THE REVEGETATION OF DISTURBED DRY TUNDRA AREAS NEAR CHURCHILL, MANITOBA.

by

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Submitted in partial fulfillment
of the requirements
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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

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MASTER OF SCIENCE

Don't it always seem to go
that you don't know what you got
till its gone
they paved paradise
and put up a parking lot

Joni Mitchell

ABSTRACT

In the vicinity of Churchill, Manitoba dry heath tundra is restricted to elevated gravel deposits such as beach ridges and eskers. These sites have been utilized for gravel excavation as well as providing suitable sites for building and road construction. In the Churchill region 413.31ha of open gravel have resulted from human activities, these scar the landscape and reduce the amount of undisturbed dry heath tundra (3752.49 ha).

When left alone these gravel areas may remain devoid of vegetation for many decades. The path of succession is dependent on the size of the disturbance and the resulting topography of the site. Redistribution of the overburden immediately following excavation can greatly improve the natural recovery of the site. Where the overburden is no longer available the site recovery may be greatly enhanced by fertilizer and seed application using *Hedysarum mackenzii*.

Moisture stress is an important limiting factor for tundra vegetation and revegetation success. Soil texture can greatly influence moisture holding capacity of a site. Snow cover can provide protection from desiccating winter winds and increased moisture in spring through melting. This will improve seedling survival and lead to increase vegetation cover.

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GENERAL INTRODUCTION AND LITERATURE REVIEW

1:1 INTRODUCTION

Churchill, Manitoba (58° 47'N 94° 11'W) is an accessible community in the subarctic that has been greatly effected by human activity. European settlement began in the 18th century with the building of Fort Prince of Wales, continuing with construction of the army base, rocket launch and construction of residential and commercial properties to the present day (Hochbaum 1970, Walker 1970). Usually gravel was required for the foundations of buildings and roads to protect the underlying permafrost (Ives 1970, Bliss 1970a, Sugden 1982, Bishop and Chapin 1989). Gravel has been excavated from beach ridges and from late glacial eskers in the vicinity of Churchill. This quarrying has caused considerable environmental damage and yet little has been done to alleviate it.

Gravel excavation requires removal of overlying top soil and vegetation (the "overburden") to expose the underlying gravel (a regolith) and allow assessment of its quality and quantity (Bailey 1981). The overburden is frequently burned or left as a heap adjacent to the open pit, and in some cases this top soil is sold (Bailey 1981). Skaller (1981), Bradshaw (1983) and Street (1985) have shown that damage due to quarrying can often be reduced by spreading the overburden onto the excavation site or the pit when gravel extraction has ended. Such treatment would be least expensive if undertaken immediately after excavation while heavy earth equipment is at the site.

1:2 OBJECTIVES FOR DETERMINING RESTORATION STRATEGIES FOR THE CHURCHILL AREA

In the vicinity of Churchill, revegetation of the disturbed gravel areas would be ecologically beneficial to the presentation and conservation of dry tundra. Enhancement of damaged ecosystems would benefit the local ecotourism industry. To determine which environmental limitations inhibit natural restoration in denuded areas, I designed a research project with four objectives:

1. To map and estimate damage to dry tundra in the vicinity of Cape Churchill.
2. To determine the sequence of natural succession in damaged dry tundra.
3. To compare different revegetation strategies using permanent quadrats in selected gravel quarries.
4. To recommend plant species which may be effective and appropriate in the restoration of damaged dry tundra, in the Churchill area.

A more complete understanding of the natural processes occurring on disturbed dry tundra and the extent of damage will allow for the implementation of an appropriate restoration strategy for the area (Webber and Ives 1978, Bradshaw 1984, Bradshaw 1987, Cargill and Chapin 1987, Forbes 1992b).

1:3 SUCCESSION

Many successional sequences have been described for post perturbation events, for example; after volcanic eruption, island emergence, sand dune formations, glacial retreat and during old field succession (Rydin and Borgegard

1991, Colinvaux 1993, Moral and Wood 1993, Whittaker 1993). Succession is defined as replacement of populations in a habitat through a regular progression to a stable state (Ricklefs 1990). Each stage or unit in succession is referred to as a seral stage (Clements 1928). There is usually a progressive increase in ecosystem complexity through the seral stages. This includes general increases in diversity, stability and uniformity between areas (Churchill and Hanson 1958).

1:3:1 MODELS OF SUCCESSION

There have been three models of successional change described for grass/shrublands; facilitation, tolerance and inhibition (Connell and Slatyer 1977, Noble and Slatyer 1980, Cargill and Chapin 1987, Walker and Chapin 1987, Smith 1992).

In the "facilitation model", the habitat is modified by the plants and benefits those in the next stage (Connell and Slatyer 1977, Bradshaw 1987, Begon et al. 1990, Smith 1992). In this model, progression is contingent on completion of the previous seral stage, i.e. a relay, floristic pathway (Connell and Slatyer 1977, Noble and Slatyer 1980, Bradshaw 1987, Colinvaux 1993). The early arriving pioneers modify their environment making it more favourable to later species than for themselves (Connell and Slatyer 1977, Cargill and Chapin 1987, Svoboda and Henry 1987, Begon et al. 1990, Colinvaux 1993, Smith 1992). For example, the build up of organic matter by early arriving species may facilitate soil improvement and invasion by later colonizers (Connell and Slatyer 1977, Colinvaux 1993). On some substrates, such as recently exposed glacial till, certain taxa such as *Dryas* spp., legumes and alders are able to fix nitrogen and therefore improve the soil nitrogen balance for later successional species (Bradshaw 1987, Svoboda and Henry 1987, Begon et al. 1990, Colinvaux 1993).

In the "tolerance model", habitat modification by early colonizers has little direct effect on subsequent species composition (Connell and Slatyer 1977, Begon et al. 1990). The later colonizers are able to thrive because of their ability to exploit resources or survive should they become limiting regardless of the presence of the initial colonizers (Connell and Slatyer 1977, Noble and Slatyer 1980, Smith 1992). The resulting community will be made up of species able to compete for the resources more efficiently or exploit resources at levels that others cannot utilize (Connell and Slatyer 1977, Smith 1992).

In the "inhibition model" the species which are most likely to invade an area first and prevent establishment by later invaders will dominate (Connell and Slatyer 1977, Begon et al. 1990, Smith 1992). Therefore, pioneer species may inhibit establishment by competitive exclusion and as a result maintain their own dominance in the area (Connell and Slatyer 1977, Noble and Slatyer 1980, Cargill and Chapin 1987).

Succession involves large numbers of simultaneous processes; consequently, aspects of all three models may function at the same time in a given community (Cargill and Chapin 1987, Walker and Chapin 1987, Rydin and Borgegard 1991, Smith 1992). The way by which succession proceeds will be dependent on the life histories of the colonizing species, their ability to exploit the resources, environmental factors, competition and response to herbivory. Pickett et al. (1987) have questioned the validity of retaining the concept of three distinct and contrasting mechanisms to describe succession. Instead, they prefer to analyse each example with an open mind with respect to the method by which it works.

1:3:2 TYPES OF SUCCESSION

There are two types of succession; primary succession and secondary succession (Walker and Chapin 1987). "Primary succession" is defined as occurring on a substrate which had not previously supported a plant community (Begon et al. 1990, Smith 1992) and includes sites exposed by glacial retreat, emergent islands, sand dunes and lava flows (Begon et al. 1990, Rydin and Borgegard 1991, Bliss and Peterson 1992, Smith 1992).

"Secondary succession" occurs at sites which have been influenced by earlier plant communities but, these communities have been partially destroyed and succession begins again from the point of disturbance (Clements 1928, Begon et al. 1990, Smith 1993). In secondary succession, the organic substrates contain dormant seeds and rootstocks which enhance the rate of revegetation recovery (Bradshaw 1987, Cargill and Chapin 1987). Areas likely to undergo secondary succession include; abandoned fields, oil exploration sites, roadsides, vehicle tracks, areas of industrial development, tundra mud-flows, peat harvest sites, forest fire sites and railroad grades (McKendrick 1987, Salonen 1990, McFarland et al. 1990, DeSteven 1991, Bliss and Peterson 1992, Smith 1992).

Borrow pits and gravel pads may undergo either primary or secondary succession depending on the presence of propagules in the gravel substrates which contain little or no organic soil (Cargill and Chapin 1987, Kershaw and Kershaw 1987). The removal of all organic layers from over the gravel leaves substrates similar in nature to glacial till (Cargill and Chapin 1987, Colinvaux 1993), i.e. in the Churchill region this consists of a mixture of finely ground bedrock and stones.

Succession commences after a catastrophic perturbation or after a gradual environmental change in the pre-existing ecosystem. Catastrophic factors, such as fire, flood and human intervention, may set an area back to an earlier seral stage. This is known as "deflected succession" (Godwin 1929, Churchill and Hanson 1958). The direction of succession will remain constant as long as the conditions driving it remain unchanged. The rate of succession is related to environmental influences, e.g. substrate and climate characteristics, availability of propaules and abundance of herbivores (Gleason 1927).

1:3:3 CLIMAX

Climax is the end point of succession when a community is stable, self replicating and, without major disturbance it will persist indefinitely (Sigafoos 1951, Smith 1992). A climax community is often considered to have maximum diversity, productivity, soil maturity and stability compared to earlier seral stages (Whittaker 1953). The concept of climax has been much debated in the scientific community. It may be appropriate to think of succession as a movement toward a steady state or equilibrium situation which may never be completely attained (Smith 1992). The end result may be a fluctuation about an average community which dominates an area (Whittaker 1953).

1:4 TERMINOLOGY/DEFINITIONS

It may be useful to define some of the frequently used terms to avoid later misunderstanding. "Revegetation" is the re-establishment of plant cover on an area from which the original vegetation has been partially or completely (Cargill and Chapin 1987, McKendrick 1991). "Restoration", on the other hand, is concerned with returning a disturbed area to its pre-disturbance state (Cargill and Chapin 1987, McKendrick 1991). Therefore, restoration would utilize local native plant species to achieve the natural plant community (Begon et al. 1990). "Rehabilitation" involves establishment of a plant community on an area that was previously unable to support plant life (McKendrick 1991). This is similar to "reclamation" in which an attempt is made to re-establish some kind of vegetation on a degraded area, transforming the area to some socially or economically useful condition (Bailey 1981, Bradshaw 1984). The type of vegetation used depends on the site characteristics as well as the economic costs and benefits (Bradshaw 1984). Abandoned gravel pads, mine sites, drill pads, roadbeds and abandoned airfields make up many of the degraded or denuded areas in the arctic (Johnson 1987, Bishop and Chapin 1989).

1:5 SOIL AMENDMENTS AND SEED AVAILABILITY

Exposed gravel in open pits is a severe habitat for plant colonization because of inadequate nutrient supply, extreme temperatures and low moisture holding capacity (Grossnickle and Reid 1984, Johnson 1987, Bishop and Chapin 1989). Artificial modification of topography and/or changes to the substrate may make gravel pits more hospitable for colonization (Johnson 1987). Factors which limit colonization, include; low soil-moisture, low nutrient supply, absence of organic particles or finer grained mineral particles in the soil, and an inadequate seed bank or seed rain (Wilson 1966, Miller 1982, Bradshaw 1983, Bradshaw 1984, Shaver and Chapin 1986, Klokk and Rønning 1987, Arnalds et al. 1987, Svoboda and Henry 1987, Runolfsson 1987, Bishop and Chapin 1989, Salonen 1990, Kohn and Stasovski 1990).

1:5:1 NUTRIENT AVAILABILITY AND FERTILIZER TREATMENTS

Nitrogen and phosphorus are often limiting in arctic soils (Wilson 1966, Haag 1974, Miller 1982, Shaver and Chapin 1986, Klokk and Rønning 1987, Truett and Kertell 1992). The application of NPK fertilizer to restore the nutrient balance in denuded sites has been undertaken in many studies with positive results (Chapin and Chapin 1980, Skriabin 1981, Bradshaw 1983, Gartner et al. 1983, McKendrick 1991, Schoenholtz et al. 1992). Chapin and Chapin (1980) applied two different fertilizer combinations a high nitrogen compound (20:10:10) and high phosphorous compound (8:32:16) at the rate of 444 kg ha^{-1} to a vegetation-free organic mat in a tundra community dominated by *Eriophorum* *vaginatum*. Ten years after the initial disturbance and fertilizer application complete vegetation cover dominated by *Carex* spp. and *E. vaginatum* had become established (Chapin and Chapin 1980). Gartner et al. (1983) found that application of NPK fertilizer (25 g m^{-2} as NH_4NO_3, 25 g m^{-2}P as P_2O_5 and 32 gm^{-2} K as K_2O) enhanced recovery by stimulating growth of *Carex* sp. and grass seedlings on disturbed tundra sites. Schoenholtz et al. (1992) applied inorganic N fertilizer for one growing season. The result was improved herbaceous biomass on mined soils thereby minimizing soil erosion (Schoenholtz et al. 1992). Phosphorus fertilizer improves native grass invasion and seedling establishment on barren areas (McKendrick 1987). After a 10 year period, McKendrick (1987) found areas without phosphorus fertilizer treatment averaged 65% canopy cover while fertilized areas had 100% canopy cover. Natural recovery of vegetation on disturbed gravel sites occurred in the absence of fertilizer application, although the recovery rate was considerably slower than in treated areas (Chapin and Chapin 1980, Skriabin 1981, McKendrick 1991).

Alternatives to costly fertilizer application exist for augmenting the nutrients in soil on disturbed areas. Sewage sludge application and planting of species which fix nitrogen can be implemented to improve the nutrient balance of soil (Webber and Ives 1978, Bradshaw 1984, Olsen and Chong 1991).

Acidified soils have been successfully revegetated using sewage sludge. At some sites biomass of vegetation quadrupled after five years (Seaker and Sopper 1984, Olsen and Chong 1991). In 1991, 60% (18 million tonnes) of the sewage sludge produced in the UK was applied to agricultural soils to improve the nutrient and organic content of light textured soil (Chander and Brookes 1991). The United States uses 48% of their five million dry metric tons of municipal sludge on agricultural lands for fertilizer and organic matter components (Seaker and Sopper 1984). This treatment is beneficial in agronomic applications as it improves soil structure, water holding capacity and bulk density and adds nitrogen, phosphorous, potassium, calcium, and organic matter which may be lacking in the soils (Seaker and Sopper 1984, Chander and Brookes 1991). In northern communities sewage sludge is readily available and would require only the cost of transport to disturbed areas. It may, therefore, be a more cost effective alternative compared to repeated fertilizer application.

Species such as legumes which naturally fix nitrogen could also be beneficial to reclamation of disturbed areas in the north (Johnson 1987). It is important to note that raw soil does not possess the root nodule organism *Rhizobium.* Legume seeds therefore require inoculation with appropriate *Rhizobium* strains to be effective (Bradshaw 1984). Certain arctic species such as *Dryas* spp. and *Hedysarum* spp. are able to fix nitrogen (Skriabin 1981, Svoboda and Henry 1987). Incorporation of these species into a restoration strategy would greatly benefit the nutrient balance of the soil.

Undisturbed areas adjacent to open gravel pits can provide a seed source for natural recovery (Salonen and Setälä 1992). Chapin and Chapin (1980) successfully used fertilizer to increase seed production in adjacent undisturbed areas, with the result that the seed rain has significantly increased into the disturbed site. They found that flowering density in adjacent sites increased by 25% after application of phosphorous and potassium. This resulted in the release of over 1000 seeds m^{-2} with germination rates of about 50%. Propagule availability is a crucial feature in the natural colonization of denuded gravel. (Bradshaw 1983, 1984).

1:5:2 WINTER DROUGHT AND SNOW COVER MANIPULATION

Snow cover may provide important protection and moisture for the colonizing vegetation (Polunin 1951, McKay 1970, McKendrick 1991, Carlsson and Callaghan 1991). Ice crystals and strong winds cause abrasion and desiccation of plant parts exposed above the snow surface (Savile 1972, Bliss 1981, Miller 1982, McGraw and Vavrek 1989, Scott et al. 1993). Restoration of vegetation may be enhanced by trapping snow on open gravel areas to protect the pioneer vegetation during winter. This may be done by utilizing snow fences on, or adjacent to denuded areas. Snow also provides important source of moisture (McKay 1970). Lack of spring moisture where snow cover is sparse may restrict establishment by colonizing vegetation (McKendrick 1987, Kohn and Stasovski 1990). Snow cover may also protect plants from damage caused by vehicle movement (Felix and Raynolds 1989a, Felix and Raynolds 1989b). Restricting arctic construction and exploration to the winter months may minimize damage to plant cover (Hemstock 1970, Felix and Raynolds 1989b, Felix et al. 1992, Hayhoe and Tarnocai 1993). Restiction of heavy traffic to winter roads serves to protect vegetation and permafrost from damage (Adam and Hernandez 1977).

1:5:3 SOIL TEXTURE AND ORGANIC MATTER APPLICATIONS

Removal of organic surface layers to facilitate gravel extraction is detrimental to future plant colonization in dry tundra sites. The lack of organic matter and soil particles results low moisture holding capability and low levels of available nitrogen and phosphorous (Runolfsson 1987, Bishop and Chapin 1989). The replacement of the organic matter is a primary goal of restoration (Johnson 1987). Pioneer vegetation fosters the accumulation of dead biomass and leaf litter which decays over time and so provides nutrients. This in turn increases the moisture holding capacity of the soil (Savile 1972, Freedman et al. 1982, Chapin and Shaver 1989, Chambers et al. 1990). Usually the primary colonizers of disturbed gravel are cushion or mat forming species, such as *Dryas integrifolia*. Plants with these growth forms are able to accumulate organic matter (McCarthy 1992). Since the natural accumulation of an organic layer in the soil is a slow process, its artificial enhancement increases the rate of vegetation recovery and reduce the risk of erosion (Cargill and Chapin 1987). During construction or gravel excavation the organic soil should be stockpiled for later replacement on the site (Bailey 1981, Gartner et al. 1983, Skaller 1981, Street 1985, Bradshaw 1983, 1984). Revegetation can be very costly in arctic areas where the overburden has not been stockpiled (Bradshaw 1983). Application of mulch on gravel areas has been ineffective since wind can easily remove mulch where there is no vegetation to hold it in place (Chambers et al. 1990). Planting grass in strips to induce organic accumulation on the gravel can enhance natural revegetation (Runolfsson 1987).

1:5:4 SEED AVAILABILITY AND ENHANCEMENT OF SEED APPLICATION

The majority of arctic and high subarctic plant species are capable of vegetative reproduction (Archibold 1984, Urbanska and Schűltz 1986, Diemer and Prock 1993). Seed production is often limited by the small amount of available heat energy during the growing season (Urbanska and Schűltz 1986, Diemer and Prock 1993). Seed production is also partly determined by the length and quality of consecutive growing seasons, hence a series of harsh years may result in decreased seed yields (Archibold 1984). Colonization of barren areas such as old gravel pits usually relies on the presence and proximity of a nearby seed source (Fridriksson 1987) or a viable seed bank (Archibold 1984).

The availability of seeds from the seed rain is determined by the proximity and composition of surrounding vegetation and the dispersal capabilities of the component species (Gorham 1955, Bishop and Chapin 1989, Salonen 1990). Gravel areas may become totally dependent on incoming seed rain because of the absence of a seed bank in its overlying organic mat (Cargill and Chapin 1987). Seeding a gravel area may improve the rate of revegetation (Hernandez 1974). Southern plant species have been used to achieve an initial vegetation cover to prevent erosion during construction (Webber and Ives 1978, Chapin and Chapin 1980, Densmore and Holmes 1987). However the use of introduced southern species such as *Poa pratensis* var. Nuggett and *Festuca rubra* var. Arctared are thought to have more negative than positive effects on these gravel pads (Younkin and Martens 1987, Cargill and Chapin 1987, Densmore 1992, Forbes 1992a). Complete vegetation cover is reached very quickly, but invasion by native species is hampered by the thatch created once these species die (Younkin and Martens 1987). Native species should be selected since they are adapted to the local environment unlike the introduced southern species (Skriabin 1981, Elliott et al. 1987, Johnson 1987). Utilization of native arctic species in revegetation projects is increasing and companies commercially produce seeds to make them available to the public.

1:6 LIFE HISTORY CHARACTERISTICS

Colonizing species (pioneers) characteristically produce large numbers of propagules, have efficient dispersal mechanisms, have dormant seeds, are able to germinate in open areas and grow quickly (Gorham 1955, Connell and Slatyer 1977, Bradshaw 1983, Rydin and Borgegard 1991, Tilman and Wedin 1991). These characteristics make early successional species superior colonizers to later successional species (Tilman and Wedin 1991). Colonizing species are often referred to as "weedy" species since they are able to survive harsh conditions and invade new areas (Salonen 1990, Forbes 1992c). Localized disturbances are essentially islands surrounded by areas at later stages in development (Bradshaw 1983). These areas may provide propagules of certain colonizer species, although, the majority of plants invade from greater distances (Bradshaw 1983, Salonen 1990). The colonizing species that are present early in succession are replaced by later arriving species. Plants of these later successional species reproduce more efficiently by vegetative means, are often evergreen and either biennials or perennials (McKendrick 1987, Salonen 1990, Tilman and Wedin 1991).

CHAPTER 2

GRAVEL EXTRACTION, LOSS OF DRY TUNDRA AND ITS RECOVERY POTENTIAL.

2:1 INTRODUCTION

Little is known about the extent of disturbance which has resulted from gravel extraction in northern Manitoba. In the vicinity of Churchill, Manitoba much of this disturbance has been within the dry tundra ecosystem. There is a concern that the dry tundra ecosystem has become locally reduced, however, no data are available on the original extent of dry heath tundra or its recent damage.

The first objective of this study was to map the extent of the dry tundra and to determine the degree to which it had been damaged. Such a map would allow a quantitative estimation of human effects on dry tundra. It would provide information which may be useful to future restoration or development plans.

The second objective was to determine the recovery potential of the abandoned gravel excavation sites within the study area. The recovery potential is an estimation of how revegetation is affected by factors such as the size of the excavation, site aspect, abiotic factors, land use, vegetation cover, adjacent vegetation and topography. Once the extent of damage to dry tundra areas is known an understanding of the natural recovery process is needed to better determine what strategies for human intervention will be most effective.

2:1:1 THE GENERAL STUDY AREA AND SPECIFIC STUDY SITES

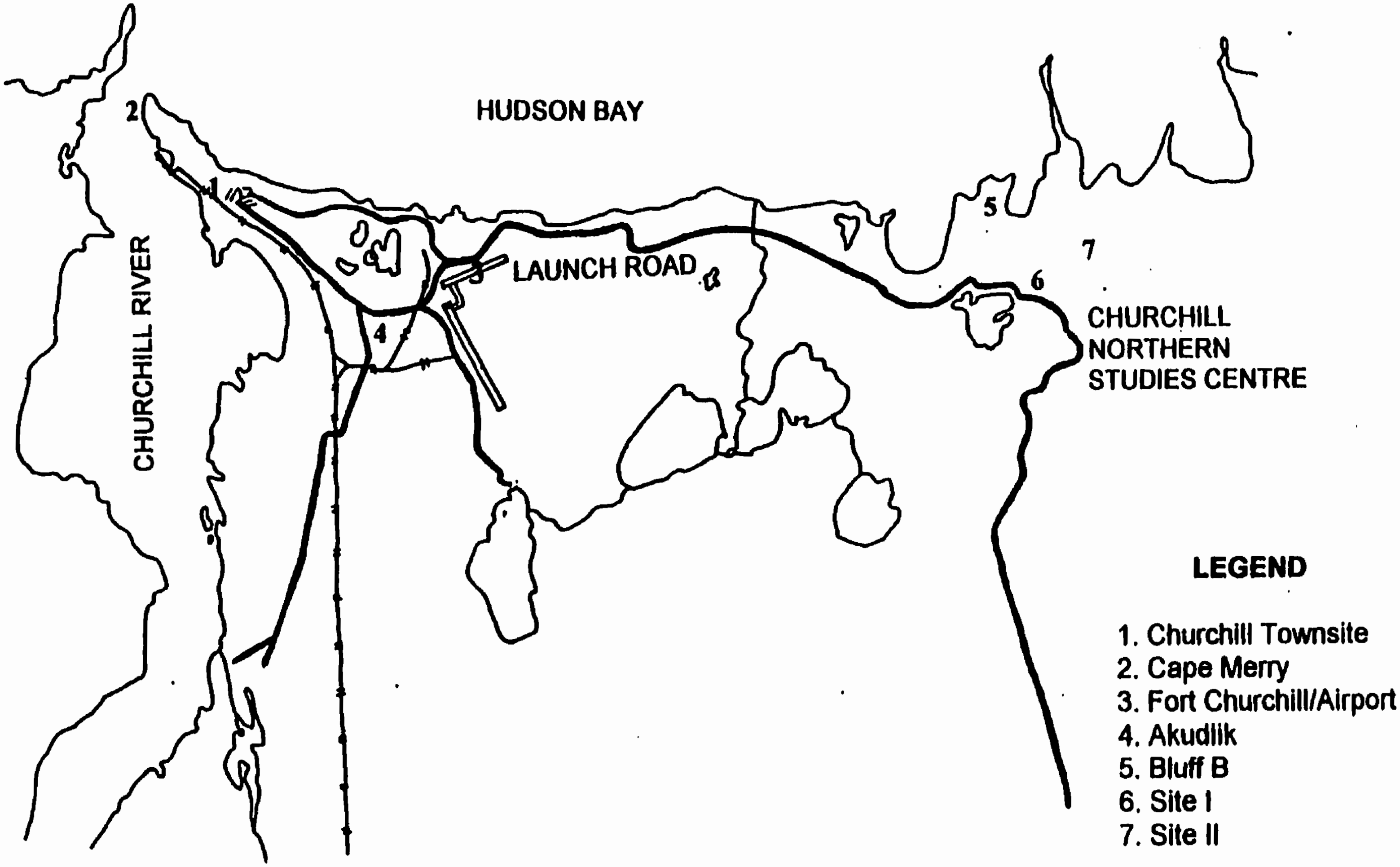
The overall study area extends from the east shore of the Churchill estuary (58° 47'N, 94° 11'W) for 26 km eastwards to the Churchill Northern Study Centre (C.N.S.C.) and from the shore of the Hudson Bay in the north to the launch road in the south (Fig 2.1). The area is considered to be an ecotone between the high subarctic and the low arctic vegetation zones (Bliss 1981a).

Low arctic tundra is characterised by a closed vegetation cover consisting of shrubs (e.g. *Salix* spp. and *Betula glandulosa*) in mesic areas; combinations of sedges and shrubs in hydric areas (e.g. *Carex* spp. and *Salix* spp.), low shrubs (e.g. *Ledum* spp., *Vaccinium* spp., *Empetrum nigrum*, *Rubus* spp. and *Salix* spp.), and rosette, cushion and mat-forming plants on windswept uplands (*Saxifraga* spp., *Lesquerella arctica* and *Dryas integrifolia*) (Polunin 1951, Barsdate and Alexander 1975, Bliss 1978, Bliss 1981a, Bliss 1981b, Sugden 1982, Bliss and Matveyeva 1992). To the south there are islands of forest (high subarctic) which give way to open lichen woodlands (low subarctic) further to the south. The areas of my study were restricted to open tundra without forest cover, specifically the windswept uplands mentioned above, here after known as "dry tundra". Specific sites of interest to this study within the general study area were Cape Merry, Bluff B, Akudlik, Fort Churchill/Airport, Site I and Site II.

2:1:1a CAPE MERRY SITE

Cape Merry National Historic Park is located 3 km northwest of Churchill

Figure 2.1 Map of the Churchill region showing the general study area.



town centre on the eastern peninsula at the mouth of the Churchill River (58° 47'11" N, 94° 11'35" W; Fig 2.1). It is a peninsula of exposed quartzite (precambrian) bedrock extending northward into Hudson Bay. Prior to 1967, vehicular access to the site was limited since there was no road. In 1967 an access road was constructed (Hochbaum 1970). To do this gravel was excavated from a large pit (1.19 ha in area) on the south-west side of the new road. Currently the vegetation on this disturbed site is sparse and dominated by bryophytes and lichens, *Dryas integrifolia* (white mountain avens), *Salix planifolia* (flat leaved willow) and *Achillea nigrescens* (yarrow). The opposite (i.e. north-east) side of the road has remained relatively undisturbed (Hochbaum 1970). The heath community on the north-east side of the road is dominated by lichens, bryophytes, *Rhododendron lapponicum* (lapland rose-bay), *Salix reticulata* (snow willow), *Equisetum variegatum* (variegated horsetail) and *Andromeda polifolia* (bog rosemary). These two communities provide a sharp contrast and illustrate the negative effects of gravel extraction in a tundra ecosystem.

2:1:1b BLUFF B

The Bluff B site is an abandoned gravel pit located south of a bedrock outcrop at Half Way Point, 20 km east of Churchill on the coast of Hudson Bay (58° 46'05" N, 93° 51'00" W; Fig 2.1). The entire area south of Bluffs A and B has been extensively excavated, with 5.68 ha disturbed. Test pits were drilled to determine gravel potential in late 1930's. The area was later utilized by the US Army as a source of gravel for road construction between 1942 and 1944.

Gravel was again removed site during the building of the NRC Rocket Range and its supply roads in 1957 (Johnson 1987, Dredge and Nixon 1992).

The vegetation in Bluff B falls into four topographic zones (Fig 2.2);

i. A mound of coarse gravel; 5 m high, particle size >16 mm. The gravel was unstable and shifting. There was vegetation on the top of the hill and near its base but not on the sides. The vegetation was composed of *Dryas integrifolia*, *Shepherdia canadensis* (soapberry) and *Salix planifolia* (flat-leaved willow).

ii. Scraper scars each with two ridges, less than 0.5 m high with a trough between them). Two scars radiated from the mound in a north-west direction. The substrate in the trough was coarse gravel and sand (actual particle size; 0.25 - 16 mm). The ridges were devoid of vegetation but the trough was vegetated with *Dryas integrifolia*, *Shepherdia canadensis* and *Salix planifolia*.

iii. A depression, 0.5 m deep, surrounded by gravel ridges parallel to the access road and west of the gravel mound. The depression was moist and supported a willow community of *Salix planifolia* and *Salix lanata* (lime willow).

iv. This vegetation zone was south of a bedrock outcrop (i.e. a bluff). The bluff provided some protection and also acted as a snow trap during the snow season. Snow-melt in the spring provided moisture which was then available for plant growth. Adjacent undisturbed areas supported a dry heath tundra community which included: lichen species, *Dryas integrifolia*, *Empetrum nigrum* (black crowberry), *Andromeda polifolia* and *Pyrola grandifolia* (large-

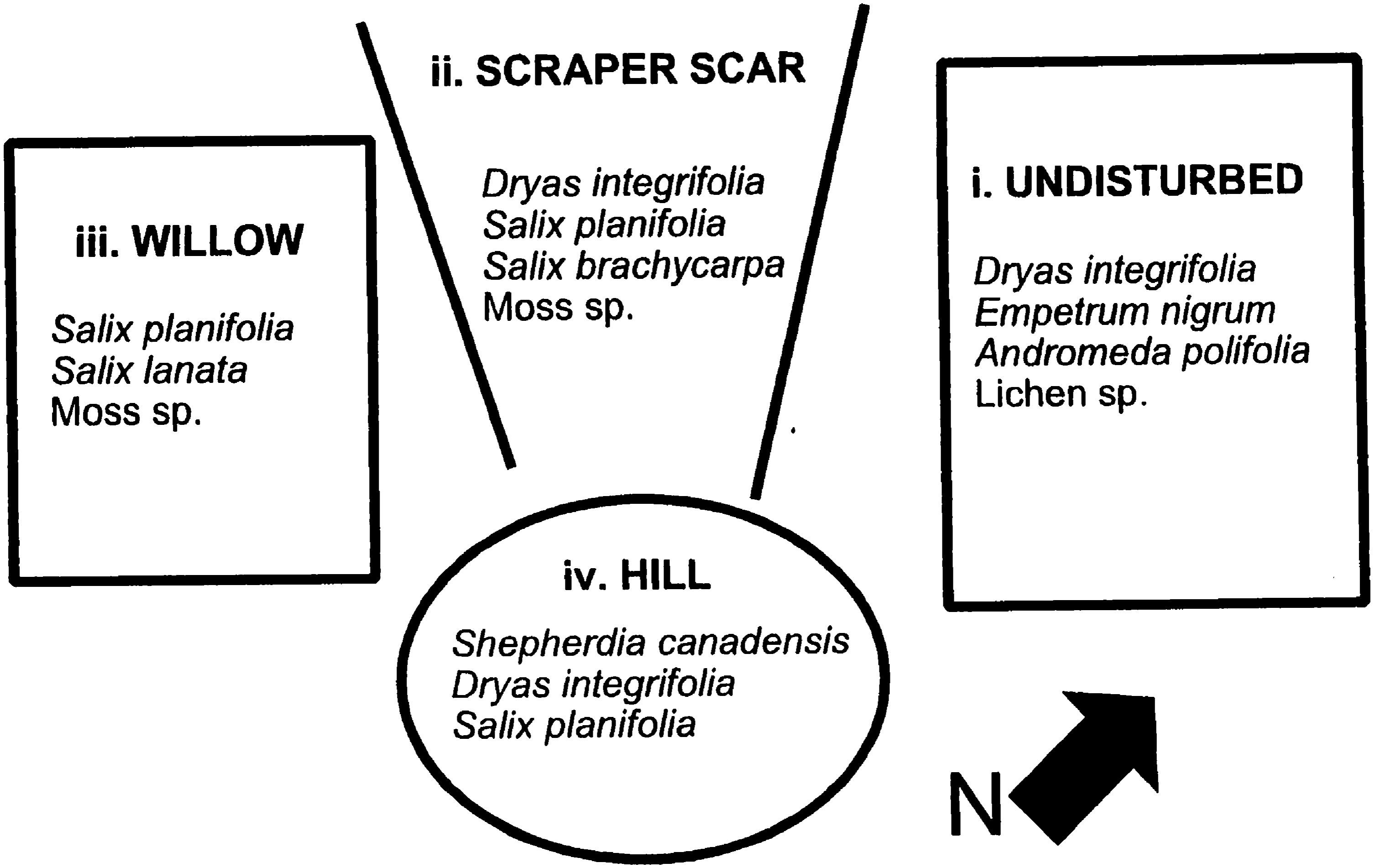


Figure 2.2 Schematic drawing showing relative positions of the four plant communities at Bluff B. The representative species for each zone are given (not to scale).

flowered wintergreen).

2:1:1c AKUDLIK

Akudlik is an abandoned village site located 3 km south of the town of Churchill at the junction of the Kelsey Blvd. and Goose Creek Road (58° 44' N, 94° 06' W; Fig 2.1). The original settlement was built by the Federal Government to house Inuit and administer the Northwest Territories. The buildings were later abandoned and were removed by 1981 leaving a flat gravelly area devoid of buildings (except for two maintenance sheds). The remaining area was a flat gravel pad, dominated by coarse sand (particle size; 0.25 mm) and strewn with debris. The vegetation in the area was dominated by *Festuca brachyphylla* (alpine fescue), *Achillea nigrescens*, *Parnassia palustris* (northern grass-of-Parnassus) and *Gentiana propinqua* (arctic gentian).

2:1:1d FORT CHURCHILL/AIRPORT

The Airport and Fort Churchill were constructed in 1942-44, and are located 8 kilometres east of the town of Churchill on a quartzite ridge (58° 45' N, 94° 04' W; [A] Fig 2.1) (Cheney & Brown Beckel 1955, Johnson 1987). The site served as a U.S. and Canadian Army training and experimental centre between 1942 and 1964 (Johnson 1987). In 1964 the American military presence decreased while the Canadian Armed Forces maintained a small detachment of personnel at the base from 1970 until their withdrawal in 1980 (Johnson 1987). The base was officially closed in August 1980 and the buildings removed by 1981 except for the airport and one service building (Johnson 1987).

The study site was located on the north side of the launch road adjacent to one of the remaining buildings (now used as a Coast Guard building). The immediate area provided both undisturbed and disturbed plant communities. The area was flat and delineated by roads into rectangular zones. The gravel substrate was hard packed and dominated by coarse and fine gravels (particle size 2 - 16 mm). The undisturbed plant community was dominated by *Hedysarum mackenzii* (wild sweet pea), *Castilleja raupii* (indian paintbrush), *Taraxacum lacerum* (Greenland dandelion), *Epilobium angustifolium* (fireweed), *Salix planifolia*, and *Polygonum viviparum* (alpine bistort). The disturbed plant community was dominated by *Elymus arenarius* (sea lime grass), *Juncus arcticus* (arctic rush), *Dryas integrifolia* and *Salix planifolia*.

