THE EFFECT OF TEMPERATURE ON METAL ACCUMULATION IN *TYPHA LATIFOLIA* AND *SCIRPUS ACUTUS*

by

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THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

In the
Department of Biology

SIMON FRASER UNIVERSITY

Summer 2009

APPROVAL

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Degree:	**Master of Science**
Title of Thesis:	**The Effect of Temperature on Metal Accumulation in *Typha latifolia* and *Scirpus acutus***

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ABSTRACT

Wetland plants have a capacity for metal sequestration and have been used to remediate such environmental contaminants. My research objective was to identify the effect of temperature on metal (Cd, Zn, Pb and Cu) accumulation in *Typha latifolia* and *Scirpus acutus*. These common wetland plant species were grown at 13, 16, and 18^{o}C to determine the effect of temperature on metal accumulation. Cd^{109} was used as a radiotracer to study the effect of temperature on uptake kinetics. *S. acutus* accumulated more metals than *T. latifolia* particularly at colder temperatures. Uptake rates appeared higher at warmer temperatures; although, this was not statistically significant. More Pb, Zn, and Cu were found in *T. latifolia* growing at 18^{o}C than at 13^{o}C; although uptake kinetics of Cd^{109} were not significantly different. *S acutus* remediation wetlands would be more effective than *T. latifolia* wetlands and would also limit the bioavailability of metals.

Keywords: Metal accumulation; *Typha latifolia; Scirpus acutus;* Temperature; Marsh; Wetland

Subject Terms: Phytoremediation; Accumulation rate; Cadmium Ecotoxicology

DEDICATION

This work is dedicated to my parents who taught me how to love and enjoy our natural world and for my children and their future.

ACKNOWLEDGEMENTS

This research project would not have been completed if it were not for a wonderfully supportive community. Thank you Dr. Leah Bendell-Young (my supervisor) for all of your guidance throughout this project, and to my committee members Drs. Lance Lesak and Aine Plant, your questions, comments, and thoroughness made me a better scientist.

This project also relied heavily on the technical contributions by Leslie Dodd, Sharon Hope, Kate Scheel, Carissa Canning, and all of the LBY graduate students. Your patience and understanding kept me going.

I would also like to thank Teck Cominco and Bill Duncan for the gracious use of the Oasis Wetland and your financial contribution. To Clem Pelletier of Rescan, thank you for allowing me the opportunity work while completing my education and your continued support of my growth as a scientist.

Lastly, I want to thank Kala Hooker:

“*…still falling for you, 1000 times more than all the leaves that have ever fallen from all the trees...*”

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CHAPTER 1: INTRODUCTION

Wetlands represent some of the most productive habitat on earth. They are often referred to as “nature’s kidneys” because of their ability to filter, metabolize, and sequester metals and chemicals. Given their well-documented ecological significance, conservation initiatives such as Ramsar and the Canadian Policy on Wetland Conservation, have attempted to limit national and international loss of wetlands (Ramsar, 2008 and Government of Canada, 1991). To promote wetland creation and restoration organizations have studied wetlands and their agricultural implications, use as a flood control mechanism, filter for removing toxic elements from aquatic ecosystems, treating urban storm water runoff, and purifying municipal wastewater (Rehbein, 2004; Kadlec and Knight, 1996; and Hammer, 1989). These activities typically rely on enhanced or constructed wetland communities.

Marsh ecosystems are the easiest wetland class to construct and at the same time provide some of the best habitat and biochemical functions of any of the wetland classes (MacKenzie and Moran, 2004). They offer some of the best potential for wetland compensation and remediation projects because of their ease of construction and functions they perform. However, understanding the influence environmental factors on wetland biochemistry is important.

The ability of wetlands and wetland vegetation to remove and store metals from soil and water systems is well documented. The Canadian Mortgage and

Housing Corporation describe how wetlands can be used as an alternative storm water management practice (CMHC-SCHL, 2008). Wetlands have also been used as buffer zones along roadways for salt and nutrient removal (Hammer, 1989; and Fritioff, Kautsky, and Greger, 2005). Marsh wetlands are particularly adept at remediating contaminants given their structure and the species that occupy them (Peer *et. al* 2006).

Metal adsorption and absorption pathways and processes have been identified for a variety of plants and metal contaminants. However, given that differences in site chemistry and plant growth alter metal accumulation (Hammer, 1989; Mitsch and Gosselink, 1993; Singh *et. al.,* 1993; Kadlec and Knight, 1996; and Fritioff, Kautsky, and Greger, 2005) it is important to study a wide variety of species, growth conditions, and metal contaminants to understand this complex biochemical system.

Temperature, light, and water are among the most important environmental factors that regulate plant growth (Went, 1953; Salisbury and Ross, 1992; and Robert, Risser, and Petel, 1999). Each of these parameters influence plant growth and are determining factors of species composition within ecosystems. They are all components of climatic conditions, which limit the range that specific species can live and provide optimal growing conditions. If climatic warming trends continue it is likely that the species composition will shift in some areas (Spittlehouse, 2008). Where temperature changes do not elcit a shift in plant communities they may result in changes to the physiological conditions to plants, such as a reduction in biomass for species growing at the colder end of their optimum range. This may in turn, influence biochemical processes, such as metal accumulation, in plants.

The effect of temperature, pH, and salinity on metal accumulation has been studied for a number of species and a positive relationship between temperature and metal accumulation has been identified (Almas and Singh, 2001; Mander and Jessen, 2002; and Fritioff, Kautsky, and Greger, 2005). However, these studies compare tissue metal concentrations between plants grown near their minimum tolerable temperature to plants grown near their maximum tolerable temperature. This difference is often in excess of 10^{o}C and does not represent temperature differences typically observed from year to year or within the modelled temperature increase associated with climate change. Temperature was selected as the parameter of interest for this study because relatively small, yet significant, changes in temperature are expected to occur over the next 70 years (NRC, 2006).

The goal of this research was to study subtle differences in temperature to determine how small changes in temperature affect metal accumulation. Understanding the relationship of small, realistic, temperature differences on metal accumulation is important to understand potential consequences of climate change. It is also useful when planning remediation projects across a wide variety of biogeoclimatic zones. An improved understanding of the effect of temperature on metal accumulation will help land and resource managers develop remediation wetlands across different biogeoclimatic zones and within the context of temperature fluctuations associated with climate change.

1.1 Study Components

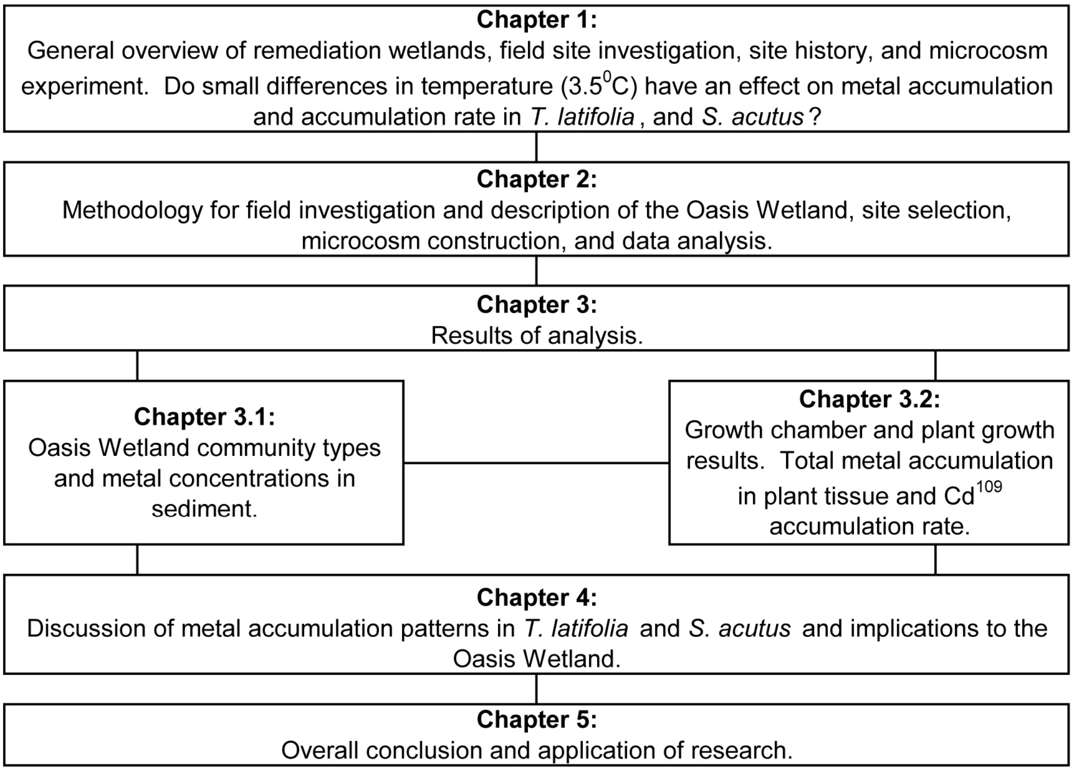
There were two components to this study, (1) field investigation of the Oasis Wetland and (2) microcosm laboratory experiment. The field investigations established community composition and ecosystem data for the Oasis Wetland. Data from previous studies on the Oasis Wetland was compiled with a focus on metal concentrations in sediments. Sediment samples were also collected for analysis and for use in the microcosm experiment. Microcosm wetland studies complemented field studies by identifying (1) whether or not *T. latifolia* and *S. acutus* accumulate significant levels of Cd, Cu, Fe, Pb, and Zn from the Oasis Wetland sediment and (2) whether or not temperature change under current climate change predictions will influence Cd, Cu, Fe, Pb, and Zn accumulation in these species. An outline of this thesis is presented in Figure 1-1. Chapter 1 presents the introduction, rationale, and application of the research. Chapter 2 presents the methodologies for the field investigation, microcosm construction, and sample and data analysis. Chapters 3 and 4 describe the results and discussion of the field investigation and microcosm experiments and Chapter 5 provides an overall conclusion of the research.

1.2 Objectives and Applications of Research

To the best of my knowledge, the effect of temperature on the accumulation of Cd, Cu, Fe, Pb, and Zn and Cd accumulation rates in *Scirpus acutus* and *Typha latifolia* have not been studied in the context of marsh wetlands in B.C. The objective of this research project is two-fold:

- To establish wetland community descriptions and environmental data for the Oasis Wetland; and
- To study the effect of temperature on net Cd, Cu, Fe, Pb, and Zn accumulation and Cd accumulation rate in *S. acutus* and *T. latifolia*.

The results of this research project will aid in the development of remediation plans where constructing wetlands to remove metals is considered the best option. It also provides the opportunity to identify potential effects on metal accumulation, in wetland vegetation with respect to global climate change.



Chapter 1:
General overview of remediation wetlands, field site investigation, site history, and microcosm experiment. Do small differences in temperature (3.5^{0}C) have an effect on metal accumulation and accumulation rate in *T. latifolia*, and *S. acutus*?

Chapter 2:
Methodology for field investigation and description of the Oasis Wetland, site selection, microcosm construction, and data analysis.

Chapter 3:
Results of analysis.

Chapter 3.1:
Oasis Wetland community types and metal concentrations in sediment.

Chapter 3.2:
Growth chamber and plant growth results. Total metal accumulation in plant tissue and Cd^{109} accumulation rate.

Chapter 4:
Discussion of metal accumulation patterns in *T. latifolia* and *S. acutus* and implications to the Oasis Wetland.

Chapter 5:
Overall conclusion and application of research.

Figure 1-1 Schematic Diagram of Thesis

CHAPTER 2: METHODOLOGY

Marsh wetlands dominated by *Scirpus acutus* and *Typha latifolia* were selected for study because they represent two common wetland associations in British Columbia. They are the easiest wetland ecosystems to construct and offer some of the highest values of any wetland class (MacKenzie and Moran, 2004). The Oasis Wetland is a *Scirpus acutus* and *Typha latifolia* marsh. It is located close to the Columbia River, which provides vast areas of aquatic habitat; however, the type of habitat the Oasis Wetland provides is unique within the immediate area. In the portion of the Columbia valley from Castlegar to the Pend Oreille – Columbia River confluence there are few low elevation marsh wetlands.

The Oasis Wetland was selected for this study because it is a marsh community. Marsh wetlands are the easiest wetlands to construct, have high ecological and habitat values, and can be important remediation options. The Oasis Wetland was also selected for study because:

1. it is a man-made system, being caused by the construction of Highway 22,
2. it has previously been studied and sampled, and
3. it is subject to current and historic pressures such as all terrain vehicle (ATV) use and metals deposition from the nearby Teck Cominco smelter (Teck Cominco, 2007).

Despite these pressures, the Oasis Wetland provides important habitat, ecological, and biochemical functions.

The Oasis Wetland was characterized to identify the dominant species growing in the wetland. Observations of the dominant species were also made to identify any potential chronic toxicity effects to vegetation growing in sediments with high metals concentrations. The compilation of historical data provided a context for the level of specific metals within sediment, water, and vegetation, and aided in the identification of metals of interest for analysis in the microcosm experiment.

To test the effect of temperature on metal accumulation three temperatures were selected for the microcosm study;

1. The coolest temperature (13^{o}C) represents cold climate northern/high elevation sites
2. The mid temperature (16.5^{o}C) represents the average growing season temperature for the southern interior B.C., the ecoregion of the Oasis Wetland (Foiles, 1965); and
3. The warmest temperature (20^{o}C) selected for study is the predicted climate change scenario for southern interior B.C (NRC, 2006*)*.

To test the effect of temperature on total metal accumulation, accumulation rate, and accumulation patterns in *S. acutus* and *T. latifolia* 18 marsh wetland microcosms were constructed and kept in climate controlled growth chambers from January 28, 2008 to April 20, 2008. The microcosms were used for two experiments (1) to identify the effect of temperature on total metal accumulation in *S. acutus* and *T. latifolia* and (2) using a radioactive isotope to identify the effect of temperature on the rate of metal accumulation in *S. acutus* and *T. latifolia*.

2.1 Field Investigation

The field assessment of the Oasis Wetland was initiated June 21, 2007 and field assessment methods followed “*Field Description of Wetland and*

Related Ecosystems in the Field," (MacKenzie, 1999) and "*Wetlands of British Columbia: A Guide to Identification*," (MacKenzie and Moran, 2004). Wetland classification followed Warner and Rubec, (1997) and MacKenzie and Moran, (2004) and used vegetation, soil and water characteristics to determine wetland class and association. Wetland classes are high-level categories described by Warner and Rubec (1997) that group ecosystems according to broad characteristics. Site associations are specific vegetation communities that are dominated by similar species. The Canadian System of Wetland Classification identifies five wetland classes, where there are numerous wetland associations in each wetland class as identified by MacKenzie and Moran (2004).

A number of standard ecosystem survey plots were established in micro-communities of interest, within the Oasis Wetland. A soil pit was dug and a GPS coordinate was taken at the centre of each plot. Photographs were taken in each cardinal direction and of the soil pit, soil surface, and other significant features such as landforms, unique vegetation, and wildlife. Ground Inspection Forms (GIF) were used to record field notes. The pH of surface water and soil water was measured using a calibrated hand-held pH probe (pHTestr10). pH, soil moisture regime, and hydrodynamic index were described according to Mackenzie and Moran (2004) (Table 2-1).

The soil survey methodologies for wetland ecosystem classification principally followed "*The Canadian System of Soil Classification*" (CSSC, 1987), "*Towards a Taxonomic Classification of Humus Forms*" (Green *et. al.*, 1993), "*Describing Ecosystems in the Field*" (Luttmerding *et. al.,* 1990), and "*Field*

Description of Wetland and Related Ecosystems in the Field" (MacKenzie, 1999). These methods suggest soil identification to a depth of 160 cm or lithic contact. The super-saturated soils in the centre of the wetland complex made deep sampling impossible. Soil pits were dug to a minimum depth of 40 cm, or when significant contact with the water table or lithic/parent material was made. Soil nutrients were described according to MacKenzie and Moran (2004) (Table 2-1). The Von Post scale of decomposition was used to described organic soils.

Table 2-1 pH, Soil Moisture Regime, Hydrodynamic Index, and Soil Nutrient Regime Descriptors (MacKenzie and Moran, 2004)

pH	Soil Moisture Regime	Hydrodynamic Index	Soil Nutrient Regime
Very Acidic	Moist	Stagnant	Very Poor
Moderately Acidic	Very Moist	Sluggish	Poor
Slightly Acidic	Wet	Mobile	Medium
Neutral	Very Wet	Dynamic	Rich
Alkaline		Very Dynamic	Very Rich
			Hyper

Vegetation species and their relative percent cover were recorded at each plot. Special focus was placed on wetland association indicators such as *Carex* spp*.* and *Salix* spp. Vegetation identification in the field followed: "*Plants of Costal British Columbia*" (Pojar and MacKinnon, 1994), "*Plants of Southern Interior British Columbia*" (Parish *et. al.,* 1996), and "*Plants of the Western Boreal Forest and Aspen Parkland*" (Johnson *et. al.,* 1995). Species not identified in the field were collected and identified in Vancouver B.C. using "*The Illustrated Flora of British Columbia: Volumes 1-6*" (Douglas *et. al.,* 2001).

2.1.1 Site History and Study area

The Oasis Wetland is a manmade feature located immediately west of Highway 22 approximately 7 km north of Trail, B.C. (Figure 2-1). It was created by the construction of Highway 22, which formed a depression suitable for wetland development. A functioning, *T. latifolia* and *S. acutus* marsh ecosystem developed because a beaver plugged a culvert at the north end of the site (Teck Cominco, 2007).

The Oasis wetland includes and is adjacent to a number of jurisdictional boundaries. The majority of the wetland is within Teck Cominco's jurisdiction but also includes a Fortis BC power line right-of-way and two power poles. The Ministry of Transportation has a right-of-way to the east of the wetland as part of Highway 22, as well as an old CPR right-of-way on the west boundary of the wetland (Craig, 2006). Currently, the Ministry of Transportation and Highways do not intend to remove the beaver dam, which would negatively affect the existing wetland (Teck Cominco, 2007). Locations of significant site features such as spring sources, culverts, the beaver dam, and the direction of water flow are detailed in Figure 2-1.

The land surrounding the Oasis Wetland has been degraded due to recreational all terrain vehicle (ATV) use. SO_2 damage and metal deposition have also occurred at the site, given its proximity to Teck Cominco's lead and zinc smelter. Sampling of the wetlands by Teck Cominco, through its Ecological Risk Assessment process, has determined that water quality is generally within provincial guidelines for the protection of freshwater aquatic life. However, metal concentrations were elevated in the sediments and metal concentrations in amphibian tissue were slightly higher than at reference sites (Teck Cominco, 2007).

Overview of Wetland Communities

The Oasis Wetland is a complex of marsh, swamp, and shallow open water wetlands; it is approximately 2.9 ha. The majority of the complex (60%) is a cattail (*Typha latifolia)* marsh; 10% of the area is a *Lemna minor* dominated shallow open water, 5% a bulrush (*Scirpus acutus*) marsh, with the remaining 25% as unclassified swamps and transition associations. The wetland complex is easily separated into three zones (south, centre, and north) because earthen berms restrict water flow at two locations (Figure 2-1).

The south zone is principally a *T. latifolia/S. acutus* complex with some small pools of open water and patches of *Salix* spp*.* dominated swamp. Water enters the south zone from the centre zone and flows out through a culvert in the southeast corner (Figure 2-1).

The centre zone is the largest of the three zones; it is dominated by a *T. latifolia* marsh and a *L. minor* shallow open water wetland. Some small *Salix* spp. and *Alnus* sp. swamp associations exist on the periphery, and near the northern berm. Water enters the centre zone from the north (past the northern berm) and exits into the south zone past the southern berm (Figure 2-1).

The north zone is primarily a *T. latifolia* marsh with some small pools of open water. Water enters this zone through an active ground water seep at

(445910, 5442925; UTM 11N, NAD 83) and flows south into the centre zone past the northern berm (Figure 2-1).

Marsh Ecosystems

The *Typha latifolia* dominated marsh is classified as a Wm05 marsh, following (MacKenzie and Moran, 2004); common in the interior and at low elevations in biogeoclimatic subzones with warm summers. They are most common in potholes and near roadside ditches where the surface substrate is saturated for most of the growing season. *Typha latifolia* dominates but occasionally there is cover of *Carex utriculata*, *Scirpus acutus* and/or *Lemna* spp.

The *Scirpus acutus* marsh is classified as a Wm06 marsh (MacKenzie and Moran, 2004); it occupies sites similar to the Wm05 marsh. Plant diversity is low, almost solely *S. acutus*. These ecosystems are usually adjacent to open water wetlands and form complexes with Wm05. Patches of Wm06 in complex with Wm05 can be the result of grazing by muskrat as *S. acutus* stores nutrients in the root mass and can more rapidly recover from grazing (MacKenzie and Moran, 2004).

