University of Alberta

Bioengineering And Reclamation To Stabilize A Lakeshore Slope

by

James William Schaefer ©

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ABSTRACT

There is little published scientific documentation on transplanting vegetation islands and live willow stakes for slope stabilization in the Canadian Aspen Parkland. Anecdotal evidence indicates survival of these transplants is dependent on transplanting during the dormant season. A severely degraded slope in Elk Island National Park, Alberta was transplanted with nondormant vegetation islands in mid August 1997 and dormant islands in mid October 1997 in a soil amended with 25% (by volume) compost. Both nondormant and dormant transplanted islands survived and continued to establish on this terraced slope, where natural growing conditions are relatively inhospitable. However, live stakes planted on slope and gully positions too steep to terrace had high mortality of both dormant and nondormant plantings. During the 1998 growing season, grass species densities increased while those of forbs and shrub/tree species declined in the transplanted vegetation islands. Species diversity also increased during the study.

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1.0 INTRODUCTION

Revegetating barren inclined sites where overlying soil has been dislodged and the C horizon exposed by wind and water erosion can be extremely challenging. Numerous factors can operate in combination to prevent natural revegetation. Soil instability both at a micro scale involving individual particle movement and at a macro scale involving forces such as mass wasting produce an inhospitable environment for plant growth and development. Available soil moisture can often be a limiting resource in this environment where a water repellent soil surface prevents water infiltration and percolation to the root zone. Nitrogen is also often a limiting nutrient either due to its absence or its being washed away by runoff. Propagules of many plants arriving on such sites are often not capable of germinating, may be blown or washed away, or the young plants expire soon after germination due to insufficient life sustaining resources. Ameliorating site conditions does not guarantee revegetation success but may increase the probabilities of plant survival.

Transplanting appropriate native vegetation to barren sites from local areas having similar biotic and edaphic conditions can introduce an adapted vegetation cover with genetic variation which requires little if any maintenance and integrates well with the surrounding vegetation. Native species are often adapted to local soil and climatic conditions, often have minimal fungus and insect susceptibility or exist in balance with them and if chosen with care can retain the biodiversity of the local area (Gray and Leiser 1982). This revegetation method may reduce the effects of soil instability and add soil nutrients such as nitrogen by nitrogen fixing plants in a much shorter time period than when attempting to establish the same plant community by seeding. Seeds from most native forbs, grasses and shrubs are currently seldom commercially available. Providing a more hospitable growing environment by combining transplanted vegetation with stable moisture retaining soils and initially providing nutrients may expedite succession toward mid seral stages which in turn can encourage soil stabilisation by reducing soil erosion and anchoring the soil in place via plant root establishment.

Introduced species may be intermixed among transplanted native vegetation in limited quantities depending on transplanting material source. The primary dilemma associated with this invasion of introduced plant species is a possible reduction in species and habitat diversity (Luken 1990).

2.0 EROSION REDUCTION

A more hospitable growing environment can be provided in numerous ways by reducing water and soil movement from sloped sites, all of which can reduce soil particle detachment. Raindrop velocities can be greatly reduced at the soil surface by using vegetation and/or its residue (Troeh and Thompson 1993). Increasing canopy and plant residue cover can reduce raindrop impact on bare soil thereby potentially reducing particle detachment. Bioengineering techniques such as terracing can be incorporated to reduce slope gradients. This will minimise the kinetic energy of water flowing downslope, consequently reducing transported soil volumes and attached nutrients.

2.1 Water Erosion

Four common methods of reducing water erosion are to: reduce raindrop impact on soil, reduce runoff volume, reduce runoff velocity and increase soil resistance to erosion. Bare eroded slopes are often difficult or impossible to revegetate naturally due to the cumulative effects of rain drop impact on the bare soil, slope angle, the ongoing removal of nutrient containing soil and the inability of the soil to absorb water. Rainfall, although required for plant growth, can also be detrimental to vegetation establishment on disturbed slopes. Raindrops average between 1 and 5 mm in diameter, and have terminal velocities ranging from approximately 4 to 9 m s^{-1} (14 to 32 km h^{-1}) (Lull 1959, Troeh and Thompson 1993). Relentless raindrop impact of this magnitude can break down soil structure producing loose soil particles, a portion of which are carried into soil pore spaces by infiltrating water. Pores become plugged thereby producing a sealed surface with low permeability; the resultant soil crust reduces soil surface permeability and reduces or prevents infiltration. This situation combined with raindrop soil compaction increases the potential for runoff. Water required to promote plant growth may be deposited on a slope but if it does not infiltrate and if not stored for future uptake by vegetation it is of little use (Troeh and Thompson 1993).

Rain at intensities greater than the infiltration rate forms a surface water film which may begin to flow downslope with kinetic energy capable of transporting soil particles and small aggregates held in suspension. Sheet erosion of this nature removes the fine silt, clay and organic matter in which most of the soil nutrients are located (Troeh and Thompson 1993). These fine soil particles are transported over the surface to a new deposition location where the particles fall from suspension and are deposited as sediment in a new area (Troeh et al. 1980). Areas receiving the nutrient rich sediment from upslope can often be recognised by the proliferation of vegetation in comparison to eroded soil areas which are often leached of soil nutrients and may be sparsely vegetated or completely barren.

Runoff seeks the path of least resistance; bare soil provides less resistance than adjacent vegetated areas allowing runoff to concentrate on bare areas. Flowing sheet runoff accumulates in low areas and forms streams which increase the erosive power. Footpaths often trodden bare of vegetation and angled down slope provide an ideal path of least resistance for these streams. The deeper the water accumulates, the faster it flows and the greater the kinetic energy and erosive power it possesses (Troeh and Thompson 1993). The erosive power increases exponentially with velocity and often quickly magnifies the erosive effects (Coppin and Richards 1990). Small rills formed by running water can increase in size to become gullies that continue to deepen and extend in length and width as they regress into slopes.

2.2 Slope Aspect

Runoff and subsequent erosion are also affected by slope aspect primarily due to the slope's microclimate being influenced by the angle of sun rays striking the exposed soil surface. South and west facing slopes in the northern hemisphere are warmer than other slope aspects, producing higher evaporation, reducing water storage and producing less plant growth especially in drier climates (Troeh et al. 1980). The resulting biomass reduction can increase the exposure of bare soil to the effects of water and wind erosion.

2.3 Wind Erosion

Raindrop impact and resultant splash are often the cause of soil particle detachment and subsequent movement by wind. Wind erosion rate is often higher if the wind is preceded by rain which tends to loosen soil particles (Troeh and Thompson 1993). Slope aspect and exposure to prevailing winds have the potential to increase wind erosion. Vegetation and litter can counteract this by reducing wind velocity at the soil surface. Attenuated wind velocity reduces the soil particle size capable of remaining in suspension and the distance particles can travel, thereby reducing soil transportation and loss.

3.0 BIOENGINEERING

Slope bioengineering combines ecological, biological and mechanical principles to produce a living structure ideally capable of maintaining slope stability and either eliminating or greatly decreasing runoff and soil erosion. Numerous methods can be used to accomplish stabilisation; many incorporate engineered structures such as terraces, gabions, geotextile or brush mats, wooden cribs or riprap when necessary to increase slope stability. These structures can be used in combination with indigenous easily rooted trees, shrubs and forbs arranged to provide ongoing soil stabilisation both at surface and at depth. As these plants mature, their roots penetrate the slope increasing shear strength and anchoring the slope, preventing tension and desiccation cracks from forming (Hemphill and Bramley 1989). Soil reinforced with a root matrix greatly increases soil shear strength and therefore provides a more stable soil (Waldron and Dakessian 1981). The increased plant density may also reduce wind velocity enough to diminish soil loss.

3.1 Root Anchoring

Root systems not only provide a soil nutrient uptake pathway between plant and soil and provide plant anchoring but also provide beneficial soil stabilisation. Root systems may vary from extremely fine fibrous systems, to branched systems, to those plants possessing a major vertical taproot. The greatest proportion of roots in vegetation are located within 30 to 40 cm of the soil surface for grasses and forbs and up to 3 m for shrubs, although a small proportion of roots penetrate deeper than this (Coppin and Richards 1990). Roots closest to the surface are primarily used to collect nutrients, while deeper roots are used to anchor the plant, absorb water and often store nutrients for over-wintering. Sixty to 80% of grass roots are located within the top 50 mm of soil making grasses ideal as a surface cover but less suited to deeper soil anchorage required to reduce mass wasting. In general, roots in well drained soils penetrate deeper and colonise a much larger soil volume than those in more moist soils (Coppin and Richards 1990).

Forbs and shrubs often provide a slope stabilising effect to a greater degree than trees. Large trees tend to have a greater proportion of above ground biomass compared to below ground anchoring biomass when contrasted with shrubs and forbs. In unstable slope positions the added above ground biomass can cause tree throw and mass wasting initiated by additional tree weight (Coppin and Richards 1990). In situations where mass wasting is problematic, shrubs and grasses may be better suited.

Grass, legume and small tree roots significantly increase soil strength at various moisture contents and the ability to enhance slope stability. This is evident with the often increased frequency of landslides on steep slopes where vegetation has been removed by logging and/or fire and root systems have decomposed reducing or eliminating their anchoring capabilities (Megahan and Kidd 1972; Wu 1976; Aramanthus et al. 1985).

Stolzy and Barley (1968) found small root hairs on field pea (*Pisum sativum*) roots extending into dense unsaturated clay loam enhanced soil reinforcement by up to 6 times that of roots with no hairs. This provides some indication of the increased reinforcing ability of fine roothairs. Soil reinforcement was also tested using alfalfa (*Medico sativa* L.), barley (*Hordeum vulgare* L.) and yellow pine (*Pinus ponderosa* Dougl.) by Waldron (1977) in gravel-sand and silty clay loam (1.4 Mg m^{-3} bulk density) and Waldron and Dakessian (1981) using barley and yellow pine in saturated clay loam (1.2 Mg m^{-3} bulk density). These researchers noted increases in soil reinforcement with shear strength increased by up to 5 times. Long roots were more resistant to slipping through the soil during soil movement than short fine roots and root slippage rather than breakage was the most common failure when reinforcing saturated fine textured soil.

Introducing vegetation to barren slopes evapotranspires soil water reducing the overall soil weight and potential lubrication between fracture planes. Reducing these factors can in turn reduce mass wasting. Vegetation can also improve infiltration, filter runoff, moderate ground surface temperature to improve site microclimate/growing conditions and enhance aesthetics (Wells 1994). The associated canopy cover and plant surface residue reduces raindrop impact on soil surfaces thereby reducing soil detachment congruent with erosion as well as supplying nutrients through decomposition of plant residue and root systems.

3.2 Terracing

Terracing is an erosion reducing method initiated to propagate agricultural crops on very steep slopes world wide by ancient as well as modern civilisations from Nepal to South America. Terraces located in the Middle East and built by the Phoenicians dating to approximately 200 BC are considered some of the earliest conservation structures in the world (Morgan 1986).

Terraces were also extensively used by the Peruvian Incas. They constructed bench terraces by installing rock walls along hill contours, then levelled and cultivated the soil behind the walls. These terraces consisted of 1 to 5 m high stone walls backfilled with rocks and gravel. The top meter was filled with fertile soil gathered from nutrient rich valley floors (Troeh et al. 1980). Some areas contained terraces with up to 7 different nutrient enhancing soil types which were considered so crucial to proper growth they were hauled overland by llamas from as far as the west coast approximately 400 km away (Cajas 1990). Some of these original terraces presently remain in use (Troeh et al. 1980).

Terracing provides a flat growing area designed to reduce soil erosion by slowing and collecting surface runoff while providing an environment conducive to plant growth. Bench terraces virtually eliminate the effect of slope caused erosion thereby allowing nutrients to remain in situ without being transported to lower slope positions. Due to the elimination of slope gradient, level terrace surfaces erode at a similar rate as level bottom land, thereby making them suitable techniques for steep slopes (Troeh and Thompson 1993).

3.3 Vegetation Islands

Terracing can be implemented in conjunction with transplanted root plugs or vegetation islands containing a variety of community specific native plant species complete with soil and microenvironment to establish vegetation patches rather than use individual plants (Munshower 1994). Transplanting vegetation islands on steep, erosion prone slopes can potentially reduce soil loss by decreasing the bare soil surface area exposed to runoff and expediting canopy cover to facilitate a reduction in the detrimental effects of raindrop impact. Concurrently, islands provide numerous roots capable of penetrating and anchoring unstable slopes without waiting years for vegetation and associated root masses to establish from seed in low nutrient soils.

Transplanting intact portions of native plant communities complete with their accompanying hospitable microclimates and microflora and fauna can retain or regain area biodiversity. Consequently providing a mosaic of plant communities which may accelerate the successional process by allowing associated seeds to germinate and young plants to establish, potentially encouraging the progression from an early successional state to a more advanced mid-successional state which may contain a greater proportion of perennial species. Perennial root systems may remain for numerous years sustaining soil anchorage compared to annual plant root systems which die yearly, limiting their effective soil anchoring capabilities but remaining important as soil amendments.

3.4 Live Staking Using Rootable Vegetative Cuttings

Specific slopes may not be suited to terracing due to various conditions including extreme slope angles or soil instability. In these situations live staking may be effective. Live staking involves insertion of live rootable vegetative cuttings into the soil. Under adequate growing conditions these stakes will root and leaf out and the expanding root mass will in time help anchor the soil (Gray and Sotir 1996). The resulting vegetation canopy may reduce rain drop impact by interception. Preferably, cuttings should be 1.5 to 4 cm in diameter and 40 to 60 cm long and be driven into the soil with not more than a quarter of their length exposed to limit desiccation. The thicker the cuttings the greater the food reserves (Gray and Leiser 1982). Two to 4 cuttings should be placed per square meter. Thirty to 50% plant loss under ideal conditions is common with this method (Schiechtl 1980). Numerous shrub species including willow (*Salix* sp), choke cherry (*Prunus virginiana* L.) and saskatoon (*Amalanchier alnifolia* Nutt.) may be used for live staking depending on availability.

Vegetation surveys will often indicate that willows occur primarily in wet areas. Willows naturally reproduce from short-lived seed that must be in contact with moisture in late spring or early summer and therefore seem to propagate in wet areas. However, a study by Kraebel (1936) indicates that willow cuttings from the species *Salix lemmonii* could grow in dry mountainous terrain of Southern California.

4.0 CARBOHYDRATES

Plant carbohydrate reserves consist of nonstructural carbohydrates comprised predominantly of fructosans, starches, reducing sugars (glucose and fructose) and nonreducing sugar (sucrose) (White 1973). These reserves are used by plants for respiration and growth and are also used as an energy source to initiate new growth prior to adequate photosynthesis sustained plant respiration (White 1973).

Perennial plants require sufficient carbohydrate reserves for winter survival, early spring growth initiation and potentially for successful rooting and continued development following transplanting induced stress. During the growing season carbohydrate reserves are dependent on the interaction between the plant and its environment and the equilibrium between respiration and photosynthesis. Reserves vary seasonally, between species and often within species, dependent on growing environment (White 1973). The majority of grass species have the lowest reserve levels during early vegetative growth, but others have lowest reserves during flowering, following seed ripening or during secondary fall growth (Daer and Willard 1981). Reserves are also affected by temperature and nutrient and water availability.

Carbohydrate reserves in deciduous trees and shrubs are at a maximum during winter and at a minimum during spring and summer (Luken 1990). They are depleted shortly before the leaves begin to emerge as the reserve substances are transported to the buds and later to the new shoots. Approximately one third of the reserve material is used to produce assimilation surfaces, which soon function with a positive balance and in turn contribute to the further formation of leaves and shoots on the new growth. Once completely formed, the foliage supplies the tree or shrub with photosynthates. Usually, flowers and developing fruit are supplied preferentially, subsequently followed by cambium and lastly, the newly forming buds and depots of starch in roots and bark. The number of floral primordia are formed dependent on the quantity of carbohydrates remaining. At the termination of the growing season surplus photosynthates are transported and stored in the woody tissue and bark of branches, trunk and roots (Larcher 1980).

5.0 DORMANCY

Dormancy is a complex survival strategy established by plants to successfully resist adverse climatic conditions and synchronise plant life cycles with seasonal changes. Plant growth must coincide with periods of favourable temperature and water availability. Dormancy length as well as initiation and termination are partially regulated by temperature and day length (photoperiodicity) which varies among species and within ecotypes of individual species. It is controlled primarily by (photoperiods) but may work in conjunction with or be substituted by reaction to changes in soil moisture, lowered temperatures and/or reduced nutrient supply (Villiers 1975).

Predormancy is the initial step indicated by termination of growth and an increased tolerance to low temperatures (Villiers 1975). This stage can be reversed resulting in renewed growth if the temperature rises or if there is an increase in day length. Full dormancy follows predormancy if temperatures and photoperiods continue to decrease and may be initiated by the first frost which triggers deciduous leaf coloration or fall and largely increases cold resistance. At this time perennial plants have completed nutrient storage in their root systems (Kimmins 1997).

An extended cold weather period, the length of which is species dependent, is required before growth may begin again. Under average temperature conditions in the northern hemisphere where frosts occur in late September or early October, plants may begin to grow again at the end of December if conditions are suitable (Kimmins 1997). Unseasonably warm temperatures and increased photo periods can result in a break in dormancy. If such a weather pattern is followed by a return to seasonably normal freezing temperatures, damage to new growth, severe plant stress and possible plant death can occur. Plant birth occurs when a seedling or stem emerges from the soil, or when a bud is released from dormancy (Luken 1990). Discoloration, wilting or failure to grow are common indicators of plant death (Luken 1990).

6.0 TRANSPLANTING TIME

Limited published information and general practice garnered from anecdotal evidence suggest transplanting is most successful when plants are dormant. In the Aspen Parkland this corresponds to early spring (April, May) prior to new growth occurring or when plants are either dormant or are approaching dormancy after mid October (Schiechtl 1980). However, anecdotal information is not quantitative and it is difficult or impossible to determine the accuracy of the information. Published studies involving native plant responses such as mortality and vigour to transplanting stresses are virtually non-existent. Very limited information is only available for a limited number of horticultural species. Any comparisons between native vegetation and studies of horticultural species may be presumptuous.

Transplanting vegetation during dormancy either in autumn or early spring is believed to potentially maximise carbohydrate reserves necessary for sustaining growth following transplanting. It is conjectured that transplanting while carbohydrate reserves are in various stages of depletion reduces the plant's survival ability. Root severing during plant removal may reduce the plant's ability to obtain soil supplied water and nutrients, in combination with possible water and temperature stress and translocation to an often less than ideal growing environment are presumed to compound causing plant mortality due to transplanting stress. As mentioned previously published studies providing quantitative information in this area are virtually non-existent.

7.0 SUCCESSION

Succession, like much of nature, is an extremely complex integration of processes and despite countless attempts still defies being classified into general acceptable theories developed by ecologists. McIntosh (1980) described succession as: "one of the oldest, most basic, yet still in some ways, most confounded of ecological concepts. Since its formalisation as the premier ecologic theory by H.C. Cowles and F.E. Clements in the early 1900s, thousands of descriptions of commentaries about and interpretations of succession have been published and extended inconclusive controversy has been generated" McIntosh (1980).

Plants often convey information about the ecological nature of a site. They exist as dynamic communities recognised by their species composition and association with specific characteristics such as climate, nutrient requirements, moisture regimes, soil type (mineral or organic) and soil pH, all of which may change over time. Some of these plants have been described by ecologists as indicator species which can be effective predictors of ecological conditions. Plant communities are comprised of numerous species combinations occurring only within their own limits of environmental tolerance. Each plant species is adapted to a range of environmental conditions in which it may persist and reproduce or transform with time (Daubenmire 1976).

Various populations become established and increase while other species decrease, not necessarily at a similar rate. This may be recognised in particular instances by a variety of adaptations involving species replacement, population structure shifts and alterations in availability of resources such as soil nutrients, water and light (Luken 1990). McCook (1994) stated that "variations occur in community succession in similar disturbances within similar ecosystems".

Grub (1985) defined succession as: "a directional change, and may be primary (starting on surfaces denuded by man). Succession does not imply that species are gained and lost through time in a sample of moderate size, merely that there is at least a directional change in the relative abundance of species." Succession could be described as a progression in a series of stages from a pioneer community to a well developed more stable community. However, this simplification of succession can and has been contested.

Disturbances, defined by White and Pickett (1985) as "any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resource substrate availability or the physical environment", include such events as mass wasting, soil erosion and trampling. These events often initiate succession, but may also retard successional pathways. Communities may regress from having diverse species content and greater biomass to ones with fewer species and less biomass. Exposure to stress such as decreased nutrients or decreased water availability may also cause communities to regress to ones of less complexity (Glenn-Lewin et al. 1992).

Primary succession occurs on sites where the A and B soil horizons are not present (Chapin 1983). Regolithic sites such as gravel pits, and river bars where deposition of coarse alluvial material has accumulated or landslides and avalanches where sheet erosion has removed the A and B horizons result in soil often low in nutrients. Soils lacking nutrients, especially nitrogen and void of organic material are likely places for primary succession to occur. Colonisation is initiated by pioneer species, also known as invader species or colonisers which are transported to the site by common means such as wind, water or animal movement. These sites often host plants which either have low nitrogen requirements or those that fix nitrogen (Kimmins 1997). Pioneer species are frequently dominated by annual herbaceous plants which produce large quantities of easily dispersed seeds, can grow on open, nutrient poor sites and can have a high growth and development rate (Chapin 1983). These species are capable of modifying soil temperatures, soil bulk density and providing added organic material which may enhance water holding capacity and nutrient levels from decaying root systems and above ground plant residue. Late seral species often produce larger seeds with lower dispersion rates, have lower growth rates and a higher root to plant biomass than pioneer species. These species provide soil amelioration and anchorage capabilities (Chapin 1983).

Secondary succession is regarded as the replacement of former vegetation after a disturbance has removed some or all of the former vegetation but a developed soil still exists containing a seed bank or vegetative propagules to begin the revegetation process. However, primary and secondary succession often merge to form a continuum where intermediate situations exist making it difficult or impossible to differentiate the two (Glenn-Lewin et al. 1992).

Plants may become redistributed in a disturbed area through clonal growth, or through propagule dispersal. This can be a slow process once again based on the previously mentioned successional traits. Vegetative reproduction and total species regeneration can take place from pieces of stem tissue (Zasada 1986). Reproductive mechanisms include:

- Tillering. This mechanism is most common in grasses and sedges. Parent plants produce vertical growth when axillary buds are no longer dormant. This growth form referred to as tillers can develop leaves and roots while remaining attached to the parent plant, but if they become detached during a disturbance such as rototilling can become independent plants. Quackgrass (*Agropyron repens* L.) exemplifies tillering (Luken 1990).

- Root suckering. This is a common form of clonal development found in trembling aspen (*Populus tremuloides* Michx.). Shoot meristems develop on intact horizontal roots producing clones of the parent plant (Luken 1990).

- Rhizomes and stolons. These are stems which grow horizontally from the parent plant and develop terminal or axillary shoots as well as adventitious roots. Rhizomes are usually fleshy and located below ground while stolons are usually non-fleshy and located above ground. Detachment of a stolon or rhizome can produce independent plants. Smooth brome (*Bromus inermis* Leyss.) is an example of a rhizomatous grass (Luken 1990) and strawberries (*Fragaria virginiana* Duchesne) are an example of a stolon producing forb.

7.1 Regeneration

Regeneration is the amalgamation of processes which result in a community having an approximately constant composition in the long term and over a large area despite the removal of individuals by death from old areas and periodic partial biomass destruction by outside influences such as wind, fire or flood (Luken 1990). Regeneration may involve internal successions (Curtis 1959) of species on sites where the earlier cover has been destroyed, but equally may involve plant propagation or plant replacement without any successional tendency (Grub 1985). "Seed availability at a given time can determine what species may potentially participate in a successional pathway" (Luken 1990).

Continual disturbances such as trampling can produce plant populations and vegetation adapted in relation to habitat, disturbance and competition by key morphological and physiological characteristics. Roots able to penetrate compacted soil and survive at low soil oxygen concentrations and shoots able to resist bruising are plant traits suited to modified soil conditions such as compaction (Grub 1985).

