University of Alberta

Wetland vegetation establishment with transferrals of wetland soil following surface mining

by

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Abstract

Wetland creation following large-scale disturbance is difficult because sources of wetland vegetation may be scarce. In this study I transferred wetland topsoil from pre-mining areas to a water storage basin devoid of vegetation at the Genesee Mine in Alberta, Canada to study the feasibility of using wetland soil as a source of wetland plant propagules following surface mining. Comparison of vegetation parameters (species richness, vegetation cover, plant height) and plant community composition showed that the wetland soil treated plots resembled the donor wetlands more than nearby opportunistic wetlands. There were indications that water and soil quality in the water storage basin may have affected plant health and community composition. Using transferred wetland soil is a viable method to introduce wetland plant propagules in reclaimed areas, but the vegetation in opportunistic wetlands suggests that natural colonization can be a viable alternative at the Genesee Mine.

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Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Opportunity for Wetland Creation

Following surface mining, extensive engineering and biological efforts are needed to return a site to a productive, desirable, and sustainable condition. In central Alberta, agricultural land use is frequently the most highly valued, but there is an opportunity during reclamation to design and produce a more natural landscape in which ecological attributes such as wetlands may be incorporated. Wetlands add to wildlife habitats in the landscape by providing cover and food sources for both wetland and upland wildlife (Green *et al.* 1992). Wetlands also reduce flooding, purify water, and hold water on the landscape for use during drought conditions. Another reason to create wetlands during reclamation is to reduce the need for application of limited topsoil resources. Water bodies associated with wetlands may not need topsoil where water is too deep to support rooted plants, thereby saving topsoil for use in agricultural reclamation areas.

During surface mining, water flows must be isolated to permit dry-condition excavation. Consequently, onsite water storage basins must be built. Slight modifications to the bank slope and shape of these water storage basins may create prime areas for wetland creation projects, but establishing vegetation in these basins is difficult since natural sources of wetland plant propagules are very rare on the disturbed site. Furthermore, water quality in the basins can be poor and soil resources are limited.

1.2 Sources of Wetland Vegetation

Establishing vegetation in a newly created wetland depends on factors and goals that vary with the intended use of the wetland, vegetation type needed, reclamation timeline, resources available, and available funding.

The simplest and cheapest method of re-vegetation is to prepare the basin with topsoil and allow for natural colonization by seed dispersal. Naturally colonized wetlands (or opportunistic wetlands) have plant communities that formed by natural colonization following disturbance. Opportunistic wetlands have an advantage over planted wetlands because they only support vegetation that is suited to the conditions at the site (Mitsch and Wilson 1996), but they also have the potential to become monocultures of invasive species (Reinartz and Warne 1993, Mulhouse and Galatowitsch 2003). Natural colonization can also take a long time depending on wetland proximity, wildlife use, and environmental conditions. Brown (1999) found that natural colonization was effective for restoring wetlands in abandoned fields where the existing vegetation was not disturbed. Prairie Pothole restorationists found that sites reliant on colonization developed plant communities that lacked many native species and were dominated by invasive species (Galatowitsch and van der Valk 1996, Mulhouse and Galatowitsch 2003, Seabloom and van der Valk 2003).

Following surface mining, newly created wetlands can be isolated from other wetlands indefinitely. The greater the distance from established wetlands, the lower the chance of plant propagules reaching the site by seed dispersal. In such cases, artificially introduced wetland plant propagules may speed up revegetation and decrease the chance of invasive species dominating the site. Planting wetland vegetation is one option but this method can be expensive and time consuming. Sources of plant and seed stocks for native species are limited. Unclear relationships between hydrology, soil, and vegetation can lead to poor choices of planted species (Mitsch *et al.* 1998). Many species of interest in central Alberta, such as *Carex sp.*, only germinate under very specific environmental conditions (Budelsky and Galatowitsch 1999), hence seeding is not successful.

Transferring propagule-rich topsoil from natural wetlands onto created wetlands is another option that may offset limitations of natural propagule dispersal. This method has been effective at establishing wetland vegetation in wetland restoration (Brown and Bedford 1997, Burke 1997) and wetland creation projects (Stauffer and Brooks 1997). Use of salvaged wetland soil has also been shown to decrease the incidence of invasive species (Brown 1998, Burke 1997). This method has the added advantage of providing an appropriate growth medium to aid in plant establishment and because topsoil is handled and stored prior to surface mining, it is easily placed in wetlands later during reclamation.

1.3 Environmental Constraints

Wetland propagule availability is not the only obstacle to creating post-mining wetlands. The environmental conditions in the early stages of land reclamation can be unsuitable for establishing plants. Both soil and water resources on surface-mined sites are limited and can result in the use of lower quality soil during reclamation of wetland areas. Sporadic water availability and quality are also impediments.

Surface mining disrupts the natural hydrologic pathways of the landscape through diversion of natural streams and groundwater flows around the mining area into onsite storage to avoid contamination of off-site waterways. Without flow-through systems the main source of water is on-site precipitation either through direct input or runoff. Runoff from exposed soils is often characterized by high concentrations of solids (Bonta 2000). Suspended solids absorb light and reduce the depth of light penetration for submerged plants (Cronk and Fennessy 2001). Solids can settle onto the soil surface and bury seeds, thereby decreasing seedling emergence (Gleason et. al. 2003, Peterson and Baldwin 2004). Some soils may be classified as sodic soils with high levels of sodium. Runoff from sodic soils can have high pH and very high concentrations of suspended solids because of the dispersive nature and structural instability of sodic subsoils (Rengasamy 2002).

Rich topsoils capable of supporting plant growth are a limited resource, causing the use of poorer quality soils in economically insignificant areas such as wetlands and wildlife habitat. The soil profile is reconstructed during land reclamation and may be quite different from natural wetland soil profiles. Stolt et al. (2000) found wetland creation sites were generally missing the B soil horizon and had shallower A soil horizons than reference sites when comparing three pairs of reference and created wetlands. Soils high in sodium can affect pore water chemistry and soil water holding capacity (Rengasamy 2002). Using wetland topsoil such as organic mats, mucks, and detritus-rich alluvium, may alleviate the need for upland topsoil while also providing an appropriate growth medium for wetland plants. Such transfers may mitigate some of the environmental limitations that occur following surface mining.

1.4 Methods and Objectives

This study investigated practical considerations of using transferred wetland topsoil to establish wetland vegetation in a post-mining water storage basin. Transferred wetland soil was chosen because of the process used for land reclamation at the study site. Reclamation followed closely after mining, causing the landscape to be in constant transition between pre- and post-disturbance. The constantly changing landscape allows wetland topsoil to be available for reclamation purposes without causing additional disturbance to natural systems. Areas that are scheduled for excavation become the primary soil-donor sites. Therefore, an available resource (wetland soil) is utilized appropriately and upland topsoil is saved for use in other areas.

Using wetland soil as a source of plant propagules during both restoration and creation of wetlands has been studied (van der Valk *et al.* 1992, Brown and Bedford 1997, Stauffer and Brooks 1997). Results of these studies generally show increases in species richness, total vegetation cover, and proportion of wetland plants over areas without the application of wetland soil. I compared wetland soil transfers to natural colonization by seed dispersal. I then expanded the scope of the study to look at the influence of different environmental aspects at my field site on the establishment of wetland species from the seed bank and to investigate the influence of the reconstructed soil profile on root penetration. Lastly this study let me assess some of the operational aspects of wetland soil transfer for future reclamation projects.

I set up a series of transferred soil, subsoil control, and donor wetland plots at the Genesee coal mine in central Alberta, Canada. The transferred soil and subsoil plots were located along the perimeter of a water storage basin on the post-mining landscape. Wetland soil for the transferred soil plots was collected from two natural wetlands (donor wetlands) on the mine holdings. Nine reference plots were set-up at each of the donor wetlands. Vegetation parameters, soil quality, and water quality were compared between the transferred soil, subsoil, and donor wetland plots. Four opportunistic wetlands that developed in the mine landscape were also studied for both vegetation parameters and water quality, but not soil parameters. A seed bank emergence study with controls and replication of the donor soil was conducted at the University of Alberta Greenhouses to study the emergence of plants from the seed bank under environmentally controlled conditions.

This study had three main objectives that are presented in the following three chapters: (a) to test the effectiveness of colonization via wetland soil transfer compared to natural colonization by seed dispersal (Chapter 2); (b) to estimate the contribution of seeds versus other plant propagules from the soil seed bank (Chapter 3); and (c) to determine if surface water quality and/or subsoil quality were effecting plant establishment and growth (Chapter 4). I conclude by discussing the results of the three study components in Chapter 5 in the context of wetland creation following surface mining at the Genesee Mine.

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Chapter 2: Vegetation establishment with transferral of natural wetland soil

2.1 Introduction

Establishing wetland vegetation is an important step when building wetland systems. The method chosen to establish vegetation depends on cost, availability of resources, and potential for vegetation establishment and growth. The cost of using certain methods of vegetation establishment and the availability of resources is often straightforward to determine, but the potential for establishment and growth can be harder to determine since each project has site-specific needs and no one method is best suited to all situations.

One method suited to highly disturbed areas such as surface mines is to transfer wetland soil from a natural or established wetland to the new wetland creation site, with plant propagules contained in the soil being the primary source of plant species to colonize the new site. Transfers of wetland soil have been effective at establishing wetland vegetation in both wetland restoration (Brown and Bedford 1997, Burke 1997) and creation projects (Stauffer and Brooks 1997). Using transferred wetland soil has the added advantages of providing an appropriate growth medium to aid in plant establishment and has been shown to decrease the incidence of invasive species (Burke 1997, Brown 1998). Wetland soil is relatively easy to come by at surface mines since wetland systems are stripped prior to mining.

A less costly or labour intensive method to establish wetland vegetation is to rely on natural colonization by seed dispersal. Natural colonization, often called the "do-nothing approach", relies on seeds dispersing to the new site by wind, water or carried by animals from natural wetlands. For natural colonization to be successful, connections need to exist between established and newly created wetlands. In small isolated wetlands, dispersal limitation in the establishment stage is the primary cause of a reduction in native species (Galatowitsch and van der Valk 1996, Seabloom and van der Valk 2003). In highly disturbed areas, such as surface mines, natural wetlands can be separated from wetland creation areas. The scale and nature of disturbance associated with surface mining is such that isolation of water flows is essential to permit dry-condition excavation, therefore wetland creation projects are often isolated from the surrounding landscape for a number of years.

Natural colonization is less costly than transferring wetland soil, but the potential for its success on a largely disturbed landscape such as a surface mine can be quite low. Before committing to any method, a short-term, small-scale study can provide a means to evaluate the potential success of each method in a given area.

My objectives were to determine if: 1) the application of a thin layer of wetland topsoil can establish a wetland plant community within two years; and 2) natural colonization can be as effective as the application of wetland topsoil in establishing a wetland plant community in both the short and long term.

My hypotheses were:

a) if the application of a thin layer of wetland soil can establish a wetland plant community within two years, I hypothesize that a plant community following soil transfer would have similar vegetation characteristics as the donor wetlands, would be dominated by wetland plants, and would be similar in composition to the donor wetland plant community;
b) if natural colonization was as effective as the application of wetland soil in the short-term, I hypothesize that after two years plots that were not treated with transferred wetland soil would have similar vegetation characteristics and communities to plots that were treated with transferred wetland soil; and
c) if natural colonization was effective in the long-term then I hypothesize that opportunistic wetlands which were vegetated without human intervention would have wetland plant communities with similar characteristics to the donor wetlands.

2.2 Methods

Approach

To evaluate the success of each vegetation establishment method in the short-term I compared vegetation parameters and plant community composition for plots of transferred wetland soil and untreated control plots to natural wetland systems (or reference wetlands). Reference wetlands are sites that are chosen to represent natural wetland systems in a given region (Brinson and Rheinhardt 1996). The closer the created wetland is to the natural wetland the more successful the project. To evaluate the success of natural colonization over a long-term period I compared vegetation parameters and plant community composition for a series of opportunistic wetland plant communities to the same reference sites. Opportunistic wetland plant communities were formed by natural colonization following disturbance. In this study I chose to use two donor wetlands as both the source of wetland soil to be transferred to the study site and as reference sites since they are relatively undisturbed and are representative of wetland systems in the immediate area.

Site Description

The study was conducted at the Genesee Coal Mine approximately 80 km west of Edmonton, Alberta, Canada (Figure 2.1). The two donor wetlands (D1 and D2) were located in undisturbed areas of the mine (Table 2.1). The donor wetland sites were the source of wetland soil for the soil transfer plots and each contained nine plots. Donor wetland plot layout mirrored the transferred soil plots in size and shape. The research site (RS) was located on the post-mining landscape and contained 24 random plots: 18 transferred soil treatment plots and six subsoil control plots (Figure 2.2). The subsoil plots were made to measure natural colonization at the RS. Four opportunistic wetlands (O1, O2, O3, and O4) were located in previously disturbed areas of the mine site with each containing six plots chosen at random.

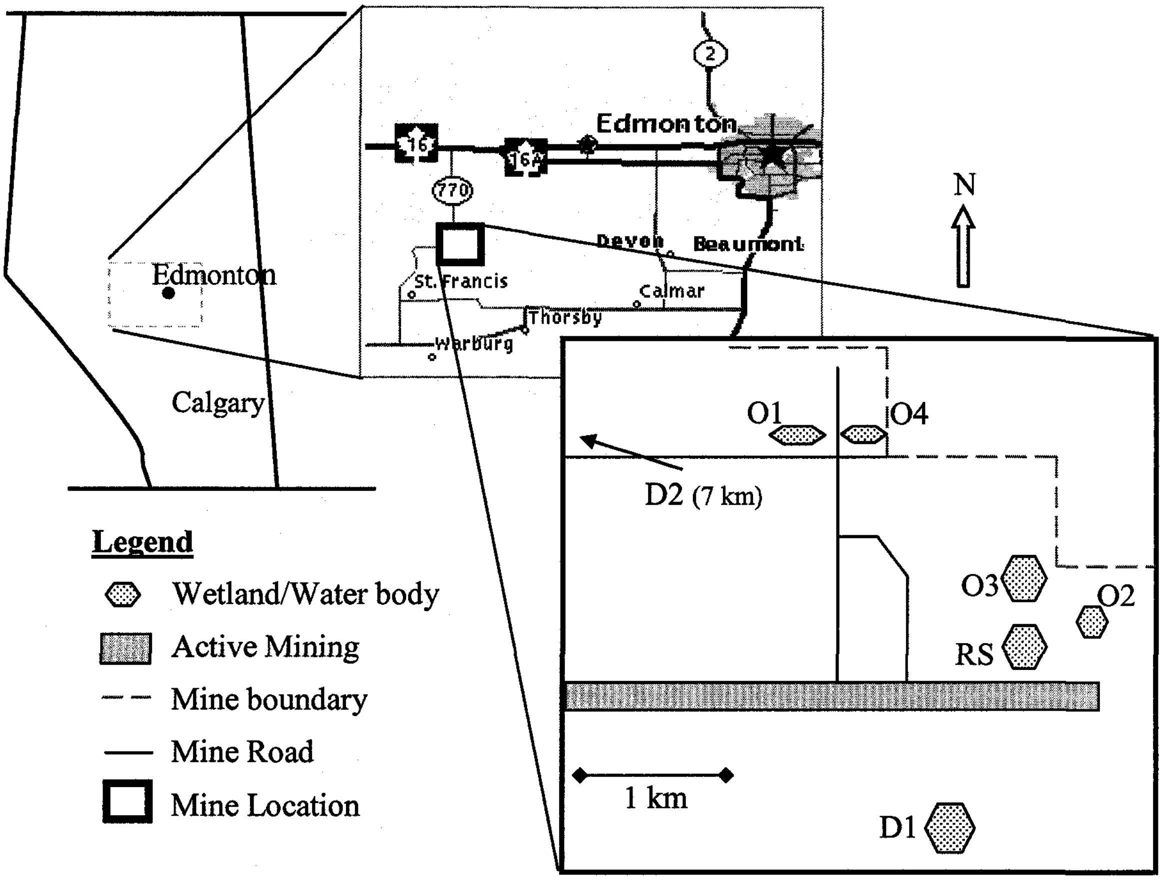

Figure 2.1: Locator and site map showing the location of the study site and the configuration of the wetlands studied.

Table 2.1: Description of the studied wetlands and their distance from the research site.

Site	**Type**	**Location**	**Description**	**Distance (km)***
D1	Donor	SW16	Seasonally flooded wet meadow within managed cattle pasture (9 donor plots)	1.6
D2	Donor	NW25	Permanently flooded wetland within managed cattle pasture (9 donor plots)	7.0
O1	Opportunistic	SE29	Created following land reclamation (1992); used for offsite cattle watering (6 plots)	2.3
O2	Opportunistic	SW22	Topsoil stripped (date unknown); receives runoff from sodic spoils (6 plots)	0.3
O3	Opportunistic	SE21	Topsoil stripped (93-94); contained with berm, may receive runoff from sodic soils (6 plots)	0.2
O4	Opportunistic	SW28	Used for excavating road building material (87-89); damage to banks from cattle pasturing prior to study (6 plots)	2.0
RS	Research Site	SE21	Water storage basin; partial subsoil and topsoil (18 transferred soil and 6 subsoil plots)	NA

* Distance from research site

2.2.1 Study Set-Up

The area surrounding the RS has been contoured with overburden material in early spring 2003 to drain surface water into a central water storage basin. The RS occupied approximately one quarter of the basin perimeter (Figure 2.2) and was covered with a layer of subsoil approximately 50 cm deep. Salvaged wetland soil was transported to the RS from the upper 15 cm horizon of the two donor wetlands in May 2003 and stockpiled there during the two weeks of plot construction. Transferred wetland soil was spread by hand approximately 10 cm deep over nine randomly selected plots per donor wetland. A degradable geotexile encircled each plot to prevent soil migration and cross-contamination. Each plot was 1.0 m wide and extending at least 1.0 m up and down gradient beyond the forecasted waterline. A 0.5 to 1.5 m space between plots served as a buffer area between plots and allowed foot access to the plots and water surface. Transplanted soil was disturbed during collection and transport and contained organic debris, mature plants, rootstocks, and plant propagules.

After the plots were constructed, the water level in the basin was raised to partially flood each plot. The basin was filled with surface runoff following rain events and was depleted by evaporation. Pumping from the mine cut was used to lower the water level following large storms and to raise the water level following long dry spells. The basin was connected to one other water storage basin (O3) during high water periods.

The area immediately surrounding the RS (~50 m radius) was devoid of vegetation at the start of the study. Vegetation in the immediate surrounding area increased during the two-year study but remained quite sparse and was limited to a few weedy species.

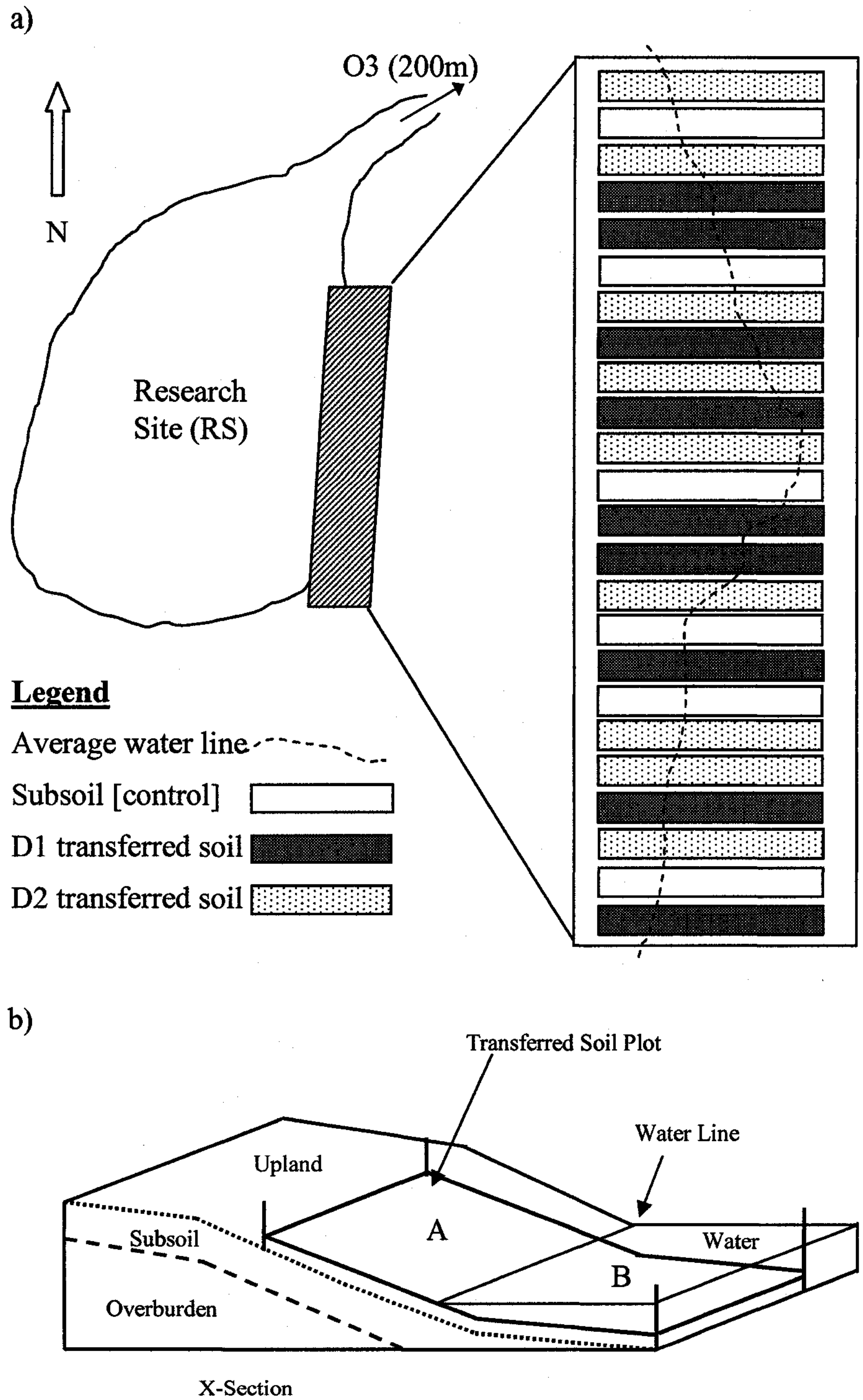

Figure 2.2: Diagram of the RS including: a) plot layout and average water line, and b) a cross sectional view of an individual plot.

2.2.2 Data Collection

I split each plot into two 1 m^2 subplots: one above (A) and the other below (B) the waterline (Figure 2.2). For each subplot I measured four vegetation characteristics: species richness, percent aerial cover of vegetation, and the maximum and average heights of all vascular plants. Cover measurements were recorded on a scale of 0–100% in increments of 5%. Average height measurements were estimated to the nearest 5 cm. I identified all plants in each subplot to the lowest possible taxonomic group and estimated their percent aerial cover during each vegetation survey. Throughout the study I conducted cover and average height measurements personally to reduce estimation bias caused by multiple observers (Kercher *et al.* 2003).

I collected data monthly at the RS from June to September in 2003 and approximately twice monthly from May to August in 2004. In 2003 I removed one of the D2 transferred soil plots and one of the subsoil plots from analysis due to flooding and erosion. In 2004 one D1 and one D2 transferred soil subplot (B) were removed due to sedimentation. I collected data monthly from June to August at both donor wetlands in both years. In early June 2004, five of my nine plots at D1 were disturbed by large machinery, hence, I was only able to conduct one complete vegetation survey at D1 that year. The remaining four plots were not affected and I collected data from them in July and August 2004. Data were collected from the opportunistic wetlands in July 2004 only.

2.2.3 Data Analysis

Evaluation of the results was separated into three parts. First I looked at differences in vegetation characteristics (height, cover, and species richness) between the different plot types (subsoil, transferred soil, donor wetland, and opportunistic wetland). Secondly I calculated a wetland indicator value for each plot to determine if the plant communities present on each plot are comprised of predominately wetland or upland species. Finally I compared the plant communities between the transferred soil plots and the other three plot types (subsoil, donor, and opportunistic).

For all statistical tests a significance level of 0.05 was used, but I also comment on results that are between 0.05 and 0.10 as marginally significant. When a difference at a significance level of 0.05 was observed for plot type I used the Games-Howell (GH) post hoc analysis to determine difference between types. GH is conservative and robust to heterogeneous variances and unequal sample sizes (Day and Quinn 1989). All analyses follow Zar (1999) unless otherwise noted.

Vegetative Characteristics

To evaluate the success of the soil transfer I compared the vegetation characteristics between the transferred soil plots and the donor wetlands using three factor (plot type, donor wetland, and subplot) ANOVA. To evaluate natural colonization compared to transferred soil on a short-term basis I compared the vegetation characteristics between the transferred soil plots and the subsoil plots at the RS using two factor (plot type and subplot) repeated measures ANOVA. To evaluate natural colonization on a long-term basis I compared vegetation characteristics between the transferred soil plots, donor wetlands, and opportunistic wetlands using two factor (plot type and subplot) ANOVA with each opportunistic wetland considered a different plot type.

Since the vegetation surveys at the donor wetlands were not highly variable within each year I used only the July results from each year for comparisons with the RS July data. I used the data collected at the opportunistic wetlands in July 2004.

Wetland Indicator

I calculated a weighted average wetland indicator value (WI) for each plot based on Wentworth *et al.* (1988) to categorize the resulting vegetation as either upland or wetland. WI values are calculated by summing the product of the abundance and indicator value for each species in a sample. WI ranges from 1.0, indicating an obligate wetland plant community, to 5.0, indicating an obligate upland plant community. An indicator value less than 3.0 indicates wetland vegetation. Wetland indicator values for each species were based on the mid-point of the national indicator range from Reed (1988). For abundance measurements, species cover estimates were standardized out of 100% and then averaged over each of the two years for both the RS and donor wetlands. Any species with less than 5% cover in a single survey was removed from that survey before averaging. I used a one-way t-test to determine if the mean indicator value for each plot type was below, above, or equal to 3.0. I then compared the transferred soil WI to the donor wetland WI and the opportunistic wetlands WI with a two factor ANOVA (plot type and subplot).

Similarity Measures

I compared the composition of the resulting vegetation on the transferred soil plots to the subsoil plots, the donor wetlands, and the opportunistic wetlands using two different measures of similarity: Sorenson's coefficient of similarity for presence-absence data and percentage similarity for abundance data (Krebs 1999). Species lists were complied for each of the RS plots based on cumulative yearly data and for the donor wetland plots based on cumulative data from both years. For abundance measurements, species cover estimates were standardized out of 100% and then averaged over each of the two years for both the RS and donor wetlands. Any species with less than 5% cover in a single survey was removed from that survey before averaging.

I calculated the similarity measures by comparing every pair of transferred soil and subsoil plots or pairs of transferred soil and donor wetland plots for each year, and pairs of transferred soil and opportunistic wetland plots for 2004 only. This procedure produced replicated measures for each transferred soil per comparison plot. I then averaged the replicated measures for each of the transferred soil plots per year before analysis. The similarity measures were compared using two factor (plot type and donor soil type) ANOVA.

2.3 Results

A total of 52 different vascular plant species were identified at the RS throughout the study period (Table 2.2). Few sedge individuals reached maturity within the time period of the study, therefore, for similarity and WI measures the genus *Carex* was treated as one species. *Carex sp.* was the dominant species at the donor wetlands with approximately 80% cover and for the transferred soil plots with 83% cover in 2003 (10% of total area) and 56% cover in 2004 (20% of total area).

Table 2.2: Cumulative species list of all identified vascular plant species in the transferred soil plots (RS), subsoil plots (S) and the donor wetland plots (D), including their wetland indicator status. "X" indicates presence in the plot type.