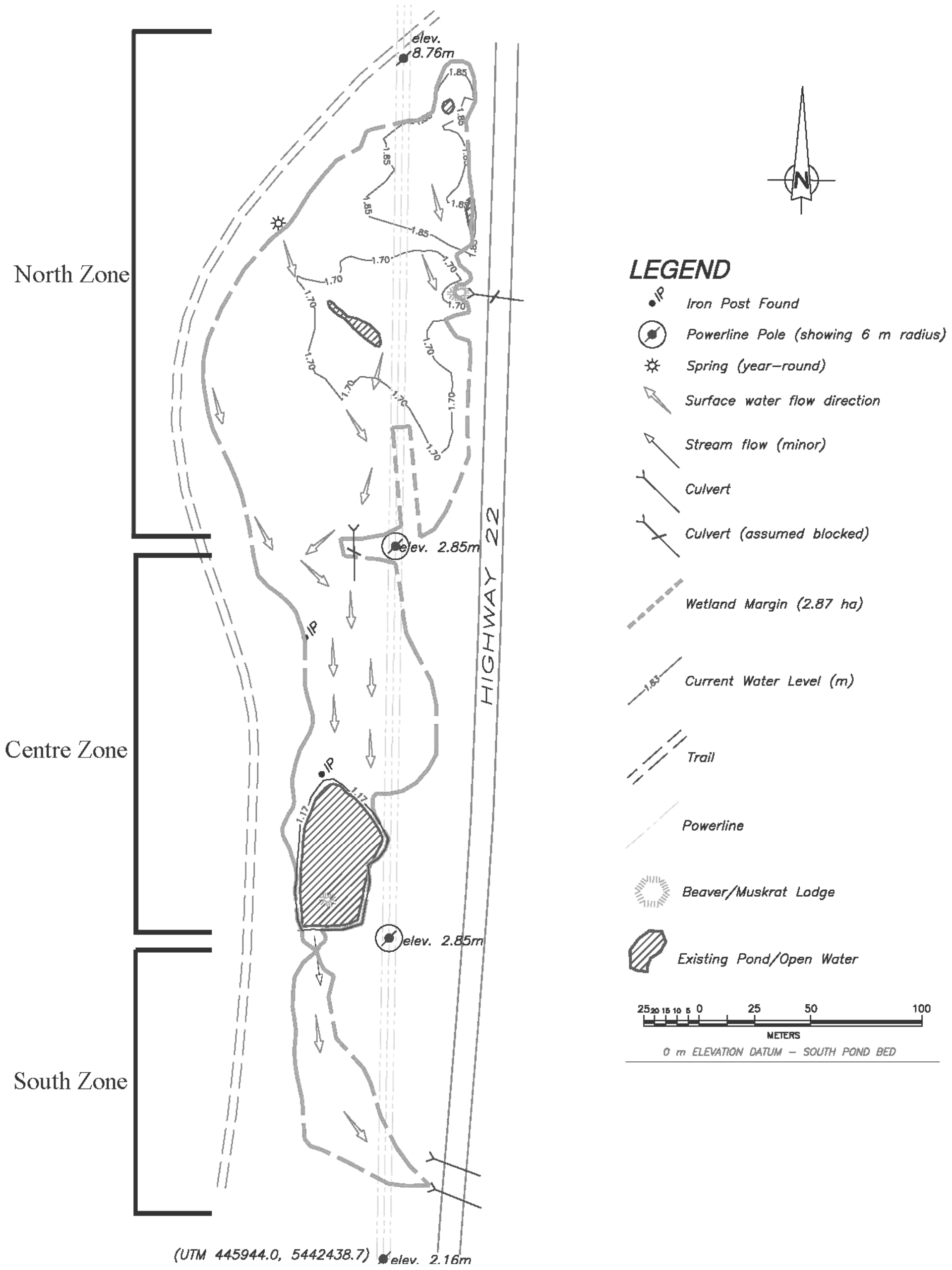


Figure 2-1 Oasis Wetland Site Feature Map (Spectrum, 2005)

Shallow Open Water Ecosystem

Lemna minor shallow open water sites commonly occur in potholes where there is substantial still or slow moving water. The nutrient status of these wetlands is eutrophic. They are among the most important habitat for fish and wildlife. The plants that grow in shallow open waters are typically a highly desired food source; shallow open water wetlands also provide good cover and have high prey densities (MacKenzie and Moran, 2004).

Swamp Ecosystem

The Ws03 Bebb's willow – Bluejoint association (MacKenzie and Moran, 2004) is uncommon but widespread at drier lower elevations of the interior. These associations can have a significant component of *Alnus incana*. The Ws03 soil and hydrology are characteristic of wetlands but they typically have a low cover of obligate hydrophytes (MacKenzie and Moran, 2004).

2.1.2 Bulk Sediment Samples

Approximately 72 kg of sediments were sampled from the Oasis Wetland (January 2008). Bulk sampling methods followed "*Part D Soil and Sediment Sampling*" (Gov. B.C., 2003). A ponar grab sampler was used to collect the sediment samples. Samples were composited into one of three 20 L high-density polyethylene (HDPE) HNO_3 acid washed buckets. The buckets were filled with sediments and lids were sealed in place ensuring no headspace to limit the potential for contamination during shipment. The samples arrived in Vancouver approximately 48 hrs after collection where they were immediately transported to SFU and used to construct nine wetland microcosms.

Individually wrapped Teflon spatulas were used to collect sediment sub-samples from each bucket. The sub-samples were refrigerated until analysed using Atomic Adsorption Spectrophotometry (AAS) at the Bendell-Young Lab at SFU.

Sediment Analysis

Sediments were prepared and analysed following Chen and Ma (2001) and Perkin-Elmer (1996). Approximately half of the sediment samples were dried at 60°C for 48 hrs. The dried samples were then sifted through a 63 µm sieve. Approximately 1.5 g of the sieved sample was digested in an aqua regia solution (1:3 HNO_3 – HCl, v/v). The samples were digested at 110°C until near dryness and diluted to a final volume of 50 mL. The prepared sediment samples were refrigerated until analysed using the AAS for Cd, Fe, Pb, and Zn. These metals were selected as parameters of interest and were the focus of all total metals throughout this thesis because:

1. they were previously identified at high levels in the Oasis Wetland (Golder, 2007);
2. some of these elements, including their radioisotopes, have been used in similar studies addressing the effect of temperature on metal accumulation (Almas and Singh, 2001);
3. they have both natural and anthropogenic sources; and
4. environmental quality guidelines for their levels in drinking water and in sediment have been established by various governments (B.C. MOE, 2006a; B.C. MOE, 2006b; CCME, 1999; and CCME, 2001)

To ensure good data quality, samples were analysed in triplicate on the AAS. Results with a relative standard deviation (RSD) > 0.4 were considered invalid and reanalysed. Stock solutions were prepared from certified analytical stock for a given parameter of interest (Cd, Fe, Pb, and Zn), and the AAS calibration was checked after every 5 samples, during analysis. To ensure data accuracy, standard reference materials (marine sediments) were prepared alongside and identically to the sediment samples; the results were compared against standard reference values. Raw data are presented in Appendix 1.

Sediment results were compared to provincial sediment quality guidelines (B.C. MOE, 2006b). Sediment quality guidelines for metals of interest are presented in Table 2-2.

Table 2-2 British Columbia Interim Sediment Quality Guideline

Metal	Guideline (mg/kg)
Cadmium	0.6
Copper	35.7
Lead	35
Zinc	135

2.2 Microcosm Experiment

2.2.1 Microcosm Construction

Two series of nine microcosms were constructed (OW-Series and C-Series) in 48.3 L HDPE tubs. The OW-Series represent wetlands with high levels of metals in their sediments and the C series represent wetlands with low levels of metals in their sediments. The OW-Series were constructed using nine kilograms of Oasis Wetland sediments and eight kilograms of reference sediment. The C series microcosms were built using 13 kg of Premier Liteway 3-in-1 (Compost: *Sphagnum*: Black Earth) reference sediment purchased from Rona Home Depot.

The density of the Oasis Wetland sediments was much higher than that of the reference soil; and, as a result accounted for approximately 1/3 of the total volume of the HDPE tubs. Thus, the reference soil was added to the OW-Series as a bulking agent to ensure similar volumes of soil in each microcosm.

Once the soil and sediments were added to the HDPE tubs, dormant plugs of *S. acutus* and *T. latifolia*, purchased from Nat's Nursery (Chilliwack B.C.), were planted in an alternating pattern and assigned a number from 1 to 162 (Figure 2-2). Three microcosms from each series were placed in one of three growth chambers programmed for temperatures of 13, 16.5, and 20^{o}C.

During the construction process samples of the reference soil and the growth media containing the dormant vegetation plugs were taken. The samples were placed in individual, Whirl-Pak® bags and refrigerated until analysed for total metals.

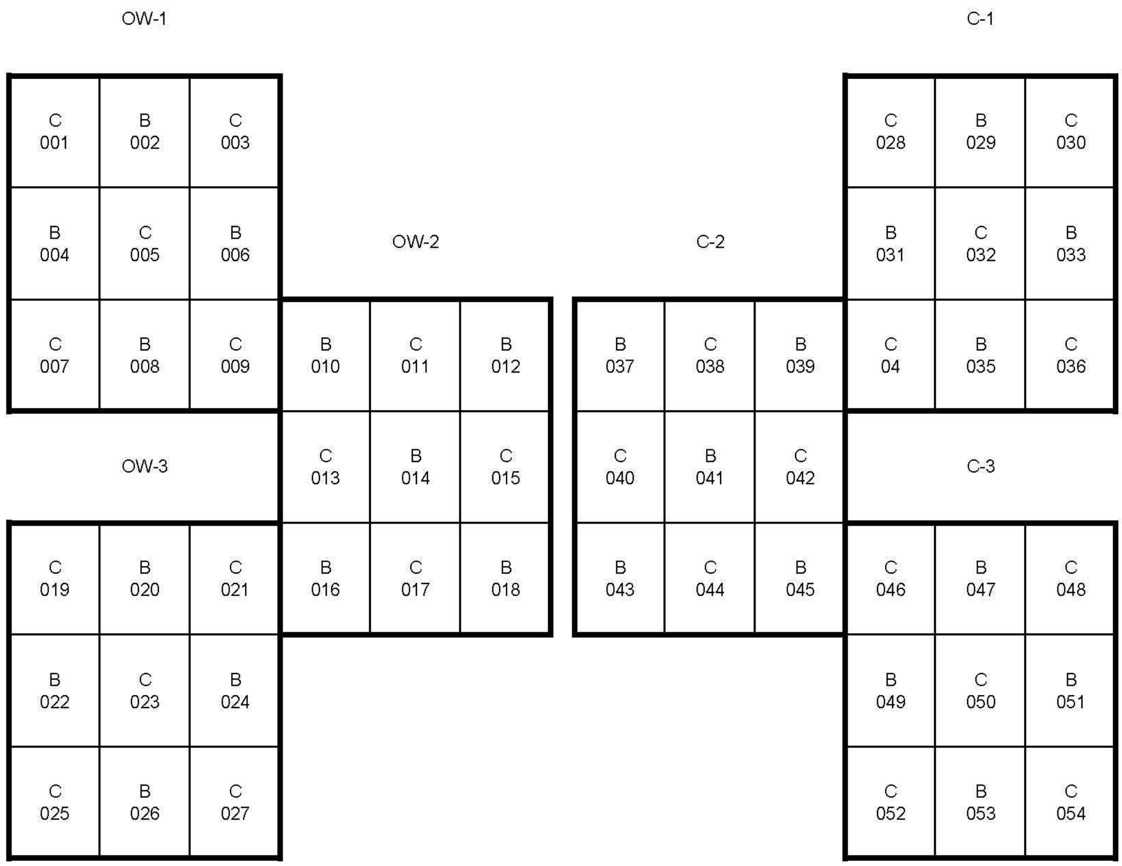


Figure 2-2 Layout of Vegetation within Microcosms and Microcosms within Growth Chambers

Figure 2-2 represents the microcosm layout in the growth chambers. All growth chambers followed the same layout
B – S. acutus, C – T. latifolia

2.2.2 Microcosm Monitoring

A temperature and relative humidity sensor was cycled through each growth chamber on one-week intervals. This monitored the growth chambers to ensure the units held their programmed temperature and relative humidity settings.

During the experiment, each microcosm was visually inspected three to five times a week. During these occasions, the microcosms were watered so that water covered the soil by approximately 2.5 cm. Once each month the microcosms went through a dry-out period; the dry-out period extended seven days past the last day water was observed above the soil surface. This was done to simulate the dynamic water levels in *S. acutus* and *T. latifolia* marshes, which allow organic soil to dry out and decompose, increase oxygen supply to the roots, and allow the oxidation of any minerals in the soil. Dry-out periods are common in natural marshes; their dynamic hydrology is an important selective pressure for vegetation.

Once each week, the height of each plant was measured using a builders tape. The volume of water added and the program variables (temperature and relative humidity) were also recorded.

2.2.3 Total Metal Accumulation Experiment

On April 20, 2008, all of the vegetation from the OW-Series wetlands, that had been planted during microcosm construction (January 18, 2008), was harvested. Plants were carefully dug out of the soil and rinsed with distilled deionised water. Plant samples were divided into three groups (roots, shoots, and leaves).

1. The root group contains all plant parts growing below the soil surface such as the roots and rhizomes;
2. The shoot group contains all plant parts growing from the soil surface to 20 cm above the soil surface; and
3. The leaf group contains all plant parts above 20 cm on the *S. acutus* shoot and the leaves of *T. latifolia*.

The group names (roots, shoots, and leaves) are used through the remainder of this report to describe the location the plant samples were taken from. Individual plant part samples were placed in Whirl-Pak® bags and refrigerated until analysed for total metals using the AAS.

Approximately 30% of the plants from the C series microcosms were also harvested at this time. The non-harvested plants in the microcosms were returned to the growth chambers for use in the Cd^{109} accumulation rate experiment. The harvested plants were prepared and stored identically to those harvested from the OW-Series microcosms.

Total Metal Analysis

Plant samples were placed on drying racks and dried at $60^{o}C$ for 72 hrs. Once the samples were dry, they were shredded by hand, and approximately 1.5 g was digested in ultra-pure HNO_3. For samples weighing less than 0.7 g, composite samples consisting of all three, plant parts were digested as a single sample. The samples were prepared following Kalra (1998) and Perkin-Elmer (1996). The plant samples were initially soaked in ultra-pure HNO_3 for 24 hrs. Once the samples had been soaked, they were heated to $110^{o}C$ on a hotplate for 4 hrs. After this initial digestion they were allowed to cool and between 1 and 2 mL of 30% H_2O_2 was added to each sample. The samples were reheated and digestion continued until the sample colour was clear. Once the sample solution was clear, the samples were heated until near dryness and diluted with Dd H_2O to a final volume of 50 mL. The prepared samples were refrigerated until analysed for Cd, Fe, Pb, and Zn using the flame AAS.

To ensure good data quality standard reference materials were prepared alongside the plant samples. The results were compared against the documented standard reference values and used to check data accuracy. The AAS was calibrated using appropriate stock solutions for each metal and calibration was checked often during analysis. The relative standard deviation (RSD) was checked after every sample to ensure data precision; results with an RSD > 0.4 were reanalysed. Raw data are available in Appendix 2.

Sediment samples were also collected from each microcosm. Samples were placed in individual Whirl-Pak® bags and stored in the refrigerator until analysed for total metals using the AAS (Section 2.1.1). Raw data are available in Appendix 1.

Data Analysis

Data were analysed using two-way ANOVA in SigmaPlot 11.0. Results were reported with a p-value, where appropriate.

2.2.4 Cd^{109} Accumulation Rate Experiment

This experiment was conducted on the C-series wetland vegetation after vegetation was harvested for use as the low-level metals vegetation in the total metal accumulation experiment (Section 2.2.3).

Ten plants of each species were used in this experiment. A 43 µl solution of 37 MBq Cd^{109} in HCl was diluted so that 4.1 MBq was added to each microcosm (0.21 MBq to each plant). This value represents the upper limit of the permitted non–hazardous waste disposal value, given the weight of each microcosm (Scheel: pers. comm., 2007). The 10 mL solutions of 0.21 MBq

Cd^{109} were poured on the soil surface at the base of each plant. Samples were collected at 1, 3, 12, 24, and 72 hrs.

Approximately 320 ± 15 mg of each plant part was collected from two plants at 1, 3, 12, 24, and 72 hr intervals. At the time of harvest, the plant samples were rinsed with double distilled water over the microcosm from which they were harvested. The samples were placed in scintillation tubes and refrigerated in lead-lined boxes for seven days until analysed.

A Canberra Model 2030 gamma counter with a Na-iodide crystal detector was used to record the 22 keV gamma emissions from each sample. The emissions from each sample were recorded over a period of one hour; every 24 hrs the detector efficiency was checked using a known source of Cd^{109}. Radio activity counts were normalized for plant mass; the raw data are presented in Appendix 3.

Once the experiment was complete (after 72 hrs), the microcosm tubs were taken from the growth chambers and sent to the radiation safety office for disposal. The growth chambers and the growth chamber room were cleaned and checked for contamination using the swipe test method (Radiation Safety Office, 2008).

Data Analysis

Rate Analysis

Data were Ln-transformed to reduce the variance associated with low sample size. The rate analysis method used in this study is a first order kinetic uptake model. It depends on concentration of Cd^{109} in plant biomass at a specific time. This allows the evaluation of specific uptake rates with respect to different growing temperatures. Kinetic equations were adapted from Ghaly, Snow, and Kamal (2008).

The uptake of dissolved Cd by *S. acutus* and *T. latifolia* can be expressed as a function of the maximum concentration of Cd in plant tissue and a specific uptake rate following:

equation (1)

$$\frac{d(Cd\rho)}{dt} = k(Cd_{\max} - Cd\rho)$$

Where:

- $Cd\rho$ = concentration of Cd in a plant at a given time Ln (cpm/ug)
- Cd_{max} = maximum concentration of Cd that can be accumulated in a specific period Ln (cpm/ug)
- k = specific uptake rate (hrs $^{-1}$)

Equation (1) can be integrated and log transformed to:

equation (2)

$$\frac{Cd_{\max}}{Cd_{\max} - Cd\rho} = 10^{\frac{kt}{2.3}}$$

The concentration of the Cd added to each wetland was identical; therefore, the value of k was assumed to be constant for each temperature group. By substituting r for k/2.3, Cd_1 for $Cd\rho/Cd_{max}$ and expressing in exponential form the final uptake rate equation (equation 3) can be written as follows:

equation (3)

$$Cd_1 = \left(1 - e^{-2.3rt}\right)$$

Two solutions (Taylor series and binomial) to this equation were presented by Ghaly, Snow, and Kamal (2008). Only the binomial solution is presented here because the three first terms between the Taylor series and binomial solutions are similar. The small residue of the remaining terms will have a minimal effect on the outcome (Ghaly, Snow, and Kamal, 2008). The binomial equation is:

equation (4)

$$Cd_1 = (2.3rt)\left[1 - \frac{1}{2}(2.3rt) + \frac{1}{6}(2.3rt)^2 - \frac{1}{24}(2.3rt)^3 + ...\right]$$

Solving the binomial equation and substituting $Cd\rho/Cd_{max}$ for Cd_1 yields:

equation (6)

$$Cd\rho = \left(2.3rt)\left[1 + \frac{2.3rt}{6}\right]^{-3} Cd_{\max}\right)$$

The linear form of the equation is:

equation (7)

$$\left(\frac{t}{Cd\rho}\right)^{\frac{1}{3}} = \frac{1}{(2.3rCd_{\max})^{\frac{1}{3}}} + \frac{(2.3r)^{\frac{2}{3}}t}{6Cd_{\max}^{\frac{1}{3}}}$$

To solve equation 7, r and Cd_{max} need to be solved for each temperature. This is done by expressing *equation 7* as a standard linear equation:

equation (8)

$$y = mx + b$$

Where:

- $y = (t/Cd\rho)^{1/3}$
- $m = (2.3\ r)^{2/3} / 6Cd_{max}^{1/3}$
- $x = t$
- $b = (2.3\ r\ Cd_{max})^{-1/3}$
- $Cd_{max} = 1/(6b^2m)$

The slope (m) and intercept (b) values can be obtained graphically for each plant at each temperature by plotting $(t/Cd\rho)^{1/3}$ vs t. The linear parameters from equation 8 must be solved simultaneously yielding:

equation (9)

$$r = \frac{1}{2.3b^3\left(\frac{1}{6b^2m}\right)}$$

By substituting k/2.3 the equation can be written as:

equation (10)

$$k = 4.3839\frac{m}{b}$$

Values of k were calculated for *S. acutus* and *T. latifolia* at each temperature setting. The linear model equation was graphically analysed to identify patterns of uptake rate due to different temperatures.

Analysis of Variance

Three factor ANOVA's were conducted on the Cd^{109} data (Appendix 3) set for each time interval (1, 3, 12, 24, and 72) to determine if any significant differences were present in the data. The three parameters tested for in the ANOVA's were temperature, species, and location. SigmaPlot version 11.0 was used to run the three factor ANOVA's.

CHAPTER 3: RESULTS

3.1 Field Investigation Results

3.1.1 Wetland Ecosystems

This section describes the characteristics of the wetland communities surveyed at the Oasis Wetland in accordance with Warner and Rubec (1997) and MacKenzie and Moran (2004).

Marsh Ecosystems

The Wm05 community surveyed at Oasis had organic veneers of well-decomposed organic soil. The soil nutrient regime was very rich, the open water pH was approximately 7.3, and the Von Post of the surface soil was nine. The Wm05 marsh comprised approximately 1.6 ha of the Oasis Wetland.

The Wm06 communities surveyed at Oasis also had organic veneers of well-decomposed humic organic soil. The soil nutrient regime was very rich, the open water pH was approximately 7.2, and the Von Post was eight. The Wm06 marsh comprised approximately 0.3 ha of the Oasis Wetland.

Shallow Open Water Ecosystem

The *Lemna minor* shallow open water community had greenish-brown water that was slightly turbid. The open water pH was approximately 7.5. The water depth ranged from approximately 25 cm to 1 m. The *Lemna minor* shallow open water community at Oasis comprised 0.3 ha of the Oasis Wetland complex.

Swamp Ecosystem

The other major wetland community at Oasis were the *Salix* and *Alnus* spp*.* swamps. They occurred on the periphery of the Wm05/Wm06 marsh and connected the wetland to the dryer upland. A comparison of site characteristics to ecosystems described in Wetlands of British Columbia (MacKenzie and Moran, 2004) yields one association similar to the swamp ecosystem present at Oasis; the Ws03 Bebb's willow – Bluejoint association. The soil was a fine textured gleysol with a distinct surface layer of woody peat. The soil nutrient regime was moderately rich, the moisture regime was wet, the hydrodynamic index rating was mobile to dynamic and the pH was slightly acidic (6.5).

3.1.2 Metals in Sediment

Results from the sediment sample analysis (2008) and compilation of historical data (2004 and 2005) show that there were high levels of Cd, Pb, and Zn in the Oasis Wetland sediment (Figure 3-1). These concentrations in the sediment samples are considered high because they exceed provincial sediment quality guidelines (B.C. MOE, 2006b) by between 3 to 50 times, in all but the 2008 Zn results.