2:1:2 CLIMATE OF THE STUDY AREA

Churchill is located in the subarctic ecoclimatic region (Scott 1995) with a growing season of approximately 110 days, (i.e. frost free days) (Dredge and Nixon 1992). Subarctic climates characteristically display cool, short summers and cold winters with little snowfall (Antevs 1928). Climate data were obtained from the Churchill Weather Station located at the airport and from the Winnipeg Climate Centre. The annual mean temperature for Churchill is -7.1 °C (calculated from data collected between 1943-90) (Fig 2.3). June, July, August and September are the only months which register mean daily temperatures above zero (Fig 2.3). The years during which the current study took place (1992-1994) had mean daily temperatures of -8, -7.6 and -6.7 °C, respectively

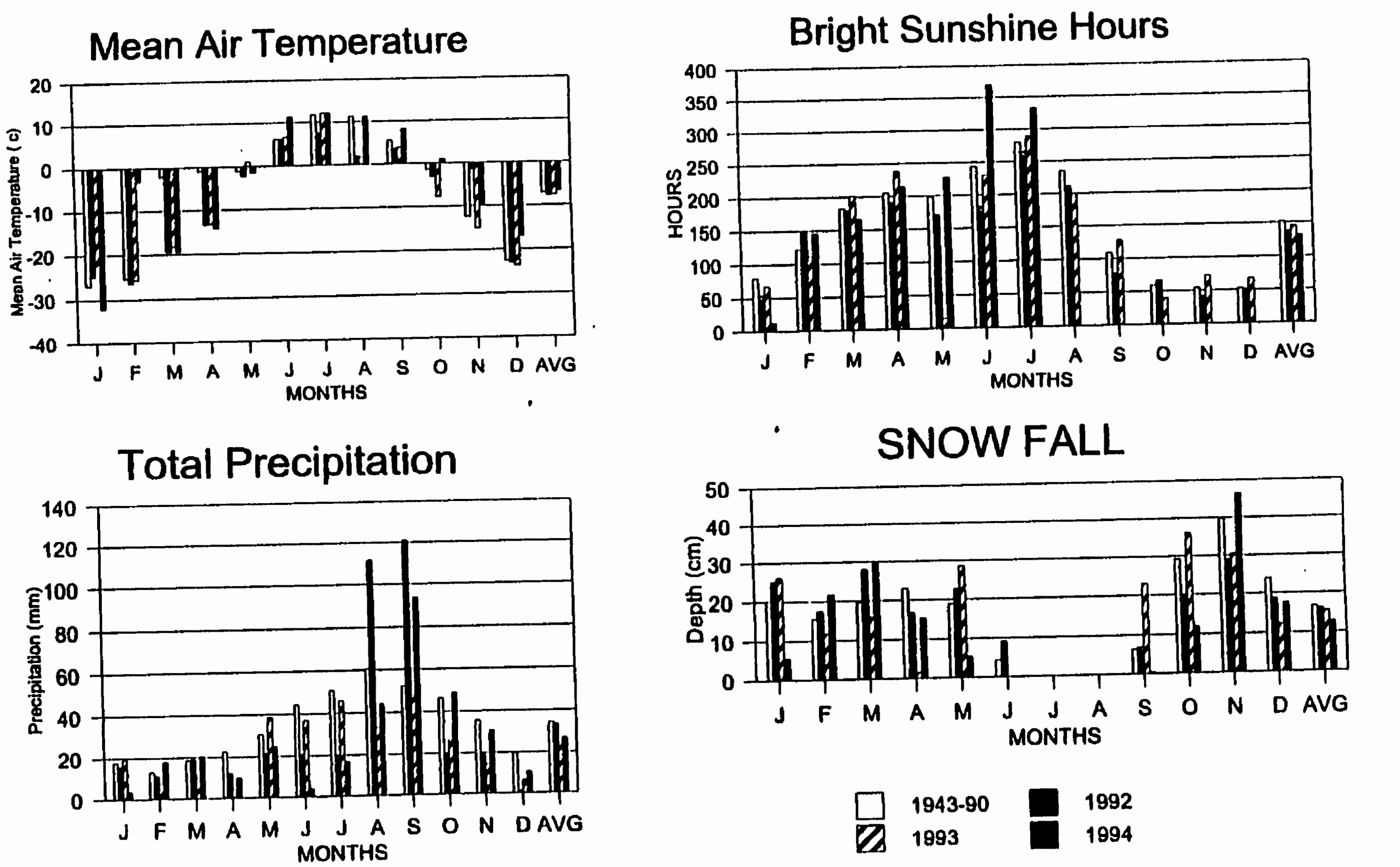


Figure 2.3 Air temperature, bright sunshine hours, total precipitation and snow fall for the period 1943-1990, with individual study years (1992, 1993 and 1994) data for the Churchill Airport, Churchill, Manitoba.

(Fig 2.3). These low temperatures retard the decay of organic matter in the area and help account for thick peat deposits in the region (Dredge and Nixon 1992).

The mean number of sunshine hours for the study area exceeded 200 between April and August for each year from 1943-1990 and during this study (Fig 2.3). The Churchill weather station has recently become automated and the sunshine hour data has not been available since August 1994.

Mean annual precipitation in Churchill is 400 mm (Dredge 1992). Monthly Precipitation is highest in August and September for each of the study years except 1993 (Fig 2.3). 1992 was considerably wetter during August and September (111.4 and 121.0 mm respectively) than 1993 which had only 32.7 mm and 48.0 mm for the same months (Fig. 2.3). The mean precipitation due to snowfall was greater for the months of October 1993 (39.8 cm) and November 1994 (46.6 cm) than for the 1943-90 mean (Fig 2.3).

Churchill has prevailing northwest winds which average 21 km/hr with extreme gust speeds up to 161 km/hr (Table 2:1) (Dredge and Nixon 1992). The wind speed for the study years was more than double that of the 47 year average (Table 2:1). The strongest winds were seen in 1993, 47.78 km/h while 1992 and 1994 were only slightly slower at 45.53 km/h and 45.94 km/h respectively (Table 2:1). These strong winds combined with low annual temperatures encourage freezing and account for the continuous permafrost in the area (Dredge and Nixon 1992).

Table 2:1 Mean annual wind speed data (+/- 1SD) for the study years 1992, 1993, 1994 and 1943-1990 for the Churchill Airport, Churchill Manitoba.

YEAR	AVERAGE ANNUAL WIND SPEED km/h
1943-1990	21.67 (+/- 2.06)
1992	45.53 (+/- 4.87)
1993	47.78 (+/- 5.28)
1994	45.94 (+/- 3.23)

2:1:3 PERMAFROST/SOILS

Churchill is located within the zone of continuous permafrost (Fig. 2.4)(Bliss 1978, Sugden 1982, Dredge and Nixon 1992, Dredge 1992, Scott 1995). "Permafrost" is defined as perennially frozen ground, in which the temperature remains continuously below 0 °C both in winter and summer (Polunin 1951, Pettapiece 1974, Brown 1977, John 1977, Tieszan 1978, Sugden 1982, Strahler and Strahler 1987, Dredge 1992). The permafrost in the Churchill region is approximately 80 m thick (Dredge 1992). In permafrost regions, the soil surface is subject to a seasonal thaw i.e. the "active layer" (Tieszan 1978, Sugden 1982). Soils in which the permafrost comes to within 1-2 m of the surface are referred to as cryosols and these are affected by vertical soil disturbances due to freeze/thaw action known as cryoturbation (Pettapiece 1974, Scott 1995).

Vegetation insulates the underlying permafrost layer from the heat of summer and the cold of winter (Bliss 1970b, Walker 1970, Billings 1973, Sugden

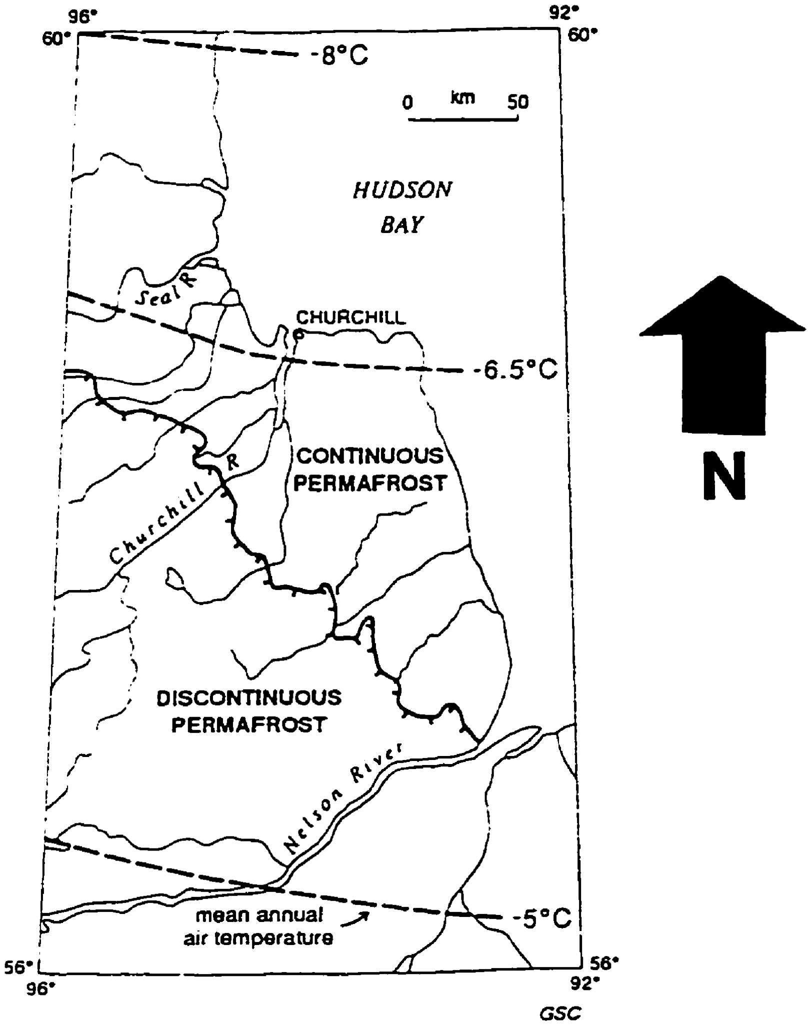


Figure 2.4 Permafrost distribution in the Hudson Bay lowlands (Dredge and Nixon 1992).

1982, Lawson 1986). Removal of the insulative vegetation will decrease the albedo or reflectance of the surface and increase soil temperatures in summer (Bliss 1970b, Rouse 1973, Webber and Ives 1978, Sugden 1982, Chambers et al. 1990). Removal of the insulative vegetation to expose an organic soil decreases albedo, resulting in raised soil temperatures, increasing seasonal thaw depths and melting upper layers of permafrost (Johnson 1969, Rouse 1973, McKendrick 1987, Forbes 1993, Emers et al. 1995) Decreasing albedo allows summer heat to be absorbed, deepening the active layer and melting more permafrost (Bliss 1970b, Billings 1973, Webber and Ives 1978, Sugden 1982). Conversely, exposure of light coloured mineral soil increases albedo and decreases the depth of thaw and could result in an increase in permafrost thicknesses (McKendrick 1987, Forbes 1993). Increasing the albedo of the soil surface changes the depth of permafrost and causes the active layer to thin (MacKay 1970, Emers et al. 1995). Changes in the depth of the active layer can cause cryoturbation and/or thermal erosion (i.e. thermokarst or a slumping or subsidence of the ground surface or erosion) (Johnson 1969, Bliss 1970b, Ives 1970, MacKay 1970, Sugden 1982, McKendrick 1987, Racine and Ahlstrand 1991). Downward percolation in permafrost areas is impeded by the impervious permafrost layer. Drainage is, therefore, lateral or the soil becomes saturated (Hill and Tedrow 1961, Walker and Peters 1977, Sugden 1982).

Root systems of arctic plants cannot penetrate the underlying permafrost layer, they are restricted to the "active layer" which is usually the upper 25 cm of the soil (Bliss 1970b, Bell and Bliss 1978, Billings et al. 1978, Tieszan 1978). The permafrost holds moisture and nutrients within it, thus they are not available to plants (Polunin 1951). Vegetation is dependent on nutrients and moisture in the active layer (Tieszan 1978). An increase in the depth of the active layer after vegetation removal may release nutrients, increase the rate of decomposition, mineralization and nutrient cycling rates (Haag 1974, Ulrich and Gersper 1978, Matthes-Sears et al. 1988). In addition a general change in the moisture regime within the area may occur and result in a shift from a dry zone to one with standing water. Dry tundra vegetation would be replaced by wet tundra plant communities (including bryophytes) (Forbes 1993).

2:1:3b GLACIAL HISTORY

The topography of the Churchill area has been greatly affected by glaciation. Glaciers scoured the bedrock in the area and deposited glacial till (Strahler and Strahler 1987, Dredge 1992). The thickness of till in the Churchill area ranges from 5-20 m (Dredge 1992). Scouring, by rocks embedded in the glaciers, resulted in occasional smoothly rounded outcroppings of bedrock. These are covered with striations oriented in the direction of the ice movement (Johnson 1987, Strahler and Strahler 1987, Dredge 1992).

The Canadian Shield and arctic archipelago were covered by the Laurentide glacier during the last glaciation of the Pleistocene epoch, the "Wisconsinan Glaciation" (Antevs 1928, John 1977). The Churchill area was completely ice covered for the entire Wisconsin Glacial period (Dredge and

Nixon 1992). The Laurentide Glacier reached its maximum spread 18,000 years ago. At that time Hudson Bay was its centre and covered by a depth of 2700 m of ice (John 1977, Johnson 1987, Dredge and Nixon 1992). The sheet margins retreated to the Churchill area about 8000 years ago (Dredge 1992). As the Laurentide Glacier began to recede 13,000 years ago, lakes formed around its margin, one of which was Lake Agassiz (John 1977, Fenton et at. 1983, Dredge and Nixon 1992). Lake Agassiz had a maximum area of 200,000 square kilometres and survived for approximately 5000 years (Dredge 1992). Eight thousand years ago the ice mass which had blocked drainage into Hudson Bay melted and Lake Agassiz suddenly drained northwards (John 1977, Dredge 1992). The Tyrell Sea flooded the Hudson Bay lowlands to a depth of 150 m and extended inland 100 km from the present coastline (Johnson 1987, Dredge 1992). Advancing glaciers had depressed the landscape by their weight and the effect of glacial retreat is a rebounding of the depressed area (John 1977, Johnson 1987). The coastline gradually receded to the present configuration of Hudson Bay as isostatic rebound occurred (John 1977, Fenton et al. 1983, Johnson 1987, Dredge 1992, Dredge and Nixon 1992). Churchill is located near the centre of the postglacial uplift which followed the melting of the Laurentide ice sheet (Scoggan, 1957, Tushingham 1992). The current rate of uplift is estimated to average 8-9 mm per year (Hansell et al. 1983, Tushingham 1992).

2:2 METHODS

2:2:1 MAPPING THE EXTENT OF UNDISTURBED TUNDRA AND TOTAL AREA OF GRAVEL EXCAVATION

Maps were drawn up using 1:50,000 topographic maps and aerial photographs. The topographic maps provided the physical features while the aerial photos were used to determine the vegetation zones and pit sizes. The areas of the dry and damaged tundra were then calculated using the Series 5000, Geo station computer program.

Figure 2:5 and 2:6 were derived from 1992 aerial photographs by Manitoba Hydro. I ground truthed information in some of the vegetation zones to ensure accuracy. Many smaller gravel excavation sites were not visible in the original photographs but I was able to incorporate them in the revised map (Fig. 2.6).

Base Maps

The base maps used were 1:50,000 land form maps. These were produced between 1958 and 1990, and show topographic features (i.e. coastlines, lakes and roads). They provided the outlines for the maps onto which additional vegetation information was superimposed following digitization.

Aerial Photos

The black and white aerial photos were taken in 1993 for Manitoba Hydro (series MH93565402 line 1-17). Gravel zones show up on aerial photos as bright white (often square) areas which are clearly visible from the shades of grey which make up the vegetated areas. I made a tracing from these photos of the coastline, roads, ponds and pits in the area between the town and the C.N.S.C., this along with the aerial photos served as my guide map. I numbered all 54 pits on this guide map. Then I visited each of the 54 pits to confirm that they were indeed abandoned gravel excavations or gravel pads. I amended the guide map to include some small sites which were not clear from the initial photo scan and numbered these as well. The photos were examined and the vegetation zones were drawn directly on to these photos. I added gravel excavation sites directly onto the photos and corrected some vegetation zone delineations.

Digitization

The base maps were initially hand traced and then digitized. Vegetation zones were also digitized and superimposed onto the base maps. The computer program used to produce the map was Series 5000, Geostation supplied by Auto-trol Co. This cartography program also supplied locations (latitude and longitude) and areas (ha) for the different map zones. The program is equipped with a data base which allows additional information to accompany map locations.

Ground Truthing

Ground truthing was undertaken during the summer of 1994 during which I visited each of the 54 gravel excavation sites.

There was an error factor of 0.0025 ha in the area calculations of the program. This was due to distortions in the aerial photos which were not ortho-corrected prior to their digitization.

2:2:1a MAP ZONES

Figure 2:6 has two zones designated; "Excavation" and "Developed Areas". This map was created to show the gravel pits since some of these are quite small and may not be visible when the additional zones are superimposed.

Although these areas refer to underlying substrates and not vegetation composition, they are indicative of dry tundra areas. The marine aggregate and esker (non-marine) substrates and exposed bedrock areas correspond with dry tundra vegetation cover.

There are seven zones delineated by Manitoba Hydro in Figure 2:5 that I identified as supporting dry heath tundra:

1.Marine aggregate areas (Wa). These are areas of coastal glacio-marine depositions of sand and gravel and they make up eskers, kames, spit-bars and beaches.

2.Marine aggregate - mineral soil areas (Wa/Ms). These are moderately well drained sites which may include eskers, kames, raised beach ridges, beaches and spits over glacio-marine deposits of sand and gravel.

3.Marine aggregate - organic soil areas (Wa/Os). These areas are imperfectly drained soils consisting of sand, silt, peat and fine grained glacio-marine deposits. These areas are ice rich and may be associated with fen, bog and peat polygon areas.

4.Exposed bedrock areas (ER). These are massive granitic formations which may be associated with marine aggregates near the coast. Vegetation cover is sparse on exposed surfaces and dominated by lichens and mosses. Shrubs and isolated trees may be found in cracks or in depressions with mineral soil.

5.Rock and aggregate complexes (RA). These are dominated by silt and clay with scattered rock and rubble present. Shrub vegetation and stunted trees and moss ground cover occur. They may be associated with bogs, fens or peat plateaus.

6.Excavation areas (EX). are found throughout the marine aggregate complexes and are potential sources of sand and gravel at or near the surface. The sand deposits are often ice-poor but the finer grained glacio-marine deposits are ice-rich.

7.Developed areas (DA). These are industrial or residentially developed areas, which include the town site, Fort Churchill, Akudlik and CNSC.

2:2:2 RECOVERY POTENTIAL

Fifty abandoned gravel minor study sites, and the four major study sites (Cape Merry, Bluff B, Fort Churchill and Akudlik) were examined between July and September 1994 (Fig. 2:5). The sites of interest were restricted to dry tundra communities; excavation sites within the forest were not considered in this study. All of the 54 sites were located adjacent to the launch road or to feeder roads (Fig. 2:5,2.6).

The 50 minor study sites and the 4 major study sites were compared in order to determine the severity and extent of damage resulting from excavation. A subjective ranking scheme was derived by assigning numerical values to each of seven characteristics: topography, vegetation cover, proximity of adjacent vegetation, size, aspect, particle size of aggregate, and usage (Table 2.2). The 54 sites were then revisited and ranked/rated to determine their recovery potential and the extent of damaged dry tundra.

Table 2:2 Features used in describing recovery potential of 50 minor and 4 major gravel sites and their corresponding rank.

A - **Topography**
0 - area with gravel mounds and scraper scars >5 m deep
1 - mounds and scraper scars 1 - 4 m
2 - scraper scars and mounds between 0.5 and 1 m
3 - undulating topography <0.5 m
4 - abandoned area that has been levelled

B - **Size of site**
0 - >10 ha
1 - 5.1 - 9.9 ha
2 - 1.1 - 5 ha
3 - .6 - 1 ha
4 - < .5 ha

C - **Aspect**
0 - north-facing
4 - south-facing
2 - east-facing, west-facing or flat

D - **Dominant particle size**
0 - cobbles (>6 cm)
1 - coarse gravel (3-6 cm)
2 - medium gravel (1-3 cm)
3 - fine gravel (0.2 - 0.8 cm)
4 - coarse sand (<0.2 cm)

E - **Vegetation cover**
0 - 0 - 19% (absent or sparse plant cover)
1 - 20 - 39% vegetation cover
2 - 40 - 59% vegetation cover
3 - 60 - 79% vegetation cover
4 - >80% or more vegetation cover

F - **Adjacent "appropriate" vegetation proximity**
0 - no surrounding vegetation
1 - appropriate seed source 20 m away
2 - appropriate seed source 10 m away
3 - appropriate seed source 5 m away
4 - seed source immediately adjacent to disturbed area - <5 m

G - **Use**
0 - site still being excavated
1 - evidence of recent use (i.e. fresh ATV trails)
2 - evidence of limited or seasonal use
3 - evidence of use minimal
4 - site completely abandoned, no evidence of disturbance

A - **Topography**. The topography of individual sites is indirectly related to snow holding ability, moisture, wind speed and potential for erosion. Undulating topography results in uneven soil moisture and, therefore, variable moisture availability to plants (Matthes-Sears et al. 1988). The ridges remain exposed (snow free) during the harsh winter months and are subject to wind and increased evapotranspiration during the summer. They are unstable, subject to erosion if not protected by a vegetation cover, and are usually dry and nutrient poor. The topography of the 54 sites was determined by physically walking through the area and noting the presence or absence of mounds, ridges or scraper scars. In cases were mounds and ridges were present a rough measurement was made on site with a metre stick. The corresponding ranking was then noted.

B - **Size**. Abandoned excavation sites in the Churchill region vary greatly in size. Gravel pads recover from the periphery towards their centres, therefore, the size of the site will greatly effect recovery potential. The smaller the pit, the more "edge effect" and, generally the more quickly the area will recover (McKendrick 1987). Therefore, the size of a pit is important because it is related to the time required to completely revegetate the site.

The size of the 54 sites was determined using the Geostation program. The pits sizes in hectares along with the corresponding latitude and longitude was generated by the Geostation program during the course of map production. The ranking value was then determined.

C - **Aspect**. Churchill experiences prevailing northwest winds hence areas facing this direction are subject to harsh conditions for the majority of the year. In the winter months such sites would be blown clear of a protective snow layer, and subject to needle ice abrasion and desiccating winds (Watson et al. 1970, Chambers et al. 1990, Carlsson and Callaghan 1991). Seeds require a stable surface with favourable conditions (moisture and warm temperatures) in which to germinate but areas subject to constant wind disturbance do no provide such "safe sites" (Sheldon 1974, Salonen 1987, Shumway and Bertness 1992). Wind also effects horizontal movement of seeds on the soil surface and effectively redistributes seeds (Chambers et al. 1991). Aspect of the 54 sites was estimated upon the visit to the site and visually estimating the site aspect. The appropriate ranking was then noted.

D - **Dominant Particle size**. The size of aggregate particles will greatly affects the development of vegetation. A lack of organic material or fine particles in the soil results in low water holding capacity and low nutrient levels (Runólfsson 1987). A mixture of sand, clay or peat in the soil column holds more water by cohesion (Salonen 1990, Chambers et al. 1991). Cohesion being the attraction of molecules to each other which in the soil column works with adhesion, the attraction of water molecules for solid surfaces (Brady 1984). The water is first attached to the soil particle by adhesion creating a film of water around the soil particle which can attract other water molecules by cohesion (Brady 1984). This combination of different particle sizes also helps to maintain organic layers at the surface (Salonen 1990, Chambers et al. 1991). This same ability of soil to hold moisture could also hold diaspores by cohesion and therefore decrease surface movement by wind of propagules off the site (Chambers et al. 1991). An estimate of the dominant particle size was determined by physical examination of the aggregate on site with a ruler. The corresponding ranking was then noted.

E - **Vegetation cover**. This criterion is an estimate of the amount of percentage vegetation cover at the site. Vegetation stabilizes substrates and provides a seed source. Plants may spread vegetatively on the site thus enhancing its recovery. Clumped, tufted, or rosette growth habits ameliorate the surrounding micro-environment and allow establishment of later colonizers (Sohlberg and Bliss 1987). Rosette vegetation present on the exposed gravel also serves to stabilize the site and prevent erosion (Smith and Correia 1992). Cover was measured by taking a visual estimate of the vegetation cover on the site. The corresponding ranking was then noted.

F - **Adjacent vegetation**. The proximity of adjacent vegetation is important to recovery potential since it may provide a source of propagules and wind-blown organic matter (Chapin and Chapin 1980, Runólfsson 1987, Salonen 1987, Salonen 1990, Salonen and Setälä 1992). Lack of surrounding vegetation decreases the numbers of potential propagules and may result in slow site colonization by vegetation (Salonen and Setälä 1992). During visits to the 54 sites the proximity of vegetation cover was noted. The distance was then paced off and the appropriate ranking was noted.

G - **Use**. Continued disturbance (excavation or other human activity) inhibits recovery potential. The use of all-terrain vehicles (ATVs) has increased greatly in arctic areas (Racine and Ahlstrand 1991) and this is evident in the Churchill region. ATVs can create a disturbance in the form of trails and alter the insulative layer and affect thaw patterns in permafrost areas even though they weigh less than 500 kg (Racine and Ahlstrand 1991). Vegetation development is generally inhibited in areas which remain under excavation or are used recreationally, whereas sites that have been abandoned may have a better recovery potential. Values for this criterion were determined through observation (presence of fresh ATV tracks, shell casings, garbage and debris) and personal communication with local people. The appropriate ranking was then noted.

Rankings were assigned to each of the 50 minor and 4 major study sites for each variable (ranging from zero to four, least to most favourable conditions) (Table 2:2). Overall scores were then used to provide an estimate of how "advanced" the recovery was.

The age of the 50 minor study areas of the 54 gravel sites were not incorporated into the subjective ranking model because, photos exist only for the following years; 1930, 1951, 1961, 1969, 1972, 1986 and 1991 (See Appendix 2). Never the less it is clear from the available air photos, that the date of disturbance for almost all sites fell between 1951 and 1961. Too little information was available to include the date of excavation in the recovery potential model. The dates of disturbance are known for the four major study areas, however, the 50 minor study sites could not be dated.

2:3 RESULTS

2:3:1 MAP PRODUCTION

Each of the seven vegetation zones was delineated on the map Figure 2:5. The total area of undisturbed dry tundra was 3752.49 ha (1, 2 and 3). The disturbed area accounts for 4112.31 ha (4 and 5) which is comprised of developed and excavation areas. The remaining 924.66 ha is naturally occurring rock and aggregate or exposed bedrock (6 and 7). This can be delineated according to substrate type:

1 - marine aggregate - 1920.74 ha
2 - marine aggregate/organic soils - 1809.79 ha
3 - marine aggregate/mineral soils - 21.96 ha
4 - developed areas - 237.52 ha
[industrial (105.35 ha) and residential (132.17)]
5 - excavated areas - 174.79 ha
6 - rock and aggregate - 147.48 ha
7 - exposed bedrock - 777.18 ha

2:3:2 RECOVERY POTENTIAL

The majority of the 54 sites examined ranged in size from 0.5-1.1 ha; 15 sites were 1.1-5 ha, 11 at 0.6-1.1 ha and 14 sites less than 0.5 ha in size (Table 2:3) . Nineteen of the 54 sites (35%) had large mounds and scraper scars (Table 2:3). Plant cover ranged between 20 and 60% for 36 of the 54 sites (Table 2:3). The majority of sites (44) were immediately adjacent to undisturbed vegetation (Table 2:3). The aggregate was predominantly cobbles (22 sites), medium (13 sites) and coarse (17 sites) gravel (Table 2:3). Forty percent were no longer disturbed by human activity or excavation (Table 2:3). In general, the sites were east/west facing or flat (25 out of 54 - 46%) (Table 2:3).

The four major study sites were examined independently. Akudlik and Bluff B had the highest total score of 14 followed by Fort Churchill/Airport (12) and Cape Merry (11) (Table 2:4). Akudlik and Fort Churchill/Airport were level and had 80% cover or more (Table 2:4). Cape Merry and Bluff B both had gravel mounds and scrapper scars remaining on site (Table 2:4). Vegetation cover at Cape Merry and Bluff B was 20 and 40% respectively (Table 2:4). Cape Merry and Bluff B were both immediately adjacent to undisturbed vegetation the other two sites were not (Table 2:4). The particle size varied on all four sites with cobbles found at Cape Merry and Fort Churchill/ Airport, coarse gravel at Bluff B and medium gravel at Akudlik (Table 2:4). All sites except Akudlik are no longer being excavated or disturbed (Table 2:4). Fort Churchill/Airport and Akudlik are the largest of the four sites (<10 ha) followed by Bluff B (5.1-9.9 ha) and Cape Merry being the smallest at between 1.1 and 5 ha (Table 2:4). Cape Merry and Fort Churchill/Airport are north facing (Table 2:4).

Table 2.3 Summary of total number of site rankings for the seven categories in the subjective ranking model (N=54)

	BEST				WORST
Criteria	4	3	2	1	0
Topography	14 (25%)	6 (11 %)	7 (13 %)	8 (15 %)	19 (35 %)
Vegetation cover	10 (19%)	13 (24 %)	11 (20%)	12 (22%)	8 (15%)
Proximity of adjacent vegetation	44 (81 %)	2 (4 %)	5 (9 %)	0	3 (6 %)
Particle size	0	2 (4 %)	13 (24 %)	17 (32 %)	22 (41 %)
Use	22 (41 %)	11 (20 %)	6 (11 %)	4 (7 %)	11 (20 %)
Size	14 (26 %)	11 (20 %)	15 (28 %)	7 (13 %)	7 (13 %)
Aspect	14 (26%)	0	25 (46 %)	0	15 (28 %)

Table 2.4 Subjective ranking summary for Fort Churchill/Airport, Cape Merry, Bluff B and Akudlik.

Criteria	Cape Merry	Fort Churchill/ Airport	Bluff B	Akudlik
Topography	0	4	0	4
Vegetation cover	1	4	2	4
Proximity of adjacent vegetation	4	0	4	0
Particle size	0	0	1	2
Use	4	4	4	2
Size	2	0	1	0
Aspect	0	0	2	2
Total	11	12	14	14
Date of Disturbance	1967	1980	1930	1981

2:4 DISCUSSION

2:4:1 ESTIMATION OF TUNDRA AREA

The areas of disturbance were dry and located adjacent to roadways near the Hudson Bay coastline. The total disturbed area is not large (412.31 ha) considering that there is approximately 3752.49 ha of remaining undisturbed dry heath tundra, but, the disturbed areas are highly visible and easily accessible. Gravel extraction was not undertaken responsibly, this has set the tone for subsequent development that has continued to the present day. There is the concern that such disturbance will continue to be deemed acceptable, leading to further degradation to this ecosystem.

The dry heath tundra ecosystem is rare in Manitoba. The dry tundra species found in Churchill, are locally abundant, but, many are on the rare species list for the province and should be protected and respected. Indeed, 27 species on the rare plant list for Manitoba are known to occur only in the Churchill region (White and Johnson 1980). The Churchill area is unique and has a tourism based economy. Protection of the land should therefore be a high priority in the area. Reclamation of the gravel areas would be a first step in the right direction. Another would be to set aside areas of dry tundra for protection similar to tall grass prairie reserves in southern Manitoba. In this way local people and tourists could be educated about the fragility of the tundra biome.

2:4:2 RECOVERY POTENTIAL

Most of the disturbed sites fall into two topographical groups: i) undulating topography (35%), and ii) flat, characteristic of gravel pads (26%). Variable topography results in soil moisture variations on the site and can lead to soil temperature variation and permafrost alteration (Matthes-Sears et al. 1988). It was believed that levelling a site would be more beneficial than leaving the undulating topography (Klokk and Ronning 1987). Levelling was considered to remove any problems that might affect vegetation recovery on site. This was evident in the four dated disturbances, two were levelled (Fort Churchill/Airport and Akudlik) and had more plant cover than the two with undulating topography (Cape Merry and Bluff B) (Table 2:4).

The majority of sites were close to undisturbed vegetation. The latter can serve as a seed source for the disturbed area (Salonen 1990, Salonen and Setälä 1992, Bliss and Grulke 1988). However, if the microsite onto which the seeds fall is not suitable for germination, i.e. not a "safe site", the proximity to vegetation is irrelevant (Sheldon 1974, Salonen 1987, Chambers et al. 1991). It is not known how far seeds can be transported from the parent plant. Bluff B and Cape Merry were immediately adjacent to undisturbed vegetation yet their plant cover was low compared with the other two sites which had no undisturbed vegetation surrounding them. Therefore, the presence of a seed source, immediately adjacent to a disturbance is not always the contributing factor for vegetation recovery.

The dominant particle size of aggregate found on site will affect the ability of the soil to hold moisture and seeds. A disturbance may have large cobbles resulting in high porosity which results in inability of the soil to hold moisture or nutrients (Brady 1984). Macro-porosity is not beneficial to keeping the seeds in the upper level of the soil column where germination can occur. Examination of the 54 sites showed that large particle size was the dominant character. The excavation which took place over time in the Churchill area may have removed all the small particulate gravel leaving behind the less desirable cobbles on site making revegetation more difficult. In fact, incorporation of sand and clay on disturbed areas may be one way to positively affect recovery on site.

The majority of the sites visited were flat or east or west facing which is neither an advantage nor a disadvantage. A north facing site is subject to harsh desiccating winds throughout the winter months, these will prevent any seedlings which may have established in the preceding spring from surviving into the following year. Disturbed areas have little or no plant cover following the initial disturbance. Therefore, the effects of the desiccating winds are compounded because there is no shelter for seedlings. Undisturbed north facing areas can provide shelter for seedlings with parent or nurse plants (Carlsson and Callaghan 1991). The north facing areas are often will be blown clear of snow which could provide a safe overwintering environment for seedlings. The south facing sites may be snow covered which gives them a decided advantage over other sites.

Continued use of the gravel areas in Churchill for industrial and recreational use compounds the initial disturbance. Although 40% of the sites

.visited were no longer being disturbed the remainder were undergoing some continued disturbance (Table 2.3 and 2.4). Seed rain into an area which is continually being re-disturbed is not beneficial to revegetation since no "safe sites" are available. In addition seedlings which are subject to damage by ATVs or heavy equipment will likely not survive.

The size of a disturbed site can also affect the recovery potential. In arctic areas seed production is an energetically costly undertaking and in most cases vegetative reproduction is the most frequent method of reproduction (Johnson 1969, Bliss 1971, Urbanska and Shultz 1986, Chambers et al. 1990, Sonesson and Callaghan 1991). Therefore, on a disturbed area the vegetation will re-invade the site clonally from the periphery in toward the centre (McKendrick 1987). On a small site peripheral invasion could easily cover it in a relatively short period. Vegetative reproduction in the arctic is slow and invasion of the disturbed area from the periphery may take decades. The sites examined showed that less than 46% were less than one hectare in area (Table 2.3 and 2.4). Compaction of a gravel pad which supports a building may be of great importance. Once the building is removed the gravel is still compacted. The area may provide a uniform level surface, but, seeds and/or roots are unable to penetrate the compacted substrate. It is not known how many of the level sites, that I studied, once supported structures.

Although the exact age of disturbances could not be determined the estimate was that most disturbance took place between 1951 and 1961 i.e.

between 46 and 36 years recovery time for most undated disturbances.

A comparison of recovery potential from each of the four major study sites showed that the length of time that the site has had to recover did not correlate with the overall score. The oldest site, in terms of abandonment, was not the one with the highest recovery potential. Cape Merry which was disturbed in 1967 and had the lowest total score (11), while Akudlik was disturbed more recently and its total score was one of the highest out of all four locations (14) (Table 2:4).

Individual aspects of the recovery potential model seem to be more important to recovery than the time factor alone. This may explain why certain sites ranked lower than expected. For instance there was abundant adjacent vegetation at the Cape Merry site but the particle size was so large that colonization was limited. Akudlik on the other hand had little or no adjacent vegetation but had a smaller particle size making it more favourable for colonization to occur than on other sites. Most seeds need to be in the upper few centimetres (or even millimetres) of the substrate to experience appropriate conditions for germination. Substrates with large particle size may result in seeds falling to depths in the soil column and thus make germination impossible. A mixture of sand in a substrate which also possesses large aggregate particles will help to keep seeds at a level which enhances germination.

2:5 CONCLUSIONS

1. Damage to the dry tundra in the Churchill region has been extensive. 3752.49 ha of undisturbed dry tundra remain while 413.31 ha have been seriously damaged (i.e. 10% of the original). Attempts should be made to restore these areas to enhance tourism potential.