Scientific Name	Common Name	Indicator	D1		D2		S
			RS	D	RS	D	
Alopecurus aequalis	Short-Awned Foxtail	OBL	X		X	X	
Artemisia absinthium	Absinthe	NIL			X		
Arabis lyrata	Lyre-Leaved Rock Cress	FACU	X	X	X		
Axyris amaranthoides	Russian Pigweed	NIL	X				
Beckmannia syzigachne	Slough Grass	OBL	X		X	X	
Bidens cernua	Nodding Beggar-Ticks	FACW				X	
Carex aquatilis	Water Sedge	OBL	X	X		X	
Carex atherodes	Awned Sedge	OBL	X	X	X	X	X
Carex bebbii	Bebb's Sedge	OBL		X			
Calamagrostis Canadensis	Bluejoint	FACW	X	X		X	
Carex lasiocarpa	Hairy-Fruited Sedge	OBL	X				
Carex retrorsa	Turned Sedge	FACW	X			X	
Cardamine pensylvanica	Pennsylvanin Bitter Cress	FACW	X	X			
Carex sp.	Sedge species	OBL*	X	X	X	X	X
Carex utriculata	Beaked Sedge	OBL	X	X	X	X	
Callitriche verna	Vernal Water-Starwort	OBL	X	X	X	X	
Carex viridula	Green Sedge	FACW				X	
Chenopodium album	Lamb's Quarters	FAC	X		X		X
Cirsium arvense	Canada Thistle	FACU	X		X	X	X
Corydalis aurea	Golden Corydalis	NIL	X				
Crepis tectorum	Narrow-Leaved Hawk's Beard	FACU			X		X
Eleocharis palustris	Creeping Spike Rush	OBL				X	
Epilobium glandulosum	Purple-Leaved Willowherb	FAC	X			X	
Equisetum arvense	Common Horsetail	FAC		X		X	
Erucastrum gallicum	Dog Mustard	NIL	X				
Euphorbia glyptosperma	Thyme-Leaved Spurge	NIL	X	X	X		X
Galium trifidum	Small Bedstraw	FACW	X	X		X	
Geum aleppicum	Larged-Leaved Avens	FAC			X		
Glyceria grandis	Tall Manna Grass	FACW	X	X	X	X	X
Glaux maritime	Sea Milkwort	FACW	X				
Gnaphalium palustris	Marsh Cudweed	FACW			X		X
Hordeum jubatum	Foxtail Barley	FAC	X		X		X
Iva axillaries	Poverty Weed	FAC	X		X		X
Juncus bufonius	Toad Rush	FACW			X		
Kochia scoparia	Kochia	FACU			X		X

Scientific Name	Common Name	Indicator	D1 RS	D1 D	D2 RS	D2 D	S
Lemna minor	Common Duckweed	OBL				X	
Matricaria matricarioides	Pineapple Weed	FACU	X				
Matricaria perforata	Scentless Chamomile	FACU			X		
Melilotus alba	White Sweet Clover	FACU	X		X		X
Mentha arvensis	Wild Mint	FAC				X	
Mitella nuda	Bishop's-Cap	FACW		X			
Phalaris arundinacea	Reed Canary Grass	FACW				X	
Plantago major	Common Plantain	FAC	X		X	X	
Polygonum amphibium	Water Smartweed	OBL	X		X	X	
Polygonum lapathifolium	Dockleaf Smartweed	FACW	X		X	X	X
Potentilla norvegica	Rough Cinquefoil	FAC	X	X	X	X	X
Poa palustris	Fowl Bluegrass	FAC	X	X	X	X	
Poa pratensis	Kentucky Bluegrass	FACU	X	X	X		
Potamogeton sp.	Pondweed species	OBL*		X	X	X	
Ranunculus sceleratus	Celery-Leaved Buttercup	OBL	X	X	X	X	
Ranunculus gmelinii	Yellow Water-Crowfoot	FACW			X	X	
Ranunculus macoonii	Macoon's Buttercup	OBL	X	X	X	X	X
Rorippa islandica	Marsh Yellow Cress	FACW	X		X	X	X
Rumex crispus	Curled Dock	FAC	X	X	X	X	
Scutellaria galericulata	Marsh Skullcap	OBL		X		X	
Scripus sp.	Bulrush species	OBL*	X	X		X	
Sium suave	Water Parsnip	OBL				X	
Sonchus arvenis	Sow Thistle	FACU	X		X	X	
Taraxacum officinale	Common Dandelion	FACU	X	X	X	X	X
Thlaspi arvense	Stinkweed	FACU	X		X		X
Trifolium hybridum	Alsike Clover	FACU	X	X	X	X	X
Urtica dioica	Stinging Nettle	FAC				X	
Veronica scutellata	Marsh Speedwell	OBL	X				
Vicia Americana	Wild Vetch	FACU	X		X		
Totals			**43**	**25**	**38**	**38**	**19**

<u>Indicator Categories</u> (adapted from Reed 1988)

OBL (Obligate Wetland) – 99% probability of occurring in wetlands under natural conditions
FACW (Facultative Wetland) – 67-99% probability of occurring in wetlands, occasionally in non-wetlands
FAC (Facultative) – Equally likely to occur in wetlands or non-wetlands
FACU (Facultative Upland) – 67-99% probability of occurring in non-wetlands, occasionally in wetlands
UPL (Obligate Upland) – Occur in wetlands in another region, but occur almost always (estimated probability >99%) under natural conditions in non-wetlands in the region specified. If a species does not occur in wetlands in any region, it is not on the National List.
NIL (Not in List) – no information available to categorize
* indicator status is average of all of the species in the genus possibly occurring at the site

2.3.1 Vegetation Characteristics

Transferred Soil and Subsoil

The transferred soil plots had higher vegetation cover, height, and species richness than the subsoil plots (Figures 2.3 and 2.4, $p<0.001$). Vegetation parameters significantly increased in all of the plots from 2003 to 2004 ($p<0.001$). In the first year D1 transferred soil plots had greater vegetation cover and greater height than D2 transferred soil plots, but by the second year there was no significant difference between the two treatments ($p>0.1$).

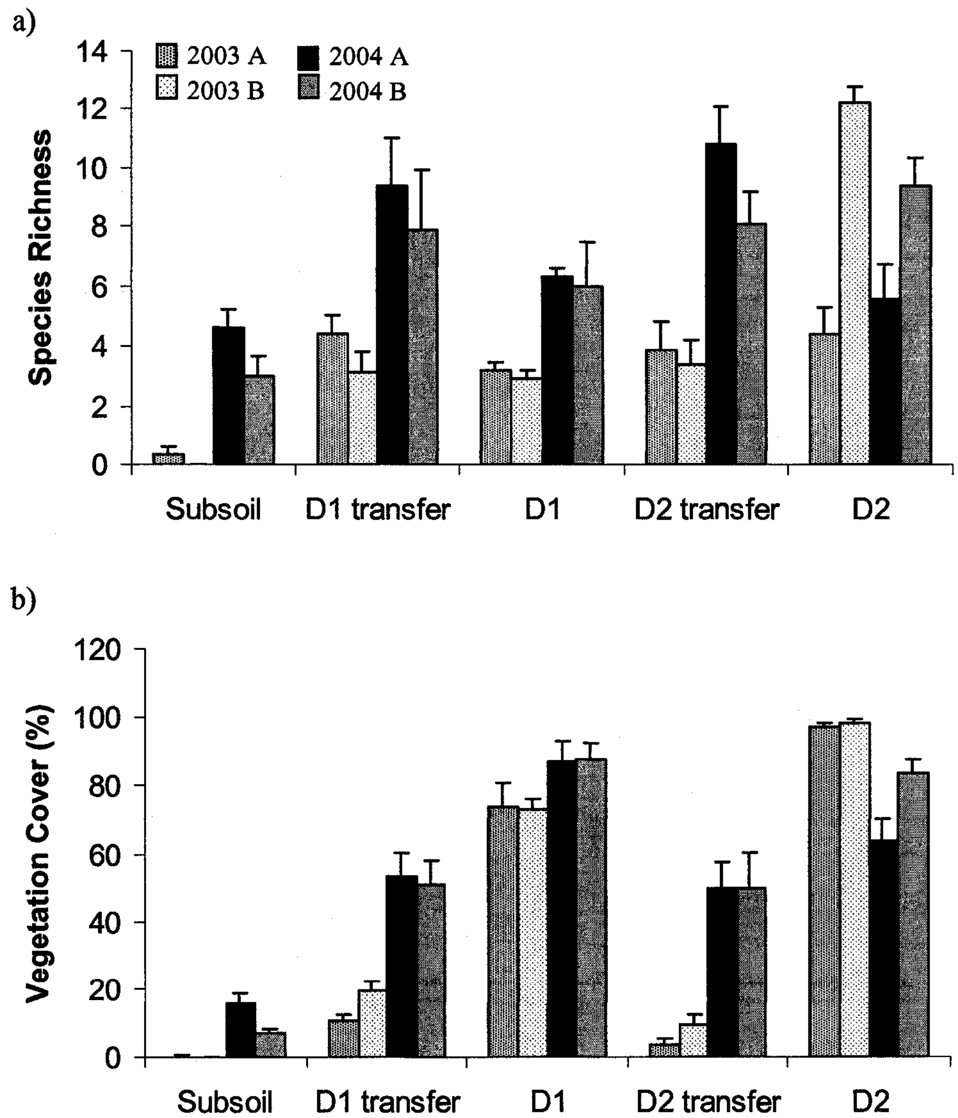

Figure 2.3: Species richness (a) and vegetation cover (b) for July 2003 and 2004 for the subsoil plots, transferred soil plots, and donor wetland plots separated by subplot. Error bars represent standard error.

Transferred Soil and Donor Wetlands

In 2003 vegetation in the transferred soil plots showed significantly reduced cover, average height, and maximum height than the donor wetland plots (Figures 2.3 and 2.4, $p<0.001$). By 2004 vegetation cover and average height were still less on the transferred soil plots than on the donor wetland plots ($p<0.001$), but there was no difference in maximum height between the sites ($p>0.2$). The D1 transferred soil plots had similar species richness to D1 donor wetland plots for both years ($p>0.1$), whereas the D2 transferred soil plots had lower species richness in 2003 than D2 donor wetland plots ($p<0.001$). In 2004 the difference between the two sites was marginal ($p=0.08$).

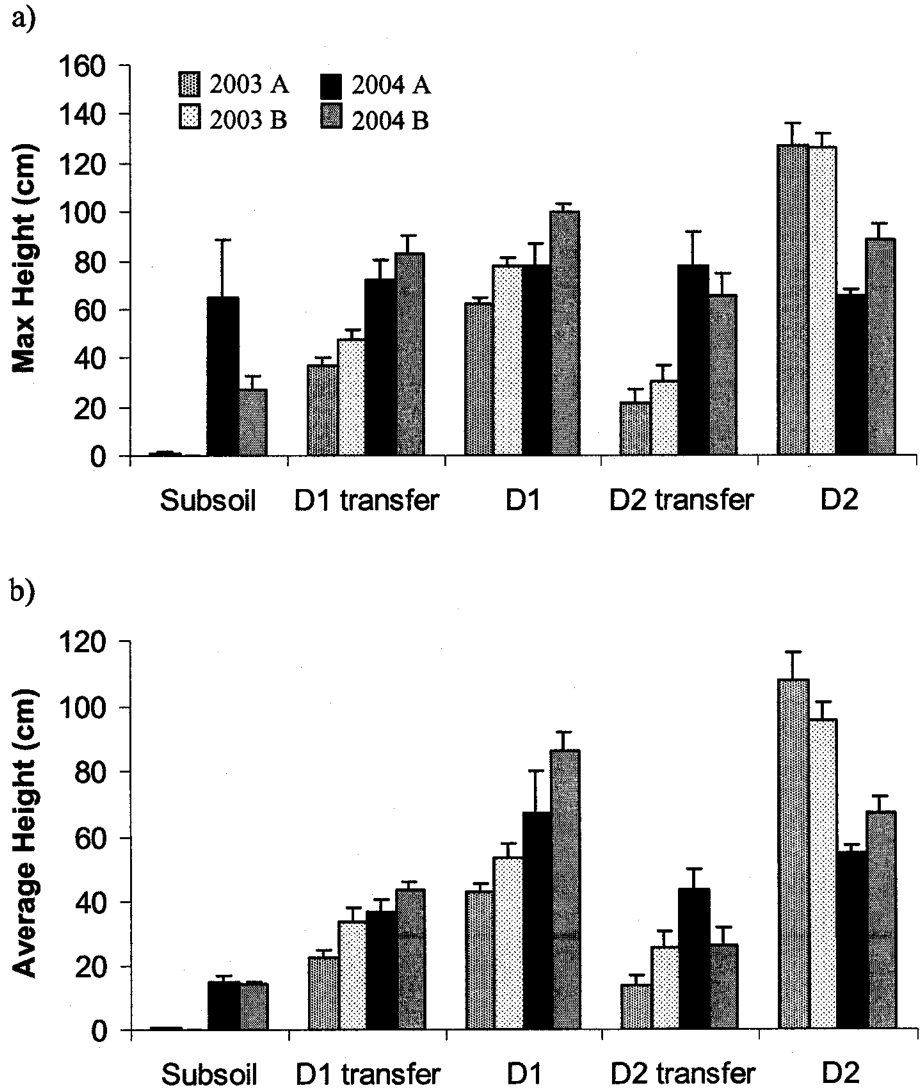

Figure 2.4: Maximum (a) and average height (b) for July 2003 and 2004 for the subsoil plots, transferred soil plots, and donor wetland plots separated by subplot. Error bars represent standard error.

Opportunistic Wetlands

The vegetation in the subsoil plots did not resemble that in the opportunistic wetlands after two years ($p<0.05$, Figure 2.5), except for maximum height at O3. The transferred soil plots and the opportunistic wetland plots had many similarities and many differences. O3 was similar to the transferred soil plots for vegetation cover, average height, and maximum height, but had lower species richness than the transferred soil plots. The other three opportunistic wetlands had higher vegetation cover and height than the transferred soil plots, except for similar average height between the transferred soil plots and O1. Species richness was similar between the opportunistic wetlands and the transferred soil plots.

The opportunistic wetlands were similar to the donor wetlands, except for maximum height. Two of the opportunistic wetlands, O1 and O3, had similar maximum heights to the donor wetlands. The other two wetlands, O2 and O4, had greater maximum heights than the donor wetlands. Vegetation height was highly variable between the donor and opportunistic wetlands. The opportunistic wetlands had more tall emergent species such as *Typha sp.*, while the donor sites had a greater dominance of sedges.

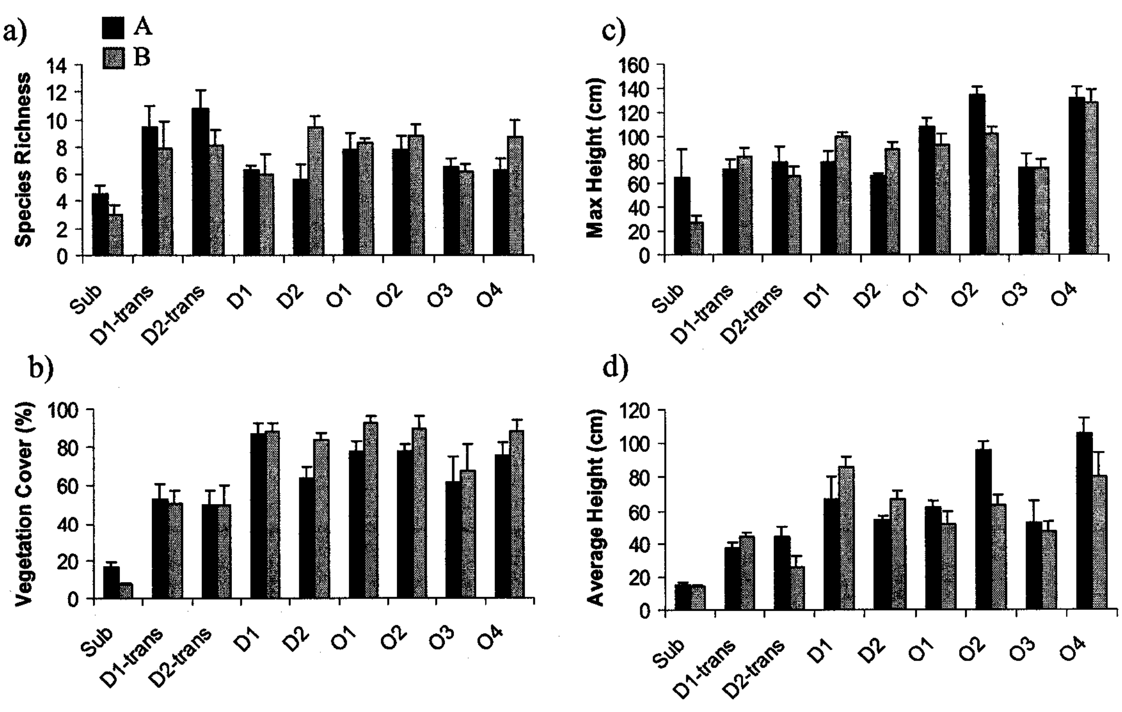

Figure 2.5: Species richness (a), vegetation cover (b), maximum height (c) and average height (d) for the opportunistic wetlands separated by subplot.

2.3.2 Wetland Indicators

The transferred soil plots WI indicated a dominance of wetland rather than upland vegetation ($p<0.01$, Figure 2.6), therefore the vegetation that grew in the transferred soil plots was primarily wetland vegetation. The D2 transferred soil plots had a higher WI than the D1 transferred soil plots ($p<0.05$), indicating that there was less dominance by wetland species for the D2 transferred soil plots than the D1 transferred soil plots. The D1 transferred soil and donor wetland plots had similar WI values, whereas the D2 transferred soil plots had a higher mean WI than the D2 donor wetland plots ($p<0.01$). The A subsoil subplots had a slightly greater proportion of upland than wetland vegetation, but the B subplots had equal amounts of both upland and wetland vegetation.

The WI for the A and B subplots for the opportunistic wetlands differed significantly. O1 and O3 A subplots had WI's significantly above 3, indicating upland vegetation. O2 had a WI for its A subplots of approximately 3. Only O4 had a WI for its A subplots that was significantly less than 3, indicating wetland vegetation. All of the B subplots had WI's below 3, except for O3 whose WI was approximately 3.

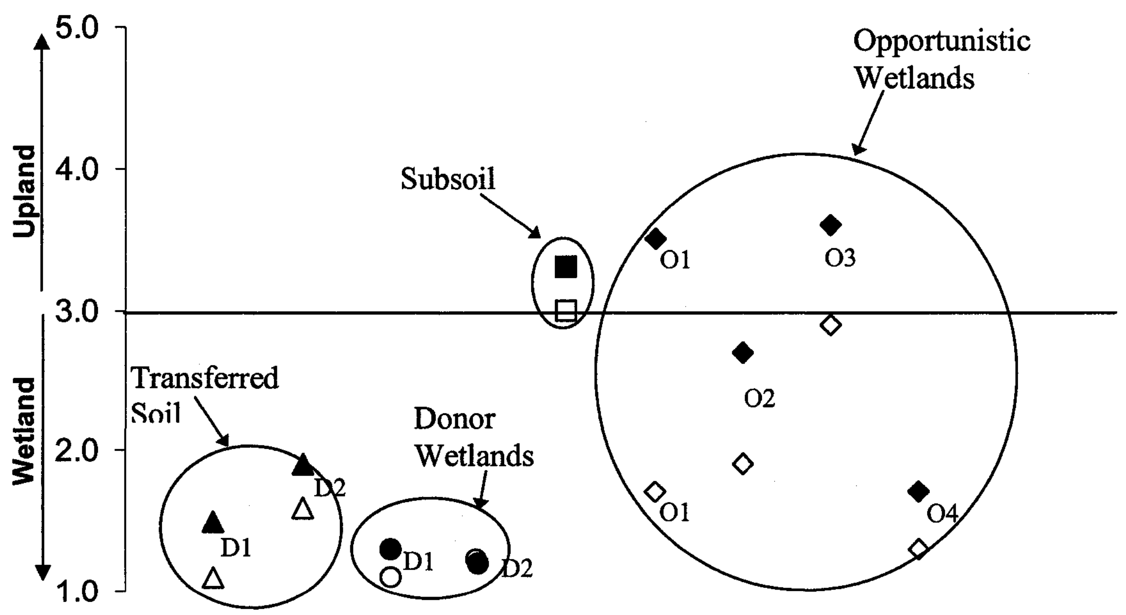

Figure 2.6: Wetland indicator values for the opportunistic (◇), transferred soil (△), subsoil (□) and donor wetland (○) plots. Solid shapes represent above waterline subplots (A) and open shapes represent below waterline subplots (B).

The four opportunistic wetlands were not similar to each other. O1 and O2 had higher WI's than D1 transferred soil plots, while O3's WI was higher than that of both D1 and D2 transferred soil plots. O4 had similar values of WI to the transferred soil plots.

2.3.3 Similarity Measures

The transferred soil plots were more similar to the donor wetland plots than the subsoil plots in 2003 (Figure 2.7, $p<0.001$). In 2004, D2 donor wetland plots remained more similar to the D2 transferred soil plots ($p<0.05$). The D1 transferred soil plots were more similar to the subsoil plots based on Sorenson ($p<0.05$), but were more similar to the D1 donor wetland plots based on percent similarity. Similarity measures were low for the subsoil plots in the first year due to the absence of vegetation, but increased in the second year.

Sorenson's coefficient for the opportunistic wetlands was lower than the coefficient for the D2 donor wetland plots, indicating that the D2 transferred soil plots were more similar to the D2 donor wetland plots than to the opportunistic wetland plots ($p<0.01$). The D1 transferred soil plots did not show this same trend. Only the O3 plots were less similar to the D1 transferred soil plots than the D1 donor wetland plots ($p<0.01$). The other three wetlands were no more similar to the D1 transferred soil plots than the D1 transferred soil plots to the D1 donor wetland plots ($p>0.30$). Percent similarity measurements were significantly less for all of the opportunistic wetlands than the donor wetlands ($p<0.01$), indicating that based on abundance the transferred soil plots were more similar to the donor sites than to the nearby opportunistic wetlands.

a)

b)

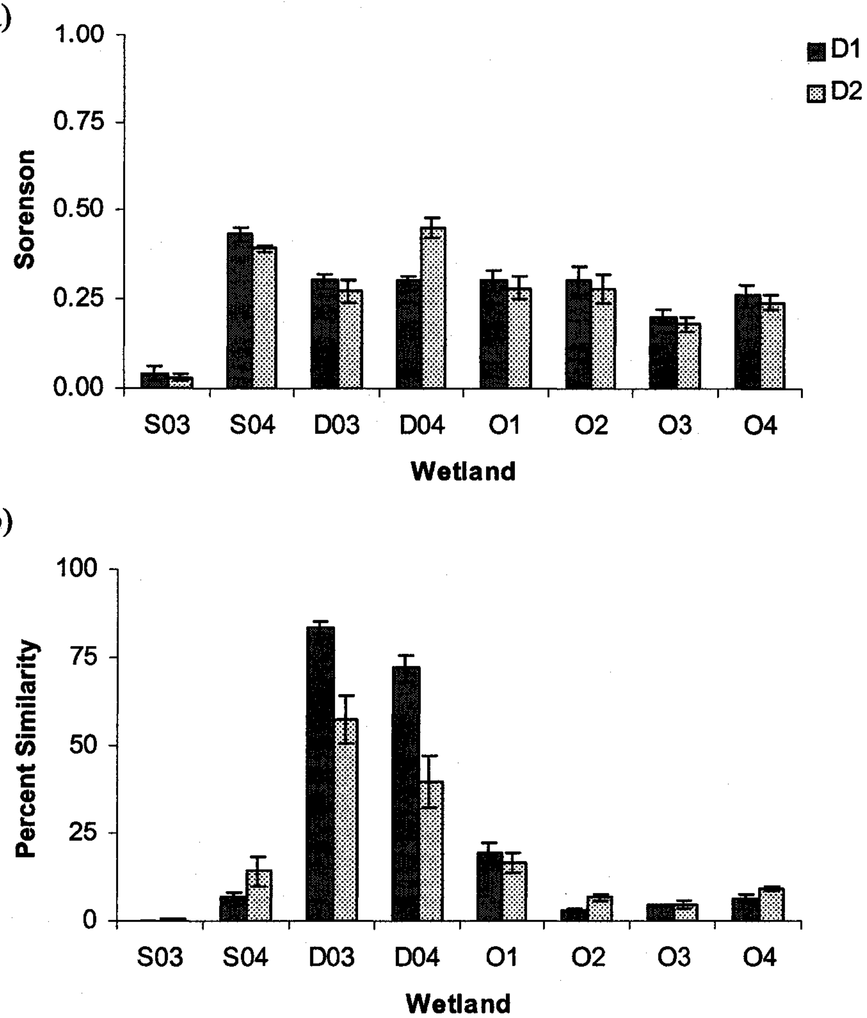

Figure 2.7: Sorenson (a) and percent similarity (b) comparing the wetland soil transfer plots (D1 & D2) to the subsoil plots in 2003 (S03) and 2004 (S04), the donor wetland plots in 2003 (D03) and 2004 (D04), and the opportunistic wetlands. Error bars represent standard error.

2.4 Discussion

Wetland Topsoil Transfer

Plots treated with transferred wetland topsoil supported wetland plant communities after two years. Transferred soil plots had maximum height and species richness similar to the donor wetlands, but vegetation cover was lower than the donor wetland plots. Given more time, vegetation cover at the RS should match the donor and opportunistic wetlands. The transferred soil plots increased in cover from 0% to an average of 60% within two growing seasons with some plots reaching 95% total cover. Brown and Bedford (1997) and Stauffer and Brooks (1997) observed similar increases in vegetation cover from the first to second year, but they found greater total cover two years following transplantation of wetland soil than I did. Vegetation establishment on the plots at the RS was very slow in the first year, but once established the vegetation spread rapidly in the second year.

Average height was also lower on the transferred soil plots than the donor wetland plots after two years. Average height is a function of plant species and the environment in which they grow. The plant community was not the same between the transferred soil plots and the donor wetlands. The occurrence of many species at the RS was erratic or limited to a few plots, resulting in low values of Sorenson's index even though many species were common to both sites. Percent similarity values were much higher than Sorenson's coefficient due to the dominance of sedges. Since sedges were the dominant species at both sites, if the assemblage of species were controlling the average height measurements I would expect them to be the same. However, they were not, because the sedges growing in the transferred soil plots were not growing as high as their counterparts on the donor plots, perhaps because there was little competition for light resources in the transferred soil plots. If light sources are limited most plant species will exhibit stem elongation to overtop neighbours and intercept more light. *Carex sp.* are no exception. Perry and Galatowitsch (2004) observed that when grown in a partial shade *Carex hystericina* was taller than when grown in full sunlight under limited competition. The plants at the donor wetlands were much denser densities than at the RS and may be taller due to competition for light resources.

The transfer of natural wetland soil was successful in establishing sedges because it transplanted live plants and rhizomes to the new wetland site. Dispersal limitations because of isolated wetlands (Seabloom and van der Valk 2003) and the low viability of *Carex sp.* seeds (Budelsky and Galatowitsch 1999, van der Valk et al. 1999) have led many researchers to recommend transplanting rhizomes (Yetka and Galatowitsch 1999) or immature individuals (Steed and DeWald 2003) instead of relying on natural dispersal for sedges. This study shows that transferral of wetland topsoil with an intact propagule bank is a viable alternative method for establishing *Carex sp.* during wetland restoration or creation.

Natural Colonization

The subsoil plots at the RS had low species richness and cover after two years, showing there was little natural colonization of plants at the RS. Poor soil conditions, including low available nutrients and low soil moisture, in the subsoil plots may have prevented some recruitment from natural colonization, magnifying the differences between natural colonization (subsoil plots) and the transferral of wetland soil. Vegetation on the subsoil plots trended towards upland rather than wetland plant communities. The subsoil plots were dominated by *Iva axillaries* P. and *Melilotus alba* D., both considered weedy species of waste areas (Royer and Dickinson 1999). Both *I. axillaries* and *M. alba* appeared on the transferred soil plots, but in low numbers compared to wetland plants. Burke (1997) found that donor soil prevented the germination of certain invading species in his study in Pennsylvania. I did not find similar results, since there did not appear to be any species limited to the subsoil plots.

At the end of the study a few wetland species were found on the subsoil plots. The source of these species is more likely the transferred soil plots rather than from offsite dispersal, as these species were rarely observed outside the transferred soil plot vicinity. For example, *Polygonum lapathifolium* appeared in some of the transferred soil plots in the first year, but did not appear in the subsoil plots until the second year. *Ranunculus sceleratus* flowered early in 2004 and produced seeds that appeared to germinate in some subsoil plots later in the season. In one case *Carex atherodes* was invading a subsoil plot with tillers from a neighbouring transferred soil plot. *C. atherodes* was also found in the buffer zones between plots in 2004.

The opportunistic wetlands have been developing for a much longer time than the wetland at the research site allowing, time for natural dispersal that might not have been evident at the research site over the two-year study period. Dispersal limitations in isolated wetlands can affect the composition of the plant community for periods as long as or longer than 12 years (Mulhouse and Galatowitsch 2003, Seabloom and van der Valk 2003).

All four opportunistic wetlands had similar vegetation cover and species richness as the donor wetlands, but they had very different plant communities. Percent similarity measures between the opportunistic wetlands and the donor wetlands were low. ranging from 1 to 21%. *Carex sp.*, although present at all of these sites, were not dominant in any of the opportunistic wetlands as they were at both of the donor wetlands. There was a higher proportion of upland species for these wetlands than at the donor wetlands. There were also more emergent species such as *Typha sp.* and *Scripus sp.* that were not found in large quantities at either the donor wetlands or the RS.

The vegetation history of the opportunistic wetlands is not known, but no formal planting of wetland vegetation took place at these sites. Some wetland vegetation may have survived disturbance, therefore seed dispersal may not be the only source of propagules to these sites. The opportunistic wetlands are much younger than the donor wetlands. Mitsch and Wilson (1996) suggested that 15 to 20 years are required to evaluate the success of a freshwater marsh creation project. Only one of the opportunistic wetlands, O4, was greater than 15 years old and it was also the only opportunistic wetland to have WI values similar to those of the transferred soil plots. The distance of the RS from vegetation, upland or wetland, was much greater than for the opportunistic wetlands. This may have reduced the amount of wildlife and waterfowl using the RS since waterfowl can be effective at dispersing wetland plant seeds to isolated wetlands (Mueller and van der Valk 2002).

The donor wetlands that were used as the reference did not have similar characteristics as the opportunistic wetlands or the RS, therefore, using the reference wetland evaluation system may not have been appropriate in this case. One of the different characteristics is basin morphology. Three of the opportunistic wetlands, O1, O3 and O4, had steeper banks and deeper water than the donor wetlands. Deep water favours tall emergent species such as bulrushes and cattails (Cronk and Fennessy 2001) rather than sedges. Also donor wetlands were within managed cattle pastures, whereas cattle grazing did not disturb the opportunistic wetlands or the RS. The donor wetlands had evidence of cattle using them for food and water, as well as trampled areas, but they did not appear to be over grazed. Grazing can affect plant community composition as it adds stress to certain species causing shifts in competitive ability (Gurevitsh *et al.* 2002). It might therefore be more correct to look at the plant communities at the various sites in isolation or rely on the WI values to determine the success of each vegetation establishment method.