Evaluating established surrounding plant communities with similar site characteristics can give an indication of community type ultimately expected on a native revegetated site. Rather than attempting to determine whether surrounding vegetation has become a climax community it may be as effective to strive for a mid seral community emulating to some extent the surrounding communities in the vicinity. Soil characteristics may vary in water holding capacity and/or nutrient availability, thereby allowing establishment of some species not present in the immediate surrounding vicinity but present in the ecotone.

8.0 SOIL AMENDMENTS

Eroded soil of the C horizon may be devoid of nutrients and organic material required for healthy plant propagation. Applying nutrients in the form of organic amendments has added benefits when compared to applying synthetic fertilisers. Organic amendment incorporation has the potential to change soil texture and reduce bulk density thereby improving the water holding capacity and increasing air spaces needed for growing plants. Root growth is severely restricted in soils with a dry bulk density of approximately 1.4 Mg m^{-3} for clays and 1.7 Mg m^{-3} for sandy soils (Coppin and Richards 1990). Humus has the advantage over clay of not drying into a hardpan (Hackett 1977).

Organic matter can greatly augment the nutrient retention characteristics of sandy soils and the drainage characteristics of clay soils. Organic matter also supplies carbon to otherwise organic carbon devoid C horizons. This carbon is essential for soil microorganisms which break down the compounds, subsequently producing nitrogen and other minerals necessary for successful vegetation growth (Coppin and Richards 1990).

The growth of small seeded annuals is directly related to soil nutrition whereas perennial plants are less dependent on soil nutrients and partially dependent on stored nutrients located in root stems (Chapin 1983). The lack of available nutrients in C horizon soils is a major deterrent to plant survival and vigour. Nitrogen is the primary limiting element on highly disturbed soils, less than 40 kg ha^{-1} may increase species diversity by allowing a large number of species to establish and survive on nutrient poor soils while not permitting a limited number of aggressive grass species to dominate (Doerr and Redente 1983).

Incorporating nutrient containing soil amendments to a site may change the species composition when compared to a site without similar amendments. Chapin (1983) indicated how early successional species such as annuals had higher rates of nutrient absorption, rapid growth rates and rapid growth responses to fertilisation while slower developing plants of mid to late successional stages had lower nutrient absorption and less dramatic growth responses to fertilisation. Plant species tend to exhibit preferences in nutrition requirements and their growth responses to nutrient availability by where they locate and propagate. Community development may be modified by changing the available nutrients (Luken 1997).

9.0 RESEARCH OBJECTIVES

Published scientific literature documenting that transplanting is not equally effective during times other than early spring or late autumn is not available for the Canadian Parkland. This research will determine whether transplanting time is crucial to plant survival and development and if bioengineering using terracing and native vegetation islands can successfully revegetate and increase stabilisation of severely eroded slopes. Therefore, the goal of this research is to reclaim a hillside ecosystem which will provide a hospitable native plant and animal environment that is aesthetically pleasing while stabilising soil conditions and minimising soil erosion.

The objectives of this research are:

- To determine if vegetation islands and live stakes can survive and propagate when planted at two different times during their annual life cycle, namely during mid August when numerous plants are blossoming or producing seed/fruit and in mid October after all visible green plant growth has terminated.
- To determine if specific plant species categories (grasses, forbs, shrubs/trees) will survive and propagate at different rates depending when they are transplanted.
- To determine if gully and slope position are associated with transplanted plant mortality, vigour and propagation.
- To determine if soil moisture varies by slope position and/or position within terraces.
- To observe if terracing will reduce runoff transported sediment to lower slope positions.

10.0 NULL HYPOTHESES

- Transplanting vegetation islands at two different times during their life cycle will not have a significant effect on plant vigour and mortality.
- All transplanted species categories (grasses, forbs, shrubs/trees) will have the same survivability and propagation rates.
- Slope position is not associated with transplanted plant survivability and propagation.
- Terracing has no effect on reducing runoff transported sediment to lower slope positions.
- Soil moisture is not associated with slope positions or terrace positions.
- Live willow stakes planted at two different times in their growing cycle will not have significant effect on their survivability

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CHAPTER II LAKESHORE SLOPE BIOENGINEERING AND RECLAMATION

1.0 INTRODUCTION

Transplanted root plugs or vegetation islands containing a variety of community specific native plant species complete with soil and microenvironment can be used to establish vegetation patches rather than use individual plants (Munshower 1994). Implementing the vegetation island transplanting method on steep erosion prone slopes can potentially reduce soil loss by decreasing the bare soil surface area exposed to runoff and expedite canopy cover growth to facilitate a reduction in the detrimental effects of raindrop impact. Concurrently, islands provide numerous roots capable of penetrating and anchoring unstable slopes without waiting years for vegetation and associated root masses to establish from seed in low nutrient soils. Grass, legume and small tree roots significantly increase soil strength at various moisture contents and increase the ability to enhance slope stability. This is evident with the often increased frequency of landslides on steep slopes where vegetation has been removed by logging and/or fire and root systems have decomposed, reducing or eliminating their anchoring capabilities (Megahan and Kidd 1972; Wu 1976; Aramanthus et al. 1985).

Transplanting intact portions of native plant communities complete with their accompanying hospitable microclimates and microflora and fauna can help retain or regain area biodiversity. Consequently providing a mosaic of plant communities may accelerate the successional process by allowing associated seeds to germinate and young plants to establish, potentially encouraging the progression from an early successional state to a more advanced mid-successional state which may contain a greater proportion of perennial species. Perennial root systems may remain for numerous years sustaining soil anchorage as opposed to annual plant root systems which die yearly, limiting their effective soil anchoring capabilities but remaining important as soil amendments.

Limited published information and general practice garnered from anecdotal evidence suggest transplanting is most successful when plants are dormant. In the Aspen Parkland this corresponds to early spring (April, May) prior to new growth occurring or when plants are either dormant or are approaching dormancy after mid October (Schiechtl 1980). However, anecdotal information is not quantitative and it is difficult or impossible to determine the accuracy of the information. Published studies involving native plant responses such as mortality and vigour to transplanting stresses are virtually non-existent. Very limited information is only available for a limited number of horticultural species. Comparisons between native vegetation and studies of horticultural species may be presumptuous.

Transplanting vegetation during dormancy, either in autumn or early spring, is believed to potentially maximise carbohydrate reserves necessary in sustaining growth following transplanting. Reserves vary seasonally, between species and often within species, dependent on growing environment (White 1973). As an example, the majority of grass species have the lowest reserve levels during early vegetative growth, while others have lowest reserves during flowering, following seed ripening or during secondary fall growth (Daer and Willard 1981).

Carbohydrate reserves in deciduous trees and shrubs are at a maximum during winter and at a minimum during spring and summer (Luken 1990). It is conjectured that transplanting while carbohydrate reserves are in various stages of depletion reduces the plant's survival ability. Root severing during plant removal may reduce the plant's ability to obtain soil supplied water and nutrients. This, in combination with temperature stress and translocation to an often less than ideal growing environment, are presumed to compound, causing plant mortality due to transplanting stress. As mentioned previously, published studies providing quantitative information in this area are virtually non-existent.

Transplanting vegetation islands is the initial step in establishing vegetation in this study but is augmented by other processes. Colonisation is initiated by pioneer species, also known as invader species or colonisers which can be transported to a site by common means such as wind, water or animal movement. If seed sources or transportation mechanisms are not present or suitable, colonisation of barren sites can be a slow process or not occur at all (Kimmins 1997). Pioneer species are frequently dominated by annual herbaceous plants which produce large quantities of easily dispersed seeds, can grow on open, nutrient poor sites and can have a high growth and development rate (Chapin 1983). These species are capable of modifying soil temperatures, soil bulk density and providing added organic material which may enhance water holding capacity and provide nutrient levels from decaying root systems and above ground plant residue. Revegetation by this means may seem rapid when weed control is necessitated but can be a relatively slow process when relied on as the sole means of providing vegetation cover to reduce effects of erosion in a timely manner. Late seral species often produce larger seeds with lower dispersion rates, have lower growth rates and a higher root to plant biomass than pioneer species. These species provide soil amelioration and anchorage capabilities (Chapin 1983).

Plants may become redistributed in a disturbed area through clonal growth, or through propagule dispersal when donor plants are naturally present or supplied through transplanting. Vegetative reproduction and total species regeneration can take place from pieces of stem tissue (Zasada 1986). However, this again can be a slow process if relied upon exclusively to supply vegetative cover. Reproductive mechanisms common to plants in the Aspen Parkland include:

- Tillering. This mechanism is most common in grasses and sedges. Parent plants produce vertical growth when axillary buds are no longer dormant.

This growth form referred to as tillers can develop leaves and roots while remaining attached to the parent plant, but if they become detached during a disturbance such as rototilling can become independent plants. Quackgrass (*Agropyron repens* L.) exemplifies tillering (Luken 1990).

- Root suckering. This is a common form of clonal development found in trembling aspen (*Populus tremuloides* Michx.). Shoot meristems develop on intact horizontal roots producing clones of the parent plant (Luken 1990).

- Rhizomes and stolons. These are stems which grow horizontally from the parent plant and develop terminal or axillary shoots as well as adventitious roots. Rhizomes are usually fleshy and located below ground while stolons are usually non-fleshy and located above ground. Detachment of a stolon or rhizome can produce independent plants. Smooth brome (*Bromus inermis* Leyss.) is an example of a rhizomatous grass (Luken 1990) and strawberries (*Fragaria virginiana* Duchesne) are an example of a stolon producing forb.

Transplanted vegetation may be combined with a wide variety of engineered structures such as terraces, gabions, geotextile or brush mats, wooden cribs or riprap when necessary to further increase slope stability beyond the ability of vegetation.

2.0 RESEARCH OBJECTIVES

Published scientific literature documenting that transplanting is not equally effective during times other than early spring or late autumn is not available for the Canadian Parkland. This research will determine whether transplanting time is crucial to plant survival and development and if bioengineering using terracing and native vegetation islands can successfully revegetate and increase stabilisation of severely eroded slopes. Therefore, the goal of this research is to reclaim a hillside ecosystem which will provide a hospitable native plant and animal environment that is aesthetically pleasing while stabilising soil conditions and minimising soil erosion.

The objectives of this research are:

- To determine if vegetation islands can survive and propagate when planted at two different times during their annual life cycle, namely during mid August during plant blossoming and seed/fruit production and in mid October after all visible green plant growth has terminated.
- To determine if specific plant species categories (grasses, forbs, shrubs/trees) will survive and propagate at different rates depending when they are transplanted.
- To determine if gully and slope position are associated with transplanted plant mortality, vigour and propagation.
- To determine if soil moisture varies by slope position and position within terraces.
- To observe if terracing will reduce runoff transported sediment to lower slope positions.

3.0 RESEARCH SITE

3.1 Research Site Location and Dimensions

The reclamation study site is located in Elk Island National Park which is 37 km east of Edmonton along Highway 16 in central Alberta. The Park is 22.5 km north-south and 10 km east-west with an area of approximately 19,680 hectares (Crown 1977). The study slope is situated along the eastern shoreline of Astotin Lake which is located near the north end of the Park. The eroded bank study site is located at 53° 40' 33" N Latitude and 112° 49' 52" W Longitude.

The study slope is within the fenced recreation area north of the sandy beach and is situated below the historic picnic shelter, known as the Pavilion. This area has been ecologically unstable for decades; producing barren eroded slopes.

Park archival and aerial photographs indicate that this site has been eroding for at least 30 years. The eroded site is approximately 60 m long and is situated on a west facing sparsely vegetated, steep, eroded slope located between the lake shoreline and the Pavilion above. An asphalt hiking trail is located parallel to the slope between the Pavilion and the slope drop-off. There are three main gullies, each approximately 13 m from top to bottom. Portions of the upper slope are vertical, naturally devoid of vegetation and continually exfoliating and slumping soil due to water erosion. The sparsely vegetated, less steep sections vary in inclination between 28 and 38 degrees.

3.2 Climate

The Park receives approximately 20% more precipitation than either the Aspen Parkland ecoregion which surrounds it or the Mid Boreal Mixedwood ecoregion located further north (Geowest Env. 1994). Average annual precipitation monitored from 1981 to 1993 (most recent data available) within the Park averages 524 mm with approximately 405 mm falling as rain during the growing season of May through September. Overwinter long term average precipitation between November 1 and March 31 is approximately 78 mm. The highest mean monthly maximum temperature occurs in July at 22 °C and the lowest mean monthly minimum temperatures occur during January and February at –17 °C (Environment Canada 1994).

3.3 Vegetation

Elk Island National Park is situated in an ecotone or transition zone where Parkland and Boreal forest species both can be found (Strong and Leggat 1992). A transition zone often exists where one group of species progressively grades into another (Johnson et al. 1995). However, changes between vegetation communities need not be progressive and may be abrupt or gradual. This area or ecotone can often be identified by a greater plant species diversity than is found in either of the individual adjoining communities (Holland et al. 1991).

The site is located in the Low Boreal Mixedwood Ecoregion which is dominated by aspen (*Populus tremuloides* Michx.) and balsam poplar (*Populus balsamifera* L.) with succession to white spruce (*Picea glauca* (Moench) Voss) (Strong and Leggat 1992). The shrub understory is often dominated by prickly rose (*Rosa acicularis* Lindl.) and beaked hazelnut (*Corylus cornuta* Marsh.). Various grass species are also present with a portion being agronomic species including smooth brome (*Bromus inermis* Leyss.) and timothy (*Phleum pratense* L.) (Geowest Env. Ltd. 1994). Native species include western wheat grass (*Agropyron smithii Rydb.*), fringed brome (*Bromus ciliatus* L.), fowl bluegrass (*Poa palustris* L.) and slender wheat grass (*Agropyron trachycaulum* (Link) Malte).

3.4 Soils

Soils at the study site are predominantly Orthic Gray and Dark Gray Luvisols. Orthic Gray Luvisols are associated with deciduous forests while Dark Gray Luvisols indicate the influence of grassland vegetation. Due to the Park's location within an ecotone or transition zone between the two ecoregions, characteristics of both ecoregions are present (Strong and Leggat 1992).

3.5 Soil Instability

A combination of factors appear to promote instability and related soil erosion on the study slope. It is partially a natural phenomenon due to the steep slope exacerbated by channelled runoff from above and further accelerated by erosion caused by recreational pedestrian traffic. Gullies have been created by water erosion down unrestricted recreational pedestrian trails. Several smaller eroded footpaths also occur above the slopes and partially descend the slope face providing sites for potential gully formation.

As the gullies and slopes continue to erode the trails and adjacent land above, the slopes are placed in jeopardy of further erosion. Barren sites such as these are often potential sites for weed propagation and are therefore areas of concern within the Park. The eroded slope is visible from the shore both north and south and is aesthetically unappealing. Recreation will remain the end land use, with restricted access to pedestrian traffic due to the sensitivity of the area to erosion.

3.6 Existing Stabilization Structures

Previously constructed bank stabilisation structures are located at the top of three eroded gullies adjacent and parallel to the asphalt hiking trail. These cribbing walls, installed in 1989, constructed of pressure treated 15 cm square timbers anchored into the hillside, appear to have curtailed major gully encroachment toward the asphalt trail (Overend 1997).

4.0 MATERIALS AND METHODS

4.1 Experimental Design and Statistical Data Analyses

The study site was divided into three gullies and three slopes (Figure 2.1). Each of these three slopes and gullies were differentiated by natural contours and breaks in the slope and were demarcated as plots. The slopes were designated alphabetically by the letters A, B and C from south to north; the gullies were designated numerically as 1, 2 and 3 from south to north with Gully 1 being divided into south, centre and north due to three distinct natural sub gullies.

The statistical design was a 2 factor replicate design incorporating slope/gully and dormant/nondormant plantings as the two factors. Statistical tests were conducted using either one way analysis of variance or categorical data analysis as required. One way analysis of variance was used to analyse the parametric soil moisture data followed by the Tukey test to determine significant difference between multiple comparisons. Categorical data analysis was used to analyse the nonparametric vegetation data using the frequency of islands in various categories of mortality and vigour. A significant difference referred to in the following results and discussion section indicates a statistically significant difference at the 0.05 significance level ($\alpha = 0.05$).

4.2 Research Site Establishment

4.2.1 Reference slope description and sampling

A reference slope was selected several hundred meters north of the bare study site downslope from the asphalt hiking trail. It was divided into three plots each 5 m wide by 8 m down slope. The southernmost upslope plot corner (nearest to the asphalt trail) is 23.7 m diagonally from the centre of the manhole cover at a bearing of 320° north north-west. This slope was chosen for its similarities in inclination, aspect and soil texture to the slope at the study site but does not have the bare vertical slope faces associated with the eroded slope. The vegetation consists of a combination of shrubs, forbs and grasses and was chosen to determine the vegetation species and density capable of growing under the above mentioned conditions. Future research is needed to determine if there are similarities between the mid seral naturally vegetated reference slope and the revegetated site species diversity, plant associations and densities.

The 5 by 8 m reference slope plots were divided into halves providing an upper and lower slope position for sampling. Three quadrats per slope position were sampled. Grass and forbs were sampled using a 0.1 m^2 quadrat and shrubs and forbs were sampled with a 1.0 m^2 quadrat. Similar measurements and criteria for quadrat positioning and sampling vegetation and soil were used as for the bare slope. Vegetation data are presented in Appendix Tables 24 to 26.

4.2.2 Slope terracing

The barren slope, comprised of actively slumping soil, terminates at the lakeshore with an approximate 1 to 1.5 m drop to edge of water. Fluctuating lake levels and saturated, unstable, slumping banks affected how close the terraces could be located to the edge. An additional determining factor involved limiting the disturbance to existing vegetation when installing terraces. If more vegetation would have been disturbed than would have been transplanted, the area was not terraced or if terraced, existing vegetation and associated below ground root structures were left intact to limit damage.

Pressure treated planks, 20 by 5 cm, supplied by Parks Canada were cut to fit the 3 slopes and 3 gully contours running perpendicular to the direction of runoff (i.e. parallel to the slope face). The planks were anchored in place by inserting 15 mm diameter by 1 m long steel concrete reinforcing bars into the slope face to hold the planks on edge. Soil behind the planks was loosened and worked to plank bottom depth by shovel and matlock. A 15 cm depth of worked soil (after walking on it 6 to 8 times by a 50 kg person to lightly compact it) was attained. All soil clods were pulverised by matlock and shovel to a relatively consistent size no larger than 2 cm.

4.2.3 Addition of spent mushroom compost amendment

A spent mushroom compost amendment was added to the worked C horizon to increase soil organic matter, soil nutrient content and improve water retention capability. The compost was comprised of a proprietary mix of well decomposed wheat straw, poultry manure, canola and soybean meal, gypsum and peat moss. This mixture had previously been steamed at 70 °C for 24 h to destroy any residual mushroom spores and weed seeds (Kostelyk 1998). A laboratory germination test was conducted prior to compost incorporation to determine weed or mushroom germination. Twelve compost samples were potted, watered, covered with translucent plastic and kept at 22 to 24 °C for 4 weeks.

The compost was spread to a lightly compacted depth (same compaction criteria as worked soil) of 5 cm to provide a soil/compost mix approximately 75/25% (by volume) and was thoroughly incorporated 20 cm into the soil by shovel to provide a homogeneous mix. The soil was levelled from front to back on each terrace and again lightly compacted by foot pressure (similar criteria as previous). A lateral levelling was also initiated to minimise runoff while still following the natural slope contours.

4.3 Research Treatments

4.3.1 Nondormant transplanting

During the first two weeks of August 1997, vegetation islands approximately 20 cm in diameter and 10 to 20 cm deep were removed by shovel from several previously chosen donor sites within 2 km of the terraced slope. Vegetation island depth and diameter were greatly dependent on soil texture; where coarse fragment glacial till inhibited 20 cm depth removal, shallower depths ranging from 10 to 18 cm were necessary. Island size was also partially dependent on vegetation species and root location. The donor areas were located adjacent to aspen stands in open areas with east, west and south aspects. Island removal too close to mature aspen was inhibited by large lateral root densities.

The chosen donor areas predominantly contained shrubs, forbs and grasses native to the Aspen Parkland. An estimated 30 to 50% of the vegetation was either in bloom or fruiting when removed in the nondormant state. The tallest shrubs (*Rosa acicularis* Lindal.) and forbs (*Solidago canadensis* L.) removed were approximately 0.75 to 1.0 m tall. The density of removed donor vegetation islands was limited to one per approximately 2 to 3 m^2 to minimise the visual as well as physical impact on the surrounding plant community.

The islands were dug, transported and transplanted within 2 h of removal from the donor site. Islands were placed 4 to 6 per plastic box, driven to the lakeshore, loaded in a rowboat, rowed to the terraced site, then carried to the specific terrace. This transportation method reduced potential compaction by repetitive pedestrian traffic on the terraced site. Transplanted islands were spaced to provide approximately 45 to 55% terrace ground cover. Initially, Slope A was not watered after transplanting but due to severe leaf wilting as a result of sunny conditions and relatively high air temperatures (28 to 32 °C) the islands were watered the following day. By this time the majority of vegetation was badly wilted and some previous wilted leaves had dried. Subsequent transplanted islands were watered immediately after transplanting and did not exhibit indications of leaf wilt following transplanting. All succeeding nondormant transplanting entailed watering each island with approximately 4 L of lake water to settle the soil around the root mass and provide moisture to the plants. Daytime ambient air temperatures on the slope varied from 27 to 32 °C during the nondormant transplanting time.

4.3.2 Dormant transplanting

Dormant transplanting was initiated October 13, 1997. Morning temperatures were -6 °C with day time highs of 6 °C. The terraced slope soil was frozen in isolated small areas (approximately 1 m long) up to 4 cm deep. The donor site was located within 2 km of the slope and had a south and east aspect. All vegetation on the donor area was considered dormant with no sign of green nondormant foliage; all leaves were either coloured or desiccated and fallen. Dormant vegetation islands similar in dimensions to the nondormant islands were removed from the open shrub/grassed area adjacent to the aspen tree line at the donor site. The islands were transplanted but not watered at this time; it was speculated that late season rain and early spring snow melt would settle the soil sufficiently around the islands and provide adequate soil moisture for the islands in the spring. Vegetation islands were transplanted in the designated slope and gully positions. The number of islands per dormant terrace were kept approximately equal to the number previously transplanted in the nondormant section.

4.3.3 Vegetation island positioning

Dormant and nondormant islands were alternated down the gully terraces (Figure 2.1). For example, the first (upper) terrace received a nondormant island(s) on the north and a dormant one on the south side, the following terrace would receive dormant on the north side and nondormant on the south side. This alternating pattern was chosen to eliminate aspect as a treatment effect by providing dormant and nondormant vegetation islands with an equal exposure to north and south shade related aspects; Gullies 2 and 3 are relatively narrow and partially shaded. Slopes were divided in half laterally; shaded aspects were not an issue allowing transplanting the left slope half (facing the slope) with nondormant vegetation islands.

4.4 Meteorological Data

Meteorological data for Elk Island National Park was obtained from the Canadian Climate Centre (Environment Canada 1994). This data included daily precipitation from May 1997 to October 1998 and the most recent long term monthly mean precipitation and mean maximum and minimum temperatures recorded between 1981 and 1993.

4.4.1 On-site meteorological data collection

In late July 1997 two standard 100 mm tube style rain gauges were installed on the terraces to monitor total on-site precipitation, no other instruments were installed during the 1997 growing season.

In late April 1998 an RT 2501 Sierra/MACA tipping bucket rain gauge, an air temperature sensor (to monitor maximum and minimum daily temperatures) and a relative humidity sensor were installed. These were all interconnected with a Campbell Scientific multiplexer into a Campbell Scientific CR 10 data recorder. A Solarex solar panel was used to maintain an adequate power supply to the 12 volt data recorder battery. Two conventional 100 mm tube style rain gauges were also set up at opposite ends of the site to verify precipitation amounts recorded by the tipping bucket gauge.