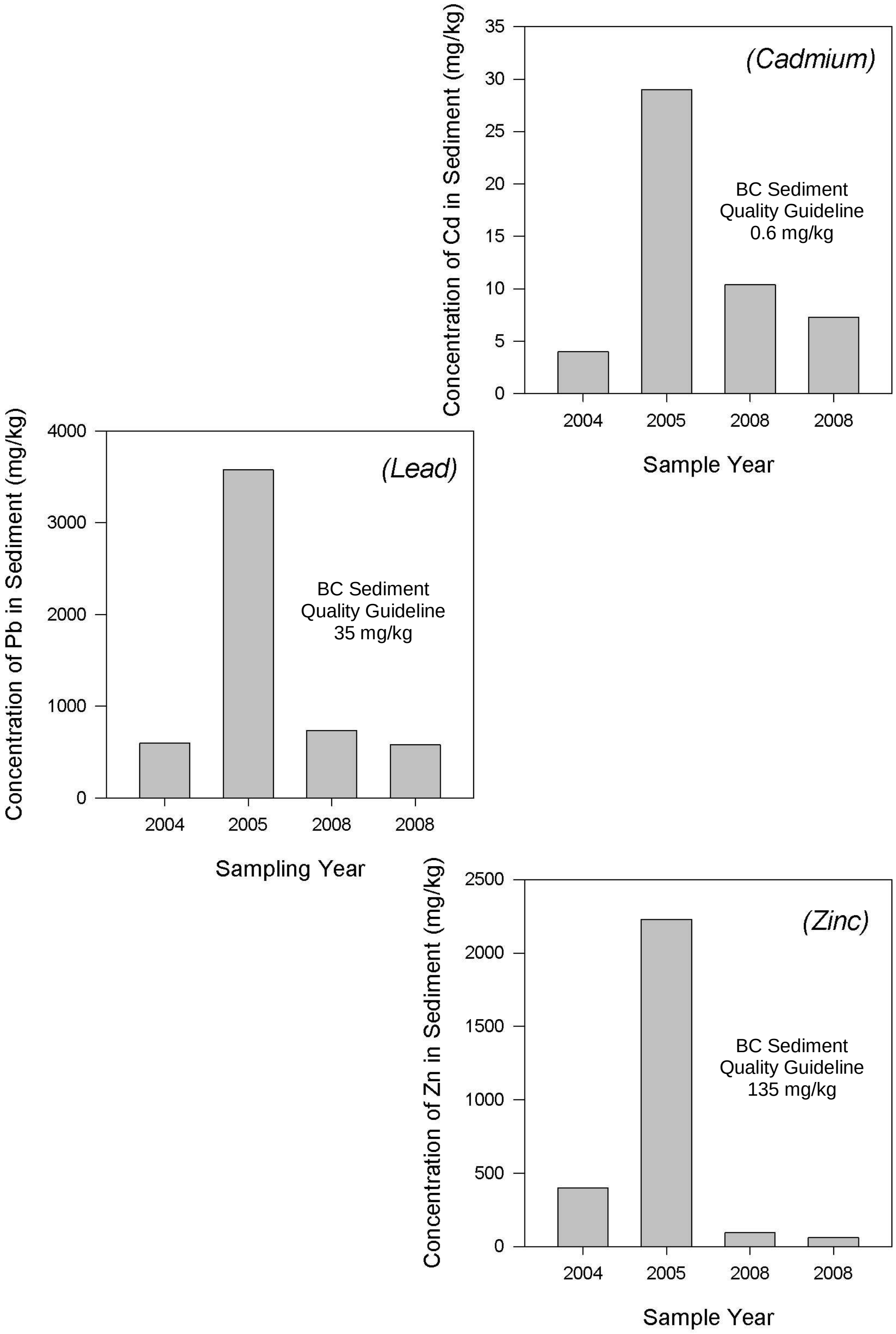


Figure 3-1 Sediment Results from the Oasis Wetland 2004, 2005, and 2008

n=1, results from 2004 and 2005 are historical results from (Golder, 2007)
2008 samples are independent samples collected from the Oasis Wetland at different locations

The Cd results from 2008 exceed the provincial guideline by approximately 15 times, the Pb results exceed the guideline by 20 times, and the Zn results are slightly below the guideline. Sample results were highest in 2005 for all metals. The fluctuation in results is likely a consequence of different sampling locations, sample times, sample collection, and analytical methodologies.

3.2 Microcosm Experiment Results

3.2.1 Growth Chamber Monitoring

There was substantial variation between the variables programmed into the growth chamber control system and the monitored values (Table 3-1).

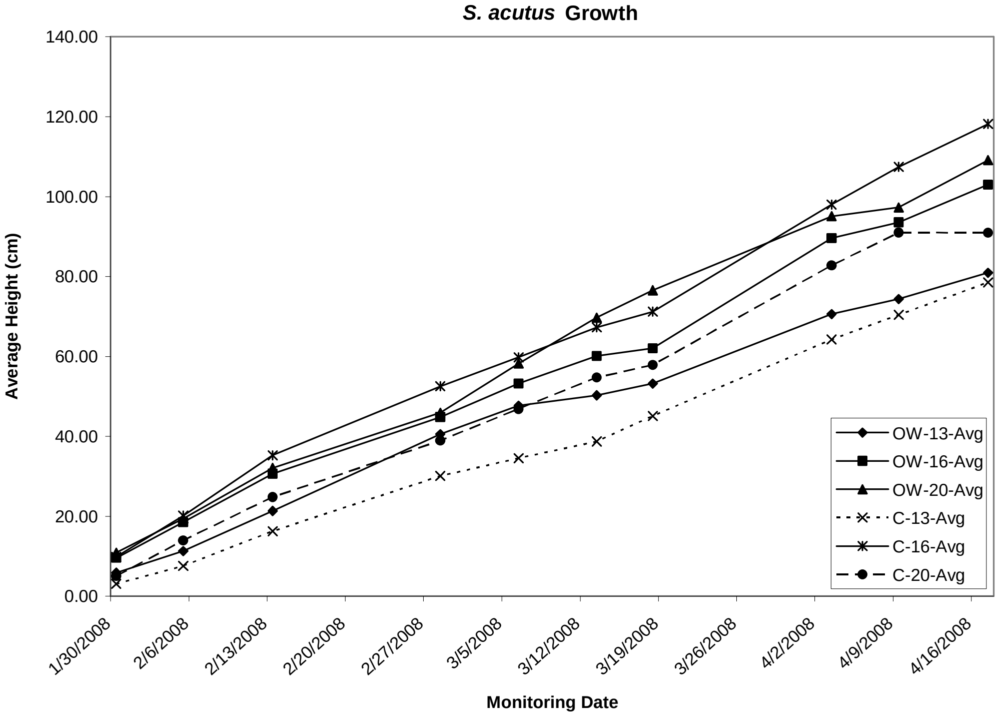
Table 3-1 Program Variables and Growth Chamber Monitoring Results

Chamber #	Name	Programmed Temperature (^oC)	Programmed Humidity (% RH)	Actual Temperature (^oC)	Actual Humidity (% RH)
5	13 Degree	13	100	13	97.68
2	16 Degree	16.5	100	16	95.69
3	20 Degree	20	100	18	72.69

The 20^{o}C chamber was approximately 2.2^{o}C cooler. However, although it was warmer than the 16^{o}C chamber it was only slightly warmer; this may have implications for the results obtained from the experiments. It is possible that effects of temperature on metal accumulation will not be significant between temperature sets 16 and 18^{o}C because they were actually very close in temperature.

3.2.2 Microcosm Monitoring

The height of each plant species was measured and recorded each week; the raw data are available in Appendix 4. *S. acutus* consistently grew taller than *T. latifolia* in all microcosms and did not decrease, where as the *T. latifolia* growth reached a plateau approximately 6 weeks into the experiment (Figure 3-2). The plateau was likely the result of competition with the *S. acutus*, which appeared to out-compete *T. latifolia*. There was no significant difference between the heights of the plants growing in the OW and C Series microcosms, suggesting that differences in nutrients, organic matter content, and mineralogy between the sediments did not bias the experiment.



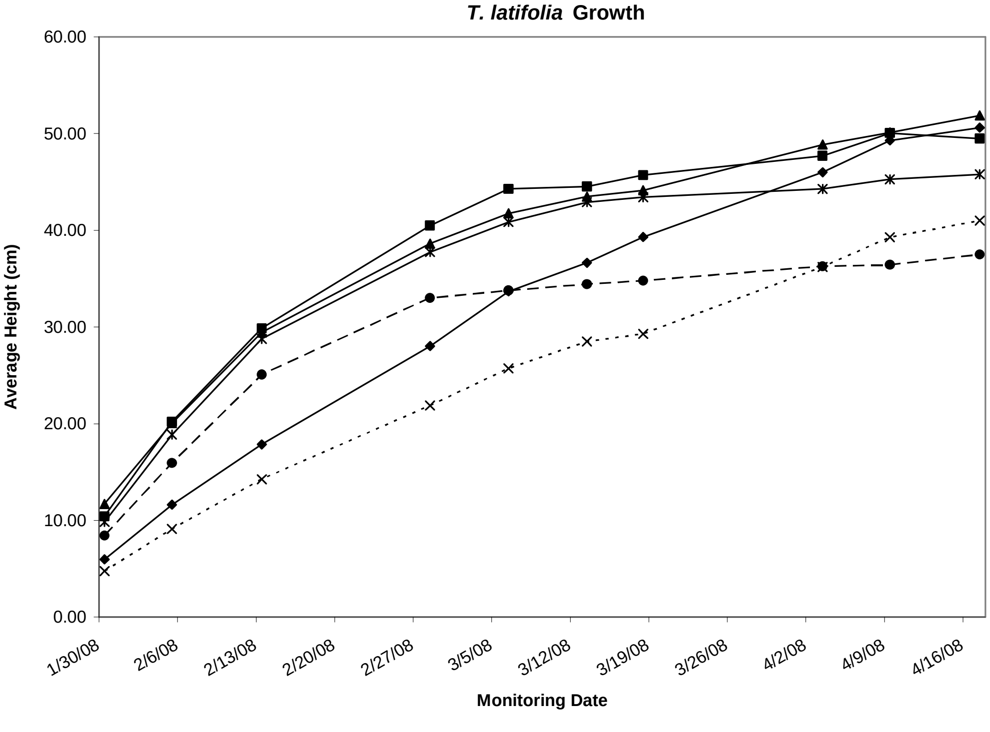


Figure 3-2 ***S. acutus*** **and** ***T. latifolia*** **Growth in OW and C Series Microcosms**

3.2.3 Total Metal Accumulation Experiment

Sediment was expected to be the largest contributor of metals in this experiment because the water used in the experiment was supplied through the Simon Fraser University water system. Although the levels of metals in this water were not analysed it was expected that metal concentrations would not exceed drinking water guidelines; which, are generally lower than sediment quality guidelines. The vegetation was also not expected to contribute much in the way of metals because plants were transplanted as dormant plugs. These plugs were collected from parent plants grown in controlled conditions at Nat's Nursery. Ross (1994) identified sediments as generally contributing the majority of metals to wetlands especially when re-cycling of metals due to senescence and decomposition of plants is not included. Sediment samples from each microcosm, the reference sediment (Section 2.2), the vegetation growth medium, and Oasis Wetland sediments were analysed for Cd, Cu, Pb, and Zn (Figure 3-3).

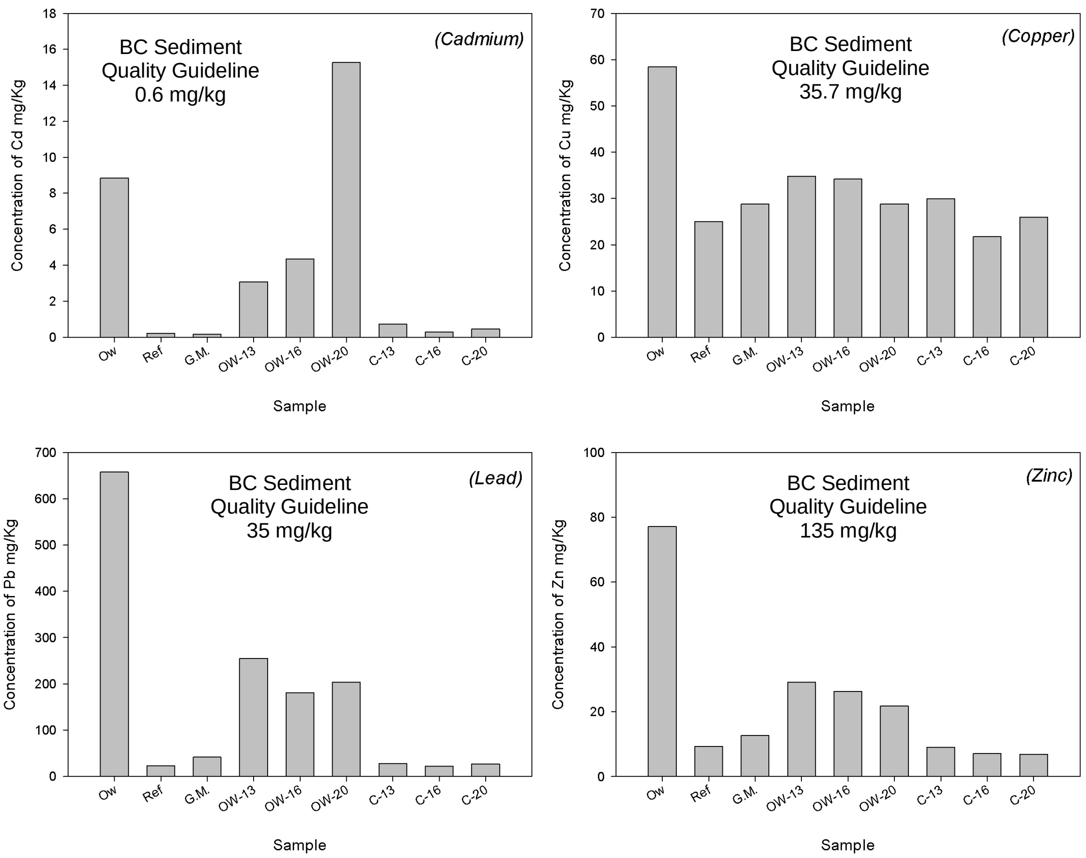


Figure 3-3 Sediment Analysis from Materials used in the Microcosm Experiment

OW – Oasis Wetland Sediment (n=2), Ref – Reference Sediment from Rona Home Depot (n=2), G.M. – Growth media from Nat's Nursery containing *T. latifolia* and *S. acutus* (n=1), OW-13, OW-16, and OW-20 Microcosms (n=1), and C-13, C-16, and C-20 Microcosms (n=1).

Metals were highest in microcosms constructed using the Oasis Wetland sediments, often by an order of magnitude (Figure 3-3). The only instance where this was not the case was for Cu, which was slightly higher in the Oasis Wetland microcosms as compared to all other sources.

There were significantly more tissue metal (Cd and Pb) concentration in the vegetation from the OW series microcosms (Table 3-2). This was expected because metal concentrations were higher in the Oasis Wetland sediment than the reference soils (Figure 3-3) and the Oasis Wetland sediment was used to construct the OW-Series microcosms.

Table 3-2 P-values of three way ANOVA C and OW Series Wetlands

Metal	Species	Wetland
Cd	0.002 - B vs C[1]	0.026 - OW vs C[2]
Cu	-	-
Fe	0.012 - B vs C[1]	-
Pb	0.03 – B vs C[1]	<0.001 - OW vs C[2]
Zn	-	-

[1] Level of significance for metal accumulation in (B) *S. acutus* vs (C) *T. latifolia*
[2] Level of significance for metal accumulation in (OW) OW-Series vs (C) C-Series microcosms

The OW-Series wetland vegetation had significantly more Cd (P = 0.026) and Pb (p<0.001) than the C-Series wetland vegetation. *S. acutus* had significantly more Cd (p=0.002), Fe (p=0.012), and Pb (0.03) than *T. latifolia*. To reduce the potential effects of interactions, given the significant difference between species for most metals, the data were analysed for each species separately. Two-way ANOVAs were used to test for differences in metal concentrations with respect to temperature and plant part in *S. acutus* and *T. latifolia* separately from the OW-Series microcosms. Average metal concentrations within plant parts and significant differences for each species are presented in Figures 3-4 (*S. acutus*) and 3-5 (*T. latifolia*).

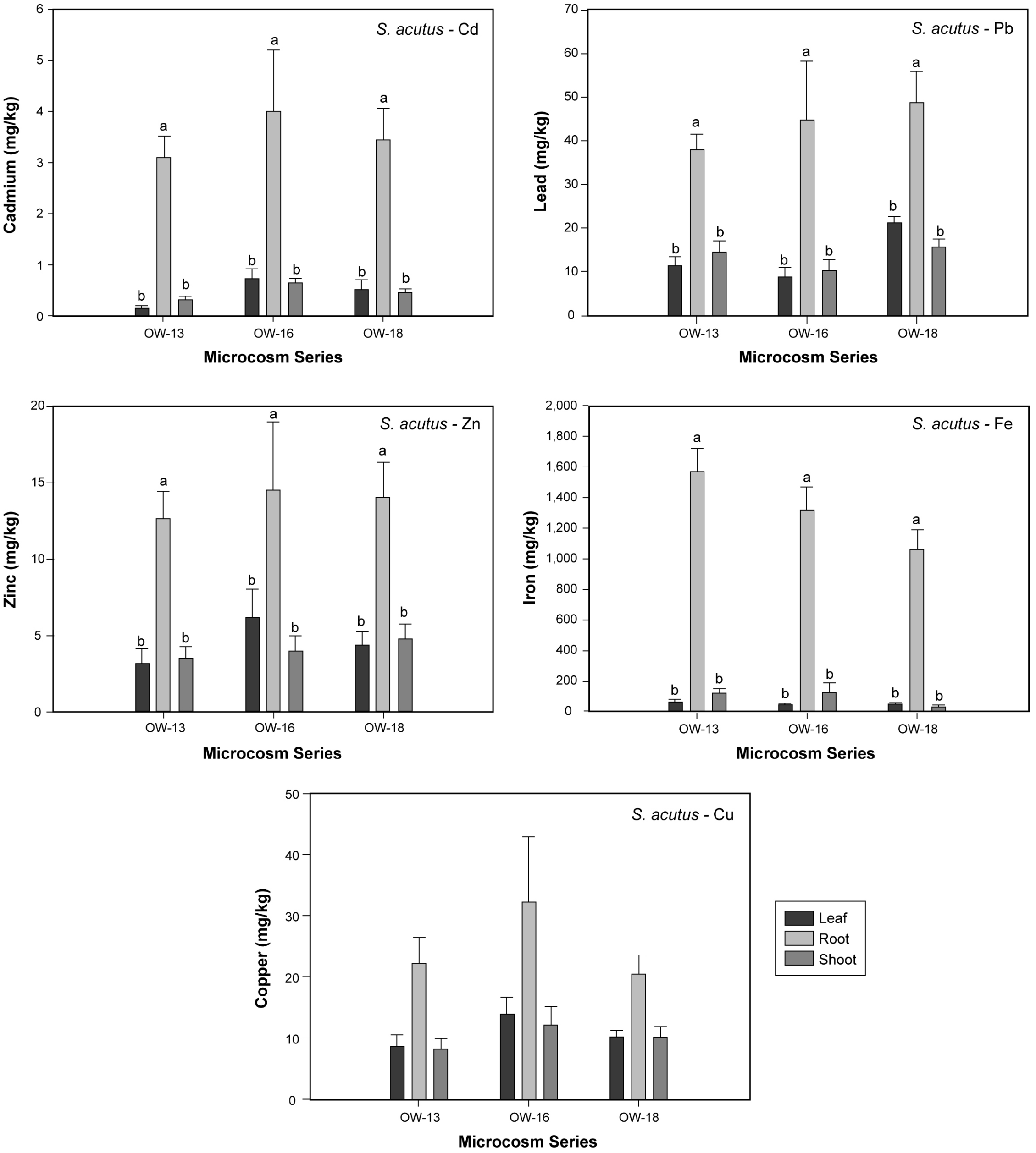


Figure 3-4 Average Metal Concentration within *S. acutus*

a/b above bars indicate significantly different concentrations between plant parts, within temperature ($p<0.05$). Average Cu root results were significantly higher than average leaf and shoot results
error bars are standard error of the mean (σ/√n)

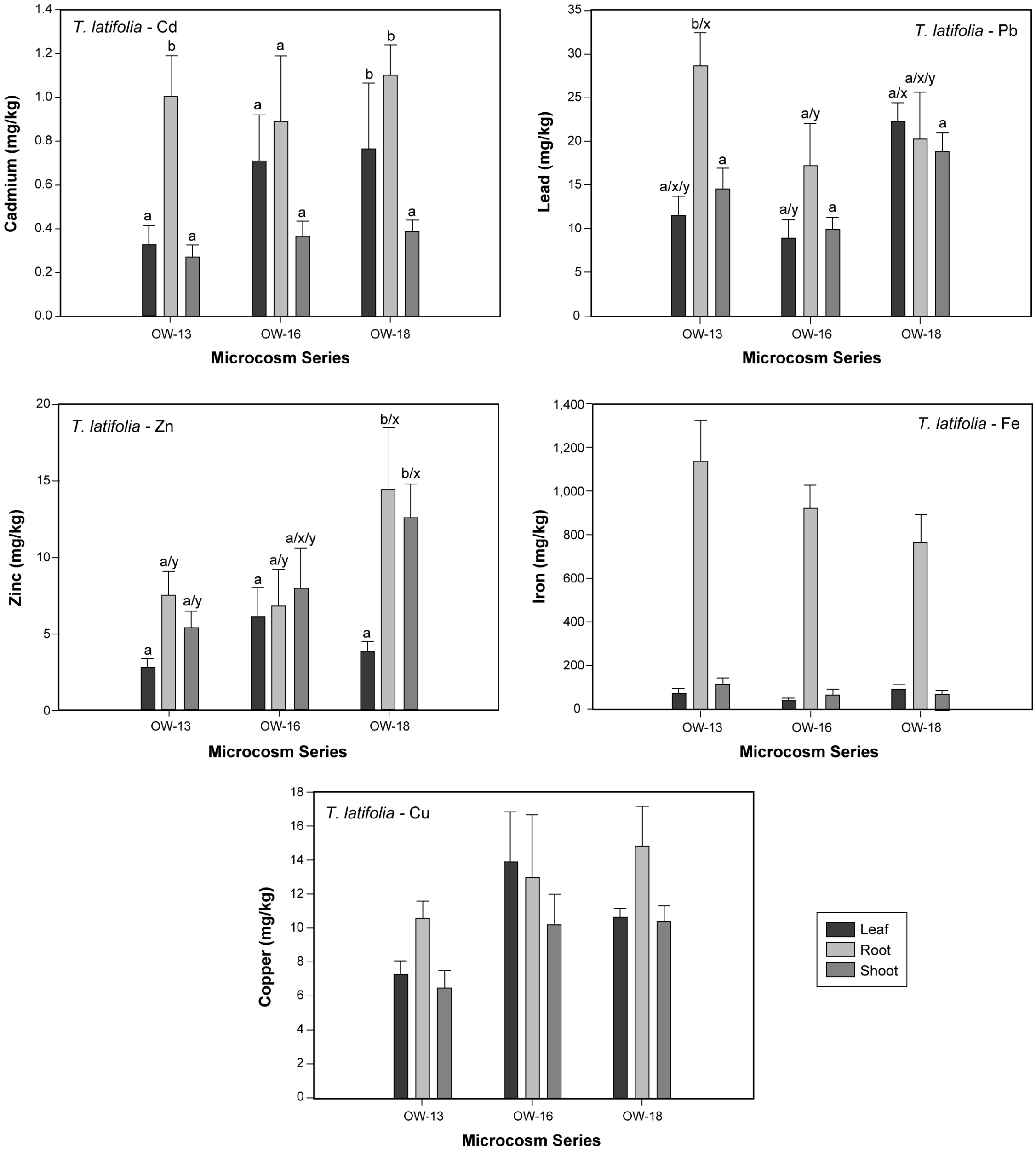


Figure 3-5 Average Metal Concentration within *T. latifolia*

a/b above bars indicate significantly different concentrations between plant parts, within temperatures ($p<0.05$).
x/y above bars indicate significantly different concentrations within plant parts between temperatures ($p<0.05$)
error bars are standard error of the mean ($\sigma/\sqrt{n}$)

Metal concentrations in *S. acutus* were not significantly different with respect to temperature. They were however, consistently, significantly different with respect to plant part. The roots of *S. acutus* had more Cd, Pb, Cu, and Zn at each temperature than the shoots and leaves. Fe levels could not statistically be assessed because there was a significant interaction in the data set (p=0.049). The consistently higher metal concentrations in the roots are likely the result of the root structure. *S. acutus* roots were very fine and fibrous providing a physical trap for metals. It is also possible that sediment trapped in the root structure contributed to the elevated metal concentrations

Metal concentrations in *T. latifolia* were significantly different within the whole plant (Cu) some plant parts (Pb and Zn) between temperatures (Table 3-3). Similar to the *S. acutus* results, Fe levels could not statistically be assessed because there was a significant interaction in the data set (p<0.001). Plant tissue metal concentrations were higher for plants grown at warmer temperatures, with the exception of Pb in *T. latifolia* root where Pb was significantly higher at 13^{o}C than 16^{o}C (Figure 3-5).