2.5 Conclusions and Recommendations

Conclusions

Transferring wetland topsoil to the RS immediately introduced propagules to the site, thereby speeding up vegetation establishment over natural colonization in the first two years. The vegetation that established on the transferred soil plots in the first two years resembled the donor wetlands and contained a greater proportion of wetland plants than the opportunistic wetlands where seed dispersal was the only source of wetland plant species.

Over a time period greater than two years, natural colonization by seed dispersal may be a viable alternative at the Genesee Mine. The plant communities present at the opportunistic wetlands contained many wetland species and wetland plants dominated the oldest of these communities. Opportunistic wetland plant communities differed from those in the donor wetlands. The donor wetlands were dominated by sedge meadow species, whereas the opportunistic wetlands were not. This may be the result of dispersal limitations associated with sedge meadow species, or it may be the result of differences between the opportunistic and donor wetlands such as bank steepness, water depth, cattle grazing, and/or time for plant community development.

Recommendations

Since both natural colonization and soil transfer cannot be ruled out as viable methods to establish wetland plants at the Genesee Mine, the choice of which method to use should be based on available resources and goals of the project. Transferring wetland soil will be more costly and labour intensive than using natural colonization, but it has the potential to produce plant communities resembling donor wetlands more quickly. Natural colonization may take much longer to establish wetland plants, especially if the site is not connected to, or is a great distance from established wetland areas. Natural colonization can also lead to plant communities with more upland than wetland plants and has the potential to be dominated by invasive species.

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Chapter 3: The contribution of different plant propagules to the developing plant community following the transfer of wetland soil

3.1 Introduction

Wetland plant establishment following a transfer of wetland soil relies on plant propagules in the soil seed bank to colonize the newly created wetland. For wetland soil transfers to be successful, the soil must contain viable plant propagules, such as seeds, rhizomes, or corms. If seeds from the soil seed bank are the main contributor to the developing plant community then conditions at the new site must be appropriate for germination and seedling emergence. Light, temperature, moisture, and the chemical environment all play roles in stimulating seeds to germinate (Galinato and van der Valk 1986).

The seed bank in wetland soils is site specific with some wetland seed banks containing many propagules of many species while others do not. In an early study of prairie pothole wetlands, van der Valk and Davis (1978) found Prairie Pothole wetlands to contain between 21,000 to 42,000 seeds/m^2 of more than 40 species in the top 5 cm of soil. In another study comparing three year old restored to natural prairie potholes Galatowitsch and van der Valk (1996) found approximately 7000 seeds/m^2 in natural wetlands and only 3000 seeds/m^2 in restored wetlands. Burke (1997) recommended studying the seed bank of a soil before performing a soil transfer to ensure the seed bank is adequate and does not contain unwanted species. Examination of a soil's seed bank also gives an opportunity to study the effects of environmental conditions on seedling emergence.

Wetland vegetation establishment in the field is subject to variable environmental conditions that can create a stressful environment for seedling emergence. Small changes in environmental conditions during early plant establishment stages can change the composition of the resulting wetland community (Vivan-Smith and Handel 1996). Water is one of the most influential factors affecting the composition of wetland plant communities. The occurrence and magnitude of soil flooding and the amount of light getting though the water column and reaching the soil surface affect the germination, survival, and reproduction of wetland plant species.

Wetland creation following surface mining can be limited by the quantity and quality of available water. Surface mining disrupts the natural hydrologic pathways of the landscape by diverting natural waterways around the mining area and requiring onsite water storage to avoid contamination of off-site surface waters. Storage basins can easily develop into wetland areas, but the quality of water is frequently poor. Because runoff is the primary source of water in a disturbed landscape, there are often high concentrations of solids in the water of these storage basins (Bonta 2000). Suspended solids can absorb light and reduce the depth of light penetration for submerged plants (Cronk and Fennessy 2001). In addition the water level of storage basins can vary largely because of pulses of water from runoff during storm events.

To study the seed bank of the wetland soil used as a source of wetland plant propagules, I performed a seed bank emergence study in a greenhouse. The greenhouse setting also allowed control of the amount and quality of water to which the soil was exposed to. My first objective was to estimate the contribution of seeds versus other plant propagules from the soil seed bank. My second objective was to determine if turbidity and water level were affecting seedling emergence.

My hypotheses were:

a) if seeds from the soil seed bank were the main contribution to the developing plant community after a soil transfer I hypothesize that the field and emergence study plant communities will be similar;
b) if the turbidity in the field was affecting seedling emergence then I hypothesize that soil samples submerged with turbid water will have different numbers of species, different numbers of individuals, and a different assemblage of species than samples submerged with clear water in the emergence study; and
c) if water levels affected seedling emergence, I hypothesize that the saturated soil treatment in the emergence study will have different numbers of species, different numbers of individuals, and a different assemblage of species than the clear water submerged soil treatment.

3.2 Methods

Approach

In a seed bank emergence study, soil is subjected to environmental conditions that will influence germination and emergence of seedlings from the soil seed bank. For wetland emergence studies soil is often subjected to two environmental conditions: a saturated soil treatment where the soil is wet, but exposed to the atmosphere and a submerged soil treatment where the soil is flooded with a few centimetres of water. These two conditions are meant to simulate conditions where the most seeds germinate in wetlands.

In the emergence study, I prepared two water level treatments (saturated and submerged) to investigate the effects of water level on seedling emergence. I also prepared two treatments of water quality (turbid water and clear water) to investigate the effects of turbidity on wetland seedling emergence. All other environmental factors were constant between treatments.

Soil was collected for the emergence study from two donor wetlands and one subsoil area and rhizomes and roots were removed. The results of the emergence study were then compared against results from a field study where roots and rhizomes were not removed to examine the contribution of seeds versus other propagules in a developing plant community.

3.2.1 Field Study

Site Description

The field study was conducted at the Genesee Coal Mine approximately 80 km west of Edmonton, Alberta, Canada (Figure 3.1). The donor wetlands, D1 and D2 (Table 3.1), were the source of wetland soil for both field and emergence studies and each contained nine plots on undisturbed areas of the wetlands. Plot layout at the donor wetlands mirrored the transferred soil plots in size and shape. The research site (RS) was located on the post-mining landscape and contained 24 random plots: 18 transferred soil treatment plots and six subsoil control plots (Figure 3.2).

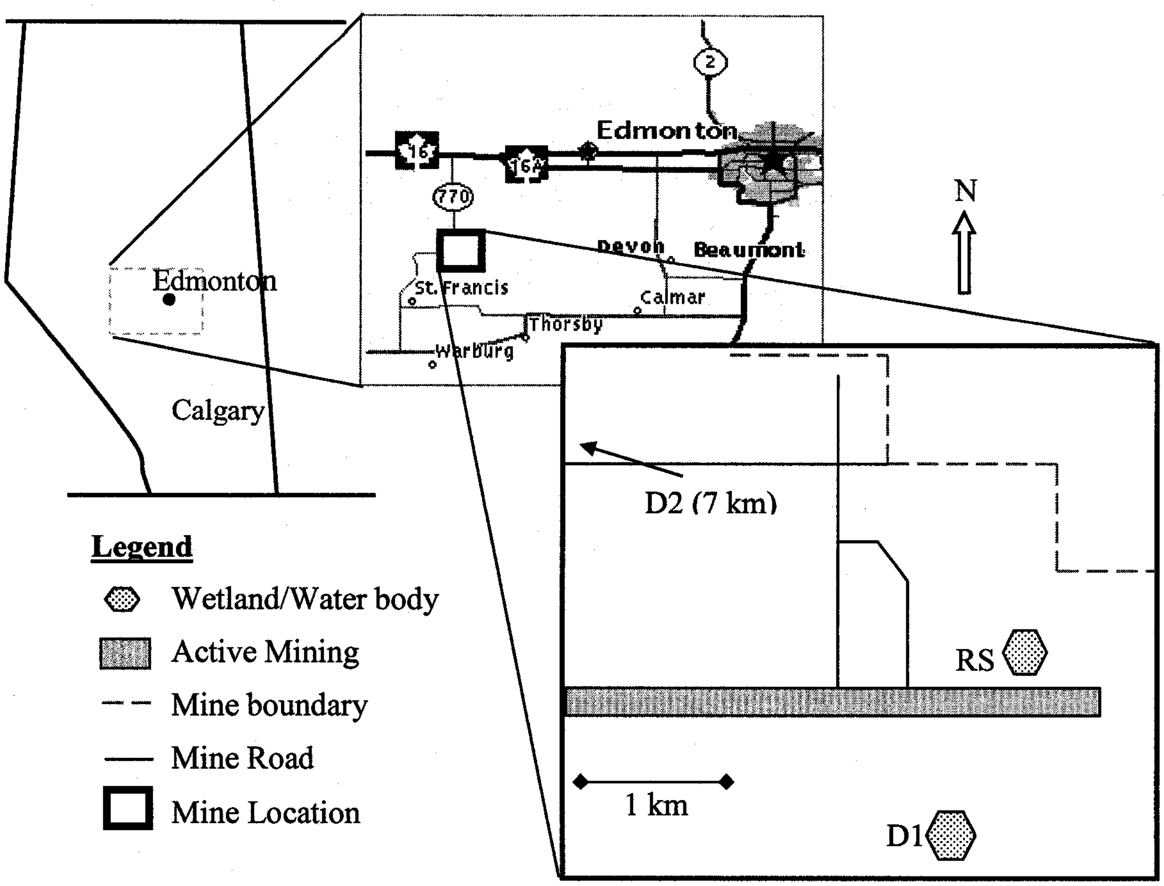


Figure 3.1: Locator and site map showing the location of the study site and the configuration of the wetlands studied.

Table 3.1: Description of the field study wetlands and their distance from the research site

Site	Type	Location	Description	Distance (km)*
RS	Research Site	SE21	Water storage basin; partial subsoil and topsoil (18 transferred soil & 6 subsoil plot)	NA
D1	Donor Wetland	SW16	Seasonally flooded wet meadow within managed cattle pasture (9 donor plots)	1.6
D2	Donor Wetland	NW25	Permanently flooded wetland within managed cattle pasture (9 donor plots)	7.0

*** Distance from research site**

Set-Up

The area surrounding the RS has been contoured with overburden material in early spring 2003 to drain surface water into a central water storage basin. The RS occupied approximately one quarter of the basin perimeter (Figure 2.2) and was covered with a layer of subsoil approximately 50 cm deep. Salvaged wetland soil was transported to the RS from the upper 15 cm horizon of the two donor wetlands in May 2003 and stockpiled there during the two weeks of plot construction. Transferred wetland soil was spread by hand approximately 10 cm deep over nine randomly selected plots per donor wetland. A degradable geotexile encircled each plot to prevent soil migration and cross-contamination. Each plot was 1.0 m wide and extending at least 1.0 m up and down gradient beyond the forecasted waterline. A 0.5 to 1.5 m space between plots served as a buffer area between plots and allowed foot access to the plots and water surface. Transplanted soil was disturbed during collection and transport and contained organic debris, mature plants, rootstocks, and plant propagules.

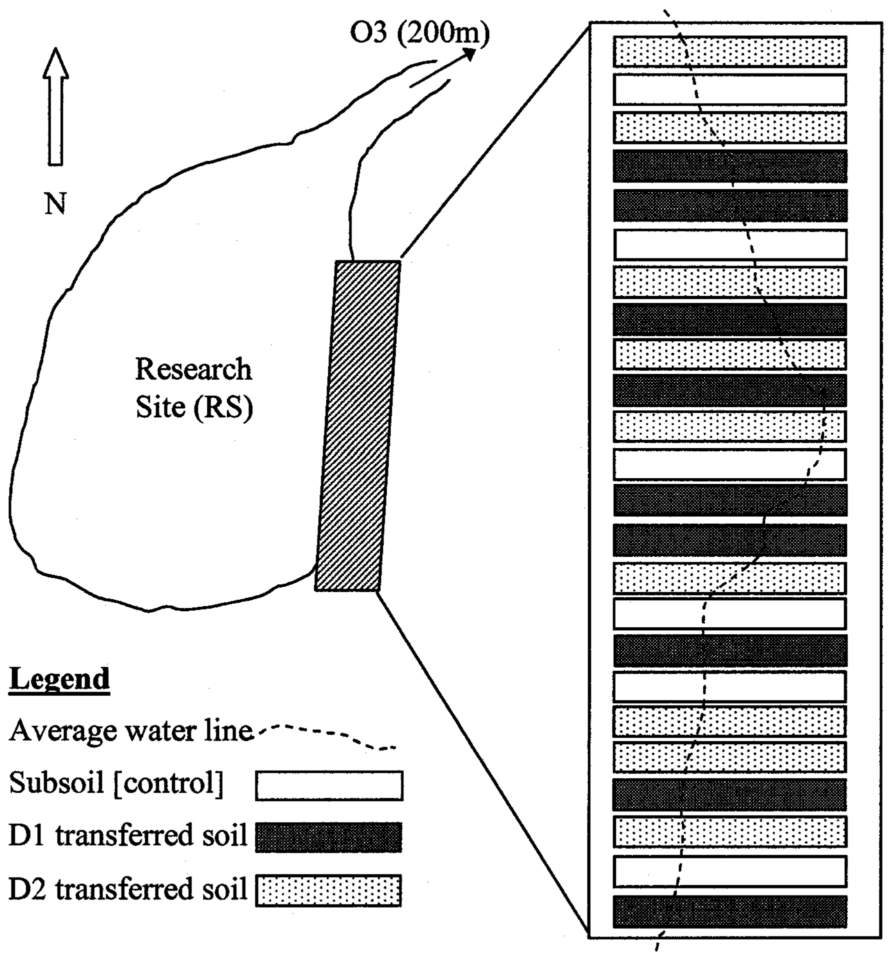
After the plots were constructed, the water level in the basin was raised to partially flood each plot. The basin was filled with surface runoff following rain events and was depleted by evaporation. Pumping from the mine cut was used to lower the water level following large storms and to raise the water level following long dry spells. The basin was connected to one other water storage basin (O3) during high water periods. There were no other surface connections to surrounding surface waters.

Data Collection

For each plot I identified all plants to the lowest possible taxonomic group throughout the first and second growing seasons. I collected data monthly at all three sites. I removed one D2 transferred soil plot and one subsoil plot from analysis due to flooding and erosion. In early June 2004 five of my nine permanent plots at D1 were disturbed by large machinery hence, I was only able to conduct one complete vegetation survey at D1 that year.

I used a staff gauge to record water level at the RS during each site visit, approximately four times monthly. During the winter of 2004 the gauge was damaged by ice and in the spring of 2004 it was moved and re-marked. To compare water levels from both years, all measurements were standardized based on setting the forecasted water line at 0 cm. The waterline for each plot was also recorded during each vegetation survey.

a)



b)

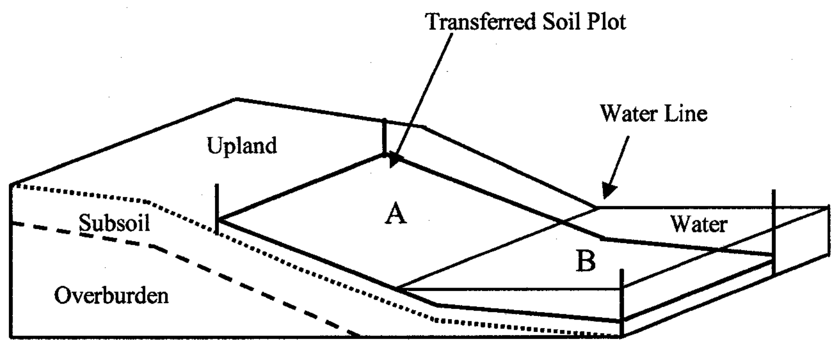


Figure 3.2: Diagram of the RS including: a) plot layout and average water line, and b) a cross sectional view of an individual plot.

Water Turbidity Testing

Water turbidity testing was conducted twice: once in June and once in August 2004, for the RS and two donor wetlands. Five consecutive turbidity measurements were made per day in the field using a HACH pocket turbidity meter. Samples outside of the turbidity meter range (i.e. >400 NTU) were diluted to bring values within the range of the meter.

3.2.2 Emergence Study

The emergence study was conducted at the University of Alberta greenhouses. The emergence study design followed van der Valk and Davis (1978) with saturated soil, submerged soil (clear water), and submerged soil with turbid (turbid water) water treatments. The turbid water treatment was meant to simulate light attenuation caused by high turbidity of the water at the RS.

Sample Collection

Soil samples were collected on October 24, 2003 after major autumn seed fall, but before major ground frost. I collected one set of samples from each of the two donor wetlands and from the subsoil at the RS. I sampled at three points (+1 m, 0 m, -1 m), with 0 m equalling the average water level, along five randomly placed transects at each of the wetlands. Transects were located on either side of the original excavation at the donor wetlands to obtain a representative sample of the soil used in the transferred soil plots. At the RS I collected samples upslope from the research plots to minimize disturbance to the research plots and to avoid contamination from high foot traffic areas. I collected each sample over 0.06 m^2 and to a depth of 5 cm. I left roots and rhizomes intact, but I trimmed remnant vegetation to within a few centimetres of the soil surface. Each sample was sealed in separate clear plastic bags before being placed in large opaque containers and stored outside to simulate a natural cold treatment.

Study Set-Up

In January 2004 the soil samples were moved inside and allowed to defrost slowly. I added tap water to each sample and agitated it by hand to break up root mats. Large roots, rhizomes, and organic debris were removed by hand. I then drained each sample through a 1 mm^2 mesh to capture seeds and most of the soil, but to drain out water. I combined equal portions of three prepared samples from the same site, one each from the +1 m, 0 m, and –1 m sampling points, resulting in five representative samples from each site.

I spread 250 ml of sample soil evenly over 500 ml of sterilized soil in 12 x 16.5 cm insert containers, each insert container equals one replicate. This resulted in a layer of sample soil just over 1 cm thick on top of 2.5 cm of sterilized potting soil. I randomly placed three replicates of each sample in each of three watering trays, 92 x 184 x 7.5 cm. Each watering tray consisted of one treatment (saturated soil, clear water, or turbid water). The samples were randomized within the trays along with nine sterilized soil controls to measure contamination from the greenhouse. Environmental controls were set for 16 hours of light per day in the greenhouse to simulate late spring germination conditions.

The trays were watered every second day for the duration of the experiment. Soil samples were kept saturated with the water level just below or equal to the soil surface for the saturated soil treatment. For the two submerged soil treatments water levels were kept 2 to 3 cm above the soil surface. Tap water was used for the saturated soil and clear water treatments, while tap water mixed with dispersive clay from the field study site was used for the turbid water treatment.

Data Collection

The study was conducted from January to April in 2004. I conducted weekly vegetation counts on each sample. To prevent shading and root competition, plants were removed from the samples as soon as they were identified. Some species were identifiable only down to genus because of growth limitations in the greenhouse. Because the replicates were small, I added the results from the three replicates per watering treatment to give a total of five representative samples per treatment per soil type.

3.2.3 Data Analysis

For all statistical tests a significance level of 0.05 was used, but I also comment on results that are between 0.05 and 0.10 as marginally significant. When a difference at a significance level of 0.05 was observed, I used the Games-Howell (GH) post hoc analysis to determine difference between treatments. GH is conservative and robust to heterogeneous variances and unequal sample sizes (Day and Quinn 1989). All statistical analyses follow Zar (1999) unless otherwise noted.

Emergence Study

I used species richness and two similarity measures to compare the plant community between the saturated soil and clear water treatments and the clear water and turbid water treatments: Sorenson's coefficient of similarity for presence-absence data and percentage similarity for abundance data (Krebs 1999). The number of individuals of each species was divided by the total number of individuals per sample to produce relative percentages of each species in the community for abundance measurements. A Kruskal-Wallis Test was used to compare the similarity indices between the soil types because of low sample size. Where I found significant differences between soil types, I used the Newmeyi multiple comparisons test (Zar 1999). Wilcoxon signed ranks test was used to compare species richness and number of individuals between the three treatments.

Field and Emergence Studies

Turbidity measurements were compared between the three field sites using single factor repeated measures ANOVA. Sorenson's coefficient was used to compare the plant communities between the emergence study and the field study. Species lists from the RS were complied using cumulative data from each year and from the donor sites using cumulative data from the entire study. I used a two-way ANOVA (donor wetland soil and emergence/field) for each year to compare the similarities between the transferred soil plots and the donor wetland plots versus the transferred soil plots and the emergence study. I also determined what species or types of species were absent from the emergence and field studies.

3.3 Results

3.3.1 Emergence Study

Saturated Soil and Clear Water Treatments

Species richness was not significantly different (Table 3.2) between the saturated soil and clear water treatments (p=0.41). Only three species were found in the subsoil samples: *Kochia scoparia*, *Lemna minor*, and *Amaranthus graecizans*. *L. minor* was observed in one replicate of one sample; probably the result of cross-contamination with the wetland soil samples during high water levels.

Table 3.2: Species richness and number of individuals for the soils and treatments in the emergence study. Mean and standard error values by sample were calculated from summed values of duplicates from the same sample. (n = 5)

		By Sample		Total by Soil	
Soil	**Treatment**	**Species Richness**	**Number of Individuals**	**Species Richness**	**Number of Individuals**
D1	Saturated Soil	7.6 (0.9)	101 (28)	17	485
	Clear Water	5.6 (0.8)	81 (23)	13	386
	Turbid Water	3.6 (0.6)	93 (31)	7	443
D2	Saturated Soil	6.6 (0.9)	43 (14)	12	216
	Clear Water	7.4 (1.2)	59 (23)	13	287
	Turbid Water	6.6 (1.1)	40 (12)	12	191
Subsoil	Saturated Soil	1.2 (0.2)	7 (0.7)	2	12
	Clear Water	1.0 (0.0)	3 (0.9)	1	15
	Turbid Water	1.4 (0.3)	6 (0.6)	3	14

The similarity measures (Table 3.3) show relative differences between the treatments for each soil. Sorenson's index was higher for the subsoil than for soil from D1 (p=0.05) and marginally higher than soil from D2 (p=0.10). This means that the plant community between the saturated soil and clear water treatments was more similar for the subsoil than the two donor soils. Percent similarity was marginally higher for D1 than D2 soil (p=0.10), but neither wetland soil was different from the subsoil (p>0.1). This means that the plant community between the saturated soil and clear water treatments was slightly more similar for soil from D1 than D2, but neither was more similar between the treatments than the subsoil.

The proportion of sedge meadow individuals decreased and the proportion of aquatic individuals increased for both donor soils in the clear water compared to the saturated soil treatments. There was little change in the abundance of emergence, mudflat, and upland individuals, but in the clear water treatment algae mats formed and floated to the surface carrying some of the donor soil. Some mudflat and upland individuals germinated on these algae mats before they were removed.

Table 3.3: Comparisons between the treatments in the emergence study including the number of similar species, Sorenson's index, and percent similarity values with standard errors.

Soil	Treatments	Number of Similar species	Sorenson Index	Percent Similarity
D1	Saturated/Clear	7	0.54 (0.06)	79 (5.6)
	Clear/Turbid	5	0.52 (0.06)	86 (3.7)
D2	Saturated/Clear	6	0.60 (0.07)	47 (7.8)
	Clear/Turbid	9	0.67 (0.05)	61 (10.1)
Subsoil	Saturated/Clear	1	0.93 (0.07)	75 (12.6)
	Clear/Turbid	1	0.67 (0.18)	64 (18.6)

Turbid Water Treatment

The turbid water treatment in the emergence study was problematic and the results were inconclusive. I was not able to keep particles suspended, resulting in a layer of sediment on top of the soil samples. In the field, although particles do settle to some extent, enough stay suspended so that light attenuation occurs. Of the three treatments the turbid water treatment received the most natural light in the greenhouse because of incorrect placement relative to the other treatments. The combination of low turbidity and high natural light resulted in an unknown amount of light reaching the soil surface. Lastly, no turbidity measurements were made therefore it is difficult to compare the results of this treatment to the results in the field.

There was no clear pattern in species composition between the turbid and clear water treatments. Plants in both treatments consisted of a mixture of aquatic, emergence, and mudflat species. The turbid water treatment had a similar number of species ($p=0.15$) and number of individuals ($p=0.9$) as the clear water treatment. Similarity measures between the soil types were not significantly different ($p>0.1$) nor were the similarity measures calculated between the turbid water and clear water treatment different from the ones calculated between the clear water and saturated soil treatments ($p>0.5$).

3.3.2 Field and Emergence Studies

The turbidity of the water at the RS was significantly higher than that for the two donor wetlands ($p<0.001$, Table 3.4). The turbidity decreased from June to August at the RS and D1, but it increased at D2. Turbidity values at the RS were approximately 16 times greater in June than in August.

Table 3.4: Mean turbidity values with standard error of the water at the three wetlands measured in June and August of 2004.

	Turbidity (NTU)	
Wetland	**June**	**August**
RS	2720 (49)	166 (2)
D1	25 (0.2)	6.7 (0.4)
D2	0.8 (0.2)	13 (0.0)

The water level in the RS storage basin was not constant throughout the two-year study (Figure 3.3). Settling and erosion rates were not consistent for many of the plots causing some plots to experience different degrees of flooding compared to neighbouring plots.

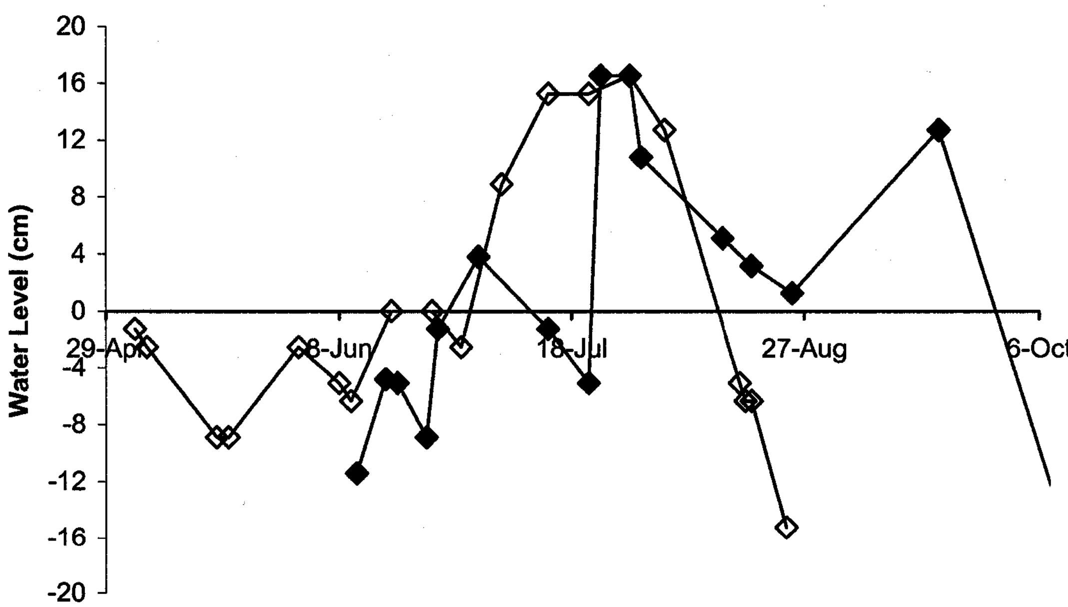


Figure 3.3: Water level at the RS from April to October; solid shapes represent 2003, open shapes represent 2004. The forecasted waterline equals 0cm.

Plant Communities

A total of 31 vascular plant species were identified in the seed bank emergence study (Table 3.5). Seven of the 31 species were unique to the emergence study and were not found in the field. Only nine of the 21 species (43%) identified in the D1 soil samples were also found as plants at D1, whereas, 16 of the 21 species (76%) identified in the D2 soil samples occurred as plants at D2.

Table 3.5: Vascular plant species from the emergence study (E) with presence or absence in the field study. Plant species occurring only in the field are not given.

