OF ROOTS (SD)	MEAN CUMULATIVE* ROOT LENGTH (mm) (SD)
CUTTINGS ONLY					
Salix arbusculoides	50.0 (0)	83.4 (23.5)	13	7.7 (7.0)	230.9 (199.0)
Salix glauca	75.0 (17.7)	100.0 (0)	13	10.5 (5.7)	310.8 (183.1)
CUTTINGS AND FERTILIZER					
Salix arbusculoides	68.8 (8.8)	92.9 (10.1)	12	5.8 (4.5)	149.3 (151.9)
Salix glauca	75.0 (0)	100.0 (0)	12	8.2 (6.7)	279.5 (194.8)
CUTTINGS AND SEED MIX					
Salix arbusculoides	75.0 (17.7)	100.0 (0)	9	9.8 (4.8)	340.0 (204.9)
Salix glauca	92.9 (10.1)	100.0 (0)	13	6.5 (4.0)	212.5 (111.7)
CUTTINGS, FERTILIZER AND SEED MIX					
Salix arbusculoides	81.3 (8.8)	92.9 (10.1)	14	7.4 (4.6)	201.6 (123.5)
Salix glauca	93.8 (8.8)	100.0 (0)	15	6.5 (3.2)	241.5 (119.5)

Statistical tests: Two Way ANOVAs for all except per cent rooted of live *S.arbusculoides* cuttings, for which a One Way ANOVA was done. Rooting of *S. glauca* cuttings did not vary.
There were no significant differences.
*Calculated for live cuttings only.

Table 3-11: Above-ground production of live *Salix arbusculoides* and *Salix glauca* cuttings in each treatment.

TREATMENT	n	MEAN NO. LEAVES (SD)	MEAN DRY LEAF WEIGHT (g) (SD)	MEAN NO. SHOOTS (SD)	MEAN CUMULATIVE SHOOT LENGTH (mm) (SD)
CUTTINGS ONLY					
Salix arbusculoides	13	5.2	0.02	1.2	10.3
		(4.0)	(0.02)	(0.9)	(6.3)
Salix glauca	13	5.9	0.04	1.4	14.4
		(2.7)	(0.02)	(0.6)	(7.8)
CUTTINGS AND FERTILIZER					
Salix arbusculoides	12	7.2	0.03	1.1	19.6
		(4.4)	(0.02)	(0.8)	(19.6)
Salix glauca	12	9.0	0.04	1.7	15.5
		(5.9)	(0.03)	(0.8)	(17.3)
CUTTINGS AND SEED MIX					
Salix arbusculoides	9	6.8	0.03	1.2	15.2
		(4.4)	(0.02)	(0.8)	(10.9)
Salix glauca	13	5.6	0.04	1.1	11.7
		(3.4)	(0.03)	(0.5)	(5.8)
CUTTINGS, FERTILIZER AND SEED MIX					
Salix arbusculoides	14	6.8	0.03	1.2	19.7
		(5.1)	(0.03)	(0.5)	(16.5)
Salix glauca	15	6.5	0.03	1.2	14.1
		(3.7)	(0.02)	(0.6)	(12.5)

Statistical tests: Two Way ANOVAs. There were no significant differences.
n=number of cuttings harvested

combined, *S. glauca* had a higher ($P<0.05$) rooting success (84% ± 12.9) than *S. arbusculoides* (69% ± 14.9). This was not surprising since cuttings that died tended not to have roots and *S. arbusculoides* had more dead cuttings. When rooting success was calculated for live cuttings only, there was no difference between *S. glauca* (100% ± 0), and *S. arbusculoides* (92% ± 12.2).

DISCUSSION

Survival and Rooting Success

Of the 6 species tested, only the two *Salix* species established well from cuttings (Table 3-12). The success of the two *Salix* species appears to be related to their ability to produce adventitious roots. Although each of the six species survived equally well during the first growing season, those species that rooted poorly (*V. uliginosum*, *B. glandulosa*, *A. crispa*, and *P. fruticosa*) had the highest percentage of stressed cuttings and a higher overwinter mortality than those species that rooted well.