2. The recovery potential of the four major study areas was not linked to the time since the disturbance. The age of the sites was not correlate with the stage of recovery. A site that was disturbed sixty years ago might be no more advanced in recovery than a site disturbed sixteen years ago implying that, other factors limit the recovery on the sites.

3. The fifty minor excavation sites were in various stages of recovery with the dominant factor limiting revegetation being texture. The excavation removed the majority of the small particulate matter. The result is a micro-topography which limits the safe sites available for seedlings to become established. Therefore, although, the majority of the sites were surrounded by undisturbed vegetation the incoming seed rain does not find appropriate sites on which to germinate.

CHAPTER 3

Natural of succession in gravel pits at Churchill, Manitoba.

3:1 INTRODUCTION

In the excavation of gravel, a front-end loader is used to remove the overburden (overlying vegetation and organic layer) to expose the underlying gravel (Bailey 1981, Bradshaw 1983, Street 1985). The loader is then used to scrape the gravel into a mound ready for transportation. Abandoned sites, have minimal soil development and are considered to be at the starting point of primary succession (Bradshaw 1983, Bradshaw 1987, Kershaw and Kershaw 1987, Cargill and Chapin 1987). The speed of rehabilitation and recovery in cold stressed environments, such as the subarctic, are slower when the vegetation and organic layer are removed (Webber and Ives 1978). Primary succession repeats itself if the disturbance, either natural churning of soil due to freeze-thaw regimes (Sigafoos 1951), or anthropogenic (excavation or mining), continues.

The objective of my study was to determine the rate and sequence of natural succession on four datable disturbed sites to climax dry tundra communities. This will provide information regarding the time frame required for the natural restoration of damaged terrain. Understanding the successional process as well as the pertinent edaphic conditions affecting the sites will lead to a restoration program might achieve enhanced rehabilitation (Bradshaw 1983, Bradshaw 1987, Cargill and Chapin 1987, Webber and Ives 1978, Forbes 1992).

3:1:1 SITE SELECTION

Several disturbed sites were examined and four of these were selected for study. The sites were; accessible by vehicle, located in dry heath tundra areas and dateable (1935, 1967, 1980 and 1981).

3:2 SITE DESCRIPTION

3:2:1 Cape Merry

Cape Merry National Historic Park is located 3 km northwest of Churchill town centre on the eastern peninsula at the mouth of the Churchill River. The study site is a gravel pit located adjacent to the gravel road 0.5 km inside the Park entrance (58° 47' 11" N, 94° 11' 35" W). In 1967 gravel was excavated from a pit on the south-west side of the road to provide gravel for road construction, resulting in a 1.19 ha pit (Hochbaum 1969). The opposite (i.e. northeast) side of the road has remained relatively undisturbed (Hochbaum 1969). At the present time, the pit is largely devoid of vegetation and contrasts with the undamaged substrate on the other side of the road, and with the dry heath tundra vegetation found within the park (detailed description in Chapt.2).

3:2:2 Bluff B

This site is an abandoned gravel pit located south of a bedrock outcrop at Half Way Point, 20 km east of Churchill on the coast of Hudson Bay (58° 46' 05"

N, 93° 51' 00" W). The total area of the gravel pit at Bluff B is 5.68 ha. The present vegetation within the pit may be delineated into four vegetation zones; i. A gravel hill (0.5 m high). The gravel constituting the mound is unstable. There is vegetation on the top of the mound and near the base (detailed description in Chapt.2). ii. A scraper scar (two ridges each less than 0.5 m wide with a depression in the centre). Two such scars radiate out from the hill in a northwest direction. The ridges are devoid of vegetation but some vegetation is concentrated in the depression (detailed description in Chapt.2).

iii. A depression (0.5 m deep), surrounded by gravel ridges. This area is parallel to the access road and west of the gravel mound community (detailed description in Chapt.2). It is moist and supports a thriving willow community.

iv. An undisturbed ("control") area supporting a dry heath tundra community. This vegetation zone is south of a rock bluff. The bluff provides some protection from north winds and acts as a snow trap which provides moisture in the spring (detailed description in Chapt.2).

3:2:3 Akudlik

This abandoned village site is 3 km south of the Town of Churchill at the junction of the Kelsey Blvd. and Goose Creek Road (58° 44' N, 94° 06' W). The site is a flat gravel pad and is currently strewn with debris and garbage. The area was abandoned by 1981 when all but three of the buildings were removed.

Although this area is one of the largest sites, it afforded no undisturbed heath area for comparison. Adjacent plant communities on the north, east and south sides are wet sedge fens or lakes while to the west the terrain is forested. Neither of these communities reflect the vegetation cover that would have been removed to build the site (detailed description in Chapt.2).

3:2:4 Fort Churchill/Airport

Fort Churchill was built in 1942 by the United States Air Force, 8 km east of the town on the quartzite ridge (58° 45' N, 94° 04' W) (Cheney and Brown Beckel 1955). The Fort was abandoned in 1980 at which time most buildings were removed.

The study site was located near one of the remaining buildings (now used as a Coast Guard building). The immediate area provided both undisturbed and disturbed plant communities (detailed description in Chapt.2).

3:3 FIELD METHODS

At each site, vegetation was surveyed within the disturbed as well as in the undisturbed "control" areas. Soil samples and temperatures were taken to determine edaphic conditions in both areas at each site. This information was used to illustrate differences between disturbed and undisturbed areas over time. The differences should help to determine if a successional sequence exists in these areas.

In 1992, ten soil samples (10 x 10 x 10 CM) were collected from randomly located 30 x 30 cm quadrats in each of the disturbed and adjacent undisturbed areas at each of the four study sites (after the method of Bishop and Chapin 1989). Samples from disturbed and undisturbed sites were collected on the same day to ensure that comparable environmental conditions occurred during the collection of edaphic data. The sampling was repeated in 1993. Samples were placed in sealed plastic bags and immediately returned to the laboratory at the Churchill Northern Studies Centre. Samples then underwent gravimetric water content analyses. The soil samples were air dried and sent to the University of Winnipeg for further testing; pH determination in the 0.01 M $CaCl_2$, dry sieving, pipette analysis for silt and clay and loss on ignition for organic matter and carbonate content.

3:3:1 VEGETATION SURVEY

A vegetation survey was conducted at each of the four study sites (Cape Merry, Bluff B, Fort Churchill/Airport and Akudlik). At each site, a 10 x 10 m study plot was placed in both undisturbed (control) and disturbed locations. Exceptions to this plan was the absence of suitable control sites at Akudlik and that the plot size was 15 x 15 m for the undisturbed plot at Fort Churchill/Airport. Within each 10 x 10 m plot where 20 randomly located quadrats were placed. Percent cover values were recorded for each species inside of each quadrat.

3:3:1:1 Correspondence Analysis and Discriminant Analysis

Vegetation data for Cape Merry, Bluff B and Fort Churchill/Airport were used in the correspondence and discriminant analysis, to show statistically similarities and differences between the sites. The 1992 and 1993 data were combined to form one data set. Akudlik data were not included because they lacked the undisturbed component of the data set. The Bluff B data were limited to only two of the four areas (undisturbed and scraper scar areas) to correspond with the other sites. The scraper scar was considered to be the most representative of the four areas at Bluff B and also had similar topography to the other disturbed sites at Cape Merry and Fort Churchill/Airport.

Correspondence and discriminant analyses were conducted separately for data from Bluff B. This included all four zones (hill, willow, scraper scar and undisturbed) since the areas were visually distinct. It was hypothesized that they would be statistically distinct and perhaps may relate to topographic, moisture differences or some other edaphic variation at the site.

The data was analysed using Canonical Analysis with the data down-weighted for rare species. All data was log transformed was log transformed

Scatter plots were drawn for the results of both analyses.

3:3:2 SOIL TEMPERATURE ANALYSIS

Shade temperatures were taken within each quadrat at depths of 5 cm, 10 cm and 15 cm July 1992 and 1993, using a soil temperature probe. The same probe was used in each of the twenty quadrats at each site. Soil temperatures at 10 and 15 cm could not be measured at Cape Merry and Fort Churchill/Airport because of the presence of bedrock close to the surface.

LABORATORY METHODS

3:3:3 GRAVIMETRIC WATER CONTENT

Gravimetric soil analysis was conducted on the fresh soil samples immediately upon their return to the laboratory at Churchill as outlined by Scott (1993) and was similar to tests conducted by Bishop and Chapin (1989). An accurately known weight of fresh soil (between 10 - 20 g) was dried at 105 - 110 °C for 24 hours. The samples were then reweighed. The percent moisture content was then calculated using the formula:

$$\frac{\text{mass of moist sample - mass of oven dry sample}}{\text{mass of oven dry sample}} \times 100$$

Following this analysis the remainder of the soil samples were air dried.

3:3:4 pH ANALYSIS (The 0.01 M $CaCl_2$ method)

The procedure for soil pH determination used in this study followed that of Scott (1993) and Bishop and Chapin (1989). The pH of each sample was determined by adding 20 ml of 0.01M $CaCl_2$ to approximately 10 g of soil in a beaker. The suspension was stirred thoroughly, then allowed to stand for 20 minutes before immersing the glass electrode and reading the pH from the metre.

3:3:5 SOIL TEXTURE ANALYSIS (Dry sieving method)

The 120 soil samples from disturbed gravel were sieved to separate coarse gravel (mesh #3/8, 15.9 mm), fine gravel (mesh #10, 2 mm), coarse sand (mesh #60, 0.25 mm), fine sand (mesh #270, 0.053 mm) and the silt and clay fractions using a sieve shaker for 15 minute durations following Scott (1993). The undisturbed soils were not used in this analysis because I was interested in the size of cobbles making up the aggregate soil and how this would effect revegetation on the site. The undisturbed soils were relatively uniform in nature. The sieve sizes used for gravel soils would have been too large for the organic undisturbed soils.

3:3:6 PIPETTE ANALYSIS FOR SILT AND CLAY

Twenty six of the 120 soil samples from disturbed sites had more than 5% silt and clay fraction by weight and therefore underwent pipette analysis following Scott (1993). The percentage of silt and clay fractions in the original soil sample were determined by this formula;

$$\text{oven dry sample (g)} - \text{calgon (0.1139 g)} = \text{sample alone (g)}$$

$$\text{sample alone (g)} \times 50 = \text{amount of silt and clay in total suspension}$$

$$\frac{\text{\% weight of Silt and Clay fraction in pipette experiment} \times \text{\% weight of silt and clay fraction after seiving}}{100}$$

3:3:7 LOSS ON IGNITION FOR ORGANIC AND CARBONATE CONTENT

The procedure to determine the amount of organic matter in soil samples followed that outlined by Scott (1993) and was similar to tests conducted by Bishop and Chapin (1989). This was done by placing 5 g of oven dried soil into a crucible of a known weight. The sample was then placed in a muffle furnace and heated to 550 °C for one hour and then reweighed. The organic matter content was calculated using the formula (the mass of the crucible has been subtracted from all values):

$$\%\ \text{organic matter} = \frac{\text{oven dry mass - incinerated mass}}{\text{oven dry mass}} \times 100$$

After incineration, the samples were stored covered, until they were incinerated again to determine the amount of carbonates present. The procedure was then repeated at a temperature of 1,000 °C to determine the carbonate content of the sample, which is calculated using the following formulae:

$$\%\ \text{ignition loss} = \frac{\text{ignition loss (g)}}{\text{mass of mineral soil (g)}} \times 100$$

$$\%\ \text{carbonate content} = \frac{\%\ \text{loss on ignition}}{0.44}$$

3:4 RESULTS

3:4:1 VEGETATION SURVEY

Disturbed areas at Cape Merry, Bluff B, and Fort Churchill/Airport displayed less vegetation cover than undisturbed sites in both 1992 and 1993 (Fig. 3.1). The mean percent cover per quadrat in all disturbed areas showed high variation indicative of the patchiness of the vegetation cover (Table 3.1). The undisturbed areas at Cape Merry and Fort Churchill/Airport showed 40 - 80% vegetation cover (Fig. 3.1). Mean percent cover values per quadrat in the undisturbed areas at Cape Merry, Fort Churchill/Airport and Bluff B showed high variation (Table 3.1). The undisturbed area at Cape Merry was dominated by *Rhododendron lapponicum*, *Vaccinium uliginosum*, moss sp., and *Salix reticulata* (Table 3.1). Fort Churchill/Airport undisturbed was dominated by *Salix planifolia*, *Taraxacum lacerum*, *Hedysarum mackenzii* and *Epilobium angustifolium* (Table 3.1) The undisturbed area at Bluff B showed less variation from 1992-1993 than Cape Merry or Fort Churchill/Airport (Fig. 3.1). Bluff B undisturbed was dominated by *Dryas integrifolia*, *Salix planifolia*, *Empetrum nigrum*, lichen sp., *Andromeda polifolia* (Table 3.1).

The disturbed area at Cape Merry was dominated by *Dryas integrifolia*, *Salix planifolia*, *Elymus arenarius* (Table 3.1). The disturbed site at Akudlik had less than 40% vegetation cover dominated by *Hedysarum mackenzii,* Grass sp. and *Festuca brachycarpa* (Fig. 3.1).

Comparing the four zones at Bluff B showed increased vegetation cover

Table 3.1 Mean percent cover per quadrat of species present in more than 5 quadrats for the vegetation survey for disturbed and undisturbed areas at Cape Merry, Bluff B, Fort Churchill/Airport and Akudlik. (+/- 1SD), N=20 (N/P denotes not present and X denotes presence in less than 5 quadrats)

	Undisturbed			Disturbed					
	Cape Merry	Bluff B	Fort Churchill /Airport	Cape Merry	Bluff B			Fort Churchill /Airport	Akudlik
Species					Hill	Willow	Scraper Scar		
Dryas integrifolia	1.2 +/- 4.23	38.25 +/- 33.38	X	6.75 +/- 12.23	9.61 +/- 16.16	X	12.3 +/- 13.71	9.28 +/- 10.31	X
Salix planifolia	N/P	X	9.9 +/- 26.17	3.25 +/- 5.74	X	17.1 +/- 31.06	2.2 +/- 6.11	4.65 +/- 8.71	N/P
Salix reticulata	11.55 +/- 12.38	X	X	N/P	N/P	N/P	X	0.55 +/- 1.23	X
Salix lanata	0.9 +/- 1.91	N/P	N/P	N/P	N/P	3.95 +/- 7.39	N/P	1.75 +/- 4.61	X
Empetrum nigrum	1.18 +/- 2.07	3.65 +/- 7.31	X	N/P	N/P	N/P	N/P	N/P	N/P
Andromeda polifolia	2.7 +/- 4.82	7.4 +/- 10.12	N/P	X	N/P	X	N/P	N/P	N/P
Artystaphylos rubra	1.3 +/- 2.68	X	N/P	N/P	N/P	N/P	N/P	N/P	N/P
Rhododendron lapponicum	8.35 +/- 7.97	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P
Vaccinium uliginosum	3.0 +/- 6.63	X	N/P	N/P	N/P	N/P	N/P	N/P	N/P
Hedysarum mackenzii	N/P	N/P	6.65 +/- 17.94	X	N/P	N/P	N/P	0.65 +/- 1.81	7.35 +/- 19.30
Castilleja raupii	N/P	N/P	6.13 +/- 8.37	N/P	N/P	N/P	N/P	N/P	N/P
Taraxacum lacerum	N/P	N/P	4.3 +/- 7.26	N/P	N/P	N/P	N/P	X	N/P
Shepherdia canadensis	N/P	X	N/P	X	45.8 +/- 45.95	N/P	X	N/P	N/P
Equisetum arvense	1.48 +/- 1.58	N/P	N/P	N/P	N/P	N/P	N/P	X	N/P
Pinguicula vulgaris	0.58 +/- 0.67	N/P	1.9 +/- 4.61	N/P	N/P	N/P	N/P	1.86 +/- 4.43	N/P
Puccinellia lucida	0.65 +/- 1.18	X	N/P	N/P	N/P	X	N/P	N/P	3.85 +/- 6.24
Achillea nigrescens	N/P	N/P	0.5 +/- 0.93	1.15 +/- 2.43	N/P	N/P	N/P	N/P	X
Pyrola grandiflora	N/P	0.6 +/- 1.10	N/P	N/P	N/P	N/P	N/P	N/P	N/P
Rubus chamaemorus	N/P	N/P	0.95 +/- 1.20	N/P	N/P	N/P	N/P	N/P	N/P
Parnassia palustris	X	N/P	0.45 +/- 1.00	N/P	N/P	N/P	N/P	X	X
Potentilla pulchella	N/P	N/P	X	1.25 +/- 2.83	N/P	X	N/P	N/P	X
Oxytropis campestris	N/P	N/P	N/P	N/P	N/P	N/P	X	N/P	N/P
Saxifraga tricuspidata	N/P	N/P	N/P	N/P	X	N/P	X	N/P	N/P
Elymus arenarius	N/P	N/P	N/P	N/P	X	N/P	X	N/P	N/P
Tofieldia pusilla	X	N/P	N/P	N/P	N/P	N/P	N/P	X	X
Juncus articus	N/P	N/P	N/P	N/P	N/P	N/P	N/P	3.9 +/- 8.90	X
Festuca brachyphylla	N/P	N/P	N/P	N/P	N/P	N/P	N/P	X	N/P
Grass sp.	N/P	N/P	X	N/P	N/P	N/P	N/P	N/P	N/P
Moss sp.	38.1 +/- 38.92	0.6 +/- 2.68	2.8 +/- 4.27	2.88 +/- 4.80	N/P	N/P	2.55 +/- 4.27	3.75 +/- 8.98	9.55 +/- 23.19
Lichen sp.	2.93 +/- 3.50	14.25 +/-20.34	N/P	N/P	X	N/P	X	N/P	N/P

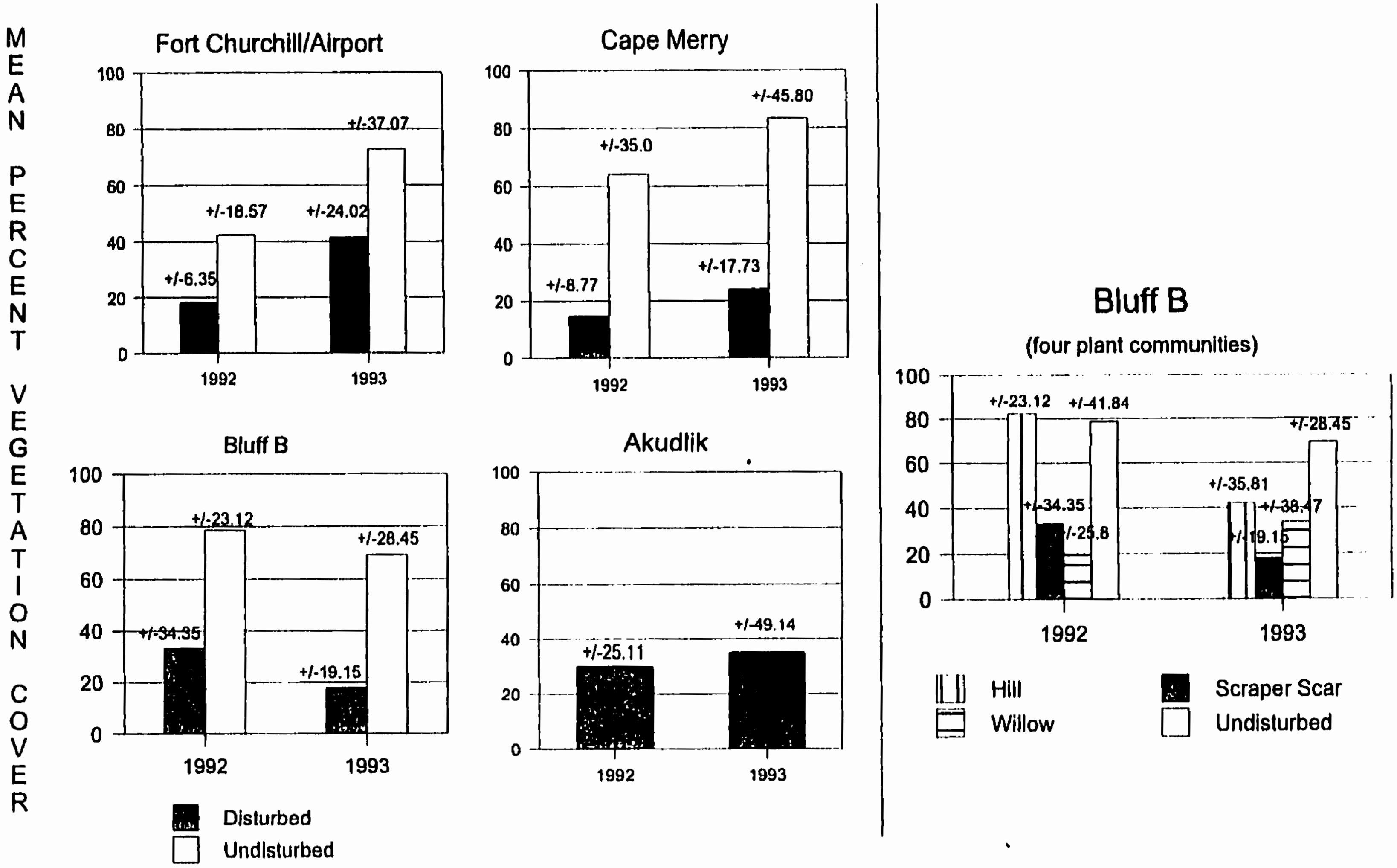


Figure 3.1 Percent vegetation cover in disturbed and undisturbed portions of the four study sites near Churchill in 1992 and 1993 (Bluff B is shown both with the breakdown for the four plant communities and the disturbed and undisturbed plots for ease of comparison).

on the Hill in 1992. The cover values were slightly higher than that of the undisturbed area (Fig. 3.1). However, in 1993, the three disturbed zones had lower cover values than that of the undisturbed area (Fig. 3.1). The hill section was dominated by *Shepherdia canadensis* (Table 3.1). The willow section was dominated by *Salix planifolia* and *Salix lanata* (Table 3.1). The scraper scar was dominated by *Dryas integrifolia, Shepherdia canadensis* and *Salix planifolia* (Table 3.1)

3:4:1:1 CORRESPONDENCE ANALYSIS AND DISCRIMINANT ANALYSIS

A scatter plot was drawn from the results of correspondence analysis (CA) (Fig. 3.2). In this figure, the undisturbed areas for each of the study sites formed a triangular pattern. Quadrats for Bluff B appeared closest to the origin whereas those of Cape Merry were located above and those for Fort Churchill/Airport to the right of Bluff B (Fig. 3.2). The disturbed areas are scattered between these undisturbed communities. The disturbed area at Bluff B has a large number of points clustered close to the undisturbed area of Bluff B. Other points are associated with the Cape Merry undisturbed site. None of the disturbed Bluff B points are associated with Fort Churchill/Airport undisturbed. Cape Merry disturbed plots form a band which extends from the origin of the scatter plot, near Bluff B undisturbed, and continues between the Airport and Cape Merry undisturbed areas. Finally, the Airport disturbed plots are closely associated with Bluff B undisturbed plots. Three are found associated with the parent community and one with Cape Merry undisturbed.

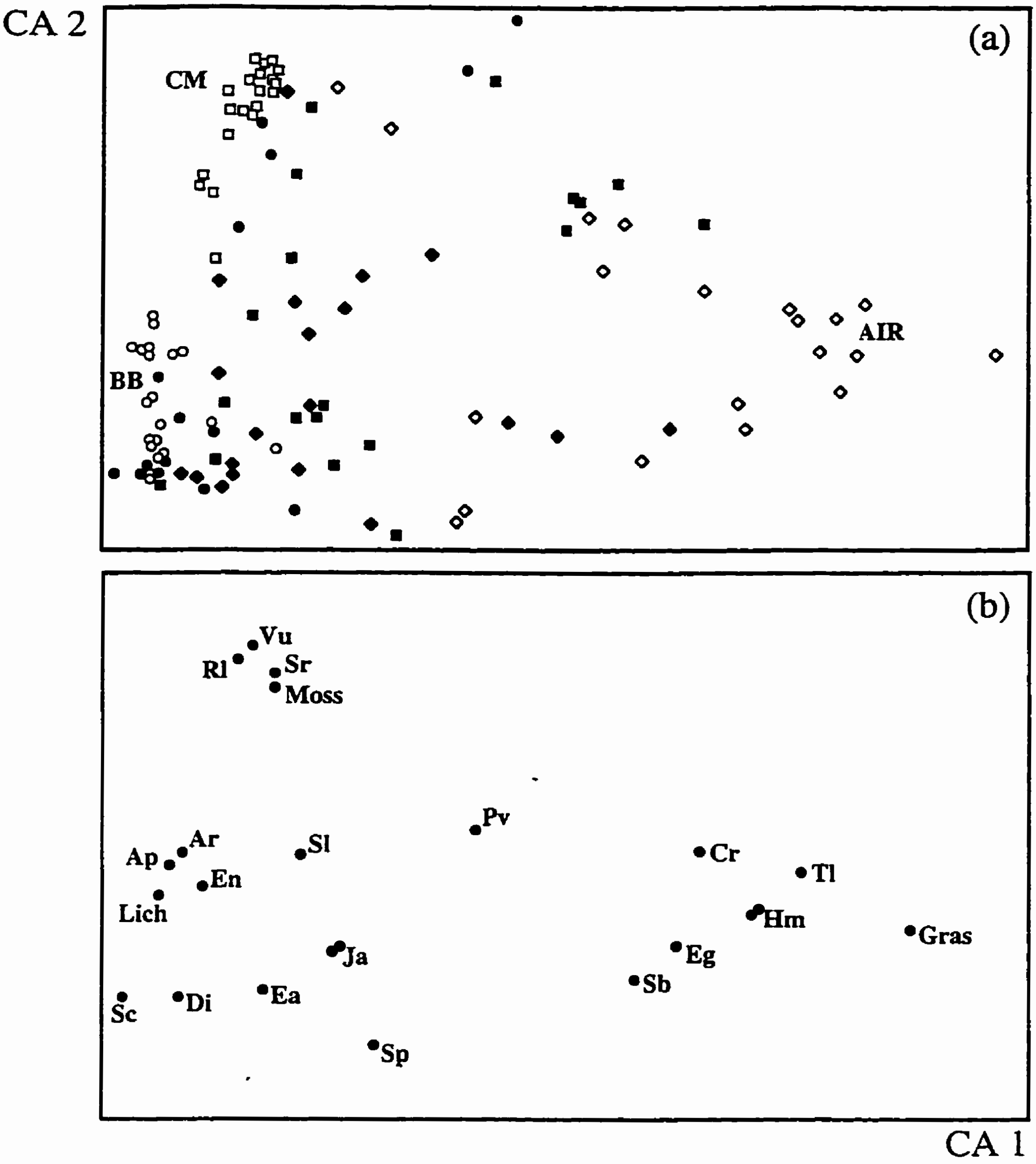


Figure 3.2. Correspondence analysis (CA) scatterplot (axis 1 vs. axis 2) for disturbed and undisturbed plots in the Cape Merry (CM), Fort Churchill/Airport (AIR), and Bluff B (BB) sites. (a) Plot Scores, symbol codes: □ = CM undisturbed, ■ = CM disturbed, ◇ = AIR undisturbed, ◆= AIR disturbed, ○ = BB undisturbed, ● = BB disturbed. (b) Species Biplot Scores, codes: Ap = *Andromeda polifolia*, Ar = *Arctostaphylos rubra*, Cr = *Castilleja raupii*, Di = *Dryas integrifolia*, Ea = *Elymus arenarius*, Eg = *Epilobium angustifolium*, En = *Empetrum nigrum*, Gras = grass spp., Hm = *Hedysarum mackenzii*, Ja = *Juncus arcticus*, Lich = lichen spp., Moss = moss spp., Pv = *Polygonum viviparum*, Rl = *Rhododendron lapponicum*, Sb = *Salix brachycarpa*, Sc = *Sheperdia canadensis*, Sl = *Salix lanata*, Sp = *Salix planifolia*, Sr = *Salix reticulata*, Tl = *Taraxacum lacerum*, Vu = *Vaccinium uliginosum*. For clarity, only the most common species are shown.

Five of the disturbed airport plots are scattered between the Bluff B and Cape Merry undisturbed areas.

The plant species associated with the three undisturbed communities in the correspondence analysis (Figure 3.2) were;

Bluff B; *Shepherdia canadensis, Dryas integrifolia, "Lichen", Empetrum nigrum* and *Andromeda polifolia.*

Cape Merry; *Rhododendron lapponicum, Salix reticulata, Vaccinium uliginosum,* and Moss.

Fort Churchill/Airport; *Taraxacum lacerum, Hedysarum mackenzii, Epilobium angustifolium, Castileja raupii,* and Grass.

A similar pattern emerged from the Bluff B data. The undisturbed area formed a tight cluster near the origin with the scraper scar being closest to it in a oval pattern (Figure 3.3). The willow and hill areas are at right angles to the undisturbed area with the hill area above and the willow to the left (Figure 3.3).

The vegetation associated with these areas was also similar to the overall pattern on the three sites.

Undisturbed; *Dryas integrifolia, Empetrum nigrum, Vaccinium uliginosum,* Lichen, *Salix reticulata, Andromeda polifolia* and *Salix brachycarpa.*

Scraper scar and Hill; *Shepherdia canadensis, Elymus arenarius* and *Epilobium angustifolium*

Willow; *Salix planifolia, S. lanata,* and Moss.

Discriminant analysis of all data for the three sites showed the

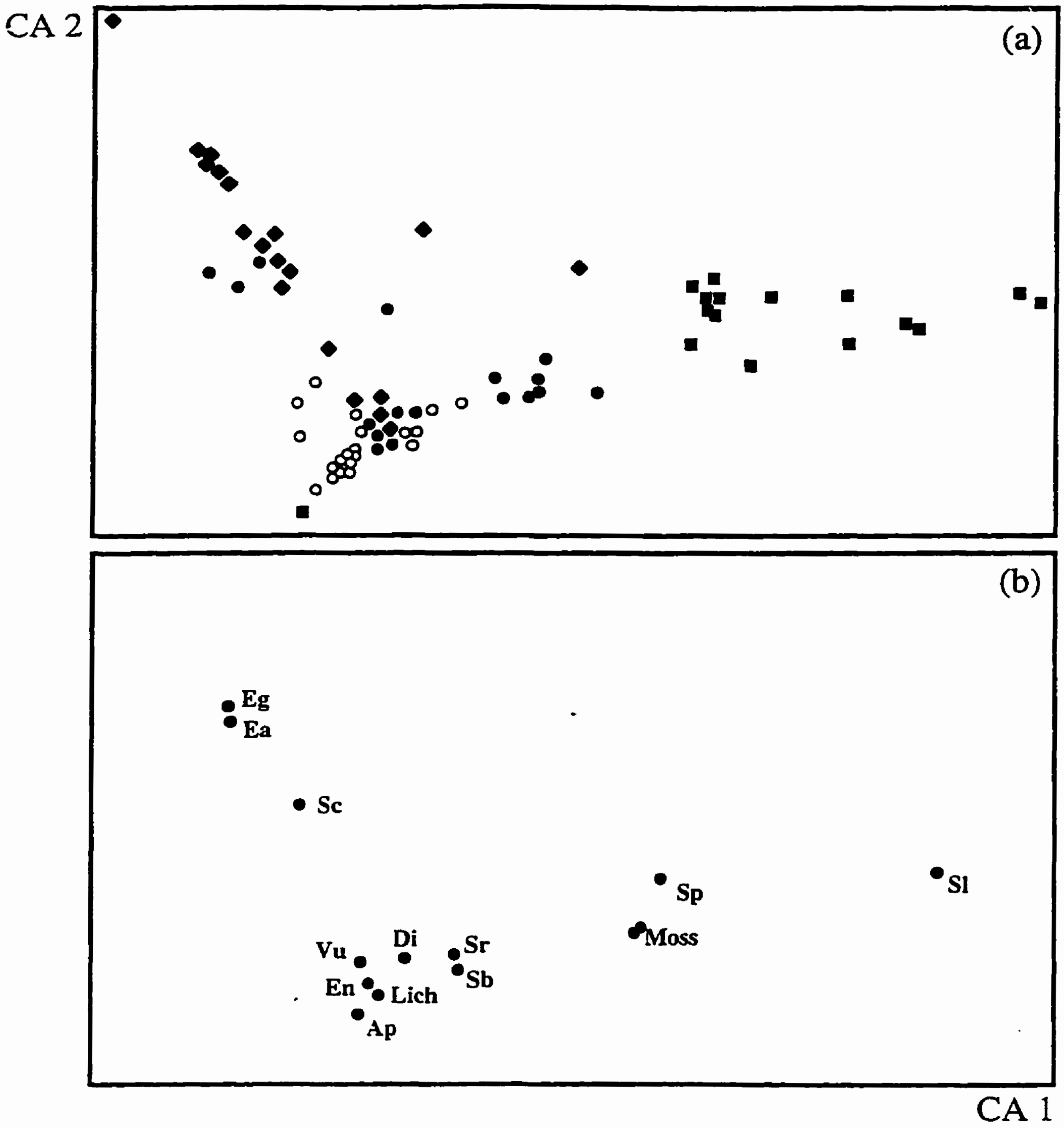


Figure 3.3. Correspondence analysis (CA) scatterplot (axis 1 vs. axis 2) for disturbed and undisturbed plots Bluff B (BB). (a) Plot Scores, symbol codes: ○ = BB undisturbed, ● = BB scraper scar (disturbed), ■ = BB willow (disturbed), ◆ = BB hill (disturbed). (b) Species Biplot Scores, codes: Ap = *Andromeda polifolia*, Di = *Dryas integrifolia*, Ea = *Elymus arenarius*, Eg = *Epilobium angustifolium*, En = *Empetrum nigrum*, Lich = lichen spp., Moss = moss spp., Sb = *Salix brachycarpa*, Sc = *Sheperdia canadensis*, Sl = *Salix lanata*, Sp = *Salix planifolia*, Sr = *Salix reticulata*, Vu = *Vaccinium uliginosum*. For clarity, only the most common species are shown.

undisturbed communities to form three distinct areas on the plot (Figure 3.4). The disturbed areas were distributed in between these. The disturbed and undisturbed areas at Bluff B were closely associated with each other. Cape Merry and Fort Churchill/Airport disturbed sites were associated with each other but not with either undisturbed community. These two were closer to the Bluff B parent community. The analysis was done for the first four axes however the correlations of correspondence analysis axes with discriminant axes showed that the majority of the variation was accounted for by the first two axes (Fig. 3.4). The Chi-squared tests showed the undisturbed sites to be statistically different from one another (Fig. 3.4).

Discriminant analysis resulted in a similar pattern for the Bluff B data (Figure. 3.5). The analysis was done for the first four axes however the majority of the variance is accounted for by the first two axes as shown by the correlations of correspondence analysis axes with discriminant axes. The four zones (undisturbed, willow, scraper scar and hill) were statistically different from one another as seen in the Chi-square tests (Fig. 3.5).

3:4:2 TEMPERATURE

The only site on which soil temperatures were taken at a depth of 15 cm was the undisturbed area at Cape Merry (Table 3.2). The disturbed area at Cape Merry and Fort Churchill/Airport were only taken to a depth of 5 cm, because rock was encountered at shallower depths. The remaining sites had soil depth taken to 10 cm (Table 3.2).