Table 3-3 Summary of Two-Way ANOVA Results for Pb, Zn, and Cu in *T. latifolia*

Metal	Plant Part	Temperature of Greatest Tissue Metal Concentration	p-Value
Pb	Root	13^{o}C	0.024
Pb	Leaf	18^{o}C	0.029
Zn	Root	18^{o}C	0.027
Zn	Root	18^{o}C	0.045
Zn	Shoot	18^{o}C	0.034
Cu	Whole	18^{o}C	0.026

Total accumulation of Cd was not significantly different between temperatures in both species indicating total uptake of Cd in *S. acutus* and *T.*

latifolia is not influenced by narrow temperature differences for these species. Fritioff, Kautsky and Greger (2005) identified a positive effect of temperature on Cd accumulation in *Elodea canadensis* and *Potamogeton natans*. However, the overall temperature difference was 15^{o}C and the species studied occupy different positions within wetlands (floating aquatic vs floating leaved submergent).

Within *T. latifolia*, plant part concentrations of Cd and Pb varied between temperatures; generally, at warmer temperatures there was no significant difference between concentrations in the leaves and roots (Figure 3-5). In the 13^{o}C chamber, significantly different concentrations of Cd and Pb were observed between the leaves and roots, where as there was no significant difference between leaf and root concentrations in the 16^{o}C and 18^{o}C chambers.

3.2.4 Cd^{109} Accumulation Rate Experiment

Accumulation rates of Cd^{109} uptake were calculated for each plant part in *T. latifolia* and *S. acutus* at each temperature by plotting $(t/Cd)^{1/3}$ vs time (Figure 3-6, 3-7, and 3-8). The linear form of Cd uptake was generated for each species, plant part, and temperature (Table 3-4). Uptake rate and modelled maximum uptake were calculated from equation 10 and the linear equation respectively (Table 3-5).

Table 3-4 Linear form of Equation 7 for Cadmium^{109} Uptake

Plant	Plant Part	Temperature	Equation	R^2
S. acutus	Leaf	13	$(t/Cd)^{1/3}= 0.09t-0.75$	0.903
		16	$(t/Cd)^{1/3}= 0.06t-0.20$	0.781
		18	$(t/Cd)^{1/3}= 0.04t+1.85$	0.179
	Root	13	$(t/Cd)^{1/3}= 0.02t+0.83$	0.947
		16	$(t/Cd)^{1/3}= 0.02t+0.79$	0.979
		18	$(t/Cd)^{1/3}= 0.02t+0.81$	0.829
	Shoot	13	$(t/Cd)^{1/3}= 0.01t+1.25$	0.771
		16	$(t/Cd)^{1/3}= -0.01t+1.3$	0.241
		18	$(t/Cd)^{1/3}= 0.04t+0.60$	0.829
T. latifolia	Leaf	13	$(t/Cd)^{1/3}= 0.04t+0.915$	0.96
		16	$(t/Cd)^{1/3}= 0.03t+1.0$	0.917
		18	$(t/Cd)^{1/3}= -0.01t+1.22$	0.358
	Root	13	$(t/Cd)^{1/3}= 0.03t+0.84$	0.918
		16	$(t/Cd)^{1/3}= 0.04t+0.78$	0.979
		18	$(t/Cd)^{1/3}= 0.03t+0.74$	0.93
	Shoot	13	$(t/Cd)^{1/3}= 0.04t+1.63$	0.825
		16	$(t/Cd)^{1/3}= -0.02t+1.49$	0.58
		18	$(t/Cd)^{1/3}= -0.01t+0.91$	0.169

Table 3-5 Cadmium^{109} Kinetic Uptake Parameters k and Cd_{max}

Plant	Plant Part	Temperature	k hr^{-1}	Cd_{max}
S. acutus	Leaf	13	-0.51	3.38
		16	-1.34	65.67
		18	0.09	1.23
	Root	13	0.09	13.44
		16	0.14	11.06
		18	0.11	12.74
	Shoot	13	0.05	7.54
		16	-0.04	-7.62
		18	0.27	12.16
T. latifolia	Leaf	13	0.17	5.50
		16	0.15	4.96
		18	-0.05	-8.49
	Root	13	0.16	7.69
		16	0.25	6.00
		18	0.17	10.86
	Shoot	13	0.11	1.55
		16	-0.07	-3.23
		20	-0.06	-15.65

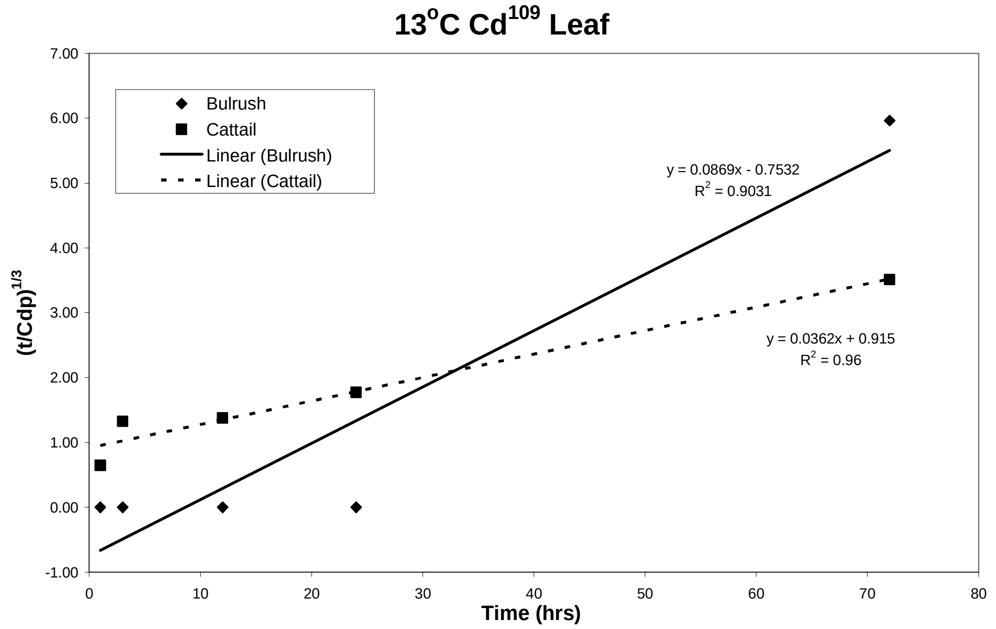


Figure 3-6a Uptake Kinetics of *S. acutus* and *T. latifolia* at 13°C (Leaf)

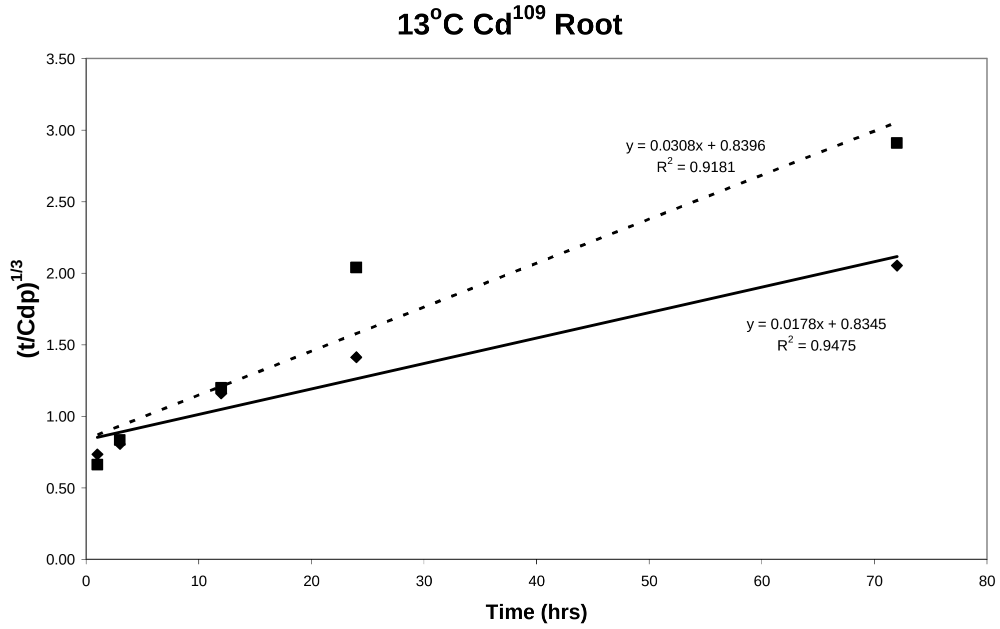


Figure 3-7b Uptake Kinetics of *S. acutus* and *T. latifolia* at 13°C (Root)

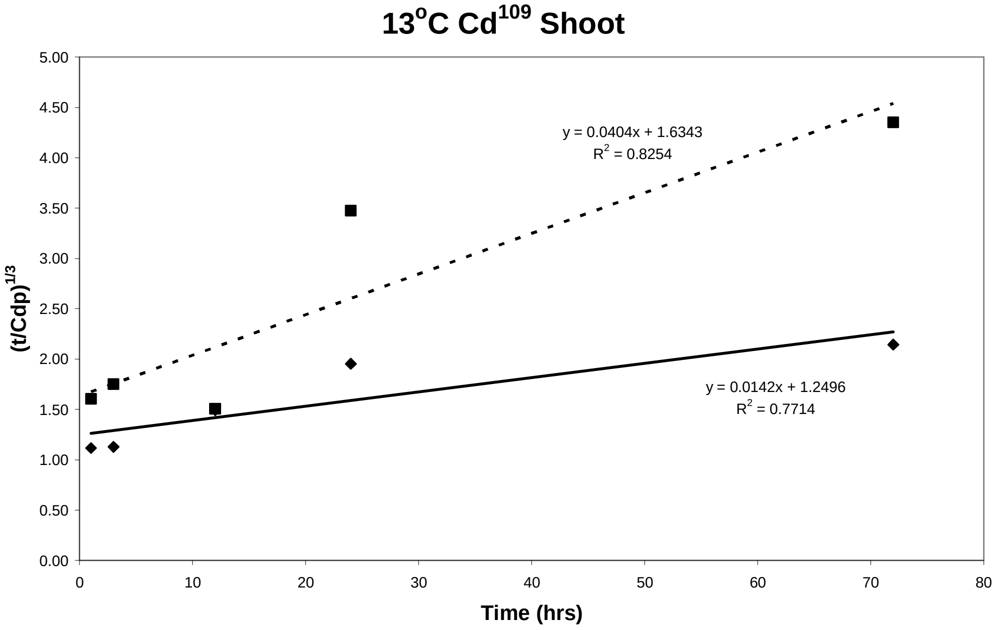


Figure 3-8c Uptake Kinetics of *S. acutus* and *T. latifolia* at 13°C (Shoot)

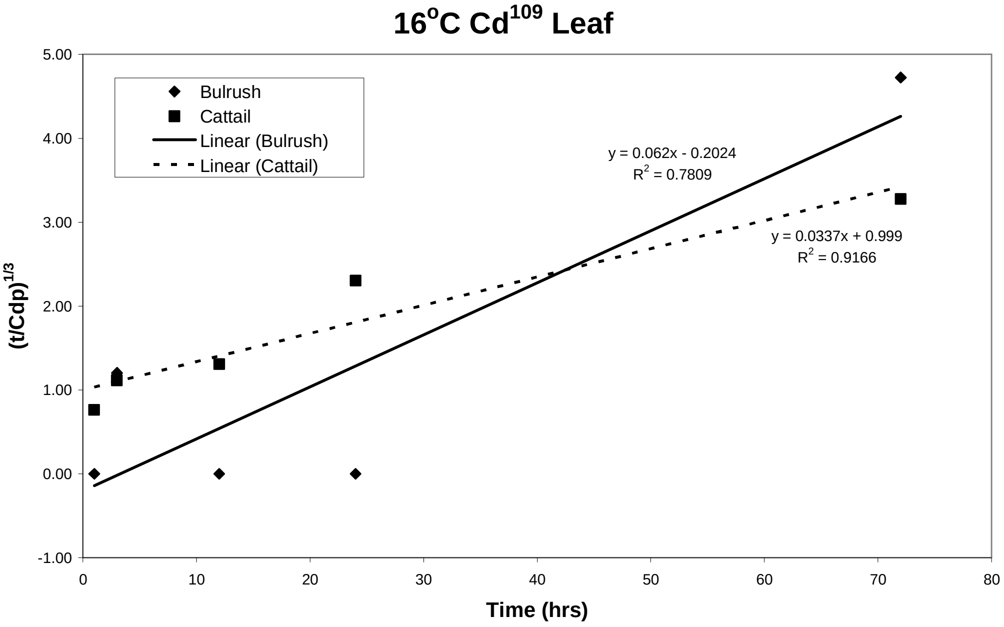


Figure 3-9a Uptake Kinetics of *S. acutus* and *T. latifolia* at 16 °C (Leaf)

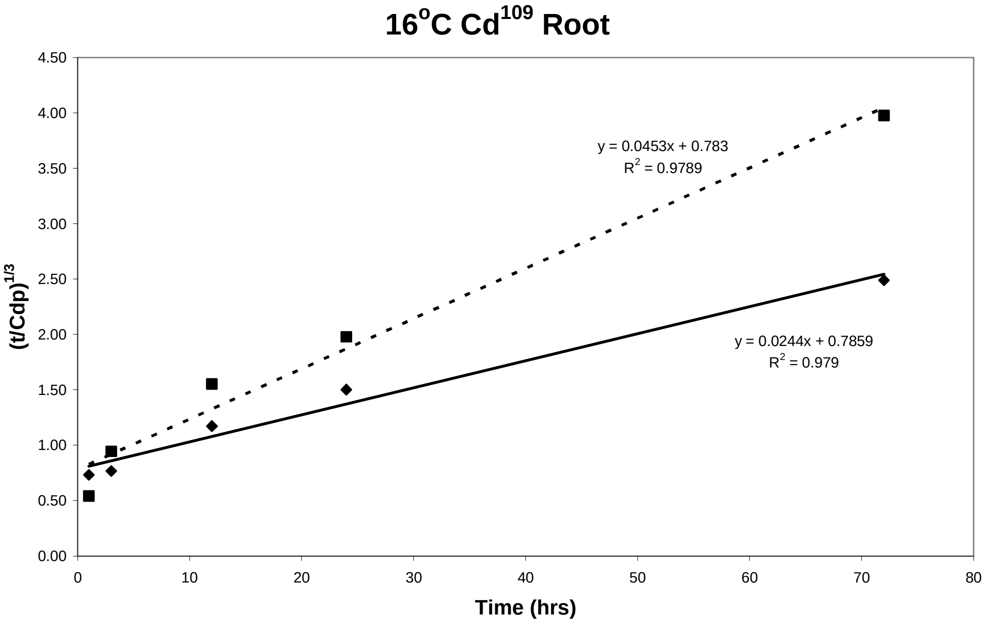


Figure 3-10b Uptake Kinetics of *S. acutus* and *T. latifolia* at 16 ^{o}C (Root)

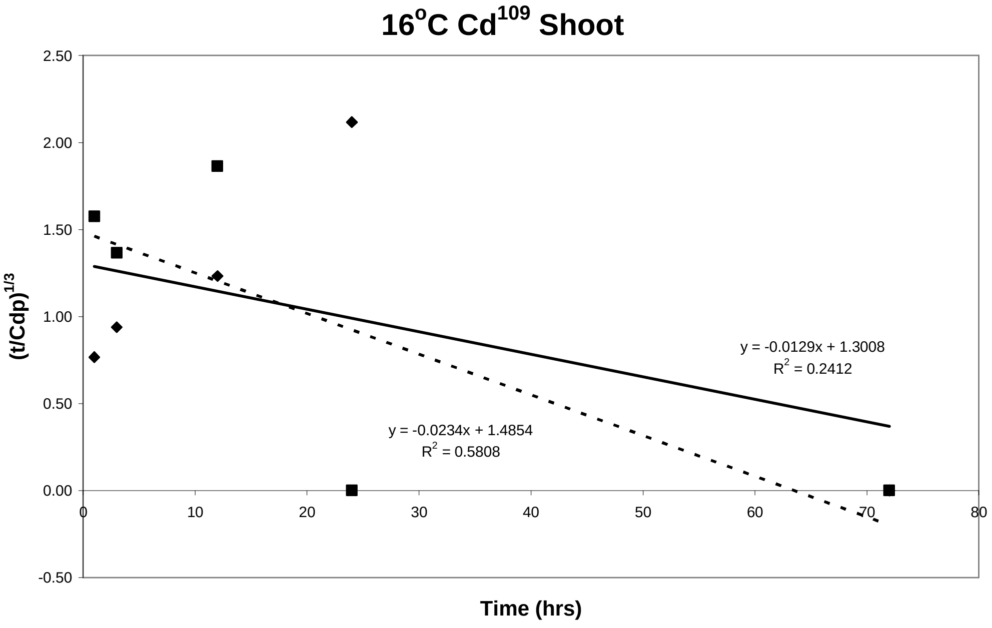


Figure 3-11c Uptake Kinetics of *S. acutus* and *T. latifolia* at 16 ^{o}C (Shoot)

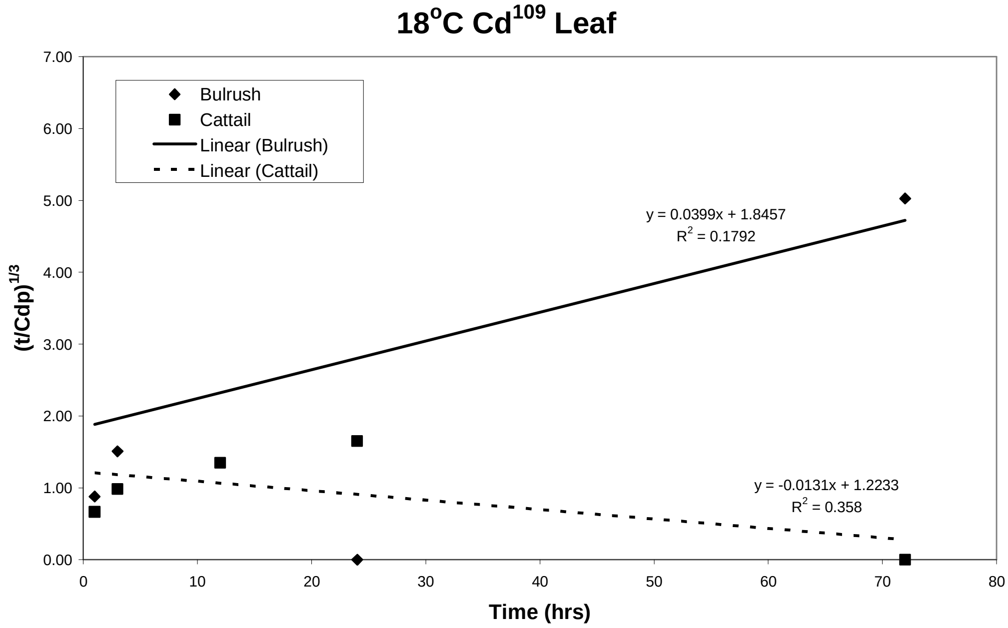


Figure 3-12a Uptake Kinetics of *S. acutus* and *T. latifolia* at 18°C (Leaf)

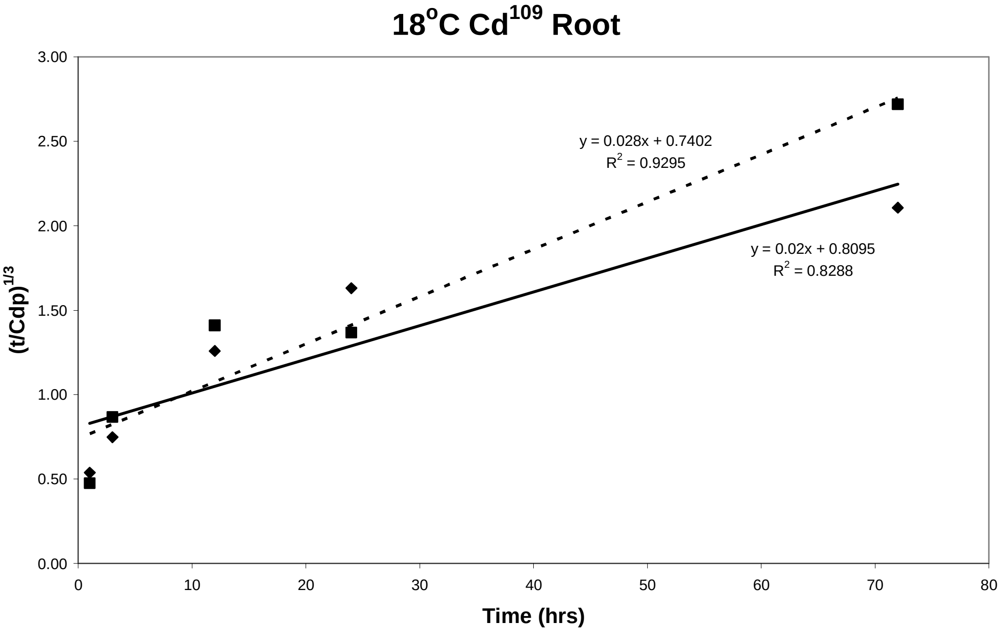


Figure 3-13b Uptake Kinetics of *S. acutus* and *T. latifolia* at 18°C (Root)

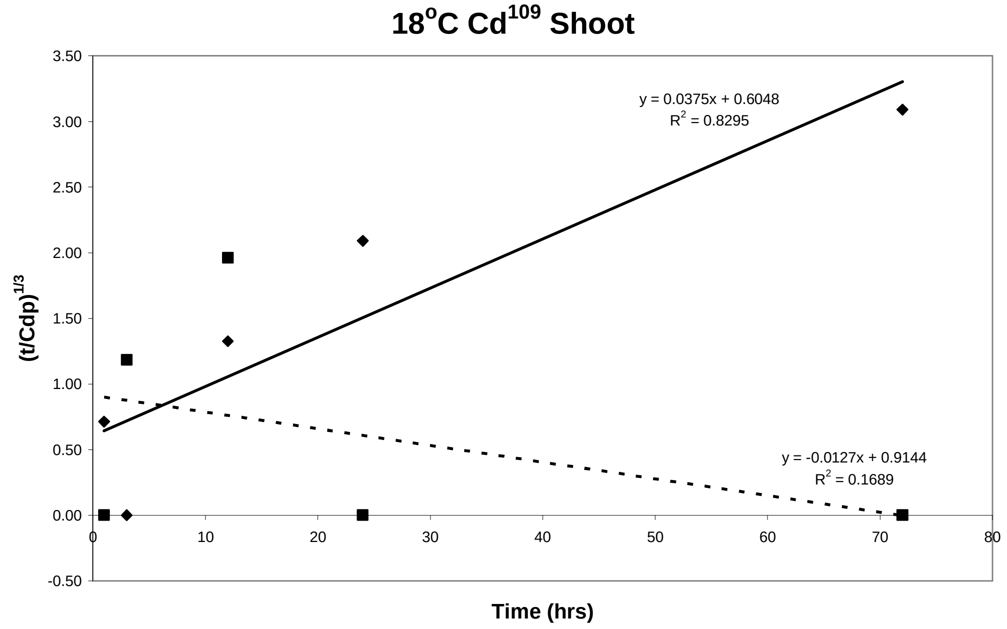


Figure 3-14c Uptake Kinetics of *S. acutus* and *T. latifolia* at 18°C (Shoot)

Average whole plant uptake rates were calculated for each species by averaging plant part k-values from the same temperature groups where R^2>0.75 and the slope was >zero (Table 3-6). Average uptake rates for *S. acutus* increase with temperature although the difference is not statistically significant (p=0.33). Average uptake rates for *T. latifolia* peak in the 16°C chamber; however, like *S. acutus*, differences are not statistically significant.