4.5 Soil Sampling and Analysis

4.5.1 Soil physical properties and nutrient analysis

Following terracing, soil was sampled for bulk density using the Uhland core method (Carter 1993). The cores provided a standard 7.5 cm diameter sample removed from the surface level C horizon and extended 20 cm deep. Soil samples were randomly obtained (by throwing a stone over the shoulder to determine the sampling site) from 3 positions per slope and 3 positions per gully (one sample each in the upper, middle and lower positions totalling 18 samples) from the undisturbed C horizon. In late September 1998, after the soil had settled for approximately one year, bulk densities were again determined within the upper 7.5 cm and the 7.5 cm below that in the amended soil profiles of both gullies and slopes. The intention was to ascertain whether there was any trend in soil compaction and increased bulk densities due to research pedestrian traffic on the upper horizon and to determine the effect of soil amendment on ameliorating the original bulk densities.

Soil nutrients were analysed using 7.5 cm diameter by 20 cm deep core samples. Composited samples were obtained, one each from the reference site, slopes and gullies before adding the compost amendment to the terraces and one composite sample for all gullies and slopes after amendment. Samples were analysed for nitrogen, potassium, phosphorus and total carbon prior to addition of soil amendments (Carter 1993). The soil samples were analysed for percent nitrogen and phosphorus using a Technicon Autoanalyzer and associated methods (Carter 1993). Extractable potassium was determined using a Perkin-Elmer 503 Atomic Absorption Spectrophotometer and associated methods (Carter 1993). Total percent carbon was determined using the Leco method (Carter 1993). A reference sample of an Ellerslie Black Chernozemic soil was also analysed at this time as a standard laboratory procedure to provide some comparison between nutrients in a relatively fertile soil compared to those at the study and reference sites.

Additional soil samples were obtained randomly within individual slopes and gullies, one sample each for upper, middle and lower slope positions. Soil texture was determined from these samples using the hydrometer method (Carter 1993). Soil electrical conductivity (EC) and pH were also determined on these samples using an aqueous soil extract of 10 g soil to 20 ml of deionized water (Carter 1993).

Similar sampling procedures were implemented on the Reference site obtaining 3 random samples to determine bulk density, soil texture, nutrients, pH and EC.

4.5.2 Soil moisture data collection

In late April 1998, 27 Campbell Scientific CS615 (30 cm) Time Domain Reflectometry soil moisture probes (TDR) were installed on Slope C to monitor soil moisture fluctuations during the growing season. These were connected to the same Campbell Scientific CR 10 data recorder as previously mentioned. A single slope was chosen as a representative site for soil moisture monitoring due to a limited number of available probes and that the chosen slope was the largest and best situated to operate the monitoring system.

The TDR probes were placed in three slope positions, on the upper, middle and lower positions. Nine probes (3 groups of 3) were installed in each slope position. Within each group of three probes, one was placed within 2.5 cm from the terrace board, another was positioned approximately in the middle of the terrace and one was positioned approximately 5 to 7 cm from the terrace back wall. This grouping was repeated 3 times per slope position along the same terrace. All probes were inserted at approximately a 40 ° angle to insure the 30 cm long probes would contact the entire 20 cm depth of amended, worked soil. Soil moisture was measured and recorded by the data logger hourly and then averaged for each 24 h period.

Monitoring soil moisture fluctuations, trends, precipitation events and air temperatures was intended to potentially help explain vegetation island growth patterns that may have been identified as being associated with soil moisture and air temperature fluctuations. There was also some speculation that soil moisture levels would differ between the board and the back of the terrace due to board warming from solar radiation and subsequent adjacent soil moisture evaporation. It was also speculated there may be a variation in moisture levels in the rear terrace position due to precipitation runoff from the terrace above increasing the soil moisture level significantly on the rear terrace position below. Soil moisture was also monitored on 3 slope positions to determine if soil moisture from higher slope positions would percolate within the top 20 cm soil horizon to terraces below, potentially indicating a time lag in soil moisture increase in lower positions following precipitation events.

4.5.3 Soil erosion

Soil erosion was monitored by observing the extent of sediment and mass soil movement both on the slope and gully walls and within the terraces. Aluminum identification tags originally installed at ground level in early May 1998 for vegetation island identification were used to visually determine the extent of sediment accumulation within the terraces during the growing season. Observations were recorded regarding depth of soil accumulated over the tags when vegetation analysis was conducted in June and August 1998.

4.6 Vegetation Analysis

4.6.1 Preliminary analysis

Preliminary plant species identification, densities, percent canopy cover and percent ground cover consisting of live vegetation, rock and litter were recorded on the slopes and gullies prior to terracing. One m^2 quadrats were used to sample tree and/or shrub data and 0.1 m^2 quadrats were used to sample forbs and grasses. Each gully or slope was measured into thirds creating 3 positions (upper, middle and lower slope positions). Four quadrat locations of each size (1 m^2 and 0.1 m^2) were sampled in each of the 3 slope positions, thereby creating 24 quadrats sampled for each gully and slope. Random quadrat positioning was determined by throwing a flat stone over the shoulder within each of the 3 slope positions and placing the quadrat where the stone landed.

Individual plant stems were counted for trees, shrubs and forbs, and tillers were counted for grasses such as Canada wild rye (*Elymus canadensis* L.). Sod forming grasses such as Kentucky bluegrass (*Poa pratensis* L.) were counted by groups of stems considered to be individual plants. Only plants rooted within the quadrat were counted. Canopy cover measurement included vegetation within the quadrat and the portion of vegetation extending in its natural stance into the quadrat. Each plant species was identified, counted and recorded. Percent canopy cover of each vegetation layer (shrub, forb and grass) was ascertained using percent cover cards which represented various percentages of 1 m^2. Percent ground cover consisting of live vegetation, rock, litter (including sticks, dead leaves and twigs) and bare ground was also estimated using percent cover cards. The criterion used to determine percent vegetation ground cover was to record whatever percent vegetation cover would have remained had the overstory vegetation been removed to a height of 2.5 cm above the ground surface.

4.6.2 Vegetation island species identification and vigour determination

In June and August 1998 all plant species located within the vegetation islands (average size 0.3 m^2) were identified and counted using the previous mentioned counting criteria. Vegetation island vigour was categorised into 3 classes. Category 1 was used to identify islands which contained 100% dead vegetation, all above ground vegetation was desiccated and no visual sign of life was present. Category 2 was used to identify islands where the overall appearance of the vegetation was yellowed or otherwise unnaturally coloured, wilted, dead (but not including the natural litter layer) and/or exhibiting little new growth.

Category 3 indicated vegetative islands that appeared healthy, determined by no visible wilting, yellowing or other abnormal discolouring and exhibited healthy new growth.

4.6.3 Vegetation island mortality determination

Percent mortality of vegetation in each island was determined as the percent vegetation that appeared dead within the island expressed as a percentage of the total visible vegetation within the island. The quantity of islands were then categorised into seven arbitrary mortality categories. These categories were further reduced to 2 arbitrary mortality categories (0-10% and 11-100%) for the discussion of results. The percentages discussed in the following section were calculated by totalling the number of islands in each category and expressing them as a percentage of the total islands for the particular treatment.

5.0 RESULTS AND DISCUSSION

5.1 Meteorological Conditions and Observations

The first major winter snowfall during the study period occurred January 1, 1998. Although Astotin Lake was frozen, daily temperatures had been as high as 4 to 6 °C with nightly lows in the -10 to -15 °C range during the late fall and early winter. Until this date there was no on-site snow cover, thereby exposing the vegetation and soil to desiccating winter winds, possibly reducing soil and vegetation moisture levels. On-site snow cover was very minimal due to wind scouring and removal which permitted only intermittent patches to remain snow covered. The transplanted vegetation islands appeared to trap snow with more success than did the bare soil areas. No more than 25 cm snow cover was observed during several visits to the site throughout the winter; as earlier stated, this was not a continuous cover. The majority of accumulated snow was located within vegetation islands. Environment Canada weather records for Elk Island National Park dating from November 1, 1997 to March 31, 1998 indicated 65.3 mm precipitation at the weather station located in a relatively sheltered area several kilometres west of the study site. This value is less than the long term average of (1981 to 1993) 97 mm (Environment Canada 1994). The study site is believed to have received even less precipitation than the weather station due to the previously mentioned conditions.

The beginning of the 1998 growing season appeared to be approximately 2 to 3 weeks earlier than previous years in this ecoregion. This was based on personal observations of spring vegetation leaf emergence, blossoming and fruit production compared to approximately the previous 7 years. This apparent advanced season may have been due in part to the moderating influences of the weather phenomena known as El Niño.

Total precipitation was 327 mm between May 1 and September 30, 1998. This precipitation level was lower than the long term average 405 mm received for the same months between 1981 and 1993 (Environment Canada 1994). Precipitation recorded at the Park weather station for the period May 1, 1997 to September 30, 1997 was 322 mm and for May 1998 to September 30, 1998 was 147 mm (Environment Canada 1994). Both these amounts are below the long term average of 405 mm.

During the growing season the maximum temperature was 33 °C in August and the minimum temperature was -0.4 °C in late September. No monthly temperature or precipitation means were calculated from on-site data due to incomplete monthly readings.

The first observable signs of dormancy indicated by major portions of vegetation beginning to dry off occurred in mid August. This may have been partially due to low soil moisture. September 30 was the apparent end of the on-site growing season, assessed by observing major leaf drop and the dormant appearance of the majority of plants. The first recorded on-site overnight temperature below 0 °C occurred on this date.

5.2 Soils and Hydrology

5.2.1 Soil moisture

The initial average volumetric soil moisture content for the study slope was 37.9% on April 29, 1998 (Figure 2.2). There was a general declining trend in volumetric soil moisture content during the summer to a minimum of approximately 16% in late August, followed by an increase to 27% by the end of September 1998 when the probes were decommissioned.

There was a significant difference in mean volumetric moisture content among each of the 3 positions within terraces using data obtained from TDR moisture probes located near the front (board), centre and near the rear of the terraces in Slope C (Figure 2.3). The mean volumetric moisture content decreased relative to the distance from the rear terrace position to the front (board) position. The mean rear terrace position soil moisture content was 31% and decreased to 23% at the board position. This soil moisture gradient from rear to front may be due to several aggregated factors. First, solar radiation may have heated the board which radiated heat to the soil located behind it, warmed the soil and caused the soil moisture to evaporate to a greater extent near the board and decreasing toward the rear. Second, the board may have provided a wicking surface to remove soil moisture from the soil/board interface causing a soil moisture gradient in relation to the distance from the board. Third, the rear terrace position may have received overflow runoff from the terrace above this moisture flowed downslope increasing soil moisture at the rear of the adjacent lower terrace.

There was also a significant difference in mean volumetric soil moisture contents due to slope position among all positions on Slope C (Figure 2.4). The mean volumetric soil moisture content varied between 30% in the upper slope position and 23% in the lower position. Increased soil moisture at the upper slope position may be due to precipitation runoff from the vertical slope walls soaking into the upper terrace.

5.2.2 Soil texture

Soil from the reference site, slopes and gullies was classified as sandy clay loam according to the Canadian System of Soil Classification (1987). Total clay fractions (<2 μm) ranged from 20 to 23% , the total silt fraction (2 to 50 μm) ranged from 27 to 36%, and the total sand fraction (>50 μm) ranged from 47 to 54% (Appendix Table 1). Soil at the Reference site was also classified as sandy clay loam with clay fractions 21 to 30%, silt fractions 20 to 25% and sand fractions 44 to 59%.

5.2.3 Soil bulk density

Bulk density on the initial undisturbed sites from a 20 cm deep profile averaged 1.69 Mg m^{-3} with a standard deviation of 0.05 (based on 18 samples). (Appendix Table 2). In late September the average bulk density for all samples had decreased to 1.16 Mg m^{-3} with a standard deviation of 0.14 Mg m^{-3} (based on 18 samples) (higher standard deviation is possibly due to uneven incorporation of the soil amendment and/or compaction due to research pedestrian traffic).

5.2.4 Soil nutrients

Before soil amendment Gullies 2, 3, and all slopes averaged 0.025% nitrogen (N) while Gully 1 had 0.11% N (Appendix Table 3). Slope potassium (K) ranged from 0.15 meq 100 g^{-1} (milliequivalents per 100 grams of soil) to 0.34 meq 100 g^{-1} soil. Phosphorus (P) levels averaged 0.025%. The average percent total carbon for all slope and gully samples was 0.90% before the soil amendment was added and ranged from 0.64% in Gully 2 to 1.40% in Gully 1. The Reference site had 0.08% N, 0.34 meq 100 g^{-1} soil K, 0.04% P and 1.08% total C. Following amendment nitrogen increased to 0.24%, phosphorous increased to 0.13%, potassium increased to 3.77 meq 100 g^{-1} of soil and % total C increased to

3.16%. As a comparison for total carbon, a fertile summerfallow soil from the University of Alberta Ellerslie Research Station contained 7.08% total C; in comparison, the amendment did not add large quantities of carbon to the soil.

The addition of organic carbon provided by plant biomass can provide the transplanted vegetation with a source of nitrogen through mineralization depending on numerous interdependent factors as described in Troeh and Thompson (1993). Ongoing organic matter additions provided by annual on-site vegetation components such as roots and above ground plant matter can potentially sustain elevated nitrogen levels (above initial C horizon levels) through mineralization which can benefit plant growth.

5.2.5 Soil pH and electrical conductivity

Soil pH varied from 7.0 to 8.6 on both the slopes and gullies. Carbonate deposits were visually evident in the undisturbed C horizon further substantiating the basic pH levels. The Reference site pH ranged from 7.0 to 7.7 and the soil/compost mix was 7.4. These pH levels indicate that all samples were somewhat alkaline. Soil salinity (electrical conductivity) averaged 1.21 dS m^{-1} ranging from 0.24 to 3.34 dS m^{-1}. The Reference site averaged 0.18 dS m^{-1} ranging from 0.12 to 0.22 dS m^{-1}. The soil/compost mix was 4 dS m^{-1}. Values greater than 4 dS m^{-1} are considered restrictive to sensitive crops (agricultural) (Carter 1993). The higher EC of the compost may be due to salts associated with the manure component of the mushroom compost; it may decline over time as the salts are leached from the soil by percolating precipitation.

5.2.7 Erosion and soil deposition

Soil erosion on both gullies and slopes was observed during summer 1997 and again in 1998. When constructed, most terraces had an average 25 mm of board protruding above the mean terrace soil level (likely due to settling of the worked soil). The protruding board height decreased (soil height increased) especially during the 1998 growing season to the extent that soil on most terraces was level with the board. Observation following some higher precipitation events indicated that eroded soil was carried by flowing water (possibly sheet erosion) from adjacent terrace(s) upslope. Gully walls and corresponding terrace sides appeared to be the major contributing source for accumulated new terrace soil. The terraces and associated vegetation prevented soil transportation more than 1 or 2 terraces downslope and appeared to prevent soil moving downslope as far as the lake. Gully walls appeared to have the greatest erosion, possibly due to their lower slope angle which fostered soil wetting to greater depth which in turn promoted soil detachment and transport. Erosion was not as evident on slope walls which tended to have a greater slope angle and apparent ability to shed precipitation without as much soil wetting, detachment and transport taking place.

Small scale soil exfoliation and resultant landsliding was also evident on all 3 slopes. The upper terrace on each of the 3 slopes retained the most soil caused by landsliding (small scale mass wasting usually less than 0.03 m^3) from the slope walls. In some cases the vegetation islands were more than 50% buried however, vegetation continued to grow through the fallen soil. These larger soil masses were not transported to lower terraces, however, the finer fractions were transported to second and third lower terrace positions. Vegetation identification tags installed at ground height in May 1998 were used as a basic indicator of water transported sediment. Many tags, situated in gully terraces near the rear terrace positions (furthest from the board) were buried up to 4 cm deep with soil transported from upslope when located in August 1998 for the vegetation count.

5.3 Vegetation

5.3.1 Mortality among dormant and nondormant vegetation islands

There was a significant difference in vegetation mortality on the slopes in June and August between dormant and nondormant islands (Table 2.1 and 2.2). In June, there was a significantly greater percentage of islands having between 0 and 10% vegetation mortality. Eighty eight percent of nondormant islands and 76% of dormant islands were in this category. Correspondingly, there was a significantly greater percentage of dormant islands (24%) in the 11 to 100% mortality categories compared to 12% for the nondormant islands. In August, significantly more nondormant islands (91%) had between 0 and 10% vegetation mortality than dormant islands (73%). In relation to this, nondormant island mortality in the 11 to 100% categories had decreased to 9% while dormant island mortalities had increased slightly to 27%.

There was also a significant difference between dormant and nondormant island mortality on the gullies in both June and August (Tables 2.3 and 2.4). In June 71% of nondormant islands had between 0 and 10% vegetation mortality, while 60% of dormant islands were in this category. There were 40% dormant islands between 11 and 100% vegetation mortality compared to 29% of the nondormant islands. In August, approximately 86% of nondormant islands had between 0 and 10% mortality compared to 71% of dormant islands in this range. In relation to this, 29% of the dormant islands had between 11 and 100% mortality compared to half that amount for the nondormant islands.

There was a significant difference in mortality between slopes and gullies in June (Table 2.5). Eighty two percent of slope islands were in categories between 0 to 10% mortality while 65% of the gully islands were in these categories. There were half as many slope islands in the 11 to 100% mortality categories compared to gully islands. Further evidence of this trend was observed when the islands were inspected during the early part of the growing season. The gully islands appeared to have a higher percent mortality. However, by August there no longer was a noticeable or significant difference between the slopes and gullies.

The general increase in islands with low or no vegetation mortality and the subsequent decrease of islands in the higher mortality categories between June and August may be attributed to increased vegetation root establishment and associated nutrient and moisture uptake.

5.3.2 Vegetation island vigour

There was a significant difference in vigour in June between dormant and nondormant islands (Tables 2.6 to 2.8). There was a significantly larger percent of nondormant healthy (Category 3) vegetation islands than dormant islands and significantly less wilted, yellowed, abnormal (Category 2) nondormant islands. In August there was no longer a significant difference in vigour between dormant and nondormant vegetation islands. This increase in Category 3 (healthy vegetation) and a corresponding reduction in Category 2 islands may have been due to an increase in transplanted vegetation rooting into the surrounding soil. The increased root mass would possibly assist the plants in attaining available nutrients and moisture from the surrounding amended soil resulting in more islands having a higher vigour.

There was a significant difference in vigour in both June and August between gullies and slopes (Table 2.9). In both June and August there were significantly more healthy (Category 3) islands located on the slopes than on the gullies. A similar corresponding trend between slopes and gullies could be determined from the Category 2 island data. There were significantly fewer Category 2 islands on the slopes compared to the gullies. In both June and August there were approximately twice as many Category 2 islands on the gullies as on the slopes. The greater vegetation vigour on the slopes may be due in part to more hours of direct sunlight; the slopes received approximately 4 to 5 h more direct sunlight per day during the growing season than the more shaded gullies. Increased vigour from June to August may have also been due to an increase in vegetation rooting and soil nutrient uptake as the islands established and roots spread to the surrounding soil. Overall increased vigour is not likely due to increased soil moisture as soil moisture generally tended to decrease as the growing season progressed. Volumetric soil moisture content was approximately 38% at the end of April 1998 and decreased to approximately 16% by the beginning of September 1998; vigour was last recorded in mid August 1998.

The discrepancy between total number of islands in June compared to August in the mortality and vigour tables was due to the inability to locate some identifying tags in June. However, before the August count a metal detector was used to locate the soil covered tags.

5.4 Vegetation Species Success

Plant species diversity increased between June and August. In June approximately 70 species were identified, this number had increased to approximately 100 identified species in August (Appendix Tables 4 to 19). There was a trend evident in all dormant and nondormant gullies and slopes toward an increase in grass/sedge densities and a general decreasing trend in forb and shrub/tree densities (Tables 2.10 and 2.11). Sod forming grasses such as *Poa*, (dominated in quantity as of September 1998) can be very aggressive, forming a dense canopy cover thereby temporarily outcompeting shade intolerant forbs, shrubs and trees. This can be a relatively short term seral stage in a successional pathway. Long term monitoring (such as 5 and 10 year monitoring) is recommended to determine successional trends in species densities.

Competition may take place between grass species within the islands and other species establishing along island edges and on bare soil. Island peripheries and bare soil areas between islands may provide a favourable environment for more shade intolerant species; competition for light and nutrients may not be as intense in these areas thereby fostering the establishment of various species unable to compete within a grass dominated island. If broad comparisons are inferred between plant community(ies) at the study site and grass dominated communities within the Park, long term successional tendencies within the Park have often been toward a latter successional stage of shrubs, aspen and/or conifers. The Reference site, located on a similar slope, may indicate what a future seral stage may resemble on the terraced site.

Long term succession may progress from grasses to a greater density of shrubs with an understory of forbs as more shrubs become established. Grasses are generally shade intolerant and as shrubs become established the grass species may decrease in density in favour of more shade tolerant forbs. A plentiful saskatoon and choke cherry seed source exists above the terraced site; seeds have been observed accumulating on the terraces below. It is likely that over time these seeds will germinate and shrubs will become established. At present roses proliferate among the existing *Bromus* and *Elymus* grasses in the lower slopes below the terraced sections. The rhizomatous roses will likely form new shoots and establish competitive shrubs within the terraces. *Elymus* and *Bromus* are however, very invasive and similarly rhizomatous, evidenced by their prolific vegetative growth and invasion into the terraces during the 1997 and 1998 growing seasons. The competition for resources among species could be intense if controlling measures are not implemented.

By the completion of the 1998 growing season smooth brome (*Bromus inermis)* had established in large quantities below the terraced section adjacent to the lakeshore and was observed to be spreading into the terraced area. There was also an increase of Canada thistle (*Circium arvense*) into the terraced sections from below. Hand roguing as opposed to herbicide treatment was used to control invasion. Although this invasion could be considered part of natural succession, the presence of the these aggressive nonnative species is not in keeping with the Park mandate of fostering native species. An ongoing program to control these nonnative species will be necessary to prevent their further proliferation and encroachment onto the site.

5.4.1 Transplanted shrub and tree success

Following transplanting, many forb and shrub/tree species did not continue to prosper to the extent that grass/sedge species did when comparing overall increases and decreases in vegetation categories (Table 2.11). This may be due to the inability of shrub species to cope with severe root disturbance. Many transplanted shrubs appeared to have one major horizontal or vertical root of significant diameter that was often severed relatively close to the plant. For example, shrubs/trees situated in the centre of a 20 cm diameter plug would have approximately 10 cm of lateral root or at most 20 cm of vertical root attached to re-establish following transplanting. This may not be an adequate root system in comparison to its established pre-transplant root system required to provide nutrient and water uptake demands.

5.4.2 Watering, ambient temperature and transplanting stress

Watering nondormant vegetation islands immediately following transplanting appeared to reduce initial leaf wilting which was assumed to be a symptom associated with transplanting stresses. Comparisons between the initial nondormant islands not watered until the following day to those watered immediately after transplanting did not reveal any indication of severe plant stress, using leaf wilt as an indicator. No long term effects between the various slopes due to a difference in initial watering were observed during the 1998 growing season.

No long term stress caused by transplanting during relatively high day time temperatures could be observed. Temperatures ranged from 27 to 32 °C under sunny conditions while transplanting the nondormant islands. In comparison, anecdotal evidence recommends horticultural plants only be transplanted on cool, cloudy days to minimise transplanting stress related mortality.

6.0 CONCLUSIONS

This study determined that transplanting dormant and nondormant vegetation islands on a terraced site in the Aspen Parkland was successful. However, there was a significant difference in mortality between dormant and nondormant 20 cm diameter vegetation islands transplanted on the Astotin Lake location. Nondormant islands had significantly lower vegetation mortality (10% or less) than did dormant islands on both slopes and gullies. Initially in June, comparisons between slopes and gullies indicated that slopes had significantly more islands with 10% or less vegetation mortality than did gullies. However, by August there no longer was a significant difference in island vegetation mortalities between gullies and slopes.