Root production is of paramount importance to the long-term success of any revegetation programme. Roots stabilize substrate as well as provide plants with the moisture and nutrients necessary for survival. The unrooted cuttings that survived the first growing season probably did so by drawing on carbohydrate reserves present in the original stem cutting. Once those reserves were depleted, roots became essential for survival.

The ability of the genus *Salix* to root from stem cuttings is well documented (Chmelar 1974; Densmore and Zasada 1978;

Table 3-12: Summary of performance of stem cuttings for all six species over two growing seasons.

SPECIES	SURVIVAL[1]	ROOTING[1] ABILITY	ROOT PRODUCTION	ABOVE-GROUND PRODUCTION	COVER
Salix arbusculoides	Good	Excellent	Increased	Increased	Increased
Salix glauca	Good	Excellent	Increased	Increased	Increased
Vaccinium uliginosum	Poor	Poor	N/M[2]	N/M	N/M
Betula glandulosa	Poor	Poor	N/M	N/M	N/M
Alnus crispa	Poor	Poor	N/M	N/M	N/M
Potentilla fruticosa	Poor	Poor	N/M	N/M	N/M

[1] Performance rated relative to other species, [2] Not Measured

Schiechtl 1980). However, this ability varies according to species and the conditions under which the species is propagated. Chmelar (1974), in a study of 107 willow taxa, concluded that species which root easily tend to produce roots along the full length of the cutting (diffuse rooting type). Those that do not root easily produce roots only at the base of the cutting (basal rooting type). *S. arbusculoides* and *S. glauca* cuttings both rooted easily and exhibited the diffuse rooting pattern.

Under laboratory conditions, Densmore and Zasada (1978) examined the ability of *S. glauca* cuttings to root when partially submerged in water. Only 4% of the cuttings produced roots and those that did exhibited the basal rooting pattern. The authors concluded that *S. glauca* stems may lack the dormant root primordia that are characteristic of other willows that root easily. In contrast to the results of Densmore and Zasada, the high rooting success and diffuse pattern recorded for *S. glauca* in this study suggests the presence of root primordia on stems. It also illustrates the influence of environmental conditions on rooting potential and the importance of testing species in the field.

The inability of *V. uliginosum*, *A. crispa*, and *B. glandulosa* to establish successfully from cuttings has been demonstrated by others. Holloway and Zasada (1979) tested the rooting capacity of *V. uliginosum* and *A. crispa* cuttings in a controlled environment and found that both hardwood and softwood cuttings of each species had poor (<12%) rooting success, even when treated with rooting hormones. However, Miller and others (1977) cite *V.*

uliginosum as suitable for propagation from stem cuttings. Results presented herein do not support this recommendation.

Dabbs and others (1974) recorded 100% survival of *A. crispa* cuttings one year after planting on a gravel slope at Sans Sault, N.W.T. (150 km northwest of the SEEDS site). However, these cuttings were planted in September, and at the time of assessment had only experienced one growing season. As in this study, by the end of the second growing season, the *A. crispa* cuttings had completely died out (Younkin and Friesen 1974). Poor survival rates (<10%) were also reported for *A. crispa and B. glandulosa* cuttings when tested in both wet and dry sand and gravel substrate in 2 locations in northern Manitoba (Nicholson *et al.* 1978).

Extrapolating from Chmelar's (1974) observations on rooting patterns, the basal rooting pattern and poor rooting success exhibited by *P. fruticosa* cuttings suggests that this species does not produce adventitious roots easily. However, Densmore and Holmes (1987) indicated that large *P. fruticosa* shrubs were successfully propagated from cuttings under greenhouse conditions. The techniques used were not described.