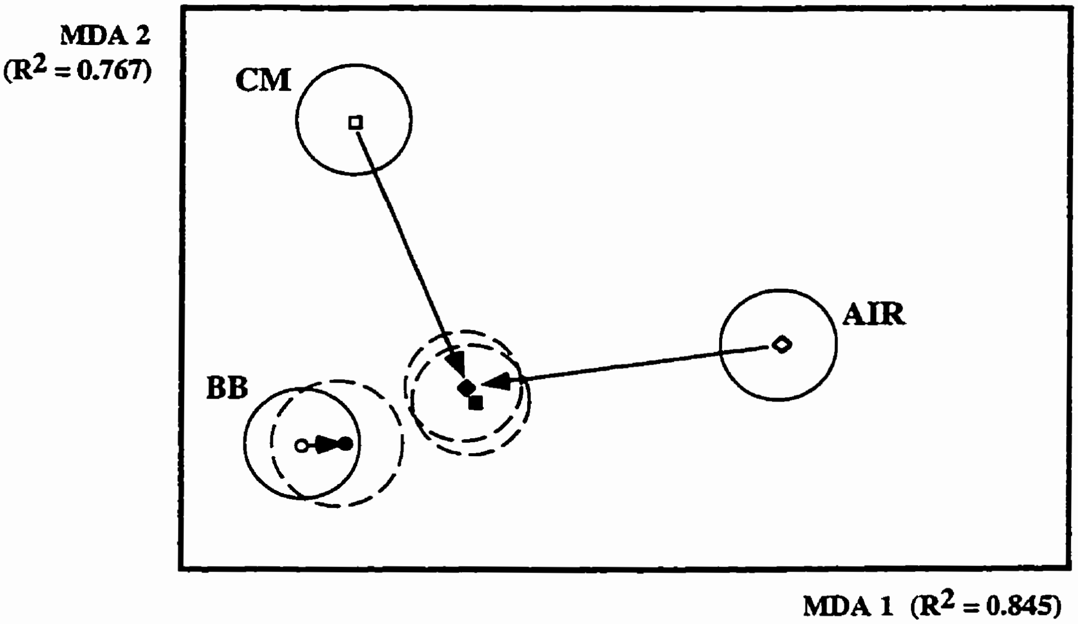


Figure 3.4. Multiple discriminant analysis of disturbed (black symbols) and undisturbed (white symbols) plots at Cape Merry (CM, ■), Fort Churchill/Airport (AIR, ◆) and Bluff B (BB, ●), based on scores from the first four correspondence analysis axes (see Figure 3.2). Symbols are positioned at the mean (centroid) of each of the six groups. Circles are 95% confidence intervals about the mean (closed circles for undisturbed, dashed circles for disturbed). Associated statistics are summarized below:

1. *Chi-Squared Tests with Successive Discriminant Axes Removed*

Axes	χ^2	df	*p*
1-4	253.5	20	< 0.001
2-4	118.2	12	< 0.001
3-4	22.3	6	0.001
4	8.0	2	0.07

2. *Correlations of Correspondence Analysis Axes with Discriminant Axes*

	Discriminant Axis			
CA Axis	1	2	3	4
1	**0.963**	0.019	0.267	0.022
2	-0.095	**0.830**	0.549	-0.024
3	-0.105	-0.213	**0.876**	0.419
4	0.023	0.106	-0.166	**0.980**

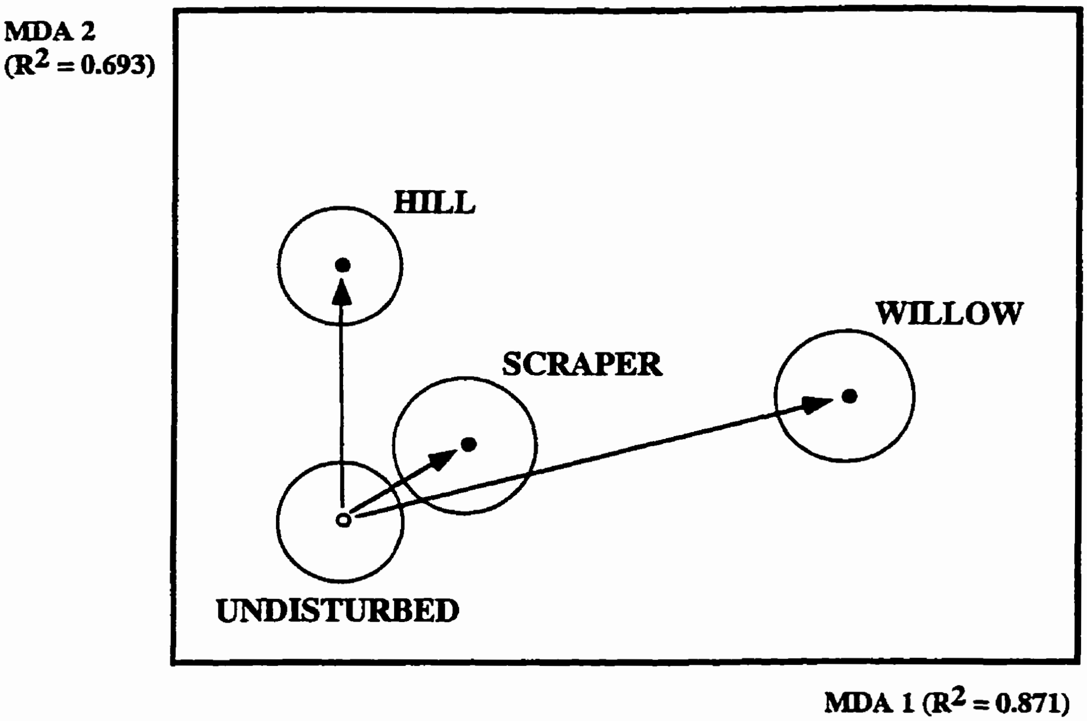


Figure 3.5. Multiple discriminant analysis of disturbed (black points) and undisturbed (white point) plots at Bluff B, based on scores from the first four correspondence analysis axes (see Figure 3.3). Points are positioned at the mean (centroid) of each of the four groups. Circles are 95% confidence intervals about the mean. Associated summary statistics:

1. *Chi-Squared Tests with Successive Discriminant Axes Removed*

Axes	χ^2	df	*p*
1-3	145.9	12	< 0.001
2-3	51.2	6	< 0.001
3	8.1	2	0.06

2. *Correlations of Correspondence Analysis Axes with Discriminant Axes*

	Discriminant Axis		
CA Axis	1	2	3
1	**0.966**	-0.144	-0.153
2	0.134	**0.974**	0.177
3	-0.106	-0.063	0.181
4	-0.024	-0.086	**0.995**

Table 3.2 Mean soil temperature at depth for Fort Churchill/Airport, Cape Merry, Bluff B and Akudlik.

Site	Mean Temperature (+/- 1SD)		
	5cm	10cm	15cm
Fort Churchill/Airport undisturbed	12.03 (+/- 2.98)	9.80 (+/- 1.91)	N/A
Fort Churchill/Airport disturbed	14.25 (+/- 4.00)	N/A	N/A
Bluff B undisturbed	18.55 (+/- 2.56)	12.60 (+/- 2.16)	N/A
Bluff B scraper scar	17.30 (+/- 2.36)	14.30 (+/- 2.13)	N/A
Bluff B willow	18.15 (+/- 3.72)	16.00 (+/- 2.88)	N/A
Bluff B hill	18.45 (+/- 2.82)	15.05 (+/- 3.58)	N/A
Cape Merry undisturbed	12.80 (+/- 5.58)	7.90 (+/- 2.7)	5.67 (+/- 0.77)
Cape Merry disturbed	14.30 (+/- 5.91)	N/A	N/A
Akudlik disturbed	15.20 (+/- 4.48)	13.45 (+/- 3.46)	N/A

The soil temperature at Bluff B were the highest overall for 5cm depth followed by Akudlik (Table 3.2). Cape Merry and Fort Churchill/Airport had the lowest temperatures (Table 3.2). The temperature at Cape Merry undisturbed decreased with depth from 12.8 ° ±5.58 at 5 cm to 5.67 ° ±0.77 at 15 cm (Table 3.2). In all cases except Bluff B the temperature at 5 cm was higher on the disturbed area than the undisturbed areas (Table 3.2). However, with Bluff B this reversed at the 10 cm depth where the undisturbed area had the lowest temperature (Table 3.2).

3:4:3 GRAVIMETRIC WATER CONTENT

The mean moisture content for samples from disturbed areas was less than 10 % in 1992 and 1993, except for the willow area at Bluff B (Fig. 3.6). Variation in the disturbed areas (+/- 0.3- +/- 1.66) was unlike the vegetated areas (+/- 3.31 - +/- 172) (Fig. 3.6). Areas covered by vegetation had higher mean moisture contents, (29-500%) (Fig. 3.6). Moisture content overall was higher in 1993 than in 1992 (Fig. 3.6), as was precipitation.

3:4:4 pH ANALYSIS

The pH of the disturbed areas at Akudlik, Bluff B and Cape Merry ranged from 6.8 to 7.2. Those at Fort Churchill/Airport were 7.49 ± 0.19 (Table 3.3). The undisturbed areas at Cape Merry and Bluff B were slightly acidic with a pH of 6.47 ± 0.20 and 6.39 ± 0.22, respectively (Table 3.3). The undisturbed area at the Fort Churchill/Airport is neutral at 6.82 ± 0.16.

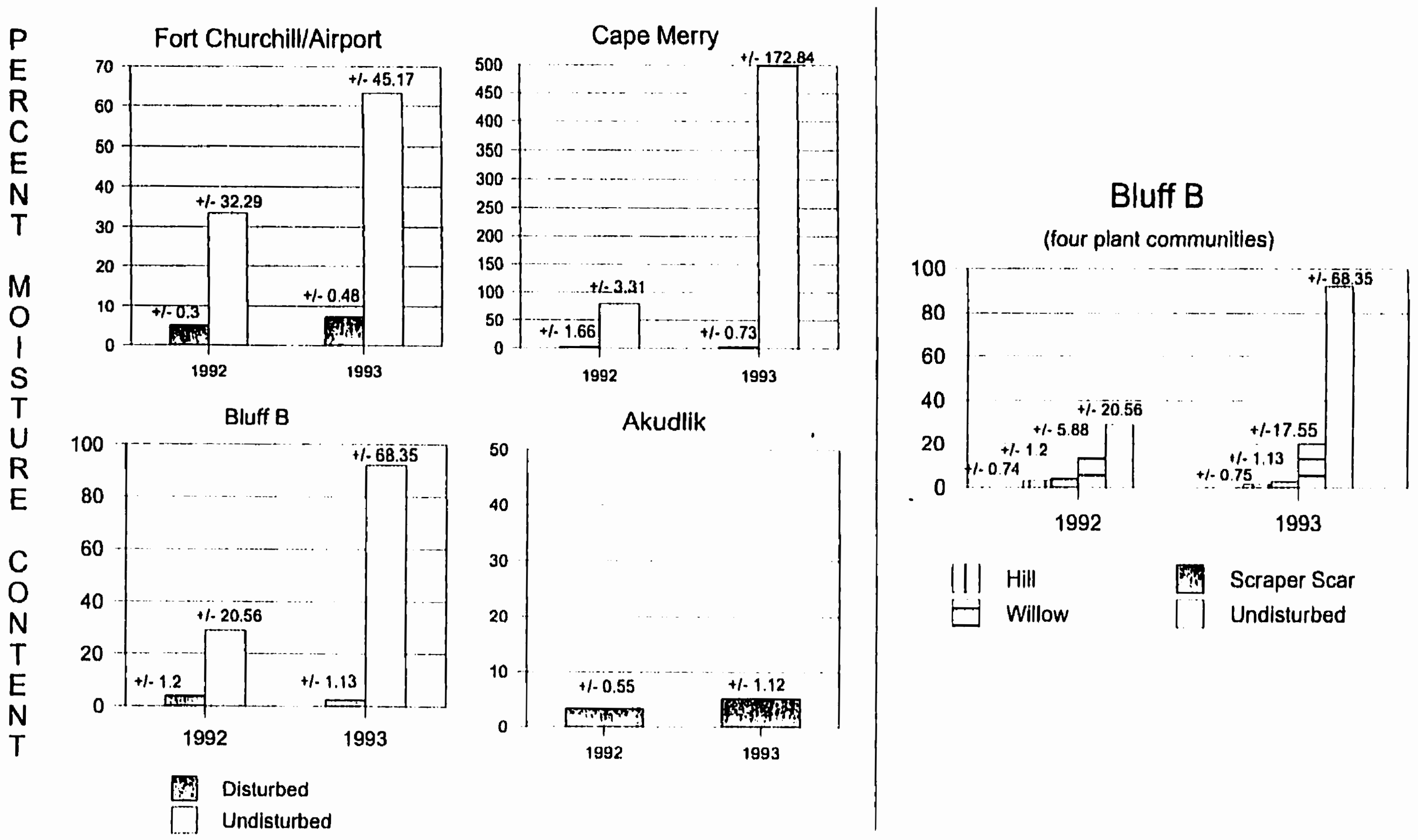


Figure 3.6 Soil moisture contents for disturbed and undisturbed sites at Fort Churchill/Airport, Cape Merry, Bluff B and Akudlik (Bluff B is shown with the breakdown of the four plant communities and also with disturbed and undisturbed plots for ease of comparison)

Table 3.3 Results of loss on ignition (percent carbonate and organic matter) and pH analysis for Fort Churchill/Airport, Cape Merry, Bluff B and Akudlik. Data was combined for 1992 and 1993.

Site	N	Mean percent carbonate (+/- SD)	pH (+/- 1SD)	Mean percent organic matter (+/- 1SD)
Fort Churchill/Airport undisturbed	20	43.89 (+/- 9.44)	6.86 (+/- 0.13)	16.90 (+/- 10.36)
Fort Churchill/Airport disturbed	20	40.62 (+/- 24.61)	7.49 (+/- 0.19)	5.89 (+/- 12.08)
Bluff B undisturbed	20	48.01 (+/- 40.01)	6.39 (+/- 0.22)	34.53 (+/-18.54)
Bluff B scraper scar	19	52.1 (+/-11.63)	6.70 (+/- 0.33)	1.26 (+/-1.07)
Bluff B willow	20	50.86 (+/- 7.96)	6.70 (+/- 0.26)	3.93 (+/- 2.89)
Bluff B hill	20	44.44 (+/- 11.55)	6.74 (+/- 0.34)	1.83 (+/- 1.84)
Cape Merry undisturbed	20	103.03 (+/- 26.94)	6.47 (+/- 0.20)	57.48 (+/- 9.77)
Cape Merry disturbed	19	51.11 (+/- 14.89)	7.02 (+/- 0.40)	0.96 (+/- 0.39)
Akudlik disturbed	20	44.86 (+/- 10.9)	6.83 (+/- 0.18)	1.40 (+/- 0.22)

3:4:5 SOIL TEXTURE ANALYSIS

Results were combined for the 1992 and 1993 samples. The majority of the soil samples at Cape Merry were dominated by coarse gravel (Table 3.4). The remaining samples; Fort Churchill/Airport, Bluff B (willow, scraper scar, hill) and Akudlik were dominated by coarse sand (Table 3.4). Mean silt, clay and fine sand contents were less than 10% for all sites (Table 3.4). Akudlik had the highest mean percentage of fine sand (Table 3.4).

3:4:6 PIPETTE ANALYSIS FOR SILT AND CLAY

The 26 samples which underwent pipette analysis were from Bluff B willow area (2), Akudlik (4) and the Airport (20). The mean amount of silt and clay in the original soil sample for Fort Churchill/Airport was 6.23% ± 5.23 (Table 3.5). The samples from Akudlik and Bluff B/Willow section were well below this value with means of 1.14% ± 0.40 and 2.90% ± 2.37 respectively (Table 3.5). The amount of clay remaining in suspension at time 7:27 was 0 for all but 9 samples which averages 1.57% ± 0.82 (Table 3.5). All of these 9 samples were from the Fort Churchill/Airport.

Table 3.4 Overall mean percent soil texture for disturbed areas at Fort Churchill/Airport, Cape Merry, Bluff B and Akudlik. (1992 and 1993 data combined +/- 1SD)

	Fort Churchill/ Airport	Cape Merry	Bluff B			Akudlik
			Scraper Scar	Hill	Willow	
	N=20	N=19	N=19	N=20	N=10	N=20
Silt and Clay	7.81 +/- 1.62	2.00 +/- 0.89	1.38 +/- 0.96	1.63 +/- 1.05	4.03 +/- 3.87	3.86+/- 1.33
Fine Sand	7.37 +/- 1.84	2.29 +/- 1.28	3.47 +/- 3.12	3.94 +/- 1.54	3.39+/- 2.03	9.29 +/- 2.93
Coarse Sand	30.73 +/- 4.54	17.11 +/- 9.17	38.30 +/- 9.84	36.79 +/- 11.62	35.07 +/- 5.33	43.05 +/- 1.16
Fine Gravel	25.95 +/- 5.50	35.19 +/- 12.16	18.93 +/- 5.62	24.19 +/- 6.05	26.11 +/- 6.65	21.11 +/- 5.25
Coarse Gravel	27.97 +/- 9.02	43.36 +/- 20.26	38.00 +/- 11.61	33.65 +/- 12.86	31.40 +/- 11.03	22.45 +/- 9.08

Table 3.5 Mean percent silt and clay fractions and clay fractions (+/- 1SE) in the original soil samples.

SITE	n	SILT & CLAY MEAN %	SILT & CLAY S.E.	CLAY MEAN %	CLAY S.E.
Bluff B (willow zone)	2	2.90	2.37	0	0
Akudlik	4	1.14	0.40	0	0
Fort Churchill/ Airport	20	6.23	5.23	1.57	0.82

3:4:7 LOSS ON IGNITION FOR ORGANIC AND CARBONATE CONTENT

Results were combined for the 1992 and 1993 samples. Average percent organic matter values were higher on the vegetated sites than the adjacent disturbed areas (Table 3.3). The vegetated areas had percent organic matter values between 16 and 57% (Table 3.3). Cape Merry had the highest organic matter content at 57.48% ± 9.77 and Fort Churchill/Airport with the lowest at 16.90% ± 10.36 (Table 3.3).

The disturbed areas at the four sites had organic matter content between 0.96% and 5.89% (Table 3.3). The organic content on these sites was very low, especially since standard deviations were high, the organic content at the Airport for example was 5.89 ± 12.08 (Table 3.3). Akudlik was the only site with a low standard deviation (1.40 ± 0.22) (Table 3.3).

Percent carbonate content was similar on the disturbed and undisturbed sites. The values ranged between 40 and 52% for all sites except Cape Merry (Table 3.3). Cape Merry had a large carbonate content at the disturbed site 103.03% ± 26.94 contrasted to the undisturbed area which was 51.11% ± 14.89 (Table 3.3). This high carbonate content of 103% at Cape Merry undisturbed may indicate the presence of dolomite (magnesium). Bluff B had a carbonate content of 48.01% ± 40.01 showing a large variation in the carbonate component of the soil (Table 3.3).

3:5 DISCUSSION

The objective of my study was to determine the rate and sequence of natural succession from an initial disturbance toward the climax dry tundra community, in the Churchill area. This will provide knowledge of the time frame in which damaged terrain would restore itself, if at all.

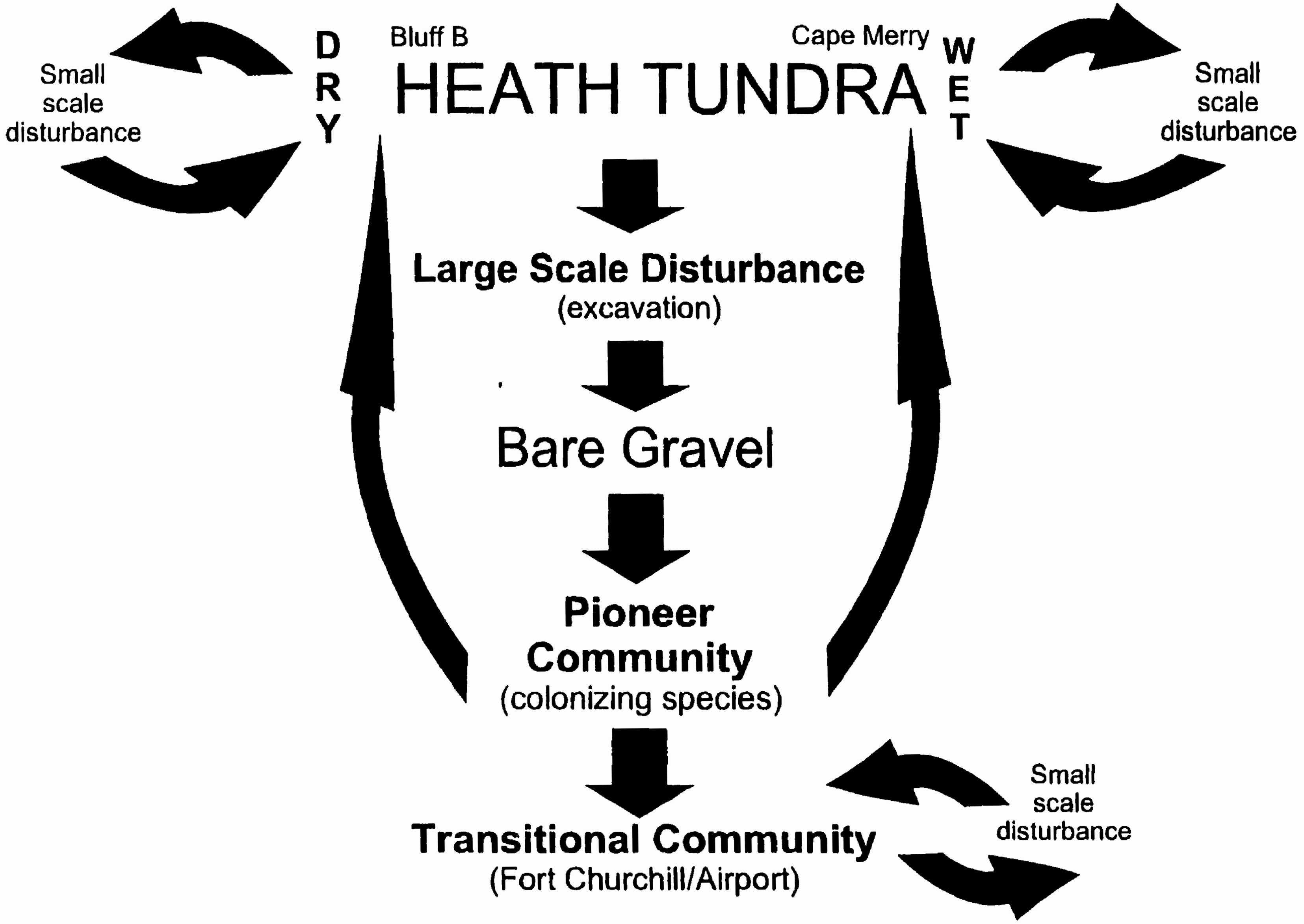
Succession can be initiated by a disturbance in the community which results in a large scale removal of vegetation and the underlying aggregate (Connell and Slatyer 1977). This opening is then invaded by primary colonizing species and succession is initiated.

Eventually a climax community is attained and may remain in an equilibrium state. In an arctic environment this theory may need modification. Under harsh environmental conditions the driving force is shifted from seral stage replacement to species establishment and survival (Svoboda and Henry 1987). A directional non-replacement model of succession, in which colonizing species are not replaced by other invaders but continue to expand and fill the available space, may be at work in these areas (Svoboda and Henry 1987, Bliss and Peterson 1992). This would account for the presence of primary colonizing species in the later stages of succession, i.e. *Dryas integrifolia*. Therefore, since the conditions are severely limiting in these areas the important factor in recovery is the establishment and survival of colonizing species. Over time these species may expand their hold on the disturbed area vegetatively, and when conditions allow seed will be produced. In this way the community will be maintained and expanded.

A model was developed to show the forces at work in heath tundra disturbances (Fig. 3.7). The model begins with heath tundra either wet or dry, the path followed through the model is dependent on the size of the disturbance. In the case of a small disturbance the area will cycle back to the original community. However, larger disturbances resulting in bare gravel will lead to a pioneer community (Fig. 3.7). Over time the pioneer community may return to either wet or dry tundra depending on the post disturbance physical composition on the site. Where this does not occur the pioneer community may lead to a transitional community (Fig. 3.7). Over time the transitional community may revert to the original tundra community, however, in some cases, the transitional community will perpetuate itself as a stable "new community" with a different species composition.

Small scale disturbance, i.e. camp sites, small holes, small scale excavation or tracks, may recover from and return to the parental community composition (Fig. 3.7). For this to occur the propagules required for recolonization should be available from the adjacent undisturbed area. Recovery is fast where the disturbance is small, because it is more likely that soil or organic matter containing propagules or subsurface rhizomes may remain intact (Forbes 1992). The small area could also become recolonized by vegetative reproduction from plants surrounding the disturbance (McKendrick 1987).

Figure: 3.7 Model of possible successional paths on disturbed areas of heath tundra



Large scale disturbances, i.e. abandoned gravel pads and excavation sites, which result in alteration of the physical composition of the area, will lead to different recovery paths. The path followed will be dependent on the number and type of propagules landing on the site, and the edaphic conditions. The propagules could come from adjacent areas which may be undisturbed parts of the predisturbance community or from different communities which may be some distance away. Seedling establishment will be dependent on the community makeup; if the area is moist then mesic species will prevail. Conversely, if the site is dry; xeric species will dominate. For example, a denuded upland region where the surface is lowered through excavation, would likely result in a post disturbance community which is hydric. The final community configuration depends on the physical composition of the site and availability of propagules.

The physical composition of the area may be so drastically altered that a transitional community is perpetuated (Fig. 3.7). This may be a consequence of the scale of the disturbance being so large that the adjacent areas provide no suitable propagules to enable the original community to reestablish. The transitional community habitat is stressful and when the plants located there are able to produce viable seed they would perpetuate the transitional community (Svoboda and Henry 1987). The result is a "new community" composed of species different from the parent community.

Prior to disturbance, the three areas; Cape Merry, Bluff B and Fort Churchill/Airport, had different species compositions (as seen in the discriminate analysis of the three sites). Cape Merry was disturbed in 1967, Bluff B in the 1930's. Initially the Fort Churchill site may not have been pristine. The Fort Churchill/Airport location was disturbed when the base was built but not afterwards, therefore, it has a different history to that of Cape Merry and Bluff B which were originally pristine undisturbed sites.

Fort Churchill was originally constructed in the 1950's at which time the entire site would have been excavated and covered by a gravel pad in preparation for building. Prior to construction the area was a bedrock outcrop, "the highest terrain in the region" (Cheney and Brown Beckel 1955). The vegetation cover prior to construction would have been similar to that at the undisturbed area at Bluff B, dominated by *Empetrum nigrum*, *Arctostaphyos rubra*, bryophytes, lichens and *Salix* spp. (Cheney and Brown Beckel 1955). The site was moderately mesic. Standing water occurred throughout the summer in some areas due to impeded drainage and snow melt occurred early (Cheney and Brown Beckel 1955). The outcrop was not smooth and would trap snow in the crevices from depths of 5 - 120 cm (Cheney and Beckel 1955). Therefore, to build a base of the scale of Fort Churchill the area would have required extensive filling with gravel and leveling.

The undisturbed study site had not been disturbed since the completion of the construction of Fort Churchill in 1942. During demolition of the base some disturbance may have taken place but this is not documented. Consequently, this site was already a successional stage and not an equilibrium community.

The Fort Churchill/Airport site was likely originally covered with heath vegetation and is now gravel covered, xeric, level and dominated by a weedy community. It is safe to assume that this vegetation will not return to the original undisturbed state.

It became clear in examining the correspondence and discriminant analysis results that the three sites, Cape Merry, Bluff B and Fort Churchill/Airport, were not reacting in the same way to disturbance. Although the sites began as separate locations on the scatter diagram prior to disturbance, once the areas had been disturbed they did not automatically return to the predisturbance configuration. In fact, following disturbance the sites seemed to begin again from a common point and to deviate toward different end results based on the physical compositions of the areas.

Once an area is disturbed it is unlikely that it will return to the predisturbance state. The physical conditions and micro topography of the area may be so altered that it will tend toward another composition. This is illustrated in the correspondence and discriminant analysis results (Fig. 3.2 and 3.4). Prior to disturbance the three communities were distinct. However, following disturbance the recovery path was not toward the predisturbance parent community. The Bluff B disturbed site did in fact tend toward the parent community over time (Fig. 3.4). Cape Merry and Fort Churchill/Airport on the other hand tended to be more closely associated with Bluff B than their respective parent communities (Fig. 3.4).

The apparently new transitional community arising in the model at Fort Churchill/Airport may be the result of changes to the physical composition of the site. Vegetation found at Fort Churchill would have to be adapted to the reduced moisture availability. Indeed the dominant species here are mesophytes (*Taraxacum lacerum*, *Hedysarum mackenzii*, *Castilleja raupii*, *Epilobium angustifolium* and *Solidago multiradiata*) and xerophytic (*Rubus chamaeomorus* and *Eriophorum variegatum*). Although other species may fall on the site in seed rain they would be unable to survive the harsh environment where as drought resistant species with a shallow root system are more able to exploit the area.

The establishment of the herbaceous plants at Fort Churchill/Airport may have inhibited the invasion by woody or shrub species (*Rhododendron lapponicum, Shepherdia canadensis, Salix spp.* and *Betula glanulosa)* due to decreased soil moisture (Densmore 1992, Cooper and VanHaveren 1994). Studies of revegetation in arctic regions using seeded exotic grass species showed that native species were inhibited by the decreased moisture and available "safe sites" remaining following seeding (Cargill and Chapin 1987, Densmore 1992). Studies by Schoenholtz et al. (1992) also showed inhibition of reforestation by a dense herbaceous cover. Therefore, the early establishment of the herbaceous species (*Hedysarum mackenzii*, *Epilobium angustifolium* and *Taraxacum lacerum)* on the Fort Churchill/Airport site, combined with the harsh physical conditions may limit the advancement of woody species on the site.

This would allow for the perpetuation and expansion of the transitional community at Fort Churchill/Airport.

Cape Merry and Bluff B differ from Fort Churchill/Airport in one way which may be affecting the recovery on the three areas and account for the apparent "new community" which is perpetuating itself at the airport site. The airport was a level gravel pad which supported a building and therefore, became compacted over time due to the weight it supported. Cape Merry and Bluff B on the other hand were excavated which resulted in undulating topography. This may have involved heavy equipment but for a limited time so little compaction would have occurred. The ability of plants to survive in compacted soil may be limited.

Gravel is excavated and the best grade is used for the gravel pads which support the buildings. This may account for why the Airport and Akudlik sites had better vegetation cover. If sand were incorporated into the gravel pad there would be an increased moisture holding capacity due to decreased particle size (Brady 1984). Bluff B and Cape Merry were excavated to provide gravel for pads and roads therefore, I assume that the gravel remaining on the sites was the gravel that could not be utilized.

The forces at work on the Cape Merry and Bluff B sites would seem to be consistent with the facilitation model of succession. The primary colonizers which invade the sites improve them for later colonizers. The tussok and mat-forming plants for example collect organic matter and shelter seedlings acting as a nurse plant facilitating their establishment (Bliss 1971, Svoboda and Henry

1987, McGraw and Vavrek 1989, Carlsson and Callaghan 1991). *Dryas integrifolia*, a woody mat-forming plant also has the ability to fix nitrogen which will help to improve the nutrient limits of the soil in areas it invades (Svoboda and Henry 1987). This influx of nitrogen will make the area more suitable for plants which cannot survive in nitrogen deficient areas. In this way the primary colonizers enhance the area for later colonizers and over time the community composition will shift toward that of the parent community.

However, the Fort Churchill/Airport site seems to fit a directional non-replacement model of succession. The transitional community will probably not lead to the previous cover of the parent community, but will perpetuate itself. The physical composition of the area has been so drastically altered that it can no longer support the parent community. It is anticipated that the pioneer species which are adapted to the harsh conditions of the site will continue to dominate and eventually produce a closed vegetation cover.

Akudlik, although not included in the correspondence or discriminant analysis shows similar responses to disturbance as seen at the Fort Churchill/Airport site. The two sites are similar in scale and soil composition. Akudlik like Fort Churchill was occupied by buildings and therefore subject to compaction. Soil texture was close to that of Fort Churchill/Airport being dominated by coarse sand and fine gravel, with very little silt and clay (Figure 3.7). The pH at Akudlik was neutral, as it was at the other disturbed areas except Fort Churchill which was slightly alkaline (Table 3.3). The percent carbonate found at Akudlik was similar to that of Fort Churchill/Airport as both soils had been derived from carbonate rocks (Table 3.3). The dominant species found at Akudlik was *Hedysarum mackenzii* which was also closely associated with Fort Churchill/Airport through Correspondence Analysis (Figure 3.2). Based on this information it can be assumed that Akudlik would react in similar fashion to Fort Churchill/Airport in the model. That is to say that the community established at Akudlik will be a transitional one which will expand itself over time into closed cover on the site.

Successional theory assumes that given enough time the disturbed area will eventually achieve the "climax" state. The question then arises as to how much time is required? Vegetation cover on a disturbed area is thought to increase over time, therefore the older of the four dated sites should be more advanced in the recovery process than the others. However, Bluff B, which is the oldest of the four sites, is not more advanced than the others. Bluff B has had 67 years of recovery time and large areas of the site remain devoid of vegetation. Fort Churchill/Airport on the other hand is relatively young being disturbed in 1981, yet this site has more consistent vegetation cover than Bluff B (Fig. 3.1 and Table 3.1). Therefore, time is not the only factor to be considered in the successional process on denuded gravel areas, edaphic conditions must also be limiting the recovery. This would explain why different sites react differently over time. Individual sites are effected by microclimate variation and site specific events such as frost heave which will result in site specific time frames for recovery. To impose a blanket time frame on all sites would be to overlook the individual variations present within the sites.

In many models of succession emphasis is placed on competition as the limit on invading plant species (Svoboda and Henry 1987). In marginal arctic environments however, like polar deserts and denuded gravel areas, it is the stress of the environment which limits the plant invasion and survival (Svoboda and Henry 1987). A gravel area devoid of soil, nutrients and shelter is an inhospitable place for germination and seedling survival.

Arctic vegetation is influenced by soil moisture and factors which are linked to it such as nutrient availability, pH, texture and temperature (Tredrow and Cantlon 1958, Oberbauer and Dawson 1992, Truett and Kertell 1992, Taylor and Seastedt 1994). Seedling establishment and survival is greatly effected by reduced soil moisture (Bliss 1971). The undisturbed areas had on average 20 - 80% more moisture holding capacity than the corresponding disturbed areas (Fig. 3.6). The undisturbed areas had a greater buildup of organic matter (16-57%) which resulted in increased moisture holding capacity (Table 3.3). The disturbed areas on the other hand had little or no organic matter buildup (1-6%) which is reflected in their low moisture holding capacity of less than 10% (Fig. 3.6, Table 3.3).

The build up of organic matter in arctic regions is a slow process due to low soil temperatures (Pruitt 1978). The disturbed areas examined have little or no organic matter build up and exhibit the neutral pH expected from a limestone gravel. Therefore, as expected the undisturbed areas had higher organic matter content than the corresponding disturbed area (Table 3.3). However, the amount of time between disturbance and sampling did not result in the expected higher organic matter content. The oldest site, Bluff B (1930), had a higher organic matter content than the younger site Cape Merry (1967) and Akudlik (1981) (Table 3.3). Fort Churchill which is the youngest site had the highest organic matter content of all disturbed areas (Table 3.3). The standard deviation indicates that there is considerable variation in the data (5.89 +/- 12.08). However, Fort Churchill/Airport is not like the other two sites, Bluff B and Cape Merry, since it is adjacent to a building. The presence of that building may greatly affect the composition of the site. The building will serve to trap snow, seeds and debris.

The moisture holding capability of soil increases as the texture becomes finer (Brady 1984). Therefore, the smaller the particles the greater their ability to hold water increases (Brady 1984). Conversely, gravel substrates have a lower moisture and nutrient holding ability due to their larger particle size (Johnson 1987, Chambers et al. 1990). Coarse textured substrate allows seeds to move vertically in the soil column away from appropriate germination sites (Chambers et al. 1991). The texture of the aggregate and soil found on the disturbed and undisturbed areas affects the soil moisture and nutrient holding capability (Brady 1984, Runolfsson 1987).

The Churchill region receives 400 mm of precipitation annually, making the ability of soil to hold moisture more important to plant establishment and survival (Dredge 1992). The disturbed areas at Bluff B, Cape Merry and Fort Churchill/Airport were all lower in moisture content than the corresponding undisturbed areas (Fig. 3.6). The silt and clay content in all samples was very low. Only three sites out of the seven (Bluff B, Willow section, Akudlik and Fort Churchill/Airport) had silt and clay fractions over 5% to qualify them for this analysis. The lack of silt and clay limits the water holding and nutrient exchange capability of the soil.

The gravimetric moisture content analysis for 1992 and 1993 showed that Cape Merry had the highest moisture content over all. In 1992 moisture content on the undisturbed plots was 80.51% with the least variation +/- 3.31 (Fig. 3.6). That would indicate that the undisturbed area was consistently moist overall. The high moisture content in 1993 of 497.83% was in part due to samples being taken following a rain storm. This sample date was less than desirable but unavoidable due to transportation restrictions. It is interesting to note that for the same day in 1993 the disturbed area moisture content was very low (3.16% +/- 0.73) (Fig. 3.6). The disturbed area moisture content in 1992 and 1993 is similar, below 5%, even though sampling in 1993 was done in the rain (Fig. 3.6). The aggregate found at Cape Merry was the coarsest overall dominated by coarse gravel (Table 3.4). The highest organic matter content over all was at the undisturbed Cape Merry site, 57.48% (Table 3.3). These results show how efficient organic soils in the area can be at absorbing many times their dry weight in moisture (Brady 1984). The contrast shown at this site between texture and organic matter content illustrates the negative effects of excavation. Although this was interesting it was not usable in statistical analysis. Therefore, moisture content data was not utilized in correspondence analysis.