Vigour was significantly greater in June than August, with more vigorous (healthy appearing) plants, on nondormant islands. However, by August there was no longer a significant difference between dormant and nondormant transplants. There was a high percentage of both healthy dormant and nondormant islands. There were significantly more healthy, vigorous islands on slopes compared to gullies and this trend did not change by the end of the study. Species diversity increased between June and August 1998. During this time only grass and sedge species density increased while forb and shrub/tree species densities diminished in all situations.

Volumetric soil moisture was significantly different among all 3 positions within terraces, being lowest at the front (board) position and highest at the rear. There was also a significant difference in volumetric moisture content among slope positions; the lower position being driest grading to wettest in the upper position.

Visually, eroded soil transportation downslope was greatly reduced by terracing and introduction of vegetation islands to the terraces. The previous rate of soil transported to Astotin Lake appears to have been greatly reduced. However, erosion of gully and slope wall faces continues. If complete erosion prevention is required alternate prevention methods may be required.

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Table 2.1: Mortality of slope dormant and nondormant vegetation islands in June 1998

	Quantity of dormant island mortalities							
	0%	1 to 5%	6 to 10%	11 to 40%	41 to 90%	91 to 99%	100%	Total islands
Slope A	24.0	43.0	14.0	19.0	8.0	0.0	0.0	
Slope B	5.0	8.0	6.0	6.0	0.0	0.0	0.0	
Slope C	18.0	50.0	20.0	21.0	5.0	0.0	0.0	247.0
Mean	14.5	25.5	10.0	12.5	4.0	0.0	0.0	
Standard deviation	9.7	22.5	7.0	8.1	4.0	0.0	0.0	
% of total	19.0	40.9	16.2	18.6	5.3	0.0	0.0	
	Quantity of nondormant island mortalities							
	0%	1 to 5%	6 to 10%	11 to 40%	41 to 90%	91 to 99%	100%	
Slope A	34.0	38.0	9.0	8.0	3.0	0.0	0.0	
Slope B	11.0	8.0	0.0	0.0	0.0	0.0	0.0	
Slope C	14.0	59.0	9.0	10.0	3.0	1.0	0.0	207.0
Mean	19.7	35.0	6.0	6.0	2.0	0.3	0.0	
Standard deviation	12.5	25.6	5.2	5.3	1.7	0.6	0.0	
% of total	28.5	50.7	8.7	8.7	2.9	0.5	0.0	

Note: There were significantly more nondormant islands in the 0%, 1 to 5% and 6 to 10% categories than in the dormant islands within the same categories (alpha = 0.05)

There were significantly fewer nondormant islands in the 11 to 40%, 41 to 90 %, 91 to 99% and 100% categories than in the dormant categories (alpha = 0.05)

Table 2.2: Mortality of slope dormant and nondormant vegetation islands in August 1998

	Quantity of dormant island mortalities							
	0%	1 to 5%	6 to 10%	11 to 40%	41 to 90%	91 to 99%	100%	Total islands
Slope A	35.0	31.0	12.0	31.0	4.0	0.0	0.0	
Slope B	7.0	6.0	3.0	9.0	0.0	0.0	0.0	
Slope C	34.0	46.0	11.0	22.0	2.0	0.0	0.0	253.0
Mean	25.3	27.7	8.7	20.7	2.0	0.0	0.0	
Standard deviation	15.9	20.2	4.9	11.1	2.0	0.0	0.0	
% of total	30.0	32.8	10.3	24.5	2.4	0.0	0.0	
	Quantity of nondormant island mortalities							
	0%	1 to 5%	6 to 10%	11 to 40%	41 to 90%	91 to 99%	100%	
Slope A	52.0	23.0	8.0	6.0	3.0	1.0	0.0	
Slope B	12.0	6.0	1.0	0.0	0.0	0.0	0.0	
Slope C	46.0	31.0	10.0	6.0	1.0	0.0	1.0	
Mean	36.7	20.0	6.3	4.0	1.3	0.3	0.3	207.0
Standard deviation	21.6	12.8	4.7	3.5	1.5	0.6	0.6	
% of total	53.1	29.0	9.2	5.8	1.9	0.5	0.5	

Note: There were significantly more nondormant islands in the 0%, 1 to 5% and 6 to 10% categories than in the dormant islands within the same categories (alpha = 0.05)

There were significantly fewer nondormant islands in the 11 to 40%, 41 to 90 %, 90 to 99% and 100% categories than in the dormant categories (alpha = 0.05)

Table 2.3: Mortality of gully dormant and nondormant vegetation islands in June 1998

	Quantity of dormant island mortalities							
	0%	1 to 5%	6 to 10%	11 to 40%	41 to 90%	91 to 99%	100%	
Gully 1	13.0	17.0	14.0	23.0	5.0	7.0	1.0	
Gully 2	5.0	9.0	6.0	9.0	7.0	0.0	0.0	
Gully 3	8.0	21.0	10.0	12.0	3.0	2.0	0.0	172.0
Mean	8.7	15.7	10.0	14.7	5.0	3.0	0.3	
Standard deviation	4.0	6.1	4.0	7.4	2.0	3.6	0.6	
% of total	15.1	27.3	17.4	25.6	8.7	5.2	0.6	

	Quantity of nondormant island mortalities							
	0%	1 to 5%	6 to 10%	11 to 40%	41 to 90%	91 to 99%	100%	
Gully 1	19.0	24.0	7.0	23.0	5.0	1.0	1.0	
Gully 2	2.0	7.0	2.0	9.0	5.0	0.0	0.0	
Gully 3	17.0	31.0	4.0	3.0	0.0	0.0	0.0	160.0
Mean	12.7	20.7	4.3	11.7	3.3	0.3	0.3	
Standard deviation	9.3	12.3	2.5	10.3	2.9	0.6	0.6	
% of total	23.8	38.8	8.1	21.9	6.3	0.6	0.6	

Note: There were significantly more nondormant islands in the 0%, 1 to 5% and 6 to 10% categories than in the dormant islands within the same categories (alpha = 0.05)

There were significantly fewer nondormant islands in the 11 to 40%, 41 to 90%, 91 to 99% and 100% categories than in the dormant categories (alpha = 0.05)

Table 2.4: Mortality of gully dormant and nondormant vegetation islands in August 1998

	Quantity of dormant island mortalities							
	0%	1 to 5%	6 to 10%	11 to 40%	41 to 90%	91 to 99%	100%	Total islands
Gully 1	19.0	29.0	6.0	17.0	5.0	2.0	2.0	
Gully 2	10.0	15.0	1.0	6.0	4.0	0.0	0.0	
Gully 3	25.0	9.0	7.0	14.0	0.0	0.0	0.0	171.0
Mean	18.0	17.7	4.7	12.3	3.0	0.7	0.7	
Standard deviation	7.5	10.3	3.2	5.7	2.6	1.2	1.2	
% of total	31.6	31.0	8.2	21.6	5.3	1.2	1.2	
	Quantity of nondormant island mortalities							
	0%	1 to 5%	6 to 10%	11 to 40%	41 to 90%	91 to 99%	100%	
Gully 1	18.0	36.0	15.0	11.0	2.0	0.0	0.0	
Gully 2	11.0	9.0	0.0	6.0	0.0	0.0	0.0	
Gully 3	30.0	12.0	10.0	5.0	0.0	0.0	0.0	165.0
Mean	19.7	19.0	8.3	7.3	0.7	0.0	0.0	
Standard deviation	9.6	14.8	7.6	3.2	1.2	0.0	0.0	
% of total	35.8	34.5	15.2	13.3	1.2	0.0	0.0	

Note: There were significantly more nondormant islands in the 0%, 1 to 5% and 6 to 10% categories than in the dormant islands within the same categories (alpha = 0.05)

There were significantly fewer nondormant islands in the 11 to 40%, 41 to 90%, 91 to 99% and 100% categories than in the dormant categories (alpha = 0.05)

Table 2.5: Mortality of all vegetation islands within all slopes and gullies in June and August 1998

	Quantity of island mortalities in June						
	0%	1 to 5%	6 to 10%	11to 40%	41 to 90%	91 to 99%	100%
Gully vegetation island quantity	64	109	43	79	25	10	2
Gully percent of islands	19.3	32.8	13.0	23.8	7.5	3.0	0.6
Slope vegetation island quantity	106	206	43	79	19	1	0
Slope percent of islands	23.4	45.4	13.0	23.8	14.2	0.2	0.0

	Quantity of island mortalities in August						
	0%	1 to 5%	6 to 10%	11 to 40%	41 to 90%	91 to 99%	100%
Gully vegetation island quantity	113	110	39	59	11	2	2
Gully percent of islands	33.6	32.7	11.6	17.6	3.3	0.6	0.6
Slope vegetation island quantity	186	143	45	74	10	1	1
Slope percent of islands	40.4	31.1	9.8	16.1	2.2	0.2	0.2

Note: There were significantly more June slope vegetation islands in the 0%, 1 to 5%, and 6 to 10% mortality categories than in the gully vegetation islands in the same categories (alpha = 0.05)

There was no significant difference in August between slope and gully vegetation mortality (alpha = 0.05)

Table 2.6: Vigour of all slope dormant and nondormant vegetation islands in June and August 1998

Vigour of all slope dormant vegetation islands

	Vigour categories for June				Vigour categories for August			
	1	2	3	Total	1	2	3	Total
Slope A	0.0	13.0	95.0		0.0	6.0	107.0	
Slope B	0.0	1.0	24.0		0.0	0.0	25.0	
Slope C	0.0	6.0	108.0	247.0	0.0	3.0	112.0	253.0
Mean	0.0	6.7	75.7		0.0	3.0	81.3	
Standard deviation	0.0	6.0	45.2		0.0	3.0	48.9	
% of total	0.0	8.1	91.9		0.0	3.6	96.4	

Vigour of slope nondormant vegetation islands

	Vigour categories for June				Vigour categories for August			
	1	2	3	Total	1	2	3	Total
Slope A	0.0	4.0	88.0		1.0	1.0	91.0	
Slope B	0.0	0.0	19.0		0.0	0.0	19.0	
Slope C	1.0	5.0	90.0	207.0	1.0	3.0	91.0	207.0
Mean	0.3	3.0	65.7		0.7	1.3	67.0	
Standard deveation	0.6	2.6	40.4		0.6	1.5	41.6	
% of total	0.5	4.3	95.2		1.0	1.9	97.1	

Note: Category 1 indicates complete vegetation death within the island

Category 2 indicates that the majority of vegetation was wilted, yellowed, abnormally colored, dead and/or had apparent less than normal new growth

Category 3 indicates normal color, lack of wilting and normal appearing new growth

Table 2.7: Vigour of gully dormant and nondormant vegetation islands in June and August 1998

Vigour of gully dormant vegetation islands

	Vigour categories for June				Vigour categories for August			
	1	2	3	Total	1	2	3	Total
Gully 1	1.0	14.0	64.0		2.0	10.0	68.0	
Gully 2	0.0	7.0	30.0		0.0	6.0	33.0	
Gully 3	0.0	12.0	44.0	172.0	0.0	2.0	56.0	177.0
Mean	0.3	11.0	46.0		0.7	6.0	52.3	
Standard deviation	0.6	3.6	17.1		1.2	4.0	17.8	
% of total	0.6	19.2	80.2		1.2	10.2	88.7	

Vigour of gully nondormant vegetation islands

	Vigour categories for June				Vigour categories for August			
	1	2	3	Total	1	2	3	Total
Gully 1	1.0	6.0	69.0		0.0	4.0	77.0	
Gully 2	0.0	3.0	26.0		0.0	4.0	27.0	
Gully 3	0.0	1.0	54.0	160.0	0.0	0.0	54.0	166.0
Mean	0.3	3.3	49.7		0.0	2.7	52.7	
Standard deviation	0.6	2.5	21.8		0.0	2.3	25.0	
% of total	0.6	6.3	93.1		0.0	4.8	95.2	

Note: Category 1 indicates complete vegetation death within the island
Category 2 indicates that the majority of vegetation was wilted, yellowed, abnormally colored, dead and/or had apparent less than normal new growth
Category 3 indicates normal color, lack of wilting and normal appearing new growth

Table 2.8: Vigour of all dormant islands compared to nondormant islands in June and August 1998

	Vigour categories in June			Vigour categories in August		
	1	**2**	**3**	**1**	**2**	**3**
Dormant quantity of islands	1	53	365	2	27	394
Dormant percent of islands	0.2	12.7	87.1	0.5	6.4	93.1
Nondormant quantity of islands	2	19	346	2	12	356
Nondormant percent of islands	0.5	5.2	94.3	0.5	3.2	96.2

Note: There was a significant difference between dormant and nondormant islands in June (alpha = 0.05)
There was no significant difference between nondormant and dormant islands in August (alpha = 0.05)

Table 2.9: Vigour of all gullies compared to all slopes in June and August 1998

	Vigour categories in June			Vigour categories in August		
	1	**2**	**3**	**1**	**2**	**3**
Gully quantity of islands	2	43	287	2	26	305
Gully percent of islands	0.6	13.0	86.5	0.6	7.8	91.6
Slope quantity of islands	1	29	424	2	13	445
Slope percent of islands	0.2	6.4	93.4	0.4	2.8	96.7

Note: There was a significant difference between slopes and gullies in both June and August (alpha = 0.05)

Table 2.10: Mean gully and slope plant quantities in June and August 1998

Dormant gullies	Mean August quantity	Mean June quantity	Mean difference
Grasses/Sedges	867.0	504.0	363.0
Forbs	195.7	316.7	-121.0
Shrubs/Trees	136.0	169.7	-33.7
Nondormant gullies			
Grasses/Sedges	1448.0	782.3	665.7
Forbs	174.0	297.7	-123.7
Shrubs/Trees	117.0	155.0	-38.0
Dormant slopes			
Grasses	1507.7	804.3	703.3
Forbs	401.0	580.0	-179.0
Shrubs/Trees	160.7	201.0	-40.3
Nondormant slopes			
Grasses/Sedges	1941.3	1391.7	549.7
Forbs	325.0	547.7	-222.7
Shrubs/Trees	119.7	162.3	-42.7

Table 2.11: Overall mean gully and slope plant quantities in June and August 1998

Total gullies	Mean August quantity	Mean June quantity	Mean difference
Grasses/Sedges	1157.5	643.2	514.3
Forbs	184.8	307.2	-122.3
Shrubs/Trees mean	126.5	162.3	-35.8
Total slopes			
Grasses/Sedges	1724.5	1098.0	626.5
Forbs	363.0	563.8	-200.8
Shrubs/Trees	140.2	181.7	-41.5

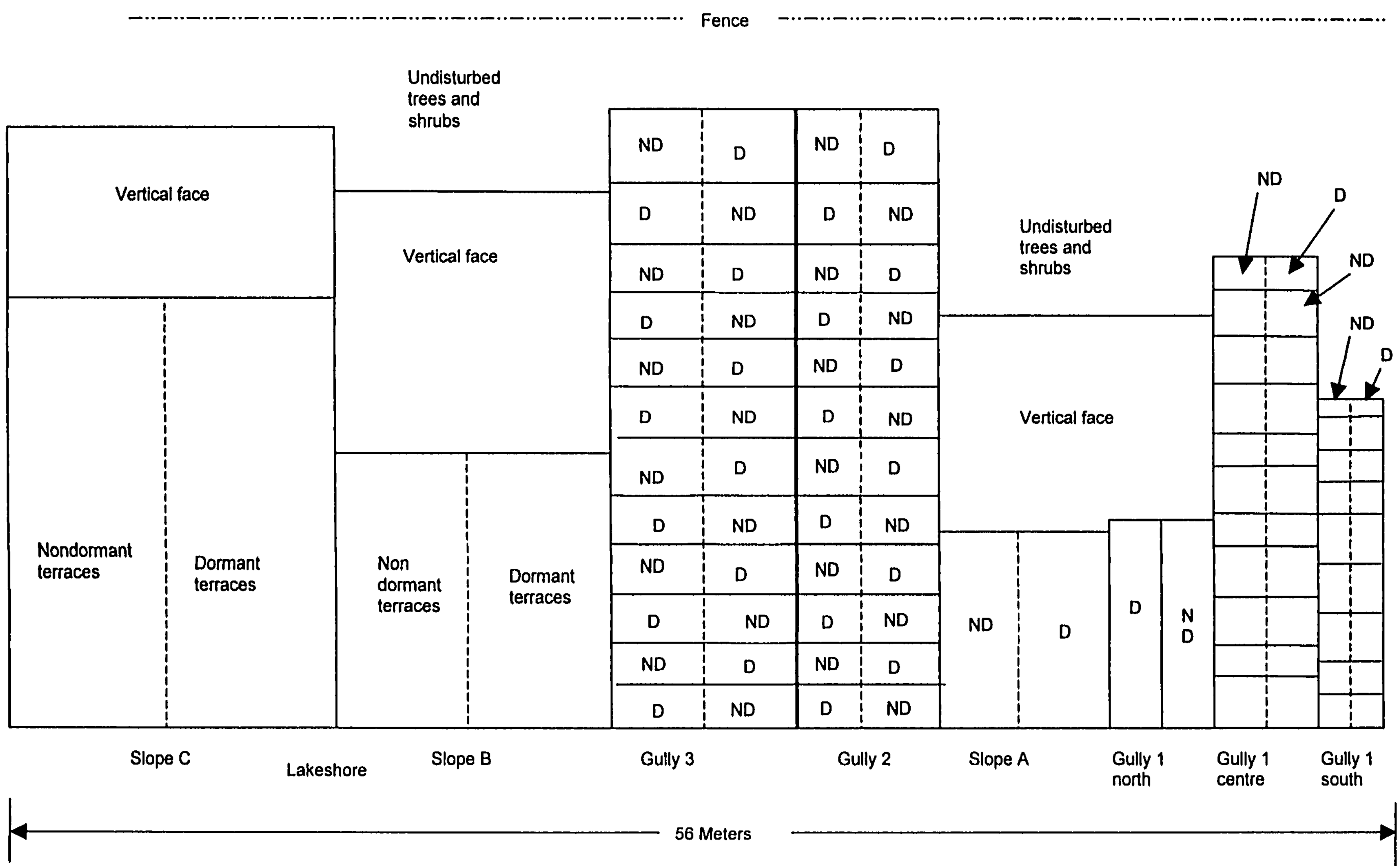

Figure 2.1: Site map indicating dormant and nondormant vegetation island plantings on terraces in 1997 (not to scale)

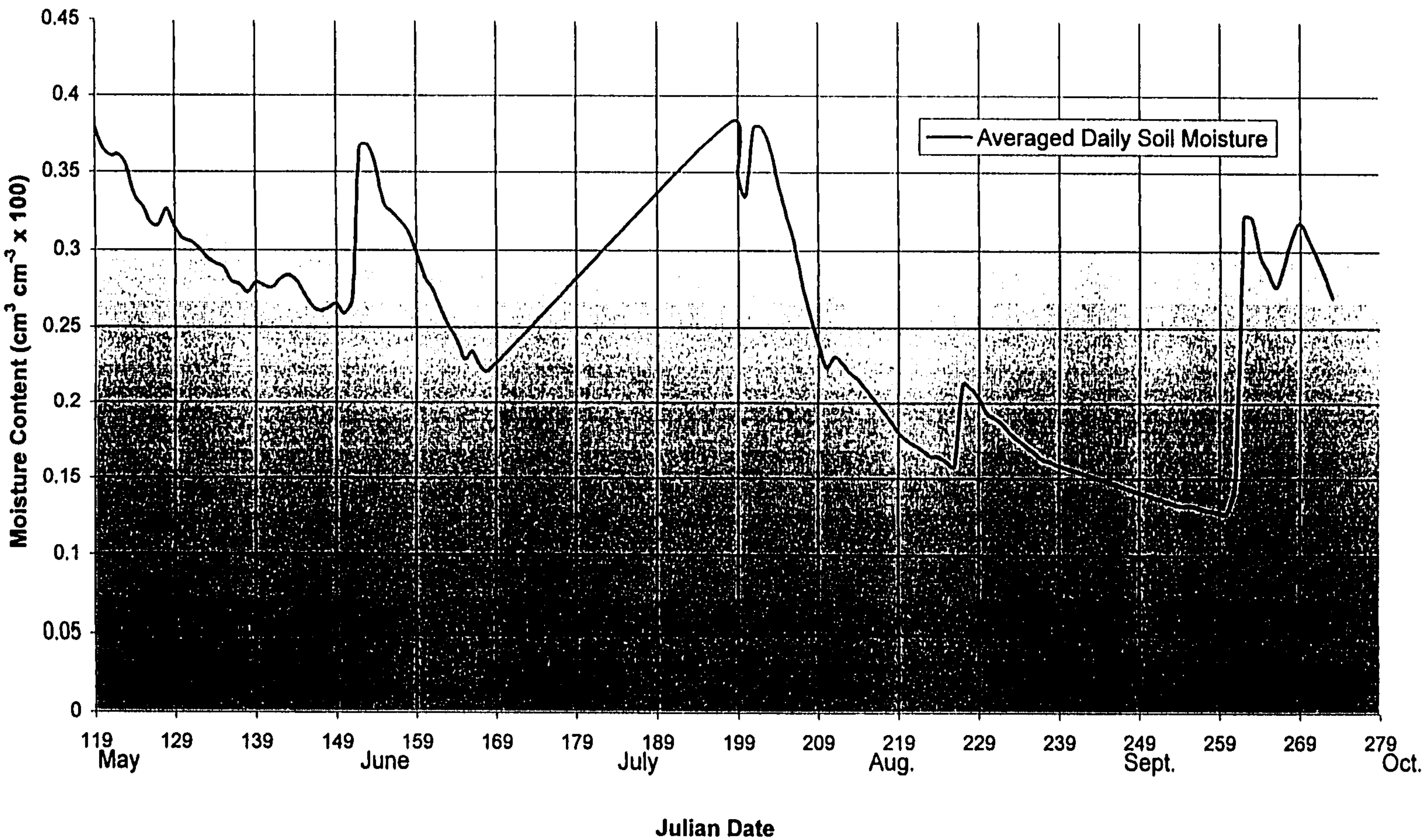

Figure 2.2 : Average daily soil moisture (0 to 20 cm depth) during 1998 growing season
(No data recorded for Julian days 169 to 197 and 240 to 253)