Plant Species	Common Name	D1			D2		
		E	RS	D	E	RS	D
Agrostis scabra	Rough Hair Grass				X		
Alopecurus aequalis	Short-awned Foxtail	X	X		X	X	X
Amaranthus graecizans	Prostrate Pigweed	X					
Beckmannia syzigachne	Slough Grass	X	X		X	X	X
Bidens cernua	Nodding Beggar-Ticks						
Calamagrostis canadensis	Bluejoint	X	X	X	X		X
Caltha natans	Floating Marsh Marigold	X					
Cardamine pennsylvanica	Pennsylvanin Bitter Cress	X	X	X			
Carex sp.	Sedge	X	X	X	X	X	X
Callitriche verna	Vernal Water-Starwort	X	X	X	X	X	X
Eleocharis palustris	Creeping Spike Rush				X		X
Epilobium glandulosum	Purple Leaved Willowherb	X	X		X		X
Geum aleppicum	Large-leaved Avens	X				X	
Gnaphalium palustris	Marsh Cudweed	X	X			X	
Hierochloe odorata	Common Sweet Grass	X					
Juncus nodosus	Knotted Rush						
Juncus sp.	Rush	X					
Lemna minor	Common Duckweed	X			X		X
Lemna trisula	Star Duckweed				X		
Mentha arvensis	Wild Mint	X					X
Plantago major	Common Plantain	X	X			X	X
Polygonum amphibium	Water Smartweed		X		X	X	X
Potentiaal norvegica	Rough Cinquefoil	X	X	X	X	X	X
Poa palustris	Fowl Bluegrass		X	X		X	X
Potamogeton sp.	Pondweed				X		
Ranunculus sceleratus	Celery-leaved Buttercup	X	X	X	X	X	X
Ranunculus gmelinii	Yellow-water Crowfoot				X	X	X
Ranunculus macoonii	Macoon's Buttercup	X	X	X		X	X
Rorippa islandica	Marsh Yellow Cress		X		X	X	X
Taraxacum officinale	Common Dandelion	X	X	X		X	X
Trifolium hybridum	Alsike Clover	X	X	X		X	X
Tyhpa sp.	Cattail				X		
	Totals	17	17	10	12	16	19

I found six species that were found only in the donor wetlands. *Mitella nuda* was only observed once during the two-year study and was therefore removed from the analysis. The other five species are perennials with rhizomes (*Equisetum arvense, Phalaris arundinacea, Scutellaria galericulata, Urtica dioica*) or tubular roots (*Sium suave*). I also found three species in both the emergence study and at the donor wetlands, but not at the RS. Two of the species are perennials from rhizomes, *Eleocharis palustris* and *Mentha arvensis*, and one was a floating aquatic perennial *L. minor*.

There were also 13 species that were found at the RS only (Table 3.6). Most of these species were also observed in the area surrounding the plots at the RS and therefore they most likely arrived at the site by seed dispersal. Five of the species are considered upland species and three were not on the wetland indicator lists compiled by Reed (1988). The remaining five are considered wetland indicator species with three equally occurring or not occurring in wetlands, one occurring in wetland 67 to 99% of the time and one occurring exclusively in wetlands according to Reed (1988).

Table 3.6: Vascular plant species occurring only in plots at the RS (S – Subsoil).

Plant Species	**Common Name**	**Indicator Status**	**RS Plots**		
			D1	**D2**	**S**
Axyris amaranthoides	Russian Pigweed	NIL	X		
Chenopodium album	Lamb's Quarters	FAC	X	X	X
Corydalis aurea	Golden Corydalis	NIL	X		
Crepis tectorum	Narrow-Leaved Hawk's Bead	FACU		X	
Erucastrum gallicum	Dog Mustard	NIL	X		
Glaux maritime	Sea Milkwort	FACW	X		
Hordeum jubatum	Foxtail Barley	FAC	X	X	X
Iva axillaries	Poverty Weed	FAC	X	X	X
Matricaria matricarioides	Pineapple Weed	FACU	X		
Matricaria perforata	Scentless Chamomile	FACU		X	
Melilotus alba	White Sweet Clover	FACU	X	X	X
Veronica scutellata	Marsh Speedwell	OBL	X		
Vicia Americana	Wild Vetch	FACU	X	X	
	Totals	13	11	7	4

Indicator Categories (adapted from Reed 1988)

OBL (Obligate Wetland) – 99% probability of occurring in wetlands under natural conditions
FACW (Facultative Wetland) – 67-99% probability of occurring in wetlands, occasionally in non-wetlands
FAC (Facultative) – Equally likely to occur in wetlands or non-wetlands
FACU (Facultative Upland) – 67-99% probability of occurring in non-wetlands, occasionally in wetlands
NIL (Not in List) – no information available to categorize

The transferred soil plots were just as similar to the donor wetland plots as they were to the emergence study samples in the first year ($p>0.5$, Table 3.7). In the second year, D1 transferred soil plots were more similar to the emergence study samples than to the donor wetland plots, but the D2 transferred soil plots were more similar to the D2 plots than to the emergence study samples ($p<0.05$).

Table 3.7: Mean and standard error values for Sorenson similarity index comparing the transferred soil plots to the donor wetlands and the emergence study samples.

		D1 - Transferred Soil	D2 - Transferred Soil
2003	Donor	0.30 (0.02)	0.27 (0.03)
	Emergence	0.30 (0.03)	0.30 (0.03)
2004	Donor	0.30 (0.01)	0.45 (0.03)
	Emergence	0.34 (0.01)	0.31 (0.02)

N= 9 for D1, 8 for D2

The emergence study had more floating or submerged aquatic species than the RS. I found four different aquatic species in the emergence study (*L. minor*, *L. trisula*, *Potamogeton sp.*, and *Callitriche verna*) accounting for 74% of the total individuals. The only floating or submersed aquatic species I found at the RS was *C. verna*. It occurred in 11 of the transferred soil plots in 2003 and 10 of the transferred soil plots in 2004. Coverage of *C. verna* was high in 2003 with 1 to 90% of the total vegetation cover, but it declined in 2004 to only 1 to 25% of the total vegetation cover.

3.4 Discussion

The varying water levels and turbidity at the RS made it difficult to compare the results of the emergence study to the results of the field study. Differences in species composition between the two studies may be the result of changing water level in the field or other environmental conditions and not be reflective of what species were present in the soil seed bank. Although many of the species occurred in the donor wetlands, the RS, and the emergence study, their occurrence was erratic or limited to a few samples. This variable occurrence reduced the similarity index values. The limited occurrence of some species could be because of their rarity in the seed bank and/or environmental conditions reduced germination and establishment.

The plant communities in the emergence and field studies were different. Brown (1998) found similar results, in that the existing vegetation at a restoration site gave a better indication of the resulting plant community following restoration than a seed bank emergence study. Although in my study the RS had no existing vegetation, the transferred soil plots had additional sources of plant propagules. Propagules in the emergence study were limited to species that were present in the soil seed bank mostly as seeds at the time of sample collection, especially since large rhizomes were discarded. Plant species on the transferred soil plots could have come from dispersal or from transplants of mature plants or rhizomes in addition to seeds in the seed bank.

The seed banks of wetland soils are not evenly distributed in space (Parker and Leck 1985, Burke 1997). Some types of species, such as submerged aquatic plants, are poorly represented in the seed bank, while others are over represented (Boedeltje *et al.* 2003). The position along the moisture gradient and the time of year when the samples are taken plays an important role in determining which species are present in the seed bank and which species are present in the vegetation (van der Valk and Davis 1978). The emergence samples were collected in the autumn during low water levels whereas the soil used for the transferred soil plots was collected in the late spring during high water levels. Although measures were taken to collect emergence samples that were representative of the soil used for the soil transfer plots, it was not possible to sample in the same area because of the disturbance caused by field sample collection.

Only perennial species were present at the donor wetlands, but absent in both the emergence study and in the transferred soil plots. Most were perennials with rhizomes, but I also found some perennial species with rhizomes in large numbers in both the emergence study and in the transferred soil plots. For example *Carex sp.* appeared in high numbers in both the field and the emergence studies. Most *Carex sp.* reproduce vegetatively and their seeds have low viability that decreases rapidly with time (van der Valk *et al.* 1999), making their abundance in the emergence study unexpected. Since I could not remove all of the small roots from the soil samples prior to the emergence study, some sedges and other perennial seedlings may have developed from the remaining small roots (or small rhizomes indistinguishable from roots) as well as from seeds. Establishment of *Carex sp.* from rhizomes (Yetka and Galatowitsch 1999) or transplants of immature individuals (Steed and DeWald 2003) has been more successful than from seeding (van der Valk *et al.* 1999) and therefore it is more likely that the sedges at the research site did not come exclusively from seed.

The developing plant community on the soil transfer plots did not come exclusively from seeds in the soil seed banks. The contribution of other plant propagules such as rhizomes and the transplantation of some mature individuals during plot set-up were also important in the resulting plant community after two years. The occurrence of 13 species at the RS only also shows that seed dispersal was also a factor in the developing plant community.

Environmental Conditions

Conditions required for germination and establishment of wetland plants differ between species (Galinato and van der Valk 1986). Three factors that affect germination of wetland plants are the amount and timing of water, and the amount of light. The recruitment of plants under different water depths is species-specific (Seabloom *et al.* 1998). Some species require saturated soil conditions to germinate, others require flooded conditions, and some require a sequence of flooded and dry conditions. Many wetland plant species require light to germinate (Galinato and van der Valk 1986) and all require light to grow. For species that germinate underwater, light attenuation caused by suspended solids in the water column can be fatal during early seedling stages or it can limit growth.

The amount and timing of flooding in wetlands plays a large part in species occurrence and survival. Species richness is maximized with an early spring draw down (McKnight 1992) that encourages the establishment of emergent, sedge meadow, and mudflat species. Draw down conditions were simulated with the saturated soil treatment in the emergence study, but I found no difference in the number of individuals of mudflat and emergent species in the saturated and submerged treatments, but this may be due to the presence of floating algae mats. I did find an increase in sedge meadow species and a decrease in submerged/floating aquatic individuals in the saturated treatment as expected.

Submerged and floating aquatic plants need consistent flooding. Variable water levels at the RS may be one reason that aquatic species were nearly absent in the field study. *C. verna*, which did appear in the field study, can germinate and grow in mudflat conditions as well as under submersed conditions (Johnson *et al.* 1995) and was therefore able to germinate and survive in the field.

Aquatic species may have been absent in the field because of reduced light penetration caused by high levels of suspended solids in the water at the RS. The turbid water treatment in the emergence study was unsuccessful; therefore, I cannot say with certainty that the lack of aquatic species on the soil transfer plots was the result of the turbidity or some other factor not studied. Turbidity and light attenuation caused by high levels of suspended solids can affect germination and growth of submersed and floating aquatic species. Zimmer *et al.* (2003) found that turbidity influenced plant abundance, species richness, and the community structure of submerged macrophytes in prairie potholes. The turbidity values encountered by Zimmer *et al.* (2003) ranged from 1.3 to 21.1 NTU, while the values for the water in the RS basin ranged from 140 to 3800 NTU. High turbidity also limited my ability to survey submerged aquatics because of low visibility through the water. If any plants existed below a depth of a few centimetres I would not have observed them during vegetation surveys.

3.5 Conclusions and Recommendations

Conclusions

Presence of a plant species in the donor wetland does not mean that it will be present in the soil seed bank. Plants that are present in a transferred soil seed bank may not emerge from the seed bank unless environmental conditions are appropriate for germination and growth. Seeds are not the only plant propagule contributing to the developing plant community following a transfer of wetland soil. In addition to seeds, other plant propagules, such as rhizomes, as well as seed dispersal at the new site contribute to the developing plant community.

It is important to provide appropriate water levels to establish wetland plants. Sedge meadow species established under both saturated and shallowly flooded conditions in both the greenhouse and in the field, while submerged and floating leaved aquatic species established better when there was shallow standing water. In addition aquatic species may require water that allows light to penetrate to the soil surface.

Recommendations

To mitigate high mortality of seedlings and promote vegetation establishment, the water level should be carefully controlled in the first year. A spring draw down followed by a very slowly rising water level would promote both the germination of seeds and allow plants to become established and to develop mechanisms to deal with flooding. Small changes to the water regime after vegetation is established will not cause adverse effects to the established plants (Budelsky and Galaowitsch 2000), but large changes should be avoided.

Water quality in the water storage basins should improve as wetland vegetation develops. Vegetating the entire catchment area of the basin will reduce runoff and in turn reduce high levels of suspended solids and turbidity. Lower turbidity allow light to penetrate deeper into the water column providing light to aquatic plants. Additional studies should measure the effects of turbidity on the establishment of aquatic species.

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Chapter 4: Water and subsoil quality during wetland establishment with transferrals of wetland soil following surface mining

4.1 Introduction

Three important components of wetlands are water, soil, and vegetation (Hammer 1992). All components affect each other. For instance, water-flooded soils become anaerobic, changing the availability of nutrients for vegetation. For plants to become established in a wetland system, water and soil conditions must be appropriate for germination and growth. The amount and quality of suitable water and soil are important factors for the establishment of wetland plants on created wetlands following surface mining.

Wetland creation can be limited by the quantity and quality of available water. Water flowing into a wetland can be a source of nutrients, soil particles, and pollutants, while water flowing out of a wetland can remove them (Hammer 1992). Surface mining disrupts the natural hydrologic pathways of the landscape by diverting natural waterways within the mining area and requiring onsite water storage to avoid contamination of regional water supplies, therefore, runoff becomes the primary input of water and evaporation becomes the primary output of water during wetland creation. Runoff in a disturbed landscape, such as a surface mine, can have high concentrations of solids (Bonta 2000). Suspended solids can absorb light reducing the depth of light penetration for submerged plants (Cronk and Fennessy 2001). Without an outflow for water to carry away suspended solids and chemicals, wetlands can concentrate salts or the suspended solids may settle onto the soil surface and bury seeds (Gleason *et al.* 2003, Peterson and Baldwin 2004).

The availability of high quality soil can also be a limiting factor during wetland creation following surface mining. Soil is stripped prior to mining and must be replaced following mining. Suitable soil for wetland areas may also be suitable for upland areas that are economically important such as agriculture. Availability of topsoil in particular can limit possible land use in some areas. Topsoil is a valuable resource that can take decades to develop (Green *et al.* 1992), so topsoil conservation and optimization is important for reclamation. Some land use types require more topsoil than others. For instance, for agriculture lands it is important to match the depth and quality of topsoil to pre-disturbance conditions (Green *et al.* 1992). On the other hand, excavated ponds where water is too deep to support rooted plants may not need topsoil for plant growth. Balancing the needs of topsoil for different landscape components is a major consideration during reclamation.

Using salvaged wetland soil instead of upland topsoil in wetland areas can help reduce the use of limited upland topsoil resources. Wetland soil will provide a source of plant propagules and an environment for wetland seed germination, while conserving upland topsoil for other areas. Where the subsoil is suitable, it may be possible to further reduce the amount of topsoil used for wetland reclamation. Subsoil that can support root growth, contribute nutrients, and is not toxic or saline may be sufficient in combination with only a thin layer of salvaged wetland soil for wetland vegetation establishment. Conversely, poor quality subsoil may be low in nutrients, high in toxic components, have poor water holding capacity, and be unsuitable for root growth. The effects of the soil profile on root development in wetland plants needs to be investigated, where soil depth is reduced in the initial establishment stage,

To study the water quality and the soil quality for wetland establishment following surface mining I performed a two-part study. To study water quality encountered during wetland establishment following surface mining I tested the water quality of nine wetlands at a surface mine that consisted of a combination of natural, pre-reclamation, and post-reclamation wetland systems. To study the below ground effects of a thin wetland soil layer over subsoil I utilised transferred soil, subsoil, and donor wetland plots set-up a year earlier to investigate available nutrients and root growth. My objectives were to: 1) determine if the surface water quality at potential wetland creation sites was poor and if so was there potential for it to improve with time as reclamation activities proceeded; and 2) determine if subsoil was an appropriate growth medium for wetland plants.

My hypotheses were:

a) water quality parameters at the pre-reclamation wetlands will be outside regulated standards and different from natural wetland systems;
b) the water quality in post-reclamation wetlands will be similar to the natural wetlands, will not exceed regulated water quality guidelines, and will be of better quality than the pre-reclamation wetland creation sites; and
c) nutrient levels and soil moisture would be similar in the subsoils and soils from the donor wetlands and roots would be found in both the subsoil and the transferred wetland soil layer on top.

4.2 Methods

Approach

I determined the quality of water for pre-reclamation wetland sites in two ways: 1) I compared various water quality parameters between pre-reclamation wetland sites and natural wetland systems in the area; and 2) I compared the same water quality parameters to published guidelines for surface water quality (Alberta Environment 1999). To determine if there was potential for the surface water quality at pre-reclamation wetland sites to improve with time and degree of reclamation I compared water quality parameters between natural wetlands to water bodies in areas in which reclamation activities were near completion (post-reclamation).

To determine if the subsoil was an appropriate growth medium for wetland plants, I investigated available nutrients in the subsoil and compared them to those in the transferred wetland soils and the donor wetlands. I also examined root growth of newly established wetland plants in the soil transfer plots to estimate their use of subsoil compared to topsoil.

Site Description

The study was conducted at the Genesee Coal Mine approximately 80 km west of Edmonton, Alberta, Canada (Figure 4.1). The soil and rooting depth portions of the study were conducted at the research site (RS) and at the two donor wetlands (D1 and D2), while the water quality study included an additional six wetlands under three categories: natural wetland, pre-reclamation, and post reclamation (Table 4.1). The two donor wetlands were located in undisturbed areas of the mine and were the source of wetland soil for the soil transfer plots and each contained nine plots. Donor wetland plot layout mirrored the transferred soil plots in size and shape. The RS was located on the post-mining landscape and contained 24 random plots: 18 transferred soil treatment plots and six subsoil control plots (Figure 4.2). The subsoil plots had no topsoil applied and were used to measure natural colonization at the site.

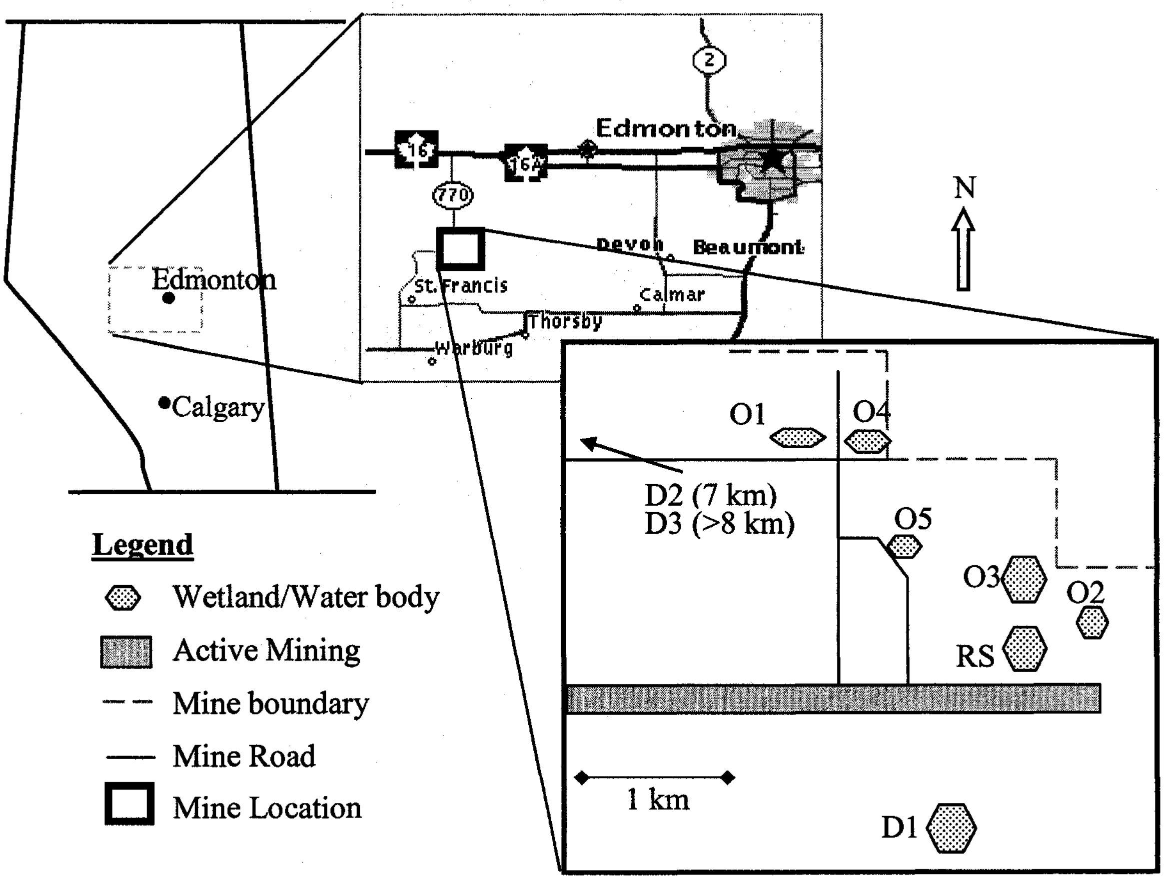

Figure 4.1: Locator and site map showing the location of the study site and the configuration of the wetlands studied.

Table 4.1: Description and water quality category of the studied wetlands and their distance from the research site.

Site	Water Quality Category	Description	Distance (km)*
O1	Post-Reclamation	Created following land reclamation (1992); used for offsite cattle watering	2.3
O2	Pre-Reclamation	Topsoil stripped (date unknown); receives runoff from sodic spoils	0.3
O3	Pre-Reclamation	Topsoil stripped (93-94); contained with berm, may receive runoff from sodic soils	0.2
O4	Post-Reclamation	Used for excavating road building material (87-89); damage to banks from cattle	2.0
O5	Pre-Reclamation	Sump used for water storage; mostly subsoil	1.5
RS	Pre-Reclamation	Water storage basin; partial subsoil and topsoil (18 transferred soil plots, 6 subsoil plots)	NA
D1	Natural Wetland	Seasonally flooded wet meadow within managed cattle pasture (Donor Wetland – 9 plots)	1.6
D2	Natural Wetland	Permanently flooded wetland within managed cattle pasture (Donor Wetland – 9 plots)	7.0
D3	Natural Wetland	Permanently flooded wetland within managed cattle pasture	> 8.0

* Distance from the research site

The area surrounding the RS had been contoured with overburden material in early spring 2003 to drain surface water into a central water storage basin. The RS occupied approximately one quarter of the basin perimeter (Figure 2.2) and was covered with a layer of subsoil approximately 50 cm deep. Salvaged wetland soil was transported to the RS from the upper 15 cm horizon of the two donor wetlands in May 2003 and stockpiled there during the two weeks of plot construction. Transferred wetland soil was spread by hand approximately 10 cm deep over nine randomly selected plots per donor wetland. A degradable geotexile encircled each plot, from 1 cm below the soil surface to 10 cm above, to prevent soil migration and cross-contamination. Each plot was 1.0 m wide and extending at least 1.0 m up and down gradient beyond the forecasted waterline. A 0.5 to 1.5 m space between plots served as a buffer area between plots and allowed foot access to the plots and water surface. Transplanted soil was disturbed during collection and transport and contained organic debris, mature plants, rootstocks, and plant propagules.

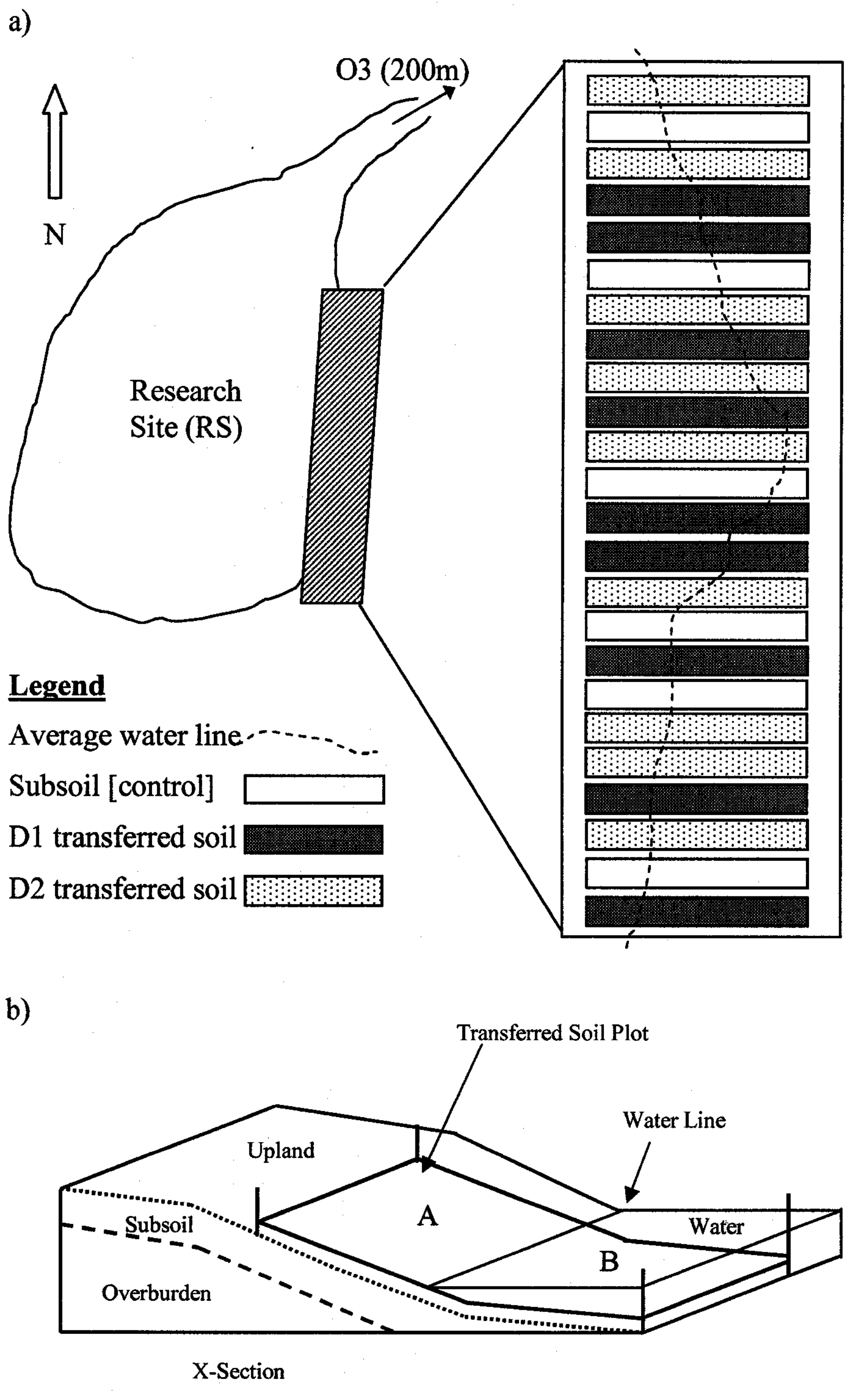

Figure 4.2: Diagram of the RS including: a) plot layout and average water line, and b) a cross sectional view of an individual plot.

After the plots were constructed, the water level in the basin was raised to partially flood each plot. The basin was filled with surface runoff following rain events and was depleted by evaporation. Pumping from the mine cut was used to lower the water level following large storms and to raise the water level following long dry spells. The basin was connected to one other water storage basin (O3) during high water periods.

The area immediately surrounding the RS (~50 m radius) was devoid of vegetation at the start of the study. Vegetation in the immediate surrounding area increased during the two-year study but remained quite sparse and was limited to a few weedy species.

4.2.1 Data Collection

Water Quality Testing

Water samples were taken from nine different wetlands (Figure 4.1, Table 4.1) during two sampling days: June 17, 2004 and July 22, 2004. One grab sample was collected from each water body each day at the same position along the shoreline. A second grab sample was collected from the RS and one of the two donor wetlands each day for quality control. Samples were collected approximately 0.5 m from the shore and just below the water surface. Two duplicated turbidity measurements were made in the field at each wetland using a HACH pocket turbidity meter. Samples outside of the turbidity meter range (i.e., >400 NTU) were diluted to bring values within the range of the meter. Water samples were delivered to the Limnology Lab at the University of Alberta the same day they were collected to be analysed for electrical conductivity, pH, nitrate + nitrite (N), soluble reactive phosphorus (SRP), and dissolved organic carbon (DOC). I retained a portion of each sample for total, suspended, and dissolved solids analysis. All water quality analyses followed Standard Methods for the Examination of Water and Wastewater Edition 20 (APHA 1998).

Soil Profile and Rooting Depth

The soil profile and rooting depth study was conducted in August 2004 to allow time for vegetation to become established and to minimize the effects of destructive sampling on the transferred soil plots. The soil profile and rooting depth study was conducted at the two donor wetlands and at the RS. Water levels in all three wetlands were low during sampling.

I split each plot into two 1 m^2 subplots: one above (A) and the other below (B) the waterline (Figure 4.2). Each subplot was divided into quarters (0.25 m^2) and one was chosen at random. I recorded vegetation characteristics (cover, species, height) for each chosen quarter. I estimated total vegetation cover and species cover to the nearest 5% on a scale from 0 to 100%. Plant species were determined to the lowest possible taxonomic group and average height measurements were recorded in increments of 5 cm. I estimated vegetation parameters personally to reduce estimation bias from multiple observers (Kercher *et al.* 2003).

Once the vegetation parameters were recorded, a hole (0.25 m x 0.25 m) was dug in the centre of the chosen subplot quarters. First a shovel was used to break through and remove the sod layer, and then a small hand trowel was used to extend the hole. The depth of the hole changed from site to site depending on soil conditions but an effort was made to dig at least 20 cm deep based on past studies of rooting depths of wetland plants (Sjors 1991, Stolt *et al.* 2000). The depth of the hole, the topsoil layer, and the deepest live root were recorded for each of the four sides of the hole. The average depth of live roots was also estimated for each side of the hole. If a parameter appeared to extend beyond the maximum depth of the hole it was noted and the hole depth value was recorded. The holes were filled in and the sod layer replaced following data collection.

Soil Testing

Soil sampling was conducted in two different sessions. I collected samples from the RS on July 6, 2004 and from the two donor wetlands during the rooting depth study in mid-August 2004. I used a stratified random sampling approach to collect two samples, one in the A subplot and one in the B subplot, from each transferred soil plot and three samples from each subsoil plot at the RS. Six samples from each plot type were combined at random to make a total of three composite samples per plot type.