Rooting success of all species may have been affected by the method that was used to select the original cuttings from the shrubs. Shrub branches were collected for cuttings without considering the location of the branch on the plant. Consequently, branches were collected from all positions on the shrubs. Several studies have indicated that some species, particularly those that are difficult to propagate vegetatively, root significantly better when the cutting was selected from near the stem base of the shrub, rather than the top (Schiechtl 1908).

The performance of the 2 *Salix* species during the second growing season suggests that long-term establishment of these species will be successful. Survival remained high for both species; 95% of the surviving cuttings were classified as vigourous, root production had increased significantly between the first and the second growing seasons, and among surviving cuttings there was an increase in above-ground production and cover. Experimental plantings at Sans Sault, N.W.T. demonstrated 100% survival of *S. arbusculoides* hardwood stem cuttings at the end of 3 growing seasons (Younkin and Friesen 1974).

Potential for Erosion Control

Contrary to some recommendations (Younkin 1976; Younkin and Martens 1985; Johnson 1987) this study suggests that planting *Salix* cuttings would not be a suitable means of stabilizing soils in highly erodible areas. Thermokarst subsidence of the trenched area in ROW 3 of the SEEDS site resulted in the channeling of surface runoff from the ROW onto the trench. Surface flow was particularly concentrated during spring snowmelt, and despite the vigourous condition of the cuttings, both *Salix* species were significantly affected by spring run-off. Initial stabilization of areas such as pipelines and ice-rich slopes would likely require the use of erosion control structures. Cuttings would be useful control agents once they became firmly established and formed a more extensive network of roots. *Salix* cuttings and other species planted on slopes and streambanks along the IPL pipeline route did not prevent slumping, and after two growing seasons most cuttings had been washed away during spring run-off (Wishart 1988).

The ability of shrub cuttings to survive Subarctic winters and to stabilize soil may be enhanced by the use of longer cuttings and increased planting depth, since production of roots is proportional to the length of the cutting that is buried (Schiechtl 1980). Mean cumulative root length was higher for both species in Experiment 2, where 30% longer cuttings were planted 30% deeper, compared to Experiment 1. This may also promote greater above-ground production. Densmore and others (1987) found that above-ground production of *S. alaxensis* cuttings was more vigourous at planting depths of 15 and 20 cm than at depths of 10 cm.

During assessment of spring survival, it was apparent that many cuttings had been affected by frost heave, a common process affecting seedling establishment in permafrost-affected soils (Shaver *et. al* 1983). Heaved cuttings were typically found lying prostrate or with only one or two centimetres of stem buried. These cuttings were more vulnerable to spring fluvial erosion. Using longer cuttings may help to minimize the adverse effects of frost heave.

Schiechtl (1980) recommends that in vertical planting, cuttings should be buried at a minimum depth of 30 cm. However, this would not always be feasible in permafrost-affected soils, where spring active layer depths can limit planting depth. In addition, in northern environments caution should be applied to the length of cuttings left above the ground as exposure above the snow can result in desiccation of the seedlings (Frey 1983). Kubanis (1982) recommends limiting cutting exposure above the ground to only a few centimetres.

Effects of Fertilizer

The application of fertilizer neither enhanced nor hindered the performance of either *Salix* species. Densmore and others (1987) found that application of fertilizer during the first and third growing seasons did not directly affect the establishment or production of *Salix alaxensis* cuttings when planted alone or with a seed mix. In their study, soil analysis indicated that, either nutrients were only available to cuttings for a limited time due to leaching from the soil, or, if the fertilizer remained present, competition from seeded grasses rendered the nutrients unavailable to the cuttings. In the latter instances, cuttings were negatively affected by the increased production of grasses on fertilized plots. Results from other revegetation studies in Alaska suggested that on areas with moderate to low nutrient levels, planted grasses used most of the available nitrogen, to the detriment of the woody plants (Native Plants Inc. 1980).