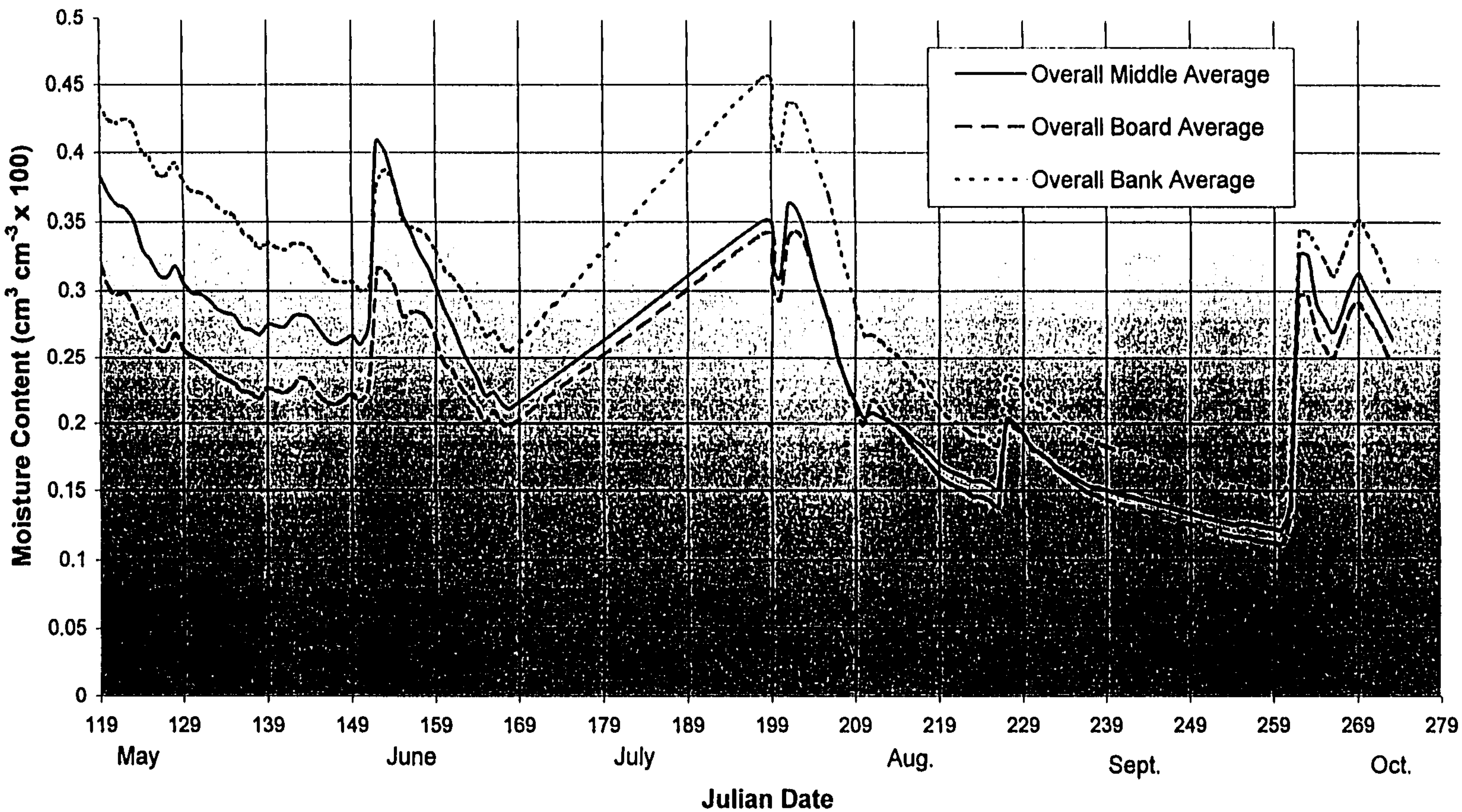

Figure 2.3: Average daily soil moisture (0 to 20 cm depth) categorised by probe position within terrace
(No data recorded for Julian days 169 to 197 and 240 to 253)
Note: Each position mean is significantly different from the others (alpha = 0.05)

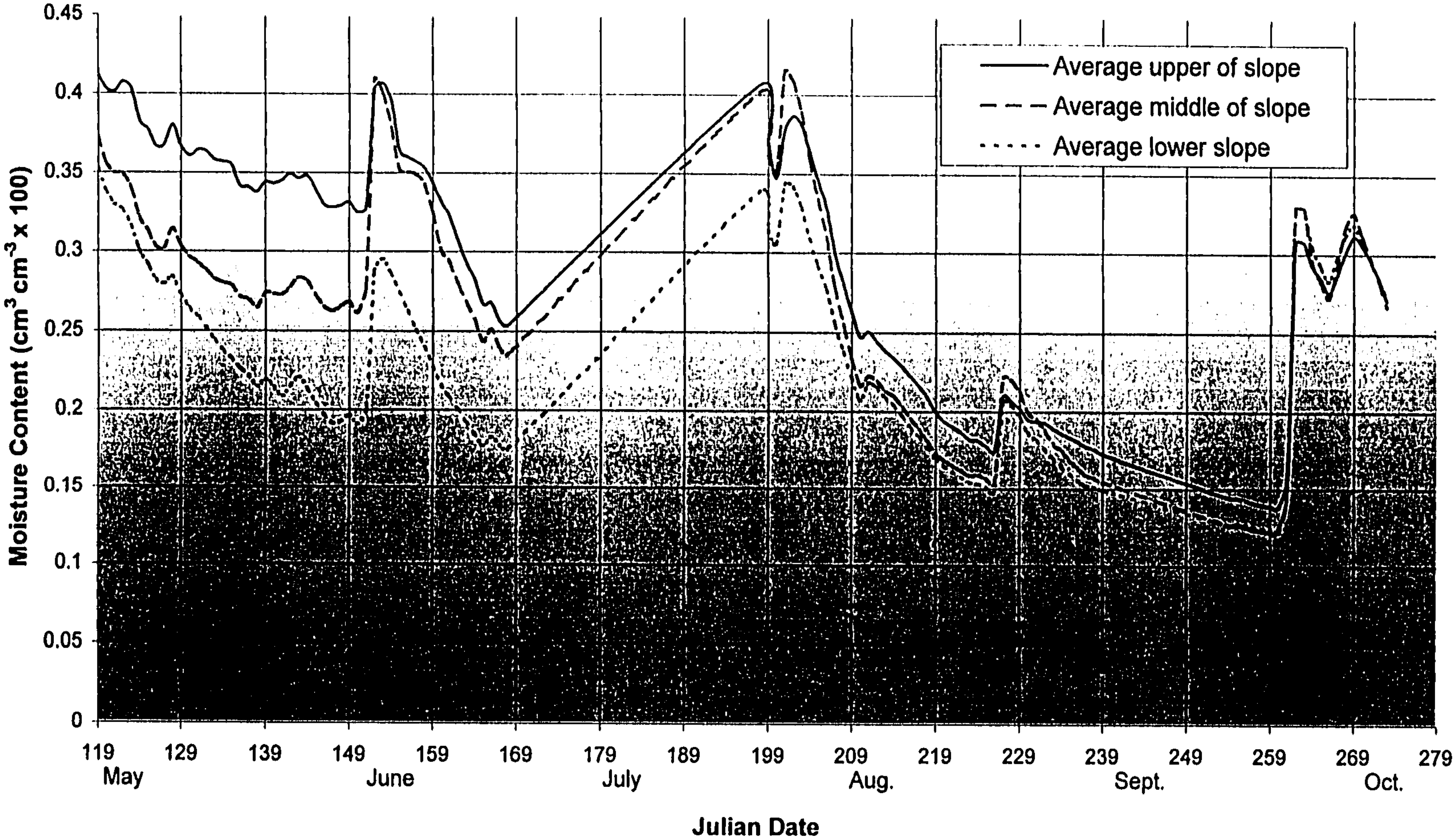

Figure 2.4: Average daily soil moisture (0 to 20 cm depth) categorised by terrace position on slope
(No data recorded for Julian days 169 to 197 and 240 to 253)
Note: Each position mean is significantly different from the others (alpha = 0.05)

CHAPTER III LIVE STAKING OF A LAKESHORE SLOPE USING WILLOWS

1.0 INTRODUCTION

Specific slopes may not be suited to terracing due to various conditions including extreme slope angles or soil instability. In these situations live staking may be initiated. Live staking involves insertion of live rootable vegetative cuttings into the soil. Under adequate growing conditions these stakes will root and leaf out and the expanding root mass will in time help anchor the soil (Gray and Sotir 1996). Preferably, the cuttings should be 1.5 to 4 cm in diameter and 40 to 60 cm long and be driven into the soil with not more than a quarter of their length exposed (Gray and Sotir 1996). The thicker the cuttings the greater the food reserves (Gray and Leiser 1982). Two to 4 cuttings should be placed per square meter (Gray and Sotir 1996). Thirty to 50% plant loss under ideal conditions is common with this method (Schiechtl 1980). Numerous shrub species including willow (*Salix* sp), choke cherry (*Prunus virginiana* L.) and saskatoon (*Amalanchier alnifolia* Nutt.) may be used for live staking depending on availability.

Vegetation surveys will often indicate that willows occur primarily in wet areas. Willows naturally reproduce from short-lived seed that must be in contact with moisture in late spring or early summer and therefore seem to propagate in wet areas. However, a study by Kraebel (1936) indicates that willow cuttings from the species (*Salix lemmonii*) could grow in xeric mountainous terrain of Southern California.

2.0 RESEARCH OBJECTIVES

Published scientific literature documenting that transplanting is not equally effective during times other than early spring or late autumn is not available for the Canadian Parkland. This research will determine whether transplanting time is crucial to plant survival and development and if live staking can augment the stabilisation of severely eroded slopes. Therefore, the goal of this research is to reclaim a hillside ecosystem which will provide a hospitable native plant and animal environment that is aesthetically pleasing while stabilising soil conditions and minimising soil erosion.

The objectives of this research are:

- To determine if live stakes can survive and propagate when planted at two different times during their annual life cycle, namely during mid August during plant growth and in mid October after all visible green plant growth has terminated.
- To determine if gully and slope position are associated with live stake survival and propagation.

3.0 RESEARCH SITE

3.1 Research Site Location and Dimensions

The reclamation study site is located in Elk Island National Park which is 37 km east of Edmonton along Highway 16 in central Alberta. The Park is 22.5 km north-south and 10 km east-west with an area of approximately 19,680 hectares (Crown 1977). The study slope is situated along the eastern shoreline of Astotin Lake which is located near the north end of the Park. The eroded bank study site is located at 53° 40' 33" N Latitude and 112° 49' 52" W Longitude.

The study slope is within the fenced recreation area north of the sandy beach and is situated below the historic picnic shelter, known as the Pavilion. This area has been ecologically unstable for decades; producing barren eroded slopes. Park archival and aerial photographs indicate that this site has been eroding for at least 30 years. The eroded site is approximately 60 m long and is situated on a west facing sparsely vegetated, steep, eroded slope located between the lake shoreline and the Pavilion above. There are three main gullies each approximately 13 m from top to bottom. Portions of the higher slope are vertical, naturally devoid of vegetation and continually exfoliating and slumping soil due to water erosion. The sparsely vegetated less steep sections vary in inclination between 28 and 38 degrees.

3.2 Climate

The Park receives approximately 20% more precipitation than either the Aspen Parkland ecoregion which surrounds it or the Mid Boreal Mixedwood ecoregion located further north (Geowest Env. 1994). Average annual precipitation monitored from 1981 to 1993 (most recent data available) within the Park averages 524 mm with approximately 405 mm falling as rain during the growing season of May through September. Overwinter long term average precipitation between November 1 and March 31 is approximately 78 mm. The highest mean monthly maximum temperature occurs in July at 22 °C and the lowest mean monthly minimum temperatures occur during January and February at –17 °C (Environment Canada 1994).

3.3 Vegetation

Elk Island National Park is situated in an ecotone or transition zone where Parkland and Boreal forest species both can be found (Strong and Leggat 1992). This area or ecotone can often be identified by a greater plant species diversity than is found in either of the individual adjoining communities (Holland et al. 1991).

The site is located in the Low Boreal Mixedwood Ecoregion which is dominated by aspen (*Populus tremuloides* Michx.) and balsam poplar (*Populus balsamifera* L.) with succession to white spruce (*Picea glauca* (Moench) Voss) (Strong and Leggat 1992). The shrub understory is often dominated by prickly rose (*Rosa acicularis* Lindl.) and beaked hazelnut (*Corylus cornuta* Marsh.). Various grass species are also present with a portion being agronomic species including smooth brome (*Bromus inermis* Leyss.) and timothy (*Phleum pratense* L.) (Geowest Env. Ltd. 1994). Native species include western wheat grass (*Agropyron smithii* Rydb.), fringed brome (*Bromus ciliatus* L.), fowl bluegrass (*poa palustris* L.) and slender wheat grass (*Agropyron trachycaulum* (Link) Malte).

4.0 MATERIALS AND METHODS

4.1 Experimental Design and Data Analysis

The statistical design chosen was a 2 factor replicate design incorporating slope/gully and dormant/nondormant plantings as the two factors. Statistical tests were implemented using categorical data analysis. A significant difference referred to in the following results and discussion section, indicates a statistically significant difference at the 0.05 significance level ($\alpha = 0.05$).

4.2 Species Selection and Installation

Beaked willow (*Salix bebbiana* Sarg.) was selected for live staking on the gully sides too steep to terrace and on the steep slope sections adjacent to the vertical walls. This species was chosen due to its abundance within the Park, adequate stem and branch dimensions, evidence of growth in upland sites (relatively dry) and ease of rooting. Other species such as choke cherry (*Prunus virginiana* L.) and saskatoon (*Amelanchier alnifolia* Nutt.) were considered but not used due to a very limited supply of usable donor shrubs.

During mid August 1997 relatively straight live stems/branches approximately 40 to 60 cm long and 1.5 to 4 cm in diameter were cut from existing willow thickets within a 2 km radius of the research site. All smaller branches were carefully cut from the stems/branches to avoid bark damage and one end sharpened to make insertion easier. These stakes were then stored with the sharpened end submersed in water until installed (maximum 2 h time lag) to limit desiccation. Care was taken to limit stem/branch removal to less than 15% of the original stems to minimise stress to the existing thicket.

A 1 cm diameter steel rod was first driven into the soil approximately 50 cm deep to create a pilot hole capable of a friction fit. The willow stake was inserted and driven in with a dead blow hammer leaving between 10 and 20 cm above the surface. Using a dead blow hammer reduced hammer rebound, stake shattering and was more energy efficient than using a steel sledge hammer. Any split or shattered top wood was trimmed off to reduce desiccation of the remaining wood.

4.3 Nondormant Staking

Stake positioning and density varied between 2 and 4 per square meter. The overall planting pattern on the 3 gullies was alternated between upper and lower half with dormant and nondormant stakes (Figure 3.1). Gully walls faced north and south. Due to the south gully face (north aspect) being in virtually constant shade nondormant stakes were planted on both north and south aspects of each gully alternating with the lower half of Gully 3, the upper half of Gully 2 and the lower half of Gully 1. This configuration was implemented to assist in distinguishing potential differing growth response with slope aspect and position. One hundred and thirty two nondormant cuttings were planted in the gullies and 86 were planted on the slopes.

4.4 Dormant Live Staking

The above procedure was repeated in mid October 1997 after the willows had dropped their leaves and become dormant. An electric hammer drill and 1.5 cm bit were used to bore pilot holes in the soil before stake insertion. This was preferred when compared to the earlier method of using the steel pilot shaft which required a great deal more manual effort when driving and removing the shaft in the high bulk density soil (1.69 Mg m^{-3}). A lack of available 1.5 to 4 cm diameter stems necessitated the use of smaller diameter stakes with some approximately 1 cm in diameter. Soil was packed between the pilot hole wall and stake in situations where the hole was larger than a friction fit with the stake. Stake positioning on both slopes and gullies alternated opposite the nondormant stakes previously planted. One hundred and fifteen dormant cuttings were planted on the gully sidewalls and 73 were planted on the slopes.

4.5 Determination Of Stake Survival

Stake survival was determined by the presence of healthy green leaves on the stakes at the time of counting. Stakes with wilted or dry leaves were classed as dead.

4.6 Meteorological Data

Meteorological data including the most recent long term monthly mean precipitation, mean maximum and minimum temperatures recorded between 1981 and 1993 as well as daily precipitation from May 1997 to October 1998 were obtained from the Canadian Climate Centre (Environment Canada 1994).

4.6.1 On-site meteorological data collection

In late July 1997 two standard 100 mm tube style rain gauges were installed on the terraces to monitor on-site precipitation. No other instruments were installed during the 1997 growing season.

In late April 1998 an RT 2501 Sierra/MACA tipping bucket rain gauge, an air temperature sensor (to monitor maximum and minimum daily temperatures) and a relative humidity sensor were installed. These were all interconnected with a Campbell Scientific multiplexer into a Campbell Scientific CR 10 data recorder. A Solarex solar panel was used to maintain an adequate power supply to the 12 volt data recorder battery. Two conventional 100 mm tube style rain gauges were also set up at opposite ends of the site to verify precipitation amounts recorded by the tipping bucket gauge.

5.0 RESULTS AND DISCUSSION

During the warm autumn of 1997 which followed the August nondormant planting; leaves had emerged from approximately 20% of the nondormant cuttings stake buds. However, none of these stakes which leafed out in the autumn of 1997 survived the winter to leaf again in the spring.

By mid June 1998 34% of dormant slope stakes and 49% of the dormant gully stakes survived. Eighteen percent of nondormant slope stakes and 33% of nondormant gully stakes survived (Table 3.1).

In mid August 1998, all live stakes were once again examined for survivability. At this time live stake survivability was either very low or absent. Of the total 406 live stakes planted on both gullies and slopes none survived on the slopes, while 5 (1% of total) survived on the gully walls (Table 3.2). Three of the 132 nondormant cuttings survived on the gullies (3%) and 2 of the 115 dormant cuttings (2%) survived on the gully walls. No cuttings survived on the slopes. Due to the low survivability rates no statistical analysis was required.

The relatively high survivability recorded during the June count may be attributed to the stakes using stored nutrients to produce leaves. As these nutrients were consumed the mortality rate increased. Following the August count the majority of stakes previously exhibiting a leaf flush had become desiccated and no longer supported leaf growth. However, the remaining 5 stakes appeared to be flourishing. There does not appear to be any pattern regarding gully positioning, aspect, or stake diameter to help determine the most successful combination for stake survival. Soil moisture may have partially been a contributing factor to survivability, however, no soil moisture tests were conducted to substantiate this. Excess stakes which remained following both planting times were incorporated among the existing trees and shrubs at the top of the slopes. (These were not included in the 406 stakes planted). None of these stakes survived either yet there appeared to be sufficient moisture and nutrients to sustain existing vegetation.

There is no definite reason why the live stakes did not survive. A lack of adequate moisture, inappropriate tree species, too great a soil bulk density and/or inadequate available nutrients may be some contributing factors to the high stake mortality. Low survivability may have been a combination of these and other unsuspected factors. Anecdotal evidence similarly lacks claims of a reliable, repetitive and successful method for live staking.

6.0 CONCLUSIONS

Survival of 5 of the original 406 live stakes planted was not enough to reach any conclusion regarding survivability due to slope and gully positioning or dormant and nondormant planting times. The most apparent conclusion is that a very small percentage of willow stakes survived live staking. Numerous speculative possibilities exist regarding the low survivability rate. These include very high (1.69 Mg m^{-3}) soil bulk density, lack of soil nutrients, lack of available soil moisture and inappropriate willow species. Further research would be required to determine if any or all of the above factors or if additional factors are involved in the high mortality rates.

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Table 3.1: Willow (*Salix bebbiana*) survival rates on gullies during June and August 1998

	June	Quantity			August	Quantity	
Gully 1	Dormant	9		Gully 1	Dormant	0	
	Nondormant	21			Nondormant	2	
Gully 2	Dormant	6		Gully 2	Dormant	1	
	Nondormant	14			Nondormant	0	
Gully 3	Dormant	41		Gully 3	Dormant	2	
	Nondormant	9			Nondormant	0	
	Total dormant gully survival	56/115*	**49%**		**Total dormant gully survival**	3/115	**3%**
	Total nondormant gully survival	44/132	**33%**		**Total nondormant gully survival**	2/132	**2%**

* Number of surviving stakes/number of stakes planted

Table 3.2: Willow (*Salix bebbiana*) survival rates on slopes during June and August 1998

	June				August	Quantity	
Slope A	Dormant	10		Slope A	Dormant	0	
	Nondormant	6			Nondormant	0	
Slope B	Dormant	8		Slope B	Dormant	0	
	Nondormant	4			Nondormant	0	
Slope C	Dormant	7		Slope C	Dormant	0	
	Nondormant	6			Nondormant	0	
	Total dormant slope survival	25/75	**34%**		**Total dormant slope survival**	0/75	**0%**
	Total nondormant slope survival	16/86	**18%**		**Total nondormant slope survival**	0/86	**0%**

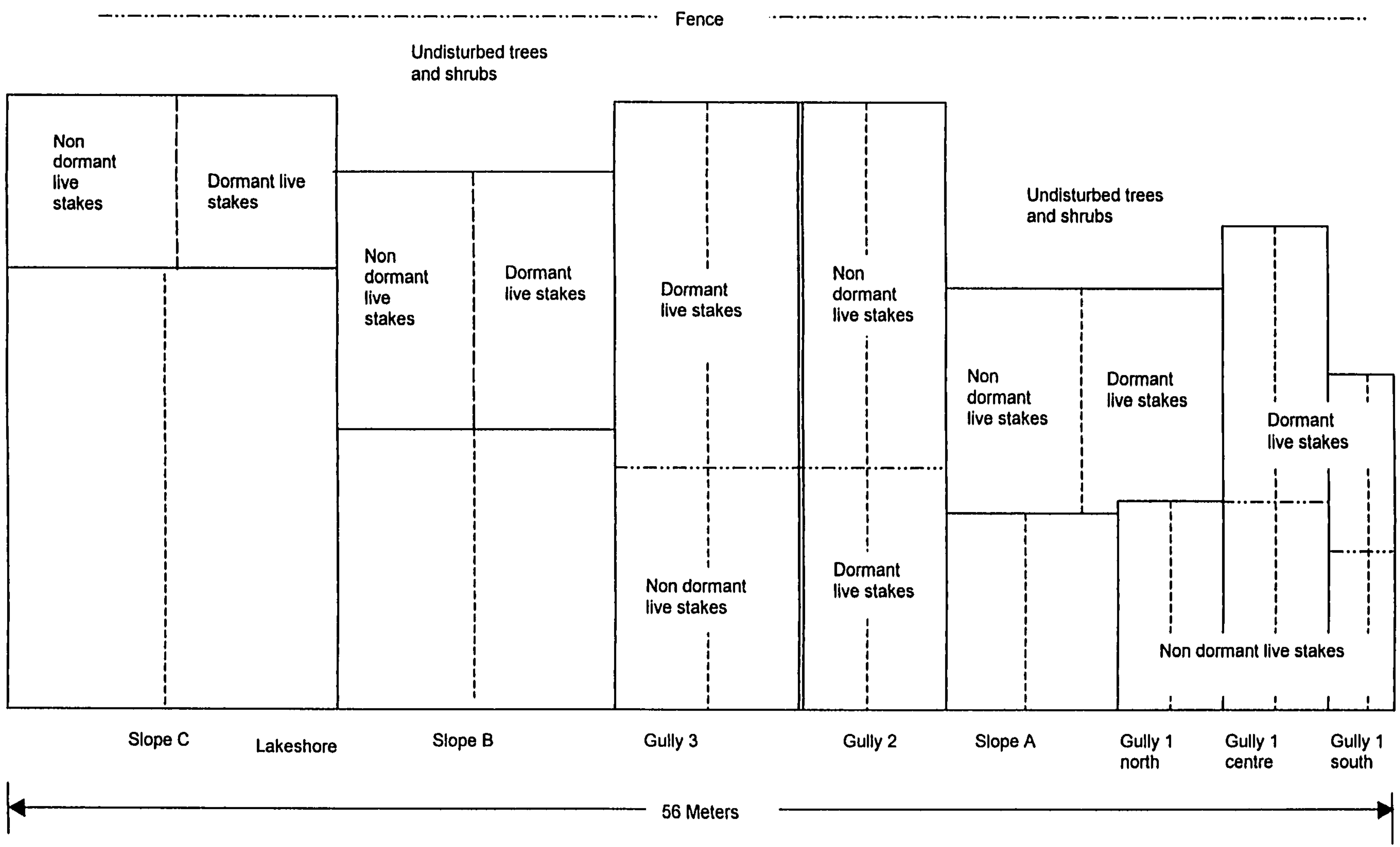

Figure 3.1: Live willow stake positioning on gullies and slopes in 1997 (not to scale)

CHAPTER IV SYNTHESIS

1.0 RESEARCH SUMMARY

This study determined that transplanting dormant and nondormant vegetation islands on a terraced site in the Aspen Parkland was successful. However, there was a significant difference in mortality between dormant and nondormant 20 cm diameter vegetation islands transplanted on the Astotin Lake location. Nondormant islands had significantly lower vegetation mortality (10% or less) than did dormant islands on both slopes and gullies. Initially in June, comparisons between slopes and gullies indicated that slopes had significantly more islands with 10% or less vegetation mortality than did gullies. However, by August there no longer was a significant difference in island vegetation mortalities between gullies and slopes.

Vigour was significantly greater in June, with more vigorous (healthy appearing) plants on nondormant islands. However, by August there was no longer a significant difference in vigour between dormant and nondormant transplants. There were significantly more healthy vigorous plants on slopes compared to gullies and this trend did not change by the end of the study.

Species diversity increased between June and August 1998 from approximately 70 species in June to approximately 100 in August. Grass and sedge species density increased while there was a decrease in forb and shrub/tree species densities in all combinations of position and planting times. The results from the live staking were inconclusive regarding dormant and nondormant planting times due to high stake mortality.