Moisture content for the Bluff B undisturbed area shows high values (90%) but, there is considerably more variation (±68.35) which would indicate the area is not consistently moist but patchy (Fig. 3.6). The disturbed area at Bluff B also had moisture content below 10% for 1992 and 1993 except the Bluff B/willow site (Fig. 3.6). The Bluff B/willow site had more variation in the moisture content values (±17.55 in 1993) than did the other areas (Fig. 3.6). Therefore, the site was not consistently moister than the other areas but patchy (Fig. 3.6).

Moisture content at Fort Churchill/Airport undisturbed peaked in 1993 with 63%, however the high variation (± 45.17) indicates the area to be patchy and not consistently moist throughout (Fig. 3.6). The moisture content for both Akudlik and Fort Churchill/Airport disturbed were less than 10% for both 1992 and 1993, with little variation indicating a consistently dry site (Fig. 3.6). Fort Churchill/Airport disturbed on the other hand had the highest silt and clay fraction of all four disturbed sites (Table 3.4). This corresponded to increased moisture holding capacity on the disturbed area of 5-7%, however this was still lower than the undisturbed area at between 30 and 60% moisture capacity (Fig.3.6). The removal of the overburden greatly effected the moisture holding ability on the disturbed areas.

Low soil temperature can limit the growth rate of plants due to decreased depth of thaw and reduced primary production (Bliss 1971, Kielland and Chapin 1992, Nadelhoffer et al 1992, Truett and Kertell 1992). In areas with low soil temperatures, soil microbes will be ineffective at decomposing organic material and this will result in limited nutrient cycling (Haag 1974, Pruitt 1978, Nadelhoffer et al. 1992).

The soil temperature data set collected for the Churchill study sites was incomplete due to problems probing to depth in the hard rocky soil. In an effort to minimize disturbance to the areas I did not dig holes to get temperature readings. Therefore, I can only draw general conclusions about the soil temperature on the sites. The disturbed areas had less vegetation cover than the corresponding undisturbed areas this would translate in to differences in albedo on the sites. Vegetation serves to insulate the underlying soil and permafrost (Pruitt 1978, Webber and Ives 1978, Chambers et al. 1990). The reduced vegetation cover on disturbed areas allows for deeper penetration of heat to alter the soil temperature. The disturbed areas had higher day time soil temperatures than the undisturbed areas (Table 3.2). Soil temperature analysis also showed decreased temperature with depth (Table 3.2) under disturbed and undisturbed conditions. These results are preliminary and require further study to draw concrete conclusions.

Presence of carbonates indicates the availability of calcium and magnesium in the soil (Scott 1993). Calcium and magnesium dominate the available cation exchange sites on soil particles, limiting acids (hydrogen ions) in the soil, resulting in a neutral or alkaline pH which is the case for disturbed soils at Bluff B, Cape Merry and Fort Churchill/Airport (Table 3.3). The disturbed areas at Bluff B and Cape Merry had a neutral soil pH, while the Fort Churchill/Airport site was slightly alkaline. The disturbed areas all exhibited a higher pH than that of the corresponding undisturbed areas (Table 3.3). The removal of the overburden not only removed the vegetation, seeds and soil microbes but replaced the top soil with regolith which is more alkaline.

The majority of subarctic plant species reproduce vegetatively since seed production is intermittent or limited due to environmental stress (Johnson 1969, Bliss 1971, Callaghan and Collins 1976, Marchand and Roach 1980, Diemer and Prock 1993, Douglas 1995). A source of invading propagules onto a disturbed site is primarily the adjacent undisturbed area although some species are capable of dispersal over large distances (Salonen 1987, Walker and Chapin 1987, Salonen and Setälä 1992). This becomes especially important in cases where the soil seed bank is not present or has been removed.

Buried seed tends to decrease northward (Leck 1980, McGraw and Vavrek 1989). It is often these buried seed banks which are composed of colonizing species which given a disturbance will recolonize the area (Leck 1980). Seed bank studies in the Churchill area have indicated that heath, carex sedge and gravel areas have little or no existing seed bank (Staniforth et al. "in press" 1998 and McGraw and Vavrek 1989). Gravel excavation however removes the upper soil layer (overburden) effectively removing any existing seed bank which may exist. Studies of seed banks on the four sites (Cape Merry, Fort Churchill/Airport, Bluff B, and Akudlik) showed that the undisturbed areas had more seedlings germinating from seed bank samples than the disturbed areas (Staniforth et al. "in press" 1998). Thus supporting the idea that the seed bank was removed or diminished following excavation.

3:6 CONCLUSIONS

1. The surface layer is critical to the recovery of a denuded area because it contains the organic component, nutrients, seeds and moisture holding properties necessary for site recovery. The removal of this layer results in a surface which is xeric, devoid of certain nutrients, microsites and not suitable for seedling germination or survival (Chambers et al. 1990). Therefore, conservation of the overburden on site following excavation will greatly enhance recovery after abandonment and respreading through, organic matter replacement and providing propagules for revegetation (McGraw and Vavrek 1989).

2. Alteration of the microtopography on site can alter the successional path. The leveling of a site following excavation can enhance recovery by reducing microsite variation.

3. Soil texture affects not only the ability of seeds to remain at the surface to facilitate germination success, but also, the moisture holding ability of the area. Moisture stress can greatly inhibit revegetation. Therefore, the texture of the aggregate on site will alter the successional path of the area by influencing the species able to survive on the site.

CHAPTER 4

HUMAN INTERVENTION IN THE REVEGETATION OF GRAVEL PITS AT CHURCHILL, MB.

4:1 INTRODUCTION

Abandoned gravel pits are usually devoid of continuous vegetation cover. The original vegetation and the organic layer in the soil (the "overburden") have usually been removed or burned (Bailey 1981). Such disturbed, stressed sites could be considered as the starting point for succession, i.e. primary or secondary succession depending on the presence or absence of propagules in the soil (Bradshaw 1987, Cargill and Chapin 1987, Kershaw and Kershaw 1987, McKendrick 1987).

The seed bank in a variety of sites in Churchill, Manitoba (*Dryas integrifolia* heath, wet bog, treeline) has been shown to be small or absent (Archibold 1984, McGraw and Vavrek 1989). The seed source is therefore, more or less limited to incoming seed rain from the surrounding vegetation (Salonen 1987, Salonen 1990). Seedling recruitment is dependent not only on the arrival of seeds at the site but also on the availability of suitable micro-sites where germination and establishment can take place (Chambers et al. 1991). In order to effectively revegetate an old gravel pit, attempts must be made to ensure; a) availability of seed and b) available micro-sites for successful germination and seedling establishment.

Primary productivity in the arctic may be limited by lack of soil, permafrost, low temperatures, short growing season, harsh winters, moisture stress and low nutrients (Warren Wilson 1966, Haag 1974, Chapin and Shaver 1985, Krebs 1985, Salonen 1987, Oberbauer and Dawson 1992, Tenhunen et al. 1992, Truett and Kertell 1992). Therefore, colonizing species in gravel pits would not only have to resist the drier conditions (physiological) in 1993 drought, but also be well adapted to the other harsh environmental factors described above. The excavation of gravel from a dry tundra site intensifies these limitations and, as a result, may cause the recovery on these areas to take centuries before a "climax" community is reached. The goal objective of this study was to attempt different revegetation strategies on two permanently established study areas. It was hoped that natural recovery would be enhanced by lessening the effects of the natural limitations on denuded gravel areas through these human interventions.

4:2 DESCRIPTION OF STUDY AREAS

Two sites were chosen based on suitability, accessibility and proximity to the Churchill Northern Studies Centre. The two sites were similar in texture of aggregate. Site I was located 1 km west of the Churchill Northern Studies Center, at the west end of a 2 km access road north of the Launch Road (58 44'56"N, 93 51'34"W) (Figure 2:5). This area had been utilized for gravel excavation between 1961 and 1972 and this had resulted in a large gravel area of 1.19 ha with several gravel mounds over 3 m high. The study area consisted of a topographically uniform surface of 30 m by 15 m which was achieved by the levelling of a gravel mound with a front-end loader in 1992 (see Klokk and Ronning 1987). The study area was devoid of vegetation in 1993 except at its southern periphery where the vegetation consisted of scattered plants of *Dryas integrifolia*, *Salix* spp. and some bryophytes. The north side of the study area was bordered by a sedge-fen while the southern border was dominated by a willow-heath community.

Site II was located 0.25 km west of the gate of the Churchill Research Range (presently the C.N.S.C.), 10 m north of Launch Road (58 45'04"N, 93 49'35"W). This area had also been used as a gravel pit and was abandoned prior to 1961. Site II was 3.78 ha in extent, and bounded by 3 m high gravel mounds. The 30 m by 15 m area which had been selected for study had been levelled in 1993, using a front-end loader. This gave a uniformly level surface, devoid of vegetation (see Klokk and Ronning 1987). Limited vegetation cover (*D. integrifolia* and *Elymus arenarius*) occurred at the periphery of the study area. This was bordered by a willow-heath community except at its northern edge which was occupied by a sedge-fen.

4:3 METHODS

4:3:1 Treatments

Two study sites were established in 1992 and 1993, Site I was approximately 35 m by 15 m and Site II was approximately 30 m by 16 m in each site thirty two, 2 x 2 m plots, with a 1 m buffer zone between each was laid out (see Chapin and Chapin 1980) (Figure 4.1 and 4.2). Treatments were randomly assigned to plots on each site. There were eight treatments, each replicated 4 times at each study site.

CONTROL-NON-SEEDED	CONTROL-SEEDED
FERTILIZER-NON-SEEDED	FERTILIZER-SEEDED
PEAT-NON-SEEDED	PEAT-SEEDED
PEAT+FERTILIZER-NON-SEEDED	PEAT+FERTILIZER-SEEDED

Ten centimetres of peat was applied to each of the 16 "peat plots" mixed into the gravel surface, and watered to prevent it from blowing away.

Fertilizer (N11:P12:K6) was applied to the 16 "fertilizer plots" plots. The fertilizer composition was 1.3% nitrate nitrogen, 3.5% ammoniacal nitrogen, 6.2% urea nitrogen, 12% available phosphoric acid and 6% soluble potash. A "time-release fertilizer" coated for 6.2% slow release of nitrogen and 1.2% slow release of K_20, was used because earlier studies (Chambers et al. 1990) had shown that the gravel had allowed leaching of the normal fertilizer out of the system. Fertilizer was broadcast evenly on each fertilizer plot in early July 1993 at a rate of 30 g m^{-2} which is comparable to studies by Shaver and Chapin

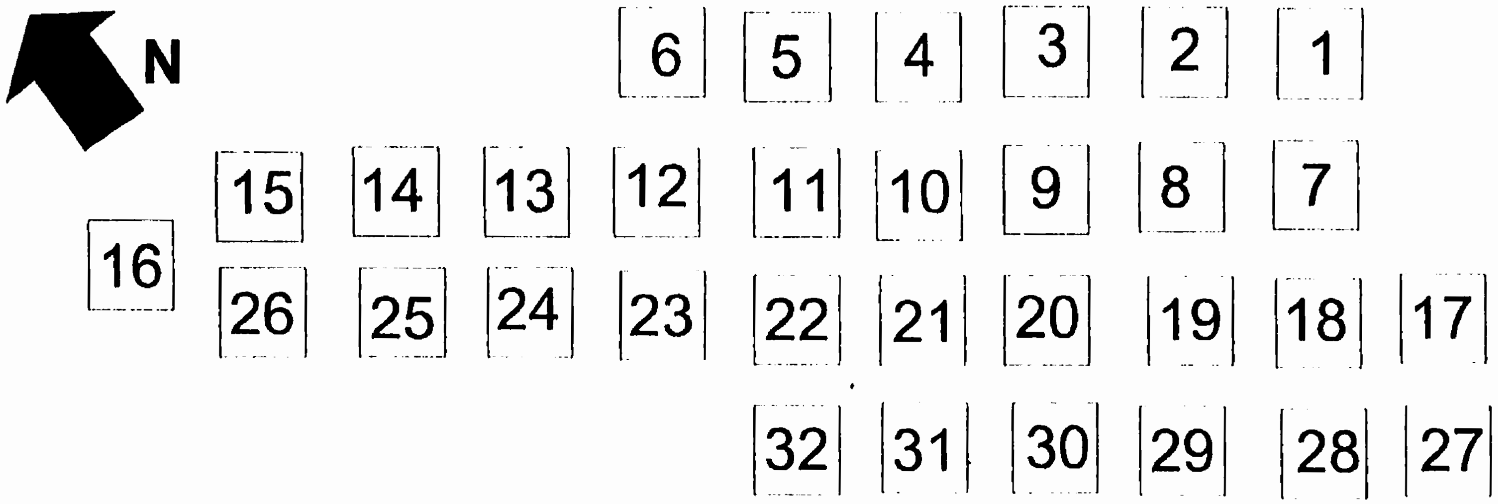


Figure 4.1 Site I showing plot layout.
Treatment assignment by plot number.

Control Non-seeded - plots 10, 15, 18, 29;
Control Seeded - plots 7, 13, 19, 25;
Fertilizer Non-seeded - plots 6, 16, 23, 27;
Fertilizer Seeded - plots 11, 21, 30, 32;
Peat Non-seeded - plots 1, 5, 22, 26;
Peat Seeded - plots 3, 4, 17, 20;
Peat + Fertilizer Non-seeded - plots 2, 9, 12, 28;
Peat + Fertilizer Seeded - plots 8, 14, 24, 31.

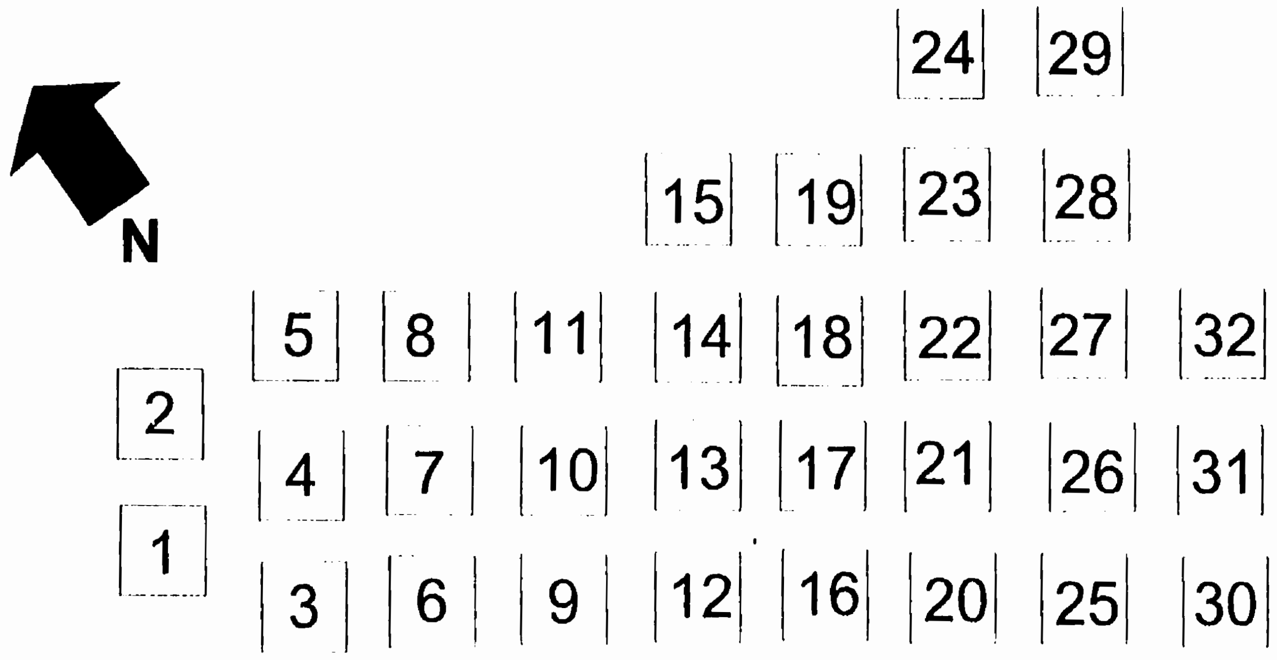


Figure 4.2 Site II showing plot layout.
Treatment assignment by plot number.

Control Non-seeded	- plots 12, 15, 22, 27;
Control Seeded	- plots 5, 13, 18, 32;
Fertilizer Non-seeded	- plots 7, 21, 26, 28;
Fertilizer Seeded	- plots 3, 9, 24, 30;
Peat Non-seeded	- plots 1, 8, 10, 16;
Peat Seeded	- plots 2, 4, 11, 19;
Peat + Fertilizer Non-seeded	- plots 20, 23, 25, 31;
Peat + Fertilizer Seeded	- plots 6, 14, 17, 29.

(1986) who applied commercial fertilizer to tussock tundra at rates of 25 g m^{-2} nitrogen, 25 g m^{-2} phosphate and 31.6 g m^{-2} potash.

Peat and fertilizer were both applied in each of the 16 "peat and fertilizer" plots. The peat was first placed on the surface of the plot and mixed into the gravel, it was then watered. The fertilizer was broadcast onto the peat surface in a similar fashion to that which had been used on the gravel surfaces.

Half of the plots were seeded with a mix of seeds of seven native species;

Salix lanata
Dryas integrifolia
Hedysarum mackenzii
Juncus arcticus
S. planifolia
Saxifraga tricuspidata
Oxytropis campestris
Elymus arenarius (rhizomes)

The seeds had been collected locally in late August and early September 1993 and applied fresh during the week of September 3, 1993 . The sowing density was approximately 1000 seeds of each of the seven species in each 2 x 2 m plot. The seeds of each species were counted or weighed, mixed together and then broadcast onto each of the 32 "seeded plots" (16 plots per site).

Thirty fresh rhizome cuttings of *Elymus arenarius* were inserted to a depth of 4 cm within each of the seeded plots in 1993. *Elymus arenarius* appeared to have failed to produce viable seed, however vegetative reproduction was prolific. Germination studies conducted by myself in 1992 on *E. arenarius* seeds in Churchill resulted in mean germination rates of less than 2% (Firlotte 1992). Propagation necessitated the use of rhizome cuttings (Firlotte 1992) each of which was 5-6 cm long and included a node. Cuttings were planted 4 cm below the gravel in five rows of six cuttings equidistant within each of the seeded plots.

The 32 control plots, (16 per site) had no seeds or cuttings artificially added. These served as the "controls".

Seedling establishment and rhizome shoots were monitored on the two sites during July and August 1993 and 1994. All seedlings and shoots were counted and their cover and species noted. The basal seedling diameters or spread were also measured using a ruler.

The vegetation adjacent to each Study Site was surveyed using thirty quadrats arranged in a random block design. The species cover was noted within each of the quadrats. The purpose of this survey was to describe the makeup of the source of the potential seed rain in the area. In addition, these data provided information about the community that would have likely dominated the area had the disturbance never taken place.

4:3:2 Snow Study

Snow depth and its density were measured in February 1994 for Sites I and II. This was done by delineating a grid on the sites and then taking depth measurements at each two metre interval (95 at Site I and II). Snow cores were taken at four metre intervals (16 at Site 1 and 15 on Site 2). The cores were placed in plastic bags and returned to the Churchill Northern Study Center for weighing. The density measure was then calculated with this formula;

D = (weight of sample in bag - 17.8 g)/(length of core x 11.175)

the resulting density value is in units of g/cm^3

17.8 g = the weight of the bag

11.175 = area of the coring cylinder (where r=1.886 cm)

Snow Water Equivalent (SWE) was calculated using the following formula;

$$\text{SWE} = \frac{\text{mass of water}}{11.175}$$

4:4 RESULTS

4:4:1 Treatments

4:4:1:1 Seedling Establishment

In 1993 Site I had 184 seedlings compared with Site II with 6 seedlings (Table 4.1 and 4.2). However, in Site II at the end of the 1994 season 1504 seedlings were recorded (Table 4.2). This was more than three times that of the 420 seedlings at Site I for the same period (Table 4.1).

The results of the 2-factor ANOVA showed that Site I and II differ in their response to the treatments (Fig. 4.3 and 4.4). Seeding was not beneficial at Site I but at Site II seeding was highly beneficial (Fig. 4.3 and 4.4). Peat treatments at Site I were not beneficial unless combined with fertilizer (Fig.4.3). However at Site II combined with seeding peat treatments were beneficial (Fig. 4.4).

In 1993, all plots in Site I had seedlings except for the control-non-seeded and peat-seeded (Table 4.1). The total numbers of seedlings ranged from 2 to 109, with the largest seedling numbers occurring in fertilized-non-seeded plots (Table 4.1). The average seedling diameters for Site I in 1993 ranged from 0.53 to 2.25 cm with the largest seedlings occurring in fertilized-non-seeded plots (Table 4.1). In 1994, all treatment plots had seedlings present, with seedling numbers ranging between 15 (peat+fertilizer-non-seeded plots) and 96 (fertilizer-non-seeded plots) (Table 4.1). In 1994, the average seedling diameter at Site I, ranged from 1.38 cm on peat-seeded plots to 4.04 cm on fertilized-non-seeded plots (Table 4.1).

Table 4.1 Total and mean seedling number by treatment on Site I during 1993 and 1994.

Treatment	Year	Mean seedling number per plot +/- 1SD (N=4)	Species number per plot (species)	Mean seedling diameter per plot (cm)	Total seedling number
Peat	1993	0.50 (+/-0.59)	1 (RO)	1.00	2
	1994	5.25 (+/-9.18)	2 (LA, DC)	2.18	21
Peat Seeded	1993	0.00	0	0.00	0
	1994	6.25 (+/-7.09)	3 (LA, MR, HM)	1.38	23
Fertilizer	1993	27.25 (+/-15.06)	6 (LA, SS, MR, DC, CA,G)	2.25	109
	1994	24.00(+/-12.08)	11 (LA, SS, MR, DC, FB, EpA) (AS, MA, TS, CA, G)	4.04	96
Fertilizer Seeded	1993	15.50(+/-5.45)	6 (LA, SS, MR, DC, CA, G)	2.24	60
	1994	21.50 (+/-11.96)	11 (LA, SS, MR, HM, EA, DC) (FB, EpA, MA, TS, CA)	3.93	86
Peat + Fertilizer	1993	1.00 (+/-2.00)	3 (LA, MR, DC)	1.13	4
	1994	5.00 (+/-4.08)	6 (LA, MR, DC, FB, MA, CA)	2.01	15
Peat + Fertilizer Seeded	1993	0.50 (+/-0.58)	2 (LA, G)	0.30	2
	1994	20.25 (+/-7.54)	6 LA, SS, MR, DI, HM, G	1.80	81
Control	1993	0.00	0	0.00	0
	1994	8.00 (+/-5.72)	4 (LA, SS, MR, DC)	1.93	32
Control Seeded	1993	1.75 (+/-2.87)	2 (LA, DC)	0.53	7
	1994	16.50 (+/-17.75)	5 (LA, SS, MR, HM, CA)	1.70	66
				Total 1993	184
				Total 1994	420

Species found : *Lesquella arctica (LA), Stellaria sp.(SS), Minuartia rubella (MR), Hedysarum mackenzii (HM), Equisetum arvense (EA), Dryas integrifolia (DI), Draba cana (DC), Festuca brachycarpa (FB), Epilobium angustifolium (EpA), Androsacae septentrionalis (AS), Melandrium affine (MA), Trisetum spicatum (TS), Cerastium alpinum (CA), Rumex occidentalis (RO) Grass (G).*

Table 4.2 Total and mean seedling number by treatment on Site II during 1993 and 1994.

Treatment	Year	Mean seedling number per plot +/- 1SD (N=4)	Species number per plot (species)	Mean seedling diameter per plot (cm)	Total seedling number
Peat	1993	0.00	0	0.00	0
	1994	0.00	0	0.00	0
Peat Seeded	1993	0.00	0	0.00	0
	1994	147.25 (+/-128.67)	4 (SS, HM, EA, RO)	2.40	589
Fertilizer	1993	0.00	0	0.00	0
	1994	25.50 (+/-30.66)	6 (LA, SS, HM, DC, EIA, G)	2.18	102
Fertilizer Seeded	1993	1.00 (+/-2.00)	2 (SS, DI)	0.50	4
	1994	41.75 (+/-20.47)	6 (LA, SS, DI, HM, AN, DC)	2.10	167
Peat + Fertilizer	1993	0.25 (+/-0.50)	1 (S)	0.50	1
	1994	18.50 (+/-19.23)	9 (LA, SS, HM, DC, RO) (EIA, G, S, Y)	1.99	74
Peat + Fertilizer Seeded	1993	0.25 (+/-0.50)	1 (G)	0.30	1
	1994	102.75 (+/-37.52)	9 (LA, SS, HM, DC, RO) (EIA, G, X, Y)	2.28	388
Control	1993	0.00	0	0.00	0
	1994	0.25 (+/-0.50)	1 (EIA)	7.50	1
Control Seeded	1993	0.00	0	0.00	0
	1994	46.00 (+/-20.70)	2 (SS, HM)	2.25	183
				Total 1993 Total 1994	6 1504

Species found : *Lesquella arctica (LA), Stellaria sp.(SS), Hedysarum mackenzii (HM), Dryas integrifolia (DI), Draba cana (DC), Festuca brachycarpa (FB), Rumex occidentalis (RO),Elymus arenarius (EIA), Salix sp. (S), Grass (G) unknown dicot X and Y.*

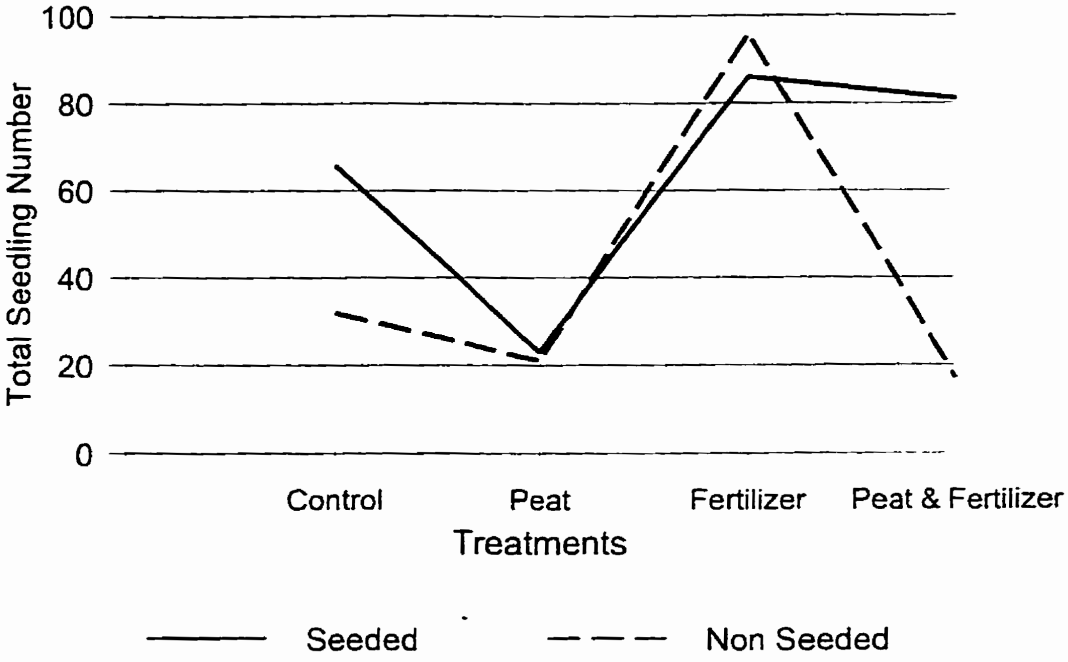


Figure 4.3 Total seedling number in 1994 in seeded and non-seeded plots of the four treatments (control, peat, fertilizer and peat and fertilizer) at Site I. The associated statistics are summarized below.

2-factor ANOVA (1st factor: seeded or not seeded, 2nd factor: treatments; control, fertilizer, peat and peat and fertilizer)conducted on the 1994 data, based on log transformed data.

	d.f.	s.s.	mean square	F-ratio	probability
Seeded or Not (S)	1	0.375	0.375	1.840	0.187 n.s.
Treatment (T)	3	2.475	0.825	4.048	0.018
Interaction (SxT)	3	0.879	0.293	1.438	0.256 n.s.
Error	24	4.892	0.204		
Total	31	8.621			

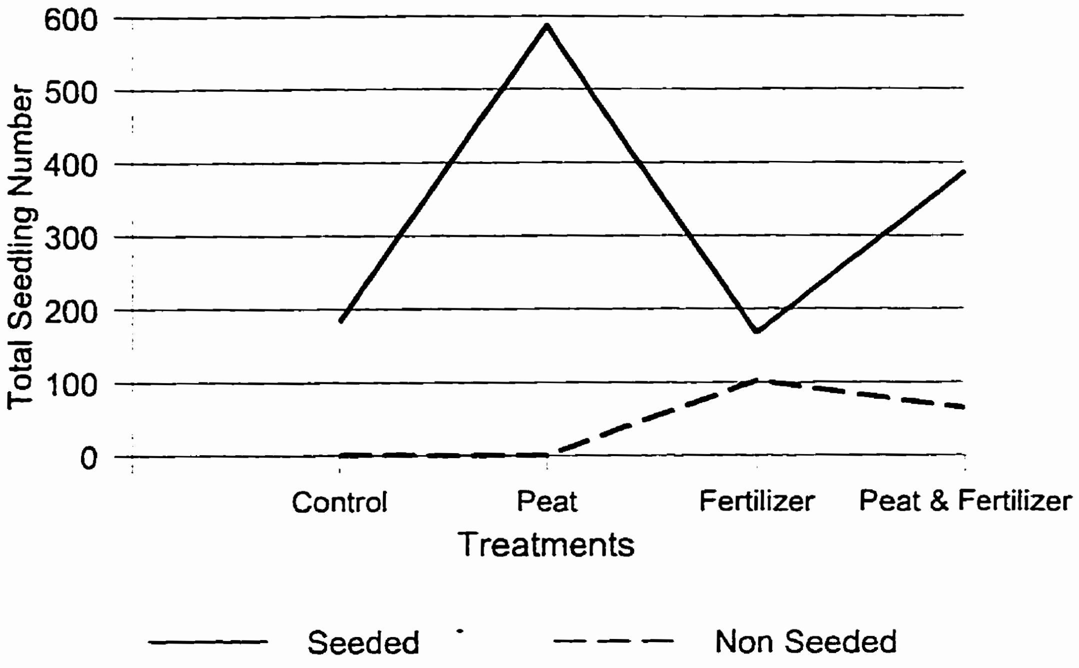


Figure 4.4 Total seedling number in 1994 in seeded and non-seeded plots of the four treatments (control, peat, fertilizer and peat and fertilizer) at Site II. The associated statistics are summarized below.

2-factor ANOVA (1st factor: seeded or not seeded, 2nd factor: treatments; control, fertilizer, peat and peat and fertilizer) conducted on the 1994 data, based on log transformed data.

	d.f.	s.s.	mean square	F-ratio	probability
Seeded or Not (S)	1	12.122	12.122	100.43	< 0.0001
Treatment (T)	3	2.184	0.728	6.032	0.003
Interaction (SxT)	3	3.181	1.060	8.786	0.004
Error	24	2.897	0.121		
Total	31	20.384			

Table 4.3 Ranking of plot treatments where 1 is the highest total seedling number and 8 is the lowest total seedling number.

	Site I			Site II	
RANK	TREATMENT	TOTAL SEEDLING NUMBER 1993/1994	RANK	TREATMENT	TOTAL SEEDLING NUMBER 1993/1994
1	Fertilizer non-seeded	109/96	1	Peat seeded	0/589
2	Fertilizer seeded	62/86	2	Peat+Fert seeded	0/411
3	Peat+Fert seeded	2/81	3	Control seeded	0/184
4	Control seeded	7/66	4	Fertilizer seeded	4/167
5	Control non-seeded	0/32	5	Fertilizer non-seeded	0/102
6	Peat seeded	0/25	6	Peat+Fert non-seeded	0/73
7	Peat non-seeded	0/21	7	Control non-seeded	0/1
8	Peat+Fert non-seeded	04/16	8	Peat non-seeded	0/0

Table 4.4 Number of seedlings of each of 23 species found in study plots by the end of 1994. Values represent means +/- 1SD.

	Control		Control Seeded		Peat		Peat Seeded		Fertilizer		Fertilizer Seeded		Peat & Fertilizer		Peat & Fertilizer Seeded	
Site	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Species																
Lesquerella arctica	14		11		20		9		17	2	8	4	9	2	11	9
Stellaria longipes	6		4	1				3	17	88	20	30		57	3	55
Minuartia rubella	9		8				1		4		18		2		4	
Dryas integrifolia										2		2			2	
Hedysarum mackenzii			39	182			13	580		4	15	129		2	60	312
Equisetum arvense								3			1					
Achillea nigrescens												1				
Draba cana	3				1				32	2	6	1	1	2		1
Festuca brachyphylla									10		12		1			
Epilobium angustifolium									2		1					
Androsace septentrionalis									1							
Melandrium affine									2		2		2			
Trisetum spicatum									3		1					
Cerastium alpinum			4						5		2		1			
Rumex occidentalis								3						2		3
Elymus arenarius		1								1				1		1
Sp.X																3
Sp.Y														6		3
Salix sp.														1		
Grass									3	5				1	1	1
Total	32	1	66	183	21	0	23	589	96	102	86	167	16	74	81	388

Table 4.5 Cover and frequency values for species found in undisturbed vegetation adjacent to Site I and Site II (n=30 per site).

Species	**Site I**		**Site II**	
	% Cover (+/- 1SD)	Frequency (n=30)	% Cover (+/- 1SD)	Frequency (n=30)
Lichen	62.29 (+/- 35.31)	28	15.79 (+/- 12.8)	28
Elymus arenarius	20	1	absent	absent
Poa sp.	absent	absent	6.42 (+/- 4.14)	12
Carex sp.	2.92 (+/- 2.72)	13	7.5 (+/- 3.54)	2
Tofieldia pusilla	1 (+/- 0)	4	1.5 (+/- 1)	4
Salix lanata	absent	absent	7.67 (+/- 6.35)	3
S. reticulata	absent	absent	1	1
Betula glandulosa	absent	absent	2	1
Polygonum sp.	absent	absent	0.5	1
Stellaria longipies	absent	absent	1	1
Dryas integrifolia	24.42 (+/- 23.16)	24	3.59 (+/- 2.71)	11
Rubus chamaemorus	absent	absent	2.69 (+/- 2.31)	8
Empetrum nigrum	11.5 (+/- 11.1)	4	35.26 (+/- 30.98)	27
Pyrola secunda	1 (+/- 0)	3	absent	absent
Andromeda polifolia	4	1	7.2 (+/- 4.76)	5
Arctostaphylos rubra	14.78 (+/- 9.57)	18	18.33 (+/- 20.99)	12
Ledum decumbens	absent	absent	12.08 (+/- 9.54)	25
Rhododendron lapponicum	13.43 (+/- 8.91)	23	7.19 (+/- 6.23)	8
Vaccinium uliginosum	10.83 (+/- 5.81)	6	10.94 (+/- 9.62)	8
V. vitis-idaea	absent	absent	1.89 (+/- 1.21)	18
Pinguicula vulgaris	1	1	absent	absent

mackenzii). *Hedysarum mackenzii* was present in plots of all treatments except the unseeded control. *Lesquerella arctica*, *Stellaria longipes* and *Minuartia rubella* were found in all treatments. Draba *cana* was found in all treatments except peat seeded.

Fertilizer-control and fertilizer-seeded plots displayed the greatest seedling species diversity with fourteen and thirteen species respectively (Table 4.4). The lowest diversity was found in the control plots at Site II with only 1 species found and the peat treatment plots which had only 2 species present on Site I and no seedlings on Site II (Table 4.4).

The adjacent undisturbed areas displayed a different species composition from that of the study plots. Of the twenty three seedling species found on the study plots only three were common to the undisturbed areas; *S. longipies*, *D. integrifolia* and *E. arenarius* (Table 4.5).

Three of the seven seeded species were present in the emergent seedling populations on the study sites. *Hedysarum mackenzii* had the highest number of seedlings at either site with 127 at Site I and 1209 at Site II by the end of 1994 (Table 4.6). All seedlings of *H. mackenzii* at Site I were located on seeded plots (Table 4.6). Site II on the other hand had 1203 seedlings of *H. mackenzii* on the seeded plots and 6 on the unseeded plots (Table 4.6). The other two seeded species found were *D. integrifolia* and *E. arenarius* (Table 4.6). *Dryas integrifolia* was present at both Site I and II seeded plots with 2 seedlings respectively (Table 4.6). *Elymus arenarius* was present at Site II in the non-seeded and seeded plots with 3 and 1 seedlings respectively (Table 4.6). Plants of *E. arenarius* were also observed to be emerging onto the seeded plots in the summer of 1996 (Firlotte field observations). Observations also in the summer of 1995 and 1996 showed that in fact the seeds *of Saxifraga tricuspidata* had begun to germinate in large numbers on the seeded (plot 32) and non-seeded plots (16, 23, 27) at Site I (Firlotte field observations).