I collected each sample by hammering a sharpened piece of PVC tube into the moist ground. The tube was extracted and the soil pushed out into sample bags. In a few cases the ground was too hard to use the PVC tube and the sample was collected carefully with a clean trowel. Soil was collected to a depth of no more than 10 cm. At the donor wetlands the soil was collected from the rooting depth analysis holes. Samples were collected from each hole and then consolidated to make three composite samples per donor wetland. Samples were refrigerated for transportation. A 100 g sub-sample was immediately delivered to the Natural Resources Analytical Lab (NRAL) at the University of Alberta for soil moisture, NH_4, and NO_3 analysis. Soil moisture was determined gravimetrically, while NH_4 and NO_3 were determined colorimetrically (Carter 1993). The remaining soil was dried at a temperature of 80°C for 24 to 48 hours. It was then ground by hand to pass through a 2 mm sieve. The dried soil was then delivered to the NRAL for total and soluble reactive phosphorus (TP, SRP), total nitrogen (TN), Mg, K, Cl, pH, and electrical conductivity (EC) testing. SRP was determined using the Auxley-Miller extractable Phosphorus method, while the cations were determined using atomic absorption (Carter 1993). The pH and EC were determined with electro probes on a 2:1 soil to water mixture.

4.2.2 Data Analysis

For all statistical tests a significance level of 0.05 was used, but I also comment on results that are between 0.05 and 0.10 as marginally significant. When a difference at a significance level of 0.05 was observed, I used the Games-Howell (GH) post hoc analysis to determine difference between treatments. GH is conservative and robust to heterogeneous variances and unequal sample sizes (Day and Quinn 1989). All analyses follow Zar (1999), unless otherwise noted.

Water Quality

I separated the water bodies/wetlands into three water quality categories based on the amount of reclamation that has been conducted around each water body. The two donor wetlands (D1 and D2) and the additional natural wetland (D3) were categorised as natural wetlands. Two of the opportunistic wetlands (O1 and O4) were categorised as post-reclamation because they were in areas of the mine site in which reclamation activities were near completion. The other opportunistic wetlands (O2, O3, and O5) and the RS were categorised as pre-reclamation since reclamation activities in the areas surrounded them was in the early stages.

I averaged duplicate samples on the same water body into a representative sample for each day. All of the data, except pH values, were transformed using a log-transformation to account for heteroscedasity (Zar 1999). I then used repeated measures

ANOVA to determine differences between the three water body categories. I also compared each water quality measurement to the "Surface Water Quality Guidelines for Use in Alberta" (Alberta Environment 1999) to determine if any of the water quality parameters were outside of recommended guidelines.

Soil Profile and Rooting Depth

For the topsoil and average root depths I averaged the four measurements from each hole to use in analysis, whereas for maximum root depth I took the deepest of the four measurements. I transformed the maximum root depth data using a square transformation to account for a negatively skewed data set as a result of the limits of the hole depth (Zar 1999). Depth of topsoil was positively skewed and I transformed the data using a log transformation prior to analysis.

I analyzed rooting parameters with a three factor ANOVA to test for significant differences between and within the plot type, subplot sampled, and soil type for the RS and the donor sites. I also ran paired sample t-tests on the transferred soil plot data between the average rooting depth and the depth of the topsoil, and the maximum rooting depth and the depth of the topsoil to determine if roots were extending down past the topsoil layer.

The above ground parameters were not similar between the donor wetlands and the RS therefore I separated the data based on wetland before calculating the correlation coefficients. I tested the significance of the correlation coefficient between the rooting parameters and the depth of the topsoil to see if the root depths observed were correlated to the depth of the topsoil. I also tested the significance of the correlation between the rooting parameters and the above ground parameters (vegetation cover, maximum height, and average height) to determine their influence on the rooting parameters.

Soil Testing

I split the soil sample data based on the donor wetlands, D1 and D2. I analysed the data using a Kruskal-Wallis nonparametric test because of low sample size. Where I found a significant difference between the three soil types (donor, transferred soil, and subsoil), I used the Nemenyi multiple comparisons test (Zar 1999) to determine which parameters differed between the soil types. All tests were considered significant at $p<0.05$, but I also comment on results that are between 0.05 and 0.10 as marginally significant.

4.3 Results

4.3.1 Water Quality

Water chemistry was different between all three categories of wetlands (Table 4.2). The pre-reclamation wetlands had higher suspended solids and turbidity, but lower DOC than the natural wetlands. The post-reclamation wetlands had higher pH and lower DOC than the natural wetlands ($p<0.05$). SRP was also higher in the post-reclamation wetlands than in the natural wetlands with marginal significance ($p=0.1$). The pre-reclamation wetlands had higher SRP, turbidity, TS, and TSS ($p\leq0.05$) than both the natural wetlands and the post-reclamation wetlands.

Table 4.2: Results of the water quality testing on the three categories of wetlands at the Genesee Mine in July 2004. Mean values of untransformed data with the standard error are given.

Parameter		**Natural Wetlands**	**Post-Reclamation**	**Pre-Reclamation**
EC	dS/m	0.75 (0.15)	0.25 (0.02)	0.37 (0.36)
pH	units	7.3 (0.03)	7.9 (0.2)	7.8 (0.2)
$NO_3 + NO_2$	µg/L	1.15 (0.34)	0.64 (0.16)	495 (429)
SRP	µg/L	13.9 (4.3)	2.3 (1.1)	23.2 (3.8)
DOC	Mg/L	33.9 (2.7)	14.2 (3.7)	10.4 (0.6)
TSS	Mg/L	172 (2)	182 (3)	759 (375)
TDS	Mg/L	870 (166)	593 (35)	1239 (216)
TS	Mg/L	1042 (165)	775 (32)	1998 (576)
Turbidity	NTU	5.5 (1.9)	8.8 (5.7)	750 (400)

Although $NO_3 + NO_2$ was higher in the pre-reclamation wetlands than in the natural wetlands (Table 4.2), the concentration of $NO_3 + NO_2$ in the pre-reclamation wetlands was highly variable ($p=0.2$) causing statistical differences between the three wetland categories to be non-significant. The concentration of $NO_3 + NO_2$ varied within approximately an order of magnitude between the four pre-reclamation wetlands (Table 4.3).

Table 4.3: $NO_3 + NO_2$ concentration in the four pre-reclamation wetlands in June and July 2004 (standard error).

	O3	O2	O5	RS	Mean
June (µg/L)	0.22	5.17	850	1490	586 (361)
July (µg/L)	1.45	3.59	1775	201	495 (429)
Mean	0.84	4.38	1313	846	

The water at the RS exceeded the Alberta Surface Water Quality Guidelines for nitrogen (1490 µg/L), pH (8.5), SRP (81.5 µg/L), turbidity (3350 NTU), and TSS (558 mg/L) in June and for pH, turbidity, and TSS in July. Water pH from the post-reclamation wetlands was above guidelines, but other water quality parameters were below standards. All water quality parameters measured at the natural wetlands were within recommended Alberta guidelines.

4.3.2 Soil Profile/Rooting Depth

Topsoil thickness and rooting depth were greater at the donor wetlands than at the RS (Table 4.4, $p<0.001$). There was no difference between samples taken above or below the average waterline ($p>0.1$) nor was there a difference between the D1 and D2 transferred soil plots ($p>0.1$). The depths of roots and topsoil were lower in the subsoil plots than in the donor wetland and transferred soil plots ($p<0.001$). There was an interaction effect between the soil type and plot type for both the maximum rooting depth and the depth of topsoil. This was driven by differences between the two donor sites and not the RS.

Table 4.4: The depth of the topsoil layer, maximum root, and average root for all soil types and locations. Mean values of untransformed data with the standard error are given.

		N	Topsoil Depth (cm)	Max Root Depth (cm)	Ave Root Depth (cm)
Donor	D1	7	19.8 (1.8)[a]	22.9 (1.6)[b]	12.1 (1.2)
	D2	18	11.4 (1.5)[a]	26.1 (0.7)[c]	11.3 (0.6)
Research Site	D1	17	6.0 (0.3)	19.1 (0.7)[d]	7.2 (0.6)
	D2	14	6.2 (0.2)	17.2 (1.1)	6.5 (0.5)
	Subsoil	10	0.0 (0.0)	10.6 (1.2)	2.7 (0.5)

Notes: [a] 2 values greater than hole depth
[b] 3 values greater than hole depth
[c] 15 values greater than hole depth,
[d] 7 values greater than hole depth

The average root depth for the transferred soil plots was slightly greater (mean difference 0.80 cm, $p=0.05$) than the depth of the topsoil. The maximum root depth for the transferred soil plots was greater than the depth of topsoil ($p<0.001$). No topsoil layer was observed in the subsoil plots.

Average rooting depth and depth of topsoil were positively correlated ($r=0.43$, $p=0.03$) at the donor wetlands. None of the above ground parameters were significantly correlated to a rooting parameter at the donor wetlands. The subsoil plots at the RS skewed the data set since there was no topsoil layer. When the subsoil plots were included in the correlation analysis, rooting parameters were correlated to all above ground parameters and to the depth of topsoil ($p<0.01$). When the subsoil plots were removed from the analysis the average rooting depth was weakly correlated only with maximum plant height ($r=0.315$) and depth of topsoil ($r=0.312$, $p<0.10$). The other above ground parameters (vegetation cover and average height) were not significantly correlated.

4.3.2 Soil Testing

Select parameters for the soils from the donor wetlands were different from those of the subsoil (Table 4.5). Both donor wetland soils had higher concentrations of PO_4, TP, and TN, and lower pH than the subsoil ($p\leq0.05$). In addition, soil from D2 had higher NO_3, NH_4, and soil moisture than the subsoil ($p<0.05$). Transferred D1 wetland soil had higher NO_3 and NH_4 than the subsoil with marginal significance ($p<0.1$), whereas the transferred D2 soil had significantly lower EC than the D2 donor wetland ($p<0.05$).

Table 4.5: Mean and standard error of the tested soil parameters for the donor soil, transferred soil, and the subsoil (n=3).

	D2		**D1**		**Subsoil**
	Donor	**Transferred**	**Donor**	**Transferred**	
TN (ppm)	8900 (300)	4500 (300)	6500 (600)	4700 (700)	1300 (100)
NO_3 (ppm)	10.7 (5.2)	1.7 (0.5)	2.6 (0.4)	5.8 (3.1)	1.0 (0.04)
NH_4 (ppm)	2.3 (0.3)	0.6 (0.1)	3.4 (0.4)	5.2 (3.2)	0.2 (0.04)
TP (ppm)	850 (35)	570 (15)	767 (87)	617 (46.7)	510 (31)
PO_4 (ppm)	8.4 (2.9)	3.0 (0.3)	8.3 (1.6)	2.8 (0.6)	1.2 (0.7)
EC (μS/cm)	1820 (242)	471 (9)	464 (182)	626 (50)	641 (49)
pH	6.3 (0.2)	7.7 (0.1)	5.6 (0.3)	7.4 (0.2)	8.4 (0.1)
K (ppm)	182 (37)	125 (11)	245 (41.9)	142 (10.7)	193 (9)
Mg (ppm)	892 (187)	840 (24)	296 (18)	540 (11)	620 (16)
Cl (ppm)	20.4 (2.9)	12.7 (2.2)	17.4 (2.0)	12.3 (1.9)	11.8 (1.3)
SM (%)	68.9 (3.2)	44.5 (5.3)	42.8 (3.3)	44.4 (12.7)	29.6 (1.0)

Note: SM stands for soil moisture (g/g x 100%)

4.4 Discussion

The water at the pre-reclamation wetlands, including the RS, had high levels of turbidity, solids, SRP, and available nitrogen. The process of land reclamation leaves areas devoid of vegetation for various time periods. Without vegetation, runoff can contain high concentrations of suspended solids (Bonta 2000) as the result of erosion. All the wetlands in the post-mining area of the mine were isolated from other surface waters, therefore a large portion of their water comes from precipitation and local runoff. The wetlands with vegetated catchment areas (post-reclamation wetlands) had lower concentrations of suspended solids and turbidity than the pre-reclamation wetlands that had little vegetation in their catchment areas. Vegetation may have reduced erosion in these catchments and subsequently reduced suspended solids in the water. Vegetation can also lower the concentration of nutrients in the water directly by plant uptake, which may explain the higher levels of SRP in the pre-reclamation wetlands than the post-reclamation wetlands. The catchments of the post-reclamation wetlands were covered with topsoil, while the pre-reclamation wetland catchments had some exposed subsoil or overburden. Some of the overburden and subsoil materials at the mine site are sodic; runoff from such soils can have high pH and very high concentrations of suspended solids because of the dispersive nature and structural instability of the soil (Rengasamy 2002). The combination of increased plant cover and the burial of sodic soils at the post-reclamation wetlands may have been the reason for the difference in water quality between the pre- and post-reclamation wetlands.

Total nitrogen and phosphorus pools, as well as available phosphorus, were higher in the donor wetland soils than in the subsoil. Available nitrogen was highest in the D1 transferred soil plots, but not for D2 soils that had highest available nitrogen in the donor wetland plots. These results may be explained by the high variability in the samples taken. One of the D1 transferred soil samples and one of the D2 donor wetland soils had an available nitrogen concentration two to three times greater than the other two. This increased the mean and the variance, but since parametric statistics were not used, the variability was partially lost in the analysis. More samples are needed to confirm these results.

The pH of soils in wetland systems is important to the stability of many chemicals in their various states. Phosphorus exists in forms most readily available to plants when soil conditions are neutral to slightly acidic (Reddy *et al.* 1999). My results followed this trend with SRP decreasing as the pH increased from the donor wetland soils to the subsoil at the research site. Stolt et al. (2000) also found higher pH in constructed wetlands than in natural systems. Soil pH greater than 9.3 can also increase the ratio of NH_3 to NH_4^+ leading to volatilization of excess NH_3. Subsoil had a pH (8.4) in the range of fair to poor for land reclamation based on values given by Valleau (1983). The pH of alkaline mineral soils often drops to a more neutral pH after flooding (Ponnamperuma 1972), but infrequent flooding and long drying periods at the RS may have prevented this from occurring. Drying soil prior to analysis can also affect the pH (Rayment 1993) thus the pH recorded for the various sites may not have been the same as under field conditions.

There are a few possible reasons for the high variability in the soil chemical results. First, there may have been human errors during chemical analysis or contamination during collection and preparation. Second, soil is heterogeneous in nature and as such one or more of the samples may have been taken in a patch of high or low available nitrogen. Available nitrogen is affected by the moisture gradient (Stolt *et al.* 2001). Although samples were taken from both above and below the average waterline, no record was kept as to how wet samples were before they were combined nor what their moisture history was. Olde Venterink *et al.* (2002) found that drying wetland soil for 12 days increased NO_3 in the soil and then re-wetting of the soil increased denitrification rates immediately. Water levels during spring 2004 at the RS were very low causing many of the B subplots to be exposed to the air, but the water level increased a few days prior to soil sampling, which may have caused a shift in nitrogen forms prior to sampling. Bruland and Richardson (2005) found that created and restored wetlands had randomized fine scale heterogeneity of soil properties. They hypothesized that this was because of mixing of soil layers during construction. Soil properties did not follow moisture or elevation gradients. Nitrogen fixers that were present on some of the transferred soil may have caused nitrogen variability and subsoil plots. The limited sampling conducted in this study was therefore insufficient to effectively characterize the soil.

The decrease in average root depth with a decrease in the depth of topsoil is noteworthy. Positive correlations between root depth and the depth of topsoil give an indication that the depth of topsoil was affecting the depth of roots and that the subsoil may not have been a good growth medium for wetland plants. A shallower topsoil depth will likely increase the concentration of roots in the topsoil layer. An increase in the concentration of roots leads to an increase in belowground competition resulting in changes in vegetation community establishment. Ashworth (1997) showed that the depth of organic topsoil was a significant factor in the presence and abundance of certain wetland plants for up to five years after wetland restoration with transferred wetland soil.

One of the causes of the correlation between the average root depth and the depth of topsoil is nutrient availability. Root proliferation during interspecific competition is associated with nitrogen uptake (Robinson *et al.* 1999). The two donor wetlands from which the transferred soils were taken generally had higher concentrations of nitrogen than the subsoil. After two growing seasons the D1 transferred wetland soil had total nitrogen concentrations not significantly different from either the high levels at the donor wetlands or the lower levels in the subsoil, in essence they fell between the two extremes. Plant uptake can account for a large portion of the loss of total nitrogen from the transferred topsoil. Other reasons for nitrogen loss include denitrification, volatilization, and leaching.

Although roots extended into the subsoil, I found that the maximum depth of roots was lower at the RS than at the donor wetlands. Stolt *et al.* (2001) found similar results in that root depths at two constructed wetlands were less than paired reference wetlands after four years and at one constructed wetland after seven years. Soil profiles also differed between the pairs of constructed and reference wetlands with shallower A horizons in the constructed wetlands (Stolt *et al.* 2001).

The difference in average root depth between the transferred soil plots and the donor wetland plots may be because roots where staying in the upper soil layers not only because of nutrient availability, but also because there was little competition for those nutrients. Evidence of a low competitive environment includes low above ground vegetation coverage and the absence of dense root mats on the transferred soil plots. There was also no correlation between above ground cover and root depth.

The average depth of roots was correlated with the maximum height of vegetation in each plot, which is a function of the species present and their development. Although I did record the species occupying the areas directly above the sample holes I was not able to determine the species of measured roots. Many of the species I found at both the donor and research sites were herbaceous perennials whose below ground structures survive from year to year and contribute to above ground growth. The roots observed at the research site have been under development for two years or less and if they were from perennials they may not have grown to the extent of the roots at the donor sites. In the future it may be necessary to identify the roots down to species to accurately determine if results are a function of the soil profile or a function of the species present.

4.5 Conclusions and Recommendations

Some of the water quality parameters in the pre-reclamation wetlands were outside guidelines and higher than natural wetlands therefore the water quality in the pre-reclamation wetlands was poor. The improved water quality in the post-reclamation wetlands over the pre-reclamation wetlands suggests that once reclamation activities are completed in the RS catchment basin and a wetland system develops, water quality will improve. High pH and low DOC are water quality issues following reclamation. Water quality monitoring during and following wetland establishment is recommended and the relationship between water quality and the amount and type of exposed soils surrounding the water bodies should be studied further.

Topsoil depth had an effect on the average rooting depth in the second year of growth following the application of wetland soil at the RS. Although roots were found in the subsoil, they were not penetrating as deeply as in the donor wetlands likely because of higher nutrient availability in the transferred soil and the short time for root development. The effects of different plant species were not studied, but different nutrient needs and foraging strategies may be important in below ground competition and the resulting vegetation community.

Low nutrient content of the subsoil may hinder the growth of wetland plants if additional sources of nutrients are not available. Increasing the depth of wetland soil applied to the site may reduce the need for fertilization. Additional wetland soil may also aid the biogeochemistry of the soil system by introducing a complete wetland microbial population to the existing subsoil system. Subsoil pH is also a source of concern during wetland establishment. I recommend that subsoil pH be close to neutral or slightly acidic to maintain availability of nutrients in the soil.

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Chapter 5: Conclusions and recommendations

5.1 Introduction

Using transferred wetland soil is a viable method to introduce wetland plant propagules in reclaimed areas at the Genesee mine in Alberta, Canada. My study supports the findings of Brown and Bedford (1997) and Stauffer and Brooks (1997) in that species richness, vegetation cover, and proportion of wetland plants were greater in transferred wetland soil sites than in naturally colonized sites. Poor water quality at the research site may have negatively affected wetland plant establishment and the reconstructed soil profile may have reduced root penetration of establishing wetland plants. The results of my study should aid in decision making and management involving wetland creation following surface mining at the Genesee Mine in Alberta, Canada and gives direction for future studies on this topic.

5.2 Linking Chapters 2 to 4

The transferred soil and subsoil plots only occupied one quarter of the water storage basin perimeter. The remainder of the perimeter and catchment area of the basin was a mixture of overburden fill material and subsoil areas with little vegetation. The exposed soils and overburden fill material were not tested for sodicity during this study, but some of the soils and fill at the site are considered sodic (Valleau 1983). Runoff from sodic soils can be very high in suspended clay particles and have high pH (Rengasamy 2002) and the water in the storage basin had both of these characteristics. High suspended solids resulted in high turbidity and reduced light penetration leading to the absence of submerged aquatic species and the reduction of emergent species in flooded areas. Settling of the suspended particles was minimal in the field, but adjustment of the pH may increase coagulation and flocculation of particles, thereby increasing settling (Droste 1997). In the emergence study I tried to raise the pH of the turbid water treatment by adding a weak base, to keep the turbidity high, but was unsuccessful. Future study is needed to determine if pH adjustment can increase settling.

Natural colonization is a two part process: first plant propagules must arrive at the site (i.e., seed dispersal); then they must become established. Low colonization rates on the subsoil plots could have been the result of dispersal limitations (i.e., propagules did not get to the site) and/or environmental conditions that caused poor growth, survival, and establishment. Overland dispersal is mainly by wind or animals and birds, especially waterfowl, and can transport seeds over great distances, however, waterfowl were rarely observed at the research site. Mueller and van der Valk (2002) determined that ducks transport seeds of prairie wetland plants on average 20 to 30 km, which would allow for dispersal from many natural wetlands both on and offsite. Increasing vegetation and habitat surrounding the basin may attract more waterfowl and other wildlife to the site and subsequently increase seed dispersal.

In my study, conditions on the subsoil plots were compromised for wetland plant establishment and growth as evidenced by subsoils low in nitrogen and phosphorus and having high pH. Vivian-Smith and Handel (1996) found that small changes in pH affected the composition of a developing wetland plant community. I my study the soil pH of the subsoil plots was much higher than for the transferred soil plots. Small environmental differences can result in different seeds germinating (Galinato and van der Valk 1986). Although colonization from offsite seed dispersal at the research site appeared insignificant over the course of two years, the vegetation present at the opportunistic wetlands on the mine site shows that it cannot be ruled out as a viable source of wetland plant propagules over longer time intervals.

Using wetland soil as a source of wetland vegetation is an intensive process and the availability of wetland soil can be limited. There are many alternatives available if there is not enough wetland soil to cover a potential wetland area. Most plant propagules that will grow out of the transferred soil will be present in only the first 1 to 5 cm of soil (Galinato and van der Valk 1986), therefore, a thin layer of wetland soil can be applied on top of a thin layer of upland topsoil. It may be difficult with the scale of machinery at a surface mine to spread such thin layers of soil without compaction. A second method is to rely on dispersal from areas treated with wetland soil to areas that are not, resulting in an interspersed patchwork of wetland soil and upland topsoil areas. Brown and Bedford (1997) found that plots not treated with wetland soil showed similar species richness and vegetation cover as the treated plots after three years. Plots in their study were approximately 10 m wide with the wetland soil spread with a bulldozer. In my study there were cases of dispersal from transferred soil plots to subsoil plots in the second year and more would likely have occurred if topsoil bordered the wetland transfer plots.

An important factor with any reclamation or restoration project is time. My study investigated vegetation establishment with transferred wetland soil over only two growing seasons. Vegetation of restored wetlands remains dynamic for one or more decades (Whigham *et al.* 2002), therefore, my results may not extend into the future. In a five-year study using wetland microcosoms Weiher *et al.* (1996) found that the community composition after one year did not predict the community after five years. In the period of my study the transferred wetland soil became lower in nutrients compared to the donor soil and as root growth continues in the upper transferred soil layer in the transferred soil plots then competition for soil resources will increase. On the other hand, there is an indication that water quality will improve over time as vegetation increases. Changes to water quality and soil nutrient availability will change the dynamics of the vegetation community.

5.3 Study Conclusions

a) Transferring wetland soil to the research site increased vegetation cover, species richness, and proportion of wetland species.
b) Natural colonization by seed dispersal can result in a wetland plant community at this site, but it may not be characteristic of natural sedge meadow wetlands currently on the site and may contain more upland plants than nearby natural wetlands.
c) Presence of a plant species in the donor wetland does not mean that it will be present in the soil seed bank. Plants that are present in a transferred soil seed bank may not emerge unless environmental conditions are appropriate for germination and growth.
d) Light attenuation caused by high concentrations of suspended solids is a short-term issue that can be mitigated by reducing runoff from exposed and sodic soils.
e) The subsoil used at the research site was not appropriate for many wetland plants because of low available nutrients and high pH.

f) The reconstructed soil profile with a shallow wetland topsoil layer reduced root penetration at the research site.
g) Due to the short duration of the study, it is uncertain whether the plant community on the transferred soil plots will persist into the future.

5.4 Recommendations

The recommendations section is presented in three parts. The first part presents general recommendations for wetland establishment following surface mining based on the conclusions of this study and additional literature review. The second section gives specific recommendations for revegetation methods based on reclamation project goals and available resources. Finally the last section gives directions for future study based on the findings of this study.

General Recommendations

a) The entire catchment area of a newly created wetland should be vegetated quickly to reduce soil erosion. Plant cover will decrease the amounts of suspended solids in runoff reaching the wetland, improve water quality, increase light penetration for aquatic plants, and may increase wildlife use of the wetland.
b) Topsoil, wetland or upland, is recommended for all areas that are shallow enough for rooted plant growth unless the subsoil is high in nutrients and has a neutral to slightly acidic pH.
c) Although using large machinery for soil collection was not directly tested against other soil collection methods in this study, I did use large machinery for soil collection and had favourable results. For this study mechanical disturbance was kept to a minimum by spreading the soil by hand. Brown and Bedford (1997) used large machinery for collection and spreading of wetland soil with similar results to hand planting. Thus, the use of large machinery in the collection and spreading of wetland soil is recommended to reduce costs.
d) Soil collection can take place in the spring or fall, but the soil should not be stored for long periods of time, because much of the site-colonizing vegetation was from

rhizomes and transplants that may not survive long storage. In addition some seeds such as *Carex sp.* lose viability quickly (Budelsky and Galatowitsch 1999, van der Valk *et al.* 1999).

e) Water levels of any created wetland at the mine need to be controlled in the first few years to maximize establishment of desired plant species. A passive control structure such as a weir can help to maintain desired water levels.

Goals and Resources

Based on this study I recommend three methods for establishing vegetation on created wetlands following surface mining. Additional methods such as planting, transplanting, or seeding are also available, but are outside of the scope of this study. The first method is to totally rely on natural colonization by seed dispersal. All areas with potential for rooted vegetation need to be covered with topsoil. The second method is to cover all areas with potential for wetland vegetation, between 1.5 m vertically above and below the anticipated waterline (Green *et al.* 1992), with wetland topsoil salvaged from natural wetlands. The last method is a combination of the first two, where wetland soil is spread in some areas and upland topsoil is spread in others in the same basin.

Recommendations are based on two different aspects. First in Table 5.1, I give recommended methods for potential revegetation of wetland areas based on project goals. Then in Table 5.2, I give the sources of vegetation based on available resources (man power, upland topsoil, and wetland topsoil). Based on a balance between goals and resources, wetland establishment following surface mining should be attainable.

Table 5.1: Recommended methods for revegetation of a wetland area following surface mining based on project goals.

	Recommendations		
Goal	**Wetland Soil-entire area**	**Wetland Soil-some areas**	**Natural Colonization**
Reduce time to vegetation cover	Best	Better	Adequate
Conserve agricultural topsoil	Best	Better	Adequate
Replace lost wetlands with same vegetation	Best	Better	Adequate
Establish wetland vegetation	Adequate	Adequate	Adequate
Low resources	Adequate	Better	Best

Table 5.2: Topsoil, manpower, and equipment availability and the corresponding methods for revegetation for wetland systems (WS – wetland soil). An "X" means that the method is available.

Resource	Availability	WS-entire area	WS-some areas	Natural Colonization
Wetland Topsoil	Unlimited	X	X	X
	Limited		X	X
	Very Limited			X
Upland Topsoil	Unlimited	X	X	X
	Limited	X	X	
	Very Limited	X		
Man Power and Equipment	Unlimited	X	X	X
	Limited		X	X
	Very Limited			X

Future Study

There are many directions available to future studies based on the results of this study. I have included a short list below.

a) A rigorous look into the effects of soil and water quality on the mine site and how it affects wetland plant establishment. Included in this would be a detailed study of available soil and its relationship to water quality from either runoff or infiltration, as well as an investigation into methods to mitigate problems associated with water and soil quality.

b) Continued monitoring of the transferred soil and subsoil plots to investigate the developing plant community and how it changes with time.

c) A new study that investigates the resulting vegetation community that results from planting or seeding compared to using a transfers of wetland soil or reliance on natural colonization.

d) A large scale study to examine the effects of spreading soil with machinery instead of by hand.

Future studies will extend the results of this project to a wider scope beyond the boundaries of the Genesee Mine water storage ponds and add to the growing body of knowledge concerning wetland creation and restoration.