Table 3-6 Average Whole Plant Cadmium^{109} Kinetic Uptake Parameters (k and Cd$_{max}$)

Species	Temperature	Average Uptake	Average Cd$_{max}$
S. acutus	13	0.07	8.12
	16	0.14	11.06
	18	0.19	12.45
T. latifolia	13	0.15	4.91
	16	0.18	5.48
	18	0.15	10.86

S. acutus accumulated significantly more Cd^{109} after 72 hrs than did *T. latifolia* ($p<0.001$) and was particularly better than *T. latifolia* at accumulating Cd^{109} at cooler temperatures. The roots of both species tended to have significantly more Cd^{109} than other plant parts; likely, because the Cd^{109} was applied directly to the soil surface.

CHAPTER 4: DISCUSSION

4.1 Total Metal Accumulation

Temperature was observed to have an effect on the accumulation of Cu, Pb, and Zn in *T. latifolia*; while there was no observable effect of temperature on accumulation of any metal in *S. acutus*.

There are two primary mechanisms responsible for metal accumulation in plants. Adsorption is a process by which metals adhere to external parts of plant structures, particularly roots and rhizomes. This is a reversible process and not necessarily influenced by light, temperature, or plant metabolism; although, the influence of light, temperature, and plant metabolism on the local chemistry can have an effect on adsorptive accumulation. Adsorption can account for substantial amounts of accumulated metals (Harris, 1999). This was the case for *S. acutus*, which had significantly more Cd, Cu, Fe, Pb, and Zn in the root than other plant parts. This mechanism is not responsible for distributing a given metal throughout a plant because the metals do not physically enter the plant but remain adhered to external structures.

Absorptive accumulation is the other mechanism responsible for metal accumulation and is the process by which metals are made available to internal plant processes. This mechanism involves active transport by crossing the plasma membrane of the root endodermal cells and passive diffusion to the root apoplast through the space between cells (Peer *et. al.,* 2006). Absorptive accumulation can be more directly influenced by temperature than adsorption (Garnham, Codd, and Gadd, 1992 and Harris, 1999). However, the degree to which temperature can affect this mechanism of accumulation depends on the chemistry of the root zone (Peer *et. al*, 2006) biomass and plant growth (Almas and Singh, 2001), and other metal and non-metal constituents (Fritioff, Kautsky, and Greger, 2005; and Peer *et. al*, 2006).

A number of studies, notably Almas and Singh (2001), and Fritioff, Kautsky, and Greger (2005), have shown that temperature has a positive effect on metal accumulation in various species. The temperature differences and the species studied were different from this investigation, a possible indication for why temperature appears to have little effect on metal accumulation in this study. Sasmaz, Obek, and Hasar (2008) show *T. latifolia*, although a known hyperaccumulator of metals, does not effectively transfer heavy metals from the root to the body. Peer *et. al*. (2006) describe metal specific plant mechanisms of tolerance and accumulation of common elements, indicating that metal accumulation is not a simple metabolic process directly related to temperature.

4.2 Accumulation Rate

Cd uptake rates between species, temperature, and plant part (Table 3-5) were different; however, the difference is not solely attributable to temperature. Average kinetic uptake values for *S. acutus* increase with temperature; however, the differences between temperatures are not statistically significant. This maybe the result of a low sample size, as the power of the ANOVA used to identify differences between temperatures was not statistically significant. It is also possible that the narrow temperature range used in this experiment is not sufficient to elicit an effect on Cd accumulation. This is further corroborated by results from the total metal accumulation experiment where Cd accumulation also did not increase with temperature for either *S. acutus* or *T. latifolia* (Figure 3-4 and 3-5).

No significant increase in Cd^{109} uptake rates were identified for *S. acutus* and *T. latifolia*; however, there exists an observable trend in uptake rates in *S. acutus*. Furthermore, the variability of plant part location for Cd^{109} accumulation was significantly different at different temperatures. That is, Cd^{109} was found throughout the plant at warmer temperatures (no significant difference in plant part concentrations at 18°C) where as, it was significantly higher in the roots than other plant parts at 13°C. Although this is not conclusive of an overall increase in metal concentrations at warmer temperatures, it does indicate that temperature does exert some influence over *S. acutus* and *T. latifolia's* ability to cycle metals within plant tissue. Continued research into the processes responsible for within plant metal cycling is warranted.

4.3 Implications for the Oasis Wetland

S. acutus and *T. latifolia* grown in the Oasis Wetland sediments accumulated significantly more Cu and Pb, than did the vegetation growing in the C-Series (control) microcosms ($p<0.001$ and $p=0.01$ respectively). These results show that vegetation growing in the Oasis Wetland will accumulate metals from the sediments. Under the current Natural Resources Canada climate change predictions for southern interior B.C. the temperature is set to increase 3.5°C above current temperatures by 2080 (NRC, 2006). This increase in temperature is enough to increase the amounts of Cu and Pb in *T. latifolia* (Table 3-3). The increase in temperature is expected to cause an overall increase in Cu levels in *T. latifolia* (whole plant) and Pb levels in *T. latifolia* leaves.

Increased temperature, resulting in increased metals in plants in the Oasis Wetland is a management concern because metals, Cu and Pb specifically, may be more bioavailable to species that browse on wetland plants, *T. latifolia* in particular.

T. latifolia marsh wetlands accounted for 1.6 ha or 60% of the Oasis Wetland. This is a substantial area and represents a potentially large increase in bioavailable metals within the region. These results do not solely apply to the Oasis Wetland but any wetland in the region with Cu and Pb in the sediment that is dominated by *T. latifolia*.

CHAPTER 5: OVERALL CONCLUSION

Developing an effective remediation wetland by selecting the best vegetation for the metal of interest and the local climate will improve the effectiveness of remediation. It will also support management and mitigation practices relating to the effect that temperature may have on the bioavailability of metals in the face of increasing temperatures due to global climate change. In the design and construction of treatment wetlands, as well as the monitoring of existing contaminated wetlands, it is important to understand the role that temperature plays on the uptake and translocation of a specific contaminant, such as metals. This importance arises from the idea that temperature effects accumulation and translocation of metals within wetland vegetation.

The total metal accumulation experiment showed that wetlands with high concentrations of Cd, Cu, Fe, and Pb in the sediment accumulate significantly greater levels in *S. acutus* when compared to *T. latifolia*. However, the small temperature differences used did not significantly effect metal accumulation in *S. acutus*. Temperature did have an effect on metal accumulation in *T. latifolia*. *T. latifolia* accumulated significantly more Zn in its roots at 18^{o}C than at 13 and 16^{o}C, Pb in its leaves at 18^{o}C than it did at 13^{o}C and more Cu in the whole plant at 18^{o}C than at 13^{o}C.

The roots of *S. acutus* and *T. latifolia* generally had the highest levels of metals. At 13^{o}C, the tissue metal concentrations in *T. latifolia* tended to be significantly higher in the roots than other plant parts where as at warmer temperatures metal concentrations were not significantly different between root and other plant parts. This indicates that warmer temperatures may translate into a more even distribution of metals in plant tissue possibly due to increased phloem transport at warmer temperatures.

Cd accumulation rates were not significantly affected by temperature. However, observationally Cd^{109} uptake rate increased with temperature in *S. acutus* and peaked at 16^{o}C in *T. latifolia*. It is possible that the small temperatures used in this study do not affect a change in metabolic accumulation. *S. acutus* was once again superior to *T. latifolia* for accumulating Cd, particularly at colder temperatures.

5.1 Application of Research

The results of this research can be applied toward the development of treatment wetlands for the remediation of metals. *S. acutus* was by far the better accumulator in terms of overall metal concentrations when compared to *T. latifolia*. The levels of metals in *S. acutus* also did not respond to temperature, as did the metals in *T. latifolia*. Remediation wetlands, where metal remediation is the goal, should be constructed using *S. acutus* rather than *T. latifolia*. This would likely result in more metals being accumulated from a system, particularly in colder climates.

The Oasis Wetland is a *T. latifolia* marsh with high levels of metals in its sediments. The results of this research show that replacing the *T. latifolia* with *S.*

acutus would improve metal accumulation in the plants, which could then be harvested and removed from the site; ultimately, removing metals present in the sediment. Changing the vegetation composition at the Oasis Wetland would also reduce the possibility the transfer of metals to species that browse on *T. latifolia* and *S. acutus*. It is expected that temperature will increase 3.5^{o}C over the next 70 years, and this increase will result in more Cu and Pb available in *T. latifolia* whole plant and leaves respectively.

Future research should focus on the actual process of metal accumulation within *T. latifolia* and *S. acutus*. This would help determine why tissue metal concentrations in *T. latifolia* were influenced by different temperatures, where as metals in *S. acutus* were not. This research would help environmental scientists and engineers develop more effective remediation wetlands, compensating for lost or damaged wetlands, while limiting contaminants of interest from becoming more bioavailable, in the face of a changing climate.

REFERENCE LIST

Almas, A.R. and B.R. Singh. 2001. Plant Uptake of Cadmium-109 and Zinc-65 at Different Temperature and Organic Matter Levels. J. Environ. Qual. 30: 869-877

British Columbia Ministry of Environment (B.C. MOE). 2006a. A Compendium of Working Water Quality Guidelines for British Columbia: Table 1 Working Guidelines for the Water Column. Accessed from: http://www.env.gov.bc.ca/wat/wq/BCguidelines/working.html#table1. Accessed on September 4, 2008.

British Columbia Ministry of Environment (B.C. MOE). 2006b. A Compendium of Working Water Quality Guidelines for British Columbia: Table 2 Working Guidelines for the Sediments. Accessed from: http://www.env.gov.bc.ca/wat/wq/BCguidelines/working.html#table2. Accessed on September 4, 2008.

Canada Soil Survey Committee (CSSC). 1987. *The Canadian System of Soil Classification*. 2nd ed. Agriculture Canada. Ottawa, Ont. Publ. 1646.

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 2001. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Mortgage and Housing Coorporation (CMHC-SCHL). 2008. Constructed Wetlands. Accessed from: http://www.cmhc-schl.gc.ca/en/inpr/su/waco/alstmaprrepr/alstmaprrepr_002.cfm. Accessed on: November 14, 2008.

Chen, M. and L.Q. Ma. 2001. Comparison of Three Aqua Regia Digestion Methods for Twent Florida Soils. Soil Sci. Soc. Am. J. 65: 491-499

Craig, J. 2006. Oasis Restoration Plan: Draft Report. Prepared for Columbia Basin Fish and Wildlife Compensation Program and Teck Cominco. Prepared by Juliet Craig, June 2006.

Douglas, G.W., D. Meidinger, J. Pojar. 2001. *Illustrated Flora of British Columbia*. Ministry of Environment Lands and Parks. Victoria B.C. Volumes 1-6.

Foiles, Marvin W. 1965. Grand fir, Abies grandis (Dougl.) Lindl. In Silvics of forest trees of the United States. p. 19-24. H. A. Fowells, comp. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC.

Fritioff, A., L. Kautsky, and M. Greger. 2005. Inluence of Tempeature and Salinity on Heavy Metal Uptake by Submersed Plants. Environmental Pollution. 133: 265-274

Garnham, G. W., G. A. Codd, G. M. Gadd. 1992. Kinetics of Uptake and Intracellular Location of Cobalt, Manganese, and Zinc in the Esturine Green Alga *Chlorella salina*. *App. Microbiol. Biotechnol.* 37, 270-276.

Golder. 2007. Summary of Wetlands Investigations for the Teck Cominco Area of Interest: Final Report. Prepared for Teck Cominco. Prepared by Golder Associates. August, 2007.

Ghaly, A.E., A. Snow, and M. Kamal. 2008. Kinetics of Manganese Uptake by Wetland Plants. American Journal of Applied Sciences. 5 (10): 1415-1423

Government of B.C. (Gov. B.C.). 2003. Part D Soil and Sediment Sampling. Province of British Columbia.

Government of Canada. 1991. The Federal Policy on Wetland Conservation. Minister of the Environment. Minister of Supply and Service Canada, 1991.

Green, R.N., R.L. Trowbridge, and K. Klinka. 1993. Towards a Taxonomic Classification of Humus Forms. For. Sci. Monogr. 29.

Hammer D.A. (editor). 1989. Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. Lewis Publishers Inc. Michigan, USA.

Harris, C.S. 1999. Bioaccumulation of Zinc in Periphyton and Invertebrates: Lotic Field and Microcosm Studies. Master of Science Thesis. Craig S. Harris. April 1999.

Johnson, D., L. Kershaw, A. MacKinnon, and J. Pojar. 1995. *Plants of the Western Boreal Forest and Aspen Parkland*. Lone Pine Publishing and the Canadian Forest Service. Canada.

Kadlec, R. H., and R. L. Knight. 1996. Treatment Wetlands. CRC Press. USA.

Kalra, Y.P. 1998. Handbook of Reference Methods for Plant Analysis. CRC Press. United States of America.

Luttmerding, H.A., D.A. Demarchi, E.C. Lea, D.V. Meidinger, and T. Vold. (editors). 1990. *Describing Ecosystems in the Field*. Second edition. B.C. Min. Env., Lands and Parks and B.C. Min. of For.,MOE Manual 11. Victoria, B.C.

MacKenzie, W.H. 1999. Field Description of Wetlands and Related Ecosystems in British Columbia. Ministry of Forest Research Program. Victoria, B.C.

MacKenzie, W.H. and J.R. Moran. 2004. Wetlands of British Columbia: A Guide to Identification. Ministry of Forest Research Program. Victoria, B.C. Land Management Handbook 52.

Mander, U. P.D. Jessen. 2002. Constructed Wetlands for Wastewater Treatment in Cold Climates. Boston Publishing Company. Newton, Massachusetts.

Mitsch, W. J., and J. G. Gosselink. 1993. Wetlands: Second Edition. Van Nostrand Reinhold. NY, USA.

Natural Resources Canada (NRC). 2006. Climate Change Impacts and Adaptation: A Canadian Perspective Projected Climate Change. Accessed from: http://adaptation.nrcan.gc.ca/perspective/summary_2_e.php

Parish, R., R. Coupe, and D. Lloyd. 1996. Plants of Southern Interior British Columbia. B.C. Ministry of Forests and Lone Pine Publishing.

Peer, A. W., I. R. Baxter, E. L. Richards, J. L. Freeman, and A. S. Murphy. 2006. Phytoremediation and hyperaccumulator Plants. Molecular Biology of Metal Homeostasis and Detoxification. Springer Berlin and Heidelberg. pp 299-340

Perkin-Elmer. 1996. Analytical Methods: Atomic Absorption Spectroscopy. The Perkin-Elmer Corporation.

Pojar, J. and A. MacKinnon. 1994. Plants of Costal British Columbia: Including Washington, Oregon and Alaska. B.C. Ministry of Forests and Lone Pine Publishing.

Radiation Safety Office. 2008. Simon Fraser University Radiation Safety Manual: Policies and Procedures. Radiation Safety Office, Simon Fraser Universiy.

Ramsar. 2008. The Ramsar Convention on Wetlands. Ramsar Convention on Wetlands. Accessed from: http://www.ramsar.org/. Accesed on: November 10, 2008.

Rehbein, C. 2004. Remedial Agriculture: Reconciling Ecological Restoration and Agriculture in the Design of a Wetland Complex. Rehbein, Christina. Masters of Environmental Studies.

Robert, F., G. Risser, and G. Petel. 1999. Photoperoid and Temperature Effect on Growth of Strawberry Plant (*Fragaria x ananassa* Dutch) Development of a Morphological Test to Assess the Dormancy Induction. Scientia Horticulturae. 82 (3-4). Pp. 217-226

Singh, J., P. N. Viswanathan, M. Guptas, and S. Devi. 1993. Uptake and Translocation of Cd^{109} by Two Aquatic Ferns in Relation to Relative Toxic Response. Bull. Environ. Contam. Toxicol. 51. 914-919.

Salisbury, F.B., and C. W. Ross. 1992. Plant Physiology: Fourth Edition. Wadsworth, Inc.

Sasmaz, A., E. Obek, and H. Hasar. 2008. The Accumulation of Heavy Metals in *Typha latifolia* in a Stream Carrying Secondary Effluent. J. Ecological Engineering. 33. 278-284

Scheel, K. 2007. Personal Communication with Kate Scheel, Radiation Safety Office. Simon Fraser University. September 27, 2007.

Spectrum Geological Services Ltd. 2005. Columbia Basin Trust Wetlands Restoration Project, Oasis B.C.: Surface Features Map Dominant Vegetation, and Surface Cover. Engineering Drawing. Prepared by Spectrum Geological Services Ltd.

Spittlehouse, D.L. 2008. Climate Change, Impacts, and Adaptation Scenarios: Climate Change and Forest and Range Management in British Columbia. Ministry of Forests and Range. Forest Sciences Program. Technical Report 045.

Teck Cominco. 2007. Preliminary Proposal for Wetland Rehabilitation/Remediation at Oasis. Draft report for discussion purposes. Bill Duncan, Teck Cominco, Trail, B.C.

Warner, B.G., and C.D.A Rubec (editors). 1997. The Canadian Wetland Classification System: The National Wetlands Working Group. Wetlands Research Centre. University of Waterloo, Waterloo, Ontario

Went, F.W. 1953. The Effect of Temperature on Plant Growth. Annual Review of Plant Physiology. 4. pp. 347-362.