In this study, fertilizer increased total plant cover, indicating that fertil[illegible] remained in the plots. The lack of cutting response to fertilizer application may have been due to competition with other species for nutrients, or to the cuttings' inability to utilize the added nutrients. In the absence of significant root production, cuttings may be unable to use fertilizer. In subsequent years, cuttings planted alone may benefit from nutrient application if fertilizer remained in the soil for more than one growing season. Where nutrient leaching is a problem, it may be wise to delay fertilizer application until the second or third year.

Seeding Grass Mixes with Cuttings

Previous studies suggested that competition for light would negatively affect cuttings that were planted with a grass seed mix. On the Alaska North Slope, the dense cover provided by seeded grasses reduced growth and survival of cuttings directly by shading and indirectly reduced cutting vigour by encouraging use of the area by voles (Densmore *et al.* 1987). Similar results were reported for northern Alberta when grasses and legumes were planted with shrub seedlings (Dunsworth *et al.* 1979). At Norman Wells, NWT, second-year stem growth of cuttings was reduced by as much as 30% in areas with high grass cover (Hardy BBT Ltd. 1986). However, contrary to these results, one year after planting cuttings along with agronomic grasses, Dabbs and others (1974) recorded high germination and growth rates for the grasses, and high overwinter survival for shrubs such as *Salix alaxensis*.

In this study, simultaneously planting native grasses with the two *Salix* species did not affect the performance of either *Salix* spp. Cover produced by the mix (19%) was probably insufficient to result in significant competition for light. The highest total plant cover produced in any treatment was only 29%; 18% was contributed by nonvascular species (mosses). The above studies documenting negative effects of companion grass crops used agronomic grasses that achieved high cover during the first growing season. The success of simultaneous treatments is influenced not only by the early (first and second year) growth rates of grasses but also by growth rates of the shrub cuttings.

To avoid competition among shrubs and grasses, Johnson and others (1981) recommended that seeding be delayed until cuttings were well established. In cases where erosion control or aesthetics are considerations this may not be a practical alternative. One alternative approach to minimizing competition is to reduce fertilizer application rates to slow the initial production of agronomic grasses; another is to select slower-establishing, less-aggressive, native grass species, such as those used in this study.

Although neither fertilizing nor seeding native grasses affected the performance of either species of *Salix*, survival of *S. arbusculoides* cuttings did differ according to treatment. Differential survival could either reflect the vigour of the original shrub, or, could result from variable growing conditions on the trench. The former possibility was controlled for as much as possible by only collecting branches that appeared vigourous. The latter is considered to be a more likely cause, as the trench surface appeared heterogeneous with respect to soil moisture, soil composition, microtopography, and the impact of fluvial erosion.

Survival of all 6 species was highly variable among revegetation plots on ROW 3, presumably for the same reasons. However, variable growing conditions did not influence relative species success, as all species were distributed equally over the entire trench. The high variability recorded for any one species illustrates the need to select taxa with wide ecological tolerances, as any large-scale revegetation programme is likely to encounter variable conditions. Although both *Salix* species performed equally well in Experiment 1, the higher survival rate and more vigourous condition of *S. glauca* cuttings in Experiment 2 suggests that this species has a wider ecological amplitude than *S. arbusculoides,* and therefore would be more consistently successful in revegetation programmes.

Performance of Species Populations

Results from Experiment 1 suggest that, in the case of *S. glauca,* obtaining cuttings from shrubs with a demonstrated ability to establish on disturbed areas, such as seismic lines, will enhance revegetation success. Although cuttings from the two areas did not have obvious phenotypical differences, the higher survival rate and vigour of the cuttings from the disturbed site suggests that some difference between populations does exist. The nature of the difference was not determined, but two explanations emerge. First, the two populations in the sample may be true ecotypes (i.e. genetically different). The existence of ecotypes is highly feasible in a species that exhibits high morphological and geographical variation (Argus 1973). Good and others (1985) have shown that some *Salix caprea* and *Betula pendula* clones taken from nutrient-deficient coal mine spoils survived better than control clones when planted on abandoned coal mine sites in Britain. Ecotypic variation has important implications when species have broad geographical distributions; revegetation programmes using species with ecotypic variation may be most successful if plant materials are procured close to the revegetation site or from plants growing on sites characterized by similar conditions.