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Appendix A: Transferred Soil and Subsoil Plots Raw Data

Appendix A-1	Vegetation cover for each subplot (A or B) for the RS plots by survey and year
Appendix A-2	Maximum height for each subplot (A or B) for the RS plots by survey and year
Appendix A-3	Average height for each subplot (A or B) for the RS plots by survey and year
Appendix A-4	Species richness for each subplot (A or B) for the RS plots by survey and year
Appendix A-5	Species percent coverage for the RS plots by vegetation survey
Appendix A-6	Root depth study aboveground parameters, hole depth, topsoil depth, average and maximum root depth for the RS plots
Appendix A-7	Rooting depth study species percent coverage for the RS plots

Appendix A-1: Vegetation cover for each subplot (A or B) for the RS plots by survey and year

			2003				2004						
Plot	Treatment	AorB	A	B	C	D	A	B	C	D	E	F	G
A1	D1	A	15	8	35	25	5	25	25	70	65	80	85
A1	D1	B	5	25	1	40	35	50	50	70	70	80	80
A2	Subsoil	A	0	0	0	15	1	5	5	10	25	15	30
A2	Subsoil	B	0	0	0	0	0	1	1	5	10	15	20
A3	D2	A	3	10	30	25	15	25	60	75	80	80	90
A3	D2	B	10	20	10	30	20	30	50	75	80	75	75
A4	D1	A	2	15	25	40	30	25	65	85	85	85	95
A4	D1	B	2	10	1	30	20	20	50	50	70	65	70
A5	D2	A	1	1	35	5	25	40	60	75	60	60	80
A5	D2	B	5	15	20	30	30	50	75	75	80	70	75
A6	D2	A	2	10	15	5	5	10	20	20	50	50	55
A6	D2	B	3	10	7	25	30	50	60	75	70	70	60
A7	Subsoil	A	0	0	0	5	1	2	10	10	20	10	15
A7	Subsoil	B	0	0	0	0	0	1	1	5	5	5	5
A8	D1	A	1	5	20	20	15	20	30	75	80	80	80
A8	D1	B	3	15	0	25	20	30	40	70	70	70	80
B1	Subsoil	A	0	1	0	5	1	2	20	15	15	20	25
B1	Subsoil	B	0	0	0	0	0	1	5	5	10	5	5
B2	D2	A	1	5	20	20	20	30	40	60	60	70	60
B2	D2	B	1	15	0	13	15	25	20	65	45	50	50
B3	D1	A	2	10	15	10	10	20	15	20	30	30	40
B3	D1	B	5	25	15	30	30	50	50	60	60	60	65
B4	D1	A	1	15	15	20	30	40	40	60	50	60	70
B4	D1	B	10	25	20	20	20	25	30	50	40	50	60
B7	D1	A	20	20	20	20	20	25	30	40	60	50	50
B7	D1	B	1	5	0	0	0	0	0				0
B8	D2	A	1	2	5	1	5	5	5	5	10	5	15
B8	D2	B	5	5	0	0	0	0	0				
C1	D1	A	1	4	15	5	1	5	5	20	25	20	25
C1	D1	B	15	25	5	15	2	5	10	20	40	40	80
C2	D2	A	1	1	5	20	10	15	20	30	60	60	55
C2	D2	B	1	3	5	15	1	5	10	15	20	25	40
C3	Subsoil	A	0	0	0	0	0	1	5	5	10	5	10
C3	Subsoil	B	0	0	0	0	0	1	5	5	5	5	5
C4	D1	A	3	2	10	15	1	5	10	25	30	25	40
C4	D1	B	10	15	10	10	5	10	15	20	25	25	40
C5	D1	A	1	15	20	20	10	25	25	30	50	50	50
C5	D1	B	20	30	20	25	15	20	20	40	30	50	50
C6	D2	A	1	1	5	10	2	10	10	20	30	40	50
C6	D2	B	1	0	1	5	0	5	10	10	20	30	40
C7	Subsoil	A	0	0	0	0	0	1	1	5	10	10	10
C7	Subsoil	B	0	0	0	0	0	1	1	5	5	5	5
C8	D2	A	1	0	1	10	5	15	15	30	50	55	60
C8	D2	B	1	1	0	2	1	1	5	15	35	40	60

2003 survey dates A-July 2, B-July 30, C-Aug 8, D-Sept 19 (C survey not used for analysis)
2004 survey dates A-May 6, B-May 20, C-Jun 1, D-Jun 24, E-Jul 21, F-Aug 3, G-Aug 16

Appendix A-2: Maximum Height for each subplot (A or B) for the RS plots by survey and year

			2003				2004						
Plot	**Treatment**	**AorB**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
A1	D1	A	30	32	50	28	20	25	28	70	130	150	155
A1	D1	B	30	45	32	50	36	40	50	75	70	70	70
A2	Subsoil	A	0	0	0	16	5	6	5	55	85	100	100
A2	Subsoil	B	0	0	0	0	0	1	3	15	45	40	50
A3	D2	A	18	50	50	50	20	30	25	80	150	170	180
A3	D2	B	43	50	55	50	30	40	50	70	90	90	85
A4	D1	A	31	35	56	30	15	25	30	45	60	60	60
A4	D1	B	40	35	40	39	25	35	45	50	60	75	70
A5	D2	A	10	9	50	30	18	35	49	60	125	120	85
A5	D2	B	20	40	60	48	30	50	50	60	75	80	80
A6	D2	A	56	35	40	3	10	15	15	60	75	80	80
A6	D2	B	34	35	55	45	27	35	40	60	90	80	75
A7	Subsoil	A	0	0	0	21	2	5	10	65	150	160	165
A7	Subsoil	B	0	0	0	0	0	1	2	5	15	25	35
A8	D1	A	21	40	50	45	20	25	30	45	45	60	55
A8	D1	B	33	50	0	40	26	33	40	50	80	85	80
B1	Subsoil	A	0	5	0	20	2	5	5	20	25	30	30
B1	Subsoil	B	0	0	0	0	0	1	1	15	35	35	35
B2	D2	A	22	20	45	20	29	30	40	45	60	65	65
B2	D2	B	35	40	0	50	26	40	45	55	70	60	65
B3	D1	A	10	25	45	32	25	26	35	40	50	50	65
B3	D1	B	32	50	56	45	35	40	50	60	105	110	105
B4	D1	A	20	35	34	30	25	35	40	50	70	65	60
B4	D1	B	33	35	40	40	35	40	45	50	80	85	90
B7	D1	A	30	35	40		30	30	35	40	80	90	90
B7	D1	B	20	45	0		0	0	0				0
B8	D2	A	15	30	45		20	28	35	60	60	60	55
B8	D2	B	30	35	0	0	0	0	0				
C1	D1	A	17	35	17	40	15	23	32	50	70	70	55
C1	D1	B	30	40	52	40	20	25	25	50	120	125	120
C2	D2	A	10	15	22	25	20	22	25	30	55	60	70
C2	D2	B	1	35	40	45	17	14	20	45	65	70	80
C3	Subsoil	A	0	0	0	0	0	1	2	10	35	40	50
C3	Subsoil	B	0	0	0	0	0	1	2	10	20	25	25
C4	D1	A	22	35	45	45	20	30	40	45	55	50	55
C4	D1	B	36	70	70	65	26	40	60	65	70	80	95
C5	D1	A	13	60	58	56	35	50	60	50	85	80	100
C5	D1	B	43	60	60	60	25	25	35	75	80	110	110
C6	D2	A	20	10	25	20	12	18	25	30	55	60	65
C6	D2	B	0	0	5	1	0	6	3	10	40	60	40
C7	Subsoil	A	0	0	0	0	0	3	4	10	30	35	45
C7	Subsoil	B	0	0	0	0	0	1	3	9	20	25	35
C8	D2	A	0	0	14	0	5	6	14	25	45	50	60
C8	D2	B	5	10	0	1	1	5	5	40	30	50	60

2003 survey dates A-July 2, B-July 30, C-Aug 8, D-Sept 19 (C survey not used for analysis)
2004 survey dates A-May 6, B-May 20, C-Jun 1, D-Jun 24, E-Jul 21, F-Aug 3, G-Aug 16

Appendix A-3: Average Height for each subplot (A or B) for the RS plots by survey and year

			2003				2004						
Plot	**Treatment**	**AorB**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
A1	D1	A	25	12	30	20	15	10	15	20	30	40	50
A1	D1	B	30	35	30	30	22	25	30	50	40	50	60
A2	Subsoil	A	0	0	0	15	5	1	2	10	20	30	30
A2	Subsoil	B	0	0	0	0	0	1	1	5	15	20	25
A3	D2	A	15	20	35	30	10	15	15	70	80	100	90
A3	D2	B	30	45	45	40	20	27	30	35	40	50	55
A4	D1	A	20	30	40	20	10	20	15	20	30	25	30
A4	D1	B	25	25	40	35	15	25	20	20	40	45	40
A5	D2	A	5	9	40	23	2	8	5	20	45	40	55
A5	D2	B	15	30	50	40	15	20	20	40	55	60	60
A6	D2	A	20	20	35	3	5	5	2	10	45	50	30
A6	D2	B	30	30	50	40	15	25	25	35	55	50	60
A7	Subsoil	A	0	0	0	15	2	1	1	10	15	30	30
A7	Subsoil	B	0	0	0	0	0	1	1	2	10	10	10
A8	D1	A	10	15	30	30	10	15	10	15	30	30	35
A8	D1	B	20	25	0	30	18	20	20	25	35	35	35
B1	Subsoil	A	0	2	0	0	2	1	1	10	10	15	25
B1	Subsoil	B	0	0	0	0	0	1	1	5	15	15	15
B2	D2	A	20	15	25	15	5	5	10	20	50	45	60
B2	D2	B	25	30	0	40	15	25	20	20	30	50	40
B3	D1	A	6	20	20	25	20	15	15	10	30	40	30
B3	D1	B	22	30	55	30	25	30	40	35	40	50	60
B4	D1	A	15	25	30	25	20	25	25	30	45	50	55
B4	D1	B	25	25	30	35	25	20	20	30	45	60	55
B7	D1	A	15	30	25		10	20	15	35	60	70	80
B7	D1	B	20	40	0		0	0	0				0
B8	D2	A	15	25	35		15	15	20	50	45	55	30
B8	D2	B	25		0	0	0	0	0				
C1	D1	A	10	15	5	20	5	10	10	15	35	30	50
C1	D1	B	25	20	45	35	10	15	15	30	50	80	60
C2	D2	A	10	10	22	15	5	6	10	20	40	25	40
C2	D2	B	1	30	20	30	8	10	10	20	40	50	45
C3	Subsoil	A	0	0	0	0	0	1	1	5	15	15	20
C3	Subsoil	B	0	0	0	0	0	1	1	5	15	20	15
C4	D1	A	12	25	35	30	10	15	10	20	40	30	50
C4	D1	B	30	60	50	60	15	30	20	40	50	70	90
C5	D1	A	10	30	35	45	18	15	20	20	35	40	50
C5	D1	B	30	45	50	50	15	20	20	45	55	80	90
C6	D2	A	15	10	22	10	5	10	10	15	25	40	35
C6	D2	B	0	0	2	1	0	1	1	5	20	30	25
C7	Subsoil	A	0	0	0	0	0	1	2	5	15	20	25
C7	Subsoil	B	0	0	0	0	0	1	1	2	15	15	15
C8	D2	A	0	0	13	2	1	2	10	15	25	30	30
C8	D2	B	5	10	0	0	1	1	1	5	15	30	30

2003 survey dates A-July 2, B-July 30, C-Aug 8, D-Sept 19 (C survey not used for analysis)
2004 survey dates A-May 6, B-May 20, C-Jun 1, D-Jun 24, E-Jul 21, F-Aug 3, G-Aug 16

Appendix A-4: Number of species for each subplot (A or B) for the RS plots by survey and year

			2003				2004						
Plot	**Treatment**	**AorB**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
A1	D1	A	4	7	10	7	10	13	17	16	17	17	14
A1	D1	B	3	6	1	8	5	8	11	17	13	14	14
A2	Subsoil	A	0	0	0	2	4	5	6	6	6	4	6
A2	Subsoil	B	0	0	0	0	0	2	3	7	5	6	5
A3	D2	A	7	7	11	8	6	7	10	16	12	10	11
A3	D2	B	4	5	2	7	6	10	10	12	12	10	11
A4	D1	A	7	6	8	10	8	10	9	17	12	16	12
A4	D1	B	9	7	1	7	5	10	13	13	15	13	15
A5	D2	A	7	6	8	10	10	12	15	14	14	17	18
A5	D2	B	5	6	1	5	5	8	13	12	10	13	13
A6	D2	A	4	5	4	7	6	10	8	13	12	15	13
A6	D2	B	4	4	3	4	7	7	9	14	9	10	10
A7	Subsoil	A	0	0	0	3	2	3	3	5	6	5	6
A7	Subsoil	B	0	0	0	0	0	1	3	4	4	2	7
A8	D1	A	7	6	4	10	6	11	8	12	15	15	13
A8	D1	B	6	3	0	9	4	6	11	12	15	17	11
B1	Subsoil	A	0	2	1	3	3	4	5	5	4	6	4
B1	Subsoil	B	0	0	0	0	0	2	2	4	3	3	3
B2	D2	A	5	4	6	8	8	11	10	10	14	12	14
B2	D2	B	5	4	0	4	2	4	5	8	4	6	6
B3	D1	A	5	4	6	1	3	5	7	11	10	11	11
B3	D1	B	5	2	2	1	1	5	7	13	5	7	3
B4	D1	A	4	5	5	2	3	8	10	9	7	6	3
B4	D1	B	5	2	4	1	2	6	6	10	5	5	6
B7	D1	A	5	3	5	1	1	4	6	4	1	1	1
B7	D1	B	4	2	0	0	0	0	0				
B8	D2	A	4	1	3	1	1	4	7	4	3	4	3
B8	D2	B	1	1	0	0	0	0	0				
C1	D1	A	5	3	6	2	5	7	9	9	6	9	7
C1	D1	B	3	2	3	1	1	4	5	7	5	4	5
C2	D2	A	3	5	10	6	5	8	9	11	12	13	12
C2	D2	B	2	4	4	3	3	5	5	9	5	6	7
C3	Subsoil	A	0	0	0	0	0	1	2	2	3	3	3
C3	Subsoil	B	0	0	0	0	0	1	2	2	1	1	1
C4	D1	A	5	4	10	8	5	7	7	13	8	12	9
C4	D1	B	5	1	2	1	1	4	6	7	1	1	1
C5	D1	A	8	2	7	3	2	5	9	10	9	11	12
C5	D1	B	4	3	4	3	1	5	6	8	4	4	4
C6	D2	A	3	3	5	7	4	5	8	11	10	11	9
C6	D2	B	4	0	5	1	0	4	3	9	7	6	7
C7	Subsoil	A	0	0	0	0	0	2	2	3	4	3	5
C7	Subsoil	B	0	0	0	0	0	1	2	2	2	2	2
C8	D2	A	4	0	7	6	5	8	5	8	9	10	11
C8	D2	B	4	1	0	1	2	4	4	9	10	10	11

2003 survey dates A-July 2, B-July 30, C-Aug 8, D-Sept 19 (C survey not used for analysis)
2004 survey dates A-May 6, B-May 20, C-Jun 1, D-Jun 24, E-Jul 21, F-Aug 3, G-Aug 16

Appendix A-5: Species percent coverage for the RS plots by vegetation survey. (1 represents the species is present but in low quantities, numbers in the unknown row represent the number of unknown species present not their percent coverage) Species key in Appendix D-3.

[2003 – D1 transferred soil plots]

	A-A1			**B-A1**			**A-A4**			**B-A4**			**A-A8**			**B-A8**		
	1	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**
AXAM								1										
BESY												20						
CAAT		75	35		50	100		75			95			80	60		5	
CASP	100			100			100			100			100			100		
CAUT		25	35		50			25	60			80		5	30		95	60
CAVE						1					1			15				
CIAR															1			
G											5							40
MEAL			35															
POLA												1						
PONO			1						30									
RACE						1						1						1
RAMA									5						1			1
ROIS			1												1			
TAOF									1						1			
THAR					1													
TRHY		1	1						5		1				1			1
Unknown	3	4	1	2	3	5	6	3	5	8	3	3	6	3	3	5	1	4

	A-B3			**B-B3**			**A-B4**			**B-B4**			**A-B7**			**B-B7**		
	1	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**
AXAM								1										
CAAT		50			50			95	90		1	100		1			50	
CASP	100			100			100			100	100		100	100	100	100		
CAUT		50	100		50	100		1						1			50	
CAVE								1										
CHAL														1				
POLA									10									
THAR		1																
Unknown	4	1		4			3											

	A-C1			**B-C1**			**A-C4**			**B-C4**			**A-C5**			**B-C5**		
	1	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**
CAAT			100		50	100		100	50		100	100		100	60		90	40
CASP	100	50		100	50		100			100			100			100		
CAUT																	10	40
CAVE		50	1						15						1			
CHAL		1																
G														1	40			20
MOSS									15									
POPR																	1	
ROIS									15									
TAOF									15									
Unknown	4			2			4	3	3	4			7		1	3		

Appendix A-5: continued [2003 – D2 transferred soil plots]

	A-A3			B-A3			A-A5			B-A5			A-A6			B-A6		
	1	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**
ALAE						5												10
ARAB		1			1													
BESY						20						40						
CAAT		95	50		95	45					95			90			90	
CASP	50			90						100			100		50	100		
CAUT								100	15			60		10			5	90
G	50			10		1				20	5						5	
GNPA															15			
KOSC									30									
MEAL			40															
POLA		5	5		5	25			15									
POPR												1						
RACE			5			10			15			1			15			1
RAMA															15			
ROIS									15						15			
TRHY		1							15									
Unknown	5	3	4	2	2	1	7	5	4	3	4	1	3	3	2	3	1	1

	A-B2			B-B2			A-B8			B-B8			A-C2			B-C2		
	1	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**
ALAE						1												
CAAT					90	60		100						100	75		100	95
CASP	50		40	100			100		100	100	100							
CAVE			10															1
G	50	50	10		5	40								1			1	
POLA		50	30		5	1									15			
RACE															15			1
ROIS			10															
TRHY			10															
Unknown	3	2	2	4	1		3						3	3	3	2	2	

	A-C6			B-C6			A-C8			B-C8		
	1	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**
CAAT		100	50									100
CASP	100										100	
G			50			100			20			
GNPA									20			
POLA			1									
RACE			1						20			
ROIS		1	1						20			
TRHY									20			
Unknown	2	1	2	4			4		1	4		

Appendix A-5: continued [2003 – SUBSOIL plots]

	A-A2	A-A7	A-B1		
	4	**4**	**2**	**3**	**4**
GNPA			50		
KOSC		50			95
MEAL	90	50			
ROIS					
THAR			50		
Unknown	1			1	1

Appendix A-5: continued [2004 – D1 transferred soil plots]

	A-A1							B-A1							A-A4							B-A4						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
ALAE				1	1	1	1					1					1	5	1	1				1	20			5
ARLY		1		1	1	1	1				1							1		1								
BESY				1	1	5						1	5	1						1			1	1	20	20	10	10
CAAQ									50	25	50	50	1					10										
CAAT		70		25						25	30	20	1					20					50	1	25	25		
CALA			20							25																		
CASP	75	10	40		20	15	25	100					90	90	50	70	50		20	15	25	100	50	90		15	50	60
CAUT									50	25	20	10	1												20			
CAVE						1					1			1												5	1	
CHAL				1	5	1					1	1	1				1	1						1			1	
CIAR				1	1	1	1						1	1				1		1	1			1	1	1		1
COAU	1	1	1	1																								
ERGA						1	1				1																	
EUGL																						1	1		10			5
G			1												1	1						1	1					
GATR											1	1						1	1	1	1							
GLGR		1							1							1							1					
GLMA	1			20	5	5	5		1		1	1	1	1	1			10	1	5	1					5	1	1
IVAX	1	1	1	15	10	5	5		1	1	1	1		1		1	1	5	5	5	1	1		1	5	5		
MEAL	1	10	20	10	10	15	15								1													
PLMA	1	1	1	5	5	5	5									1			5	5	1	1	1	1	1	5	5	5
POLA											1	5	5	5				1	5	1					1	5	15	5
PONO	5	10	5	10	10	15	15	1	1	1	1	10	1	1	45	30	25	15	20	35	30							
POPA														1					1	1	1						5	
RACE													1	1				1							1		1	
RAGM								1	1		1																	
RAMA	1	1	1	1	5	1		1	1		1	1	1	1	5	1	20	10	20	20	25		1	1	1	5	5	5
ROIS					1									1	1				10							1	1	1
SOAR					1		5																			1		1
TAOF	20		15	15	10	15	15	1		1	1		1	1	5		5	5		5	5			1	1	1	1	1
THAR	1	1	1			1	1				1																	
TRHY		1	1	1	5	5	5				1	5	1	5		1	1	5	15	15	20				1	1	1	1
Unknow		1	4							4						2	1						2	3				

	A-A8							B-A8							A-B3							B-B3						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
ALAE				5	1		1				5	5	1					10	25	5	5				10	5		1
BESY		1			1		5										10											
CAAQ		25		20					50	1	70							50					50	50	50		1	
CAAT		75		10																				20			1	
CACA				5																								
CALA																								20				
CARE																									5			
CASP	100		80		20	20	25	100	50	90		60	60	80	100	100	90		30	30	40	100	50			85	90	80
CAUT																								20	5		1	
CAVE												1	1					1	5	10			1	1	1	1	1	
CHAL			1			1	5			1	1	5	1	5			1	5	5	10	5				1			
CIAR				1	1	1	1				1	1	1	1				1	1	1	1				1			
ERGA				1	1						1																	
EUGL	1	1	1	10	1					1	10			1													1	
G	1							1		5					1										5			
GATR					1	1	1					1	1					1							1			
GLGR		1							1		1	5	20	15		1		1							10	10	10	20
GLMA					10	10	15					5	5	1				1		1								
IVAX		1	10	30	20	10	15	1	1	5	10	5	5	1		1	1	20	10	10	10		1	1	10			
PLMA		1	1	1	5	5	5						1															
POLA					1	5	1					1	5				1	1	20	20	10							
PONO	1	1	1	5	20	15																						
POPA						10	5						5						1	5	10							
RACE						1							1															
RAMA	1	1	1			5			1	1	1	5	5	1	1				1	1	5							
SOAR					1							1	1	1														
TAOF	1		10	5	10	10	5	1		1	1	1	1	1														
THAR										1	1																	
TRHY		1		1	5	5	15		1		1	5	1	1					1	5	5				1	1		
Unknow		1								2						2	2						1	1				

Appendix A-5: continued

	A-B4							B-B4							A-C1							B-C1						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
ALAE				10													25	5	10	20	25							
BESY		1		5	10	1	5			20	20	5	10	1												50	25	35
CAAQ			25	60					80	60	20																	
CAAT		30	25	20							5						75	30					90	90				
CASP	100	70	50		70	70	80	100	20	20		80	80	90	100	100			60	50	40	100	5		40	25	50	30
CAUT											50																	
CAVE			1	1	5	10			1						1	1	1	25		1			5	10	10	1	5	
CHAL			1		1					1	1	5	5	1			1	5	10		5							
CIAR				1		1					1							1										
EUGL														1	1	1	1	5	1	10	5							
G	1		1					1							1		1											
GATR																									1			1
GLGR		1		1					1		1	5	5	5		1				20					50	20	25	10
GLMA	1				1	10														10	1							
IVAX		1	1	1					1	1	5					1	1	15	1	1	1		1	1	1			
POLA			1	5	15	20	15			1	1	10	10	5														
PONO		1																1										
RAMA																				1								
TRHY					1						1				1			5	10	1					1	1		
SCSP																					25							25
Unknow		2	2						1							2	2							2				

	A-C4							B-C4							A-C5							B-C5						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
ALAE					10	10	20																					
AXAM				20																								
BESY		1			25	15	20																					
CAAQ									90		30						1	20							45			
CAAT		100	80	40	50						30	100	100			100	95	50	60						45			
CALA										80																		
CASP	100					40	50	100						100	100					65	50	100	100	90		90	80	90
CAVE		1		1	5	5			1	1	1					1	1	1	1	10			1	5	5			
CHAL										1	30						1		1	1	1			1		5	1	1
CIAR				1													1	1	5	1	5							
EUGL				5		5																						
G	1		10												1		1											
GATR																			5		5							
GLGR		1																5	10	5	10		1	1	5		15	10
GLMA					5	10	1											5	5	5	1							
IVAX	1	1	5	20	5	5	5		10	20	10					1	5	20	10	10	5		1	1	1			
PLMA	1			5		5	5													1	1							
PONO				1														1		1	1				1			
RACE																									1	1	5	1
RAMA																					5							
ROIS		1		10	5	5	1				1																	
TAOF	1		1	1	5	1	5											1			1				1	1		
THAR			1	1																								
TRHY						1	1				1							1	1	5	5							
Unknow		1	2						1	2						2	2						1	1				

Appendix A-5: continued [2004 – D2 Transferred soil plots]

	A-A3							B-A3							A-A5							B-A5						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
ALAE				20		1					20	5		1				10			1				15	5		5
ARLY																1	1					1	1	1				
BESY					5	5	1		1	20	20	20	15	15		10	40		15	15	5		25	20	30	20	20	20
CAAT		50	25	25	10	1			80	75	25	25	1				1	10		10			25	50	50			
CACA				1														20										
CASP	80				20	20	40	100	10			25	70	60					10		10	50		10		70	60	60
CAUT						1					20												25					
CHAL			1	5	1	1				1	1	1	1	1			1			1				1	1	1		
CIAR				1	1		1				1									1	1			1	1	1	1	1
CRTE																		1	1	1	1						1	
G	5	1	1	1		1		1	10	5					30	5						50	20	20				
GLGR		1														1												
IVAX		1	1	1	10	1	5		1	1	1	1			60	70	50	20	10	15	15		1	1	1		1	1
MEAL	10	50	75	50	50	55	50								1	1	1	5	10	10	5							
PLMA															1		1	1	5	5	10							
POLA			1		1					1	5	10	1	5				1		1	1			1	1		1	1
PONO					1										1	1	1	1	5	1						1	5	1
POPA												5	10	10					15	20	20						5	1
RACE							1						1	1	1	5	1	10	1	5	1			1		1	1	1
RAGM			1	1				1	1	1	1	1			1		1				1	1	1	1	5			1
RAMA	1	1	1	1	5		1	1	1	1	5	5	5	5	1	1	1	1	1		1							
ROIS		1		1			1	1			1	1	1	1		1		10	10	10	5	1	1			1	5	1
RUCR									1						1	5	1	10	5	10	1			1	1	1	1	1
SOAR					1	5	5												1	1	1						1	
TAOF	5		1	1			1							1	1		1	1		5	5				1			
THAR				1									1			1												
TRHY				1	1		1				1	1		5					1	5	10				1	5	5	5
Unknown			1					1	2	2							2							1				

	A-A6							B-A6							A-B2							B-B2						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
ALAE				30	15		5			15	20	5	10	10		50	90	40	10	5	5			10	10		15	5
ARLY	25	1	1					1	1	1					1	1	1											
BESY				20	50	40	25			15	5	15	20	15		50	5	10	45	60	50		30	10	15	40	30	20
CAAT			30	10					50	70	75					1		5					30	80	40			
CACA				1						1	1							10										
CASP	50	50				10	15	50	25			60	60	75	5				10		5	75				30	40	50
CHAL			1			1													1	1	1							
CIAR											1	1	1			1	1		1	1	5							
CRTE				1	1	1	1																					
G	25	50	60					50	25						90							25			1			
IVAX		1	1	10	1	20	25				1			1	5	1	1	5	5	5	1		30	1	40	10		1
PLMA		1			1		1	1			1		1	1														
POLA				1	5	5	1										1	1	5	5	1			1	1	30	15	20
POPA					5	10	5						5	5					10	10	20							
RACE	1	1	5	5	1	1	1	1	1		1	10	1	1	1	1	1	10	5	5	5						1	
RAGM		1						1	1	1	1				1	1			5									
RAMA	1	1	1	1		5	5	1	1		1	1		1		1	1				5							
ROIS				5	15	5					1	1	1		1	1		10	5	10	1						1	
RUCR					1	1					1	1		1	1	1	1	10	10	5	5							
TAOF	1		1	5		5	5			1	1	1	1	1						1	1				1			1
TRHY				1		5	15				1		1					1	1	1	5				1			
VIAM				1	1	1	1																					
Unknown						1				2							1						1					

Appendix A-5: continued

	A-B2							B-B2							A-B8							A-C2						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
ALAE		50	90	40	10	5	5			10	10		15	5							15			75	25	10		15
ARLY	1	1	1																			1		1				
BESY		50	5	10	45	60	50		30	10	15	40	30	20									50		50	40	40	40
CAAT		1		5					30	80	40						80	90		1								
CACA				10																								
CASP	5				10		5	75				30	40	50	100	100			95	100	80	50	50	25	15	10	10	10
CAVE																	1	5										
CHAL					1	1	1										20	5	5		5			1		1		
CIAR		1	1		1	1	5																		1			
G	90							25			1								1			50						
IVAX	5	1	1	5	5	5	1		30	1	40	10		1		1							1	1	10	5		1
JUBU																											1	5
MAPE																										1	1	1
POLA			1	1	5	5	1			1	1	30	15	20						1						10	15	10
POPA					10	10	20																			1	5	
RACE	1	1	1	10	5	5	5						1				1	1				1	1	1	1	10		5
RAGM	1	1			5																	1	1		1		5	
RAMA		1	1				5																					
ROIS	1	1		10	5	10	1						1											1	1	5	5	5
RUCR	1	1	1	10	10	5	5																1		5	10	5	10
SOAR					1																					1	1	1
TAOF						1	1				1			1														
TRHY				1	1	1	5				1														1		1	1
Unknow			1						1							2	3						2	2	1			