Table 4.6 Numbers of seedlings of seeded species appearing at Sites I and II by the end of 1994.

Species	Site I Seeded	Site I Non-Seeded	Site II Seeded	Site II Non-seeded
Elymus arenarius	0	0	1	3
Juncus arcticus	0	0	0	0
Salix lanata	0	0	0	0
S. planifolia	0	0	0	0
Dryas integrifolia	2	0	2	0
Saxifraga tricuspidata	0	0	0	0
Hedysarum mackenzii	127	0	1203	6
Oxytropis campestris	0	0	0	0

4:4:2 Snow Study

4:4:2:1 Snow Depth

Snow depth varied greatly on Sites I and II. For Site I, the mean snow depth was 16.30 cm ±19.77 but snow depths ranged from 0 cm to 80 cm (Table 4.7). The southeast end of Site I was almost blown free of snow but snow depth increased toward the southern side of the site which was in the lee of gravel

Table 4.7 Mean snow depth, density and snow water equivala (SWE) for Site I and II in February 1994.

	SITE I	SITE II
Mean snow depth (cm) N=95	16.3 +/- 19.77	43.8 +/- 33.94
epth Range (cm)	0 - 80	5.0 - 130
Mean Density (g/cm3)	0.43 +/- 0.10 N=16	0.33 +/- 0.06 N=15
Mean SWE (mm)	62.34 +/- 79.25 N= 16	81.11 +/- 52.0
SWE range (mm)	2.95 - 316.57	25.50 - 196.24

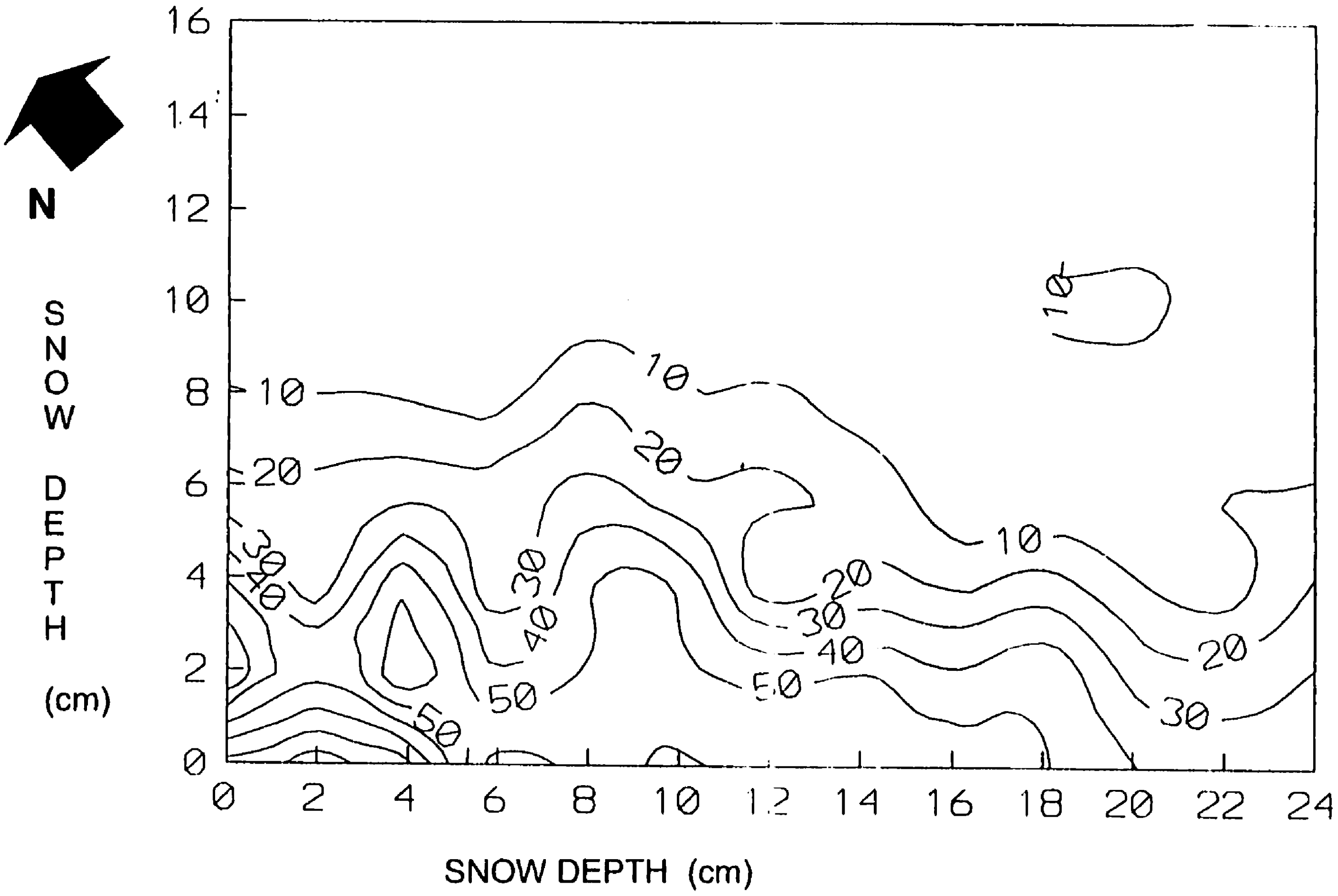


Figure 4.5 Contour map showing snow depth (cm) distribution on Site I.

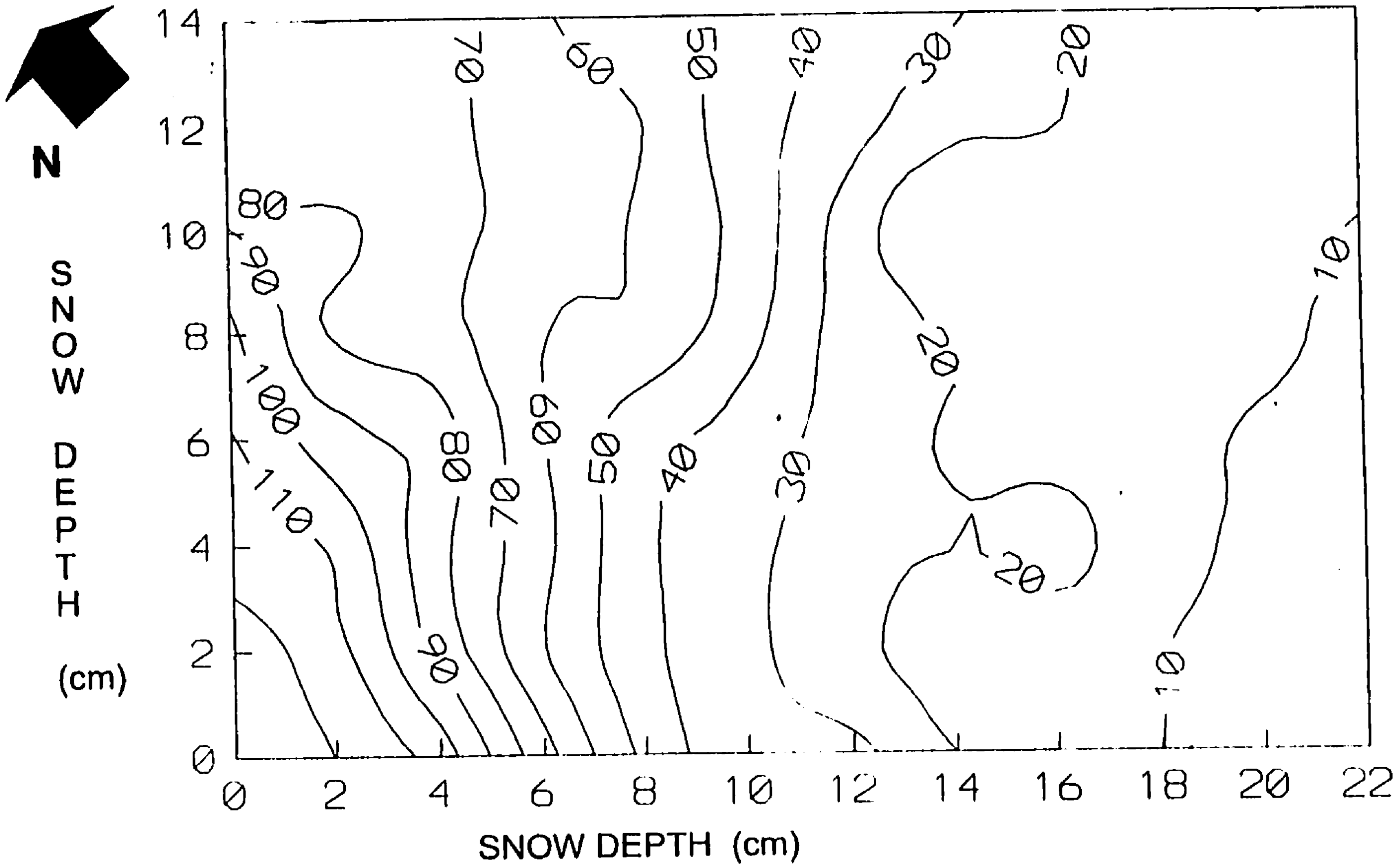


Figure 4.6 Contour map showing snow depth (cm) distribution on Site II.

mounds and willow bushes (Figure 4.5). The deepest snow on Site I was located on its west side adjacent to a gravel mound (Figure 4.5).

However, at the southwest corner of the Site I, a depth of 80 cm was found, there were no comparable depths found adjacent to this one unlike at the west side where the depths are similar and clustered together. This is seen in the contour map of the site (Figure 4.5). I believe this was a result of depth being taken over the edge of the plot. The site drops off on the east and south sides. Since in the winter it is very had to get ones bearings and I believe I may have misjudged the edge of the site.

The mean snow depth for Site II was 43.95 cm ±33.94 (Table 4.7). The snow depth increased from southeast to northwest, from 5 to 130 cm (Figure 4:6). This site was surrounded by gravel mounds on three sides in a U-shape configuration. This successfully trapped the snow on the site (Figure 4:6). The extreme west side of the site had the deepest snow (adjacent to gravel mounds) (Figure 4:6). The prevailing northwest wind in the area accounted for accumulations of snow on the lee or east sides of mounds (Figure 4:6).

4:4:2:2 Snow Density

The mean densities for snow on Site I and II in February 1994 were 0.43 ±0.10g/cm^3 and 0.33 ±0.06g/cm^3, respectively (Table 4.7). The snow water equivalent (SWE) values were higher as snow depth increased, therefore, there was more water available for plants on Site II than Site I should other factors, such as drainage and evaporation have been similar. Site I had an average

SWE of 62.34 mm ±79.25 mm and ranged between 2.95 - 318.57 mm (Table 4.7). At Site II the average SWE was 81.11 mm ±52.00 mm and ranged between 25.50 - 196.24 mm (Table 4.7).

4:5 DISCUSSION

The objective of the final part of this study was to determine whether it was possible to speed up the natural recovery by mitigating the physical limitations affecting denuded gravel areas in the Churchill region. The use of permanent study sites was beneficial in outlining these limitations as well as the means to overcome them. Emergent seedlings and existing vegetation in the harsh climate of the tundra is limited by a number of physical factors; wind abrasion in winter, desiccating wind, reduced nutrient availability and moisture stress (Warren Wilson 1966, Haag 1974, Krebs 1985, Chapin and Shaver 1987, Salonen 1987, Oberbauer and Dawson 1992, Tenhunen et al 1992, Truett and Kertell 1992). There is no way, short of global warming, that we can increase temperatures in the arctic region. However, human intervention can alleviate moisture stress and nutrient limits on denuded gravel areas.

Plants growing in undisturbed tundra, unlike those in open gravel pits are afforded some protection from wind by the vegetation and will benefit from accumulated organic litter (Muc 1977). Natural vegetation and its litter help to accumulate snow in winter and provide nutrients in summer. Suitable germination sites for incoming seed and protection from harsh wind may be provided by any standing vegetation. Standing vegetation may catch windborne seeds and also act as a seed source for their own seeds (Chambers et al. 1991).

Gravel will not trap and accumulate leaf litter to the same extent as standing vegetation. Seeds landing in open gravel pits and any resulting

Gravel will not trap and accumulate leaf litter to the same extent as standing vegetation. Seeds landing in open gravel pits and any resulting seedlings are unlikely to be afforded protection from desiccating winds. The absence of the overburden means that the nutrient status of the substrate will be low. Suitable micro-sites for germination are limited due to the evaporation caused by desiccating wind at the surface of the gravel. In the current study, an attempt was made to alleviate this problem by adding peat to the gravel substrate. The peat provides an organic layer which reduces water loss and the leaching of nutrients, this in turn facilitates germination of incoming seeds.

Peat and gravel surfaces are subject to disturbance by wind which can inhibit seeds from finding a safe site for germination (Salonen 1987). Seeds possessing appendages will have an advantage over naked seeds in this environment (Salonen 1987, Chambers et al. 1991). Seeds which were smooth and wind-dispersed would be at a disadvantage since they are not easily trapped on gravel or peat surfaces (Spence 1990, Chambers et al. 1991). Crevices in gravel may not allow sufficient surface variation to trap and hold small, wind-born seeds. Small seeds would be easily blown away with dry peat. Furthermore, there is usually no leaf litter on gravel or open peat surfaces to trap wind dispersed seeds (Runolfsson 1987).

Fertilizer application resulted in increased seedling establishment at both Sites. Fertilized-non-seeded plots on Site I had the highest mean seedling number per plot, species number and average seedling diameter over all (Table

4.1). Adding fertilizer to the peat and the manual addition of seeds greatly enhanced the seedling numbers and the species diversity. This was evident at Site II where the peat+fertilizer-seeded resulted in a mean number of seedlings of 102.75 per plot (Table 4.2).

Seeds tend to spread outward from parent plants. The objective for revegetation projects is to encourage growth and survival of potential parent plants in adjacent areas. This will lead to the development of a future seed source. Application of seed resulted in higher seedling numbers for all treatments except the fertilizer-non seeded treatment at Site I. Seeding accounted for 61% of the total numbers of seedlings at Site I and 88% of the total seedling number at Site II. *Hedysarum mackenzii* seedlings contributed 30% and 80% to the total number of seedlings at Sites I and II, respectively.

The seven species seeded onto Sites I and II were chosen for their ability to improve the sites. Mat or cushion forming species, *D. integrifolia* and *Saxifraga tricuspidata*, can trap organic debris and build up soil, thus making the area more suitable for secondary colonizers (Svoboda and Henry 1987). Cushion plants act as nurse plants for seedlings protecting them from the harsh climatic conditions (Bliss 1971, Svoboda and Henry 1987, McGraw and Vavrek 1989, Carlsson and Callaghan 1991). Willow species were selected because they are also able to accumulate organic debris, provide leaf litter in the fall and to trap snow once established (Schaefer and Messier 1995). Plants with extensive roots or rhizomes like *Elymus arenarius*, stabilize shifting soil and make the area more suitable for plant species not adapted to physical disturbance. Legumes (e.g. *Hedysarum mackenzii*) having nitrogen fixing bacteria (*Rhizobium*) associated with their roots and will amend the soil around them with nitrogen compounds. In this way, legumes provide nitrogen compounds which are then available for other plants. There are species in the Churchill region which may be capable of nitrogen fixation, two legumes which are *Hedysarum mackenzii*, and *Oxtropis campestris* and *Dryas integrifolia* (Cargill and Chapin 1987, Svoboda and Henry 1987 and Chapin and Bledsoe 1992)

The application of seeds of the legume *H. mackenzii* was successful, showed the highest seed germination and seedling numbers (up to 500 per plot) of the seven species which were applied as seed to the study plots. This species, however, did not occur naturally in the adjacent undisturbed areas or in the unseeded plots. Therefore, it is likely limited by its ability to disperse over distance, due in part to the large seeds (>2 mm) (Bishop and Chapin 1989). They have no wing to aid in wind dispersal. They must therefore rely on other vectors, (zoochory, geochory or hydrochory) for long distance dispersal.

The variation in the response to the different treatments seen on the two sites was significant. Therefore, the sites themselves must differ at some fundamental level. Differences in the physical structure or composition of the two sites confounds the results of the treatments. The U-shaped gravel ridges surrounding Site II provide shelter and help to mitigate the effects of desiccating winds. A decrease in the summer and winter winds on the site will decrease evapotranspiration. The same gravel ridges serve to trap snow in winter providing protection against desiccation and ice abrasion. Site I is open to these winds throughout the year. Therefore, the seedlings are subjected to more desiccating winds than at Site II which may account for the improved seedling survival on this site. Indeed, the application of fertilizer was positive at both Sites. However, the combination of fertilizer, snow cover and shelter at Site II may account for the difference between the sites in overall seedling numbers.

The nutrient status at Site I was the dominant limiting factor since the fertilized treatments fared the best. Fertilizer treatments ranked first and second for Site I and fourth and fifth for Site II (Table 4:3). However, at Site II fertilizer seemed to have less importance than organic matter restoration. Peat seeded treatments ranked first at Site II and sixth at Site I (Table 4:3). Unfortunately there are no data for soil nutrients prior to the treatments. Site I is raised which may remove it from the source of water and nutrients more so than Site II which is located in slightly depressed area. The height of Site I also exposed it more than Site II to wind abrasion and desiccation. Site II was more sheltered in summer and more completely snow covered in winter.

Snow cover was different on the two Sites. The crests of gravel ridges (eskers and beach ridges) in the Churchill area blow clear of snow but drifting occurs on their leeward sides (Cheney and Brown Beckel 1955, Billings and Bliss 1959). Site I and II showed drifting in the leeward sides of the ridges on the sites (Fig.4.3 and 4.4). Deep snow affords protection for plants in the harsh winter months, supplies meltwater in the spring but also decreases the length of the growing seasons (Polunin 1951, Krebs 1985, McKendrick 1991, Sonesson and Callaghan 1991, Schwarzenbach 1996).

Site II had the greater snow depths of the two sites which may, in part, account for the higher seedling number (3 times that of Site I) in 1994 and improved response to the seeded treatments. The increased snow cover and depth resulted in more available water, reflected in the SWE for Site II of 81.11 mm. In the spring the resulting melt provides needed moisture for seedling establishment. The greater snow depth would afford more protection for seedlings on Site II than those exposed on Site I. Increased snow depth can have a negative effect if the snow took longer to melt in the spring and reduced the already short growing season (Sonesson and Callaghan 1991, Schaefer and Messier 1995). This may have been the reason for no seedlings emerging on Site II in the 1993 season.

Wind increases the density of snow by altering the stellate configuration of the individual crystals into needles which, when blown together, resulted in a tighter fit and increased density of between 0.3 and 0.5 g/cm^3 (Hare 1970, Pruitt 1978). Undisturbed snow on the other hand had intact snow crystals and more air. The density in this case was between 0.05 and 0.3 g/cm^3 (Pruitt 1978). Site I was subjected to more wind action than Site II accounting for the higher snow density at this site (0.433 g/cm^3) (Hare 1970). Site II was more sheltered and this resulted in densities of less than 0.3 g/cm^3 (Hare 1970). None of the plots at Site II had been exposed to wind action. Seedlings on these plots were all covered with snow in winter and, therefore, protected from dessication, snow abrasion, intensely low temperatures and drought (Polunin 1951, Hare 1970, McKay 1970, Carlsson and Callaghan 1991, Kudo 1991 Oberbauer and Dawson 1992, Schaefer and Messier 1995). Approximately half of Site I was blown clear of snow, and therefore exposed to wind damage, abrasion, intense chill and extreme drought (Hare 1970).

Site II may have been limited by seed rain since seeding had such a marked effect there. The seeded treatments ranked in the top four places for Site II (Table 4:3). Seeding at Site I did not have such high numbers as at Site II, but still ranked highly overall (Table 4:3). The same gravel ridges that afford this site protection from winds may also limit the seed rain onto the site by altering wind direction. This implies that there may have been little dispersal onto the site to date. On the other hand the required "safe sites" may not have existed until organic matter and fertilizer were applied.

Non-seeded peat plots on both Site I and II had the lowest rank in Site II and second last at Site I. Seedling establishment on bare peat was likely inhibited due to an organic crust that formed when the peat surface dried after rain (Sheldon 1974, Skaller 1981, Salonen 1987). Roots are not able to penetrate into the encrusted peat and conversely seedlings would be prevented from breaking through the crust from below (Bradshaw 1987). The encrusted, smooth peat surface prevented seed entrapment and wind action blew seeds across its surface (Chambers et al. 1991). In treatments where seeds were manually incorporated into the peat surface, the seedling numbers were much higher than those of the peat plots where seedling establishment was left to a more natural process.

Gravel areas, unlike the smooth peat surface, have small crevices which trap seeds and provide micro-sites for germination and establishment. This was evident in the field where seedlings were seen growing behind large cobbles (>8cm diameter) and in depressions (Firlotte, field observation). The cobbles decreased the harshness of the micro-climate at the micro-site level. The control-unseeded and control-seeded plots had greater species richness than either the peat-non-seeded or the peat-seeded plots respectively for both sites. The control plots with their uneven surface may be able to trap seeds that would be blown off the smooth peat surface.

Seeds may percolate down in the gravel column as a result of precipitation, physical disturbance or cryoturbation (Chambers et al. 1991). Small seeds, like those of *Saxifraga* spp., would easily fall through crevices in the gravel and become incorporated into a deeply located seed bank rather than germinate near the surface. Seeds of *Hedysarum mackenzii* are large enough to remain on or near the soil surface and this may account for the higher germination success of this species (e.g. 327 seedlings at plot 4, Site II).

Seeds can be introduced to an area from the surrounding vegetation and by means of biological vectors such as geese and caribou (Bradshaw 1987). Willow catkins (*Salix* spp.) blown in from the surrounding area were seen on some plots along with goose droppings and caribou tracks on the study sites. Natural recolonization of open gravel areas appeared to be by vegetative spread from plants at the periphery of the disturbance or, from clumps of vegetation which may have survived the initial disturbance (McKendrick 1987).

Sites I and II were surrounded by undisturbed tundra which served as a potential seed source. However, seedlings found in the study plots on Sites I and II were not of the same species as those seen in the adjacent undisturbed tundra. The seed source must have been from the site itself, an existing seed bank, or from long distance dispersal. Studies show seed banks do not exist in this area (McGraw and Vavrek 1989). Preliminary seed bank studies undertaken in 1993 showed that indeed there were no seeds present in the soil samples from Site I (Staniforth unpublished data). Site II on the other hand, had 17 seedlings (16-*Sagina nodosa*, 1-*Solidago multiradiata*) germinate from 10 x 10 cm soil samples. This does not indicate that a significant number of seeds were present in the gravel. Such small numbers of seedlings will not result in closed vegetation cover on site especially since none of these species were found in the emergent seedling population. Therefore, I believe the source of the seedlings in the study plots was not the surrounding undisturbed tundra. Since *Lesquerella arctica*, *Elymus arenarius* and *Stellaria longipes* were not present adjacent to the plots, but were found in the emergent seedling population. The undisturbed areas would be the source in cases of marginal invasion by means of vegetative spread. The undisturbed areas may provide the seed source for later colonization once the site becomes modified by the initial colonizing species. The initial seed source must therefore be by long distance dispersal.

Grazing by geese and the presence of caribou tracks were seen at Site I and II. Site I was frequently visited by geese who grazed the site and left droppings. Geese and caribou can have a damaging effect on the emergent seedlings by grazing and trampling (McKendrick 1987, Henry and Gunn 1991). This was evident in the grazing damage done to seedlings at Site I. Conversely, the geese and caribou will manure the site and thus supply nutrients and seeds which will increase plant production (Haag 1974, Schwarzenbach 1996). Geese will produce droppings once every four minutes while feeding, these droppings will enhance the available nitrogen on site and increase above-ground primary production during the growing season (Bazely and Jefferies 1985, Jefferies et al 1992). Caribou may introduce debris on their hooves to the area which can benefit the vegetation colonizing the area, similar to cases of muskox transporting debris on hooves and wool (Schwarzenbach 1996). The trampling by the caribou on the area may also help to "plant" or deposit the seeds below the soil surface, similar to the bison effects on prairie. Hoof prints can also serve as a micro-site to enhance germination (Harper et al. 1965). Evidence of this was not seen on the sites however over time these effects could become evident.

4:6 CONCLUSIONS

1. Fertilizer application at a rate of 30 g m^{-2} to disturbed gravel areas improves vegetation recovery by an average of 300% (Site I - 96/32).

2. Peat application alone can inhibit seedling establishment on disturbed gravel areas by 35% in the short term (Site I - 21/32).

3. Seed application 250 seeds m^{-2} improved recovery on the gravel areas by 206% at Site I and by 400% at Site II.

4. In every treatment seed application improved recovery with the exception of one treatment at Site I (the fertilizer non-seeded treatment at Site I was slightly higher than the seeded treatment by 10 seedlings which is not significant).

5. The combination of seed application (using *Hedysarum mackenzii*) and fertilizer addition greatly improved the recovery of denuded gravel areas in the Churchill region.

6. Plants in undisturbed areas immediately adjacent to gravel pits generally did not contribute to the population of emergent seedlings. A possible exception to this was *Dryas integrifolia*.

7. Snow cover is important to seedling recovery because it provides protection from desiccating winter winds. Snow melt in spring can also provide much needed moisture.

CHAPTER 5

GENERAL CONCLUSIONS

5:1 INTRODUCTION

Little research has been done to compare appropriate species for restoration programs in northern Manitoba (Bailey 1981). The objective of this section of the study was to suggest the suitability of native plant species for potential restoration projects. This information would form the basis for recommendations for species selection for restoration of damaged dry tundra areas. Life history characters must be considered in the scheme. Rooting systems are important to site stabilization, nitrogen fixing capabilities are important to restoring the nutrient balance in the soil. The suitable species will then be combined with appropriate revegetation techniques (from Chapter 4) to produce a plan for revegetation following excavation or development. Future research prospects in the area of revegetation in the Churchill region will also be considered as well as the overall conclusions reached with this study.

5:2 DISCUSSION

Suitable revegetation species

Hedysarum mackenzii stands out from my studies as the best species for use in revegetation of disturbed gravel areas. The numbers of seedlings achieved through one seed application of 250 seeds m^{-2} was over 1000 seedlings per site. Considering the ease of seed collection this seems to be an ideal species for a revegetation program.

Hedysarum mackenzii did not require seed scarification to achieve high germination. The other legume *Oxytropis campestris*, included in the seedling trials, failed to produce any seedlings during the study period. This species may have benefited from scarification which may make it a suitable species. Further study is required to ascertain this.

Hedysarum mackenzii is a legume with nitrogen fixing capabilities. This makes it beneficial for improving the soil nutrient balance. This ameloration of the site should make the area more hospitable for later colonizing species.

Elymus arenarius with an extensive rhizome may prove to be beneficial as a revegetation species for substrate stabilization (Fridriksson 1987). The limited seed production may be overcome by utilizing rhizome cuttings and a rooting hormone to promote root growth. The transplanting of clumps of *E. arenarius*, which would then spread out via the rhizomes, onto disturbed areas form established populations may also prove beneficial.

Lesquerella arctica was found in large numbers on permanent study Site I

(99 seedlings), although seeds of this species were never applied to the plots. Due to its high numbers this may be a species worth investigating for future revegetation programs. The seedlings ability to survive in the harsh wind blown conditions found on Site I and spread providing ground cover which may over time accumulate organic matter make it a potential species for revegetation programs.

Suitable revegetation techniques

Levelling the area following excavation will also be beneficial to revegetation. The undulating wind-swept topography characteristic of excavation sites leads to a patchy vegetation cover and soil moisture variation (Klokk and Ronning 1987, Matthes-Sears et al. 1988). Levelling will remove the tendency for seeds to cluster in one area and allow for a more complete restoration of vegetation on site (Klokk and Ronning 1987).

Snow management may become important once seedlings are established. Snow cover throughout the harsh winters will protect the fragile seedlings from desiccating winds which could inhibit their continued growth. Deep snow cover is not required since it could shorten the growing season however, a moderate snow cover, as seen on Site II, improves the survivorship of seedlings until they can trap their own protective snow cover. The manipulation of snow cover could be achieved through the use of seasonal snow fencing.

Restoration of organic soil would be the first priority for future excavation projects (McGraw 1980, Johnson 1987). The overburden can be stockpiled and upon completion of gravel removal it can be redistributed on the area (Street 1985). The redistribution of organic matter on disturbed areas will lead to improved recovery time.

Fertilizer application was found to greatly enhance seedling establishment on gravel areas. The nutrient shortage on denuded gravel areas seemed to be the major limitation to seedling establishment. A single fertilizer application considerably enhanced the vegetation recovery. Fertilizer application combined with seed application may also improve revegetation on denuded gravel areas.

Providing shelter to denuded gravel areas to mitigate the negative effects of wind maybe beneficial to site recovery. Shelter in the form of temporary fencing or the planting of a shrub (willow) border around gravel areas may serve to trap snow and decrease wind. The accumulation of snow will provide protection and moisture. Decreasing the effects of summer winds on the denuded gravel area may decrease evapotranspiration and improve seedling survival

Future research

-seed bank

Studies are required to understand the existing seed bank in the Churchill region. The threat of major development in the area creates the need for an understanding of the soil seed banks. Increased knowledge can only assist in the formulation of appropriate management and revegetation programs for gravel excavation and revegetation sites.

-seed rain

The adjacent undisturbed areas are assumed to be the source of seed rain onto disturbed areas. Studies should be undertaken to determine if this assumption is correct. Studies are needed also to ascertain the amount of incoming seed rain and the species involved and their germination requirements. The distance which seeds are transported from parent plants is unknown and would benefit future restoration programs

- Further study on seed production in adjacent undisturbed areas. The application of fertilizer on these areas to increase seed production and therefore, enhance recovery of the disturbed area could be a source of future research projects.

-snow cover and distribution

Due to the desiccating winter winds in the area and extensive movement of snow by wind a more detailed study of snow cover should be undertaken in the disturbed areas of Churchill.

-snow management

The town is about to embark on a major beautification scheme. Knowledge of snow cover and its benefit to vegetation would be beneficial to this scheme. The town has tried in vain to establish grass (Red Fescue) in the square. Snow cover throughout the winter will probably be a great benefit to keeping this fragile southern species alive from season to season. Studies utilizing snow fencing to manage snow cover could be undertaken in this situation.

-shelter belts

Utilizing native shrub borders to serve as snow traps and to decrease the desiccating winds may prove beneficial to revegetation strategies. Further study is needed to determine if this will indeed have a positive effect of revegetation on gravel areas.

5:3 CONCLUSIONS

1. The maps produced in Chapter 2 outlined the extent of disturbance in dry tundra areas at 10% (412.31 ha) with 3752.49 ha remaining undisturbed. The disturbed areas are high profile sites adjacent to roads. Considering that the economy of Churchill is focussed on tourism, restoration of these areas would be beneficial to the overall economy of the area. On a provincial level the dry tundra ecosystem is rare and should be protected from further disturbance. Conservation of this biome through reclamation of these disturbed sites would be a positive step.

2. Soil texture is an important determinant to the seedling survival due to its effects on moisture holding capabilities. Alteration of soil texture could therefore, enhance site recovery. Introduction of smaller soil particles and organic micelles, either silt, clay or fine sand and peat to denuded sites could improve restoration by increasing moisture holding capacity

3. The microtopography remaining on the disturbed area will effect the successional path of the site. A site with undulating topography will result in patchy vegetation cover due to varied moisture regimes and snow cover. The levelling of the abandoned excavation sites will alleviate these microtopographic variations and result in a closed cover over time.

4. Fertilizer application will improve revegetation on abandoned excavation sites. Such sites are nutrient limited due to the removal of the overburden. Fertilizer application serves to help restore the nutrients to the site and increases the

potential for vegetation growth.

5. Seed application increases recovery of disturbed sites. Adequate seed application ensures that propagules are reaching the site in high numbers. The seed application in this study improved recovery by 206% over control plots. Seed application combined with the other treatments (fertilizer, peat and peat and fertilizer combined) resulted in improved recovery in all but one instance.

6. Peat application alone inhibited recovery by 35%. The surface layer of the peat became crust like which inhibited penetration by seeds. The smooth surface resulted in horizontal movement of seeds and debris which limited colonization of these sites.

7. Snow cover can enhance seedling survival by protecting them from desiccating winds. Snow cover can also be a moisture source in the spring following the melt.

The Town of Churchill is about to implement a beautification strategy in which local species are being transplanted onto the town site. These will provide a showcase of the local vegetation. I was consulted on species collection and assisted in choosing appropriate species as well as logistical methods for their safe removal and transplantation. These projects should begin in the summer of 1998 with education and culminate the following season with the planting on the site. Indeed, this is a positive step for the town toward an improved town profile.

Appendix 1: List of Plants encountered during the course of this study at Churchill, Manitoba.

Achillea nigrescens
Andromeda polifolia
Androsace septentrionalis
Anemone multifida
Arctostaphylos alpina
Arctostaphylos rubra
Astragalus alpinus
Betula glandulosa
Carex sp.
Castilleja raupii
Cerastium alpinum
Dryas integrifolia
Elymus arenarius
Empetrum nigrum
Epilobium angustifolium
Epilobium latifolium
Equisetum arvense
Equisetum variegatum
Euphrasia arctica
Festuca brachyphylla
Gentiana propinqua
Heysarum mackenzii
Hordeum jubatum
Juncus arcticus
Ledum decumbens
Lesquerella arctica
Lichen sp.
Melandrium affine
Minuartia rubella
Moss sp.
Oxytropis campestris
Parnassia palustris
Pinguicula vulgaris
Plygonum vivaparum
Poa sp.
Potentilla pulchella
Puccinellia lucida
Pyrola grandiflora
Pyrola secunda
Rhododendron lapponicum

Rubus chamaemorus
Rumex occidentalis
Sagina nodosa
Salix brachycarpa
Salix candida
Salix lanata
Salix planifolia
Salix reticulata
Saxifraga oppositifolia
Saxifraga tricuspidata
Shepherdia canadensis
Solidago multiradiata
Spergularia marina
Stellaria longipes
Taraxacum lacerum
Tofieldia pusilla
Trisetum spicatum
Vaccinium uliginosum
Vaccinium vitis-idaea

Appendix 2: Description of available aerial photos, from 1930 - 1991, of the Churchill study area.

1930 - (A2671-74) This photo was taken prior to the initiation of any excavation except for sites across river at Fort Prince of Wales. This is a base line photo as it shows the coast on which old Fort Churchill was to be placed. The town site is outside the area of this photo.

1951 - (A11022-71) This photo shows the Churchill River estuary region including the Cape Merry peninsula and the town site. This is a base line photo for the pits used as a source of gravel for the town-site. All of these pits except those of the Cape Merry site where under excavation by this date. This would indicate that excavation had begun at site 2B within the 21 year interval since the last photos had been taken. No precise date can be determined.

1961 - (A17406-96/A17406-98) These two photos show the town site and Fort Churchill location, eastward to the CNSC site. These photographs serve as a base line for everything east of the airport. It is known (personal communication with townspeople) that the sites in the eastern zone were under excavation long before 1961, however a precise date cannot be determined.

1969 - (A21072-lines 4-7) This series of air photos, include Fort Churchill, Akudlik and Cape Merry. This is the first evidence of excavation at Cape Merry, however excavation initiation date for that site is known to be 1967. This is the base line photograph for the Akudlik site. The date that this site was abandoned is also known (1981).

1972 - (A22955) This series shows the entire 26 km study area. All sites had been disturbed prior to this date.

1986 - (MB86035) Cape Merry which is known to have been excavated in 1967 is the only site included in this series.

1991 - (MB91010) These were the most recent photos available to me. They showed the entire 26 km study area from the town-site to the CNSC buildings. These air photos served as an outline for the recovery potential guide map.