Volumetric soil moisture contents were significantly different among all 3 positions within terraces, being lowest at the board position and highest at the rear. There was also a significant difference in volumetric soil moisture content among slope positions; the lower position being driest and grading to wettest in the upper position.

The vegetation growth during the 1998 growing season was vigorous. In this study, covering approximately 40 to 50% of the terraced site with transplanted vegetation islands appeared to be adequate. Eventhough by the end of the 1998 growing season grasses were dominant, future succession may gravitate toward trees and shrubs, partially influenced by the abundance of the choke cherry and saskatoon seed source located on land directly above the terraced site. Fallen seeds may germinate and establish on the terraces providing shrub and tree cover and potentially outcompete shade intolerant species. This may become another phase of on-site successional vegetation development.

2.0 RECOMMENDATIONS AND OBSERVATIONS

The research results from this study provide evidence that transplanting nondormant vegetation islands on a terraced Aspen Parkland site is successful in establishing plant communities and can provide an essential component when reclaiming a relatively barren site. Information from this study can provide an incentive to use similar methods on future suitable reclamation sites. It could be speculated that transplanting vegetation islands when either in the dormant or nondormant state may be successful in the Aspen Parkland and the possibility of preferentially transplanting nondormant rather than dormant vegetation islands.

The use of vegetation islands with little or no grass may also be beneficial in decreasing competition thereby possibly increasing the survival of transplanted forbs and shrub/trees. However, donor sites adjacent to forested areas often consist of mid-seral plant communities containing high densities of shade intolerant grass species. Islands removed from under forest canopies may not survive; associated forest species are often shade tolerant and may not establish when transplanted on exposed sites. Grass devoid islands may be difficult to procure but locating donor areas in which invasive sod forming grass species are either not present or constitute a small percentage of total biomass is recommended when practical.

Although transplanting horticultural species is normally recommended only during cool, overcast days there appeared to be no observable difference in vigour or mortality between those native vegetation islands transplanted on hot (27 to 32 °C) sunny days and those transplanted on cooler days. Based on this observation it may not be necessary to transplant only on cooler days, thereby increasing the number of potential days suitable for transplanting native islands. Watering vegetation islands within the first day following transplanting is recommended to reduce initial transplanting stress if a water source is available. Watering not only provides moisture for essential plant life processes but also increases the soil/root contact by reducing large voids in the disturbed soil and may expedite amalgamation with the surrounding nutrient enhanced soil.

Vegetation counts undertaken in June and August did not include the surrounding existing vegetation outside the vegetation islands. If future counts are to be undertaken, the method used in this study may become increasingly arduous as surrounding vegetation either encroaches or vegetation spreads beyond the existing islands. In this situation it may be more prudent to use another form of measurement such as quadrats or line transects.

Live staking was not successful. This method should not be used on dry, steep sloped areas with high soil bulk densities. Developing a successful method of live staking dry sites would be greatly beneficial in the reclamation field. Live staking may be more successful on lower slope positions closer to a constant high soil moisture area such as along the lakeshore bank. The existing bank extending upslope several meters from the water edge is presently very unstable and is actively slumping into the lake. Large desiccation cracks due in part to lower lake levels and decreasing soil moisture content are present and continue to enlarge. The addition of live willow stakes in this area may assist in stabilising the bank. Backsloping the bank to less than the angle of repose may also decrease the tendency to slump. In addition, vegetation such as cattails (*Typha latifolia* L.) could be transplanted along the shoreline to decrease erosive wave action which at present is also partially responsible for bank erosion. Rocks (rip rap) could also be placed along the bank to reduce wave action. These could be transported and placed on the ice during the winter and would then become positioned following spring break-up.

Erosion on gully walls appears to be more severe than on vertical walls associated with the slopes. Rain appears to run off the vertical faces without saturating and loosening the soil, overhanging vegetation also shields and protects the vertical faces. Gully walls, less steeply sloped, have a tendency to absorb water, thereby saturating the top soil layer which eventually becomes detached and is transported downhill with the water. No recommendation can be suggested at present to reduce this phenomenon and thereby reduce soil erosion in this area.

It is not recommended to use results of one specific research project to extrapolate its results beyond the bounds of the immediate project. If these results are proven to be repeatable on a broader scale, it could increase the seasonal timeframe in which it is presently believed possible to successfully reclaim disturbed sites using transplanted vegetation islands. This would allow reclamation using vegetation islands to proceed throughout the growing season rather than be restricted to early spring and late autumn when working conditions are often less than ideal.

3.0 FUTURE RESEARCH

Future research could focus on using larger vegetation islands to determine whether island size has a significant effect on plant survival, particularly forbs and shrub/tree species. Less hostile environments may also produce differing growth results. Sites with reduced wind exposure and less direct sun exposure such as an east or north-east aspect may provide a more hospitable growing environment in which temperatures and soil moisture levels would remain more constant.

Varying the soil amendment volume may also be beneficial to study. Determining an optimum organic amendment volume when establishing vegetation islands on nutrient deficient C horizon soils could optimise both material and labour costs involved with amendment transportation and incorporation. Modifying the amendment volume, source and ultimately the nutrient combination and quantity may influence plant species growth responses and presumably direct plant community successional development depending on the desired outcome.

Qualitative observations indicated that slope terracing and vegetation islands contained runoff transported sediment within the terraces and substantially reduced sediment transport to the lake, although the extent could only be estimated. Increased snow trapping ability provided by the increased presence of vegetation will potentially increase the melt water available for infiltration, storage and subsequent plant use (depending on soil conditions at time of melt). Increased soil moisture may provide one of the essential elements necessary for successful site reclamation. Increased canopy cover from the transplanted vegetation will increase shading and may prevent drying due to evaporation, thereby possibly making more moisture available for plant uptake. Evapotranspiration will likely remove some of this soil moisture. The importance of soil moisture with respect to slope stabilisation could be a topic for further studies.

Although the soil moisture retained by the terraces is not believed to be a threat to terrace stability given the present yearly precipitation quantities, soil saturation and ensuing soil instability such as slumping could also be part of further research. Determining various volumetric soil moisture contents and monitoring the possible subsequent soil instability caused by varying soil moisture could provide beneficial research results for future terraced sites. Correlations could possibly be determined between varying combinations of terrace size, vegetation density, soil physical properties and volumetric soil moisture. This could be largely influenced by timing of the snow melt and soil conditions. Further research could determine how this may affect on-site vegetation communities and soil instability. Additional research on other slopes and sites within the Aspen Parkland could help determine whether results from this study could be duplicated, thereby increasing the bioengineering knowledge base. Information gathered from these potential studies may also be beneficial in helping further understand terrace related mass soil failures world-wide.

APPENDIX

Table 1: Average soil texture for gullies and slopes (0 to 20 cm)

Location	Fraction	Average % soil	Standard deviation
Slope A	silt+clay(<50μm)	48.1	3.3
	total clay(<2μm)	21.0	0.9
	total silt(2-50μm)	27.1	2.6
	total sand(>50μm)	51.9	3.3
Slope B	silt+clay(<50μm)	37.0	1.0
	total clay(<2μm)	34.3	0.9
	total silt(2-50μm)	37.6	1.4
	total sand(>50μm)	40.2	1.0
Slope C	silt+clay(<50μm)	45.9	1.5
	total clay(<2μm)	20.2	0.8
	total silt(2-50μm)	25.7	0.8
	total sand(>50μm)	54.1	1.5
Reference site	silt+clay(<50μm)	48.1	7.4
	total clay(<2μm)	24.7	4.9
	total silt(2-50μm)	23.4	3.0
	total sand(>50μm)	51.9	7.4
Gully 1	silt+clay(<50μm)	49.7	4.5
	total clay(<2μm)	21.1	3.3
	total silt(2-50μm)	28.6	3.7
	total sand(>50μm)	50.3	4.5
Gully 2	silt+clay(<50μm)	48.8	1.6
	total clay(<2μm)	21.7	1.3
	total silt(2-50μm)	27.1	0.8
	total sand(>50μm)	51.2	1.6
Gully 3	silt+clay(<50μm)	45.4	1.1
	total clay(<2μm)	21.0	0.4
	total silt(2-50μm)	24.4	0.7
	total sand(>50μm)	54.6	1.1

Overall average soil texture for gullies and slopes

Fraction	Average % soil	Standard deviation
silt+clay(<50μm)	45.8	4.6
total clay(<2μm)	23.2	5.4
total silt(2-50μm)	28.4	4.7
total sand(>50μm)	50.4	5.3

Soil texture: sandy clay loam

Table 2: Bulk densities (Mg m^{-3}) in undisturbed soil August 1997 and settled soil at the end of September 1998

Date	Reference site	Slope A	Slope B	Slope C	Mean	Standard deviation
August 1997 (20 cm depth)	1.36	1.72	1.62	1.73	1.69	0.05
	Depth	**Slope A**	**Slope B**	**Slope C**		
September 1998	Upper 7.5 cm	1.06	1.48	1.08	1.21	0.24
	Lower 7.5 cm	1.18	1.22	1.23	1.21	0.03
September 1998		**Gully 1**	**Gully 2**	**Gully 3**		
	Upper 7.5 cm	1.22	1.02	1.29	1.18	0.14
	Lower 7.5 cm	1.01	0.97	1.10	1.03	0.07

Table 3: Soil nutrient analysis of gullies and slopes July 1997

Site	Nitrogen %	Phosphorous %	Total Carbon %	Potassium meq 100 g^{-1} soil
Gully 1	0.11	0.02	1.40	0.21
Gully 2	0.02	0.02	0.64	0.15
Gully 3	0.03	0.03	0.76	0.28
Slope A	0.03	0.03	0.87	0.30
Slope B	0.03	0.03	0.74	0.34
Slope C	0.02	0.03	1.01	0.24
Compost	1.86	0.34	22.17	39.54
Soil/compost mix	0.24	0.13	3.16	3.77
Reference site	0.08	0.04	1.08	0.34
Ellerslie summer fallow*	0.57	0.10	7.08	0.47

*University of Alberta Soils Laboratory; values shown are for a fertile soil

Table 4: Total quantity of dormant plants in Gully 1 categorized by species in June and August 1998

Grasses	August	June	Difference
Agropyron repens	181	16	165
Agropyron trachycaulum	23	3	20
Calamagrostis canadensis	84	32	52
Elymus canadensis	14	46	-32
Poa palustris	14	0	14
Poa pratensis	762	410	352
Total	1078	507	571
Forbs			
Anemone canadensis	0	2	-2
Anemone riparia	0	1	-1
Aralia nudicaulis	8	13	-5
Aster ciliolatus	12	26	-14
Aster conspicuus	2	4	-2
Aster laevis	7	8	-1
Cirsium arvense	0	1	-1
Epilobium angustifolium	5	0	5
Equisetum arvense	6	5	1
Fragaria virginiana	6	1	5
Galeopsis tetrahit	4	4	0
Galium boreale	56	75	-19
Heracleum lanatum	1	0	1
Hieracium umbellatum	2	3	-1
Lactuca tatarica	1	4	-3
Lathyrus ochroleucus	5	12	-7
Maianthemum canadense	6	21	-15
Mertensia paniculata	4	3	1
Monarda fistulosa	1	2	-1
Petasites palmatus	5	6	-1
Smilacina stellata	6	14	-8
Solidago canadensis	64	78	-14
Sonchus arvensis	7	3	4
Sonchus asper	0	1	-1
Stachys palustris	3	3	0
Taraxacum officinale	9	13	-4
Thalictrum venulosum	43	74	-31
Vicia americana	9	9	0
Viola canadensis	1	1	0
unidentified forb	0	2	-2
Total	273	387	-114
Shrubs/Trees			
Amelanchier alnifolia	2	2	0
Apocynum androsaemifolium	3	4	-1
Corylus cornuta	1	11	-10
Populus balsamifera	0	1	-1
Prunus pensylvanica	1	0	1
Prunus virginiana	2	1	1

Table 4: Total quantity of dormant plants in Gully 1 categorized by species in June and August 1998 (cont.)

Shrubs/Trees	**August**	**June**	**Difference**
Ribes oxyacanthoides	22	18	4
Rosa acicularis	24	34	-10
Rubus idaeus	72	74	-2
Symphoricarpos albus	42	53	-11
Symphoricarpos occidentalis	9	10	-1
Total	178	208	-30

Table 5: Total quantity of nondormant plants in Gully 1 categorized by species in June and August 1998

Grasses	August	June	Difference
Agropyron repens	197	29	168
Agropyron trachycaulum	32	1	31
Calamagrostis canadensis	100	67	33
Elymus canadensis	11	72	-61
Hordeum jubatum	1	0	1
Phleum pratense	3	0	3
Poa palustris	20	0	20
Poa pratensis	990	479	511
Total	1354	648	706
Forbs			
Achillea sibirica	0	2	-2
Aralia nudicaulis	1	4	-3
Aster ciliolatus	28	29	-1
Aster conspicuus	3	1	2
Aster laevis	6	10	-4
Capsella bursa-patoris	1	1	0
Chenopodium album	1	0	1
Disporum trachycarpum	0	2	-2
Epilobium angustifolium	8	6	2
Equisetum arvense	10	10	0
Fragaria virginiana	14	18	-4
Galeopsis tetrahit	3	1	2
Galium boreale	25	46	-21
Heracleum lanatum	0	1	-1
Hieracium umbellatum	0	1	-1
Lathyrus ochroleucus	7	8	-1
Maianthemum canadense	2	15	-13
Mertensia paniculata	2	2	0
Mitella nuda	0	1	-1
Monarda fistulosa	2	0	2
Muhlenbergia glomerata	6	1	5
Petasites palmatus	1	2	-1
Smilacina stellata	4	15	-11
Solidago canadensis	55	52	3
Sonchus arvensis	8	6	2
Stachys palustris	4	6	-2
Stellaria longifolia	2	2	0
Taraxacum officinale	18	39	-21
Thalictrum sparsiflorum	1	2	-1
Thalictrum venulosum	49	80	-31
Vicia americana	3	11	-8
Viola canadensis	1	1	0
Zizia aptera	1	0	1
unidentified forb	0	5	-5
Total	266	375	-109

Table 5: Total quantity of nondormant plants in Gully 1 categorized by species in June and August 1998 (cont.)

Shrubs/Trees	**August**	**June**	**Difference**
Amelanchier alnifolia	6	13	-7
Apocynum androsaemifolium	1	0	1
Corylus cornuta	0	2	-2
Populus balsamifera	0	1	-1
Prunus pensylvanica	1	0	1
Prunus virginiana	6	1	5
Ribes oxyacanthoides	2	1	1
Rosa acicularis	48	44	4
Symphoricarpos albus	25	21	4
Symphoricarpos occidentalis	9	3	6
unidentified woody species	0	2	-2
Total	98	88	10

Table 6: Total quantity of dormant plants categorized by species in Gully 2 in June and August 1998

Grasses	August	June	Difference
Agropyron repens	5	3	2
Agropyron trachycaulum	0	3	-3
Calamagrostis canadensis	12	6	6
Elymus canadensis	11	7	4
Hordeum jubatum	0	1	-1
Poa pratensis	648	464	184
Total	676	484	192
Forbs			
Achillea millefolium	2	4	-2
Agrimonia striata	1	11	-10
Artemisia campestris	1	1	0
Aster ciliolatus	7	8	-1
Aster laevis	17	6	11
Chenopodium album	1	1	0
Epilobium angustifolium	1	5	-4
Equisetum arvense	7	17	-10
Fragaria virginiana	3	6	-3
Galeopsis tetrahit	1	0	1
Galium boreale	15	27	-12
Hieracium umbellatum	2	8	-6
Lactuca tatarica	3	1	2
Lathyrus ochroleucus	5	7	-2
Petasites palmatus			
Solidago canadensis	17	31	-14
Sonchus arvensis	6	4	2
Sonchus asper	0	1	-1
Stachys palustris	17	10	7
Stellaria longifolia	1	9	-8
Taraxacum officinale	5	10	-5
Thalictrum venulosum	7	32	-25
Vicia americana	3	5	-2
unidentified forb	2	1	1
Total	122	217	-95
Shrubs			
Amelanchier alnifolia	4	3	1
Populus balsamifera	0	3	-3
Ribes oxyacanthoides	0	1	-1
Rosa acicularis	28	33	-5
Rubus idaeus	14	20	-6
Symphoricarpos albus	6	8	-2
Symphoricarpos occidentalis	16	20	-4
Total	68	88	-20

Table 7: Total quantity of nondormant plants categorized by species in Gully 2 in June and August 1998

Grasses	**August**	**June**	**Difference**
Agropyron repens	87	6	81
Bromus ciliatus	1	3	-2
Calamagrostis canadensis	18	15	3
Elymus canadensis	8	27	-19
Festuca hallii	65	0	65
Hordeum jubatum	0	1	-1
Phleum pratense	10	0	10
Poa pratensis	794	439	355
Total	983	491	492
Forbs			
Achillea millefolium	17	30	-13
Aster ciliolatus	1	1	0
Aster laevis	12	1	11
Chenopodium album	2	0	2
Collomia linearis	0	4	-4
Epilobium angustifolium	1	2	-1
Fragaria virginiana	0	5	-5
Galeopsis tetrahit	1	2	-1
Galium boreale	20	22	-2
Hieracium umbellatum	2	2	0
Lactuca tatarica	0	1	-1
Polygonum aviculare	0	2	-2
Potentilla norvegica	0	2	-2
Solidago canadensis	2	12	-10
Sonchus arvensis	5	7	-2
Stachys palustris	0	1	-1
Taraxacum officinale	10	19	-9
Thalictrum venulosum	3	10	-7
Vicia americana	1	9	-8
unidentified forb	0	1	-1
Total	77	132	-55
Shrubs/Trees			
Apocynum androsaemifolium	0	1	-1
Ribes oxyacanthoides	5	6	-1
Rosa acicularis	6	8	-2
Rubus idaeus	15	17	-2
Salix sp.	1	0	1
Symphoricarpos albus	3	9	-6
Symphoricarpos occidentalis	14	16	-2
Total	44	57	-13

Table 8: Total quantity of dormant plants categorized by species in Gully 3 in June and August 1998

Grass	**August**	**June**	**Difference**
Agropyron repens	40	2	38
Calamagrostis canadensis	82	18	64
Elymus canadensis	92	13	79
Elymus innovatus	0	9	-9
Poa pratensis	632	478	154
unidentified grass	1	1	0
Total	846	520	326
Forbs			
Achillea millefolium	13	1	12
Agastache foeniculum	4	0	4
Agrimonia striata	9	11	-2
Aralia nudicaulis	0	1	-1
Aster ciliolatus	1	7	-6
Aster laevis	24	26	-2
Brassicaceae sp.	0	3	-3
Cerastium arvense	1	0	1
Chenopodium album	1	0	1
Crepis tectorum	1	0	1
Epilobium angustifolium	3	8	-5
Equisetum arvense	3	4	-1
Fragaria virginiana	9	18	-9
Galeopsis tetrahit	0	17	-17
Galium boreale	55	86	-31
Hieracium umbellatum	1	2	-1
Lactuca tatarica	7	3	4
Lathyrus ochroleucus	7	17	-10
Lepidium densiflorum	1	0	1
Matricaria matricarioides	0	1	-1
Petasites palmatus	3	15	-12
Plantago major	1	1	0
Polygonum aviculare	3	0	3
Sonchus asper	0	1	-1
Stachys palustris	18	17	1
Stellaria longifolia	0	1	-1
Thalictrum venulosum	21	80	-59
unidentified forb	0	10	-10
Total	187	328	-141

Table 8: Total quantity of dormant plants categorized by species in Gully 3 in June and August 1998 (cont.)

Shrubs/Trees	August	June	Difference
Amelanchier alnifolia	1	8	-7
Prunus virginiana	0	2	-2
Ribes oxyacanthoides	4	4	0
Rosa acicularis	55	65	-10
Rubus idaeus	7	13	-6
Solidago canadensis	56	65	-9
Sonchus arvensis	2	0	2
Symphoricarpos albus	21	28	-7
Symphoricarpos occidentalis	14	24	-10
Total	160	209	-49

Table 9: Total quantity of nondormant plants categorized by species in Gully 3 in June and August 1998

Grasses	**August**	**June**	**Difference**
Agropyron repens	87	0	87
Agropyron trachycaulum	17	0	17
Calamagrostis canadensis	47	15	32
Carex sp.	1	2	-1
Elymus innovatus	0	3	-3
Poa palustris	25	0	25
Poa pratensis	1830	1188	642
Total	2007	1208	799
Forbs			
Achillea millefolium	41	76	-35
Agrimonia striata	0	4	-4
Aster ciliolatus	2	3	-1
Aster ciliolatus	5	13	-8
Aster conspicuus	3	0	3
Aster laevis	22	20	2
Epilobium angustifolium	1	5	-4
Equisetum arvense	0	14	-14
Fragaria virginiana	6	17	-11
Galeopsis tetrahit	0	1	-1
Galium boreale	22	49	-27
Geum macrophyllum	1	0	1
Geum rivale	1	0	1
Lathyrus ochroleucus	0	6	-6
Mertensia paniculata	1	3	-2
Petasites palmatus	0	2	-2
Plantago major	2	4	-2
Solidago canadensis	2	2	0
Solidago canadensis	10	25	-15
Sonchus arvensis	10	9	1
Taraxacum officinale	42	77	-35
Thalictrum venulosum	4	31	-27
Vicia americana	4	17	-13
unidentified forb	0	2	-2
Total	179	378	-199
Shrubs/Trees			
Amelanchier alnifolia	10	8	2
Populus tremuloides	0	1	-1
Ribes oxyacanthoides	2	8	-6
Rosa acicularis	17	25	-8
Rubus idaeus	20	40	-20
Rubus pubescens	0	4	-4
Symphoricarpos albus	32	35	-3
Symphoricarpos occidentalis	46	75	-29
Total	127	196	-69

Table 10: Total quantity of dormant plants categorized by species in Slope A in June and August 1998

Grasses/Sedges	August	June	Difference
Agropyron repens	47	13	34
Agropyron trachycaulum	0	1	-1
Bromus ciliatus	2	0	2
Calamagrostis canadensis	128	62	66
Calamagrostis montanensis	15	12	3
Carex aena	0	6	-6
Carex sp.	5	0	5
Elymus canadensis	25	8	17
Phleum pratense	0	7	-7
Poa palustris	36	18	18
Poa pratensis	0	7	-7
Total	258	134	124
Forbs			
Achillea millefolium	0	2	-2
Agrimonia striata	0	4	-4
Aster ciliolatus	16	20	-4
Aster conspicuus	7	3	4
Aster laevis	23	16	7
Chenopodium album	7	2	5
Collomia linearis	0	1	-1
Epilobium angustifolium	12	25	-13
Equisetum arvense	3	2	1
Fragaria virginiana	8	30	-22
Galeopsis tetrahit	1	0	1
Galium boreale	88	141	-53
Geum rivale	2	0	2
Heracleum lanatum	3	1	2
Lactuca tatarica	0	2	-2
Lathyrus ochroleucus	7	9	-2
Maianthemum canadense	0	2	-2
Monarda fistulosa	2	1	1
Muhlenbergia glomerata	1	0	1
Petasites palmatus	0	7	-7
Polygonum aviculare	1	0	1
Polygonum scabrum A57	5	1	4
Smilacina stellata	1	2	-1
Solidago canadensis	119	143	-24
Sonchus arvensis	8	1	7
Stachys palustris	50	34	16
Stellaria longifolia	6	8	-2
Taraxacum officinale	6	7	-1
Thalictrum venulosum	50	108	-58
Trifolium pratense	1	0	1
Vicia americana	3	9	-6
Viola canadensis	0	4	-4
Viola renifolia	0	1	-1
Total	430	586	-156

Table 10: Total quantity of dormant plants categorized by species in Slope A in June and August 1998 (cont.)