It is possible that the differential population survival is related to the condition of the shrubs from which the cuttings were collected. For example, if the shrubs were present on the seismic line prior to its installation, they would have been denuded to ground level and as a reaction would have experienced hormonal imbalances and, at least in the short-term, compensatory growth (McNaughton 1983; Archer and Tiezen 1980). If this imbalance still exists, these individuals may be predisposed to vegetative propagation. The likelihood of a continuing hormonal imbalance would be increased if other disturbances, such as browsing by wildlife, have periodically recurred since installation of the line.
At the SEEDS site, *Salix arbusculoides* shrubs that were denuded to ground level during installation of the ROWs, achieved canopy production of almost 50% of pre-harvest volume and height within one growing season following denudation (Kershaw *et al.* 1988).

CONCLUSIONS

EXPERIMENT 1

Only two of the 6 species tested, *Salix arbusculoides* and *S. glauca*, were capable of establishing from stem cuttings on exposed mineral soil. The other species, *Vaccinium uliginosum*, *Betula glandulosa*, *Alnus crispa*, and *Potentilla fruticosa* failed to produce significant roots and few cuttings survived two growing seasons.

For all species except *S. glauca*, there was no significant difference between the performance of cuttings taken from the disturbed site and that of cuttings taken from the undisturbed site. *S. glauca* cuttings taken from plants established on a seismic line were more vigourous and had a higher survival rate than cuttings taken from plants established in the undisturbed forest. For *S. glauca*, then, use of cuttings collected from previously disturbed areas will likely increase the opportunity for successful cutting establishment.

EXPERIMENT 2

Applying fertilizer had no effect on the performance of cuttings from either species of *Salix*, during the first growing season. Simultaneously applying a native grass seed mix and planting shrub cuttings did not affect cutting performance for either species.

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4. CONCLUSIONS

The need for revegetation programmes specific to Canada's Subarctic will persist with continued development in this region. The ever-increasing disturbance of terrain during industrial-related activities and the need to stabilize these disturbed sites with self-sustaining plant communities, place increasing importance on developing programmes designed to promote the establishment of native plant communities similar to those found on natural disturbances. The harsh climates of Subarctic regions require that such programmes incorporate innovative and sophisticated revegetation techniques (Johnson 1987). Planting *Epilobium angustifolium* rhizome cuttings with fertilizer is one such technique. Additional avenues of research that have been suggested include: seeding native grasses with agronomic species; seeding mixes composed of native grasses, forbs and shrubs; and using various combinations of herbaceous native species (seeds and seedlings) with native shrub cuttings (Johnson 1978; Cargill and Chapin 1987; Walker *et al.* 1987). Results from this study indicate that, depending on the native species selected, each of these approaches is feasible as long as knowledge of how these taxa interact influences the choice of species to be used.

Restoration of newly disturbed soils is essentially a form of secondary succession (Cargill and Chapin 1987). Therefore, such programmes will be most successful if our knowledge of successional theory is applied when selecting species. Will the species inhibit, tolerate, or facilitate the invasion and growth of other species? If these relationships are understood, the direction that revegetation will take, and the success of the programme, can be predicted. All of the trial species that germinated and established in this study are potentially suitable for programmes with restoration-oriented goals, however, their long-term performance must be monitored to confirm their suitability and to facilitate specification of those situations in which they may be useful, particularly how they can be used with other species. For example, first-year cover values of Alyeska polargrass were similar to those of some of the previously tested agronomic species that proved later to retard the invasion of native species (Younkin 1976; Younkin and Martens 1987). Alyeska polargrass may therefore, be suitable for seeding with agronomic species but not with other native species. *Calamagrostis canadensis* may also prove to exclude other species in the long-term.