Appendix 3: Percent cover data collected in 1992 (quadrats 1-10) and 1993 (quadrats 11-20) for the four study areas a. Bluff B , b. Cape Merry, c. Fort Churchill /Airport and d. Akudlik. Data was collected both with in the disturbed area and undisturbed area at each site (except at Akudlik where only disturbed areas were found) Bluff B distrubed areas were divided into three plant communities hill, willow and scraper scar.

a. Bluff B - undisturbed	Quadrats																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dryas integrifolia	0	86	90	100	45	35	45	80	85	21	7	8	37	36	11	10	0	0	45	24
Salix planifolia	0	0	0	0	0	0	0	0	0	10	30	0	0	0	0	0	0	0	0	0
Salix reticulata	0	0	0	4	18	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix lanata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix brachycarpa	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Castilleja raupii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epilobium angustifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astragalus alpinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stellaria longipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Festuca brachyphylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxytopis campestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	10	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	17	3	22	0
Elymus arenarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shepherdia canadensis	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	10	0
Taraxacum lacerum	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	17	0	0	0	0	15	5	6	0	0	0	0	0	26	23	0	25	8	0	12
Vaccinium uliginosum	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0.5	1	0
Vaccinium vitas-idaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	1	0	0	0	0	0	0	0	4	0	2	0	2	0	0	1	0	2
Parnassia palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Puccinellia lucida	0	0	4	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artystaphylos rubra	0	0	0	0	0	0	0	0	0	6	0	21	0	0	0	21	0	0	0	0
Saxifraga tricuspidata	0	0	0	3	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla pulchella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinguiqula vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastium alpinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gentiana propinqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juncus arcticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sagina nodosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spergularia marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga oppositifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carex sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grass sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moss sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen sp.	0	2	6	3	12	7	6	16	2	16	4	3	15	5	46	11	25	90	3	13

Appendix 3: continued

a. Bluff B - hill	Quadrats																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dryas integrifolia	0	2	7	0	0	4	0	10	10	17	0	6	2	0.1	0	35	43	0	56	0
Salix planifolia	0	0	0	0	80	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0
Salix reticulata	0	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	5	8	0
Salix lanata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix brachycarpa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Castilleja raupii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epilobium angustifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astragalus alpinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Hedysarum mackenzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stellaria longipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Festuca brachyphylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxytopis campestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	10	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0
Elymus arenarius	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
Shepherdia canadensis	100	0	0	100	4	100	100	100	100	80	90	14	0	7	26	0	0	80	15	0
Taraxacum lacerum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium vitas-idaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Parnassia palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Puccinellia lucida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artystaphylos rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga tricuspidata	0	0	0	0	0	2	0	0	0	0	0	0	0	4	0	1	0	0	1	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla pulchella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinguiqula vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastium alpinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gentiana propinqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juncus arcticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sagina nodosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spergularia marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga oppositifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carex sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grass sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moss sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0

Appendix 3: continued

a. Bluff B - willow	Quadrats																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dryas integrifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Salix planifolia	0	22	7	0	0	12	5	0	0	0	0	0	12	0	1	23	80	0	80	100
Salix reticulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix lanata	12	1	0	8	0	4	0	4	12	0	0	0	0	8	30	0	0	0	0	0
Salix brachycarpa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Castilleja raupii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epilobium angustifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astragalus alpinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stellaria longipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Festuca brachyphylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxytopis campestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elymus arenarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shepherdia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taraxacum lacerum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium vitas-idaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parnassia palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Puccinellia lucida	0.5	0	0.5	0	0	0	0.5	2	2	0	0	0	0	0	0	0	1	0	0	0
Artystaphylos rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga tricuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla pulchella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinguiqula vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastium alpinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gentiana propinqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juncus arcticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sagina nodosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spergularia marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga oppositifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carex sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grass sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moss sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3: continued

a. Bluff B - scraper scar	Quadrats																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dryas integrifolia	0	27	12	45	6	0	1	11	9	10	0	38	0	0	26	0	20	20	21	0
Salix planifolia	0	0	0	0	5	0	0	0	1	0	0	1	0	0	0	0	5	27	5	0
Salix reticulata	0	0	0	0	30	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Salix lanata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix brachycarpa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Castilleja raupii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epilobium angustifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astragalus alpinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stellaria longipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Festuca brachyphylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxytopis campestris	0	0.5	0	0	0	0.1	0	0	0	0	0	0	6	0	0	0	0	0	0	0
Empetrum nigrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elymus arenarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shepherdia canadensis	0	0	95	0	0	0	0	0	0	27	0	0	0	0	0	0	0	0	0	0
Taraxacum lacerum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium vitas-idaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parnassia palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Puccinellia lucida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artystaphylos rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga tricuspidata	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla pulchella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinguiqula vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastium alpinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gentiana propinqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juncus arcticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sagina nodosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spergularia marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga oppositifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carex sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grass sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moss sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen sp.	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3: continued

b. Cape Merry - undisturbed	Quadrats																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dryas integrifolia	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Salix planifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix reticulata	6	0	15	10	36	20	8	24	0	12	4	2	33	3	8	5	39	2	2	2
Salix lanata	0	0	0	0	0	0	1	0	0	0	0	0	1	7	3	0	5	1	0	0
Salix brachycarpa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Castilleja raupii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epilobium angustifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astragalus alpinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stellaria longipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Festuca brachyphylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxytopis campestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	6	6	2	0	0	0	0	0	0.1	0	0	2	5	0	0	0	0	2	0.5	0
Elymus arenarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shepherdia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taraxacum lacerum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	0	0	2	0	0	0	0	0	0	0	0	0	0	9	2	10	1	10	17	3
Vaccinium uliginosum	0	6	0	0	8	1	27	1	13	4	0	0	0	0	0	0	0	0	0	0
Vaccinium vitas-idaea	0	0	0	0	0	0	0	1	0	0	0	25	5	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parnassia palustris	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Puccinellia lucida	0	4	0	0	1	0	0	0	0	2	0	0	0	0	0	0	2	3	1	0
Artystaphylos rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1	5	0	0	4	8
Saxifraga tricuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum arvense	1	3	4	1	2	0	3	2	1	2	1	0.5	0	2	6	0.5	0.5	0	0	0
Tofieldia pusilla	0	0.5	0	0	0	0	0.5	0	0.5	0	0	0	0.5	0	0	0	0	0	0	0
Potentilla pulchella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinguiqula vulgaris	0	0	1	0	1	1	0	0	0.5	0	0.5	0.5	0.5	1.5	2	0	0	1	2	0
Rhododendron lapponicum	2	17	11	23	0	18	2	2	6	19	7	23	0	0	1	10	0	9	12	5
Rubus chamaemorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastium alpinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gentiana propinqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juncus arcticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sagina nodosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spergularia marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga oppositifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carex sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grass sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moss sp.	0	13	17	0	8	10	16	10	90	32	2	42	100	0	100	24	30	90	100	6
Lichen sp.	3	3	7	5	0	0	1	0	10	0	12	5	0	2	0	3	0.5	5	0	2

Appendix 3: continued

b. Cape Merry - disturbed	Quadrats																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dryas integrifolia	0	0	5	0	3	0	2	0	0	5	0	0	0	0	33	7	35	0	10	0
Salix planifolia	0	0	0	0	6	18	0	0	0	11	0	8	0	0	6	0	0	16	0	0
Salix reticulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Salix lanata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix brachycarpa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Castilleja raupii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epilobium angustifolium	0	0	0	0	5	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0
Astragalus alpinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	5	0	0	0	0
Stellaria longipes	0	0	0	4	0	0	3	1	7	0	0	0	0	0	0	0	0	1	0	0
Festuca brachyphylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Oxytopis campestris	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elymus arenarius	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	20	0	0	0	0
Shepherdia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Taraxacum lacerum	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Vaccinium uliginosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium vitas-idaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parnassia palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Puccinellia lucida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artystaphylos rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga tricuspidata	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	8
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla pulchella	2	0	0	1	0	0	0	11	2	0	0	0	0	0	2	7	0	0	0	0
Pinguiqula vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastium alpinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achillea nigrescens	1	0	2	4	0	0	0	0	0	0	10	0	3	3	0	0	0	0	0	0
Gentiana propinqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juncus arcticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sagina nodosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spergularia marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga oppositifolia	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carex sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grass sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moss sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3: continued

c. Fort Churchill/Airport - undisturbed	Quadrats																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dryas integrifolia	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Salix planifolia	0	0	0	0	0	0	0	0	0	17	80	0	90	0	11	0	0	0	0	0
Salix reticulata	0	0	0	0	0	0	73	31	0	0	0	0	0	0	0	0	0	0	0	0
Salix lanata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix brachycarpa	0	0	0	0	20	0	0	4	0	0	0	0	0	0	20	0	0	0	0	2
Castilleja raupii	6	0	0	16	0	0	8	0.5	0	0	2	14	0	7	0	0	9	23	9	28
Epilobium angustifolium	3	11	6	0	14	12	0	0	6	6	10	17	6	0	0	0	9	0	2	0
Astragalus alpinus	0	2	0	2	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	6
Hedysarum mackenzii	5	14	2	5	0	0	0	0	3	3	0	3	0	0	0	0	0	0	80	18
Stellaria longipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Festuca brachyphylla	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	6	0
Oxytopis campestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elymus arenarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shepherdia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taraxacum lacerum	2	3	18	3	0	0	1	5	3	0	0	0	0	4	4	28	0	13	2	0
Andromeda polifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium vitas-idaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	1	4	1	0
Parnassia palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Puccinellia lucida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artystaphylos rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga tricuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla pulchella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Pinguiqula vulgaris	0	0	0	2	0	0	1	2	0	0	0	3	0	0	0	0	20	7	0	3
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus	1	0	0	0	4	4	0	0	0	2	4	0	0	1	2	0	0	8	0	0
Cerastium alpinum	0.5	0	0	1	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0
Achillea nigrescens	3	0	1	0	0.5	0.5	0	0	3	0	0	0	0	1	0	0	0	0	1	0
Gentiana propinqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Juncus arcticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sagina nodosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia arctica	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spergularia marina	0	0	0	0	0	0	0	0	0	0	0	0	0	13	1	0	0	0	0	0
Betula glandulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga oppositifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carex sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grass sp.	0	0	0	0	0	0	0	0	0	0	0	20	10	0	0	90	0	0	10	0
Moss sp.	13	0	2	13	0	0	5	7	4	6	0	0	0	0	0	0	6	0	0	0
Lichen sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3: continued

c. Fort Churchill/Airport - disturbed	Quadrats																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dryas integrifolia	0.5	12	17	2	7	16	11	18	1	6	0	11	0	2	1	40	3	10	26	2
Salix planifolia	0	1	0	19	0	1	3	6	8	0	0	3	2	0	0	0	14	0	16	0
Salix reticulata	1	0	0	0	2	0	0	0	2	5	0	0	1	0	0	0	0	0	0	0
Salix lanata	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	8	0	4	36	4
Salix brachycarpa	0	0	0	0	0	0	0	0	0	0	20	0	0	11	1	0	0	0	0	0
Castilleja raupii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epilobium angustifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astragalus alpinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0	1	0	0	1	0	0	8	0	0	0	0	0	0	2	1	0	0	0
Stellaria longipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Festuca brachyphylla	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Oxytopis campestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elymus arenarius	3	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shepherdia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taraxacum lacerum	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0
Andromeda polifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium vitas-idaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parnassia palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Puccinellia lucida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artystaphylos rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga tricuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	2	0	0	0.5	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Potentilla pulchella	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Pinguiqula vulgaris	1	1.5	0	0	1	0	1	0.5	0	0	0.1	3	20	1	0	1	0	4	0	3
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastium alpinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gentiana propinqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juncus arcticus	0	0	0	0	0	0	0	0	0	0	2	0	13	5	0	31	0	23	0	4
Sagina nodosa	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spergularia marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga oppositifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carex sp.	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grass sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moss sp.	0	0	0	0	0	0	0	0	0	0	1	7	8	0	40	6	5	2	0	6
Lichen sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3: continued

d. Akudlik - disturbed	Quadrats																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dryas integrifolia	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	16	0	0	0
Salix planifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix reticulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0
Salix lanata	1	0.1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix brachycarpa	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	10	0	0	0
Castilleja raupii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epilobium angustifolium	0	0	0	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astragalus alpinus	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	4	0	2	0	0	0	18	4	81	0	0	0	0	0	0	0	3	0	35	0
Stellaria longipes	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Festuca brachyphylla	0	3	0	0	0	0	0	0	0	0	3	5	0	11	0	3	0	0	3	7
Oxytopis campestris	0	2	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elymus arenarius	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shepherdia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taraxacum lacerum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium vitas-idaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4	1	0	0	0
Parnassia palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Puccinellia lucida	20	0	6	4	0	11	4	6	2	18	0	0	0	0	0	0	0	0	0	0
Artystaphylos rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga tricuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	2	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla pulchella	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1	2
Pinguiqula vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastium alpinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achillea nigrescans	0	0	0	0	0	0	0	0	0	0	0	1	0	0	15	8	0	0	1	0
Gentiana propinqua	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0.5	0	0	0	12
Juncus arcticus	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	25	0	3	0
Sagina nodosa	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	2	0	0
Androsace septentrionalis	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0.5	6	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spergularia marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxifraga oppositifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carex sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grass sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moss sp.	26	0	4	0	0	0	1	3	0	6	70	0	0	0	0	1	80	0	0	0
Lichen sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4: Results of soil tests on samples from the four study areas a. Bluff B, b. Cape Merry, c. Fort Churchill/Airport and d. Akudlik. Soil samples were taken from the disturbed and undisturbed areas (except at Akudlik). Soil tests conducted were; gravimetric moisture content, loss on ignition for organic and carbonate content, pH and textural analysis (which was only conducted on samples from the disturbed areas). Soil samples were collected in 1992 (quadrats 1-10) and 1993 (quadrats 11-20).

a. Bluff B scraper scar		Loss on Ignition		Temperature (at depth)			Dry Sieving - Textural analysis				
	Gravimetric MC		%ORGANIC				% SILT	% FINE	% COARSE	%FINE	%COARSE
Quadrat	% MOISTURE	%CARBONATE	MATTER	5cm	10cm	pH	& CLAY	SAND	SAND	GRAVEL	GRAVEL
1	3.125	52.617989	0.74118	14	10	6.5	1.15	3.16	40.74	17.91	37.27
2	5.14	49.552974	1.25745	17	17	7	0.55	2.04	35.75	20.99	40.47
3	4.8	43.07213	2.037891	14	12	7.1	0.59	1.06	32.78	18.44	47.07
4	3.91	46.505555	1.02134	18	16	6.9	1.06	0.94	32.84	20.45	44.64
5	6.76	33.953967	1.70114	15	12	6.1	0.59	1.28	59.21	14.6	24.38
6	3.39	33.953967	0.9033	20	15	6.3	1.11	1.31	40.16	11.37	45.9
7				18	16						
8	3.26	54.706568	1.48296	15	13	6.65	0.77	1.32	56.03	9	32.55
9	5.33	60.383508	0.6083	16	13	7.2	3.9	10.79	38.6	14.66	32.27
10	4.97	55.310498	0.76847	12	10	6.4	1.61	5.71	39	15.43	38.1
11	2.16	58.6943421	0.58227	20	17	6.7	0.98	2.61	43.95	32.94	19.41
12	5.57	60.6876203	1.592013	19	17	6.8	2.61	4.6	26	23.35	43.26
13	2.03	44.3755405	0.879906	20	15	7	1.38	2.52	43.34	18.54	34.1
14	1.95	42.0454258	0.502867	19	15	6.9	0.86	2.2	36.49	20.27	40.2
15	3.45	62.2632775	0.963292	20	13	6.85	2.67	6.47	32.7	22.1	36.1
16	2.24	52.7842078	0.661132	19	14	6.5	0.86	1.13	43.24	21.72	33.2
17	2.91	40.5485847	0.981059	16	15	6.2	1.8	10.22	43	28.39	16.82
18	2.37	82.9381713	5.290587	18	15	7.3	0.23	0.76	14.87	15.66	69.36
19	2.47	53.3665718	1.430964	17	15	6.5	2.71	6.52	39.34	14.35	37.17
20	1.71	62.1738246	0.462272	19	16	6.7	0.67	1	29.71	19.25	49.41
a. Bluff B - UNDISTURBED											
1	67.31	11.03543	6.7049	17	10	6.7					
2	11.25	71.994366	54.8837	22	17	6.2					
3	9.78	1.8976365	11.1446	18	13	6.35					
4	7.67	2.8152104	9.5398	21	14	6.1					
5	21.17	6.9702659	12.6611	16	12	6.4					
6	28.36	21.54681	22.833	14	10	6.5					
7	12.33	22.123986	28.6231	15	10	6.5					
8	5.61	58.695894	45.7006	14	12	6.4					
9	46.16	76.306877	51.6902	16	10	6.8					
10	33.75	25.90032	27.1528	20	11	6.1					
11	26.13	4.7979994	15.6504	17	14	6.5					
12	10.6	10.652028	10.0609	22	15	6.4					
13	86	48.247361	38.5002	19	12	6.7					
14	45.31	19.203932	26.761	21	15	6.3					
15	14.38	69.141574	51.6269	19	10	6.2					
16	69.19	98.317176	28.8442	21	15	6.7					
17	166.62	121.72159	64.5518	21	14	6.4					
18	215.48	120.87025	61.5299	19	11	6.1					
19	49.51	53.52885	42.5766	19	12	6.1					
20	91.77	24.761431	26.374	20	15	6.25					

Appendix 4: continued

d. Akudlik - DISTURBED	Gravimetric MC	Loss on Ignition		Temperature (at depth)			Dry Sieving - Textural analysis				
Quadrat	% MOISTURE	%CARBONATE	%ORGANIC MATTER	5cm	10cm	pH	% SILT & CLAY	% FINE SAND	% COARSE SAND	%FINE GRAVEL	%COARSE GRAVEL
1	3.33	50.377537	1.70696	21	17	6.7	4.15	9.45	37.02	20.33	23.22
2	3.11	36.067957	1.38959	18	17	6.7	2	11.56	62.46	18.17	6.06
3	4.46	45.75176	1.41546	19	16	6.8	4.03	8.23	43.04	20.64	24.4
4	2.61	40.535284	0.97448	19	16	7	2.68	8.62	43.28	19.42	26.01
5	3.68	36.618553	1.09925	18	15	6.9	3.33	10.42	43.5	18.27	24.66
6	3.65	38.656037	1.2151	20	16	6.7	4.97	10.62	41.67	24.97	17.88
7	2.9	41.663187	1.23977	20	18	6.55	5.68	11.58	44.5	13.81	24.47
8	3.74	42.677151	1.02751	20	17	6.6	1.59	19.78	38.38	16.31	23.73
9	3.36	48.968904	1.68334	17	14	6.8	4.69	9.39	40.14	15.52	30.41
10	4.05	45.614342	1.44863	22	20	7.1	4.45	9.2	49.55	27.15	9.68
11	6.52	40.805728	1.68483	10	10	6.9	4.03	9.59	40.6	19.54	26.28
12	4.3	33.290133	1.64196	11	11	6.75	3.63	7.55	56.05	15.8	17.7
13	4.77	33.226008	1.52188	11	10	7.2	2.83	8	63.11	22.24	3.78
14	4.76	54.910503	1.53173	10	1	6.9	3.13	9	34.6	28.3	24.99
15	3.93	47.135623	1.37763	11	11	6.5	2.03	7.52	38.44	22.6	29.45
16	6.37	70.282071	1.53732	11	1	6.8	5.9	5.9	30.1	24.2	34
17	6.31	53.161419	1.43133	12.5	11	7.1	3.95	6.86	29.31	19.26	41.7
18	6.54	68.272959	1.33448	10	9	6.8	6.68	6.07	33.64	29.63	23.02
19	3.67	26.717305	1.27958	12.5	11	6.9	4.12	8.29	58.85	15.31	13.7
20	5.53	42.392243	1.38099	11	10	6.9	3.26	8.1	32.65	32.35	23.84

Appendix 4: continued

Fort Churchill/Airport - DISTURBED		Loss on Ignition		Temperature (at depth)			Dry Sieving - Textural analysis				
	Gravimetric MC										
Quadrat	% MOISTURE	%CARBONATE	%ORGANIC MATTER	5cm	10cm	pH	% SILT & CLAY	% FINE SAND	% COARSE SAND	%FINE GRAVEL	%COARSE GRAVEL
1	5.37	58.498244	1.00713	17		7.5	9.02	9.51	27.2	24.58	29.7
2	5.33	46.082438	1.09826	18		7.7	8.7	11.02	32.66	22.38	25.03
3	5.16	61.393774	1.14504	2		7.6	6.17	7.97	31.9	16.95	34.9
4	5.24	63.297994	1.07697	18		7.6	9	9.45	30	20.44	31.18
5	5.05	62.969065	1.29154	18		7.7	7.9	10.02	36.24	25.61	20.34
6	4.76	79.221121	0.97166	18		7.5	5.52	6.46	35.3	30.9	22.1
7	4.85	69.346249	1.14645	18		7.3	8.16	7.16	28.72	31.31	24.75
8	5.19	70.763812	1.33287	18		7.2	6.72	5.6	28.04	37.1	22.5
9	4.44	51.187455	1.04432	18		7.3	6.34	5.85	33.92	27.63	25.6
10	4.75	62.577989	0.86431	18		7.4	6.71	9.26	31.53	34.17	18.25
11	7.59	3,1168003	19.4212	11		7.7	9.37	7.46	25.16	23.25	34.76
12	7.13	16.492876	20.1411	10		7.7	6.24	4.66	30.47	23.34	32.51
13	7.71	2.221214	23.5917	11		7.7	9.06	7.03	38.98	23.21	21.67
14	6.58	18.012622	29.17	10		7.6	8.16	6.7	30.19	27.89	27.32
15	6.34	14.266645	24.6922	10		7.8	11.37	8.65	38.94	26.86	14.11
16	6.89	30.108436	17.6935	10		7.5	5.26	4.4	20.61	21.22	47.58
17	7.46	23.80719	27.4093	10		7.1	10	6.15	34.34	35.55	14.06
18	7.4	34.852071	20.244	11		7.4	7.62	7.91	30.36	22.98	31.29
19	6.84	14.445397	27.0488	10		7.2	6.25	5.03	25.03	19.6	44.25
20	7.67	29.708585	23.0384	11		7.5	8.66	6.88	27.05	20.04	37.48
c. Fort Churchill/Airport - UNDISTURBED											
1	50.85	38.568352	10.2766	16	11	7					
2	26.17	32.601108	12.7082	17	13	6.7					
3	9.03	31.631832	5.35367	15	12	6.7					
4	33.33	42.653529	26.516	15	14	6.75					
5	17.17	39.699765	7.17029	10	8	6.9					
6	13.55	33.356112	5.82924	15	11	6.9					
7	105.9	52.122216	37.3612	15	10	6.8					
8	65.52	44.977809	22.5473	14	11	6.6					
9	7.85	34.016675	5.95673	15	11	6.7					
10	4.49	35.62284	6.45453	12	11	6.5					
11	87.8	37.794349	9.4633	6	8	7					
12	153.88	58.187774	30.3203	6.5	7	6.6					
13	21.16	36.390741	7.91621	10	8	6.9					
14	37.95	48.281918	13.9303	11	10	7					
15	45.87	54.682328	13.9298	10	8	6.9					
16	37.26	56.279648	26.5076	10	9	6.9					
17	125	44.768609	27.0785	10	8	6.7					
18	64.85	50.976893	30.7044	10	8	6.8					
19	30.07	63.386266	26.9381	11	9	6.9					
20	28.06	41.777332	11.1234	10	9	7.1					

Appendix 4; continued

b. Cape Merry - DISTURBED		Loss on Ignition		Temperature			Dry Sieving - Textural analysis				
	Gravimetric MC		%ORGANIC	(at depth)			% SILT	% FINE	% COARSE	%FINE	%COARSE
Quadrat	% MOISTURE	%CARBONATE	MATTER	5cm	10cm	pH	& CLAY	SAND	SAND	GRAVEL	GRAVEL
1	2.62	58.734899	1.01347	20		6.4	1.99	1.78	12.38	46.53	37.45
2	-0.25	9.3062915	0.32289	22		7.4	0.5	0.35	1.86	11.35	85.8
3	2.53	33.278812	0.85048	20		6.2	1.12	1.81	18.68	35.31	42.9
4	2.13	50.096434	0.7079	20		6.65	2.29	1.82	22.3	46.57	26.9
5	3.11	49.558361	0.64666	20		6.9	2.25	2.23	28.28	42.49	24.74
6	6.53	61.723529	1.39039	20		6.9	0.37	0.54	2.11	9.54	87.1
7	2.65	41.481588	0.98443	20		6.5	2.2	4.07	31.23	46.53	15.8
8	2.13	42.656617	1.16096	22		7	1.53	2.63	19.05	41.7	35.19
9	2.82	63.034996	0.62137	20		7.2	1.28	1.08	19.83	47.9	29.84
10	3.4	54.829179	0.95666	20		7.1	2.44	2.2	21.65	48.35	25.26
11	3.66	48.352995	0.67326	10		7.1	3.24	2.28	34.15	37.44	22.93
12	2.08	42.908475	0.86099	9		7	2.45	1.82	17	41.26	37.41
13				7							
14	2.66	58.660535	0.1599	7		6.9	2.23	1.8	7.97	31.1	56.97
15	3.72	48.237745	1.70428	8		7	2.9	3.69	14.96	29	49.27
16	3.39	59.022696	1.53143	10		7	4.04	5.57	21.41	33	36
17	4.25	49.836716	1.13693	9		7.5	1.79	4.15	7.5	45.19	41.31
18	3.12	76.95099	1.22098	9		7.6	1.45	2.19	8.83	16.6	70.66
19	2.14	47.859171	0.85611	7		7.4	2.31	1.76	24.44	30.73	40.85
20	3.38	74.500236	1.36	10		7.6	1.66	1.66	11.27	28.1	57.5
b. Cape Merry - UNDISTURBED											
1	83.48	88.29316	55.8189	20	8	6.4					
2	78.125	115.46895	6.452	17	1	6.1					
3	80.37	109.58688	58.2525	15	7	6.4					
4	79.13	57.318881	44.5113	19	11	6.75					
5	82.36	131.80214	64.2201	16	7	6.4					
6	76.63	71.911843	45.6523	19	9	6.5					
7	8.37	101.93604	58.6985	19	13	6.7					
8	87.55	119.024542	61.8775	19	12	6.5					
9	80.26	140.98058	66.2772	16	8	6.3					
10	76.8	87.097303	55.6698	19	8	6.7					
11	381.48	132.46082	74.5994	7	6	6.3					
12	333.36	139.31874	68.0953	7	6	6.2					
13	891.3	100.17273	52.636	6	6	6.65					
14	474.33	73.951529	44.0387	9	7	6.3					
15	72.3	125.37626	66.1644	8	7	6.5					
16	351.3	52.164862	35.5161	6	6	6.6					
17	499.3	111.39981	59.7581	8	7	6.2					
18	478.3	125.32611	63.7074	7	7	6.7					
19	454.95	103.09831	65.0064	8	6	6.7					
20	411.72	73.948822	46.695	7	7	6.4					

Appendix 4: continued

a. Bluff B hill	Gravimetric MC	Loss on Ignition		Temperature (at depth)			Dry Sieving - Textural analysis				
Quadrat	% MOISTURE	%CARBONATE	%ORGANIC MATTER	5cm	10cm	pH	% SILT & CLAY	% FINE SAND	% COARSE SAND	%FINE GRAVEL	%COARSE GRAVEL
1	4.03	39.953077	1.45793	12	10	6.9	0.52	4.1	42.2	18.91	33.84
2	2.098	45.50972	0.63419	21	17	6.5	1.1	3.33	35.1	28	32.51
3	3.65	48.574566	1.0979	18	16	6.8	1.36	3.01	23.84	20	51.8
4	3.16	46.28208	3.08831	13	12	7	2.16	3.8	41.02	30.42	22.64
5	4.02	41.492103	1.10888	16	10	7.1	3.85	5	42.72	22.2	26.18
6	2.68	50.587033	0.6238	20	19	6.5	2.81	5.33	41.63	34.5	15.91
7	2.31	50.973189	0.56832	20	18	6.5	1.37	6	50.1	21.44	21.24
8	3.03	53.594552	0.75612	14	12	6.6	2.7	4.73	44.03	28.81	19.92
9	3.99	37.115423	1.47868	20	17	6.8	1.5	5.61	36.6	17.27	39.02
10	2.57	44.065541	8.00645	18	15	7	0.76	2.26	30.24	27.1	39.63
11	2.12	45.355302	2.95407	19	14	6.3	0.56	3.1	31.12	28.53	36.52
12	1.94	42.509398	0.72441	21	19	7.1	2.2	3.02	34.64	19.26	41
13	0.87	83.885537	5.25985	16	17	7.1	0.64	0.21	1.65	39.33	58.2
14	0.39	39.595285	0.97491	2	18	6.5	0.63	3	30.69	25.34	40.26
15	1.62	39.085201	1.6766	19	17	6.8	4	7	56.4	25.5	7.07
16	2.82	48.330419	1.03863	20	17	6.9	1.87	5.25	49.43	20.6	26.82
17	0.91	33.659548	1.23614	2	19	7.2	1.2	3.13	37.35	17.1	41.28
18	1.36	23.016849	1.79698	22	17	7	0.59	2.52	25.79	17.92	52.93
19	0.82	39.911322	0.90226	19	18	6.1	1.54	4.14	36.03	20	36.34
20	0.82	37.17375	0.56708	21	18	6.1	1.14	4.2	43.17	21.51	29.81

Bluff B willow	Gravimetric MC	Loss on Ignition		Temperatur (at depth)			Dry Sieving - Textural analysis				
Quadrat	% MOISTURE	%CARBONATE	%ORGANIC MATTER	5cm	10cm	pH	% SILT & CLAY	% FINE SAND	% COARSE SAND	%FINE GRAVEL	%COARSE GRAVEL
1	11.14	50.215728	2.42402	15	12	6.9	9.74	4.47	35.04	23.34	27.41
2	12.36	51.536492	1.018735	17	13	6.5	3.8	2.9	36.03	25.5	31.73
3	8.49	54.270901	1.03562	15	12	6.8	3.12	2.9	33.62	22.9	37.38
4	9.67	47.942009	1.44704	14	13	6.75	3.7	3.6	43.43	29.7	19.63
5	21.76	64.256543	2.91855	13	13	6.8	12.35	8.7	42.43	20.63	15.86
6	12.95	62.037165	2.44263	16	12	7	2.1	2.54	31.6	31.78	31.96
7	9.02	58.686667	2.62766	15	11	6.8	1.29	1.76	35.94	37.36	23.01
8	12.37	46.647695	2.69691	16	12	6.6	1.56	2.28	28.21	31.38	36.47
9	26.57	57.311054	6.70232	14	11	6.8	0.96	2.46	27.1	14.76	54.82
10	11.42	55.903781	9.41665	15	10	6.5	1.7	2.05	37.34	23.22	35.77
11	5.52	57.435703	2.26395	22	19	6.8					
12	10.26	43.661007	1.57866	22	21	6.8					
13	21	43.611599	7.75479	22	19	6.6					
14	5.17	40.148081	1.48742	22	19	6.5					
15	30.62	45.042068	10.3308	15	14	7					
16	13.81	34.78743	4.09124	20	18	7					
17	55.88	56.369304	7.26008	22	17	6.9					
18	9.33	47.154149	2.27609	22	20	6.5					
19	7.54	41.944387	2.86307	24	16	7.2					
20	43.23	58.228669	6.70285	22	17	6.5					

Appendix 4: continued

d. Akudlik - DISTURBED		Loss on Ignition		Temperature (at depth)			Dry Sieving - Textural analysis				
	Gravimetric MC		%ORGANIC				% SILT	% FINE	% COARSE	%FINE	%COARSE
Quadrat	% MOISTURE	%CARBONATE	MATTER	5cm	10cm	pH	& CLAY	SAND	SAND	GRAVEL	GRAVEL
1	3.33	50.377537	1.70696	21	17	6.7	4.15	9.45	37.02	20.33	23.22
2	3.11	36.067957	1.38959	18	17	6.7	2	11.56	62.46	18.17	6.06
3	4.46	45.75176	1.41546	19	16	6.8	4.03	8.23	43.04	20.64	24.4
4	2.61	40.535284	0.97448	19	16	7	2.68	8.62	43.28	19.42	26.01
5	3.68	36.618553	1.09925	18	15	6.9	3.33	10.42	43.5	18.27	24.66
6	3.65	38.656037	1.2151	20	16	6.7	4.97	10.62	41.67	24.97	17.88
7	2.9	41.663187	1.23977	20	18	6.55	5.68	11.58	44.5	13.81	24.47
8	3.74	42.677151	1.02751	20	17	6.6	1.59	19.78	38.38	16.31	23.73
9	3.36	48.968904	1.68334	17	14	6.8	4.69	9.39	40.14	15.52	30.41
10	4.05	45.614342	1.44863	22	20	7.1	4.45	9.2	49.55	27.15	9.68
11	6.52	40.805728	1.68483	10	10	6.9	4.03	9.59	40.6	19.54	26.28
12	4.3	33.290133	1.64196	11	11	6.75	3.63	7.55	56.05	15.8	17.7
13	4.77	33.226008	1.52188	11	10	7.2	2.83	8	63.11	22.24	3.78
14	4.76	54.910503	1.53173	10	1	6.9	3.13	9	34.6	28.3	24.99
15	3.93	47.135623	1.37763	11	11	6.5	2.03	7.52	38.44	22.6	29.45
16	6.37	70.282071	1.53732	11	1	6.8	5.9	5.9	30.1	24.2	34
17	6.31	53.161419	1.43133	12.5	11	7.1	3.95	6.86	29.31	19.26	41.7
18	6.54	68.272959	1.33448	10	9	6.8	6.68	6.07	33.64	29.63	23.02
19	3.67	26.717305	1.27958	12.5	11	6.9	4.12	8.29	58.85	15.31	13.7
20	5.53	42.392243	1.38099	11	10	6.9	3.26	8.1	32.65	32.35	23.84

Appendix 5: Pipette extractions at time 0 and time 7:27.
for Akudlik (Ak), Bluff B - willow (BBw) and
Fort Churchill/Airport (AIR).

Time 0 Sample	sample wt (g)	sample - calgon (0.1139g) wt (g)	sample * 50g
Ak 1	0.117	0.003	0.15
Ak 2	0.118	0.0037	0.185
Ak 3	0.119	0.0047	0.235
Ak 4	0.117	0.036	0.18
BBw 1	0.116	0.0025	0.125
BBw 2	0.121	0.0074	0.37
AIR 1	0.119	0.0051	0.255
AIR 2	0.118	0.0038	0.19
AIR 3	0.13	0.0162	0.81
AIR 4	0.127	0.0127	0.635
AIR 5	0.136	0.0224	1.12
AIR 6	0.123	0.0095	0.475
AIR 7	0.127	0.013	0.65
AIR 8	0.123	0.009	0.45
AIR 9	0.122	0.007	0.385
AIR 10	0.131	0.0172	0.86
AIR 11	0.158	0.0443	2.215
AIR 12	0.127	0.0128	0.64
AIR 13	0.125	0.0113	0.565
AIR 14	0.123	0.008	0.44
AIR 15	0.124	0.0104	0.52
AIR 16	0.126	0.0121	0.605
AIR 17	0.123	0.0183	0.915
AIR 18	0.126	0.0116	0.58
AIR 19	0.135	0.0206	1.03
AIR 20	0.157	0.043	2.15

Time 7:27 Sample	sample wt (g)	sample - calgon (0.1139g) wt (g)	sample * 50g
Ak 1	0.103		
Ak 2	0.112		
Ak 3	0.11		
Ak 4	0.107		
BBw 1	0.097		
BBw 2	0.113		
AIR 1	0.098		
AIR 2	0.092		
AIR 3	0.104		
AIR 4	0.106		
AIR 5	0.114	0.0001	0.005
AIR 6	0.08		
AIR 7	0.069		
AIR 8	0.091		
AIR 9	-0.88		
AIR 10	0.119	0.0051	0.255
AIR 11	0		
AIR 12	0.119	0.0051	0.255
AIR 13	0.119	0.0051	0.255
AIR 14	0.117	0.0031	0.155
AIR 15	0.117	0.0031	0.155
AIR 16	0.115	0.0011	0.055
AIR 17	0.119	0.0051	0.255
AIR 18	0.119	0.051	0.255
AIR 19	0.117	0.003	0.115
AIR 20	0.112	0	2.15

Appendix 6: Snow depth, density and snow water equivalent (SWE) for Site I and Site II in February 1994.

Site I

Point	Sample weight (g)	Depth (cm)	Density (g/cm3)	SWE (mm)
1	45.4	9	0.4514	40.6264
2	356	60.5	0.5266	318.5682
3	22.5	5	0.4027	20.1342
4	150.3	33	0.4076	134.4966
5	54.8	12	0.4087	49.038
6	32.9	12.5	0.2355	29.4407
7	75	12	0.5593	67.1141
8	21.6	6	0.3221	19.3289
9	19.1	3	0.5697	17.0917
10	3.8	1	0.34	34.004
11	146.2	24	0.5451	130.8277
12	46.5	12	0.3468	41.6107
13	9.5	2	0.4251	8.5011
14	40.9	8.5	0.4306	36.5996
15	3.3	0.5	0.5906	2.953
16	86.9	21	0.3703	77.7629

Site II

Point	Sample weight (g)	Depth (cm)	Density (g/cm3)	SWE (mm)
1	28.8	6	0.4295	25.7718
2	28.5	8	0.3188	25.5034
3	38.4	11	0.3124	34.3624
4	60	20.5	0.2619	53.6913
5	108.2	26	0.3724	96.8233
6	55.6	14	0.3554	49.7539
7	55.2	16	0.3087	49.396
8	69.3	18	0.3445	62.0134
9	97.3	22	0.3958	87.0694
10	85.3	25	0.3053	76.3311
11	99.2	25.5	0.3481	88.7696
12	131.1	37	0.3171	117.3154
13	219.3	53.5	0.3668	196.2416
14	209	59	0.317	187.0246
15	74.4	42	0.1585	66.5772

Appendix 7: Total seedling numbers in 1993 and 1994 at Site I and II in the four treatments (Contol, PeatFertilizer and Peat and Fertilizer) in seeded and non-seeded trials.