Shrubs/Trees	August	June	Difference
Amelanchier alnifolia	0	3	-3
Apocynum androsaemifolium	0	1	-1
Corylus cornuta	0	1	-1
Prunus virginiana	4	3	1
Ribes oxyacanthoides	7	7	0
Rosa acicularis	67	71	-4
Rubus idaeus	77	84	-7
Symphoricarpos albus	10	30	-20
Symphoricarpos occidentalis	71	48	23
unidentified woody species	0	1	-1
Total	236	249	-13

Table 11: Total quantity of nondormant plants categorized by species in Slope A in June and August 1998

Grasses/Sedges	August	June	Difference
Agropyron repens	156	28	128
Agropyron trachycaulum	76	112	-36
Bromus ciliatus	6	0	6
Calamagrostis canadensis	59	83	-24
Carex aena	3	4	-1
Elymus canadensis	104	164	-60
Koeleria macrantha	1	0	1
Festuca hallii	0	1	-1
Phleum pratense	3	5	-2
Poa palustris	116	51	65
Poa pratensis	1148	907	241
Total	1672	1355	317
Forbs			
Achillea millefolium	12	13	-1
Agrimonia striata	2	5	-3
Agrostis scabra	2	0	2
Aralia nudicaulis	0	1	-1
Aster ciliolatus	82	125	-43
Aster conspicuus	7	3	4
Aster laevis	14	18	-4
Chenopodium album	2	4	-2
Comandra umbellata	1	0	1
Descuraiania sophia	1	0	1
Epilobium angustifolium	0	2	-2
Equisetum arvense	3	3	0
Equisetum pratense	20	20	0
Fragaria virginiana	56	90	-34
Galeopsis tetrahit	1	2	-1
Galium boreale	75	164	-89
Geum rivale	1	0	1
Heracleum lanatum	2	0	2
Hieracium umbellatum	0	1	-1
Lactuca tatarica	0	0	0
Lathyrus ochroleucus	2	11	-9
Maianthemum canadense	3	4	-1
Monarda fistulosa	0	1	-1
Muhlenbergia glomerata	10	0	10
Polygonum aviculare	7	3	4
Polygonum scabrum	1	0	1
Smilacina stellata	4	5	-1
Solidago canadensis	12	28	-16
Sonchus arvensis	4	9	-5
Sonchus asper	0	1	-1
Stachys palustris	3	0	3
Stellaria longifolia	1	1	0

Table 11: Total quantity of nondormant plants categorized by species in Slope A in June and August 1998 (cont.)

Forbs	August	June	Difference
Taraxacum officinale	78	128	-50
Thalictrum venulosum	1	7	-6
Urtica dioica	1	0	1
Vicia americana	10	10	0
Viola canadensis	0	1	-1
unidentified forb	3	6	-3
Total	418	660	-242
Shrubs/Trees			
Amelanchier alnifolia	1	1	0
Populus balsamifera	0	7	-7
Prunus virginiana	6	8	-2
Ribes oxyacanthoides	6	6	0
Rosa acicularis	61	78	-17
Rubus idaeus	32	35	-3
Symphoricarpos albus	15	29	-14
Symphoricarpos occidentalis	47	46	1
Total	168	210	-42

Table 12: Total quantity of dormant plants categorized by species in Slope B in June and August 1998

Grasses	**August**	**June**	**Difference**
Agropyron repens	38	6	32
Elymus canadensis	34	4	30
Elymus innovatus	0	7	-7
Poa palustris	4	0	4
Poa pratensis	484	348	136
Total	560	365	195
Forbs			
Achillea millefolium	1	0	1
Agrimonia striata	0	1	-1
Artemisia campestris	5	4	1
Aster ciliolatus	4	0	4
Aster conspicuus	1	2	-1
Aster laevis	13	16	-3
Calamagrostis canadensis	37	6	31
Chenopodium album	1	6	-5
Epilobium angustifolium	2	4	-2
Equisetum arvense	3	1	2
Fragaria virginiana	1	3	-2
Galeopsis tetrahit	2	6	-4
Galium boreale	35	34	1
Lactuca tatarica	4	2	2
Lathyrus ochroleucus	2	8	-6
Papaver rhoeas	1	1	0
Petasites palmatus	1	4	-3
Polygonum aviculare	1	2	-1
Solidago canadensis	33	48	-15
Sonchus arvensis	0	2	-2
Stachys palustris	5	2	3
Taraxacum officinale	3	3	0
Thalictrum venulosum	23	69	-46
Vicia americana	1	0	1
Viola canadensis	1	5	-4
unidentified forb	2	14	-12
Total	180	229	-49
Shrubs/Trees			
Amelanchier alnifolia	1	2	-1
Prunus virginiana	0	1	-1
Rosa acicularis	17	22	-5
Rubus idaeus	10	18	-8
Rubus pubescens	0	1	-1
Symphoricarpos albus	5	4	1
Symphoricarpos occidentalis	10	10	0
Total	43	58	-15

Table 13: Total quantity of nondormant plants categorized by species in Slope B in June and August 1998

Grasses	**August**	**June**	**Difference**
Agropyron repens	13	0	13
Calamagrostis canadensis	9	0	9
Elymus canadensis	0	8	-8
Poa palustris	14	0	14
Poa pratensis	903	500	403
Total	939	508	431
Forbs			
Achillea millefolium	4	8	-4
Agrimonia striata	0	1	-1
Aster ciliolatus	14	14	0
Aster conspicuus	0	2	-2
Aster laevis	5	2	3
Equisetum arvense	2	26	-24
Fragaria virginiana	6	10	-4
Galium boreale	5	11	-6
Heracleum lanatum	1	0	1
Lathyrus ochroleucus	0	2	-2
Lonicera dioica	2	2	0
Plantago major	1	1	0
Solidago canadensis	3	11	-8
Sonchus arvensis	2	2	0
Taraxacum officinale	28	38	-10
Thalictrum venulosum	2	6	-4
Trifolium hybridum	0	6	-6
Trifolium repens	0	13	-13
Vicia americana	2	9	-7
Viola canadensis	1	8	-7
unidentified forb	0	3	-3
Total	78	172	-94
Shrubs/Trees			
Ribes oxyacanthoides	7	14	-7
Rosa acicularis	14	15	-1
Rubus idaeus	10	13	-3
Rubus pubescens	0	1	-1
Symphoricarpos albus	4	0	4
Symphoricarpos occidentalis	1	32	-31
Total	36	75	-39

Table 14: Total quantity of dormant plants categorized by species in Slope C in June and August 1998

Grasses	**August**	**June**	**Difference**
Agropyron repens	40	4	36
Calamagrostis canadensis	133	95	38
Elymus canadensis	25	10	15
Phleum pratense	15	20	-5
Poa palustris	30	11	19
Poa pratensis	1894	991	903
Total	2137	1131	1006
Forbs			
Achillea millefolium	15	8	7
Agastache foeniculum	7	1	6
Agrimonia striata	7	19	-12
Artemisia campestris	2	4	-2
Aster ciliolatus	17	25	-8
Aster laevis	64	77	-13
Chenopodium hybridum	1	0	1
Epilobium angustifolium	5	21	-16
Equisetum arvense	8	4	4
Fragaria virginiana	39	63	-24
Galium boreale	116	159	-43
Geum macrophyllum	2	1	1
Hieracium umbellatum	1	14	-13
Lactuca tatarica	13	6	7
Lathyrus ochroleucus	13	79	-66
Lathyrus venosus	1	4	-3
Lonicera villosa	0	3	-3
Matricaria matricarioides	0	2	-2
Monarda fistulosa	7	8	-1
Petasites palmatus	7	35	-28
Polygonum scabrum	2	0	2
Solidago canadensis	110	142	-32
Sonchus arvensis	14	4	10
Stachys palustris	62	77	-15
Stellaria longifolia	4	27	-23
Taraxacum officinale	19	11	8
Thalictrum venulosum	29	78	-49
Vicia americana	15	24	-9
Viola canadensis	1	9	-8
unidentified forb	10	7	3
Total	581	905	-324
Shrubs/Trees			
Amelanchier alnifolia	0	12	-12
Corylus cornuta	1	0	1
Populus tremuloides	0	1	-1
Prunus virginiana	3	2	1
Ribes oxyacanthoides	0	1	-1

Table 14: Total quantity of dormant plants categorized by species in Slope C in June and August 1998 (cont.)

Shrubs/Trees	August	June	Difference
Rosa acicularis	70	111	-41
Rubus idaeus	53	78	-25
Symphoricarpos albus	37	41	-4
Symphoricarpos occidentalis	39	50	-11
Total	203	296	-93

Table 15: Total quantity of nondormant plants categorized by species in Slope C in June and August 1998

Grass/Sedges	August	June	Difference
Agropyron repens	93	69	24
Agropyron trachycaulum	1	0	1
Bromus ciliatus	8	0	8
Calamagrostis canadensis	109	116	-7
Carex aena	0	1	-1
Elymus canadensis	3	0	3
Phleum pratense	65	166	-101
Poa palustris	233	0	233
Poa pratensis	2701	1960	741
Total	3213	2312	901
Forbs			
Achillea millefolium	84	105	-21
Agrimonia striata	10	14	-4
Agrostis scabra	4	0	4
Aralia nudicaulis	0	1	-1
Aster ciliolatus	34	57	-23
Aster conspicuus	5	4	1
Aster laevis	53	65	-12
Aster puniceus	0	1	-1
Chenopodium album	1	0	1
Corydalis aurea	0	1	-1
Epilobium angustifolium	1	0	1
Equisetum arvense	1	9	-8
Fragaria virginiana	11	32	-21
Galeopsis tetrahit	0	1	-1
Galium boreale	33	69	-36
Geum macrophyllum	1	1	0
Geum rivale	2	1	1
Heracleum lanatum	2	3	-1
Hieracium umbellatum	1	3	-2
Lathyrus ochroleucus	0	8	-8
Maianthemum canadense	0	4	-4
Petasites palmatus	0	4	-4
Polygonum aviculare	1	1	0
Potentilla gracilis	1	0	1
Smilacena stellata	0	2	-2
Solidago canadensis	61	69	-8
Sonchus arvensis	7	13	-6
Stachys palustris	10	13	-3
Stellaria longifolia	0	12	-12
Taraxacum officinale	120	199	-79
Thalictrum venulosum	26	77	-51
Vicia americana	7	33	-26
Total	476	802	-326

Table 15: Total quantity of nondormant plants categorized by species in Slope C in June and August 1998 (cont.)

Shrubs/Trees	**August**	**June**	**Difference**
Amelanchier alnifolia	0	3	-3
Ribes oxyacanthoides	4	7	-3
Rosa acicularis	32	36	-4
Rubus idaeus	71	93	-22
Salix sp.	2	0	2
Symphoricarpos albus	2	8	-6
Symphoricarpos occidentalis	44	55	-11
Total	155	202	-47

Table 16: Mean total number of dormant plants categorized by species in all gullies in June and August 1998

Grasses	August	June	Mean difference
Agropyron repens	75.3	7.0	68.3
Agropyron trachycaulum	7.7	2.0	5.7
Calamagrostis canadensis	59.3	18.7	40.7
Elymus canadensis	39.0	22.0	17.0
Elymus innovatus	0.0	3.0	-3.0
Hordeum jubatum	0.0	0.3	-0.3
Poa palustris	4.7	0.0	4.7
Poa pratensis	680.7	450.7	230.0
unidentified grass	0.3	0.3	0.0
Forbs			
Achillea millefolium	5.0	1.7	3.3
Agastache foeniculum	1.3	0.0	1.3
Agrimonia striata	3.3	7.3	-4.0
Anemone canadensis	0.0	0.7	-0.7
Anemone riparia	0.0	0.3	-0.3
Aralia nudicaulis	2.7	4.7	-2.0
Artemisia campestris	0.3	0.3	0.0
Aster ciliolatus	6.7	13.7	-7.0
Aster conspicuus	0.7	1.3	-0.7
Aster laevis	16.0	13.3	2.7
Brassicaceae sp.	0.0	1.0	-1.0
Cerastium arvense	0.3	0.0	0.3
Chenopodium album	0.7	0.3	0.3
Cirsium arvense	0.0	0.3	-0.3
Crepis tectorum	0.3	0.0	0.3
Epilobium angustifolium	3.0	4.3	-1.3
Equisetum arvense	5.3	8.7	-3.3
Fragaria virginiana	6.0	8.3	-2.3
Galeopsis tetrahit	1.7	7.0	-5.3
Galium boreale	42.0	62.7	-20.7
Heracleum lanatum	0.3	0.0	0.3
Hieracium umbellatum	1.7	4.3	-2.7
Lactuca tatarica	3.7	2.7	1.0
Lathyrus ochroleucus	5.7	12.0	-6.3
Lepidium densiflorum	0.3	0.0	0.3
Maianthemum canadense	2.0	7.0	-5.0
Matricaria matricarioides	0.0	0.3	-0.3
Mertensia paniculata	1.3	1.0	0.3
Monarda fistulosa	0.3	0.7	-0.3
Petasites palmatus	2.7	11.3	-8.7
Plantago major	0.3	0.3	0.0
Polygonum aviculare	1.0	0.0	1.0
Smilacina stellata	2.0	4.7	-2.7
Solidago canadensis	27.0	36.3	-9.3
Sonchus arvensis	4.3	2.3	2.0
Sonchus asper	0.0	1.0	-1.0

Table 16: Mean total number of dormant plants categorized by species in all gullies in June and August 1998 (cont.)

Forbs	August	June	Mean difference
Stachys palustris	12.7	10.0	2.7
Stellaria longifolia	0.3	3.3	-3.0
Taraxacum officinale	4.7	7.7	-3.0
Thalictrum venulosum	23.7	62.0	-38.3
Vicia americana	4.3	7.3	-3.0
Viola canadensis	0.3	0.3	0.0
unidentified forb	0.7	4.3	-3.7
Shrubs/trees			
Amelanchier alnifolia	2.3	4.3	-2.0
Apocynum androsaemifolium	1.0	1.3	-0.3
Corylus cornuta	0.3	3.7	-3.3
Populus balsamifera	0.0	1.3	-1.3
Prunus pensylvanica	0.3	0.0	0.3
Prunus virginiana	0.7	1.0	-0.3
Ribes oxyacanthoides	8.7	7.7	1.0
Rosa acicularis	36.0	44.7	-8.7
Rubus idaeus	31.0	35.7	-4.7
Symphoricarpos albus	23.3	30.3	-7.0
Symphoricarpos occidentalis	13.0	18.0	-5.0

Table 17: Mean total number of nondormant plants categorized by species in all gullies in June and August 1998

Grasses/Sedges	August	June	Mean difference
Agropyron repens	123.7	11.7	112.0
Agropyron trachycaulum	16.3	0.3	16.0
Bromus ciliatus	0.3	1.0	-0.7
Calamagrostis canadensis	55.0	32.3	22.7
Carex sp.	0.3	0.7	-0.3
Elymus canadensis	6.3	33.0	-26.7
Elymus innovatus	0.0	1.0	-1.0
Festuca hallii	21.7	0.0	21.7
Hordeum jubatum	0.3	0.3	0.0
Phleum pratense	4.3	0.0	4.3
Poa palustris	15.0	0.0	15.0
Poa pratensis	1204.7	702.0	502.7
Forbs			
Achillea millefolium	19.3	35.3	-16.0
Achillea sibirica	0.0	0.7	-0.7
Agrimonia striata	0.0	1.3	-1.3
Aralia nudicaulis	0.3	1.3	-1.0
Aster ciliolatus	12.0	15.3	-3.3
Aster conspicuus	2.0	0.3	1.7
Aster laevis	13.3	10.3	3.0
Capsella bursa-patoris	0.3	0.3	0.0
Chenopodium album	1.0	0.0	1.0
Collomia linearis	0.0	1.3	-1.3
Disporum trachycarpum	0.0	0.7	-0.7
Epilobium angustifolium	3.3	4.3	-1.0
Equisetum arvense	3.3	8.0	-4.7
Fragaria virginiana	6.7	13.3	-6.7
Galeopsis tetrahit	1.3	1.3	0.0
Galium boreale	22.3	39.0	-16.7
Geum macrophyllum	0.3	0.0	0.3
Geum rivale	0.3	0.0	0.3
Heracleum lanatum	0.0	0.3	-0.3
Hieracium umbellatum	0.7	1.0	-0.3
Lactuca tatarica	0.0	0.3	-0.3
Lathyrus ochroleucus	2.3	4.7	-2.3
Maianthemum canadense	0.7	5.0	-4.3
Mertensia paniculata	1.0	1.7	-0.7
Mitella nuda	0.0	0.3	-0.3
Monarda fistulosa	0.7	0.0	0.7
Muhlenbergia glomerata	2.0	0.3	1.7
Petasites palmatus	0.3	1.3	-1.0
Plantago major	0.7	1.3	-0.7
Polygonum aviculare	0.0	0.7	-0.7
Potentilla norvegica	0.0	0.7	-0.7
Smilacina stellata	1.3	5.0	-3.7
Solidago canadensis	23.0	30.3	-7.3

Table 17: Mean total number of nondormant plants categorized by species in all gullies in June and August 1998 (cont.)

Forbs	August	June	Mean difference
Sonchus arvensis	7.7	7.3	0.3
Stachys palustris	1.3	2.3	-1.0
Stellaria longifolia	0.7	0.7	0.0
Taraxacum officinale	23.3	45.0	-21.7
Thalictrum sparsiflorum	0.3	0.7	-0.3
Thalictrum venulosum	18.7	40.3	-21.7
Vicia americana	2.7	12.3	-9.7
Viola canadensis	0.3	0.3	0.0
Zizia aptera	0.3	0.0	0.3
unidentified forb	0.0	2.7	-2.7
Shrubs/Trees			
Amelanchier alnifolia	5.3	7.0	-1.7
Apocynum androsaemifolium	0.3	0.3	0.0
Corylus cornuta	0.0	0.7	-0.7
Populus balsamifera	0.0	0.3	-0.3
Populus tremuloides	0.0	0.3	-0.3
Prunus pensylvanica	0.3	0.0	0.3
Prunus virginiana	2.0	0.3	1.7
Ribes oxyacanthoides	3.0	5.0	-2.0
Rosa acicularis	23.7	25.7	-2.0
Rubus idaeus	11.7	19.0	-7.3
Rubus pubescens	0.0	1.3	-1.3
Salix sp.	0.3	0.0	0.3
Symphoricarpos albus	20.0	21.7	-1.7
Symphoricarpos occidentalis	23.0	31.3	-8.3
unidentified woody species	0.0	0.7	-0.7

Table 18: Mean total number of nondormant plants categorized by species in all slopes in June and August 1998

Grasses/Sedges	August	June	Mean difference
Agropyron repens	87.3	32.3	55.0
Agropyron trachycaulum	25.7	37.3	-11.7
Bromus ciliatus	4.7	0.0	4.7
Calamagrostis canadensis	59.0	66.3	-7.3
Carex aena	1.0	1.7	-0.7
Elymus canadensis	35.7	57.3	-21.7
Festuca hallii	0.0	0.3	-0.3
Koeleria macrantha	0.3	0.0	0.3
Phleum pratense	22.7	57.0	-34.3
Poa palustris	121.0	17.0	104.0
Poa pratensis	1584.0	1122.3	461.7
Forbs			
Achillea millefolium	33.3	42.0	-8.7
Agrimonia striata	4.0	6.7	-2.7
Agrostis scabra	2.0	0.0	2.0
Aralia nudicaulis	0.0	0.7	-0.7
Aster ciliolatus	43.3	65.3	-22.0
Aster conspicuus	4.0	3.0	1.0
Aster laevis	24.0	28.3	-4.3
Aster puniceus	0.0	0.3	-0.3
Chenopodium album	1.0	1.3	-0.3
Comandra umbellata	0.3	0.0	0.3
Corydalis aurea	0.0	0.3	-0.3
Descurainia sophia	0.3	0.0	0.3
Epilobium angustifolium	0.3	0.7	-0.3
Equisetum arvense	2.0	12.7	-10.7
Equisetum pratense	6.7	6.7	0.0
Fragaria virginiana	24.3	44.0	-19.7
Galeopsis tetrahit	0.3	1.0	-0.7
Galium boreale	37.7	81.3	-43.7
Geum macrophyllum	0.3	0.3	0.0
Geum rivale	1.0	0.3	0.7
Heracleum lanatum	1.7	1.0	0.7
Hieracium umbellatum	0.3	1.3	-1.0
Lactuca tatarica	0.0	0.0	0.0
Lathyrus ochroleucus	0.7	7.0	-6.3
Lonicera dioica	0.7	0.7	0.0
Maianthemum canadense	1.0	2.7	-1.7
Monarda fistulosa	0.0	0.3	-0.3
Muhlenbergia glomerata	3.3	0.0	3.3
Petasites palmatus	0.0	1.3	-1.3
Plantago major	0.3	0.3	0.0
Polygonum aviculare	2.7	1.3	1.3
Polygonum scabrum	0.3	0.0	0.3
Potentilla gracilis	0.3	0.0	0.3
Smilacena stellata	1.3	2.3	-1.0

Table 18: **Mean total number of nondormant plants categorized by species in all Slopes in June and August 1998 (cont.)**

Forbs	**August**	**June**	**Mean difference**
Solidago canadensis	25.3	36.0	-10.7
Sonchus arvensis	4.3	8.0	-3.7
Sonchus asper	0.0	0.3	-0.3
Stachys palustris	4.3	4.3	0.0
Stellaria longifolia	0.3	4.3	-4.0
Taraxacum officinale	75.3	121.7	-46.3
Thalictrum venulosum	9.7	30.0	-20.3
Trifolium hybridum	0.0	2.0	-2.0
Trifolium repens	0.0	4.3	-4.3
Urtica dioica	0.3	0.0	0.3
Vicia americana	6.3	17.3	-11.0
Viola canadensis	0.3	3.0	-2.7
unidentified forb	1.0	3.0	-2.0
Shrubs/Trees			
Amelanchier alnifolia	0.3	1.3	-1.0
Populus balsamifera	0.0	2.3	-2.3
Prunus virginiana	2.0	2.7	-0.7
Ribes oxyacanthoides	5.7	9.0	-3.3
Rosa acicularis	35.7	43.0	-7.3
Rubus idaeus	37.7	47.0	-9.3
Rubus pubescens	0.0	0.3	-0.3
Salix sp.	0.7	0.0	0.7
Symphoricarpos albus	7.0	12.3	-5.3
Symphoricarpos occidentalis	30.7	44.3	-13.7

Table 19: Mean total number of dormant plants categorized by species in all slopes in June and August 1998

Grasses/sedges	**August**	**June**	**Mean difference**
Agropyron repens	42	8	34
Agropyron trachycaulum	0	0	0
Bromus ciliatus	1	0	1
Calamagrostis canadensis	87	52	35
Calamagrostis montanensis	5	4	1
Carex aena	0	2	-2
Carex sp.	2	0	2
Elymus canadensis	28	7	21
Elymus innovatus	0	2	-2
Phleum pratense	5	9	-4
Poa palustris	23	10	14
Poa pratensis	793	449	344
Forbs			
Achillea millefolium	5	3	2
Agastache foeniculum	2	0	2
Agrimonia striata	2	8	-6
Artemisia campestris	2	3	0
Aster ciliolatus	12	15	-3
Aster conspicuus	3	2	1
Aster laevis	33	36	-3
Calamagrostis canadensis	12	2	10
Chenopodium album	3	3	0
Chenopodium hybridum	0	0	0
Collomia linearis	0	0	0
Epilobium angustifolium	6	17	-10
Equisetum arvense	5	2	2
Fragaria virginiana	16	32	-16
Galeopsis tetrahit	1	2	-1
Galium boreale	80	111	-32
Geum macrophyllum	1	0	0
Geum rivale	1	0	1
Heracleum lanatum	1	0	1
Hieracium umbellatum	0	5	-4
Lactuca tatarica	6	3	2
Lathyrus ochroleucus	7	32	-25
Lathyrus venosus	0	1	-1
Lonicera villosa	0	1	-1
Maianthemum canadense	0	1	-1
Matricaria matricarioides	0	1	-1
Monarda fistulosa	3	3	0
Muhlenbergia glomerata	0	0	0
Papaver rhoeas	0	0	0
Petasites palmatus	3	15	-13
Polygonum aviculare	1	1	0
Polygonum scabrum	2	0	2

Table 19: Mean total number of dormant plants categorized by species in all slopes in June and August 1998 (cont.)