Results from this study indicate that the two most often used revegetation techniques, planting shrub cuttings and sowing herbaceous seed mixes, can be successfully combined, providing the herbaceous species have slow initial growth rates. Using this criterion, the following species should be tested with shrub cuttings to determine suitable combinations: local *Arctagrostis latifolia*, *Epilobium angustifolium* (rhizomes), *Betula glandulosa*, and *Ledum groenlandicum*. Since fertilizer does not enhance the establishment of cuttings, it would probably be best not to use it in conjunction with seed mixes. However, results of this study indicated that the above trial species grew slowly even when supplied with fertilizer, therefore the need for fertilizer could be assessed on a case-specific basis to ensure that the grasses establish well but do not benefit at the expense of the cuttings.

Fertilized Alyeska polargrass and *C. canadensis* are likely not suitable for use with cuttings, however, since both species develop slowly in the absence of fertilizer, they may in fact be suitable under some conditions, if not fertilized. Individual *A. Tilesii* seedlings appeared to develop rapidly relative to the other species, and so are expected to produce significant cover during the second growing season. Therefore, this species may also prove to be too aggressive for seeding with shade intolerant species. Long-term results are needed to properly evaluate the success of any such combinations.

Fertilizer studies should be undertaken in conjunction with seed mix trials, as nutrient manipulation can be used to influence the direction of recovery. Johnson (1978), for example, has shown that the effect of fertilizer on species' cover and phytomass, changes both with the amount of added nutrients and whether a species is sown alone or as part of a seed mix. Depending on revegetation goals, planting shrub cuttings without a seed mix and applying fertilizer should also be considered as this would enhance invasion by mosses which can assist in mitigating permafrost degradation (Viereck 1982).

The design of revegetation programmes for any region in Canada requires extensive field testing because practitioners will not recommend revegetation materials or methods that have not been proven to work under specific conditions. At present, there are numerous proposed developments for Canada's Subarctic, including a new pipeline from the Mackenzie Delta to southern Canada. A large component of the area that would be impacted by such a project is dominated by Subarctic boreal forest similar to that found at the SEEDS site. Successful revegetation of these lands will be contingent upon field research such as that described herein.

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APPENDIX A

GROWTH CHAMBER GERMINATION EXPERIMENTS USING SELECTED SUBARCTIC NATIVE PLANT SPECIES

INTRODUCTION

Prior to establishing revegetation treatments in the field, germination experiments were conducted in growth chambers for each of the species proposed for use in field experiments. Although germination rates obtained for any species under controlled laboratory conditions do not necessarily reflect germination or establishment rates that will occur under field conditions, such experiments were considered useful to indicate approximate germination rates that might be expected in the field. These data were then used to assist in determining appropriate seeding rates for field experiments and to indicate if seed coat scarification was necessary. The experiments were not designed to determine species' germination requirements or absolute germination rates.

METHODS AND MATERIALS

In January and April 1987, the following Subarctic shrub and herb species were tested in three separate growth chamber experiments: *Arctagrostis latifolia*, *Carex membranacea*, *Betula glandulosa*, *Ledum groenlandicum*, *Arctostaphylos rubra*, *Empetrum nigrum* and *Vaccinium uliginosum*. The seeds had been collected and air dried in the summer of 1986 at the SEEDS study area, and stored in paper bags at -23°C since September 1986. For some shrub species, fruit produced the previous summer remained on the plants in the spring so it was possible to collect and test seed that was produced in two different years, to determine if different cohorts could be sewn together without complicating the field experiments.