	B-C2							A-C6							B-C6							A-C8						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
ALAE				10	10	10	10				5			5					10		25				25	20	10	15
BESY				20	10	20	10				25	25	35	25					20	20	25		25			20	20	20
CAAT				50					50	50		25	20															
CASP	75	50	90		70	50	60	75						25				10		5								
CAVE											25																	
CHAL			1	10	1	5	5			1	1	1	5				25	30	20	20	10							
CIAR											1	1	1	1														
EUGL												1							10	20	15			1	1			
G	25	50	10					25	50	50						10	1					50		50				
GLGR				1		15	10																					
IVAX		1	1	1					1	1	5	10	20	10		90	75	60	5	5	5	1	1	1	1	1	5	10
HOJU																												5
PLMA																									1		5	5
POLA							10						1					1	20	20	10							
POPA												10	10	5												10	20	15
POPR											10																	
RACE	1	1	1	10	10	10	5			1	1	1						1				10	25	1	20	10	15	10
RAMA																												5
ROIS										1	10	10	1	1				1	5				25		5	10	10	
RUCR				1				1	1	1	10	15	10	10							5	40	25	50	50	30	25	25
TRHY				1							1		1	10				1							1	1	1	5
Unknow		1														2							3					

	B-C8						
	1	2	3	4	5	6	7
ALAE					30	30	20
BESY		95		20	25	25	30
CASP							20
CHAL			1	20	10	5	5
G	50	1	50	10			
IVAX		1	50	20	10	5	1
PLMA					5	5	1
POLA				1	1	5	5
RACE			1	10	10		10
RAGM	50	5				10	
ROIS					1	1	1
RUCR				10	10	10	10
TRHY				1	1	1	1

Appendix A-5: continued [2004 – SUBSOIL plots]

	A-A2							B-A2						A-A7							B-A7]					
	1	2	3	4	5	6	7	2	3	4	5	6	7	1	2	3	4	5	6	7	2	3	4	5	6	7
CAAT												10	25													
CASP											1															20
CHAL			1						50	25	30	15	20			1	10	1	20	25		5	10	50	50	20
CIAR							1					1														
EUGL	1			1	1		1	50		1	5	5	10				5	1		1				5		20
G	1	1								1							1	1	1							
GLGR		1																								
HOJU						20	15																			
IVAX		1	90	75	40	30	30	50	25	50	30	20	20		50	75	60	70	40	30	100	95	80			15
MOSS					10																					
MEAL	100	100	10	10	30	30	25			1				100	50	25	15	30	40	25						
POLA			1	1	10				25	25	40	40	20													
PONO																										10
RAMA																										10
TAOF			1	5	15	20	20													1			10	45	50	20
THAR	1	1	1	10						1																
TRHY																		1	5	10			1	1		
Unknow														1	1							1				

	A-B1							B-B1						A-C3						B-C3					
	1	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7
CHAL			5	5	1	10									5	5	15	30	20		25	40	100	100	100
CIAR						5	1						20				5	5	5						
EUGL				1																					
G	1	25	1	10																					
GLGR		25																							
IVAX	1	50	90	80	50	60	60	75	90	90	60	90	60	100	95	90	80	65	75	100	75	60			
HOJU					20	10	15																		
MEAL										1															
POLA											40														
ROIS										5															
TAOF	100		5	5	30	10						5	20												
THAR								25	10	5	1	5													
TRHY						5	25																		
Unknow		1	1																						

	A-C7						B-C7					
	2	3	4	5	6	7	2	3	4	5	6	7
CHAL		50	40	20	25	20		50	20	50	50	50
CRTE				5		5						
EUGL	50									50	50	50
G			20									
IVAX	50	50	40	60	50	60	100	50	80			
HOJU				15	25	15						
TAOF						1						

Appendix A-5: continued [notes]

Notes: ***Survey Dates***

2003 1-June, 2-July, 4-September (August survey was conducted in error making it ineligible for data analysis)

2004 1-May 6, 2-May 20, 3-June 1, 4-June 24, 5-July 21, 6-August 3, 7-August 17

2003 Additional Data

CHAL was found on A7-A and G was found on B1-A during survey 4

2004 Additional Data*: Because of the infrequency of species occurrence the following information was left off the above tables*

Plot	Species	Survey	Plot	Species	Survey
A1-A	MOSS	5	B7-A	CAVE	2,3,4
	GEAL	3,4		CHAL	4
A3-A	EUGL	1		IVAX	2,3,4
	GEAL	4		CASP*	
	POPR	4	B8-A	CAUT	6
A4-A	POPR	4	C1-B	TAOF	4
	RUCR	6	C2-A	POTS	6
	VESC	4	C4-A	ARLY	4
	VIAM	6		POPA	6
A4-B	EPGL	7	C5-A	POLA	5
	MAMA	5	C6-A	ARLY	1,3
	POAM	7		MOSS	2
A5-B	CAVE	4		PONO	6
A6-A	HOJU	6	C6-B	CIAR	4
	ARAB	5		POAM	4
A8-B	MOSS	5	C8-A	ARLY	1
B3-A	MEAL	4		TAOF	5,6,7
	SOAR	7	C8-B	MEAL	4
	TAOF	7			
B3-B	RACE	4			

* CASP was present in all seven 2004 surveys and accounted for 100% of the vegetation cover

Appendix A-6: Root depth study aboveground parameters, hole depth, topsoil depth, average and maximum root depth for the RS plots (Depths are measured in cm from soil surface)

Plot	Soil	Sub	Cov.	M. H.	A. H.	Hole	Topsoil Depth				Max Root Depth				Ave. Root Depth			
	Source	plot	(%)	(cm)	(cm)	Depth	A	B	C	D	A	B	C	D	A	B	C	D
A1	D1	A	60	65	40	16	5	6	5	5	7	10	12	15	3	2.5	2.5	3
A1	D1	B	40	70	55	20	3	5	5	7	>20	>20	>20	>20	8	8	10	9
A2	Subsoil	A	15	35	25	20	0	0	0	0	9		13	13	5		4	4
A2	Subsoil	B	10	55	20	18					3		4	4	1		2	1
A3	D2	A	50	100	60	17	3	7	8	4	8	12	12	14	6	9	7	8
A3	D2	B	65	80	55	18	5	7	6	7	18	10	10	12	7	5	8	7
A4	D1	A	80	50	40	19	9	8	8	9	16	16	10	15	6	9	6	7
A4	D1	B	80	75	40	17	7	6	5	7	17	17	16	12	7	6	10	8
A5	D2	A	45	50	20	20	6	5	6	7	13	17	10	19	5	9	5	5
A5	D2	B	70	65	50	22	5	5	8	10	5	17	15	18	5	10	10	10
A6	D2	A	40	65	30	20	5	3	7	9	8	9	8	11	5	5	7	10
A6	D2	B	35	70	45	26	5	6	5	5	25	20	19	23	7	10	9	8
A7	Subsoil	A	5	15	10	20					1	12	14	5	1	8	5	4
A7	Subsoil	B	0	0	0	20							4	2			1	1
A8	D1	A	45	65	20	22	10	7	5	6	20	19	20	10	12	10	6	5
A8	D1	B	60	85	50	22	5	5	3	8	22	22	17	21	8	9	5	10
B1	Subsoil	A	15	25	20	20					15	12	9	12	3	6	2	2
B1	Subsoil	B	5	35	35	24					10			5	5			2
B2	D2	A	30	65	50	21	8	6	5	9	16	18	15	20	7	9	10	8
B2	D2	B	20	50	35	30	3	6	7	7	5	10	10	17	3	5	5	9
B3	D1	A	40	45	25	20	4	5	6	3	16	12	7	9	4	6	3	8
B3	D1	B	70	110	60	24	8	5	6	2	>22	>22	20	>21	13	7	9	7
B4	D1	A	70	50	40	22	6	5	6	7	17	16	18	20	9	10	6	9
B4	D1	B	60	55	50	18	3	4	10	9	>17	>17	>12	>15	10	5	10	7
B6	D2	A	0	0	0	8												
B7	D1	A	50	95	70	20	5	5	5	5	>20	>20	>20	>20				
B7	D1	B	5	35	30	9												
B8	D2	A	0	0	0	1	10											
C1	D1	A	20	100	75	16	6	8	7	8	>17	15	16	14	6	5	9	12
C1	D1	B	20	100	60	14	8	5	5	8	>14	10	>15	15	12	6	8	8
C2	D2	A	40	50	30	27	8	7	8	5	20	12	22	16	6	5	6	6
C2	D2	B	10	40	35	16	7	10	4	7	12	17	10	12	7	10	6	6
C3	Subsoil	A	5	55	55	20	0	0	0	0	10	5	5	10	2	1	2	1
C3	Subsoil	B	0	0	0	22	0	0	0	0	0	11	10	9	0	8	4	5
C4	D1	A	50	45	25	22	6	4	4	8	22	18	17	24	10	5	6	12
C4	D1	B	10	50	30	23	5	7	7	9	18	17	12	14	6	5	5	9
C5	D1	A	80	80	60	19	6	7	6	5	20	18	18	19	11	12	9	11
C5	D1	B	10	80	70	23	6	5	6	7	18	>20	18	20	8	5	7	10
C6	D2	A	40	60	30	20	5	5	9	7	10	5	17	19	7	3	8	13
C6	D2	B	5	20	20	24	4	3	5	5	5	4	4	8	2	2	2	4
C7	Subsoil	A	5	20	20	22	0	0	0	0	14	6	3	10	6	3	3	4
C7	Subsoil	B	0			21	0	0	0	0	11	6	0	5	4	4	0	3
C8	D2	A	25	30	15	23	6	4	8	8	8	7	13	16	3	3	2	5
C8	D2	B	30	50	25	18	6	7	6	7	17	13	17	15	6	6	5	10

Appendix A-7: Rooting depth study species percent coverage for the RS plots

	A1		A2		A3		A4		A5		A6		A7		A8		B1		B2	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
ALAE						5		5				10			5					10
BESY	5				20	5			25	20	45	50			1				70	
CAAQ		1																		
CAAT																1				
CASP	30	90				90	50	45		60		40			15	80				50
CAVE								1												
CHAL				30				1					15		5	5				
CIAR	1						1	1	1			1			1	1	5			
EPGL								5												
EUGL													10						1	
GATR															1					
GLGR								5								10				
GLMA	15						1	5							5					
HOJU			20																	
IVAX	15		80	40	1			1	10	1	10		70		5	1	90	100	1	
JUBU											1									
MEAL			1		50															
PLMA								5	15		1				5					
POLA		10		30		1		5	1										5	40
PONO	5						20			10					15					
POPA									5		20				5				10	
RACE									1		5									
RAMA							10	5	10		5				5					
ROIS											5									
RUCR									1										5	
SOAR					5			5												
TAOF	30				10		1	1							5	1	5		5	
TRHY	1				1		15		25	5	1	1			15				1	

	B3		B4		B7	C1		C2		C3		C4		C5		C6		C7		C8	
	A	B	A	B	A	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
ALAE	5							10				1								10	1
BESY			1				40	25	40			40				25				20	40
CASP	40	80	90	100	100	60	60		60			10	100	95	100						15
CHAL	5									100				5			100	100			
CIAR	1							1								1					
GLGR		20																			
GLMA												5									
IVAX	10	1						10				5				25				1	10
JUBU								10													
MAPE								5													
PLMA												10								20	
POLA	10		10																		10
PONO																5					
POPA	10											5				15					
RACE								1												1	1
ROIS								5				5								10	1
RUCR								10								15				10	15
SOAR								5												1	
TAOF	1	1										5								5	
TRHY	5							5				1				10				10	
SCSP						40															

Appendix B: Donor and Opportunistic Wetland Plots Raw Data

Appendix B-1	Vegetation cover for each subplot (A or B) for the donor wetland plots by survey and year
Appendix B-2	Maximum height for each subplot (A or B) for the donor wetland plots by survey and year
Appendix B-3	Average height for each subplot (A or B) for the donor wetland plots by survey and year
Appendix B-4	Species richness for each subplot (A or B) for the donor wetland plots by survey and year
Appendix B-5	Species percent coverage for the donor wetland plots by vegetation survey
Appendix B-6	Root depth study aboveground parameters, hole depth, topsoil depth, average and maximum root depth for the donor wetland plots
Appendix B-7	Root depth study species percent coverage for the donor wetland plots
Appendix B-8	Vegetation parameters (VC-vegetation cover, AH-average height, MH-max height, SR-species richness) for each subplot (A or B) for the opportunistic wetlands by transect July 04
Appendix B-9	Percent coverage of species for the opportunistic wetlands

Appendix B-1: Vegetation cover for each subplot (A or B) for the donor wetland plots by survey and year

			2003			2004			
Site	**Plot**	**AorB**	**A**	**B**	**C**	**A**	**B**	**C**	**D**
D2	A3	A	95	100	100		75	95	90
D2	A3	B	60	100	100		90	95	100
D2	A5	A	85	99	100		75	90	95
D2	A5	B	99	100	100		80	85	100
D2	A6	A	95	90	95		50	80	90
D2	A6	B	95	95	100		80	80	90
D2	B2	A	50	100	100		15	50	80
D2	B2	B	90	100	100		50	70	100
D2	B6	A	50	100	100		50	55	70
D2	B6	B	99	100	100		50	95	100
D2	B8	A	60	100	95		50	50	90
D2	B8	B	80	100	100		90	95	100
D2	C2	A	70	95	90		20	50	75
D2	C2	B	60	100	100		75	80	100
D2	C6	A	70	100	100		60	50	75
D2	C6	B	60	90	95		70	65	95
D2	C8	A	40	90	90		60	60	90
D2	C8	B	90	100	95		50	90	100
D1	A1	A	95	99	80	80	99	90	95
D1	A1	B	90	75	50	50	68	75	80
D1	A4	A	95	99	75	80	90	95	100
D1	A4	B	70	75	60	50	85	95	95
D1	A8	A	99	45	75	90	80	75	80
D1	A8	B	80	78	80	60	90	90	90
D1	B3	A	100	65	80	90			80
D1	B3	B	90	64	75	60	90	90	95
D1	B4	A	100	73	90	80			
D1	B4	B	95	80	80	80			
D1	B7	A	90	70	90	90			
D1	B7	B	60	55	75	60			
D1	C1	A	99	50	80	50			
D1	C1	B	85	75	80	60			
D1	C4	A	95	90	80	70			
D1	C4	B	70	70	85	50			
D1	C5	A	95	75	95	90			
D1	C5	B	70	85	85	40			

Notes:

- 2003 survey dates A-June, B-July, C-August
- 2004 survey dates A-May, B-June, C-July, D-August
- No May 2004 survey took place at D2
- Plots B3-A, B4, B7, C1, C4, C5 were disturbed in early Jun 04

Appendix B-2: Maximum Height for each subplot (A or B) for the donor wetland plots by survey and year

			2003			2004			
Site	**Plot**	**AorB**	**A**	**B**	**C**	**A**	**B**	**C**	**D**
D2	A3	A	105	120	120		50	70	85
D2	A3	B	115	110	125		65	80	140
D2	A5	A	90	100	120		50	70	75
D2	A5	B	125	110	130		60	90	110
D2	A6	A	100	80	90		56	70	75
D2	A6	B	110	100	120		56	75	100
D2	B2	A	110	152	130		55	62	90
D2	B2	B	110	140	140		50	70	130
D2	B6	A	110	130	147		50	75	105
D2	B6	B	110	150	160		60	120	150
D2	B8	A	110	130	135		55	70	100
D2	B8	B	113	130	140		65	115	120
D2	C2	A	105	150	135		45	60	100
D2	C2	B	120	140	140		65	85	130
D2	C6	A	100	165	160		50	50	95
D2	C6	B	120	140	135		65	85	130
D2	C8	A	90	120	130		45	64	80
D2	C8	B	100	120	120		60	80	150
D1	A1	A	92	60	67	37	60	60	90
D1	A1	B	110	70	79	49	80	90	85
D1	A4	A	120	70	89	50	85	90	90
D1	A4	B	105	75	50	55	95	100	100
D1	A8	A	120	65	70	35	70	85	80
D1	A8	B	110	80	90	50	110	105	100
D1	B3	A	100	60	75	40			90
D1	B3	B	90	80	75	55	100	105	95
D1	B4	A	95	70	65	45			
D1	B4	B	100	80	75	50			
D1	B7	A	105	68	80	50			
D1	B7	B	100	70	50	62			
D1	C1	A	104	60	55	45			
D1	C1	B	100	100	120	45			
D1	C4	A	103	60	60	40			
D1	C4	B	100	70	70	45			
D1	C5	A	95	50	80	45			
D1	C5	B	120	80	75	50			

Notes:

- 2003 survey dates A-June, B-July, C-August
- 2004 survey dates A-May, B-June, C-July, D-August
- No May 2004 survey took place at D2
- Plots B3-A, B4, B7, C1, C4, C5 were disturbed in early Jun 04

Appendix B-3: Average Height for each subplot (A or B) for the donor wetland plots by survey and year

			2003			2004			
Treatment	**Plot**	**AorB**	**A**	**B**	**C**	**A**	**B**	**C**	**D**
D2	A3	A	85	83	85		30	60	60
D2	A3	B	60	75	101		45	70	75
D2	A5	A	85	86	90		40	65	40
D2	A5	B	90	84	103		40	60	90
D2	A6	A	85	63	75		40	60	60
D2	A6	B	90	68	96		35	55	75
D2	B2	A	90	105	115		20	50	60
D2	B2	B	95	98	114		20	65	60
D2	B6	A	90	120	120		30	60	60
D2	B6	B	100	125	128		45	95	105
D2	B8	A	80	120	130		40	50	75
D2	B8	B	85	105	115		40	90	110
D2	C2	A	95	130	120		35	50	85
D2	C2	B	50	105	96		60	60	110
D2	C6	A	95	145	135		40	50	65
D2	C6	B	70	98	110		40	50	100
D2	C8	A	80	115	120		40	50	75
D2	C8	B	80	100	99		40	60	120
D1	A1	A	60	25	50	27	55	40	40
D1	A1	B	50	25	45	30	70	70	70
D1	A4	A	80	50	40	40	65	80	50
D1	A4	B	100	50	75	45	70	95	65
D1	A8	A	90	40	60	20	50	80	60
D1	A8	B	100	70	60	45	85	85	80
D1	B3	A	80	45	50	25			60
D1	B3	B	50	60	65	45	75	95	90
D1	B4	A	80	45	50	20			
D1	B4	B	90	60	55	35			
D1	B7	A	90	50	65	40			
D1	B7	B	90	50	70	35			
D1	C1	A	95	50	65	40			
D1	C1	B	95	50	55	35			
D1	C4	A	90	40	45	30			
D1	C4	B	98	55	50	40			
D1	C5	A	89	40	60	30			
D1	C5	B	95	63	65	40			

Notes:
- 2003 survey dates A-June, B-July, C-August
- 2004 survey dates A-May, B-June, C-July, D-August
- No May 2004 survey took place at D2
- Plots B3-A, B4, B7, C1, C4, C5 were disturbed in early Jun 04

Appendix B-4: Number of Species for each subplot (A or B) for the donor wetland plots by survey and year

Treatment	Plot	AorB	2003 A	2003 B	2003 C	2004 A	2004 B	2004 C	2004 D
D2	A3	A	6	7	5		9	6	11
D2	A3	B	9	13	11		11	11	8
D2	A5	A	6	7	6		8	7	7
D2	A5	B	9	13	10		9	11	11
D2	A6	A	7	8	8		8	11	9
D2	A6	B	9	13	13		12	12	13
D2	B2	A	7	5	6		4	5	6
D2	B2	B	9	11	13		8	8	10
D2	B6	A	3	3	4		5	7	5
D2	B6	B	4	10	8		7	5	9
D2	B8	A	2	1	1		1	1	4
D2	B8	B	10	9	12		9	6	7
D2	C2	A	4	5	4		7	8	8
D2	C2	B	11	14	14		10	12	8
D2	C6	A	1	1	1		6	3	6
D2	C6	B	9	12	11		9	10	13
D2	C8	A	2	3	3		1	2	4
D2	C8	B	8	15	13		9	10	12
D1	A1	A	7	3	5	6	7	6	6
D1	A1	B	4	3	2	4	6	10	7
D1	A4	A	4	3	3	4	5	7	4
D1	A4	B	3	3	2	3	4	3	4
D1	A8	A	4	3	3	9	9	6	6
D1	A8	B	5	3	2	4	6	5	7
D1	B3	A	7	4	4	6			7
D1	B3	B	9	4	4	4	6	6	4
D1	B4	A	10	5	4	7			
D1	B4	B	10	4	5	7			
D1	B7	A	7	2	3	5			
D1	B7	B	4	2	3	5			
D1	C1	A	12	4	2	7			
D1	C1	B	6	3	2	3			
D1	C4	A	6	3	4	5			
D1	C4	B	3	2	2	5			
D1	C5	A	6	2	4	6			
D1	C5	B	3	2	2	4			

Notes:

- 2003 survey dates A-June, B-July, C-August
- 2004 survey dates A-May, B-June, C-July, D-August
- No May 2004 survey took place at D2
- Plots B3-A, B4, B7, C1, C4, C5 were disturbed in early Jun 04

Appendix B-5: Species percent coverage for the donor wetland plots by vegetation survey. (1 represents the species is present but in low quantities, numbers in the unknown row represent the number of unknown species present not their percent coverage) Species key in Appendix D-3.

[D1 donor wetland plots]

	A1-A							A1-B							A4-A						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
CAAQ					25	30	5				60	40	40	60				80	75	35	50
CAAT	1	99	80	50	50	60	80		50	50	20	40	40	20	10	30	25	5	10	25	35
CABE													10	20							
CACA																	1			20	
CAUT	90	1	15	50	25		10	100	50	50	20	10	10		90	70	75	15	5	20	10
CAVE				1	1		1					1	1	1							
EUGL				1	1																
G				1		1														5	
GATR	10					1							1								
GLGR							1							5							5
MOSS	20	1	1	20	20	10	10	10	1		1	10	5	10	5	1		1	5	1	
POPR	1		5									10							10		
SCSP					1	1															
Unknown	2		1					2					2		1					1	

	A4-B							A8-A							A8-B						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
CAAQ				60	50	90	70			20	50	45	50	50				80	80	80	75
CAAT		25	25	1	30	5	30		40	40	25	50	25	30		10	50	10	10	10	5
CAUT	100	75	75	40	20			100	60	40	25	5	5		100	90	50	10	10	10	
CAVE											1	2	5	5						1	1
EUGL											1	1									
G											1	1	1								
GATR								1													
GLGR														5							20
MOSS	5	1			1	5	1	30	5		50	30	15	10	5	1		1	1	1	5
RACE																					1
TAOF														1							
ARLY															1						
Unknown	1							1			1	2			2				2		

	B3-A					B3-B							B4-A				B4-B			
	1	2	3	4	7	1	2	3	4	5	6	7	1	2	3	4	1	2	3	4
CAAQ				50	20				90	75	50	70	1		5	25			20	60
CAAT	90	50	45	1	20		35	40	1	20	10	5	40	20	50	10	10	15	5	5
CABE					10															
CACA	1		15			1		10									1		5	20
CAUT	10	25	15	30		70	60	45	10	1	20		50	40	25	25	60	70	50	10
CAVE					1															
EUGL											1									
GATR						1											1			
GLGR					20															
MOSS	25	1		10	10	40	1		1	1	1	1	50	10		25	40	1		1
POPA				1													1			
POPR	1					1				1			1				1			
RACE																				1
TAOF													5							
SCSP		25	25	10	5	5	5	5		5	20	25	5	20	20	15	20	15	20	5
ARLY						1														
Unknown	2					2							2			1	1			

Appendix B-5: continued

	B7-A				B7-B				C1-A				C1-B				C4-A			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
CAAQ	1		1	80			20	80	1	5		50		1	25	55			15	30
CAAT	5	5	25	5	20	5	5	1	1	5	25		10				10	30	40	5
CACA																	1	1	15	30
CAUT	85	95	75	15	80	95	75	5	90	95	70	1	90	100	75	5	80	70	30	35
G								15	1			50				40	1			
GATR	1								1											
MOSS	5			1	5			1	1			1	5				30			1
POPA	1								5					1						
POPR										1			1							
SCGA									5											
TAOF									5				1							
Unknown	1			1	1				2				1				1			

	C4-B				C5-A				C5-B			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
CAAQ				20			15	30				25
CAAT	60	5	25		35	50	40	1	85	5	40	
CACA				20	30		15	30				25
CAUT	40	95	75	20	35	50	30	20	15	95	60	50
G				40				20				
MOSS				1	5			1				1
POPA									1			
TAOF					1							
Unknown	1				1							

[D2 donor wetland plots]

	A3-A						A3-B						A5-A					
	1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
ALAE							25	10	5	10	10	10						
BESY								20	15	10	5	10						
BICE		1	1					1	1			1		1				
CAAQ																10		
CAAT	95	100	100	90	95	90	75	30	40	50	50	50	95	100	95	80	90	80
CACA																5		5
CAVE										1	1							
CIAR				1	1	1												
ELPA								10	5	10	5							
EQAR	1	1	1	5	5	1	1	1	1		5	1	5	1	1	5	5	
GATR	1	1		1	1	1		1		1	1	1	1	1	1	1	1	1
GLGR						1		1	35	10	10	30			5			
LEMI							50	30	1									
PHAR																		5
PLMA				1	1	1												
RACE	1			1			1	10	1	1	1							
ROIS		1	1				1	1	1					1				
RUCR							1	1	1									
SCGA	1	1	1	5	1	5				1		1	1	1	1	5	5	1
TAOF				1		1											1	1
TRHY				1		5							1	1	1	5	5	10
Unknown	1						2				2		1					

Appendix B-5: continued

	A5-B						A6-A						A6-B					
	1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
ALAE	10	5	1	10	10	10					5		5	5	5	20	10	10
BESY		5	1	10		10								5	5	20	10	10
BICE		10	5			1		1						5	10			5
CAAT	40	30	45	50	40	70	80	80	80	70	80	80	75	55	65	25	25	50
CACA							1	20	10	10								
CARE	30	50	40	10	10			10										
CIAR											1	1				1	1	1
ELPA	1	1	1	10	10	5							5	10	5	25	5	1
EQAR				1	5	1	5	1	1	10	5	1		1	1	5	5	5
G							10											
GATR		1			1	1	1	1	1	5	1	1	1	15	1	1	1	
GLGR		1	10	1	10	5								1	10		5	10
LEMI	20	5	1										5					
MOSS		1							1									
PLMA											1	1						
POPA									10		10	10					20	
ROIS	1	1	1				1			1	1	1	1	1	1	1		
RUCR		5	1			1								1	1	1		
SCGA	1				1		1	1	1	1		1	1	1	1	5	5	5
SISU				1	5	1									1	1		1
TAOF						1		1		5		5		1	1		5	1
TRHY					1											1		1
Unknown	1								1		1		1					

	B2-A						B2-B						B6-A					
	1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
ALAE							5	1	1	10	20	5						
BESY								1	5	10	10							
BICE									1			5						
CAAQ	80		10				50		15									
CAAT	10	100	60	60	70	50		90	60	50	20	70	100	100	50	75	60	70
CACA			10				1							1	25	20	5	10
CAUT							20	5	10		20	1						
CAVE										1	5							
ELPA									1	20		5						
G	10												1					
GATR	1	1	5		5	5		1	1			5					1	
GLGR		1							15	5	10	20						
LEMI							10	1	1									
PHAR		1	20	20	20	25									15	1	10	15
PLMA								1	1									
POLA												5						
POPA						10												1
RACE						1	5	1		1	1	1						
ROIS								5	1									
SCGA	1	1	5	10	1	10							1	1	15	5	5	5
SISU				5	1			1	1	1		1						
TAOF																1	5	
SCSP							5											
Unknown	2						3											

Appendix B-5: continued

Site	B6-B						B8-A						B8-B					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
ALAE		1		1	5	1							25	15	1	10	10	5
BESY		5	1											5	10	10	5	5
BICE		5	1			1								5	1			
CAAQ				5														
CAAT	95	65	60	70	90	80	100	100	100	100	100	90	65	45	60	70	50	70
CARE		15											5					
CAUT		1	10	20	5	10												
CAVE																1	1	
ELPA	5	1	1	1	1										10	1	5	
GATR					1	1	1						1	1	1	1		1
GLGR		5	20			10								20	25	10	30	10
LEMI	10	5	1										10					
MOSS														5				
RACE				1									1	1	1			
ROIS						1							1		1			
RUCR													1	5	1			
SCGA						1						10				1		
SISU		5	10			1						1						
TAOF												1				1		1
Unknown	1												2		2			

Site	C2-A						C2-B						C6-A					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
ALAE							10	5	5	10	5	5				10		
BESY								15	5	10		5						
BICE								1	5									
CAAQ			30	10					10		25							
CAAT	85	85	60	50	60	50	75	35	35	50	25	60	100	100	100	80	100	85
CAVI		20						1										
CIAR					5	5	1		1	5	1					1	1	5
ELPA								5	5	10						10		
GATR	5	1	1	1	5	5			1	1		1						
GLGR								15	30	20	25	20						
LEMI							20	5	1									
MOSS								10			1							
MEAR																5		1
PHAR					1	10												
POPA					1	5					1							
POTS						1						5						10
RACE							10	5										
ROIS							1	5	1									
RUCR				15			1	1	1	1	5							
SCGA	5	5	10	1	5	10	1	10	15	5	1	5				1	1	5
SISU		1		5	5	1			1	1	1	1						
TAOF					1						5							1
URDI				20	10	20												
Unknown	1						3											