SITE 1
CONTROL SEEDED

	1993					1994				
Species/plot	**7**	**13**	**19**	**25**	TOTAL	**7**	**13**	**19**	**25**	TOTAL
Lesquerella arctica	6							8	3	
Stellaria sp						2			2	
Minuartia rubella						1		5	2	
Dryas integrifolia										
Hedysarum mackenzii						0	0	11	28	39
Equisetum arvense										
Achillea nigrescens										
Draba cana				1						
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum								3	1	
Rumex occidentalis										
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	6	0	0	1	7	3	0	27	36	66

SITE II
CONTROL SEEDED

	1993					1994				
Species/plot	**5**	**13**	**18**	**32**	TOTAL	**5**	**13**	**18**	**32**	TOTAL
Lesquerella arctica										
Stellaria sp								1		
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0	19	67	54	42	182
Equisetum arvense										
Achillea nigrescens										
Draba cana										
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis										
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	0	0	0	19	67	55	42	183

Appendix 7: continued

SITE 1 1993
CONTROL NON-SEEDED

	1993					1994				
Species/plot	**10**	**15**	**18**	**29**	TOTAL	**10**	**15**	**18**	**29**	TOTAL
Lesquerella arctica						2	2	7	3	
Stellaria sp							6			
Minuartia rubella							1	6	2	
Dryas integrifolia										
Hedysarum mackenzii					0	0	0	0	0	0
Equisetum arvense										
Achillea nigrescens										
Draba cana							1	2		
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis										
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	0	0	0	2	10	15	5	32

SITE II
CONTROL NON-SEEDED

	1993					1994				
Species/plot	**12**	**15**	**22**	**27**	TOTAL	**12**	**15**	**22**	**27**	TOTAL
Lesquerella arctica										
Stellaria sp										
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0					0
Equisetum arvense										
Achillea nigrescens										
Draba cana										
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis										
Elymus arenarius							1			
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	0	0	0	0	1	0	0	1

Appendix 7: continued

SITE 1
FERTILIZER SEEDED

	1993					1994				
Species/plot	**11**	**21**	**30**	**32**	TOTAL	**11**	**21**	**30**	**32**	TOTAL
Lesquerella arctica	2	5	1			1	6	1		
Stellaria sp	12	14	8	10		6	7	1	6	
Minuartia rubella	1		1			6	11		1	
Dryas integrifolia										
Hedysarum mackenzii					0	0	4	1	10	15
Equisetum arvense									1	
Achillea nigrescens										
Draba cana		1		4		1	1		4	
Festuca brachyphylla						2	2	3	5	
Epilobium angustifolium						1				
Androsace septentrionalis										
Melandrium affine							1	1		
Trisetum spicatum									1	
Cerastium alpinum		1					2			
Rumex occidentalis										
Elymus arenarius										
Grass		2								
Sp.X										
Sp.Y										
TOTAL	15	23	10	14	62	17	34	7	28	86

SITE II
FERTILIZER SEEDED

	1993					1994				
Species/plot	**3**	**9**	**24**	**30**	TOTAL	**3**	**9**	**24**	**30**	TOTAL
Lesquerella arctica						4				
Stellaria sp	3					21		5	4	
Minuartia rubella										
Dryas integrifolia	1					2				
Hedysarum mackenzii					0	13	16	60	40	129
Equisetum arvense										
Achillea nigrescens								1		
Draba cana						1				
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis										
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	4	0	0	0	4	41	16	66	44	167

Appendix 7: continued

SITE 1
FERTILIZER NON-SEEDED

	1993					1994				
Species/plot	**6**	**16**	**23**	**27**	TOTAL	**6**	**16**	**23**	**27**	TOTAL
Lesquerella arctica	2		1	7		4	1	4	8	
Stellaria sp	5	26	11	6		2	9	6		
Minuartia rubella	4	2	1	10				2	2	
Dryas integrifolia										
Hedysarum mackenzii					0					0
Equisetum arvense		1								
Achillea nigrescens										
Draba cana	4	7	2	5		7	17	3	5	
Festuca brachyphylla						1	5	2	2	
Epilobium angustifolium							1		1	
Androsace septentrionalis							1			
Melandrium affine							1		1	
Trisetum spicatum							3			
Cerastium alpinum		4		1			4		1	
Rumex occidentalis										
Elymus arenarius										
Grass	2	2		2		3				
Sp.X										
Sp.Y										
TOTAL	17	42	15	31	105	17	42	17	20	96

SITE II
FERTILIZER NON-SEEDED

	1993					1994				
Species/plot	**7**	**21**	**26**	**28**	TOTAL	**7**	**21**	**26**	**28**	TOTAL
Lesquerella arctica						1	1			
Stellaria sp						2	6	14	66	
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0		3		1	4
Equisetum arvense										
Achillea nigrescens										
Draba cana									2	
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis										
Elymus arenarius						1				
Grass							3		2	
Sp.X										
Sp.Y										
TOTAL	0	0	0	0	0	4	13	14	71	102

Appendix 7: continued

SITE 1 1993
PEAT SEEDED

	1993					1994				
Species/plot	**3**	**4**	**17**	**20**	TOTAL	**3**	**4**	**17**	**20**	TOTAL
Lesquerella arctica							1	6	2	
Stellaria sp										
Minuartia rubella								1		
Dryas integrifolia										
Hedysarum mackenzii						0	0	6	7	13
Equisetum arvense										
Achillea nigrescens										
Draba cana										
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis										
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	0	0	0	0	1	13	9	23

SITE II
PEAT SEEDED

	1993					1994				
Species/plot	**2**	**4**	**11**	**19**	TOTAL	**2**	**4**	**11**	**19**	TOTAL
Lesquerella arctica										
Stellaria sp						2			1	
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0	148	327	59	46	580
Equisetum arvense						3				
Achillea nigrescens										
Draba cana										
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis								3		
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	0	0	0	153	327	62	47	589

Appendix 7: continued

SITE 1
PEAT NON-SEEDED

			1993					1994		
Species/plot	**1**	**5**	**22**	**26**	TOTAL	**1**	**5**	**22**	**26**	TOTAL
Lesquerella arctica						18	1	1		
Stellaria sp										
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0					0
Equisetum arvense										
Achillea nigrescens										
Draba cana						1				
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis			1	1						
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	1	1	2	19	1	1	0	21

SITE II
PEAT NON-SEEDED

			1993					1994		
Species/plot	1	8	10	16	TOTAL	1	8	10	16	TOTAL
Lesquerella arctica										
Stellaria sp										
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0					0
Equisetum arvense										
Achillea nigrescens										
Draba cana										
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis										
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	0	0	0	0	0	0	0	0

Appendix 7: continued

SITE 1
PEAT NON-SEEDED

	1993					1994				
Species/plot	**1**	**5**	**22**	**26**	TOTAL	**1**	**5**	**22**	**26**	TOTAL
Lesquerella arctica						18	1	1		
Stellaria sp										
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0					0
Equisetum arvense										
Achillea nigrescens										
Draba cana						1				
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis			1	1						
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	1	1	2	19	1	1	0	21

SITE II
PEAT NON-SEEDED

	1993					1994				
Species/plot	1	8	10	16	TOTAL	1	8	10	16	TOTAL
Lesquerella arctica										
Stellaria sp										
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0					0
Equisetum arvense										
Achillea nigrescens										
Draba cana										
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis										
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	0	0	0	0	0	0	0	0

Appendix 7: continued

SITE 1
PEAT AND FERTILIZER SEEDED

	1993				SUM	1994				TOTAL
Species/plot	**8**	**14**	**24**	**31**		**8**	**14**	**24**	**31**	
Lesquerella arctica	1					7	3		1	
Stellaria sp						3				
Minuartia rubella							3		1	
Dryas integrifolia							2			
Hedysarum mackenzii	0	0	0	0	0	3	7	28	22	60
Equisetum arvense										
Achillea nigrescens										
Draba cana										
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis										
Elymus arenarius										
Grass	0	0	1	0	1	0	0	1	0	1
Sp.X										
Sp.Y										
TOTAL	1	0	1	0	2	13	15	29	24	81

SITE II
PEAT AND FERTILIZER SEEDED

	1993					1994				
Species/plot	**6**	**14**	**17**	**29**	TOTAL	**6**	**14**	**17**	**29**	TOTAL
Lesquerella arctica						4	3	2		
Stellaria sp						4	14	1	36	
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0	137	61	101	13	312
Equisetum arvense										
Achillea nigrescens										
Draba cana								1		
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis							1	1	1	
Elymus arenarius							1			
Grass				1				1		
Sp.X									3	
Sp.Y									3	
TOTAL	0	0	0	1	1	145	80	107	56	388

Appendix 7: continued

SITE 1
PEAT AND FERTILIZER NON-SEEDED

	1993					1994				
Species/plot	**2**	**9**	**12**	**28**	TOTAL	**2**	**9**	**12**	**28**	TOTAL
Lesquerella arctica				1		1	5		3	
Stellaria sp										
Minuartia rubella				2					2	
Dryas integrifolia										
Hedysarum mackenzii					0					0
Equisetum arvense										
Achillea nigrescens										
Draba cana				1					1	
Festuca brachyphylla									1	
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine									2	
Trisetum spicatum										
Cerastium alpinum									1	
Rumex occidentalis										
Elymus arenarius										
Grass										
Sp.X										
Sp.Y										
TOTAL	0	0	0	4	4	1	5	0	10	16

SITE II
PEAT AND FERTILIZER NON-SEEDED

	1993					1994				
Species/plot	**20**	**23**	**25**	**31**	TOTAL	**20**	**23**	**25**	**31**	TOTAL
Lesquerella arctica						1			1	
Stellaria sp							33	1	23	
Minuartia rubella										
Dryas integrifolia										
Hedysarum mackenzii					0	1	1			2
Equisetum arvense										
Achillea nigrescens										
Draba cana							2			
Festuca brachyphylla										
Epilobium angustifolium										
Androsace septentrionalis										
Melandrium affine										
Trisetum spicatum										
Cerastium alpinum										
Rumex occidentalis						1	1			
Elymus arenarius							1			
Grass									1	
Sp.X										
Salix sp.				1					1	
Sp.Y									6	
TOTAL	0	0	0	1	1	3	38	1	32	74

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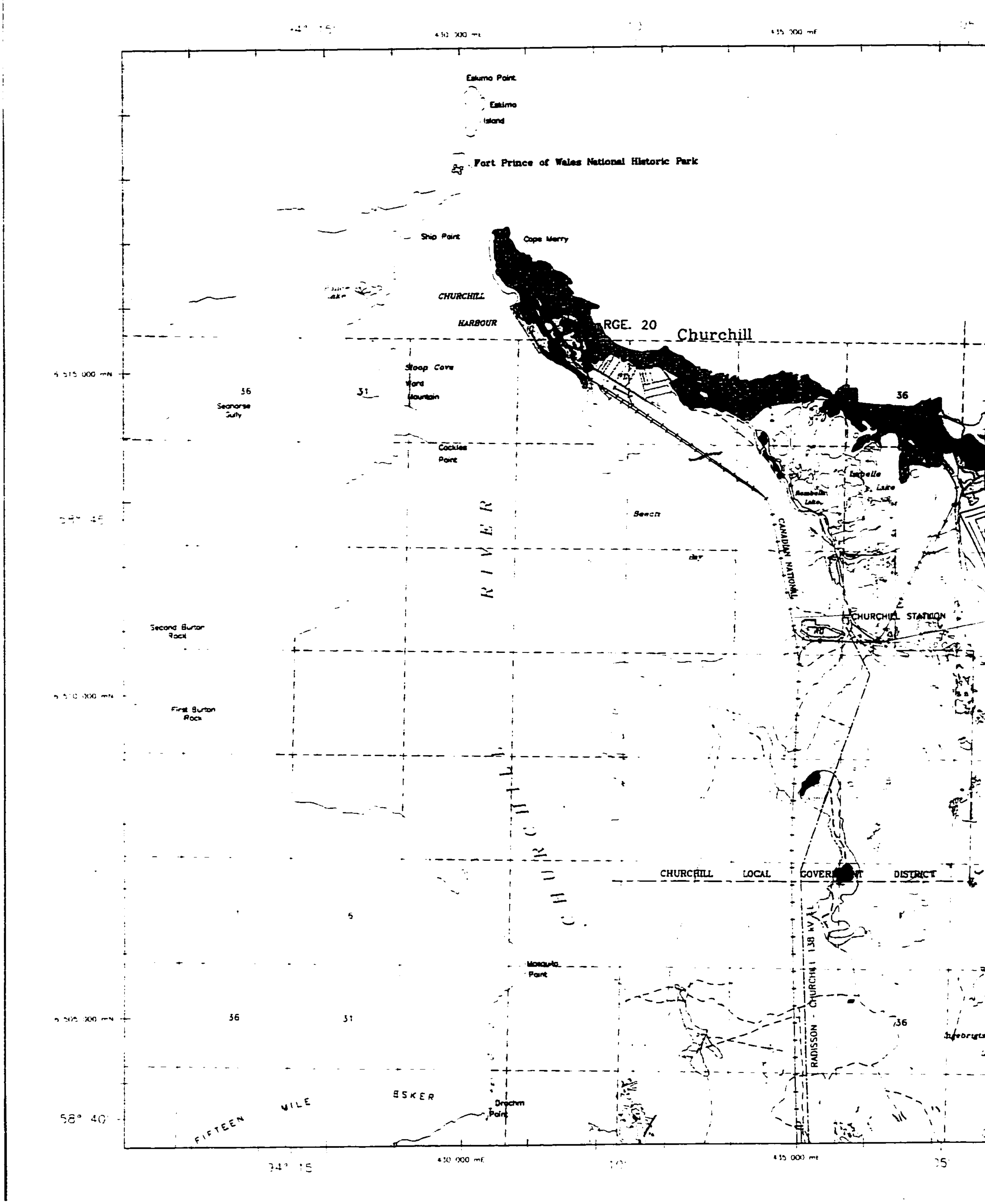
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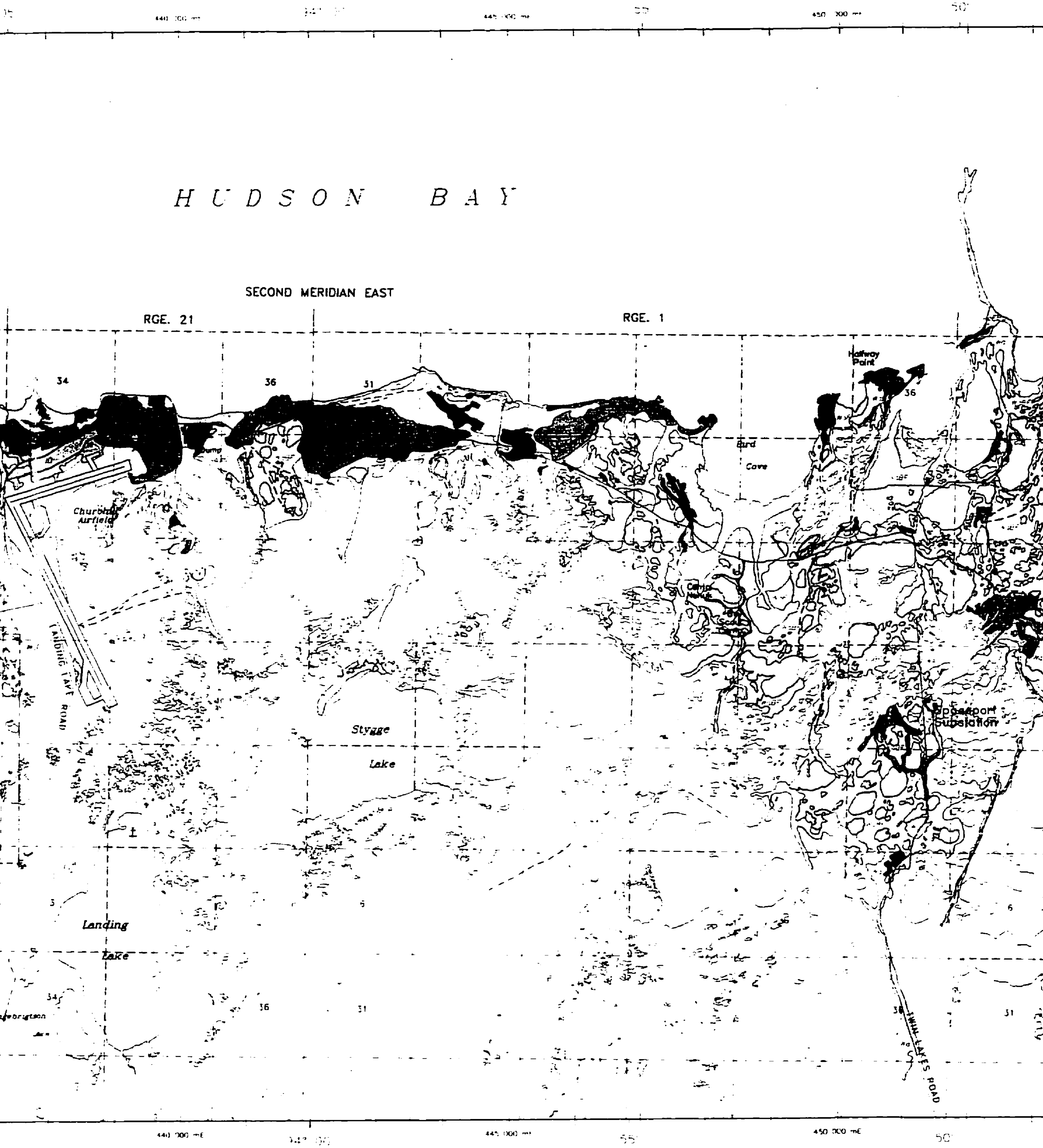440 000 mE
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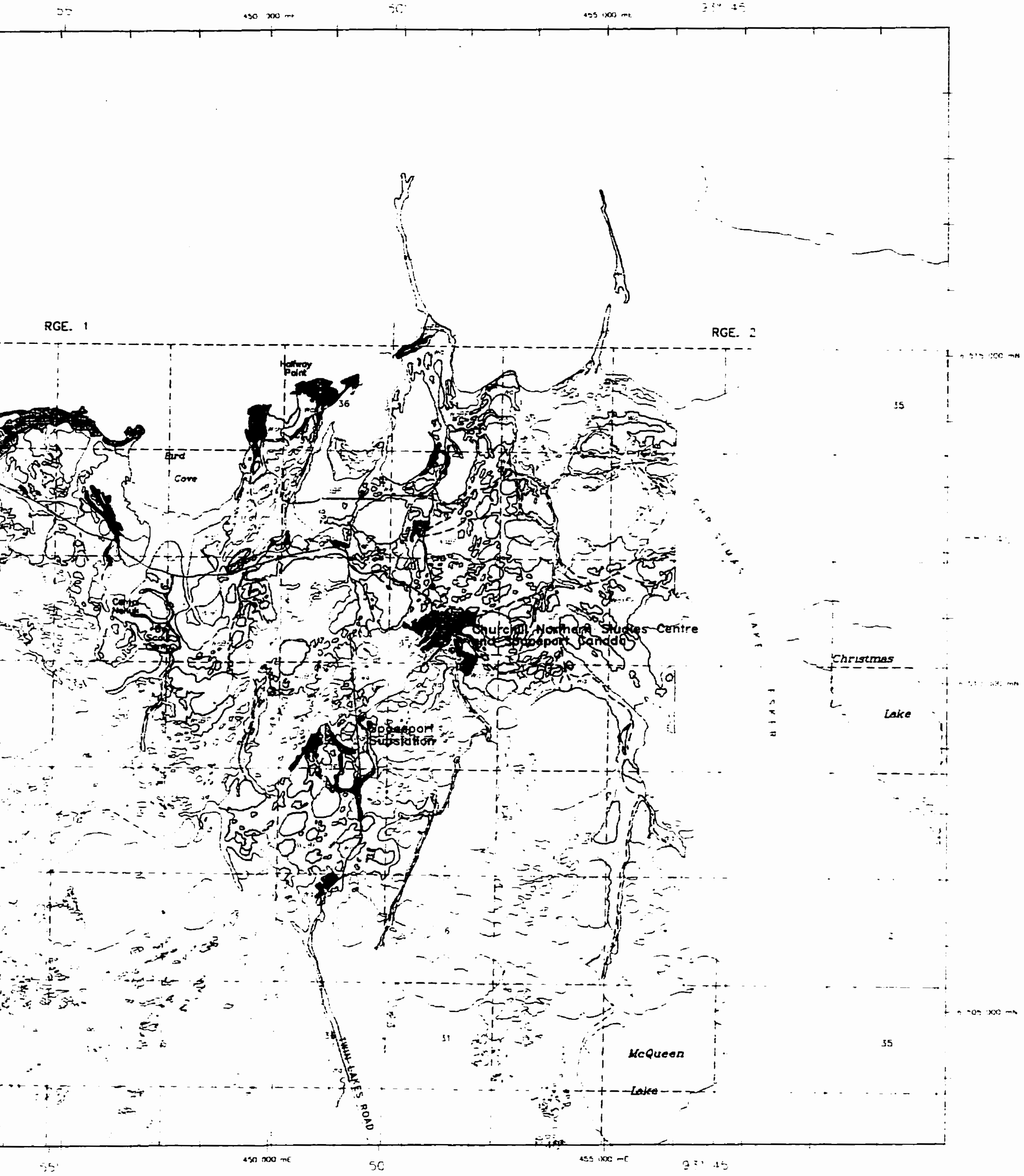
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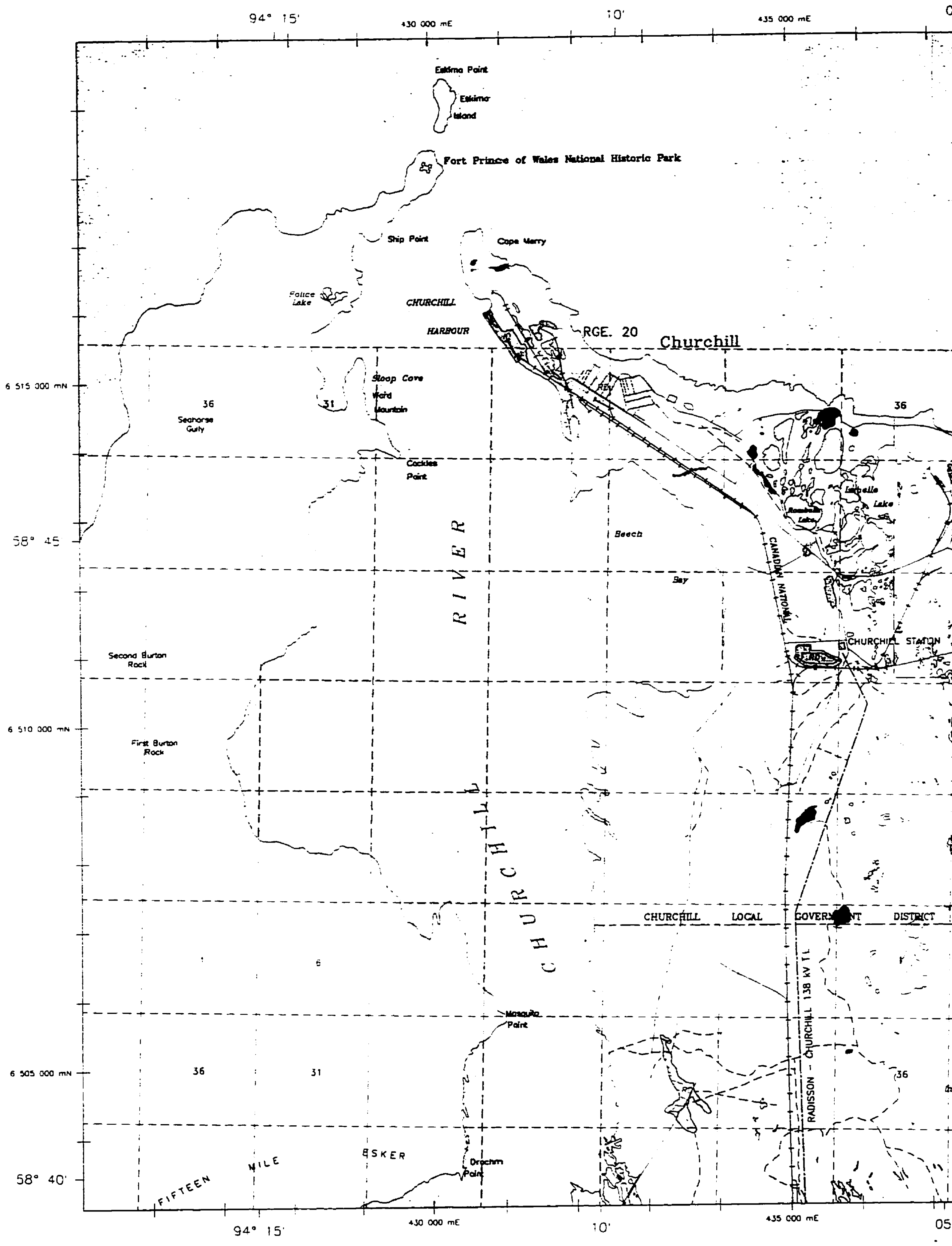
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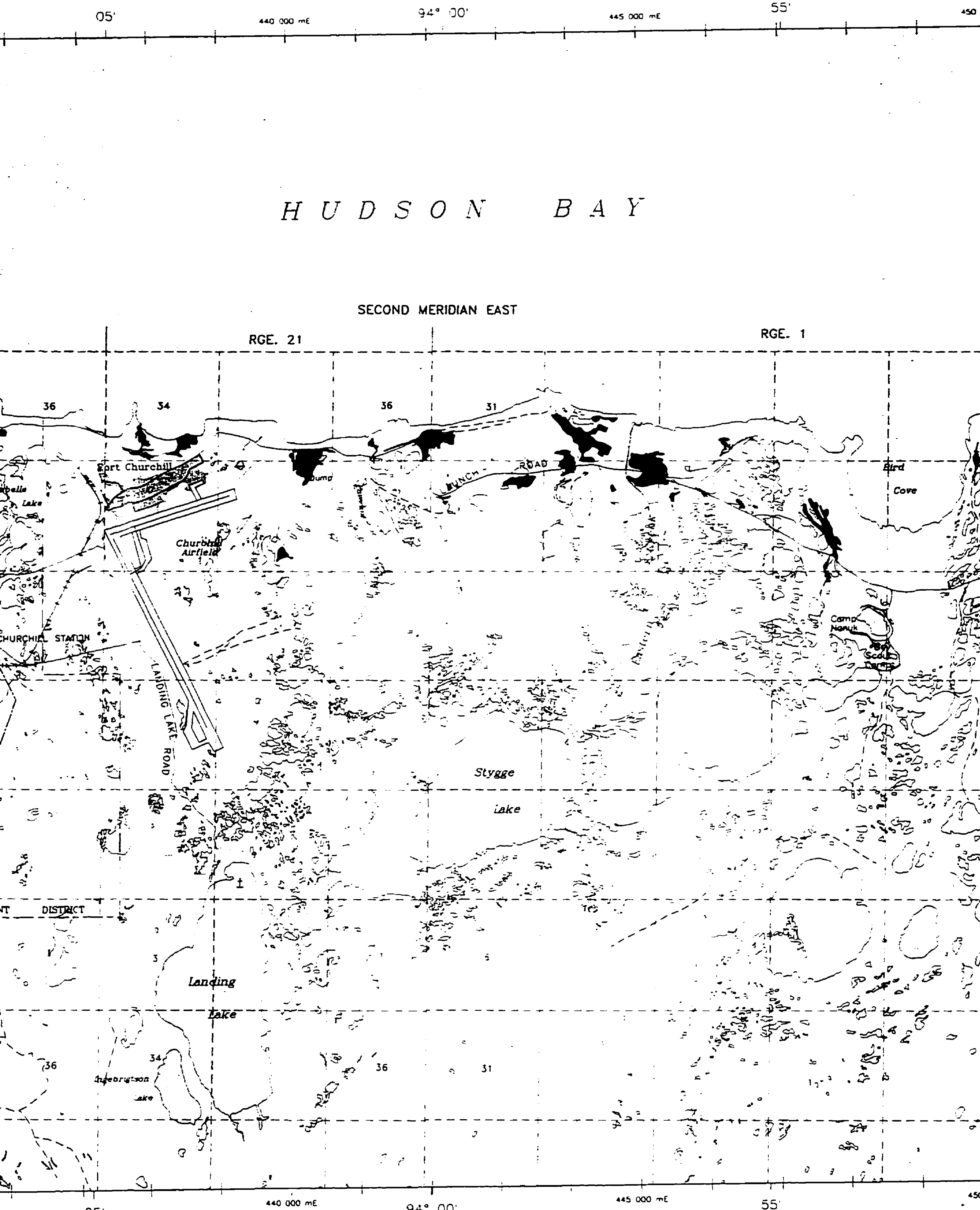
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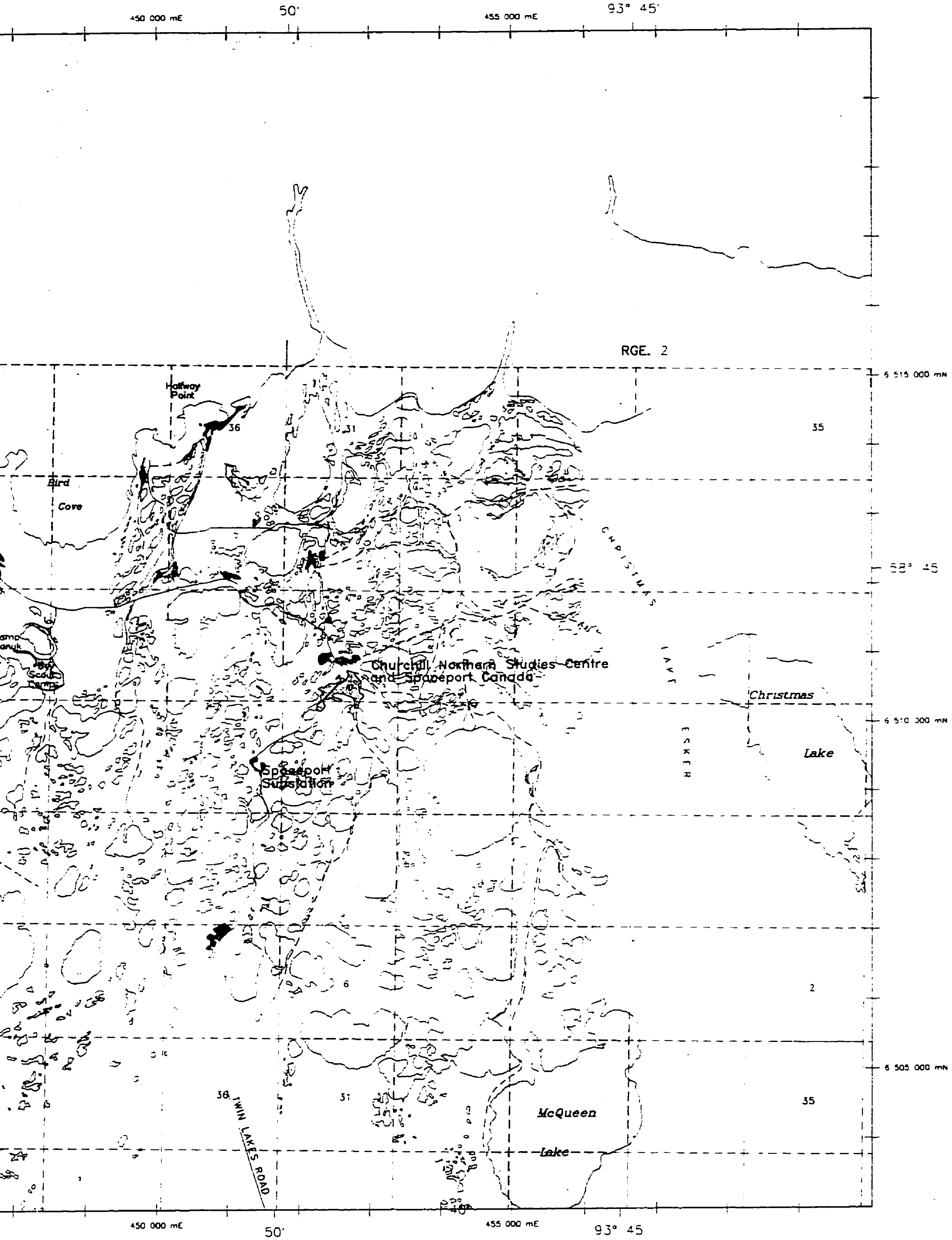
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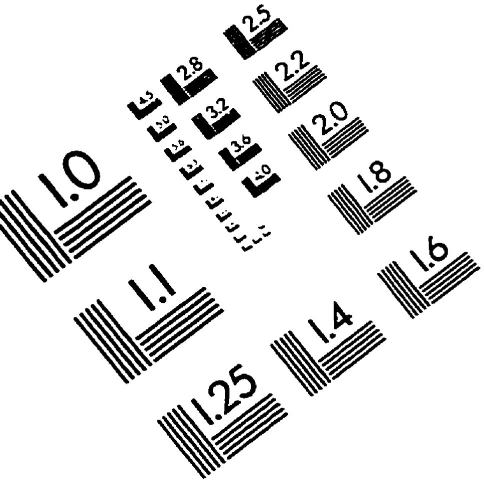

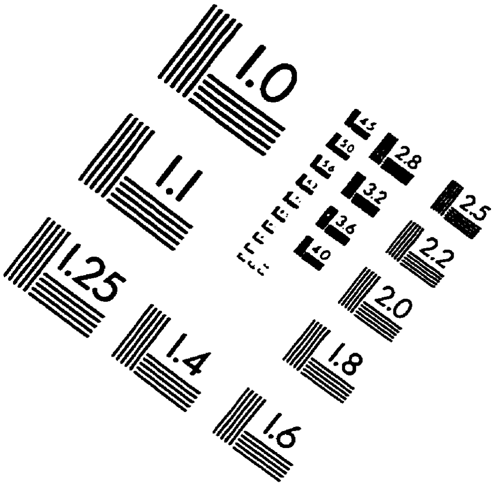

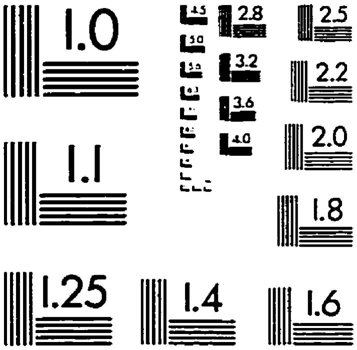

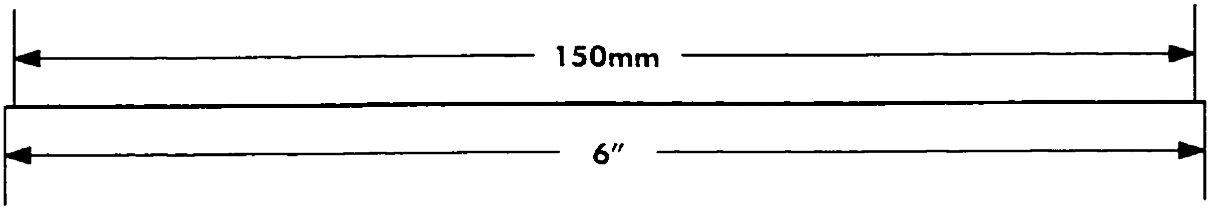

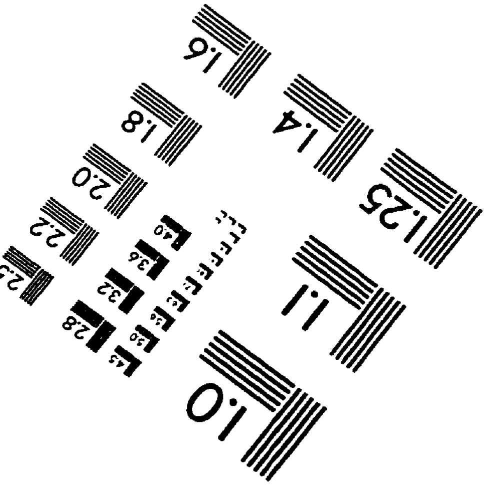

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