For each experiment, 50 seeds of each species were placed on tissue paper, in duplicate petrie dishes, and moistened with distilled water. The dishes were checked every other day, remoistened if necessary, and any new germination was recorded. A seed was considered to have germinated when the radical became visible. For the second and third experiments, but not the first, seeds were removed from the dishes as they germinated. In each experiment, 2 seed treatments of each species were tested: scarified and unscarified. Scarification was achieved by gently rubbing the seed coat with fine sand paper. The duration of each experiment was 55 days.

For each experiment, growth chamber conditions were selected to simulate, as much as possible, typical spring growing conditions at the SEEDS study site. Experiment 1 exposed seeds that had been frozen for 19 weeks to the following light and temperature regimes: 20 hour daylength (0500h to 0100h); light intensity of 150 micron m^{-2} s^{-1}; 50% blue /50% red light; 3°C from 0400h to 0500h, ramping to 16°C from 0500h to 1300h, 16°C from 1300h to 1500h, and ramping down to 3°C from 1500h to 0400h.

Experiment 2 was initiated to replicate conditions in Experiment 1 because for a few days undistilled water had mistakenly been used to moisten the seeds; the only change was that the seeds used had been frozen for 29 weeks. Experiment 3 also used seeds that had been frozen for 29 weeks, and was designed to compare germination rates under slightly ameliorated conditions. The same light regime and temperature pattern was used but the maximum and minimum temperatures were increased to 20°C and 7°C, respectively. Data for each experiment are given as total mean per cent germination (n=2) after 55 days, ± SD (Table A-1).

Table A-1: Mean germination (%)(n=2) after 55 days, of selected native shrub and herb species, in three growth chamber experiments.

SPECIES	SEED YEAR	SCARIFIED	Mean Germination (%)		
			Experiment 1	Experiment 2	Experiment 3
Arctagrostis latifolia	1986	S[1]	9	40	42
		U[2]	18	50	60
Carex membranacea	1986	S	0	0	0
		U	0	0	0
Betula glandulosa	1986	S	6	6	0
		U	4	10	0
Ledum groenlandicum	1985	S	53	24	86
		U	45	42	48
	1986	S	--[3]	--	--
		U	--	42	66
Arctostaphylos rubra	1985	S	--	--	0
		U	--	--	0
	1986	S	0	0	0
		U	0	0	0
Empetrum nigrum	1985	S	0	0	2
		U	0	0	0
	1986	S	0	0	0
		U	0	0	0
Vaccinium uliginosum	1986	S	0	0	8
		U	0	0	4

[1] S = Scarified, [2] U = Unscarified [3] Not tested.

For each experiment day length was 20 h (0500h to 0100h); light intensity was 150 micron m^{-2} s^{-1}; and light quality was 50% blue /50% red.

Experiment 1 - daily minimum temperature was 3°C, daily maximum was 16°C, seeds frozen for 19 weeks.

Experiment 2 - temperatures as in Experiment 1, seeds frozen for 29 weeks.

Experiment 3 - daily minimum temperature was 7°C, daily maximum temperature was 20°C, seeds frozen for 29 weeks.

APPENDIX B

ASSESSMENT OF POTENTIAL FOR REVEGETATION FROM *IN-SITU* PROPAGULES

INTRODUCTION

Excavating and backfilling the simulated pipeline trench resulted in a disturbance characterized by exposed mineral soil mixed with the organic surface layer (including lichens, mosses and various shrubs and herbs) that was originally in place. Organic soils are known to contain buried seeds and vegetative material that can be significant to the revegetation of disturbed sites. The objective of this study was to quantify the contribution that buried propagules (seeds, rhizomes and stems) could potentially contribute to revegetation of the trench.

METHODS AND MATERIALS

Excavation of the trench in ROW 2 was completed during the first week of July, 1986. On July 15, 1986, 100 soil cores (10 cm x 10 cm) were collected at 1.5 m intervals along the length of the trench. Each sample was placed in a tray (20.5 cm x 10 cm x 4.5 cm) and stored in a field greenhouse. Samples were watered daily and monitored for 50 days. All new growth observed in each tray was recorded, by species, as either a seedling or a resprouting shoot. Data were analysed as mean number of seedlings or resprouting individuals per soil sample (79 cm^2).