APPENDICES

Appendix 1 – Metals Concentrations in Sediment Samples

Sample	Empty (g)	Total Wet (g)	Wet Weight (g)	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Pb mg/Kg	Zn mg/Kg
Standard	-	-	-	0.59	50.00	27.97	0.81	36.44	8.47
OW 2	5.44	125.61	120.17	0.58	50.00	66.27	10.58	747.85	95.52
OW 3	5.55	142.44	136.89	0.52	51.52	61.02	8.60	683.27	71.03
Ref 1	5.52	66.94	61.43	0.52	50.60	25.40	0.49	35.17	9.77
Ref 2	5.58	55.10	49.52	0.53	50.00	31.25	0.00	17.05	11.36
G.M.	5.41	102.82	97.41	0.50	50.00	33.86	0.20	48.80	14.94
OW-13-1	5.50	116.97	111.47	0.52	50.00	30.77	2.12	161.54	24.04
OW-13-2	5.59	124.72	119.13	0.54	50.00	41.44	3.22	367.40	32.23
OW-13-3	5.53	119.43	113.90	0.53	50.00	43.81	4.95	320.95	40.95
C-13-1	5.42	109.31	103.89	0.52	50.00	43.52	0.81	30.95	11.61
C-13-2	5.53	119.26	113.73	0.52	50.00	30.77	0.46	32.69	8.65
C-13-3	5.47	113.54	108.06	0.51	50.00	28.21	1.25	30.16	10.70
OW-16-1	5.47	146.49	141.02	0.54	50.00	40.04	4.26	178.77	26.07
OW-16-2	5.51	149.59	144.07	0.54	50.00	34.51	4.82	222.01	30.78
OW-16-3	5.59	145.87	140.28	0.52	50.00	39.81	5.50	203.88	31.07
C-16-1	5.54	78.63	73.09	0.52	50.00	23.26	0.58	23.26	7.75
C-16-2	5.44	97.14	91.70	0.53	50.00	27.46	0.35	20.83	8.52
C-16-3	5.47	138.58	133.11	0.50	50.00	23.86	0.00	29.82	7.95
OW-20-1	5.57	136.65	131.08	0.52	50.00	27.88	2.07	139.42	15.38
OW-20-2	5.56	110.93	105.37	0.55	50.00	29.09	2.40	225.45	18.18
OW-20-3	5.52	94.99	89.47	0.52	50.00	39.42	6.38	315.38	39.42
C-20-1	5.43	73.54	68.11	0.53	50.00	24.53	0.00	31.13	7.55
C-20-2	5.56	43.55	38.00	0.50	50.00	33.80	0.83	31.81	7.95
C-20-3	5.48	45.68	40.21	0.55	50.00	29.04	0.68	27.22	7.26
Standard	-	-	-	0.56	50.98	34.65	0.62	41.95	10.94

Appendix 2 – Metals Concentrations in OW and C Series Microcosm Vegetation

Species	Wetland	Location	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Fe mg/Kg	Pb mg/Kg	Zn mg/Kg
C	OW-13-1	Leaf	1.055	50	9.005	0.237	90.047	25.118	4.739
C	OW-13-1	Root	1.02	50	11.275	0.686	446.078	25.490	7.353
C	OW-13-1	Shoot	0.998	50	10.020	0.351	135.271	29.058	9.018
C	OW-13-1	Leaf	1.063	50	8.467	0.376	23.518	13.641	3.293
C	OW-13-1	Root	1.073	50	12.582	2.237	1686.859	50.792	12.116
C	OW-13-1	Shoot	1.006	50	11.431	0.348	74.553	17.893	11.431
B	OW-13-1	Lower	1.104	50	6.793	0.226	58.877	16.304	2.717
B	OW-13-1	Root	1.081	50	9.713	1.665	846.438	30.527	9.251
B	OW-13-1	Upper	1.152	50	2.604	0.000	4.340	13.455	0.868
C	OW-13-1	Leaf	1.086	50	6.446	0.138	55.249	13.812	2.302
C	OW-13-1	Root	1.136	51.8	9.120	0.365	642.940	19.607	3.192
C	OW-13-1	Shoot	1.08	50	9.259	0.185	78.704	19.907	9.722
B	OW-13-1	Lower	1.064	50	12.218	0.376	176.222	17.387	3.759
B	OW-13-1	Root	1.042	50	45.106	3.551	1407.869	34.069	20.633
B	OW-13-1	Upper	1.042	50	10.557	0.000	60.940	2.879	4.319
S	OW-13-1	Leaf	1.084	50	11.993	0.000	88.100	8.303	3.229
S	OW-13-1	Root	1.154	50	9.532	1.256	1074.090	15.165	6.932
B	OW-13-1	Composite	0.795	50	13.208	0.440	383.648	17.610	10.063
C	OW-13-1	Leaf	0.878	50	8.542	0.114	62.642	7.973	5.695
C	OW-13-1	Root	1.409	50	6.742	0.887	745.209	29.099	4.613
C	OW-13-1	Shoot	0.632	50	6.329	0.158	15.823	21.361	6.329
C	OW-13-2	Composite	1.425	50	9.825	0.211	1185.965	9.474	3.860
B	OW-13-2	Composite	1.006	50	8.449	0.249	646.123	12.425	4.970
C	OW-13-2	Leaf	0.919	50	7.073	0.326	114.255	6.529	1.632
C	OW-13-2	Root	1.046	50	5.258	0.574	1324.092	9.560	1.434
C	OW-13-2	Shoot	0.997	50	5.015	0.652	210.632	6.520	3.009

Appendix 2 – Metals Concentrations in OW and C Series Microcosm Vegetation (Continued)

Species	Wetland	Location	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Fe mg/Kg	Pb mg/Kg	Zn mg/Kg
B	OW-13-2	Lower	1.013	50	2.468	0.197	24.679	9.378	0.494
B	OW-13-2	Root	0.98	50	24.490	4.031	2209.184	38.776	17.347
B	OW-13-2	Upper	1.146	50	3.490	0.000	34.904	13.089	0.873
C	OW-13-2	Leaf	1.202	50	6.656	0.374	24.958	3.328	1.664
C	OW-13-2	Root	1.04	50	15.385	0.817	1182.692	30.288	16.346
C	OW-13-2	Shoot	1.078	50	4.638	0.093	125.232	6.957	2.783
B	OW-13-2	Lower	1.165	50	5.150	0.129	167.382	4.292	1.717
B	OW-13-2	Root	1.054	50	19.450	4.127	1802.657	48.861	13.283
B	OW-13-2	Upper	1.076	50	5.576	0.465	120.818	13.011	1.859
C	OW-13-2	Leaf	0.669	50	5.232	0.000	164.425	8.969	0.747
C	OW-13-2	Root	1.066	50	11.257	0.188	1810.507	32.364	6.567
C	OW-13-2	Shoot	0.657	50	4.566	1.979	220.700	6.849	3.044
B	OW-13-2	Lower	1.058	50	9.452	0.520	132.325	24.575	4.253
B	OW-13-2	Root	1.029	50	21.380	1.506	1997.085	28.183	5.831
B	OW-13-2	Upper	1.139	50	4.829	0.088	4.390	5.707	1.317
C	OW-13-3	Leaf	1.051	50	5.709	0.285	66.603	18.078	1.903
C	OW-13-3	Root	1.185	50	12.236	1.224	1666.667	26.160	10.127
C	OW-13-3	Shoot	1.007	50	6.951	0.199	213.505	17.378	4.469
B	OW-13-3	Lower	1.025	50	11.707	0.488	190.244	14.146	5.366
B	OW-13-3	Root	0.544	50	0.000	5.882	2463.235	73.529	18.382
B	OW-13-3	Upper	1.075	50	13.953	0.093	51.163	9.302	6.047
B	OW-13-3	Composite	0.864	50	20.255	0.810	1001.157	9.838	11.574
B	OW-13-3	Composite	1.294	50	17.002	0.425	1023.957	14.683	7.342
C	OW-13-3	Composite	0.643	50	11.664	0.389	1034.215	41.213	9.331
B	OW-13-3	Lower	1.124	50	11.566	0.356	84.520	16.014	5.783
B	OW-13-3	Root	1.136	50	25.968	4.137	1668.134	50.616	14.085

Appendix 2 – Metals Concentrations in OW and C Series Microcosm Vegetation (Continued)

Species	Wetland	Location	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Fe mg/Kg	Pb mg/Kg	Zn mg/Kg
B	OW-13-3	Upper	1.098	50	18.215	0.228	86.521	18.670	6.375
C	OW-13-3	Leaf	1.076	50	11.617	0.279	162.639	11.152	4.647
C	OW-13-3	Root	1.973	50	4.562	0.380	243.284	13.178	2.027
C	OW-13-3	Shoot	1.274	50	5.102	0.314	62.794	16.091	3.140
C	C-13-1	Leaf	1.264	50	9.098	0.316	15.823	0.000	3.165
B	C-13-2	Lower	1.113	50	3.145	0.314	8.985	9.434	0.898
B	C-13-2	Root	0.685	50	42.336	1.314	1102.190	13.139	12.409
B	C-13-2	Upper	1.887	50	5.829	0.053	23.847	6.094	1.590
B	C-13-3	Upper	1.922	50	2.081	0.000	5.203	0.260	1.041
C	C-13-3	Leaf	1.496	50	6.016	0.301	50.134	15.709	2.005
C	C-13-3	Shoot	1.855	50	4.313	0.216	18.868	3.774	3.504
C	C-13-3	Shoot	1.201	50	4.163	0.042	33.306	17.485	3.747
B	C-13-3	Composite	2.295	50	2.614	1.024	135.076	13.072	1.307
S	OW-20-1	Leaf	1.11	50	17.117	0.000	171.171	13.964	4.955
S	OW-20-1	Root	1.169	50	24.380	1.497	667.237	37.639	5.988
B	OW-20-1	Lower	1.08	50	12.500	0.093	50.926	21.759	5.556
B	OW-20-1	Root	1.019	50	28.950	4.809	1236.506	70.167	19.627
B	OW-20-1	Upper	1.054	50	8.539	0.000	42.694	20.398	2.846
S	OW-20-1	Leaf	1.244	50	17.685	0.201	48.232	9.646	4.421
S	OW-20-1	Root	1.487	50	73.638	19.099	1738.399	224.277	74.311
B	OW-20-1	Composite	1.673	50	8.667	0.717	74.716	15.242	3.586
S	OW-20-1	Composite	1.323	50	22.676	0.718	340.136	22.298	5.669
B	OW-20-1	Lower	1.09	50	9.174	0.321	22.936	21.101	3.211
B	OW-20-1	Root	1.297	50	25.058	4.742	574.402	35.852	16.191
B	OW-20-1	Upper	1.018	50	7.367	0.000	34.381	28.978	4.912
S	OW-20-1	Leaf	1.687	50	8.595	0.030	29.638	12.152	3.260

Appendix 2 – Metals Concentrations in OW and C Series Microcosm Vegetation (Continued)

Species	Wetland	Location	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Fe mg/Kg	Pb mg/Kg	Zn mg/Kg
S	OW-20-1	Root	1.449	50	15.873	2.622	617.667	43.478	10.697
B	OW-20-1	Lower	1.384	50	15.535	0.470	25.289	15.896	7.225
B	OW-20-1	Root	1.158	50	16.839	4.275	660.622	40.155	13.385
B	OW-20-1	Upper	1.257	50	13.922	0.517	47.733	21.082	9.149
C	OW-20-1	Composite	1.297	53.8	12.444	1.410	539.244	32.769	14.518
B	OW-20-2	Lower	1.009	50	8.424	0.793	39.643	19.822	6.938
B	OW-20-2	Root	0.914	50	24.070	3.282	1323.851	61.816	13.129
B	OW-20-2	Upper	1.03	50	4.369	0.485	29.126	15.534	2.913
C	OW-20-2	Leaf	1.1	50	10.455	0.273	122.727	20.000	5.000
C	OW-20-2	Root	1.395	50	14.337	1.075	433.692	21.864	15.412
C	OW-20-2	Shoot	1.096	50	10.036	0.411	2.737	20.073	18.704
B	OW-20-2	Lower	1.093	50	15.554	0.549	82.342	15.096	8.692
B	OW-20-2	Root	1.137	50	20.229	4.881	1244.503	49.252	16.711
B	OW-20-2	Upper	1.326	50	8.673	0.113	60.332	16.214	3.017
S	OW-20-2	Root	0.968	50	19.628	3.099	1689.050	57.851	18.595
C	OW-20-2	Leaf	1.086	50	10.589	0.552	124.309	18.877	5.525
C	OW-20-2	Root	1.492	50	16.756	0.838	918.231	0.000	20.777
C	OW-20-2	Shoot	1.207	50	6.628	0.497	37.283	19.470	6.628
B	OW-20-2	Lower	1.267	50	9.866	0.513	39.463	5.919	2.762
B	OW-20-2	Root	1.255	50	24.701	1.594	1175.299	35.458	9.163
B	OW-20-2	Upper	1.001	50	14.985	0.000	59.940	28.472	3.996
C	OW-20-2	Leaf	1.023	50	10.753	0.293	107.527	32.747	2.444
C	OW-20-2	Root	1.362	50	6.975	0.734	469.897	16.153	4.038
C	OW-20-2	Shoot	1.139	50	7.463	0.307	65.847	9.658	5.707
C	OW-20-3	Leaf	0.97	50	11.340	2.474	97.938	24.227	4.124
C	OW-20-3	Root	1.474	50	11.872	1.119	739.484	28.155	14.586

Appendix 2 – Metals Concentrations in OW and C Series Microcosm Vegetation (Continued)

Species	Wetland	Location	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Fe mg/Kg	Pb mg/Kg	Zn mg/Kg
C	OW-20-3	Shoot	1.316	50	10.258	0.304	68.389	17.857	14.438
B	OW-20-3	Lower	0.648	50	3.858	0.617	0.000	23.920	1.543
B	OW-20-3	Root	0.439	50	18.223	4.328	1685.649	58.087	11.390
B	OW-20-3	Upper	1.455	50	7.904	0.515	20.619	19.244	4.124
B	OW-20-3	Lower	1.02	50	7.843	0.098	9.804	3.922	4.412
B	OW-20-3	Root	0.648	50	27.778	1.698	1913.580	62.500	17.747
B	OW-20-3	Upper	1.66	50	4.518	1.446	12.048	9.036	1.506
S	OW-20-3	Composite	0.593	50	27.825	1.433	1129.848	48.904	9.275
B	OW-20-3	Lower	1.153	50	9.107	0.434	17.346	13.443	4.337
B	OW-20-3	Root	1.323	50	4.535	0.756	347.695	18.519	4.913
B	OW-20-3	Upper	1.126	50	11.101	0.266	57.726	19.094	4.440
C	OW-20-3	Leaf	1.043	50	9.108	0.575	38.351	25.407	2.876
C	OW-20-3	Root	1.089	50	8.264	0.643	449.954	12.856	4.591
C	OW-20-3	Shoot	1.273	50	10.605	0.353	141.398	12.962	12.176
B	OW-20-3	Lower	1.149	50	6.527	0.566	4.352	16.101	1.305
B	OW-20-3	Root	1.221	50	27.846	5.160	1654.382	89.681	24.161
B	OW-20-3	Upper	1.232	50	10.552	0.487	52.760	15.828	4.870
C	OW-20-3	Leaf	1.214	50	11.120	0.577	74.135	14.003	2.883
C	OW-20-3	Root	1.309	50	10.695	0.764	546.218	16.425	6.112
C	OW-20-3	Shoot	1.242	50	9.662	0.201	32.206	19.726	9.259
C	C-20-1	Leaf	0.756	50	15.873	0.000	119.048	18.519	4.630
C	C-20-1	Root	1.153	50	14.310	0.607	255.854	12.142	6.071
C	C-20-1	Shoot	0.935	50	17.647	0.160	155.080	11.230	20.856
B	C-20-2	Lower	1.322	50	17.398	0.643	7.564	10.590	6.430
B	C-20-2	Root	1.518	50	40.843	1.021	391.963	13.175	8.564
B	C-20-2	Upper	2.375	50	5.684	0.232	8.421	4.842	2.316

Appendix 2 – Metals Concentrations in OW and C Series Microcosm Vegetation (Continued)

Species	Wetland	Location	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Fe mg/Kg	Pb mg/Kg	Zn mg/Kg
B	C-20-2	Lower	1.809	50	15.202	0.553	30.404	9.674	4.146
B	C-20-2	Root	1.136	50	59.419	1.144	1465.669	17.606	13.204
B	C-20-2	Upper	2.287	50	19.458	0.262	65.588	7.433	6.559
C	C-20-2	Leaf	0.45	50	13.333	1.333	77.778	25.556	4.444
C	C-20-2	Root	1.361	50	15.430	0.331	235.121	9.184	6.613
C	C-20-2	Shoot	0.976	50	13.832	0.410	51.230	8.197	9.734
B	C-20-2	Lower	1.16	50	6.897	0.517	4.310	15.517	2.586
B	C-20-2	Root	1.237	50	66.289	1.051	873.080	17.785	11.318
B	C-20-2	Upper	2.217	50	11.276	0.338	36.085	3.608	2.932
C	C-20-3	Leaf	0.81	50	14.815	0.309	74.074	8.642	4.938
C	C-20-3	Root	1.9	50	15.263	0.526	55.263	5.263	3.421
C	C-20-3	Shoot	1.04	50	15.385	0.000	28.846	12.500	8.654
S	OW-16-1	Composite	0.818	50	17.115	0.183	525.672	27.506	7.335
C	OW-16-1	Leaf	1	50	13.500	0.600	105.000	6.500	6.500
C	OW-16-1	Root	1.015	50	9.852	1.034	128.079	17.241	2.956
C	OW-16-1	Shoot	1.093	50	9.607	0.183	18.298	4.575	3.202
B	OW-16-1	Lower	1.03	50	12.136	0.825	38.835	2.913	2.913
B	OW-16-1	Root	1.015	50	24.138	2.020	1408.867	14.286	8.374
B	OW-16-1	Upper	1.79	50	5.028	0.754	11.173	1.117	1.117
C	OW-16-1	Leaf	0.641	50	10.920	0.702	62.402	8.580	1.560
C	OW-16-1	Root	1.548	50	12.274	1.615	387.597	19.703	9.367
C	OW-16-1	Shoot	1.155	50	8.225	0.519	56.277	6.494	3.896
B	OW-16-1	Lower	1.817	50	10.732	0.550	68.795	4.128	3.302
B	OW-16-1	Root	1.514	50	58.785	6.341	1354.029	71.004	25.099
B	OW-16-1	Upper	1.406	50	13.869	0.889	49.787	6.757	8.179
S	OW-16-1	Leaf	1.53	50	11.765	0.294	55.556	5.556	6.536

Appendix 2 – Metals Concentrations in OW and C Series Microcosm Vegetation (Continued)

Species	Wetland	Location	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Fe mg/Kg	Pb mg/Kg	Zn mg/Kg
B	OW-16-1	Composite	1.86	50	21.237	1.989	655.914	14.247	9.677
C	OW-16-1	Leaf	1.043	50	10.067	0.623	76.702	12.943	3.356
C	OW-16-1	Root	1.875	50	18.133	0.960	533.333	23.200	12.000
C	OW-16-1	Shoot	1.282	50	9.360	0.468	179.407	10.920	5.850
B	OW-16-2	Composite	0.738	50	17.615	0.610	115.176	28.455	8.130
C	OW-16-2	Leaf	1.282	50	14.041	1.677	97.504	10.140	7.800
C	OW-16-2	Root	1.252	50	13.978	1.198	239.617	11.182	5.591
C	OW-16-2	Shoot	1.717	50	13.978	0.262	17.472	9.027	15.725
C	OW-16-2	Composite	2.061	50	12.858	0.655	43.668	14.071	6.308
B	OW-16-2	Lower	1.083	50	23.084	0.785	41.551	15.697	6.464
B	OW-16-2	Root	0.824	50	44.296	1.881	1498.786	27.306	9.709
B	OW-16-2	Upper	1.268	50	17.744	1.065	39.432	13.801	5.915
C	OW-16-2	Composite	1.703	50	15.854	0.528	193.776	15.561	8.221
C	OW-16-2	Composite	1.813	50	15.444	0.745	228.902	20.132	9.377
B	OW-16-2	Lower	1.378	50	11.974	0.435	65.312	15.965	3.991
B	OW-16-2	Root	1.015	50	22.660	5.567	1251.232	64.532	14.778
B	OW-16-2	Upper	1.575	50	14.286	0.063	50.794	5.079	8.254
C	OW-16-2	Leaf	1.252	50	9.984	0.000	47.923	11.981	3.195
C	OW-16-2	Shoot	1.338	50	6.353	0.000	29.895	11.584	6.726
B	OW-16-3	Lower	1.923	50	2.340	0.130	2.600	4.680	0.520
B	OW-16-3	Root	1.08	50	23.148	4.630	1481.481	51.389	14.352
B	OW-16-3	Upper	1.683	50	7.130	0.386	17.825	8.318	2.080
C	OW-16-3	Leaf	0.925	50	9.189	0.324	81.081	17.838	2.703
C	OW-16-3	Shoot	0.98	50	7.653	0.459	86.735	7.143	2.551
B	OW-16-3	Lower	1.137	50	1.759	0.396	30.783	7.036	0.880
B	OW-16-3	Root	0.52	50	23.077	4.038	1730.769	45.192	16.346

Appendix 2 – Metals Concentrations in OW and C Series Microcosm Vegetation (Continued)

Species	Wetland	Location	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Fe mg/Kg	Pb mg/Kg	Zn mg/Kg
B	OW-16-3	Upper	1.249	50	2.802	0.040	8.006	4.404	1.201
C	OW-16-3	Leaf	1.141	50	6.573	0.219	52.585	4.820	2.191
C	OW-16-3	Root	1.059	50	18.886	0.661	528.801	21.719	5.666
C	OW-16-3	Shoot	1.328	50	6.777	0.151	60.241	7.530	5.648
C	OW-16-3	Leaf	0.904	50	6.084	0.111	16.593	9.956	3.872
C	OW-16-3	Root	1.034	50	10.155	0.000	831.721	17.892	4.352
C	OW-16-3	Shoot	1.221	50	4.914	0.450	16.380	8.190	5.733
B	OW-16-3	Root	0.455	50	28.571	1.758	1219.780	24.176	14.286
B	C-16-1	Lower	1.602	50	18.414	0.437	43.695	8.115	6.866
B	C-16-1	Root	1.193	50	34.786	0.754	1257.334	9.640	11.735
B	C-16-1	Upper	1.624	50	2.463	0.216	0.000	3.695	0.924
C	C-16-1	Composite	3.237	50	11.585	0.402	71.053	4.016	7.414
B	C-16-1	Lower	1.49	50	16.107	0.537	36.913	7.047	7.047
B	C-16-1	Root	2.133	50	41.256	0.985	471.167	5.860	14.768
B	C-16-1	Upper	1.803	50	5.824	0.166	8.319	4.714	3.050
B	C-16-2	Lower	1.277	50	16.836	0.548	35.239	5.873	3.132
B	C-16-2	Root	2.028	50	24.901	0.715	946.746	9.862	6.164
B	C-16-2	Upper	1.956	50	8.947	0.204	23.006	7.413	3.579
C	C-16-2	Leaf	1.129	50	12.400	0.664	66.430	2.657	7.086
C	C-16-2	Root	1.69	50	18.343	0.414	41.420	4.438	11.538
C	C-16-2	Shoot	0.668	50	8.234	0.524	74.850	5.240	5.240
C	C-16-2	Leaf	1.437	50	5.915	0.000	17.397	6.959	2.784
C	C-16-2	Root	1.231	50	13.404	0.203	154.346	10.967	5.686
C	C-16-2	Shoot	0.744	50	8.065	0.000	9.409	4.032	9.409
B	C-16-2	Lower	2.466	50	4.866	0.223	10.138	3.041	2.028
B	C-16-2	Root	1.641	50	48.751	0.823	719.074	12.492	12.188

Appendix 2 – Metals Concentrations in OW and C Series Microcosm Vegetation (Completed)

Species	Wetland	Location	Sample Weight Dry (g)	Final Volume mL	Cu mg/Kg	Cd mg/Kg	Fe mg/Kg	Pb mg/Kg	Zn mg/Kg
B	C-16-2	Upper	1.353	50	7.021	0.185	29.564	7.761	1.109
C	C-16-3	Leaf	1.617	50	8.658	0.340	58.751	4.947	7.112
C	C-16-3	Root	1.157	50	15.125	0.778	609.334	11.236	4.322
C	C-16-3	Shoot	0.599	50	5.843	0.501	41.736	12.521	3.339
C	C-16-1	Leaf	1.106	50	10.398	0.362	122.061	6.781	4.069
C	C-16-1	Root	1.451	50	19.986	0.586	251.551	8.959	8.270
C	C-16-1	Shoot	0.527	50	13.283	0.569	28.463	16.129	5.693
C	C-16-1	Leaf	1.663	50	6.013	0.090	48.106	4.209	2.105
C	C-16-1	Root	1.933	50	15.520	0.543	152.613	4.656	10.605
C	C-16-1	Shoot	0.818	50	12.225	0.550	24.450	14.670	7.335
T	Standard1	New	1.081	50	4.625	1.388	212.766	6.938	0.000
T	Standard2	New	1.075	50	3.256	1.349	204.651	13.953	0.000
T	Standard3	New	1.82	50	2.198	1.291	129.121	9.066	0.000
T	Standard4	New	1.252	50	1.198	1.318	95.847	9.185	0.000
T	Standard5	New	1.507	50	6.636	2.322	295.289	9.954	0.000
T	Standard6	New	1.368	50	6.213	2.156	259.503	14.254	0.000
T	Standard7	New	1.448	50	4.489	2.003	248.619	7.251	0.000
T	Standard8	New	1.232	50	2.029	1.096	146.104	4.870	0.000
T	Standard1	Old	1.027	50	4.869	1.120	204.479	12.658	0.000
T	Standard2	Old	1.094	50	5.027	1.828	274.223	9.141	0.000
T	Standard3	Old	1.243	50	1.609	0.885	108.608	7.241	0.000
T	Standard4	Old	1.633	50	0.612	0.674	64.299	8.879	0.000
T	Standard5	Old	1.952	50	6.148	2.126	266.393	9.990	0.000