Appendix B-5: continued

	C6-B						C8-A						C8-B					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
ALAE	15	1	5		10	5							20		10	20	15	5
BESY		15	10	5		1								15	1	5	10	1
BICE			5											1	1			1
CAAQ				5											1			
CAAT	85	70	70	65	40	50	100	100	100	100	90	80	40	25	50	25	20	40
CAUT													20	15	35	20	5	5
CAVI														15				
CIAR		1	1	1	10	1												
ELPA		5			5	5								15	1	20	15	5
GATR	5	1	1	1	10	5		1					1	1	1	1	1	1
GLGR			10		10	10						5		5	10	10	30	20
LEMI	10	1											30	5				
MOSS		1												1				
MEAR		5		15	10	20												
PLMA				1	5	1												
POAM									1					1	1			
POTS												5						5
RACE		5											10	5	1	1	1	
RAMA					1	1												1
ROIS	1	5	1			1							1		1			
RUCR	1	5	1										10	10	1			
SCGA			1	1			1	1	1		10	5					1	10
SISU	1			5	10	5								1		1		1

Notes: ***Survey Dates***
D1 (1-June 2003, 2-Jul 2003, 3-Aug 2003, 4-May 2004, 5-June 2004, 6- Jul 2004, 7-Aug 2004)
D2 (1-June 2003, 2-July 2003, 3-August 2003, 4-June 2004, 5-July 2004, 6-August 2004)

***Additional Data**: Because of the infrequency of species occurrence the following information was left off the above tables*

D1			D2					
Plot	Species	Survey	Plot	Species	Survey	Plot	Species	Survey
A1-B	PONO	6	A3-A	EPGL	6	B6-A	CIAR	5
A4-B	POPA	7		MEAR	2	B6-B	PONO	4
A8-A	PONO	4		SISU	6	B8-B	POTS	6
B4-A	EQAR	1	A3-B	MOSS	2	C2-A	CACA	4
	MINU	2		POAM	4	C2-B	CAUT	2
	RAMA	4		RAGM	4		CAVE	5
B4-B	RUCR	1	A5-A	POPA	5	C6-B	Unknown	1
C1-A	CAVE	4		G	4		G	3
	EUGL	4	A5-B	RAGM	5		TAOF	1
	POTS	4	A6-A	SOAR	5		TRHY	6
	TRHY	1	A6-B	PONO	6	C8-B	CARE	2
			B2-B	PONO	5		CAVE	5
				RUCR	2			

Appendix B-6: Root depth study aboveground parameters, hole depth, topsoil depth, average and maximum root depth for the donor wetland plots (Depths are measured in cm from soil surface)

Plot	Site	Sub	Cov.	M. H.	A. H.	Hole	Topsoil Depth				Max Root Depth				A. Root Depth			
		plot	(%)	(cm)	(cm)	Depth	A	B	C	D	A	B	C	D	A	B	C	D
A3	D2	A	70	65	50	30	8	6	4	4	>	>	>	>	4	4	4	4
A3	D2	B	100	100	60	25	>	>	>	>	>	>	>	>	10	10	10	10
A5	D2	A	80	90	55	27	10	6	4	10	>	>	>	>	14	12	17	15
A5	D2	B	100	105	80	28	>	>	>	>	>	>	>	>	18	15	15	12
A6	D2	A	80	85	70	28	13	10	17	11	>30	>25	>25	>23	13	13	18	12
A6	D2	B	100	90	75	27	10	11	15	11	26	25	22	20	11	13	13	10
B2	D2	A	100	80	50	28	17	10	9	13	22	24	>26	>22	15	14	10	10
B2	D2	B	100	110	70	30	15	15	10	22	30	24	22	>22	13	15	10	10
B6	D2	A	100	90	65	26	17	13	10	12	>22	23	20	>24	13	10	11	17
B6	D2	B	100	130	110	24	20	13	10	19	20	>24	>21	22	15	21	10	13
B8	D2	A	90	95	90	26	9	9	7	10	>28	22	24	>24	13	10	8	10
B8	D2	B	100	105	95	22	10	18	8	5	>24	>30	>22	>24	11	15	10	5
C2	D2	A	80	105	75	29	6	8	10	5	20	22	24	24	9	8	13	9
C2	D2	B	100	120	100	25	5	7	8	8	>23	>19	25	19	6	13	8	20
C6	D2	A	80	90	70	20	6	4	2	6	>21	19	20	>20	13	13	5	10
C6	D2	B	100	120	80	24	9	10	4	4	>26	>26	22	>17	10	9	5	8
C8	D2	A	90	80	75	20	10	9	11	7	>20	19	15	>21	9	11	11	15
C8	D2	B	100	145	120	23	3	5	4	4	21	21	19	15	15	10	9	9
A1	D1	A	95	60	55	28	20	22	24	21	19	22	19	18	7	7	5	10
A1	D1	B	80	90	65	23	19	20	18	20	>22	14	22	16	9	10	11	13
A4	D1	A	95	80	50	26	>22	>26	>26	>22	>22	>26	>26	>22	13	18	15	15
A4	D1	B	95	85	60	23	19	13	14	21	19	15	15	20	10	10	10	13
A8	D1	A	70	95	30	23	10	12	14	10	21	19	18	18	10	8	12	11
A8	D1	B	80	65	50	20	>20	>20	>20	>20	>20	>20	>20	>20	15	20	15	14
B3	D1	B	80	95	65	30	24	22	23	24	28	21	17	19	16	10	14	17

Notes: > means that it is greater than the depth of the hole

Appendix B-7: Rooting depth study species percent coverage for the donor wetland plots

[D2]

	A3		A5		A6		B2		B6		B8		C2		C6		C8	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
ALAE		5		1		5												
BESY		1				5		5								1		25
BICE				1		5		5										5
CAAT	70	60	80	80	90	80	40	50	40	85	100	100	80	50	80	50	70	50
CIAR						1										5		
ELPA				5														
EPGL	1																	
EQAR	1	5		5														
GATR				10		1	10	10		1			5					
GLGR		20						30		10				30				25
MEAR																40		
PHAR			10				50		40	5								
PLMA	1															5		
PONO						1	1											
POPA							1		1					10				
ROIS							1											
RUCR						1												
SCGA	10		1		1		1	1	10				5	5	10		30	
SISU		5																
TAOF	5		10		10	1	1	1	1			1	1		1			
TRHY	10					1												
URDI													5					
VEAM																	1	

[D1]

	A1		A4		A8		B3
	A	B	A	B	A	B	B
BOAR					5	1	
CAAQ	100						
CASP		60	100	90	70	90	60
CAVE		10	1		5		
GLGR		10				10	
MOSS	1	15			20		10
PONO		10			1		
RACE		1				1	
RAMA						1	
SCSP				5			30

Appendix B-8: Vegetation parameters (VC-vegetation cover, AH-average height, MH-max height, SR-species richness) for each subplot (A or B) for the opportunistic wetlands by transect July 04

SITE	Transect	AorB	VC (%)	AH (cm)	MH (cm)	SR
O3	1	A	10	20	35	6
O3	1	B	10	40	55	4
O3	2	A	50	35	80	8
O3	2	B	50	45	75	6
O3	3	A	90	75	80	8
O3	3	B	70	45	80	6
O3	4	A	50	30	60	5
O3	4	B	95	30	65	8
O3	5	A	70	50	70	4
O3	5	B	80	40	60	6
O3	6	A	100	105	120	8
O3	6	B	100	80	105	7
O2	1	A	70	100	130	8
O2	1	B	100	75	110	8
O2	2	A	65	100	130	7
O2	2	B	100	45	80	8
O2	3	A	75	110	165	5
O2	3	B	60	80	110	8
O2	4	A	90	100	120	12
O2	4	B	95	55	85	10
O2	5	A	85	75	120	7
O2	5	B	85	70	105	12
O2	6	A	80	90	140	8
O2	6	B	100	60	120	7
O4	1	A	50	75	100	5
O4	1	B	60	45	110	12
O4	2	A	80	110	160	3
O4	2	B	95	50	140	10
O4	3	A	70	100	115	7
O4	3	B	80	80	100	8
O4	4	A	70	90	110	6
O4	4	B	95	75	120	12
O4	5	A	90	130	150	9
O4	5	B	95	140	170	5
O4	6	A	95	130	150	8
O4	6	B	100	90	130	5
O1	1	A	80	50	90	10
O1	1	B	80	80	95	8
O1	2	A	70	75	100	11
O1	2	B	100	50	110	9
O1	3	A	90	60	105	7
O1	3	B	100	60	100	9
O1	4	A	95	75	105	9
O1	4	B	90	50	100	9
O1	5	A	60	60	110	7
O1	5	B	100	50	100	8
O1	6	A	70	50	140	3
O1	6	B	90	20	50	7

Appendix B-9: Percent coverage of species for the opportunistic wetlands (1 means present in small #'s)

Species	O3--1		O3--2		O3--3		O3--4		O3--5		O3--6	
	B	A	B	A	B	A	B	A	B	A	B	A
Agrostis sp.	1	95		20			30		25	25	10	20
Anemone sp.							5	15				
Carex sp.					30	5						
Calamagrostis canadensis							10					
Callitriche verna		1										
Cirsium arvense			10	1							1	10
Eleocharis palustris									25			
Equisetum arvense		1			5	10	25	15		10		30
Unknown Monocot	30				15							
Glaux martima			1									
Phleum pratense	1				1	25	25	10		1	1	
Plantago major			5									
Polygonum amphibium			5	1								
Potentiaal norvegica				1								
Poa palustris									30	30		
Poa pratensis					25	50		30	25	30		
Ranunculus macoonii			10									
Rorippa islandica			5									
Scirpus sp.											80	15
Sonchus arvensis								1			1	1
Taraxacum officinale					15	10		15			1	
Thlaspi arvensis	30		60	60								
Trifolium hybridum	30		10		1			15		5	1	20
Urtica dioica	10	5		10								
Vicia americana					1	1		1			5	1

Appendix B-9: continued

Species	O2--1		O2-2		O2--3		O2--4		O2--5		O2--6	
	B	A	B	A	B	A	B	A	B	A	B	A
Agrostis sp.				1						1		
Beckmannia syzigachne					1		5		10	5	20	
Cirsium arvense	5	5	20	25	5	1	5	5		1	5	1
Eleocharis palustris		1							35	25		15
Epilobium glandulosum							1				1	
Equisetum arvense			10		1	1				5		
Unknown Monocot			10	15								
Gwum aleppicum								1				
Glyceria grandis	10								10			
Hordeum jubatum							1		1	1		5
Unknown Moss	5		10				1	1				
Melilotus alba				1								
Phleum pratense								1		5		
Potentiaal norvegica							1					
Poa palustris	1	80			5	40	40	75	10	25	30	60
Ranunculus macoonii								1				1
Scutellaria galericulata	1						1					
Sonchus arvensis		1	10	25		5	1	5		1	1	5
Taraxacum officinale	1	5		1		1	1	5		1	1	
Thlaspi arvensis		1										
Trifolium hybridum	1	5	15	30		5	1	1		5	15	
Typha sp.	80	5	20	5	90	50	40	10	25	5	30	15
Salix sp.						1			5			

Appendix B-9: continued

Species	O4--1		O4--2		O4--3		O4--4		O4--5		O4--6	
	B	A	B	A	B	A	B	A	B	A	B	A
Alopecurus aequalis									1			
Alisma plantago-aquatica	25		10	1	30				5	5	15	
Beckmannia syzigachne		5		1	5		30	15	40	10	15	10
Carex sp.												25
Callitriche verna	10	15					1					
Cirsium arvense				1		1		1				
Eleocharis palustris	30	55	30	25	20	20	10	15	5	10	15	25
Epilobium glandulosum		1						1				
Glyceria grandis		5		5			10	25	30	65	40	25
Glaux martima		1										
Gnaphalium palustris		1										
Unknown Moss		1		1		10		5				
Matricaria perforata		1		1		1		1				
Melilotus alba				15	10							
Potentiaal norvegica						1						
Ranunculus sceleratus						1						
Rorippa islandica		1			1				1		1	10
Sagittaria cuneata	10						30	1	10	5		
Scutellaria galericulata					1	1		1			1	
Sparganium sp.									1			
Taraxacum officinale								5			1	
Trifolium hybridum		5		40				15				
Typha sp.	25	5	60	5	40	60	20	15	1		15	

Appendix B-9: continued

Species	O1--1		O1--2		O1--3		O1--4		O1--5		O1--6	
	B	A	B	A	B	A	B	A	B	A	B	A
Agrostis sp.		5			5	1	5					20
Beckmannia syzigachne	1		5		5		5		5			
Carex sp.	60			10			70	10	35			10
Cirsium arvense		5				1						
Eleocharis palustris	15		60		30						80	
Epilobium glandulosum	5		1		10	5						
Equisetum arvense												25
Unknown Monocot										10		
Glyceria grandis					40	1	5		5			
Glaux martima			1		1							
Juncus sp.							5					
Unknown Moss			1				1	15	15	5		10
Matricaria perforata	1											
Melilotus alba	5	40		45								
Phleum pratense	1	10	1	5		10	5	15		25		20
Poa palustris			10	20		60		25	5	25	10	
Sonchus arvensis	5	20	1	10	1	15		1				
Taraxacum officinale	1	5					1	15	1	10		1
Trifolium hybridum	5	10	10	10		10	5	15	30	25		20
Typha sp.			20								10	
Urtica dioica			1	5		1		1				
Vicia americana		1		1				1		1		
Salix sp.										1		

Appendix C: Emergence Study Raw Data

Appendix C-1: Cumulative number of individuals of each species per sample for the saturated soil treatment in the emergence study (S-subsoil samples)

Species		D2-1	D2-2	D2-3	D2-4	D2-5	D1-1	D1-2	D1-3	D1-4	D1-5
Alopecurus	aequalis	3	6	10	2	12	1	0	3	3	2
Agrostis	scabra	0	2	1	0	0	0	0	0	0	0
Amaranthus	graecizans	0	0	0	0	0	11	3	6	5	0
Anemone	riparia	0	0	0	0	0	3	0	0	0	0
Barbarea	orthoceras	0	0	0	0	0	3	0	0	3	0
Beckmannca	syzichachne	5	7	6	7	2	0	0	1	2	0
Calamagrostis	canadensis	0	0	1	1	0	0	0	0	0	4
Caltha	natans	0	0	0	0	0	0	0	1	1	0
Carex	sp.	1	5	8	1	2	1	2	4	2	5
Callitriche	Verna	4	26	19	1	5	174	57	23	25	112
Eleocharis	palustris	0	0	3	0	0	0	0	0	0	0
Epilobium	glandulosum	0	0	0	0	0	0	1	1	0	0
Unknown	monocot	0	0	0	0	0	1	0	1	1	2
Geum	aleppicum	0	0	0	0	0	0	0	0	1	0
Hierochloe	odorata	0	0	0	0	0	0	0	0	0	2
Juncus	sp.	0	0	0	0	0	0	0	0	3	0
Lemna	Minor	12	15	38	0	1	0	0	0	0	0
Mentha	arvensis	0	0	0	0	0	0	1	0	0	0
Plantago	Major	0	0	0	0	0	0	0	1	0	1
Polygonum	amphibium	0	0	1	0	0	0	0	0	0	0
Potentilla	norvegica	2	0	0	0	0	0	0	4	2	2
Ranunculus	sceleratus	0	0	2	0	0	0	0	0	0	0
Ranunculus	gmelinii	0	1	0	0	0	0	0	0	0	0
Taraxacum	officinale	0	0	0	0	0	0	0	0	1	1
Unknown	sp.	0	2	0	0	2	0	1	0	0	1
Total Number of Individuals:		**27**	**64**	**89**	**12**	**24**	**197**	**68**	**54**	**52**	**136**

Note: S1 – 2 Kochia scoparia, 1 unknown species
S2 – 1 Kochia scoparia
S3 – 1 Kochia scoparia, 1 unknown species
S4 – 1 Kochia scoparia
S5 – 2 Kochia scoparia, 2 Lemna minor, 1 unknown species

Appendix C-2: Cumulative number of individuals of each species per sample for the clear water submerged soil treatment in the emergence study (S-subsoil samples)

Species		D2-1	D2-2	D2-3	D2-4	D2-5	D1-1	D1-2	D1-3	D1-4	D1-5
Alopecurus	Aequalis	0	1	2	0	0	0	0	0	0	0
Agrostis	Scabra	3	0	0	0	0	0	0	0	0	0
Amaranthus	Graecizans	0	0	0	0	0	3	4	1	14	0
Anemone	Riparia	0	0	0	0	0	1	0	1	0	0
Barbarea	Orthoceras	0	0	0	0	0	1	0	0	0	0
Beckmannca	Syzichachne	9	2	5	10	1	1	0	0	0	0
Carex	sp.	1	9	5	0	0	5	0	0	2	0
Callitriche	Verna	3	4	10	1	9	131	35	14	37	108
Eleocharis	Palustris	0	2	3	1	0	0	0	0	0	0
Epilobium	Glandulosum	1	0	0	2	0	0	0	0	0	0
Unknown	Monocot	1	4	12	4	5	0	2	0	1	0
Gnaphalium	Palustris	0	0	0	0	0	0	1	1	0	0
Juncus	sp.	0	0	0	0	0	0	0	0	2	0
Lemna	Minor	10	32	83	13	3	0	4	0	6	1
Lemna	Trisula	0	1	2	0	2	0	0	0	0	0
Marchantia	Polymorpha	0	0	1	1	0	0	0	0	0	0
Potentilla	Norvegica	0	0	0	0	0	1	0	1	1	1
Potamogeton	sp.	0	5	17	1	0	0	0	0	0	0
Ranunculus	Sceleratus	0	0	3	1	0	2	0	0	0	0
Ranunculus	Gmelinii	0	0	0	1	0	0	0	0	0	0
Rorippa	Islandica	0	0	1	0	0	0	0	0	0	0
Taraxacum	Officinale	0	0	0	0	0	0	0	0	0	2
Trifolium	Hybridum	0	0	0	0	0	0	0	1	0	0
Typha	sp.	0	0	1	0	0	0	0	0	0	0
Unknown	sp.	0	1	0	0	0	0	1	0	0	0
Total Number of Individuals:		**30**	**62**	**146**	**38**	**20**	**148**	**50**	**22**	**66**	**120**

Note: S1 – 1 Kochia scoparia, 1 unknown species
S2 – 1 Kochia scoparia
S3 – 4 Kochia scoparia
S4 – 6 Kochia scoparia
S5 – 2 Kochia scoparia

Appendix C-3: Cumulative number of individuals of each species per sample for the turbid water submerged soil treatment in the emergence study (S-subsoil samples)

Species		D2-1	D2-2	D2-3	D2-4	D2-5	D1-1	D1-2	D1-3	D1-4	D1-5
Alopecurus	aequalis	0	3	2	0	1	0	0	2	0	0
Agrostis	scabra	0	4	0	0	0	0	0	0	0	0
Amaranthus	graecizans	0	0	0	0	1	1	0	3	6	0
Beckmannca	syzichachne	4	4	3	3	1	0	0	0	0	0
Calamagrostis	canadensis	0	0	0	0	0	0	0	0	1	0
Carex	sp.	3	1	2	5	1	0	1	0	0	4
Callitriche	verna	0	0	4	0	9	182	28	26	32	130
Eleocharis	palustris	0	0	3	0	0	0	0	0	0	0
Epilobium	glandulosum	0	0	0	2	0	0	0	0	0	0
Unknown	monocot	4	4	5	4	4	0	2	3	1	0
Lemna	minor	2	6	53	3	4	1	2	0	6	3
Lemna	trisula	0	0	0	0	6	0	0	1	0	0
Marchantia	polymorpha	0	0	0	1	0	0	0	0	0	0
Potentilla	norvegica	0	0	0	0	0	0	1	0	0	0
Potamogeton	sp.	0	9	9	4	0	0	0	0	0	0
Ranunculus	sceleratus	0	0	3	0	0	0	0	0	0	0
Unknown	sp.	2	4	0	1	1	1	0	2	2	0
Total Number of Individuals:		**15**	**35**	**84**	**23**	**28**	**185**	**34**	**37**	**48**	**137**

Note: S1 – 3 Kochia scoparia, 1 Lemna minor, 1 unknown species
S2 – 3 Kochia scoparia
S3 – 1 Amarantus graecizans, I unknown species
S4 – 1 Kochia scoparia, 1 Lemna minor
S5 – 2 Kochia scoparia

Appendix D: Soil and Water Quality Data

Appendix D-1: Water quality results for all water bodies tested both sampling days

Sample	Date	Time	Cond. uS/cm	DOC mg/L	Turbid. NTU	pH	NO_2+ NO_3 ug/L	SRP ug/L	SS mg/L	TS mg/L	DS mg/L
RS	17-Jun-04	9:45	462.4	12.36	3200	8.34	1427.80	82.2	640	4495	3855
RS	17-Jun-04	10:00	453.5	12.38	3500	8.34	1551.91	81.0	476	4575	4099
O2	17-Jun-04	10:12	588.7	13.27	1600	7.12	5.17	15.4	440	2905	2465
O3	17-Jun-04	10:28	332.2	10.41	300	8.18	0.22	5.7	80	1240	1160
O5	17-Jun-04	11:35	366.2	12.77	2300	8.22	847.96	32.4	434	4135	3701
O4	17-Jun-04	11:50	181.8	12.7	5.3	9.88	1.43	1.9	32	810	778
O1	17-Jun-04	12:00	256.5	9.7	1.5	9.08	0.11	1.9	60	845	785
D3	17-Jun-04	12:35	427.2	33.59	10	7.51	1.96	1.8	34	1000	966
D2	17-Jun-04	12:50	1170.2	24.2	0.8	8.02	2.03	1.0	40	1725	1685
D1	17-Jun-04	11:00	174.8	34.45	6.7	8.71	1.45	3.9	54	835	781
D1	17-Jun-04	11:10	147.2	34.9	9.9	7.26	2.37	6.2	36	810	774
RS	22-Jul-04	10:51	355.5	10.27	575	8.46	199.9	20.5	446	1783	1336
RS	22-Jul-04	10:55	359.7	9.92	575	8.43	201.19	25.7	466	1850	1384
O3	22-Jul-04	10:26	404.2	11.98	140	7.43	1.45	13.6	308	1145	837
D1	22-Jul-04	11:22	912.5	36.62	6.1	7.23	1.83	21.0	173	795	623
D2	22-Jul-04	12:15	895.8	29.85	2.0	7.29	1.12	7.0	169	1355	1186
D2	22-Jul-04	12:15	869.3	27.24		7.35	0.66	5.4			
O1	22-Jul-04	9:54	266.7	10.47	14.5	8.10	0.79	1.2	185	810	625
O4	22-Jul-04	9:45	229.2	17.94	3.1	7.75	0.48	3.3	179	740	561
O2	22-Jul-04	11:02	441.2	10.12	290	7.64	3.59	24.2	390	1355	965
D3	22-Jul-04	12:30	460.8	36.53	8.5	7.28	0.73	14.6	175	975	800
O5	22-Jul-04	10:37	275.8	9.25	1900	7.51	1775.43	32.0	1880	3675	1795

Appendix D-2: Soil quality results (T-transferred soil, D-donor wetland, OB-overburden fill material, P-stockpile of soil)

Soil	Date	Moisture (%)	EC (uS/cm)	P (%)	PO_4-P (ppm)	pH	N (%)	NO_3-N (ppm)	NH_4-N (ppm)	K (ppm)	Mg (ppm)	Cl (ppm)
Subsoil	6-Jul-04	29.86	739	0.057	1.14	8.44	0.122	1.01	0.11	196.3	644.1	11.30
Subsoil	6-Jul-04	27.74	589	0.047	1.21	8.52	0.121	0.97	0.20	176.0	624.5	14.18
Subsoil	6-Jul-04	31.19	596	0.049	1.38	8.34	0.142	1.10	0.23	207.0	590.2	9.94
D2-T	6-Jul-04	33.82	461	0.056	2.67	7.68	0.453	1.15	0.38	139.3	887.9	8.44
D2-T	6-Jul-04	49.94	464	0.055	2.73	7.82	0.409	1.39	0.48	131.4	816.0	15.32
D2-T	6-Jul-04	49.69	488	0.060	3.58	7.56	0.499	2.64	0.84	103.2	816.4	14.34
D2-P	6-Jul-04	47.12	603	0.052	2.93	6.52	0.516	0.98	0.61	85.3	1059.0	13.12
D2-D	19-Aug-04	64.78	2300	0.089	11.84	6.19	0.864	20.67	2.01	243.5	518.8	26.06
D2-D	19-Aug-04	58.05	1520	0.078	2.73	6.04	0.940	8.11	2.07	116.3	1103.3	17.58
D2-D	19-Aug-04	68.84	1640	0.088	10.6	6.70	0.835	3.34	2.86	187.1	1052.8	17.44
OB	6-Jul-04	16.71	930	0.051	1.08	8.57	0.132	1.20	0.00	187.6	406.4	9.24
D1-T	6-Jul-04	33.89	564	0.057	2.29	7.65	0.395	3.94	0.49	121.4	518.8	12.56
D1-T	6-Jul-04	29.58	726	0.057	2.10	7.06	0.417	11.88	11.26	156.3	538.3	9.00
D1-T	6-Jul-04	69.57	588	0.071	4.04	7.51	0.601	1.64	3.87	149.5	555.7	15.42
D1-P	6-Jul-04	42.52	328	0.074	3.22	5.46	0.736	9.48	46.93	183.8	483.5	13.48
D1-D	24-Aug-04	37.29	203	0.060	5.06	6.06	0.403	2.41	3.70	223.3	320.2	13.88
D1-D	24-Aug-04	42.41	813	0.089	10.15	5.09	0.941	3.39	2.54	186.3	260.3	17.72
D1-D	24-Aug-04	48.72	375	0.081	9.54	5.52	0.603	1.89	3.89	326.4	307.9	20.62

Appendix D-3: Key to short forms of species used in the appendices

Short Form	Species	Common Name	Short Form	Species	Common Name
ALAE	Alopecurus aequalis	Short-Awned Foxtail	IVAX	Iva axillaries	Poverty Weed
ARAB	Artemisia absinthium	Absinthe	JUBU	Juncus Bufonius	Toad Rush
ARLY	Arabis lyrata	Lyre-Leaved Rock Cress	KOSC	Kochia Scoparia	Kochia
AXAM	Axyris amaranthoides	Russian Pigweed	LEMI	Lemna Minor	Common Duckweed
BESY	Beckmannca syzigachne	Slough Grass	MAMA	Matricaria matricarioides	Pineapple Weed
BICE	Bidens cernua	Nodding Beggar-Ticks	MAPE	Matricaria perforata	Scentless Chamomile
CAAQ	Carex aquatilis	Water Sedge	MEAL	Melilotus alba	White Sweet Clover
CAAT	Carex atherodes	Awned Sedge	MEAR	Mentha arvensis	Wild Mint
CABE	Carex bebbii	Bebb's Sedge	MINU	Mitella nuda	Bishop's-Cap
CACA	Calamagrostis canadensis	Bluejoint	PHAR	Phalaris arundinacea	Reed Canary Grass
CALA	Carex lasiocarpa	Hairy-Fruited Sedge	PLMA	Plantago major	Common Plantain
CARE	Carex retrorsa	Turned Sedge	POAM	Polygonum amphibium	Water Smartweed
CAPE	Cardamine pensylvanica	Pennsylvanin Bitter Cress	POLA	Polygonum lapathifolium	Dockleaf Smartweed
CASP	Carex sp.	Sedge species	PONO	Potentilla norvegica	Rough Cinquefoil
CAUT	Carex utriculata	Beaked Sedge	POPA	Poa palustris	Fowl Bluegrass
CAVE	Callitriche verna	Vernal Water-Starwort	POPR	Poa pratensis	Kentucky Bluegrass
CAVI	Carex viridula	Green Sedge	POTS	Potamogeton sp.	Pondweed species
CHAL	Chenopodium album	Lamb's Quarters	RACE	Ranunculus sceleratus	Celery-Leaved Buttercup
CIAR	Cirsium arvense	Canada Thistle	RAGM	Ranunculus gmelinii	Yellow Water-Crowfoot
COAU	Corydalis aurea	Golden Corydalis	RAMA	Ranunculus macoonii	Macoon's Buttercup
CRTE	Crepis tectorum	Narrow-Leaved Hawk's Beard	ROIS	Rorippa islandica	Marsh Yellow Cress
ELPA	Eleocharis palustris	Creeping Spike Rush	RUCR	Rumex crispus	Curled Dock
EPGL	Epilobium glandulosum	Purple-Leaved Willowherb	SCGA	Scutellaria galericulata	Marsh Skullcap
EQAR	Equisetum arvense	Common Horsetail	SCSP	Scripus sp.	Bulrush species
ERGA	Erucastrum gallicum	Dog Mustard	SISU	Sium suave	Water Parsnip
EUGL	Euphorbia glyptosperma	Thyme-Leaved Spurge	SOAR	Sonchus arvenis	Sow Thistle
GATR	Galium trifidum	Small Bedstraw	TAOF	Taraxacum officinale	Common Dandelion
GEAL	Geum aleppicum	Larged-Leaved Avens	THAR	Thlaspi arvense	Stinkweed
GLGR	Glyceria grandis	Tall Manna Grass	TRHY	Trifolium hybridum	Alsike Clover
GLMA	Glaux maritima	Sea Milkwort	URDI	Urtica dioica	Stinging Nettle
GNPA	Gnaphalium palustris	Marsh Cudweed	VESC	Veronica scutellata	Marsh Speedwell
HOJU	Hordeum jubatum	Foxtail Barley	VIAM	Vicia americana	Wild Vetch

G is an unknown grass or sedge
MOSS is unknown moss species