Forbs	August	June	Mean difference
Smilacina stellata	0	1	0
Solidago canadensis	87	111	-24
Sonchus arvensis	7	2	5
Stachys palustris	39	38	1
Stellaria longifolia	3	12	-8
Taraxacum officinale	9	7	2
Thalictrum venulosum	34	85	-51
Trifolium pratense	0	0	0
Vicia americana	6	11	-5
Viola canadensis	1	6	-5
Viola renifolia	0	0	0
unidentified forb	4	7	-3
Shrubs/Trees			
Amelanchier alnifolia	0	6	-5
Apocynum androsaemifolium	0	0	0
Corylus cornuta	0	0	0
Populus tremuloides	0	0	0
Prunus virginiana	2	2	0
Ribes oxyacanthoides	2	3	0
Rosa acicularis	51	68	-17
Rubus idaeus	47	60	-13
Rubus pubescens	0	0	0
Symphoricarpos albus	17	25	-8
Symphoricarpos occidentalis	40	36	4
unidentified woody species	0	0	0

Table 20: Dormant gully plant totals and means in June and August 1998

Grass	August	June	Difference
Gully 1	1078.0	507.0	571.0
Gully 2	676.0	484.0	192.0
Gully 3	847.0	521.0	326.0
Mean	867.0	504.0	363.0
Standard deviation	201.7	18.7	192.2
Forbs			
Gully 1	273.0	389.0	-116.0
Gully 2	124.0	219.0	-95.0
Gully 3	190.0	342.0	-152.0
Mean	195.7	316.7	-121.0
Standard deviation	74.7	87.8	28.8
Shrubs/Trees			
Gully 1	180.0	212.0	-32.0
Gully 2	68.0	88.0	-20.0
Gully 3	160.0	209.0	-49.0
Mean	136.0	169.7	-33.7
Standard deviaiton	59.7	70.7	14.6

Table 21: Nondormant gully plant totals and means in June and August 1998

Grasses/Sedges	August	June	Difference
Gully 1	1354.0	648.0	706.0
Gully 2	983.0	491.0	492.0
Gully 3	2007.0	1208.0	799.0
Mean	1448.0	782.3	665.7
Standard deviation	518.4	376.9	157.4
Forbs			
Gully 1	266.0	380.0	-114.0
Gully 2	77.0	133.0	-56.0
Gully 3	179.0	380.0	-201.0
Mean	174.0	297.7	-123.7
Standard deviaiton	94.6	142.6	73.0
Shrubs/Trees			
Gully 1	180.0	212.0	-32.0
Gully 2	44.0	57.0	-13.0
Gully 3	127.0	196.0	-69.0
Mean	117.0	155.0	-38.0
Standard deviation	68.5	85.2	28.5

Table 22: Dormant slope plant totals and means in June and August 1998

Grass	August	June	Difference
Slope A	1826.0	917.0	909.0
Slope B	560.0	365.0	195.0
Slope C	2137.0	1131.0	1006.0
Mean	1507.7	804.3	703.3
Standard deviation	835.3	395.2	442.9
Forbs			
Slope A	430.0	585.0	-155.0
Slope B	182.0	243.0	-61.0
Slope C	591.0	912.0	-321.0
Mean	401.0	580.0	-179.0
Standard deviation	206.0	334.5	131.7
Shrubs/Trees			
Slope A	236.0	249.0	-13.0
Slope B	43.0	58.0	-15.0
Slope C	203.0	296.0	-93.0
Mean	160.7	201.0	-40.3
Standard deviation	103.2	126.1	45.6

Table 23: Nondormant slope plant totals and means in June and August 1998

Grasses/Sedges	August	June	Difference
Slope A	1672.0	1355.0	317.0
Slope B	939.0	508.0	431.0
Slope C	3213.0	2312.0	901.0
Mean	1941.3	1391.7	549.7
Standard deviation	1160.7	902.6	309.6
Forbs			
Slope A	421.0	666.0	-245.0
Slope B	78.0	175.0	-97.0
Slope C	476.0	802.0	-326.0
Mean	325.0	547.7	-222.7
Standard deviation	215.7	329.8	116.1
Shrubs/Trees			
Slope A	168.0	210.0	-42.0
Slope B	36.0	75.0	-39.0
Slope C	155.0	202.0	-47.0
Mean	119.7	162.3	-42.7
Standard deviation	72.7	75.7	4.0

Table 24: Plant density, species composition and ground cover of the reference area on July 15, 1997

South area top half of slope	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species compsition canopy 1 m^2	% Ground cover Live veg.	Rock	Litter	Bare ground
Quadrat 1	*9 Rosa acicularis*	*4 Galium boreale*	89% shrubs	5	2	90	2
	13 Elaeagnus commutata	*4 Smilacina stellata*	8% forbs				
	20 Amelanchier alnifolia	*22 Carix* sp.	3% grass				
	4 Symphoricarpos occidentalis						
	18 Symphoricarpos albus						
	9 Prunus virginiana						
Quadrat 2	*2 Elaeagnus commutata*	*4 Galium boreale*	78% shrubs	12	0	85	3
	3 Rosa acicularis	*1 Lathyrus ochroleucus*	21% forbs				
	16 Amelanchier alnifolia	*27 Carex* sp.	1% grass				
	19 Symphoricarpos occidentalis	*2 Aster ciliolatus*					
	1 Populus tremuloides						
Quadrat 3	*19 Amelanchier alnifolia*		0 % shrubs	25	0	74	1
	6 Rosa acicularis		0 % forbs				
			0 % grass				
South area bottom half of slope							
Quadrat 1	*19 Prunus virginiana*	*3 Galium boreale*	88% shrubs	8	0	47	45
	9 Rosa acicularis	*3 Aster conspicuous*	10% forbs				
	6 Amelanchier alnifolia	*8 Carex sp.*	2% grass				
	12 Symphoricarpos occidentalis						
	1 Symmphoricarpos albus						

Table 24: Plant density, species composition and ground cover of the reference area on July 15, 1997 (cont.)

				% Ground cover			
South area bottom half of slope	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species compsition canopy 1 m^2	Live veg.	Rock	Litter	Bare ground
Quadrat 2	33 *Prunus virginiana*	6 *Galium boreale*	95% shrubs	9	0	65	26
	4 *Symphoricarpos albus*	9 *Carex* sp.	2% forbs				
	2 *Symphoricarpos occidentalis*	2 *Agropyron trachycaulum*	3% grass				
	12 *Rosa acicularis*						
	5 *Amelanchier alnifolia*						
Quadrat 3	6 *Prunus virginiana*	17 *Galium boreale*	67% shrubs	86	0	4	10
	7 *Rosa acicularis*	1 *Smilacina stellata*	31% forbs				
	3 *Sheperdia canadensis*	25 *Poa pratensis*	2% grass				
	14 *Symphoricarpos albus*						
Center area top half of slope Quadrat 1							
	25 *Amelanchier alnifolia*	4 *Thalictrum venulosum*	84% shrubs	13	0	85	2
	4 *Apocynum androsaemifolium*	5 *Aster ciliolatus*	15% forbs				
	4 *Symphoricarpos albus*	3 *Galium boreale*	<1% grass				
	6 *Symphoricarpos occidentalis*	5 *Carex* sp.					
	21 *Prunus virginiana*	20 *Poa pratensis*					
Quadrat 2							
	14 *Amelanchier alnifolia*	24 *Carex* sp.	92% shrubs	15	0	83	1
	12 *Prunus virginiana*	8 *Poa pratensis*	7% forbs				
	1 *Rosa acicularis*	23 *Symphoricarpos occidentalis*	<1% grass				

Table 24: Plant density, species composition and ground cover of the reference area on July 15, 1997 (cont.)

				% Ground cover			
Center area top half of slope	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species compsition canopy 1 m^2	Live veg.	Rock	Litter	Bare ground
Quadrat 3	43 *Prunus virginiana*	8 *Thalictrum venulosum*	67% shrubs	10	0	89	1
	2 *Rosa acicularis*	5 *Carex* sp.	32% forbs				
	6 *Amelanchier alnifolia*	9 *Poa pratensis*	<1% grass				
	9 *Symphoricarpos occidentalis*						
	1 *Apocynum androsaemifolium*						
Center area bottom half of slope							
Quadrat 1	5 *Amelanchier alnifolia*	2 *Galium boreale*	60% shrubs	11	0	89	3
	8 *Rosa acicularis*	6 *Aster ciliolatus*	38% forbs				
	12 *Prunus virginiana*	12 *Carex* sp.	2% grass				
	2 *Elaeagnus commutata*						
	11 *Symphoricarpos occidentalis*						
	6 *Symphoricarpos albus*						
Quadrat 2	12 *Rosa acicularis*	4 *Thalictrum venulosum*	45% shrubs	13	0	82	5
	12 *Prunus virginiana*	1 *Achillea millefolium*	45% forbs				
	4 *Elaeagnus commutata*	13 *Aster ciliolatus*	10% grass				
	9 *Amelanchier alnifolia*	22 *Carex* sp.					
	4 *Symphoricarpos occidentalis*						
	1 *Symphoricarpos albus*						

Table 24: Plant density, species composition and ground cover of the reference area on July 15, 1997 (cont.)

Center area bottom half of slope	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species compsition canopy 1 m^2	% Ground cover Live veg.	Rock	Litter	Bare ground
Quadrat 3	10 *Sheperdia canadensis*	11 *Elymus canadensis*	82% shrubs	68	0	4	28
	7 *Rosa acicularis*	3 *Thalictrum venulosum*	7% forbs				
		4 *Aster ciliolatus*	11% grass				
		1 *Vicia americana*					
		3 *Agropyron trachycaulum*					
		8 *Poa pratensis*					
		2 *Galium boreale*					
North area top half of slope							
Quadrat 1	19 *Prunus virginiana*	11 *Galium boreale*	50% shrubs	14	0	81	5
	6 *Amelanchier alnifolia*	7 *Carex* sp.	49% forbs				
	3 *Rosa acicularis*	6 *Poa pratensis*	1% grass				
	10 *Syphoricarpos albus*	4 *Thalictrum venulosum*					
	2 *Apocynum androsaemifolium*						
Quadrat 2	15 *Amelanchier alnifolia*	4 *Achillea millefolium*	88% shrubs	11	0	88	<1
	6 *Rosa acicularis*	2 *Galium boreale*	11% forbs				
	27 *Prunus virginiana*	26 *Carex* sp.	1% grass				
	7 *Symphoricarpos occidentalis*						
	2 *Symphoricarpos albus*						
	3 *Apocynum androsaemifolium*						
Quadrat 3	23 *Prunus virginiana*	2 *Elymus innovatus*	77% shrubs	10	0	89	<1
	7 *Amelanchier alnifolia*	21 *Carex* sp.	20% forbs				
	7 *Rosa acicularis*	7 *Galium boreale*	3% grass				

Table 24: Plant density, species composition and ground cover of the reference area on July 15, 1997 (cont.)

North area bottom half of slope	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species compsition canopy 1 m^2	% Ground cover			
				Live veg.	Rock	Litter	Bare ground
Quadrat 1	17 *Prunus virginiana*	1 *Smilacina stellata*	66% shrubs	13	0	83	4
	8 *Rosa acicularis*	11 *Galium boreale*	43% forbs				
	10 *Amelanchier alnifolia*	7 *Symphoricarpos albus*	<1% grass				
	9 *Symphoricarpos occidentalis*	9 *Carex* sp.					
Quadrat 2	18 *Amelancier alnifolia*	9 *Carex* sp.	66% shrubs	14	0	85	<1
	1 *Lonicera involucrata*	4 *Galium boreale*	43% forbs				
	16 *Apocynum androsaemifolium*		<1% grass				
	12 *Rosa acicularis*						
	10 *Symphoricarpos occidentalis*						
	21 *Symphoricarpos albus*						
Quadrat 3	12 *Prunus virginiana*	5 *Galium boreale*	77 % shrubs	14	0	85	<1
	14 *Amelanchier alnifolia*	1 *Smilacina stellata*	22 % forbs				
	4 *Rosa acicularis*	7 *Carex* sp.	<1 % grass				
	26 *Symphoricarpos albus*						
	3 *Apocynum androsaemifolium*						

Table 25: Plant density, species composition and ground cover on the research site gullies July 9-10, 1997

Gully 1 Top (2.3 m wide)	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species composition canopy 1 m^2	% Ground cover Live veg.	Rock	Litter	Bare ground
Quadrat 1	3 *Amelanchier alnifolia*		85% shrubs 11% forbs 4% grass	9	0	<1	90
Quadrat 2			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 3	1 *Amelanchier alnifolia* 1 *Alnus crispa*		54% shrubs 4% forbs 42% grass	5	0	0	95
Quadrat 4	2 *Amelanchier alnifolia*		98% shrubs 1% forbs 1% grass	2	0	0	98
Middle (3.5 m wide)							
Quadrat 1	5 *Amelanchier alnifolia* 2 *Alnus crispa*		98% shrubs 2% forbs <1% grass	4	0	0	96
Quadrat 2	2 *Rosa acicularis*		100% shrubs 0 % forbs 0 % grass	0	<1	0	99

Table 25: Plant density, species composition and ground cover on the research site gullies July 9-10, 1997 (cont.)

				% Ground cover			
Middle (3.5 m wide)	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species composition canopy 1 m^2	Live veg.	Rock	Litter	Bare ground
Quadrat 3	1 *Alnus crispa* 5 *Amelanchier alnifolia* 11 *Rosa acicularis*	21 *Galium boreale* 7 *Sonchus arvensis* 1 *Aster conspicuous* 1 *Poa pratensis*	86% shrubs 13% forbs <1% grass	14	<1	1	84
Quadrat 4	8 *Rosa acicularis* 2 *Amelanchier alnifolia*		98% shrubs 2% forbs 0% grass	11	0	0	89
Gully 1 Bottom (6.5m wide)							
Quadrat 1			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 2	1 *Spiraea betulifolia* 1 *Prunus virginiana*		100% shrubs 0 % forbs 0 % grass	5	0	0	95
Quadrat 3	4 *Amelanchier alnifolia* 2 *Spiraea betulifolia* 4 *Rosa acicularis*		86% shrubs 9% forbs 5% grass	3	<1	<1	96
Quadrat 4	8 *Rosa acicularis*		100% shrubs 0 % forbs 0 % grass	5	0	0	95

Table 25: Plant density, species composition and ground cover on the research site gullies July 9-10, 1997 (cont.)

				% Ground cover			
Gully 2 **Top (1m wide)**	**Density (1 m^2)** **trees, shrubs**	**Density (0.1 m^2)** **forbs, grasses**	**Species composition canopy 1 m^2**	**Live veg.**	**Rock**	**Litter**	**Bare ground**
Quadrat 1	*1 Amelanchier alnifolia*		100% shrubs 0 % forbs 0% grass	2	10	<1	87
Quadrat 2		*1 Galium boreale*	0 % shrubs 0 % forbs 0 % grass	1	0	0	99
Quadrat 3			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 4			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Gully 2 **Middle (4 m wide)**							
Quadrat 1			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 2			0 % shrubs 0 % forbs 0 % grass	0	0	0	100

Table 25: Plant density, species composition and ground cover on the research site gullies July 9-10, 1997 (cont.)

				% Ground cover			
Gully 2	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species composition canopy 1 m^2	Live veg.	Rock	Litter	Bare ground
Middle (4 m wide)							
Quadrat 3			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 4	2 *Rosa acicularis*		100% shrubs 0 % forbs 0 % grass	1	<1	0	98
Bottom (4 m wide)							
Quadrat 1	1 *Rosa acicularis*		100% shrubs 0 % forbs 0 % grass	1	0	0	99
Quadrat 2	26 *Rosa acicularis* 2 *Amelanchier alnifolia*	2 *Elymus canadensis*	92% shrubs 7% forbs <1% grass	12	<1	0	87
Quadrat 3	27 *Rosa acicularis*	3 *Equisetum arvense*	94% shrubs 2% forbs 4% grass	4	<1	<1	95
Quadrat 4	17 *Rosa acicularis*	2 *Vicia americana*	98% shrubs 2% forbs 0 % grass	4	0	0	96

Table 25: Plant density, species composition and ground cover on the research site gullies July 9-10, 1997 (cont.)

Gully 3	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species composition canopy 1 m^2	% Ground cover			
				Live veg.	Rock	Litter	Bare ground
Top (1.5 m wide)							
Quadrat 1			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 2			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 3			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 4			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Middle (2.5 m wide)							
Quadrat 1			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 2			0 % shrubs 0 % forbs 0 % grass	0	0	0	100

Table 25: Plant density, species composition and ground cover on the research site gullies July 9-10, 1997 (cont.)

				% Ground cover			
Middle (2.5 m wide)	**Density (1 m^2) trees, shrubs**	**Density (0.1 m^2) forbs, grasses**	**Species composition canopy 1 m^2**	**Live veg.**	**Rock**	**Litter**	**Bare ground**
Quadrat 3			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 4			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Gully 3 Bottom							
Quadrat 1			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 2			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 3			0 % shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 4	*1 Rosa acicularis*		100% shrubs 0 % forbs 0 % grass	1	0	0	99

Table 26: Plant density, species composition and ground cover on the research site slopes July 9-10, 1997

Slope A	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species composition canopy 1 m^2	% Ground cover: Live veg.	Rock	Litter	Bare ground
Top							
Quadrat 1			0% shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 2			0% shrubs 0% forbs 0 % grass	0	0	0	100
Quadrat 3			0% shrubs 0 % forbs 0 % grass	0	0	0	100
Quadrat 4			0% shrubs 0% forbs 0% grass	0	0	0	100
Middle							
Quadrat 1	10 *Amelanchier alnifolia*	3 *Agropyron trachycaulum*	97% shrubs 0% forbs 3% grass	1	<1	0	98
Quadrat 2	12 *Rosa acicularis*		99% shrubs 0% forbs <1% grass	1	<1	<1	97
Quadrat 3	8 *Rosa acicularis*	1 *Cirsium arvense* 1 *Epilobium angustifolium*+(	87% shrubs 6% forbs 7% grass	6	<1	<1	92

Table 26: Plant density, species composition and ground cover on the research site slopes July 9-10, 1997

				% Ground cover			
Slope A middle	Density ($1\ m^2$) trees, shrubs	Density ($0.1\ m^2$) forbs, grasses	Species composition canopy $1\ m^2$	Live veg.	Rock	Litter	Bare ground
Quadrat 4	*9 Rosa acicularis*		100% shrubs 0% forbs 0% grass	4	0	0	96
Slope A bottom							
Quadrat 1	*12 Rosa acicularis*	*2 Vicia americana* *1 Galium boreale* *1 Elymus canadensis* *21 Taraxacum officianale* *3 Equisetum arvense* *1 Cirsium arvense* *1 Plantago major*	72% shrubs 19% forbs 9% grass	20	1	3	76
Quadrat 2	*9 Rosa acicularis*	*2 Vicia americana* *5 Taraxacum officianale* *1 Equisetum arvense* *10 Elymus canadensis* *1 Plantago major*	91% shrubs 4% forbs 5% grass	6	<1	<1	93
Quadrat 3	*1 Populus tremuloides* *8 Rosa acicularis* *5 Symphoricarpos albus*	*1 Equisetum arvense* *9 Elymus canadensis*	32% shrubs 3% forbs 24% grass	19	<1	27	53
Quadrat 4	*16 Rosa acicularis*	*4 Galium boreale*	98 % shrubs 2 % forbs 0% grass	22	0	0	88

Table 26: Plant density, species composition and ground cover on the research site slopes July 9-10, 1997 (cont.)

				% Ground cover			
Slope B top	**Density (1 m^2) trees, shrubs**	**Density (0.1 m^2) forbs, grasses**	**Species composition canopy 1 m^2**	**Live veg.**	**Rock**	**Litter**	**Bare ground**
Quadrat 1			0% shrubs 0% forbs 0% grass	0	0	0	100
Quadrat 2			0% shrubs 0% forbs 0% grass	0	<1	<1	99
Quadrat 3	*1 Populus balsamifera*	*1 Sonchus arvenis*	37% shrubs 17% forbs 0% grass 46% trees	4	<1	0	95
Quadrat 4	*2 Rosa acicularis*		100% shrubs 0% forbs 0% grass	2	0	0	98
Slope B Middle							
Quadrat 1	*1 Rosa acicularis* *1 Amelanchier alnifolia*		100% shrubs 0% forbs 0% grass	<1	0	<1	99
Quadrat 2	*2 Rosa acicularis*	*1 Equisetum arvense*	96% shrubs 4% forbs 0% grass	<1	<1	<1	99

Table 26: Plant density, species composition and ground cover on the research site slopes July 9-10, 1997 (cont.)

				% Ground cover			
Slope B Middle	**Density (1 m^2) trees, shrubs**	**Density (0.1 m^2) forbs, grasses**	**Species composition canopy 1 m^2**	**Live veg.**	**Rock**	**Litter**	**Bare ground**
Quadrat 3	*7 Rosa acicularis*	*1 Equisetum arvense*	98% shrubs 1% forbs 1% grass	<1	1	<1	98
Quadrat 4	*5 Rosa acicularis*		100% shrubs 0% forbs 0% grass	1	0	0	99
Slope B Bottom							
Quadrat 1	*28 Rosa acicularis*	*1 Equisetum arvense* *1 Vicia americana* *1 Cirsium arvense*	96% shrubs 3% forbs <1% grass	5	<1	<1	94
Quadrat 2	*13 Rosa acicularis* *5 Symphoricarpos albus* *2 Amelanchier alnifolia*	*1 Cirsium arvense* *1 Vicia americana*	85% shrubs 15% forbs 0% grass	4	0	<1	95
Quadrat 3	*2 Prunus virginiana* *1 Rosa acicularis*		95% shrubs 5% forbs 0% grass	1	0	0	99
Quadrat 4			0% shrubs 0% forbs 0% grass	0	0	0	100

Table 26: Plant density, species composition and ground cover on the research site slopes July 9-10, 1997 (cont.)

				% Ground cover			
Slope C Top	**Density (1 m^2) trees, shrubs**	**Density (0.1 m^2) forbs, grasses**	**Species composition canopy 1 m^2**	**Live veg.**	**Rock**	**Litter**	**Bare ground**
Quadrat 1		2 Sonchus arvensis	0% shrubs 100% forbs 0% grass	<1		<1	99
Quadrat 2		1 Sonchus arvensis	0% shrubs 100% forbs 0% grass	<1	<1	<1	98
Quadrat 3			0% shrubs 0% forbs 0% grass	0	<1	<1	99
Quadrat 4			0% shrubs 0% forbs 0% grass	0	0	0	100
Slope C Middle							
Quadrat 1			0% shrubs 0% forbs 0% grass	0	0	<1	99
Quadrat 2	*14 Rosa acicularis*	*1 Cirsium arvense*	99% shrubs 1% forbs 0% grass	7	<1	2	90

Table 26: Plant density, species composition and ground cover on the research site slopes July 9-10, 1997 (cont.)

				% Ground cover			
	Density (1 m^2) trees, shrubs	Density (0.1 m^2) forbs, grasses	Species composition canopy 1 m^2	Live veg.	Rock	Litter	Bare ground
Slope C Middle Quadrat 3			0% shrubs 100% forbs 0% grass	<1	<1	<1	98
Quadrat 4	*10 Rosa acicularis*		100% shrubs 0% forbs 0% grass	2	0	0	98
Slope C Bottom Quadrat 1	*1 Rosa acicularis*		100% shrubs 0% forbs 0% grass	<1	<1	<1	98
Quadrat 2	*9 Rosa acicularis*		100% shrubs 0% forbs 0% grass	<1	<1	<1	98
Quadrat 3	*24 Rosa acicularis*	*2 Stachys palustris* *1 Cirsium arvense* *2 Vicia americana* *1 Lactuca tatarica*	96% shrubs 4% forbs 0% grass	3	<1	<1	96
Quadrat 4	*16 Rosa acicularis*	*2 Cirsium arvense*	97% shrubs 3% forbs 0% grass	1	0	0	99