Appendix 3 – Cd^{109} Data

Temp	Species	Position	Sample Time (hrs)	Sample (mg)	Pk1 cpm	Pk1 cpm/ug	Ln PK1	Average (PK1)	(t/Cd)	(t/Cdp)^1/3
13	Bulrush	lower	1	605.00	2.55	4.21	1.44			
13	Bulrush	lower	1	291.00	0.00	0.00	0.00	0.72	1.39	1.12
13	Bulrush	lower	3	549.00	1.33	2.43	0.89			
13	Bulrush	lower	3	343.00	9.30	27.11	3.30	2.09	1.43	1.13
13	Bulrush	lower	12	272.00	0.03	0.12	-2.10			
13	Bulrush	lower	12	517.00	5776.60	11173.31	9.32	3.61	3.32	1.49
13	Bulrush	lower	24	282.00	8.90	31.56	3.45			
13	Bulrush	lower	24	200.00	3.97	19.83	2.99	3.22	7.45	1.95
13	Bulrush	lower	72	245.00	159.50	651.02	6.48			
13	Bulrush	lower	72	194.00	656.23	3382.65	8.13	7.30	9.86	2.14
13	Bulrush	root	1	477.00	0.00	0.00	0.00			
13	Bulrush	root	1	160.00	24.97	156.04	5.05	2.53	0.40	0.73
13	Bulrush	root	3	105.00	29.70	282.86	5.64			
13	Bulrush	root	3	308.00	98.40	319.48	5.77	5.71	0.53	0.81
13	Bulrush	root	12	306.00	894.68	2923.80	7.98			
13	Bulrush	root	12	205.00	337.15	1644.63	7.41	7.69	1.56	1.16
13	Bulrush	root	24	178.00	329.17	1849.25	7.52			
13	Bulrush	root	24	23.00	305.47	13281.16	9.49	8.51	2.82	1.41
13	Bulrush	root	72	34.00	122.87	3613.73	8.19			
13	Bulrush	root	72	113.00	534.58	4730.83	8.46	8.33	8.65	2.05
13	Bulrush	upper	1	258.00	0.00	0.00	0.00			
13	Bulrush	upper	1	317.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Bulrush	upper	3	181.00	0.00	0.00	0.00			
13	Bulrush	upper	3	157.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Bulrush	upper	12	186.00	0.00	0.00	0.00			
13	Bulrush	upper	12	308.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 3 – Cd^{109} Data (Continued)

Temp	Species	Position	Time (hrs)	Sample (mg)	Pk1 cpm	Pk1 cpm/ug	Ln PK1	Average (PK1)	(t/Cd)	(t/Cdp)^1/3
13	Bulrush	upper	24	408.00	0.00	0.00	0.00			
13	Bulrush	upper	24	202.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Bulrush	upper	72	389.00	0.77	1.97	0.68			
13	Bulrush	upper	72	488.00	0.00	0.00	0.00	0.34	212.24	5.96
16	Bulrush	lower	1	603.00	0.00	0.00	0.00			
16	Bulrush	lower	1	941.00	79.65	84.64	4.44	2.22	0.45	0.77
16	Bulrush	lower	3	1076.00	63.50	59.01	4.08			
16	Bulrush	lower	3	600.00	14.50	24.17	3.18	3.63	0.83	0.94
16	Bulrush	lower	12	505.00	591.73	1171.75	7.07			
16	Bulrush	lower	12	1598.00	500.13	312.97	5.75	6.41	1.87	1.23
16	Bulrush	lower	24	309.00	2.48	8.04	2.08			
16	Bulrush	lower	24	750.00	14.60	19.47	2.97	2.53	9.50	2.12
16	Bulrush	lower	72	75.00	0.00	0.00	0.00			
16	Bulrush	lower	72	782.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Bulrush	root	1	220.00	0.00	0.00	0.00			
16	Bulrush	root	1	299.00	49.07	164.10	5.10	2.55	0.39	0.73
16	Bulrush	root	3	701.00	849.97	1212.51	7.10			
16	Bulrush	root	3	197.00	98.45	499.75	6.21	6.66	0.45	0.77
16	Bulrush	root	12	56.00	40.32	719.94	6.58			
16	Bulrush	root	12	176.00	687.33	3905.30	8.27	7.42	1.62	1.17
16	Bulrush	root	24	50.00	6.93	138.67	4.93			
16	Bulrush	root	24	106.00	1084.10	10227.36	9.23	7.08	3.39	1.50
16	Bulrush	root	72	161.00	182.95	1136.34	7.04			
16	Bulrush	root	72	227.00	2.27	9.99	2.30	4.67	15.42	2.49
16	Bulrush	upper	1	289.00	0.00	0.00	0.00			
16	Bulrush	upper	1	591.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 3 – Cd^{109} Data (Continued)

Temp	Species	Position	Time (hrs)	Sample (mg)	Pk1 cpm	Pk1 cpm/ug	Ln PK1	Average (PK1)	(t/Cd)	(t/Cdp)^1/3
16	Bulrush	upper	3	371.00	0.00	0.00	0.00			
16	Bulrush	upper	3	402.00	12.53	31.18	3.44	1.72	1.74	1.20
16	Bulrush	upper	12	289.00	0.00	0.00	0.00			
16	Bulrush	upper	12	254.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Bulrush	upper	24	289.00	0.00	0.00	0.00			
16	Bulrush	upper	24	289.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Bulrush	upper	72	379.00	1.48	3.91	1.36			
16	Bulrush	upper	72	260.00	0.00	0.00	0.00	0.68	105.53	4.73
20	Bulrush	lower	1	565.00	16.10	28.50	3.35			
20	Bulrush	lower	1	439.00	3.87	8.81	2.18	2.76	0.36	0.71
20	Bulrush	lower	3	372.00	0.00	0.00	0.00			
20	Bulrush	lower	3	472.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Bulrush	lower	12	667.00	21.30	31.93	3.46			
20	Bulrush	lower	12	692.00	636.07	919.17	6.82	5.14	2.33	1.33
20	Bulrush	lower	24	348.00	0.00	0.00	0.00			
20	Bulrush	lower	24	19.00	3.62	190.35	5.25	2.62	9.14	2.09
20	Bulrush	lower	72	589.00	1.10	1.87	0.62			
20	Bulrush	lower	72	626.00	44.02	70.31	4.25	2.44	29.52	3.09
20	Bulrush	root	1	521.00	71.85	137.91	4.93			
20	Bulrush	root	1	14.00	38.78	2770.24	7.93	6.43	0.16	0.54
20	Bulrush	root	3	155.00	181.58	1171.51	7.07			
20	Bulrush	root	3	145.00	197.68	1363.33	7.22	7.14	0.42	0.75
20	Bulrush	root	12	470.00	91.27	194.18	5.27			
20	Bulrush	root	12	353.00	307.80	871.95	6.77	6.02	1.99	1.26
20	Bulrush	root	24	201.00	73.33	364.84	5.90			
20	Bulrush	root	24	295.00	51.37	174.12	5.16	5.53	4.34	1.63

Appendix 3 – Cd^{109} Data (Continued)

Temp	Species	Position	Time (hrs)	Sample (mg)	Pk1 cpm	Pk1 cpm/ug	Ln PK1	Average (PK1)	(t/Cd)	(t/Cdp)^1/3
20	Bulrush	root	72	7.00	4.15	592.86	6.38			
20	Bulrush	root	72	86.00	705.35	8201.74	9.01	7.70	9.35	2.11
20	Bulrush	upper	1	200.00	0.27	1.33	0.29			
20	Bulrush	upper	1	211.00	3.03	14.38	2.67	1.48	0.68	0.88
20	Bulrush	upper	3	475.00	2.72	5.72	1.74			
20	Bulrush	upper	3	464.00	0.00	0.00	0.00	0.87	3.44	1.51
20	Bulrush	upper	12	404.00	0.35	0.87	0.00			
20	Bulrush	upper	12	348.00	0.38	1.10	0.10	0.05	248.18	6.28
20	Bulrush	upper	24	320.00	0.00	0.00	0.00			
20	Bulrush	upper	24	208.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Bulrush	upper	72	451.00	1.40	3.10	1.13			
20	Bulrush	upper	72	427.00	0.00	0.00	0.00	0.57	127.12	5.03
13	Cattail	leaf	1	308.00	0.50	1.62	0.48			
13	Cattail	shoot	1	243.00	0.00	0.00	0.00	0.24	4.13	1.60
13	Cattail	root	1	112.00	199.40	1780.36	7.48			
13	Cattail	leaf	1	173.00	0.00	0.00	0.00	3.74	0.27	0.64
13	Cattail	shoot	1	562.00	0.00	0.00	0.00			
13	Cattail	root	1	516.00	513.27	994.70	6.90	3.45	0.29	0.66
16	Cattail	leaf	1	219.00	0.00	0.00	0.00			
16	Cattail	shoot	1	360.00	0.60	1.67	0.51	0.26	3.92	1.58
16	Cattail	root	1	815.00	75.67	92.84	4.53			
16	Cattail	leaf	1	401.00	0.00	0.00	0.00	2.27	0.44	0.76
16	Cattail	shoot	1	219.00	1.58	7.23	1.98			
16	Cattail	root	1	233.00	10090.57	43307.15	10.68	6.33	0.16	0.54
20	Cattail	leaf	1	244.00	0.00	0.00	0.00			
20	Cattail	shoot	1	237.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 3 – Cd^{109} Data (Continued)

Temp	Species	Position	Time (hrs)	Sample (mg)	Pk1 cpm	Pk1 cpm/ug	Ln PK1	Average (PK1)	(t/Cd)	(t/Cdp)^1/3
20	Cattail	root	1	274.00	1.32	4.81	1.57			
20	Cattail	leaf	1	300.00	57.85	192.83	5.26	3.42	0.29	0.66
20	Cattail	shoot	1	453.00	8388.30	18517.22	9.83			
20	Cattail	root	1	107.00	729.45	6817.29	8.83	9.33	0.11	0.48
13	Cattail	leaf	3	264.00	0.00	0.00	0.00			
13	Cattail	shoot	3	519.00	1.58	3.05	1.12	0.56	5.38	1.75
13	Cattail	root	3	165.00	0.75	4.55	1.51			
13	Cattail	leaf	3	263.00	0.77	2.92	1.07	1.29	2.32	1.32
13	Cattail	shoot	3	475.00	6.95	14.63	2.68			
13	Cattail	root	3	331.00	694.60	2098.49	7.65	5.17	0.58	0.83
16	Cattail	leaf	3	178.00	1.87	10.49	2.35			
16	Cattail	shoot	3	348.00	0.00	0.00	0.00	1.18	2.55	1.37
16	Cattail	root	3	152.00	11.53	75.88	4.33			
16	Cattail	leaf	3	173.00	0.00	0.00	0.00	2.16	1.39	1.11
16	Cattail	shoot	3	534.00	1.33	2.50	0.92			
16	Cattail	root	3	126.00	63.32	502.51	6.22	3.57	0.84	0.94
20	Cattail	leaf	3	328.00	0.00	0.00	0.00			
20	Cattail	shoot	3	555.00	20.60	37.12	3.61	1.81	1.66	1.18
20	Cattail	root	3	190.00	128.90	678.42	6.52			
20	Cattail	leaf	3	265.00	0.22	0.82	-0.20	3.16	0.95	0.98
20	Cattail	shoot	3	349.00	0.00	0.00	0.00			
20	Cattail	root	3	12.00	118.43	9869.44	9.20	4.60	0.65	0.87
13	Cattail	leaf	12	251.00	0.00	0.00	0.00			
13	Cattail	shoot	12	90.00	98.43	1093.70	7.00	3.50	3.43	1.51
13	Cattail	root	12	39.00	383.80	9841.03	9.19			
13	Cattail	leaf	12	210.00	0.00	0.00	0.00	4.60	2.61	1.38

Appendix 3 – Cd^{109} Data (Continued)

Temp	Species	Position	Time (hrs)	Sample (mg)	Pk1 cpm	Pk1 cpm/ug	Ln PK1	Average (PK1)	(t/Cd)	(t/Cdp)^1/3
13	Cattail	shoot	12	262.00	58.48	223.22	5.41			
13	Cattail	root	12	89.00	454.40	5105.62	8.54	6.97	1.72	1.20
16	Cattail	leaf	12	88.00	0.00	0.00	0.00			
16	Cattail	shoot	12	498.00	20.17	40.50	3.70	1.85	6.48	1.86
16	Cattail	root	12	429.00	441.92	1030.11	6.94			
16	Cattail	leaf	12	177.00	7.60	42.94	3.76	5.35	2.24	1.31
16	Cattail	shoot	12	253.00	0.00	0.00	0.00			
16	Cattail	root	12	202.00	123.90	613.37	6.42	3.21	3.74	1.55
20	Cattail	leaf	12	489.00	0.43	0.89	-0.12			
20	Cattail	shoot	12	551.00	14.95	27.13	3.30	1.59	7.55	1.96
20	Cattail	root	12	15.00	270.23	18015.56	9.80			
20	Cattail	leaf	12	275.00	0.00	0.00	0.00	4.90	2.45	1.35
20	Cattail	shoot	12	445.00	10.75	24.16	3.18			
20	Cattail	root	12	311.00	67.25	216.24	5.38	4.28	2.80	1.41
13	Cattail	leaf	24	207.00	0.65	3.14	1.14			
13	Cattail	shoot	24	505.00	0.00	0.00	0.00	0.57	41.95	3.47
13	Cattail	root	24	127.00	717.57	5650.13	8.64			
13	Cattail	leaf	24	312.00	0.00	0.00	0.00	4.32	5.56	1.77
13	Cattail	shoot	24	541.00	0.00	0.00	0.00			
13	Cattail	root	24	622.00	177.85	285.93	5.66	2.83	8.49	2.04
16	Cattail	leaf	24	322.00	0.00	0.00	0.00			
16	Cattail	shoot	24	396.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Cattail	root	24	335.00	16.90	50.45	3.92			
16	Cattail	leaf	24	204.00	0.00	0.00	0.00	1.96	12.24	2.30
16	Cattail	shoot	24	694.00	0.00	0.00	0.00			
16	Cattail	root	24	337.00	165.42	490.85	6.20	3.10	7.75	1.98

Appendix 3 – Cd^{109} Data (Completed)

Temp	Species	Position	Time (hrs)	Sample (mg)	Pk1 cpm	Pk1 cpm/ug	Ln PK1	Average (PK1)	(t/Cd)	(t/Cdp)^1/3
20	Cattail	leaf	24	198.00	0.00	0.00	0.00			
20	Cattail	shoot	24	510.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Cattail	root	24	130.00	71.07	546.67	6.30			
20	Cattail	leaf	24	167.00	12.67	75.85	4.33	5.32	4.51	1.65
20	Cattail	shoot	24	166.00	1296.18	7808.33	8.96			
20	Cattail	root	24	15.00	275.80	18386.67	9.82	9.39	2.56	1.37
13	Cattail	leaf	72	284.00	0.00	0.00	0.00			
13	Cattail	shoot	72	578.00	3.32	5.74	1.75	0.87	82.42	4.35
13	Cattail	root	72	257.00	7.13	27.76	3.32			
13	Cattail	leaf	72	334.00	0.00	0.00	0.00	1.66	43.33	3.51
13	Cattail	shoot	72	450.00	0.40	0.89	-0.12			
13	Cattail	root	72	103.00	40.08	389.16	5.96	2.92	24.63	2.91
16	Cattail	leaf	72	148.00	0.00	0.00	0.00			
16	Cattail	shoot	72	82.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Cattail	root	72	183.00	10.95	59.84	4.09			
16	Cattail	leaf	72	113.00	0.00	0.00	0.00	2.05	35.19	3.28
16	Cattail	shoot	72	573.00	0.00	0.00	0.00			
16	Cattail	root	72	347.00	3.43	9.89	2.29	1.15	62.83	3.98
20	Cattail	leaf	72	207.00	0.00	0.00	0.00			
20	Cattail	shoot	72	251.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Cattail	root	72	221.00	4.43	20.06	3.00			
20	Cattail	leaf	72	228.00	0.00	0.00	0.00	1.50	0.00	0.00
20	Cattail	shoot	72	153.00	0.00	0.00	0.00			
20	Cattail	root	72	246.00	317.47	1290.51	7.16	3.58	20.10	2.72

Appendix 4 – Microcosm Monitoring Data

ID	Species	Planted Date	Height (cm) 30/01/08	Water (l) 30/01/08	Height (cm) 5/02/08	Water (l) 5/02/08	Height (cm) 13/02/08	Water (l) 13/02/08	Height (cm) 28/02/08	Water (l) 28/02/08	Height (cm) 6/03/08
1	Cattail	18-Jan-08	2	0	9	2.8	18	1.4	29	4	36
2	Bulrush	18-Jan-08	0	0	0	2.8	0	1.4	0	4	0
3	Cattail	18-Jan-08	13.5	0	25	2.8	38	1.4	55	4	64
4	Bulrush	18-Jan-08	19	0	27.5	2.8	36	1.4	70	4	87
5	Cattail	18-Jan-08	10	0	20	2.8	30.5	1.4	43	4	49
6	Bulrush	18-Jan-08	10	0	17	2.8	29	1.4	42	4	47
7	Sedge	18-Jan-08	31	0	35.5	2.8	39	1.4	44	4	43
8	Bulrush	18-Jan-08	1	0	4	2.8	15.5	1.4	26	4	31
9	Cattail	18-Jan-08	8	0	14.5	2.8	21	1.4	33	4	48
10	Bulrush	18-Jan-08	0	0	0	2.8	3	1.4	0	4	0
11	Cattail	18-Jan-08	1	0	6	2.8	11	1.4	22	4	26
12	Bulrush	18-Jan-08	0.5	0	8.5	2.8	18	1.4	28	4	34
13	Cattail	18-Jan-08	7	0	15	2.8	23	1.4	30	4	36
14	Bulrush	18-Jan-08	10.5	0	16	2.8	30	1.4	61	4	67
15	Cattail	18-Jan-08	13	0	19	2.8	28	1.4	45	4	55
16	Bulrush	18-Jan-08	3	0	7	2.8	27.5	1.4	59	4	62
17	Cattail	18-Jan-08	5	0	9.5	2.8	13	1.4	27	4	33
18	Bulrush	18-Jan-08	0.5	0	6.5	2.8	23	1.4	51	4	66
19	Cattail	18-Jan-08	7	0	11	2.8	15.5	1.4	24.5	8	30
20	Bulrush	18-Jan-08	7	0	9.5	2.8	15.5	1.4	31	8	41
21	Cattail	18-Jan-08	0	0	0	2.8	0	1.4	0	8	0
22	Bulrush	18-Jan-08	9	0	22	2.8	40.5	1.4	62	8	66
23	Cattail	18-Jan-08	0	0	0.5	2.8	0	1.4	6	8	0
24	Bulrush	18-Jan-08	0	0	0	2.8	0	1.4	13	8	18
25	Cattail	18-Jan-08	4	0	6.5	2.8	10	1.4	16	8	22
26	Bulrush	18-Jan-08	15.5	0	29	2.8	39.5	1.4	84	8	101
27	Cattail	18-Jan-08	7	0	15	2.8	24	1.4	34	8	39

Appendix 4 – Microcosm Monitoring Data (Continued)

Water (l) 6/03/08	Height (cm) 13/03/08	Water (l) 13/03/08	Height (cm) 18/03/08	Water (l) 18/03/08	Height (cm) 3/04/08	Water (l) 3/04/08	Height (cm) 9/04/08	Water (l) 9/04/08	Height (cm) 17/04/08	Water (l) 17/04/08
0	42	0	44	4	54	4	59	4	61	0
0	0	0	0	4	0	4	0	4	0	0
0	69.5	0	71	4	82	4	84	4	88	0
0	96	0	94	4	114	4	127	4	145	0
0	55	0	58	4	58	4	59	4	59	0
0	58	0	66	4	82	4	82	4	93	0
0	48	0	47	4	48	4	46	4	47	0
0	33	0	35	4	61	4	70	4	81	0
0	42	0	45	4	48	4	48	4	48	0
0	0	0	0	4	0	4	0	4	0	0
0	28	0	32	4	38	4	40	4	43	0
0	36	0	37	4	46	4	52	4	56	0
0	43	0	46	4	54	4	58	4	59	0
0	66	0	79	4	121	4	115	4	116	0
0	60	0	66	4	77	4	84	4	87	0
0	62	0	71	4	99	4	99	4	109	0
0	37	0	41	4	49	4	57	4	52	0
0	64	0	70	4	78	4	93	4	112	0
0	35	0	39	4	51	4	59	4	63	0
0	46	0	49	4	86	4	91	4	95	0
0	0	0	0	4	0	4	0	4	0	0
0	66	0	65	4	64	4	65	4	61	0
0	0	0	0	4	0	4	0	4	0	0
0	18	0	19	4	23	4	23	4	33	0
0	23	0	23	4	25	4	25	4	24	0
0	108	0	107	4	144	4	150	4	151	0
0	42	0	46	4	62	4	68	4	74	0

Appendix 4 – Microcosm Monitoring Data (Continued)