The inability to regulate greenhouse conditions may have negatively affected the ability of some buried seeds to germinate.

Greenhouse conditions were generally hot (often reaching 45°C), and the soil was frequently dry, despite daily watering. Therefore, these data are not considered to be an accurate measure of total viable buried propagules. Nevertheless, they do provide a general indication of the potential revegetation contribution of *in-situ* propagules, and some of the species that would be involved.

RESULTS

Vascular plant growth was recorded in 11% of the samples. Of these, some samples had more than one individual present (Table B-2); the maximum number present in any one sample was seven. *Equisetum* spp. was present in 6% of the samples, grasses in 6%, and dicotyledonous species in 2%. Over the 50 days, mosses established in 27% of the samples. The term individual was based on the appearance of plants and shoots. (Some of the *Equisetum* shoots may in fact have been portions of the same genetic individual.)

Table B-2: Mean number of 'individuals' (SD) that germinated or resprouted from soil samples (n=100) taken from the trench immediately following excavation.

	MEAN NUMBER OF INDIVIDUALS (-79cm2)	
SPECIES	# of Seedlings	# of Resprouted Shoots
Equisetum spp.	0.59 (4.18)	0.59 (4.18)
Grass spp.	0.07 (0.29)	0.02 (0.14)
Dicotyledon spp.	0.02 (0.14)	0.02 (0.14)

APPENDIX C

SURVEY OF MEANS BY WHICH INVADING VASCULAR SPECIES ESTABLISHED ON UNTREATED SECTIONS OF THE TRENCH

INTRODUCTION

The objective of this study was to determine the relative contribution of buried rhizomes, roots and shoots to revegetation of the trench, during the first growing season.

METHODS

In late August, 1987, 29 (25 cm x 25 cm) quadrats were randomly-located in untreated sections of the trench. All vegetation within each quadrat was excavated, identified to species and recorded as either a seedling, resprouted shoot or rhizome tiller. Without excavating entire rhizome systems, tillers and resprouted shoots of certain species, (e.g. *Equisetum spp.*) could not always be definitively identified as 'individuals', therefore, data were analysed as frequency (presence or absence in a quadrat) of either seedlings, rhizome tillers or resprouted stem shoots, for each species. Seedlings that established on the trench could have derived from in-situ (buried) seeds or from an external source (seed rain). These two sources could not be distinguished.

RESULTS

The predominant method of vascular plant establishment on the trench was by seed (Table C-1). With the exception of both *Equisetum* spp., all herbaceous species had established as seedlings only. The primary means of establishment for both *Equisetum* species, was by rhizomatous growth, although some seedlings were also present. With the exception of *Salix* spp. (unidentifiable cotyledons), all shrubs were present as a result of resprouting from stems.

Table C-1: Establishment method of native species that invaded untreated sections of the trench surface, as measured by per cent presence of seedlings, rhizome tillers or resprouted shoots, in 25 x 25 cm quadrats (n=45).

	TYPE OF INDIVIDUAL (% Frequency)(n=45)		
SPECIES	SEEDLING	RHIZOME TILLER	RESPROUTED SHOOT
Arctostaphylos rubra	0	0	2
Artemisia Tilesii	4	0	0
Betula glandulosa	0	0	2
Carex spp.	9	2	0
Epilobium angustifolium	16	0	0
Equisetum arvense	4	34	0
Equisetum scirpoides	9	69	0
Ledum groenlandicum	0	0	4
Rosa acicularis	0	0	1
Salix spp.	51	0	2
Salix myrtillifolia	2	0	7
Unidentified dicotyledon	13	0	0
Unidentified grass	24	0	0
Vaccinium vitis-ideae	0	0	7