ID	Species	Planted Date	Height (cm) 30/01/08	Water (l) 30/01/08	Height (cm) 5/02/08	Water (l) 5/02/08	Height (cm) 13/02/08	Water (l) 13/02/08	Height (cm) 28/02/08	Water (l) 28/02/08	Height (cm) 6/03/08
28	Cattail	23-Jan-08	3	0	8	1.4	13	1.4	17	8	17
29	Bulrush	23-Jan-08	0	0	0	1.4	0	1.4	0	8	0
30	Cattail	23-Jan-08	8	0	14.5	1.4	19.5	1.4	31	8	39
31	Bulrush	23-Jan-08	4	0	10.5	1.4	25	1.4	43	8	47
32	Cattail	23-Jan-08	5.5	0	10.5	1.4	12	1.4	13	8	12
33	Bulrush	23-Jan-08	0	0	0	1.4	0	1.4	0	8	0
34	Cattail	23-Jan-08	7	0	13.5	1.4	21	1.4	23	8	23
35	Bulrush	23-Jan-08	4.5	0	7	1.4	15	1.4	30	8	40
36	Cattail	23-Jan-08	7	0	12.5	1.4	21	1.4	31	8	36
37	Bulrush	23-Jan-08	0.5	1.4	7	1.4	17	1.4	34	8	38
38	Cattail	23-Jan-08	9	1.4	16	1.4	25	1.4	35	8	38
39	Bulrush	23-Jan-08	0	1.4	0	1.4	0	1.4	10	8	15
40	Cattail	23-Jan-08	0	1.4	0	1.4	0	1.4	0	8	0
41	Bulrush	23-Jan-08	5	1.4	11.5	1.4	20	1.4	43	8	51
42	Cattail	23-Jan-08	4	1.4	5	1.4	6	1.4	17	8	22
43	Bulrush	23-Jan-08	4	1.4	11	1.4	27	1.4	43	8	45
44	Cattail	23-Jan-08	0	1.4	0	1.4	0	1.4	0	8	0
45	Bulrush	23-Jan-08	1	1.4	3	1.4	16	1.4	41	8	47
46	Cattail	23-Jan-08	7	1.4	11	1.4	20	1.4	26	8	32
47	Bulrush	23-Jan-08	10	1.4	24	1.4	47	1.4	72	8	76
48	Cattail	23-Jan-08	4	1.4	11.5	1.4	25	1.4	43	8	53
49	Bulrush	23-Jan-08	2.5	1.4	7	1.4	10	1.4	19	8	33
50	Cattail	23-Jan-08	3	1.4	7	1.4	9	1.4	28	8	35
51	Bulrush	23-Jan-08	8	1.4	12	1.4	17	1.4	23	8	22
52	Cattail	23-Jan-08	7	1.4	13	1.4	19	1.4	25	8	30
53	Bulrush	23-Jan-08	0	1.4	5	1.4	17	1.4	33	8	35
54	Cattail	23-Jan-08	2	1.4	5	1.4	9	1.4	17	8	23

Appendix 4 – Microcosm Monitoring Data (Continued)

Water (l) 6/03/08	Height (cm) 13/03/08	Water (l) 13/03/08	Height (cm) 18/03/08	Water (l) 18/03/08	Height (cm) 3/04/08	Water (l) 3/04/08	Height (cm) 9/04/08	Water (l) 9/04/08	Height (cm) 17/04/08	Water (l) 17/04/08
0	17	0	17	4	17	4	20	4	25	0
0	0	0	0	4	0	4	0	4	0	0
0	45	0	46	4	59	4	60	4	61	0
0	49	0	53	4	76	4	86	4	103	0
0	12	0	0	4	0	4	0	4	0	0
0	0	0	0	4	0	4	0	4	0	0
0	24	0	23	4	23	4	24	4	25	0
0	46	0	48	4	67	4	76	4	99	0
0	41	0	46	4	62	4	65	4	67	0
0	40	0	32	4	67	4	70	4	73	0
0	41	0	42	4	41	4	53	4	54	0
0	25	0	39	4	58	4	50	4	52	0
0	0	0	0	4	0	4	0	4	0	0
0	54	0	63	4	73	4	86	4	103	0
0	26	0	30	4	37	4	41	4	40	0
0	46	0	59	4	82	4	87	4	90	0
0	0	0	0	4	0	4	0	4	0	0
0	52	0	58	4	94	4	99	4	100	0
0	34	0	36	4	45	4	46	4	47	0
0	75	0	97	4	128	4	130	4	131	0
0	57	0	60	4	70	4	75	4	76	0
0	47	0	57	4	79	4	82	4	84	0
0	42	0	44	4	66	4	69	4	79	0
0	24	0	26	4	42	4	55	4	71	0
0	35	0	37	4	51	4	57	4	59	0
0	45	0	54	4	69	4	94	4	115	0
0	25	0	29	4	36	4	40	4	41	0

Appendix 4 – Microcosm Monitoring Data (Continued)

ID	Species	Planted Date	Height (cm) 30/01/08	Water (l) 30/01/08	Height (cm) 5/02/08	Water (l) 5/02/08	Height (cm) 13/02/08	Water (l) 13/02/08	Height (cm) 28/02/08	Water (l) 28/02/08	Height (cm) 6/03/08
55	Sedge	18-Jan-08	24	0	29	2.8	33	2.8	37	12	39
56	Bulrush	18-Jan-08	17	0	30	2.8	42	2.8	58	12	79
57	Sedge	18-Jan-08	33	0	33	2.8	35	2.8	38	12	38
58	Bulrush	18-Jan-08	5	0	12	2.8	20	2.8	23	12	32
59	Sedge	18-Jan-08	21	0	20	2.8	20	2.8	21	12	20
60	Bulrush	18-Jan-08	24.5	0	44	2.8	56	2.8	96	12	117
61	Sedge	18-Jan-08	28	0	29	2.8	32	2.8	37	12	34
62	Bulrush	18-Jan-08	7	0	23	2.8	44	2.8	57	12	83
63	Cattail	18-Jan-08	8	0	13	2.8	19.5	2.8	28	12	29
64	Bulrush	18-Jan-08	13	0	20	2.8	38	2.8	50	12	37
65	Cattail	18-Jan-08	2	0	11.5	2.8	26	2.8	42	12	50
66	Bulrush	18-Jan-08	14.5	0	21	2.8	28	2.8	51	12	77
67	Sedge	18-Jan-08	28	0	30	2.8	30	2.8	34	12	35
68	Bulrush	18-Jan-08	0	0	0	2.8	0	2.8	0	12	0
69	Cattail	18-Jan-08	16	0	27	2.8	37	2.8	47	12	52
70	Bulrush	18-Jan-08	0	0	0	2.8	0	2.8	0	12	0
71	Cattail	18-Jan-08	18	0	29	2.8	39	2.8	44	12	49
72	Bulrush	18-Jan-08	16	0	22	2.8	49	2.8	58	12	80
73	Cattail	18-Jan-08	1	0	13	5.6	32	2.8	45	12	52
74	Bulrush	18-Jan-08	3	0	14	5.6	32	2.8	45	12	45
75	Cattail	18-Jan-08	2	0	0	5.6	0	2.8	5	12	0
76	Bulrush	18-Jan-08	11.5	0	22	5.6	37	2.8	45	12	60
77	Sedge	18-Jan-08	17	0	18	5.6	17	2.8	15	12	23
78	Bulrush	18-Jan-08	15	0	19	5.6	28	2.8	44	12	65
79	Cattail	18-Jan-08	24.5	0	37	5.6	45	2.8	47	12	52
80	Bulrush	18-Jan-08	15	0	25	5.6	43	2.8	70	12	82
81	Cattail	18-Jan-08	22	0	30	5.6	37	2.8	51	12	50

Appendix 4 – Microcosm Monitoring Data (Continued)

Water (l) 6/03/08	Height (cm) 13/03/08	Water (l) 13/03/08	Height (cm) 18/03/08	Water (l) 18/03/08	Height (cm) 3/04/08	Water (l) 3/04/08	Height (cm) 9/04/08	Water (l) 9/04/08	Height (cm) 17/04/08	Water (l) 17/04/08
0	38	0	38	8	35	4	36	16	40	0
0	89	0	98	8	122	4	120	16	132	0
0	36	0	36	8	35	4	30	16	40	0
0	42	0	47	8	56	4	70	16	91	0
0	18	0	18	8	24	4	19	16	27	0
0	118	0	117	8	133	4	130	16	131	0
0	37	0	35	8	35	4	34	16	39	0
0	99	0	104	8	128	4	137	16	135	0
0	29	0	30	8	30	4	29	16	30	0
0	62	0	79	8	113	4	117	12	117	0
0	54	0	56	8	79	4	79	12	78	0
0	75	0	84	8	107	4	110	12	122	0
0	31	0	36	8	36	4	38	12	45	0
0	0	0	0	8	0	4	0	12	20	0
0	57	0	56	8	65	4	80	12	83	0
0	0	0	0	8	0	4	0	12	0	0
0	49	0	49	8	49	4	44	12	49	0
0	100	0	105	8	123	4	122	12	126	0
0	57	0	58	8	60	4	59	12	60	0
0	55	0	59	8	87	4	94	12	103	0
0	0	0	0	8	0	4	0	12	0	0
0	78	0	84	8	97	4	110	12	129	0
0	26	0	25	8	25	4	22	12	29	0
0	80	0	99	8	130	4	123	12	152	0
0	53	0	54	8	52	4	53	12	55	0
0	108	0	119	8	140	4	132	12	160	0
0	49	0	50	8	56	4	57	12	60	0

Appendix 4 – Microcosm Monitoring Data (Continued)

ID	Species	Planted Date	Height (cm) 30/01/08	Water (l) 30/01/08	Height (cm) 5/02/08	Water (l) 5/02/08	Height (cm) 13/02/08	Water (l) 13/02/08	Height (cm) 28/02/08	Water (l) 28/02/08	Height (cm) 6/03/08
82	Cattail	23-Jan-08	9	0	15	2.8	23	2.8	29	12	31
83	Bulrush	23-Jan-08	0	0	19	2.8	38	2.8	59	12	79
84	Cattail	23-Jan-08	5	0	20.5	2.8	34	2.8	42	12	44
85	Bulrush	23-Jan-08	11	0	28	2.8	43	2.8	47	12	60
86	Cattail	23-Jan-08	2	0	8.5	2.8	0	2.8	0	12	0
87	Bulrush	23-Jan-08	0	0	0	2.8	6	2.8	29	12	34
88	Cattail	23-Jan-08	8	0	22	2.8	37	2.8	45	12	47
89	Bulrush	23-Jan-08	6	0	13.5	2.8	15	2.8	34	12	40
90	Cattail	23-Jan-08	11	0	16	2.8	20	2.8	32	12	33
91	Bulrush	23-Jan-08	10	1.4	19	2.8	25	2.8	50	12	56
92	Cattail	23-Jan-08	17.5	1.4	20.5	2.8	28	2.8	52	12	36
93	Bulrush	23-Jan-08	15.5	1.4	30	2.8	42	2.8	62	12	72
94	Cattail	23-Jan-08	11	1.4	20	2.8	34	2.8	37	12	37
95	Bulrush	23-Jan-08	1.5	1.4	8.5	2.8	15	2.8	21	12	23
96	Cattail	23-Jan-08	12.5	1.4	16.5	2.8	24	2.8	29	12	30
97	Bulrush	23-Jan-08	2	1.4	11.5	2.8	24	2.8	30	12	30
98	Cattail	23-Jan-08	4	1.4	9.5	2.8	13	2.8	14	12	17
99	Bulrush	23-Jan-08	14	1.4	27.5	2.8	46	2.8	51	12	77
100	Cattail	23-Jan-08	10.5	1.4	20	4.2	38	2.8	42	12	43
101	Bulrush	23-Jan-08	0	1.4	5.5	4.2	22	2.8	50	12	53
102	Cattail	23-Jan-08	0	1.4	3	4.2	19	2.8	32	12	40
103	Bulrush	23-Jan-08	3	1.4	9.5	4.2	24	2.8	30	12	32
104	Cattail	23-Jan-08	13	1.4	24.5	4.2	35	2.8	44	12	46
105	Bulrush	23-Jan-08	2	1.4	9	4.2	22	2.8	43	12	53
106	Cattail	23-Jan-08	7.5	1.4	13	4.2	24	2.8	32	12	34
107	Bulrush	23-Jan-08	0	1.4	0	4.2	0	2.8	0	12	0
108	Cattail	23-Jan-08	7	1.4	14	4.2	22	2.8	32	12	35

Appendix 4 – Microcosm Monitoring Data (Continued)

Water (l) 6/03/08	Height (cm) 13/03/08	Water (l) 13/03/08	Height (cm) 18/03/08	Water (l) 18/03/08	Height (cm) 3/04/08	Water (l) 3/04/08	Height (cm) 9/04/08	Water (l) 9/04/08	Height (cm) 17/04/08	Water (l) 17/04/08
0	32	0	32	8	32	8	30	8	30	0
0	88	0	86	8	121	8	124	8	122	0
0	46	0	44	8	45	8	46	8	48	0
0	72	0	76	8	119	8	119	8	16	0
0	0	0	6	8	0	8	0	8	0	0
0	40	0	48	8	72	8	90	8	112	0
0	46	0	46	8	46	8	46	8	46	0
0	40	0	32	8	70	8	74	8	90	0
0	33	0	33	8	33	8	32	8	32	0
0	56	0	58	8	94	12	102	8	108	0
0	35	0	36	8	34	12	31	8	39	0
0	92	0	99	8	111	12	127	8	140	0
0	37	0	37	8	38	12	37	8	36	0
0	25	0	30	8	52	12	60	8	67	0
0	31	0	31	8	30	12	28	8	30	0
0	29	0	29	8	54	12	63	8	73	0
0	17	0	18	8	20	12	21	8	20	0
0	93	0	98	8	130	12	143	8	141	0
0	42	0	42	8	42	8	43	8	44	0
0	66	0	71	8	77	8	89	8	100	0
0	42	0	42	8	55	8	60	8	62	0
0	38	0	48	8	72	8	73	8	86	0
0	47	0	47	8	46	8	47	8	47	0
0	72	0	77	8	104	8	119	8	127	0
0	38	0	39	8	51	8	52	8	55	0
0	0	0	0	8	0	8	0	8	0	0
0	36	0	34	8	36	8	37	8	36	0

Appendix 4 – Microcosm Monitoring Data (Continued)

ID	Species	Planted Date	Height (cm) 30/01/08	Water (l) 30/01/08	Height (cm) 5/02/08	Water (l) 5/02/08	Height (cm) 13/02/08	Water (l) 13/02/08	Height (cm) 28/02/08	Water (l) 28/02/08	Height (cm) 6/03/08
109	Cattail	18-Jan-08	0	0	0	1.4	0	1.4	0	8	0
110	Bulrush	18-Jan-08	0	0	0	1.4	0	1.4	0	8	0
111	Cattail	18-Jan-08	17	0	25	1.4	36	1.4	57	8	62
112	Bulrush	18-Jan-08	8	0	30	1.4	51.5	1.4	89	8	103
113	Cattail	18-Jan-08	11.5	0	29.5	1.4	41	1.4	46	8	48
114	Bulrush	18-Jan-08	20	0	27	1.4	39	1.4	63	8	75
115	Sedge	18-Jan-08	36.5	0	39.5	1.4	43	1.4	45	8	45
116	Bulrush	18-Jan-08	6.5	0	12	1.4	19	1.4	38	8	42
117	Cattail	18-Jan-08	15	0	29	1.4	40	1.4	50	8	53
118	Bulrush	18-Jan-08	18.5	0	30	1.4	32	1.4	32	8	31
119	Cattail	18-Jan-08	10	0	27.5	1.4	46	1.4	61	8	68
120	Bulrush	18-Jan-08	0	0	0	1.4	0	1.4	0	8	0
121	Cattail	18-Jan-08	8	0	17	1.4	24	1.4	34	8	35
122	Bulrush	18-Jan-08	13	0	26	1.4	45	1.4	51	8	57
123	Cattail	18-Jan-08	5	0	12	1.4	21	1.4	33	8	36
124	Cattail	18-Jan-08	10.5	0	20.5	1.4	29	1.4	39	8	44
125	Bulrush	18-Jan-08	22	0	31	1.4	44.5	1.4	73	8	84
126	Cattail	18-Jan-08	18	0	26.5	1.4	39	1.4	54	8	58
127	Cattail	18-Jan-08	6.5	0	15	1.4	22	1.4	21	8	21
128	Bulrush	18-Jan-08	13	0	25	1.4	60.5	1.4	83	8	114
129	Cattail	18-Jan-08	15	0	24	1.4	35	1.4	48	8	53
130	Bulrush	18-Jan-08	5	0	14.5	1.4	27	1.4	50	8	67
131	Cattail	18-Jan-08	7.5	0	16	1.4	26	1.4	38	8	43
132	Bulrush	18-Jan-08	0	0	0	1.4	0	1.4	0	8	0
133	Cattail	18-Jan-08	7.5	0	21	1.4	31	1.4	45	8	53
134	Bulrush	18-Jan-08	9	0	26.5	1.4	49	1.4	59	8	65.5
135	Cattail	18-Jan-08	14	0	20	1.4	28	1.4	41	8	46

Appendix 4 – Microcosm Monitoring Data (Continued)

Water (l) 6/03/08	Height (cm) 13/03/08	Water (l) 13/03/08	Height (cm) 18/03/08	Water (l) 18/03/08	Height (cm) 3/04/08	Water (l) 3/04/08	Height (cm) 9/04/08	Water (l) 9/04/08	Height (cm) 17/04/08	Water (l) 17/04/08
0	0	0	0	8	16	4	22	8	29	0
0	0	0	0	8	0	4	0	8	0	0
0	64	0	64	8	64	4	65	8	65	0
0	107	0	106	8	156	4	159	8	157	0
0	47	0	46	8	48	4	48	8	46	0
0	86	0	93	8	143	4	145	8	144	0
0	44	0	46	8	46	4	45	8	47	0
0	42	0	52	8	77	4	70	8	89	0
0	54	0	54	8	53	4	53	8	54	0
0	30	0	30	8	67	4	90	12	113	0
0	70	0	74	8	70	4	95	12	73	0
0	0	0	2	8	15	4	0	12	0	0
0	35	0	36	8	36	4	37	12	36	0
0	64	0	66	8	102	4	112	12	124	0
0	36	0	36	8	36	4	36	12	38	0
0	47	0	47	8	47	4	48	12	48	0
0	82	0	99	8	140	4	149	12	149	0
0	59	0	60	8	60	4	59	12	59	0
0	20	0	19	8	19	4	18	8	19	0
0	131	0	134	8	139	4	143	8	149	0
0	55	0	56	8	55	4	56	8	56	0
0	72	0	74	8	100	4	110	8	153	0
0	44	0	46	8	47	4	46	8	46	0
0	0	0	0	8	0	4	0	8	0	0
0	57	0	58	8	71	4	73	8	76	0
0	82	0	88	8	136	4	145	8	158	0
0	35.5	0	44	8	46	4	45	8	48	0

Appendix 4 – Microcosm Monitoring Data (Continued)

ID	Species	Planted Date	Height (cm) 30/01/08	Water (l) 30/01/08	Height (cm) 5/02/08	Water (l) 5/02/08	Height (cm) 13/02/08	Water (l) 13/02/08	Height (cm) 28/02/08	Water (l) 28/02/08	Height (cm) 6/03/08
136	Cattail	23-Jan-08	0	4.2	5	1.4	25.5	1.4	41	8	46
137	Bulrush	23-Jan-08	10	4.2	15.5	1.4	27	1.4	47	8	58
138	Cattail	23-Jan-08	4	4.2	12.5	1.4	27	1.4	37	8	41
139	Bulrush	23-Jan-08	8	4.2	24.5	1.4	50	1.4	69	8	68
140	Cattail	23-Jan-08	0.5	4.2	8	1.4	21	1.4	39	8	44
141	Bulrush	23-Jan-08	6	4.2	13.5	1.4	26	1.4	45	8	57
142	Cattail	23-Jan-08	12	4.2	16	1.4	23	1.4	31.5	8	33
143	Bulrush	23-Jan-08	17	4.2	31	1.4	49	1.4	81	8	91
144	Cattail	23-Jan-08	5	4.2	13	1.4	21	1.4	28	8	33
145	Bulrush	23-Jan-08	8.5	0	19.5	1.4	37.5	1.4	58	8	65
146	Cattail	23-Jan-08	14	0	27	1.4	45.5	1.4	51	8	55
147	Bulrush	23-Jan-08	0	0	0	1.4	0	1.4	0	8	0
148	Cattail	23-Jan-08	9	0	17	1.4	24	1.4	31	8	32
149	Bulrush	23-Jan-08	10	0	19	1.4	32	1.4	53	8	62
150	Cattail	23-Jan-08	17	0	34	1.4	52	1.4	59	8	61
151	Bulrush	23-Jan-08	3.5	0	10.5	1.4	29	1.4	41	8	49
152	Cattail	23-Jan-08	12.5	0	25.5	1.4	40	1.4	48	8	53
153	Bulrush	23-Jan-08	11.5	0	26	1.4	38	1.4	59	8	67
154	Cattail	23-Jan-08	18	0	22.5	1.4	2	1.4	9	8	10
155	Bulrush	23-Jan-08	16.5	0	33	1.4	46	1.4	56	8	73
156	Cattail	23-Jan-08	19.5	0	36	1.4	51.5	1.4	58	8	59
157	Bulrush	23-Jan-08	11	0	16.5	1.4	27.7	1.4	38	8	44
158	Cattail	23-Jan-08	11	0	21.5	1.4	32	1.4	46	8	51
159	Bulrush	23-Jan-08	22	0	42	1.4	64	1.4	75	8	82
160	Cattail	23-Jan-08	15	0	26	1.4	38.5	1.4	50	8	54
161	Bulrush	23-Jan-08	4	0	11	1.4	32	1.4	61	8	61
162	Cattail	23-Jan-08	0	0	0	1.4	0	1.4	0	8	0

Appendix 4 – Microcosm Monitoring Data (Completed)

Water (l) 6/03/08	Height (cm) 13/03/08	Water (l) 13/03/08	Height (cm) 18/03/08	Water (l) 18/03/08	Height (cm) 3/04/08	Water (l) 3/04/08	Height (cm) 9/04/08	Water (l) 9/04/08	Height (cm) 17/04/08	Water (l) 17/04/08
0	49	0	49	8	54	4	56	4	57	0
0	60	0	60	8	80	4	97	4	111	0
0	42	0	41	8	41	4	43	4	40	0
0	69	0	68	8	117	4	133	4	138	0
0	47	0	47	8	52	4	53	4	53	0
0	60	0	64	8	90	4	93	4	108	0
0	39	0	39	8	45	4	45	4	46	0
0	102.5	0	118	8	136	4	130	4	151	0
0	35	0	35	8	35	4	36	4	38	0
0	81	0	91	8	112	4	124	6	130	0
0	53	0	53	8	53	4	54	6	55	0
0	0	0	0	8	0	4	0	6	0	0
0	32	0	33	8	32	4	32	6	33	0
0	79	0	83	8	118	4	117	6	133	0
0	60	0	61	8	60	4	62	6	62	0
0	65	0	63	8	84	4	104	6	119	0
0	62	0	64	8	53	4	54	6	51	0
0	73	0	82	8	105	4	110	6	135	0
0	12	0	12	8	13	4	13	4	19	0
0	80	0	80	8	130	4	142	4	145	0
0	61	0	60	8	60	4	60	4	60	0
0	51	0	68	8	92	4	110	4	125	0
0	54	0	52	8	56	4	56	4	57	0
0	83	0	66	8	104	4	122	4	125	0
0	55	0	55	8	54	4	56	4	56	0
0	71	0	83	8	106	4	115	4	116	0
0	0	0	7	8	12	4	14	4	14	0